Development of an Aqueous Scintillator to Detect Gamma Rays from Radioactive Cesium-137 and Cobalt-60

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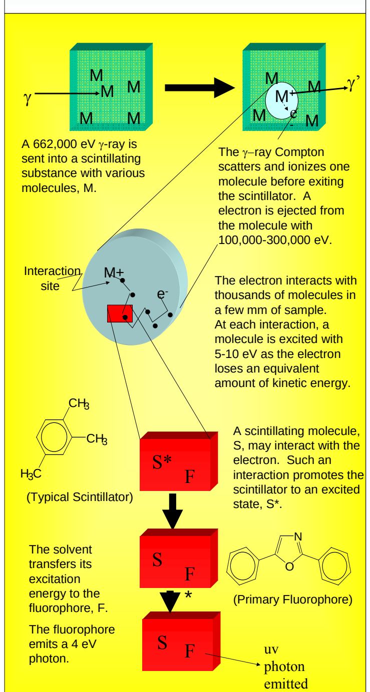
Abstract

We are developing an aqueous scintillating cocktail that is sensitive to gamma rays from radioactive Cs-137 and Co-60 button sources. The cocktail is a water-based solution of surfactant micelles that solubilize an organic scintillator (toluene) and a pair of wave shifting chemicals (PPO and dimethyl POPOP) that are ordinarily immiscible with water.

A digital acquisition software program (B.E.T.T.Y), as well as a picoammeter, are used to measure the amount of scintillation from each sample. By mass, our best cocktails are 40 % water, 30 % surfactant, and 30 % scintillator.

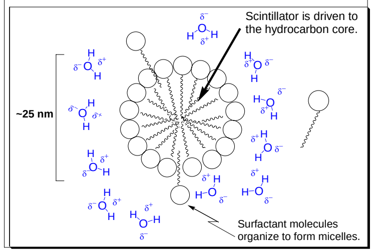
We performed many tests in our search to produce the ideal connection between our cocktail, a wavelength-shifting light guide, and PMT. After running tests with the PMT, light guide, and cocktail in "horizontal", "periscope", and "vertical" setups, we determined that the vertical position is best. The vertical setup gives the most reproducibility and the greatest signal intensity.

Scintillation Basics



Micelles and Mixing

Micelles are dynamic molecular assemblies that solubilize organic scintillator within an aqueous environment. The surfactant molecules that make micelles have polar heads that interact favorably with water. Surfactant molecules have nonpolar tails that form the middle of a micelle. The micelle interior is where organic scintillator is driven and made soluble.

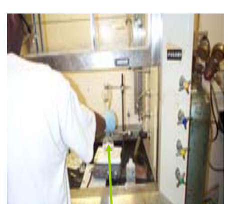


Experimental Setup

PMT
The photomultiplier tube detects photons emitted from the scintillation cocktail.

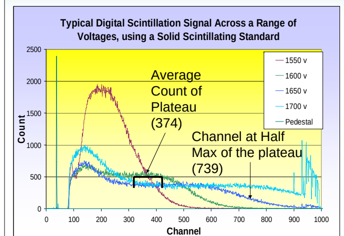
Wavelength Shifting Bar
The wavelength shifting bar converts the wavelength of the light emitted by the solution to a longer wavelength and directs it into the PMT.

Beaker with Cocktail
The beaker contains the scintillating cocktail and allows a connection to be made to the wavelength shifting bar without spilling the solution.



Cocktail Production
Our scintillating solutions, also known as "cocktails," react with gamma rays, producing photons that are detected by the PMT. To ensure proper mixing of the cocktail components, water is slowly added to a flask that contains surfactants and scintillator.

Results with B.E.T.T.Y

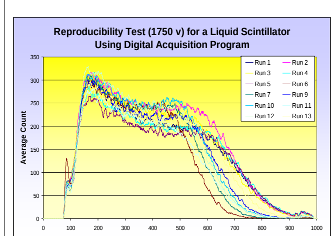


As the PMT voltage is increased, the scintillation signal becomes more broad and a plateau takes shape. We are characterizing the Compton Edge by identifying the plateau. We then find the average count along a 50 to100 channel range on this plateau. Once we find the average count, this number is divided by two. The highest energy channel at which this count is located is the "Channel at Half Maximum."

An ideal voltage provides a plateau of data that falls and reaches zero before channel 1000. In the above chart, the data for 1600 V is best, because it demonstrates these qualities.

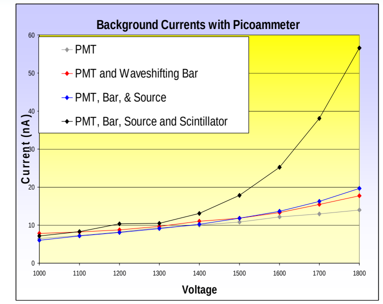
B.E.T.T.Y Daq
Used to convert PMT signal into useful data format on computer.

Picoammeter
The picoammeter measures current generated by the PMT.



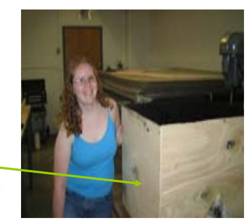
The chart above is data from a reproducibility test with pure liquid scintillator connected to the PMT in the vertical setup. The data shows a fair amount of variability (channel at half maximum fluctuation of 20% over 13 runs.) We can expect similar results when performing tests with scintillation cocktails.

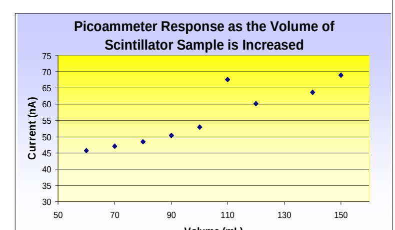
Results with Picoammeter



In order to use results from the picoammeter, we must know how much of the data we collect is the result of a scintillator, and how much is "background current." The background current is any current produced by the instrument or setup without a scintillator present. We conducted current tests across a range of voltages, adding a piece of the setup after each test. The third run was with a source that produces gamma rays without the scintillator. This was compared to a run with the scintillator present.
At higher voltages, the scintillator current increases at a rate faster than the increase of any background current.

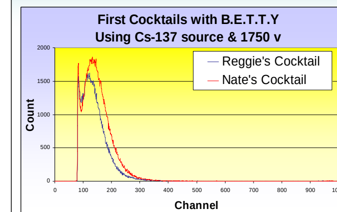
Black Box
The Black Box contains the PMT and does not allow external light in.





As the volume of the liquid scintillator increases so does the current. By increasing the volume of the sample, the probability that light will emit and travel through the wavelength shifting bar is increased. Therefore if a cocktail gives a weak signal, we can increase the output current by increasing the cocktail's volume.

Early Cocktail Results



Tests were run using the first two cocktails we created. A scintillation signal is present, but the data did not form the plateaus that we need to define the Compton edge. The runs were taken at a voltage near the PMT limit. Better results may be obtained if we test larger volumes of each cocktail.

The blue tint to the two cocktails on the right indicate the presence of dimethyl POPOP and PPO. The flasks on the left do not have these chemicals. Dimethyl POPOP and PPO are chemicals that shift uv photons from scintillation to visible wavelengths. This prevents self-quenching by the scintillator.

Conclusion

Our research will be continued during the 2005-2006 school year. So far this summer we have developed the ideal setup of the PMT and liquid scintillator, learned to take data from the PMT with the picoammeter and B.E.T.T.Y Daq, built a Black Box to take with us back to school, and have begun to make cocktails. As we continue our research we hope to develop the ideal cocktail. The ideal cocktail is transparent and at least 60% water by mass. The remaining 40% should contain enough dissolved scintillator to give us a strong signal.

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