Name of research institute or organization:

Helmholtz Zentrum München (GmbH)

Title of project:

Influence of environmental parameters on secondary neutrons from cosmic rays at high altitudes in Alpine region

Part of this programme:

Virtuelles Alpenobservatorium VAO-II
Teilprojekt TPII/02: Einfluss von Umweltparametern und solaren Eruptionen auf die kosmische Strahlung im alpinen Raum
EURADOS Working Group 11 - High energy radiation fields

Project leader and team:

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Project description:

Introduction

The Earth is continuously exposed to high-energy particles from the galactic space and from the Sun. Interaction of these primary particles with the atoms in the Earth's atmosphere produces a complex field of secondary cosmic radiation, which includes for example neutrons, protons, pions, photons, electrons and muons. The secondary neutrons are of particular interest because they contribute up to 60% to the ambient dose equivalent, H*(10), from cosmic radiation at flight altitudes.

Since the 1950's, a number of ground-based detectors (neutron monitors, NMs) record continuously the secondary neutrons from cosmic radiation at ground level, forming a global NM network [1]. Two NMs at Jungfraujoch play a key role as part of this network [2]. The first IGY NM is in operation since 1958. In 1966 it was enlarged to an 18-IGY NM with 18 counter tubes and installed in a detector housing at the terrace of the Sphinx observatory (3,570 m a.s.l.). The second NM, a 3-NM64 with three counter tubes, was put in operation in 1985. This NM is situated in the housing on the roof of the building of the scientific station (3,475 m a.s.l.). It is important to note that NMs are mainly sensitive to high-energy neutrons, and they do not provide detailed information on the spectral fluence rate distribution of secondary neutrons, which is required if neutron fluence rate as a function of neutron energy and ambient dose equivalent are to be quantified.

In order to provide experimental data on the spectral fluence rate distribution in the energy range from thermal up to several GeV, an extended-range Bonner sphere spectrometer (ERBSS) has to be used. In 2005, the Helmholtz Center Munich (HMGU) has installed an ERBSS system at the environmental research station "Schneefernerhaus" (UFS) close to the summit of the Zugspitze mountain, Germany (2,650 m a.s.l.; cut-off rigidity: 4.1 GV in January/February 2008 [3]), to perform continuous measurements of the spectral fluence rate distribution of secondary neutrons from cosmic radiation [4]. In 2007, a second ERBSS system was installed at the Koldewey Station of the French - German Arctic Research Base AWIPEV, located in Ny-Ålesund, Spitsbergen, at sea level (N 78° 55' 24'' and E 11° 55' 15'' , cut-off rigidity: 0 GV in January/ February 2008 [3]) [5].

Measurements with NMs and ERBSS at ground level have shown that snow cover affects the fluence rate of secondary neutrons. This effect could be explained by the seasonal changes of the amount of ground albedo neutrons (from thermal energies to several MeV) depending on the amount of snow and water in the environment surrounding the detectors [6]. The present project aims at quantitatively comparing the readings of NMs with those of an ERBSS in the period with permanent snow cover and during the snowless period. The data measured at Jungfraujoch are also compared to those measured at Zugspitze mountain during the same time period.

Extended range Bonner sphere spectrometer

The HMGU ERBSS system is composed of 3.3 cm diameter spherical ^{3}He (partial pressure of 172 kPa) proportional counters (type SP9, Centronic Ltd.) and 15 polyethylene (PE) spheres of different diameters (2.5, 3, 3.5, 4, 4.5, 5, 5.5, 6, 7, 8, 9, 10, 11, 12, 15 inch; see Fig.1) showing specific energy responses to neutrons. Furthermore, two additional 9 inch spheres are used that include lead shells of different thickness (0.5 and 1 inch), to increase the response for high-energy (E > 20 MeV) neutrons [7]. A bare ^{3}He proportional counter without any surrounding material is used to get a high response to thermal neutrons. The signals from these SP9 proportional counters are amplified in ACHEM7E charge sensitive preamplifiers and a Multiport II, both produced by Canberra Industries Inc. The fluence response functions of all spheres with a ^{3}He proportional counter in their center were calculated by means of Monte Carlo (MC) simulations [8, 9] and experimentally validated at 13 neutron energies between thermal and 14.8 MeV [10, 11] as well as with quasi-mono-energetic neutron fields with peak energies at 244 MeV and 387 MeV [12].

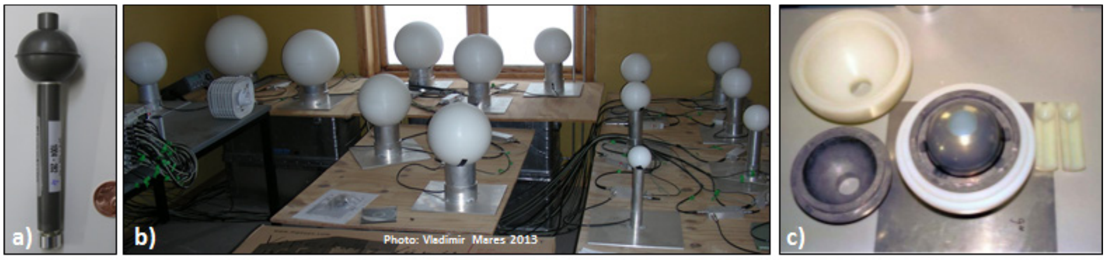


Figure 1. a) SP9 ^{3}He proportional counter (Centronic Ltd.); b) the extended range Bonner sphere spectrometer system installed at the Koldewey Station in Ny-Ålesund, Spitsbergen; c) 9 inch sphere with lead shell (Photos: V. Mares).

Measurement locations

Due to technical reasons it was impossible to place the ERBSS system directly inside the NM detector housing. Nevertheless, the locations below the roof of the building of the scientific station and in the Sphinx astronomical cupola were very close to the NMs and optimally met the objectives of the project. In Fig. 2 the locations of the installed ERBSS are shown.

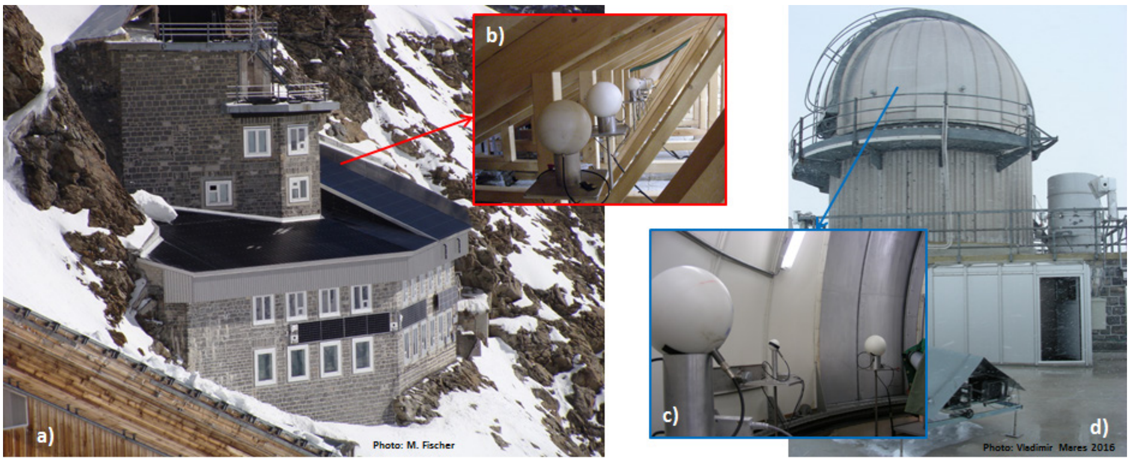
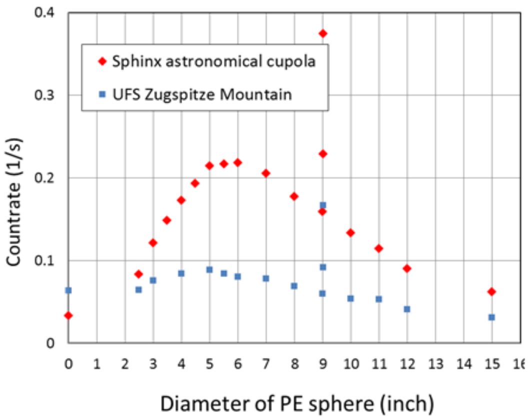


Figure 2. Measurement locations: a) below the roof of the building of the scientific station close to the 3-NM64 location; d) in the Sphinx astronomical cupola, close to the 18-IGY NM installed in detector housing at the terrace (Photos: a) M. Fischer; b), c), d) V. Mares).

Spectral distribution of neutrons measured with ERBSS – first results
Figure 3 (left) shows the mean count rates measured in June 2016 in the Sphinx astronomical cupola at winter conditions with large amounts of snow in the area surrounding Jungfraujoch, and those measured at the UFS station at Zugspitze. The two high data points at 9 inch represent the count rates from the 9 inch PE spheres with lead shells. Data are corrected for a reference pressure of 740 and 643 mbar for the UFS and Sphinx station, respectively. Figure 3 demonstrates that the count rates measured at Sphinx (3,570 m a.s.l.) are about a factor of 2 greater than those at UFS (2,650 m a.s.l.). The figure also shows the different count rates for the bare detector between Sphinx and UFS, suggesting a larger fraction of low-energy (thermal) neutrons at UFS than at Sphinx.

To deduce information on the neutron fluence energy distribution, the counts measured with the single ERBSS channels must be unfolded. Figure 3 (right) shows the unfolded spectral fluence rate distribution using the mean count rates obtained at Sphinx and UFS. The neutron spectral distributions exhibit four regions with different fluence intensity: a) the Maxwell-Boltzmann peak, b) a flat epithermal region, c) an evaporation peak due to neutrons from highly excited residual nuclei in the near environment, and d) a cascade peak that is due to a broad minimum in the neutron cross sections in air.



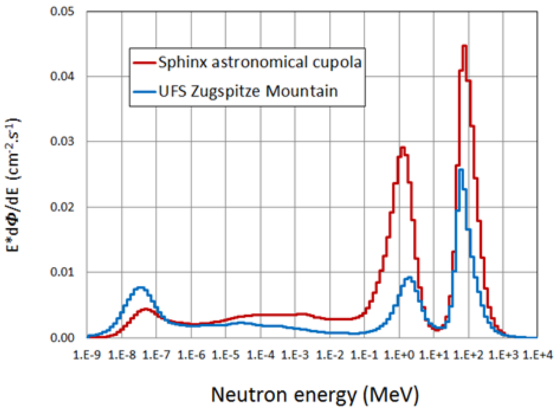


Figure 3. Mean count rates measured in June 2016 at the UFS Zugspitze and in Sphinx astronomical cupola at Jungfraujoch (left), and resulting spectral neutron fluence rate distribution (right).

The neutron spectral distributions shown in Fig. 3 (right) differ in their intensity and shape. These differences are expected because of different elevations of the measurement locations (920 m elevation difference), and environmental geometry. Sphinx is located on the summit of Jungfraujoch, while UFS is situated on the steep mountain slope about 300 m below Zugspitze summit. Figure 4 shows the normalized spectral fluence rate distribution where a large variation of the height of thermal and evaporation peaks are well documented. It is interesting to note that the cascade peaks in Figure 4 are very similar in both spectra.

Both the Sphinx and the UFS neutron spectra were folded with the same fluence-to-dose h*(10) conversion coefficients to estimate the neutron ambient dose equivalent, H*(10). For this, the conversion coefficients from ICRP 74 [13] extended to high energies with data from Pelliccioni [14] were used. The resulting H*(10) dose rate measured in Sphinx is 161 nSv/h which is 2.2 times higher than at UFS Zugspitze (73.5 nSv/h) measured in June 2016.

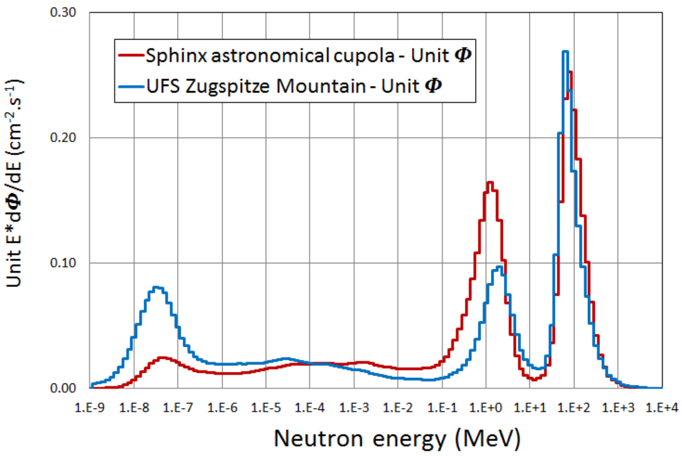


Figure 4. Comparison of spectral neutron fluence rate distribution measured in June 2016 at the UFS Zugspitze and in Sphinx astronomical cupola at Jungfraujoch (see Fig. 3 right) normalized to the total neutron fluence.

Conclusions

During the first measurement campaign in June 2016, the HMGU extended-range Bonner sphere spectrometer was used to characterize the secondary neutrons from cosmic radiation in Sphinx astronomical cupola and on the roof of the building of the scientific station at Jungfraujoch, for the first time. This novel spectrometry results are extremely interesting since they confirm that the secondary cosmic neutrons measured at ground level are strongly affected by environmental conditions.

The second measuring campaign during summer condition without snow cover in area surrounding Jungfraujoch is scheduled for August/September 2017.

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Key words:

Secondary cosmic rays, secondary neutrons, Neutron Monitors, spectral distribution of secondary neutrons, Bonner sphere spectrometer

Scientific publications and public outreach 2016:

Conference papers

Third Virtual Alpine Observatory (VAO) Symposium 2017, Bolzano, Italy, March 28-30, 2017.

Theses

Brall, T., Influence of environmental parameters and Solar eruptions on the cosmic radiation in Alpine region, PhD Thesis, 2015-2018, in preparation.

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