A Modular Neutron Detector

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Abstract. Taking advantage of the reduced size of helium proportional counters (compared in equal terms of efficiency with the boron ones) a new mobile neutron detector was realized at SVIRCO Observatory and Terrestrial Physics Laboratory (IFSI-Roma Research Unit) during 2006. Each component was designed in a modular way so fitting together a different number of elements and using different counters it is possible the assembly of a detector with a length varying from 80 cm to 210 cm. Such innovative system allows the realization of a detector equipped with a helium counter type LND 25382 (65 cm) as well as one utilizing a LND 25373 (191 cm) just using a different amount of modules. We describe the design and realization of the detector.

Keywords: Neutrons, modular detector, proportional counters

I. INTRODUCTION

SVIRCO Observatory (formerly Station) has been performing uninterrupted measurements since 1957, when an international network of ground-based detectors for continuous cosmic ray measurements was worldwide established during the 1st International Geophysical Year. The purpose of studying time variations of primary cosmic rays (Studio Variazioni Intensità Raggi COsmici: S.V.I.R.CO.) and their modulation in the heliosphere, by means of the continuous records of their nucleonic component, has ever been part of SVIRCO activity which has included also the design and the development of new detectors, with different geometries and counters (see Storini & Signoretti [1]).

In the 80ths a new high multiplicity neutron detector, was realized by SVIRCO staff with the purpose to improve the registration of solar particle events [2]. It was made up of seven standard BP-28 counters assembled around a core of lead (producer) by means of a modular polyethylene frame (reflector). With a couple of such units four summer campaigns were carried out from 1989 to 1992 on Mt. Gran Sasso (2100 m a. s.l.) near L’Aquila (Italy).

During the years 2002-2006 a series of tests was performed at SVIRCO to evaluate the possible use of helium proportional counters in the standard IQSY detectors instead of the more expensive boron ones. The results suggested the possible replacement of the standard BP-28 ($^{10}$BF$_3$ filling gas) counters with the LND 25373 ($^3$He filling gas) and a new 3NM-64-$^3$He was fully realized and accurately tested. It has been operating inside the Antarctic Laboratory for Cosmic Rays (LARC) since January 2007 [3].

II. DESIGN OF THE MODULAR NEUTRON DETECTOR

The comparative tests performed on the proportional boron and helium counters, either in the standard NM-64 configuration or in a lead free monitor (neutron flux meter; see, for instance, Mishev et al. [4]), have proved the efficiency of helium counters to be equal or a bit higher (7%) than the boron ones. These results have been obtained with the LND $^3$He counters type 25373 which have the same length (190.8 cm) of the boron standard BP-28 with a diameter of only 5.08 cm instead of 14.8 cm. Actually the 2 inch diameter design is very common for helium proportional counters which are available in a wide set of sensitive length just in this size. This opportunity suggested us the design of a modular neutron monitor with an adaptable structure for different length counters. The skills resulting from the construction of the high multiplicity neutron detector assisted us in the realization of the new instrument.

Each module (see Figure 1) is composed by a polyethylene framework, acting as outer reflector and having a tongue and groove joint to lock into one another. The frame element has a round shape and includes a pedestal. The central hole encloses a lead ring (producer) housing an interlocking polyethylene allow cylinder (inner moderator).

The whole structure of the detector, which is composed by elements clasped within each other, is closed by a plate at both ends. The frontal plate has a hole for the counter and a bay for the electronics head, whereas the rear one is plane. Up to six tie-rods of stainless steel can be used to block in the whole frame preventing also the movement of all the elements boxed up with a strict mechanical accuracy.
III. REALIZATION OF A MOBILE NEUTRON DETECTOR

A mobile neutron monitor has been built at SVIRCO Observatory & TPL in Rome (41.86°N, 12.47°E, altitude about s.l.; cutoff rigidity ~ 6 GV) to be used for measurements outside the laboratory. The assembly has been performed with seven modules and two end plates (Figure 2, upper panels). The detector has been equipped with a $^3$He counter type LND 25382 (diameter 50.8 mm, length 652 mm; Figure 2, middle panels). The counter has been fastened to the electronics box (Figure 2, lower panel) creating a compact assembly. A special flanged collar ensures the best mechanical and electrical connection between the shielded box and the counter. Furthermore sliding the tube into the collar, before blocking, it is possible to achieve a perfect alignment between the anode head and the pre-amplifier shielded input, preventing electrical noise and possible pulse corruption. Note that this electronics head, provided with the flanged collar, can fit a wide set of 2 inch counters with different lengths.

Fig. 2 (top) shows the modular neutron detector equipped with a LND 25382 counter and assembled on a hand cart to be easily moved inside the laboratory. The overall dimensions of the stand alone instrument (without cart) are: width 37 cm, height 50 cm, length 79 cm. The total mass is about 265 Kg and in detail the mass of each loose component is:

- Outer reflector (7 polyethylene elements): 9.4 Kg each.
- Producer (7 lead rings): 22.3 Kg each.
- Inner moderator (7 polyethylene elements): 0.36 Kg each.
- End plates (2 polyethylene elements): ~ 14.2 Kg each.
- Tie rods (4 stainless steel bars plus 8 lock nuts): 2.5 Kg each.
- Electronics head (box, collar, board): ~ 1 Kg
- Tube type LND 25382: 1.5 Kg.

IV. THE AMPLIFIER WITH A SPECTRUM STABILIZER

Spectral resolution is a very important parameter for proportional counters (see Figure 3, centre). Comparative spectra (pulse height distributions), taken at the amplifier output with a multichannel analyzer, show that the best resolution is achieved by an accurate choice of the time constants in the amplifier circuit. If time constants are too short, the neutron pulse may be cut before the complete charge is collected by the anode. Alternately, if the constants are too long, the contribution from noise increases. Both situations result in bad resolution and unwanted spectra features may be introduced. In addition the time constants determine the counting rate capability: the counting rate increases with a shorter time constant while a lower counting rate is determined by a longer time constant. Actually counting rate and resolution are a compromise. Moreover poor resolution lets the pulses scatter over a wide range of the distribution. This results in a narrower valley in which to set the discriminator threshold. The comparative spectra of boron and helium counters point out that using helium counters there are no margin for any sources of instability without shifting the counting rate. Furthermore parallel operation of more than one detector is possible only with separate high voltage power supplies or gain matching. We have experienced that the best way to solve the inconveniences related to helium counter spectrum is to equip also the modular neutron detector with an amplifier circuit completed with a spectrum stabilizer. We have already designed this circuit for the 3NM-64-$^3$He operating in Antarctica since January 2007.
The amplifier-discriminator we have realized for helium counters is characterized by a variable gain to balance high voltage variations (the higher is the voltage the lower is the gain and the other way round). This device has greatly improved the accuracy of the threshold setting as result of the stability of the pulse height distributions in spite of high voltage variations in a wide range around the operative value. A complete stabilization from 1320 to 1420 Volts has been achieved for the selected LND 25382 counter. In addition the choice of the time constants ensures a proper balance between counting rate and resolution as shown also by the full width at half maximum: in both pulse height distributions, taken at 1320 and 1420 Volts, a FWHM of 7.5% has been obtained (Figure 3, right center).

V. TESTING THE MOBILE NEUTRON DETECTOR

Functional and comparative tests of the new mobile neutron monitor are in progress at SVIRCO Observatory & TPL in Rome. The unit has been running since the end of 2006 contemporary with the standard 20NM-64 detector of the Observatory. Data have been recorded with a timing of 1 minute by the same acquisition system and corrected for pressure variations with the same attenuation coefficient (0.70%/hPa) and reference level (1009.25 hPa). Furthermore the corrected data have been normalized to the average hourly rate of 9-12 February 2007.

The detector responses to the incoming cosmic ray particles have been compared on three hours or daily bases, because of the low counting rate of the mobile detector (∼2450 counts/hour) which is approximately 0.45% of the 20NM-64 (∼555000 counts/hour). A good correspondence in the data acquired by both detectors (taking into account the statistical errors due to the low counting rate of the helium detector) is shown in Figure 3 (bottom) for the period January-April 2009. In the examined period the temperature variations inside the Observatory were restrained in a narrow range (2°C). As a matter of fact during previous tests it was observed that the counting rate of the mobile detector increased according with inner ambient temperature rising. In particular, in the period 29 April - 10 September some failures occurred in the air conditioning system of the Observatory and the temperature increased together with the counting rate of the detector (see Figure 4).

The ratio between the normalized daily counting rate of the mobile detector and the one of the whole 20NM-64 has been plotted to eliminate the effects of primary cosmic ray variations. In the same graph the hourly temperature data together with the daily simple moving average (SMA) have been reported as well. Figure 4 points out the correlation between the temperature and the counting rate ratio showing out the sensitivity of the helium counter to the environmental temperature. Hence, air conditioned housings are recommended for helium detectors.

Since 2001 Moraal et al. [5] have planned to construct a mobile neutron detector, based on helium counters, for calibration purposes. Its design and performance were described in several papers (e.g. [6], [7], [8], and [9]):
the temperature sensitivity of the neutron monitors was well documented and the dependence on environmental factors illustrated.

VI. SUMMARY AND CONCLUSIONS

It has been shortly described the experimental work performed at SVIRCO Observatory & TPL (Rome) to design and realize a modular neutron detector fit to be equipped with counters of different length (up to 2 m). The modular design has made each loose component reasonably light, since the weight of the heaviest element (lead ring) is lower than 23 Kg. Thereby only one operator is required for transporting and assembling the whole neutron monitor even in its biggest arrangement (about 800 Kg). Moreover the small configurations may be also provided with hand-carts to be easily moved.

We consider that the chances to vary arrangement and size of this new detector together with the possibility to transport and install it in easy way, make the new instrument really useful for measurements outside the observatories such as educational activities and research campaigns. Furthermore, we are planning to assemble another modular detector with the longer LND 25373 (191 cm) counter.

Tests are still in progress at SVIRCO observatory to fix the effects of ambient temperature together with other environmental factors on the detector performance and stability. The obtained results will be reported in detail in a forthcoming paper. It will be interesting to check our findings with the ones discussed in a recent paper by Krueger et al. [10].

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REFERENCES