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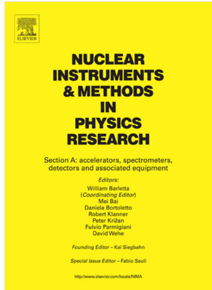

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Neutron detection capabilities of Water Cherenkov Detectors

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Abstract

In this work we show the neutron detection capabilities of a water Cherenkov detector (WCD). The experiments presented here were performed using a simple WCD with a single photomultiplier tube (PMT) and a ^{252}Cf neutron source. We compared the use of pure water and water with non contaminant additive as the detection volume. We show that fast neutrons from the ^{252}Cf source can be detected over the flux of atmospheric particles background. Our best estimation for the neutron detection efficiency is at the level of (19)% for pure water and (44)% for the water with the additive. We also present the simulation of the response of the WCD to neutrons using a simulated ^{252}Cf source. We implemented a detailed model of the WCD and of the neutron source spectra using Geant 4. The results of our simulations show the detailed mechanism for the detection of neutrons using WCD and support the experimental evidences presented. Since both active volumes studied, H_2O pure and with additive, are cheap, non-toxic and easily accessible materials, the results obtained are of interest for the development of large neutron detectors for different applications. Of special importance are those related with space weather phenomena as well as those for the detection of special nuclear materials. We conclude that WCD used as neutron detectors can be a complementary tool for standard neutron monitors based on ^{3}He.

Keywords: Neutron detection, Water Cherenkov Detector, Cherenkov effect, Space Weather, Homeland Security

1. Introduction

Water Cherenkov Detectors (WCD) of large volumes (with typical detection masses that span from one to thousand of tons of water) using ultrapure water are sensitive to charged relativistic particles and high energy photons. These detectors are used in a variety of implementations: from a diversity of astrophysical studies, [1, 2, 3, 4] to the detection of Special Nuclear Material (SNM) for homeland security [5, 6] Fissile elements as uranium or plutonium produce simultaneous emissions of multiple neutrons. In this field, it is worth to notice that ^{3}He based neutron detectors have had a growing application for homeland security. This is so because the ^{3}He based ionization tubes are non-cryogenic, safe, non corrosive, highly efficient for thermal neutron detection, and have a low gamma sensitivity. ^{3}He based neutron detectors in combination with moderator materials (such as polyetylene) are efficient for the detection of fast neutrons emitted from nuclear fission. However, for this reason, the homeland security application of ^{3}He detectors have produced a crisis in the ^{3}He supply and its price was significantly increased. Therefore, neutron detectors of large solid angle, cheap materials and good noise rejection levels are desirable. In this context WCD employing different dopants [5] are explored but, up to the moment, only Gd dopants were considered for this purpose. It is also worth noting that ground based space weather oriented experiment that uses neutron monitors to study low energy cosmic ray flux variations can use WCD as an alternative detector. In particular the LAGO and Auger collaborations use WCD to indirectly measure changes in the flux of low energy cosmic rays and relate this change with solar activity indicators.[7]

As a continuation of the work presented in the RICH 2016 workshop, where a proof of concept of a WCD measuring neutrons using pure water was shown, [8] we present in this work the study of WCD for neutron detection comparing the use of pure water and a non contaminant additive with a single PMT. We performed experiments with a ^{252}Cf neutron source, using pure water and water with a non contaminant additive to compare the capability of a WCD to detect neutrons. We use a compound that uses Cl as an additive to increase the neutron signal due to the interaction with ^{35}Cl.

2. Detector, experimental and simulation layout

The WCD installed in the Neutron Physics department laboratory at Bariloche is an autonomous, reliable, simple and inexpensive detector. We have built two versions one of 0.5 m^3 and other of a 1.0 m^3, consisting of a stainless steel commercial

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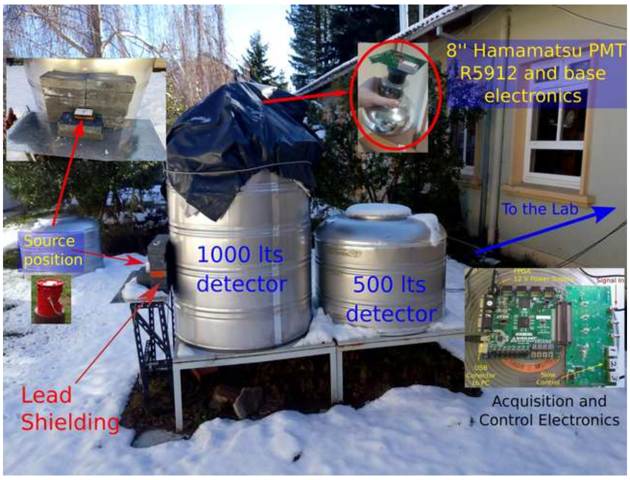

Figure 1: View of the experimental set up with both 0.5 m^3 and 1.0 m^3 water Cherenkov detectors, where the latest is used in this work. The position of the neutron source, and the lead shielding to reduce the gamma contribution can be seen. Also the acquisition and control electronic is shown.

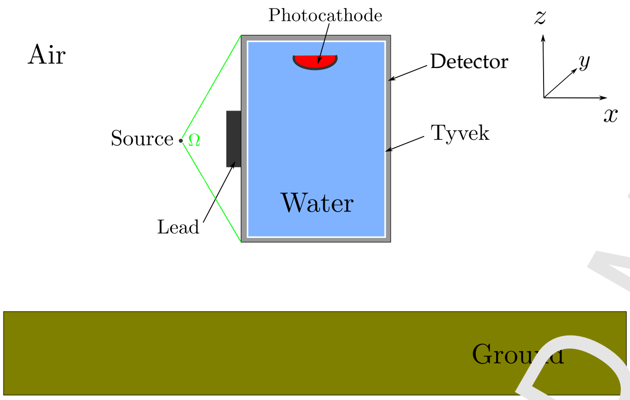

Figure 2: Scheme of the detector geometry simulated using Geant 4.

water tank of cylindrical shape, with 1 m of diameter and different heights. Both detectors have a 9" Hamamatsu R5912 PMT, plus a digitizer board of custom design. [9] In Figure 1, a picture of both detectors can be seen, with the PMT placed at the detector lid. Also shown is the lead shielding, to avoid gamma contamination, with the position of the Cf neutron source placed at the middle of the height of the detector. The detectors also have a 0.12 mm thick inner coating of Tyvek®, that is an UV diffusive and reflective fabric. Its features were studied in reference [10].

Figure2 shows the simulation scheme of the detector geometry build using Geant 4. [11] The detector is composed by using a 96 cm diameter by 133 cm tall and 0.5 mm thick stainless steel cylinder, which is full of water (or additive with 5% in mass) and has an hemisphere of 5 cm tall and 10.16 cm of radii located at 80% over the detector height, that simulates the PMT photo cathode. Between the water and stainless steel volume there is a thin layer (0.12 mm) that has the reflective and refractive properties of Tyvek® [10]. The QE reported by Hamamatsu for the R5912 was also used to sort the acceptance or rejection of a Cherenkov photon in to the PMT. [12]

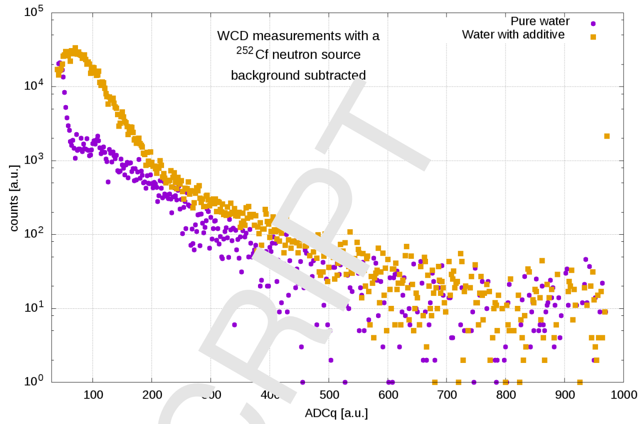

Figure 3: Spectra of the experiments using a ^{252}Cf neutron source, after background subtraction. Purple circles are measurements with pure water and orange squares are using water with a 2.5% of additive, increasing the signal resulting in a huge difference.

3. Results

3.1. Experimental results using a ^{252}Cf neutron source

We performed measurements with lead shielding, to avoid the gamma photons emitted by the Cf source, leaving mainly fast neutrons entering to the detector. In Figure 3 we show the experimental results of the measurements with the Cf neutron source with background subtracted. The measurements were made in 300 s and the subtracted background was measured immediately before the irradiations. In violet circles it is showed the measurement using pure water, and in yellow squares using water with additive. The units of charge of the recorded events are ADC_q, i.e., the integral of a single, 300 ns-long pulse as a function of time (measured in time intervals of 25 ns) after the subtraction of the signal baseline. It is clear from the figure that the signal using the additive are more intense than the one with pure water. In section 4 we will show the neutron detection efficiency results comparing both situations.

3.2. Simulation results using Geant4

The simulations were performed using the spectral shape of fast neutrons from a ^{252}Cf source.[13] We show in Figure 4 Top, the gamma particles generated in the active volume of the detector in both cases. In red it can be seen the gammas emmited in pure H_2O, where the most prominent is the 2.22 MeV line. In the case of additive added to the water more energetic gammas are emmited due to the interaction of neutrons with the elements in it, resulting in an increase of the signal. This increase can be seen also in Figure 4, bottom, where the electrons are showed, produced by the interaction of the gammas particles with the water. The compton border can be seen showing the most energetic particles giving more signal.

4. Neutron detection efficiency

Using the punctual source approximation, and as a first approximation for a detection efficiency calculation, we arrived at

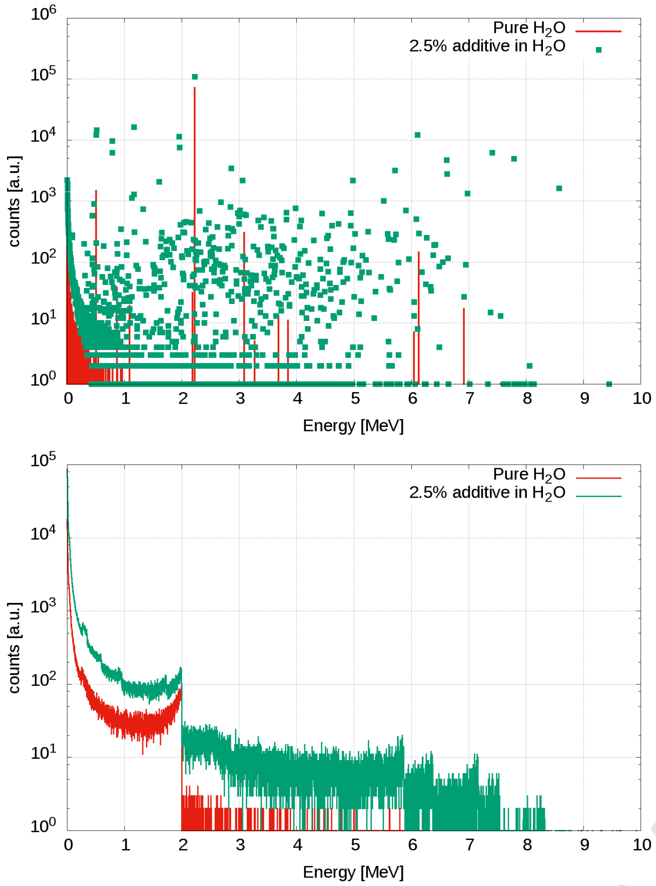

Figure 4: Top: gamma particles produced in the simulation using the spectra of a ^{252}Cf source with pure water and water with a 2.5% concentration of additive. The 2.22 MeV peak can be noted in both cases and the high energy gammas produced in the interaction of the neutrons with the additive. Bottom: electrons produced inside the detector by the interaction of gammas with the active volume, wich are produced mostly by Compton interaction.

the formula:

$$\varepsilon_D \simeq \frac{N_{Pb} - N_{background}}{N_S\, e^{-\lambda t_d}\, \frac{\Delta\Omega}{4\pi}\, t_m}, \tag{1}$$

where $\left(N_S\, e^{-\lambda t_d}\right)$ is the neutron emission rate of the source the day of the experiment, N_s is the neutron emission rate at the calibration time, λ the decay probability per time unit, t_d the time difference between the calibration and experiment, $\left(\frac{\Delta\Omega}{4\pi}\right)$ is the solid angle, t_ma the acquisition time (300 s), and the integral of the number of counts (N_{Pb}) subtracting the background $\left(N_{background}\right)$. Table 1 shows the calculated efficiencies using H_2O with and without additive, from experimental results and simulations.

Sensitive volume	Experimental results [%]	Simulation [%]	Captures in	
			^{1}H [%]	^{35}Cl [%]
Pure water	19±2	10.18	10.17	0
Water with additive	44±10	24.19	15.57	7.91

Table 1: Efficiencies calculated for the experimental results showed in 3, simulations as showed in 4, and captures in ^{1}H and ^{35}Cl from the simulations.

5. Conclusions

In this work, the feasibility of neutron detection using a simple water Cherenkov detector with pure water and a non contaminant additive containing Cl has been proven. We demonstrate that the addition of a Cl based compound to the water in low proportions, results in an increase of twice the efficiency in the experiment. This additive is an easy to get, cheap, and non contaminant material, it has clear advantages over other systems employing Gd or other chemical elements to increase the neutron absorption. The usage of a single PMT has a direct effect on the reliability and the final cost of the WCD. This results are of great interest for non proliferation, homeland security and low energy cosmic rays phenomena.

The employed detector presents a clear advantage over systems that employ Gd to increase the neutron absorption, and/or more that one PMT.

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