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A new modular cosmic-ray detector

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Abstract. Comparing the mean features of helium proportional counters with the ones of the standard boron trifluoride tubes, it appears at glance that, in equal term of efficiency and for the same active length, the ^{3}He filled counters are characterized by a very smaller diameter which optimizes their spectral resolution and minimizes wall effects. Moreover helium counters are usually designed in standard diameters and the 2 inch size is commonly available in a wide set of sensitive lengths. This manufacturing characteristic suggested us the realization of a modular neutron detector with a variable geometry to be adapted to counters of different lengths. At first a small modular detector (length of 80 cm) was assembled in Rome at SVIRCO Observatory and TPL during 2006. In March 2010 a second larger modular neutron monitor (length of 216 cm) was realized as well to be used for cosmic ray registration with a higher counting rate and better reliability. A short description of both modular cosmic-ray detectors is given.

1 Introduction

Since the beginning of 2002 several tests have been performed at SVIRCO [1] Observatory and Terrestrial Physics Laboratory (SVIRCO and TPL, Research Unit of IFSI-Roma/INAF; 41.86°N, 12.47°E, altitude about s.l.; cutoff rigidity ∼6 GV) to evaluate the performances of helium proportional counters and their utilization in neutron detectors with different geometries.

At first helium filled counter performances were investigated by recording simultaneous data from a completely bare counter, a second counter provided with moderator (polyethylene tube) and a third one operating in a lead-free detector configuration (i.e. the counter tube equipped with the moderator and the reflector, but without the producer; it is the so-called neutron flux meter, e.g. Mishev et al., 2009). Afterwards one boron trifluoride counter of SVIRCO standard super neutron monitor (the one introduced during the International Quiet Solar Year: NM-64; Hatton and Carmichael, 1964) was replaced with a helium one to verify its compatibility with the $^{10}BF_3$ counters of the standard super neutron monitors.

Finally, with the financial support of the Italian PNRA, a 3NM-64_^{3}He was assembled and accurately calibrated in Rome. The geometry of this detector is just the same as the standard 3NM-64 one, with regard to the polyethylene reflector, moderator and the lead producer whereas the proportional counters are the LND 25373 (length 190.8 cm, diameter 5.08 cm; see http://lndinc.com/). It was shipped to the Antarctic Laboratory for Cosmic Rays (LARC) on King George Island (South Shetlands - Fildes Bay - Ardley Cove: 62.20°S – 301.04°E; 40 m a.s.l.; cutoff rigidity about 3 GV), where it operates since January 2007 (Signoretti and Storini, 2009a; Storini et al., 2009a,b).

2 The small mobile detector

Another LND helium filled counter was tested at SVIRCO with the aim to realize a mobile neutron detector to be used for measurement campaigns. The shorter LND 25382 tube (length 65.2 cm; see http://lndinc.com/) has the same 2 inch diameter design as the longer LND 25373. Actually this diameter is very common for helium filled counters which are available in a wide set of sensitive length just in this size.

The quite common diameter of helium filled counters suggested us the design of a modular neutron monitor with an adaptable structure for proportional counters with different

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[1] SVIRCO is the acronym for “Studio Variazioni Intensitá Raggi COsmici”

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Fig. 1. Upper panel: The components of the modular detector structure. Lower panel: From 1 to 6 it is reported the step by step assembly of the mobile modular detector.

lengths. A first small mobile detector was built with a modular geometry at SVIRCO and TPL during 2006 (see, for details, Signoretti and Storini, 2009b).

The overall dimensions of the small mobile detector, without the hand-cart, are: width 37 cm, height 50 cm, length 79 cm and its total mass is about 265 kg.

3 The new modular cosmic-ray detector

With the aim to realize a new instrument for continuous cosmic ray registration with a higher counting rate and reliability, we determined to use the LND 25373 helium counter again, since we had investigated its performances on the long term basis. In March 2010 a bigger modular detector was assembled and equipped with the LND 25373 tube. In this configuration the detector has reached the length of 216 cm with mass of ∼800 kg.

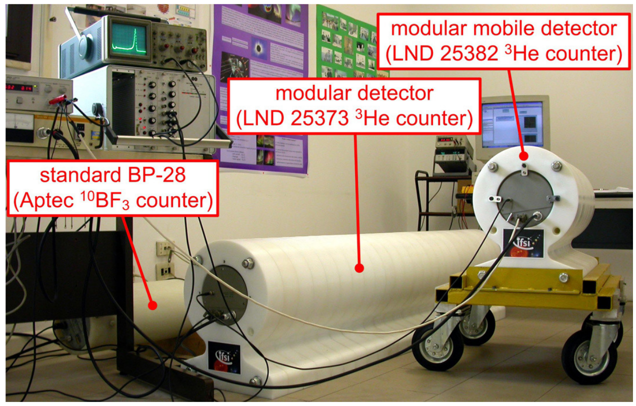

Fig. 2. Modular detectors in the testing configuration (see the text for details).

The small and the big neutron detectors are realized with the same modules (7 for the small one, 23 for the other) and are closed by a plate at both ends. The frontal plate has a hole for the tube and a bay for the electronic box, which is fixed on the counter head, whereas the rear one is plane. Each module (Fig. 1, upper panel) is composed by a polyethylene round shaped frame (outer reflector) with a tongue and groove joint to lock into one another. The central hole of the frame encloses a lead ring (producer) housing an interlocking polyethylene allow cylinder (inner moderator) which realizes the modular slot of the proportional counter. Four tie-rods block in the whole frame preventing any movement of the single elements which are boxed up with a strict mechanical accuracy.

The step by step assembly of the new modular neutron monitor is shown in the lower panels of Fig. 1 (panels 1 to 6).

4 Testing the modular detectors

The small mobile neutron monitor, equipped with the helium counter LND 25382 (Fig. 2, right detector), has been operating since the end of 2006 contemporary with the standard 20NM-64 detector of SVIRCO. The test has been running in a separated room, inside the Observatory, to verify the reliability of the new detector in various environmental/operating conditions.

Taking into account also the results reported by Krueger et al. (2008) and references therein, we looked forward to a higher overall temperature coefficient of the new mobile detector with regard to the standard super neutron monitor; this is expected since Chalk River type BP 28 counters (i.e. the standard $^{10}BF_3$ tubes of the NM-64; Fowler, 1963) are characterized by a negative coefficient which partially balances the positive ones of the other detector components (lead and polyethylene); on the contrary helium filled counters demonstrate a positive temperature coefficient.

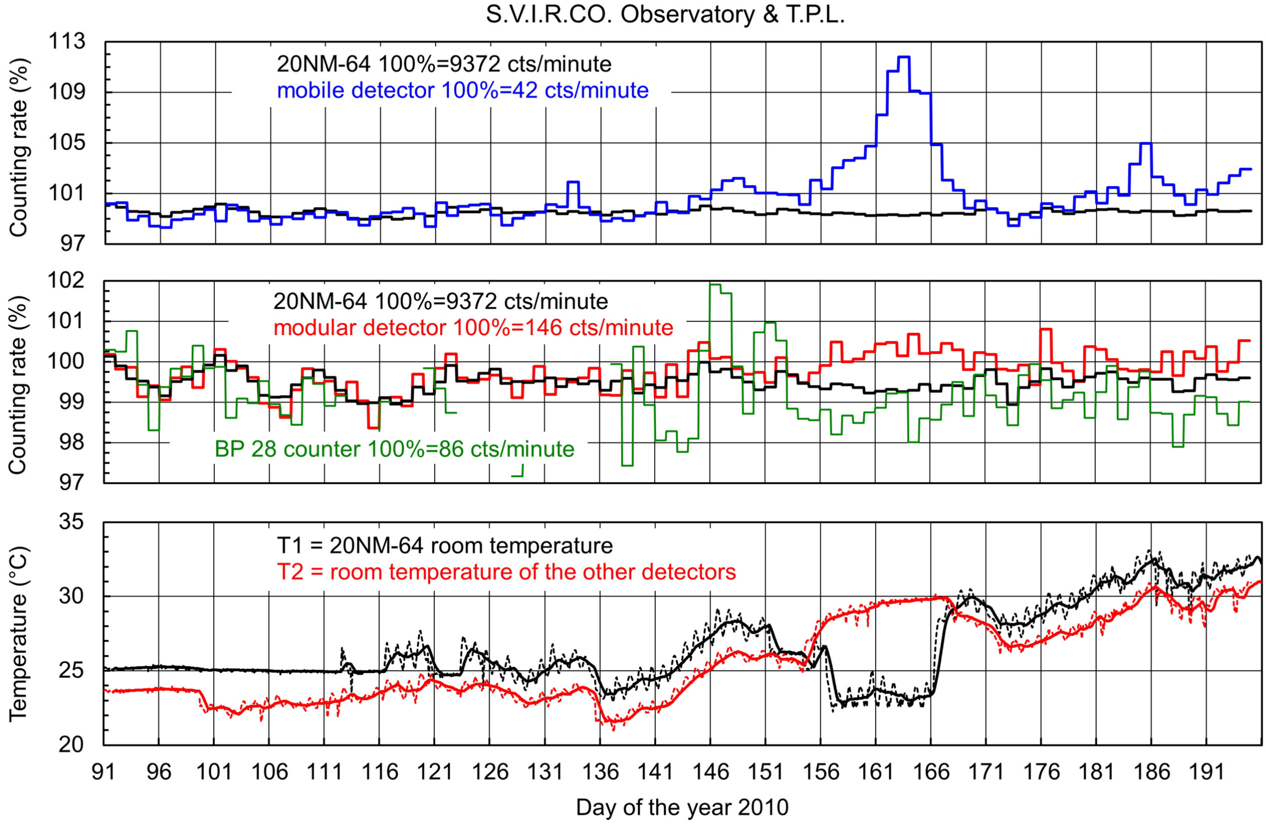

Fig. 3. Daily normalized rates for the mobile detector and the 20NM-64 during 1 April – 13 July 2010 (upper panel). Time history of the daily normalized rates for the modular detector, the bare BP 28 and the 20NM-64 for the same period (middle panel). Measured and averaged room temperatures (lower panel).

Moreover the 3NM-64_^{3}He, we had tested in the past for Antarctica (see the Introduction), proved to be fairly affected by temperature variations although the positive coefficient of LND 25373 helium counters. Nevertheless, an unexpected large instrumental temperature sensitivity affected the mobile detector and a good correspondence in the records of both monitors was found only when they were kept at the same fixed temperature. All the more so the mobile detector should be hosted in a housing equipped with a very efficient air conditioning system.

On 1 April 2010 a new modular bigger detector has been included in the test run (Fig. 2, center detector). Data are recorded with a timing of 1 min by the same acquisition system as the standard neutron monitor.

Records are routinely corrected for pressure variations with an attenuation coefficient of 0.70%/hPa at the pressure reference level of 1009.25 hPa.

Although the new detector was assembled with the same modules and electronics as the smaller one, it shows a reduced temperature sensitivity; the large and nonlinear effects which affect the performances of the mobile detector were not found.

Actually the temperature sensitivities of the two detectors seem to be very different; hence, being such sensitivity dependent on the helium counter type, the behaviour of the longer one (LND 25373) appears to be more adequate for our purposes. On the other hand, we have proved the LND 25373 stability from several years of measurements, even if this number of years is still to small when compared to the one related to the world-wide BP 28 counters use.

A bare standard BP 28 counter (Fig. 2, bottom left), complete with its moderator tube, has been also added in the tests which are still in progress to fix the instrumental temperature effects together with other environmental factors on the performances and reliabilities of both the modular detectors.

The data for the period 27–31 March 2010 were selected to evaluate the average daily counting-rate of the detectors operating at SVIRCO (20NM-64, mobile and modular detectors, bare BP 28 counter); these averages, used to normalize the counting rates, are reported inside each panel of Fig. 3 (to notice the counting rate of the new modular detector increased by a factor of about 3.5 compared with the one of the mobile detector). The upper and middle panels of Fig. 3 illustrate the time history of the normalized daily counting rate of each detector for the period 1 April to 13 July 2010. In the lower panel of the same figure and for the same period, it is shown the time histories of the measured room temperatures: T1 inside the Observatory (20NM-64) and T2 inside the room housing the other monitors (modular, mobile) and bare BP 28.

During the examined period several malfunctioning and failures of the air-conditioning system occurred and the temperature in the rooms varied in a wide range, particularly from 6 June (Doy: 157) to 18 June (Doy: 169) the difference in temperature inside the two rooms raised up to 7°C. In this time interval the counting rate of the modular monitor vs. the one of the standard 20NM-64 (assumed as calibrator) shows a moderate increase (see middle panel of Fig. 3) compared with the boost ($>10\%$) in the rate of the mobile detector (see upper panel of Fig. 3). On the other hand, the rate of the bare boron counter decreases because of its negative temperature coefficient. The variations in the counting rate of the BP 28 counter, during the period between Doy 136 and Doy 153, should be ascribed to malfunctions of the amplifier/discriminator circuit (it was replaced with a new one just on June 2 [Doy 153]). Certainly, with a more long time series of data it will be possible to go deeper into the matter. For this reason, tests on the new detectors are still currently performed aiming to fix their features in different environmental conditions, with specific attention to their temperature sensitivity. The obtained results will be compared with the ones reported by Krueger and Moraal (2010).

5 Conclusions

Uninterrupted cosmic-ray measurements have been performed at SVIRCO Observatory (formerly Station) since July 1957 (Storini and Signoretti, 2009). SVIRCO activity includes the design and development of new monitors, characterized by different geometries and counters.

In this paper we showed that a modular design of detectors makes possible to obtain cosmic-ray monitors equipped with helium filled counters of different lengths (from about 0.80 m up to 2.00 m).

The use of these modular detectors, after the final tests, will be relevant not only for their use outside the observatories (i.e. during measurement campaigns for determined time intervals or outreach purposes) but also for measurement sites with high particle counting-rates, such as mountains or polar areas. This is particularly true because the easy way the new detectors can be moved, even in the biggest configuration (overall weight about 800 kg). In fact, only one operator is required to set up the whole detector, as the modular design has made each loose component reasonably light, since the weight of the heaviest element (lead ring) is about 23 kg. As a result of its geometry the modular detector can also be plainly moved from an observational site to another.

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