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Abstract. A neutron spectrometer, the European Low-Energy Neutron Spectrometer (ELENS), has been constructed to study exotic nuclei in inverse kinematics experiments. The spectrometer consisting of scintillator bars can be used in the neutron energy range of 100 keV to 10 MeV. To increase the light collection efficiency a special wrapping method was developed for each bars of ELENS. By using the specially heat treated reflector foil 15-20% better light collection is available. The development of wrapping process, the results of the test experiments are also presented.

1. Introduction

The most exotic nuclei are usually the most interesting ones but their production rate decreases exponentially with the increase of the proton-neutron asymmetry. In order to counterbalance this effect, high-efficiency detector setups and thick reaction targets are required. The information of interest is then extracted from the kinematical characteristics of the reaction products such as their scattering angles and energies. Using inverse kinematics, the kinetic energy of the emitted neutrons is relatively low and a short flight path is sufficient for the time-of-flight measurements. The detection of the slow neutrons with good efficiency, as well as the measurement of their energy and angular resolution requires specially designed spectrometers. The detection of a low-energy recoil product is often rather difficult, one needs to detect the neutrons at small angles, while their energies usually go below 1 MeV. Such neutrons interact with the hydrogen content of the detector material predominantly by elastic scattering on the protons. The recoiled protons have low-energy and they produce only a small number of photons in the scintillator material during their slowing down process, due to the quenching effect [1]. Such photons should be collected with high efficiency, so very good light collection and small light attenuation is necessary along the detector bars. An important part of the development was the investigation of different wrappings. Such neutron spectrometers have been built recently by Beyer et al. [2] and by Perdikakis et al. [3] and used successfully to study the strength distribution of the Gamow-Teller resonance [4] and have also been developed at RIKEN [5], [6] and at GSI [7]. In the present work we report the development and the concept of the new wrapping method.

2. Properties of ELENS system

The array consists of 16 plastic scintillator bars, each of them attached to photomultiplier tubes (PMTs) at both ends. The UPS89 fast plastic scintillator material was chosen, which has similar properties to NE102. The size of the detector is: $10 \times 45 \times 1000$ mm^3. A variable detector support was constructed for ELENS. The array is designed to measure neutron energies in the kinetic energy region from a few hundreds keV to a few MeV.

3. The wrapping

The quality of scintillation detectors is determined primarily by the quality of the scintillator material and the detector wrapping. The size and geometrical arrangements of the bars provide high detection efficiency, and at the same time high angular resolution for ELENS. The main problem of similar configurations is the inefficient light transport over long distances in thin ($d/l \ll 1$) tubes. Efficient light transport can only be achieved by specular reflectance materials of high reflectivity. A very good light collection is necessary to pick up the small signals, so a proper wrapping material, and the perfect fitting of the foil onto the plastic was an important criterion. There are several possible candidates, such as wrapping materials for plastic scintillators. The popular materials are: 3M Radiant Mirror Films, Teflon tapes, plastic tapes, gold coated tapes, aluminum foils, white diffuser paint or tape, etc. The main properties of these are the high reflection rate. In addition, these materials must be mechanically stable and flexible within certain limits. The detector paddles in the case of ELENS are wrapped with a specially treated VM2000 multilayer reflector foil (Enhanced Specular reflector), which has been produced by 3M. It is a multilayer reflective foil based on a novel technology [8]. This foil has a good reflection coefficient of $R > 97\%$ for $\lambda \geq 400$ nm, and R = $(98.5 \pm 0.3)\%$ at 430 nm wavelength of light [9]. Because of the thickness and rigidity of the multilayer material, it is very difficult to fold, wrap or create any kind of a crease in VM2000 foil, without decreasing of the light guidance parameters.

4. The novel wrapping method

There are many methods for the optimal wrapping (with VM2000) but all these methods are using some mechanical interactions on the foil. The VM2000 is composed of several different layers, so it is sensitive for the external mechanical influences as cuts or abrasions. Any abrasion or cut may compromise the optical properties of the foil. Along the cut edges the thickness of the material changes (gets thinner) or microscopic cracks

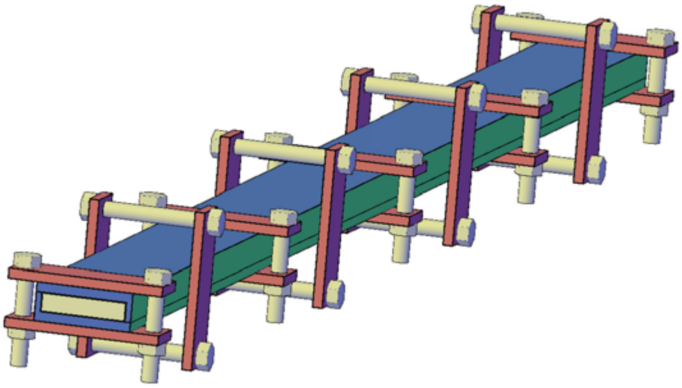

Figure 1. The "baking set" for the heat treating with foil.

are generated and therefore the reflection is reduced. In order to ensure a proper fitting of the reflective wrapping foils to the scintillator bars, the foils were formed by special heat treating prior to the actual wrapping process. A special baking set was made and a heating and cooling cycle was performed, while the foil was placed into the form. In the first step we prepared a special baking set with two bake molds and between them a bake form (see Figure 1). The material of the baking set was aluminum and all surfaces of interest were perfectly flat and smooth. The size of the form was smaller than the plastic scintillator, i.e. $(1000 \times 44.5 \times 9.5)$ mm^3. A sheet of VM2000 foil was cleaned and laid between the molds and the form. This must be a very precise process, as any stretching, stress or shrink of the reflective film can compromise the optical properties of the foil. The use of a clean room was also important. When the foil covered perfectly the aluminum bake form with the help of the exterior aluminum mold fixture, then we fixed it from outside with iron clamps. The distance between the clamps was 10 cm. The wrapping mold with the foil was put into a cylindrical electric oven and it was baked during 2 hours at 115°C. The experimental experiences support this value. The material of the foil is stable and the parameters of reflection is constant till 125°C temperature. After removing the mold from the oven it was cooled over 24 hours. The formed foil was stored for a week before any true wrapping was performed. The optical parameters of the foil did not change after such a procedure. The scintillator paddles have been wrapped with one layer of treated foil, a layer of aluminum foil and finally using black insulating tape to ensure proper light propagation through the bar as well as light-tightness.

5. Test of the ELENS detector with monoenergetic neutrons

The response of the ELENS detectors for monoenergetic neutrons has been investigated at the Physikalisch-Technische Bundesanstalt in Germany. Using the ^{7}Li$(p,n)^8$Be reaction, different quasi-monoenergetic neutrons were produced with kinetic energies of 240, 471, 925 and 2014 keV. Three types of wrapping were compared. In Table 1, the light collection efficiencies of the bars wrapped with Teflon tape as well as with

Table 1. The relative light-collection efficiencies of the detector bars at various energies and with various wrappings. The uncertainties are less than 2%.

	Neutron energy			
Wrapping	210 keV	471 keV	925 keV	2014 keV
Teflon tape	95%	96%	96%	98%
VM2000	100%	100%	100%	100%
VM2000*	116%	115%	118%	120%

specially treated VM2000 foil are compared to bars which were wrapped with VM2000 foil without baking. The values were normalized to data obtained with the simple VM2000 foil. We concluded that using the specially treated VM2000 foil (referred to as VM2000* in Table 1), we can gain about 15-20% in light collection efficiency. The light attenuation length [10] of a plastic scintillator bar is defined as the length reducing the light signal by a factor of e and depending upon bulk transmission of the scintillator, its thickness and shape. A measurement to study the effective attenuation length of the bars of ELENS was performed by moving a ^{60}Co source along the paddle. The obtained light attenuation length is (128.2 ± 1.7) cm, i.e. light can travel relatively long distances in the scintillator material without significant attenuation. The light attenuation of the detector material with the specially treated VM2000 reflecting foil, is less than 50%. The advantage of the wrapping used is also reflected by the fact that our measured speed of the light in the scintillator bar is (17.28 ± 0.3) cm/ns.

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