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Environmental radiation dosimetry at Argentine Antarctic Marambio Base (64° 13′ S, 56° 43′ W): preliminary results

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A B S T R A C T

The preliminary results obtained in the first environmental radiation dosimetry campaign performed in the Antarctic region are presented. This experiment is carried out in the framework of CORA (COsmic Rays in Antarctica) Project, a collaboration between Argentine and Italian institutions. After a feasibility study performed in the Antarctic summer 2013, a new campaign has been carried out, started in March 2015, to measure various components of cosmic ray induced secondary atmospheric radiation at the Argentine Marambio Base (Antarctica; 196 m a.s.l., 64°13′ S, 56°43′ W). Due to a very few dosimetric data available in literature at high southern latitudes, accurate measurements are performed by using a set of different active and passive detectors. Special attention is dedicated to measure the neutron ambient dose equivalent in different energy ranges, by using an active detector, the Atomtex Rem Counter, for neutron energy between 0.025 eV–14 MeV and a set of passive bubble dosimeters, sensitive to thermal neutrons and neutrons in the energy range 100 keV–20 MeV. The results obtained in the first six months of measurements for X and γ radiation and for low and intermediate energy neutrons ($E_n \leq 20$ MeV) are presented in this paper and show that at high latitude, also at sea level and at distance from the South Magnetic Pole, the ambient dose equivalent is significant, in particular for the high contribution of neutron component. This involves that at higher altitude (i.e. Antarctic Plateau, over 3000 m a.s.l.) the yearly ambient dose equivalent could be higher than the limit of 1 mSv recommended for general public by the International Commission on Radiological Protection (ICRP).

1. Introduction

The radiation environment around the Earth arises as a result of the interaction of primary galactic cosmic rays (GCR) with nuclei of elements constituting the atmosphere. Primary particles (94% protons, 4% alpha particles, 2% heavy nuclei) entering into the upper layers of the atmosphere, mainly interact with oxygen (21%) and nitrogen (78%) nuclei and produce secondary particles, consisting of protons, neutrons, electrons, positrons, mesons and gamma radiation, which can penetrate deeper into the atmosphere, undergoing further collisions, that leads to a cascade of particles. The radiation environment and consequently the human being exposure, varies with altitude, because of the shielding effect of the atmosphere, with latitude, because of the geomagnetic field shape, and with solar activity because of the modulation effect of solar wind on GCR. (Schraube et al., 1997; Pelliccioni, 2000; Ferrari et al., 2001a; Dorman, 2004; Usoskin et al., 2005; Kowatari et al., 2005, 2007; Spurny et al., 2008; Nakamura, 2008; Vainio et al., 2009; Cheminet et al., 2013; Storini et al., 2015). Sites at high altitude

Abbreviations: CORA, COsmic Rays in Antarctica; GCR, Galactic Cosmic Rays; IAA, Istituto Antartico Argentino; INFN, Istituto Nazionale di Fisica Nucleare; IAPS, Istituto di Astrofisica e Planetologia Spaziale; INAF, Istituto Nazionale di Astrofisica; LET, Linear Energy Transfer.

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and high latitude are of special interest for assessment of environmental radiation dose due to cosmic rays (Zanini et al., 2007, 2009). While wide literature is available on environmental dosimetry at high altitude, in fact in many high mountain research stations continuous radiation monitoring is performed (Florek et al., 1996; Hajek et al., 2002; Mayta et al., 2009; Kubančák et al., 2014; Mishev et al., 2009; Mishev, 2016; Zanini et al., 2005, 2009; Cheminet et al., 2013; Hubert et al., 2016), few dosimetric data are recorded at high latitude. In particular, in northern hemisphere, at Ny-Ålesund Base (Svalbard; sea level, 78°55′ N, 11°55′ E) neutron spectrometry and dosimetry is continuously carried out with a Bonner spheres system by Helmholtz Institute (Rühm et al., 2009; Pioch et al., 2011); otherwise in the Antarctic and Sub Antarctic region there is no systematic dosimetry data collection and few experimental data are available in literature (Report CCH, 1987; Kruetzmann, 2007; Bakshi, 2013).

There are several reasons that suggest the need to investigate the contribution of secondary cosmic rays to environmental radiation in Antarctica, as the South Magnetic Pole displacement (Korte and Mandea, 2008), the Earth magnetic field variation in Antarctic region (Rajaram, 2002; Bieber et al., 2013), the South Atlantic Anomaly (SAA) growing and deeping (De Santis et al., 2012), the lowering solar activity (also in growing cycles) (Hathaway, 2010) and the influence of cosmic ray variability on the total ozone (Lastovicka et al., 2003); all these phenomena could affect the secondary radiation environment in Antarctica (Smart and Shea, 2009; Herbst et al., 2013). The campaign described in this paper represents the first systematic dosimetric study aimed to the assessment of secondary cosmic radiation exposure at high southern latitudes. In fact the population resident for long periods in the Antarctic scientific bases, in particular at those located at higher altitude and closer to magnetic pole, as Dome C (3220 m a.s.l., 75°05′ S, 123°19′ E), Dome F (3810 m a.s.l., 77°30′ S, 37°30′ E), Dome A (4093 m a.s.l., 80°22′ S, 77°21′ E) could be exposed to yearly ambient dose equivalent higher than the limit of 1 mSv per year recommended for general public (ICRP 60, 1991).

The complexity in measuring the secondary atmospheric cosmic rays is due to the variety of radiation field components, that requires the use of different detectors for the electromagnetic and charged component (low LET) and for the neutron component (high LET). In particular, special attention is to be paid to the assessment of the neutron ambient dose equivalent, because of the high neutron RBE (Relative Biological Effectiveness) and the extended energy range of interest (from thermal energies to hundred of GeV). The CORA Project (COsmic Rays in Antarctica) is carried out in the framework of a collaboration between Italian and Argentine Institutions (INFN, IAPS-INAF, UNLP, IAA) at Argentine Marambio Base (Antarctica; 196 m a.s.l., 64°14′ S, 56°37′ W, Rc = 2.31 GV) and it is aimed to perform the first complete, accurate and systematic assessment of the contribution of different components of secondary cosmic rays in atmosphere to environmental dose in the Antarctic region. After a feasibility study performed at Marambio Base in 2013 (4 January-20 May 2013) with a reduced set of instruments (i.e. MDU-01 Liulin-type LET spectrometer and superheated bubble detectors), a more complete campaign has been carried out, started in March 2015, by using various active and passive detectors, both for electromagnetic and charged component (Low LET) and for neutron component (High LET). In this paper the results obtained in six months of measurements are described; for the low and medium energy neutron component, the data analysed concern the energy interval 25 meV–20 MeV. The data obtained by Rem Counter Atomtex BDKN-03, sensitive in the range 25 meV–14 MeV, are compared with the readings of two types of bubbles dosimeters: BDT dosimeters, sensitive to thermal neutrons and BD-PND dosimeters, sensitive in the energy range 100 keV–20 MeV.

2. Materials and methods

In this paper the records of the detectors sensitive to low and intermediate energy neutrons and to low LET radiation used in 2015 campaign, are analysed and listed in Table 1. In addition, the data obtained in the 2013 feasibility study at Marambio Base, in the period 4 January-20 May 2013, are reported and compared with 2015 dosimetric data. The comparison concerns the results from bubble detectors BDT (0.025 eV $\leq$ E_n $\leq$ 4 eV), BD-PND (100 KeV $\leq E_n \leq$ 20 MeV) and MDU-01 Liulin-type LET spectrometer, used in both campaigns.

2.1. Neutron detectors

The active neutron dosimeter (BDKN-03, ATOMTEX, Minsk, Republic of Belarus; Fig. 1) used in the campaign, is a hand-carried measurement instrument designed to measure neutron ambient dose equivalent rate, based on a ^{3}He proportional counter allocated in a polyethylene moderator. An operation algorithm provides measurement continuity and real time statistical processing of measurement results; the instrument is sensitive to ambient dose equivalent rate in the interval 0.1 μSv/h–10 mSv/h, to integral ambient dose equivalent in the interval 0.1 μSv–10 Sv and to neutron flux density in the interval 0.1–10^4 neutron s^{-1} cm^{-2}. In addition, a set of passive bubble dosimeters (BD and BD-PND, Bubble Technology Industries, Ontario, Canada; Fig. 2) is used. The detectors are constituted by vials filled by tissue equivalent gel in which superheated freon drops are dispersed; when the detector is activated, by setting the content of the vials to environmental pressure, the entire system is in unstable state; as a consequence, when a neutron interacts with the gel, producing secondary charged particles, the energy transfer to the freon drops produces bubbles trapped in the gel. Their number is related to the neutron ambient dose equivalent. BDT detectors are sensitive to neutrons in the energy range 25 meV–4 eV; BD-PND detectors are sensitive to neutrons in the energy range 100 keV–20 MeV.

2.2. X and γ ray detector

The X and γ ray dosimeter (BDKG-04 detector, ATOMTEX, Minsk, Republic of Belarus), is constituted by a scintillation plastic detector (30 × 15 mm) and thickness 150 μm, sensitive to X and γ ray dose rate in the interval 0.05 μGy/h–10 Gy/h and to integral dose in the

Table 1
Detectors used at Marambio Antarctic Base.

Active detectors	Passive detectors
1. Rem Counter Atomtex BDKN-03 ***Neutron Energy range:*** *25* meV $\leq E_n \leq$ *14* MeV ***Measurement range:*** *0.1* μSv/h-*10* mSv/h *Intrinsic percent error: 20%*	**1. BDT** ***Neutron energy range:*** *25* meV $\leq E_n \leq$ *4* eV *Intrinsic percent error: 30%*
2. Atomtex BDKG-04 ***X - γ energy range:*** *50* keV $\leq E_n \leq$ *3* MeV ***Measurement range:*** *0.03 μG* y/h *-10* Gy/h *Intrinsic percent error: 20%*	**2. BD-PND** ***Neutron energy range:*** *100* keV $\leq E_n \leq$ *20 MeV* *Intrinsic percent error: 30%*
3. Liulin-I MDU-1 ***LET range:*** *0.135-69.4* keV/μ *Intrinsic percent error: 15%*	