On the simulation of limit thresholds for ISOLDE decay station neutron detector

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(Dated: August 26, 2015)

The recently comissioned ISOLDE decay station neutron detector (IDSN) efficiency was calibrated with a standard ^{252}Cf neutron source, using lower threshold limits set at 0, 31 keV and 59.5 keV, and upper threhold of 3840 keV. Geant4 simulations were run to compare with the experimental efficiency where new detector limits were sought to fit the experimental data. Suitable values of limit thresholds were found that properly fit the simulation with experimental lower neutron energies, below 1 MeV, but strongly departs from data above it. It is concluded that the simulation is incomplete at this point, and so a review must be done on the nuclear physics and scintillation light Geant4 packages in order to properly reproduce the detector properties.

Keywords: IDSN, Geant4

I. Introduction

The recently comissioned ISOLDE decay station neutron detector (IDSN), has been developed to allow for studies on neutron-rich nuclei, in which delayed neutron emission dominates beta decay. In particular, it has been proposed to be used for spectroscopic measurement of delayed neutron emission can 0along the cadmium isotopic chain to track the evolution of single particle states [1], as well as to perform spectroscopy of the beta-delayed neutron emission of the $^{51-53}K$ isotopes to study the population of single-particle or particle-hole states both below and above the neutron separation threshold [2].

IDSN is comprised of three different sized scintillating detector modules, $3x3x60cm^3$, $3x6x120cm^3$, and $5x5x200cm^3$; labeled small, medium, and large, respectively. Neutrons are detected indirectly, measuring the scintillation light of scattered protons after neutron collisions. Neutron energy is determined via time of flight technique, and so the detector thickness increases the detector efficiency, but increases the energy uncertainty as well [3]. The different sizes can be used to optimize detection for different situations, since small modules are designed to be sensitive at low-energy neutrons of the order of 100 keV, while the large modules are designed for neutrons up to 20 MeV. The IDSN module design consists of scintillating plastic bars coupled to photo-multiplier-tubes (PMT) using optical epoxy. The PMTs are of one or two inch diameters depending on the scintillator cross section. Wrapping materials such as aluminized Mylar improves the light collection and reduces attenuation within the bars.

In order to avoid the effects of random pulses, such as dark currents, two PMT are attached to view the same volume at different ends. This way they detect true scintillation light in coincidence. The longitudinal position within a bar is calculated by the time difference between the left and right PMT times, multiplied by the measured speed of the scintillation light. [4]

The plastic scintillators light output response is linear with energy for electromagnetic and electron sources. Thus it can be measured by either the energy deposited by cosmic rays muons, compton scattering of gamma rays, and full photoabsorption of low energies gamma

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rays. A photo-peak absorption can occur to low energies, leading to a peak in the enery spectrum that can be related with a known gamma energy, while compton edge of photons can also be used as a standard to calibrate the detector.

Since not every particle passing thorugh the scintillator deposit energy, it is important to characterize the detector efficiency. This can be experimentally measured using a neutron source of well known intensity by comparing the recorded events with the incoming neutron flux. IDSN modules have been calibrated [4], comparing to a standard calibrated detector made of Elijen 2-inch organic liquid scintillator, In Fig 1 I show the IDSN efficiency for a 252Cf source using as a threshold the photo-absoption peak of ^{241}Am at 59.5 keV, and a gamma source of ^{133}Ba at 31 keV.

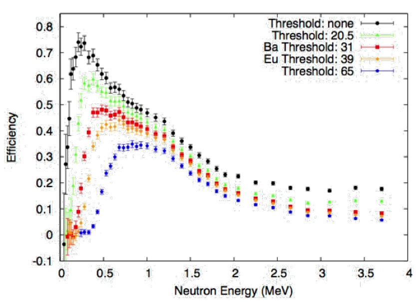


FIG. 1: *Efficiency of a small IDSND bar measured with a ^{252}Cf source with various threshold cuts in keVee*

In ordinary experimental circumstances, due to enviromental conditions, the efficiency of the system is very difficult to be determined. And so, a simulation of the full detector setup with its enviroment is necessary to reconstruct the expected efficiency [5]. Geant4 is a toolkit for the simulation of the passage of particles through matter. It is a software package that allows for each component of the detector, its setup and surroundings to be build indepently. The software then runs Monte Carlo events for the desired experiment and provides results. In this way, its important to compare the results of simulation against measured known quantities, and so the necessary physics and setups must be selected in order to fit the best with experimental results.

In order to simulate the IDSN bars, two threshold can be modelled. The first one occurs when a large amount of light is deposited in the bar or the PMTs are biased too high, these signales are beyond the acquistion range and thus are discarded. The other case occurs for the lowest energy signals [4]. The purpose of this work is to model the values of these limits to fit properly the experimental data.

II. Methods

A framework developed [6] for the small IDSN modules was used for testing their efficiency. It consists on a box of $3x3x60cm^3$ made of a polyvinyltoluene BC-408. For the moment the PMT were ignored and the needed information was scored in the main scintillator as well as in two cubes placed at both ends of the bar. Fig 2 shows a picture of the simulated bar.

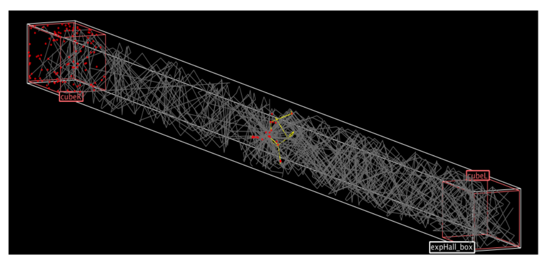
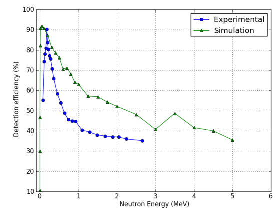
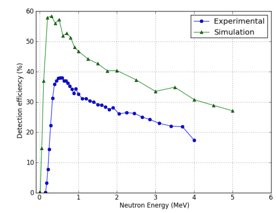


FIG. 2: *BC-408 Scintillator Sample - 3 x 3 x 60 cm^3*

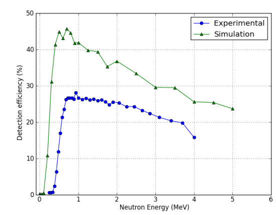
As mentioned above,, the neutrons are detected with the scintillation light, produced by the interactions of the incoming neutrons with the C and H atoms compounding the scintillator material. There are many particles involved in this process, protons, alphas, deuterons, ^9Be, ^{12}C as well as by electrons and γ rays. In BC-408, the scintillation yield, defined as the number of scintillation photons produced as a function of the energy deposited at the material is known to be approximately 10000 $photons/MeV$ of deposited energy. In the simulation it was fixed to 3000 photons/MeV, to account for the PMT quantum efficiency of nearly 30%. When running the simulations, the number of events, as well as the value of the neutron beam energy in MeV, and the values of the lower and uper threshold in GeV are user defined. Then, the program shows in its output the total number of hits or photons detected on the cubes on either side of the bar. A plot of efficiency against neutron beam energy, for energies up to 6 MeV can be built if the value of the neutron energy is allowed to vary. The larger the number of events, the better results are obtained due to the stadistical nature of the Monte Carlo simulation, although running a very large number of events can be time-consuming. The experimental data used in this work corresponds to those mentioned above and shown in Fig 1. At first, the code was run using the same thresholds than those determined by the experiment. Then the code was run allowing for different lower thresholds, while keeping the upper fixed, in order to adjust the plot the best with the experimental data. Finally, with the new determined lower thresholds, the upper thresholds were changed to find the best fit with the experimental data, if possible. The purpose of this work is to evaluate how well the experimental values match the simulation results, and evaluate in what neutron energies region they can be taken as reliable.



(a) *No threshold*



(b) *Threshold of 31 keV*

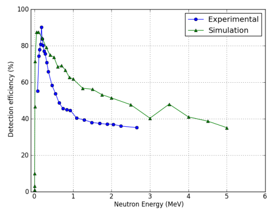


(c) *Threshold of 59.5 keV*

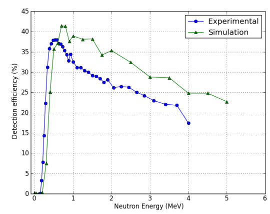
FIG. 3: *Comparison between efficiency plots setting the thresholds as experiment calibration values*

III. Results

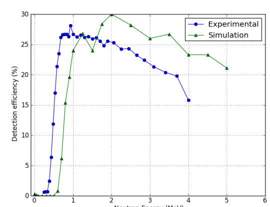
Figure 3 shows the plots of the obtained data using a Geant4 simulation setting the lower and upper threshold the same as its theoretical values. As it can be seen, in these cases the efficiency plots, as calculated by Geant4, show similar curves than those on the experimental plots, but they present higher values. In order to optimize the simulations, the lower and upper thresholds are allowed to vary. First, varying the lower threshold while keeping the upper constant, it has the overall effect of decreasing the height of the peak, see Fig 4. Figure 5 shows plots of the previous experimental settings, but changing both the lower and upper thresholds in order to obtain better fits.



(a) *No threshold, using 4 keV in the simulation*

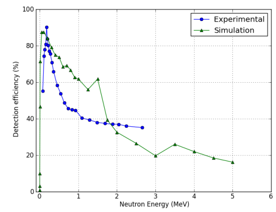


(b) *Threshold of 31 keV, using 80 keV in the simulation*

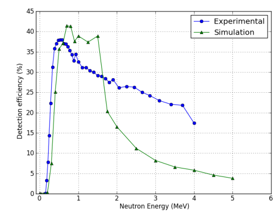


(c) *Threshold of 59.5 keV, using 190 keV in the simulation*

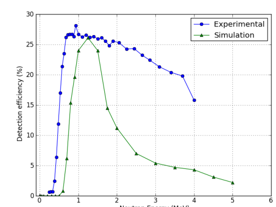
FIG. 4: *Comparison between efficiency plots setting the lower thresholds to fit the peak, while keeping the upper threshold as 3840 keV*



(a) *No threshold, using 4 keV in the simulation*



(b) *Threshold of 31 keV, using 80 keV in the simulation*



(c) *Threshold of 59.5 keV, using 190 keV in the simulation*

FIG. 5: *Comparison between efficiency plots setting the lower thresholds to fit the peak while keeping the upper threshold as 500 keV*

IV. Discussion

From these results, it is shown that IDSN detectors show a lower efficiency than would correspond according the simulation, for the neutron energy range studied, and the experimental thresholds. If the lower thresholds are increased, and the upper is kept fixed, the peak in the efficiency plot decreases and so its height can be the same as in the experimental setup. If both limits are allowed to vary, the efficiency plot properly adjusts to the experimental data for energies bellow the peak, but quickly diverges for higher neutron energies. When decreasing the upper threshold value on the simulation, the shape of the simulated plots departs from experimental data, and it is not posible to match them again. As a result, at this point the results of this simulation is not consistent with what is observed experimentally, and therefore the simulation is still incomplete. In order to improve the simulation results, Geant4's nuclear physics and scintillation light packages must be investigated to find the excess efficiency.

V. Aknowledgements

The author is grateful to Dr M. Madurga for supply helpful guidance and references. He is also thankful with E. Vagena for providing the framework to run this simulations, and to R. Lica, for his valuable advices when preparing this work.

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