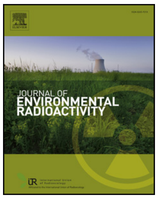
Journal of Environmental Radioactivity 190–191 (2018) 31–38

Contents lists available at ScienceDirect

Journal of Environmental Radioactivity

journal homepage: www.elsevier.com/locate/jenvrad



Development of a national cosmic-ray dose monitoring system with Health Canada's Fixed Point Surveillance network

Chuanlei Liu*, Weihua Zhang, Kurt Ungar, Ed Korpach, Brian White, Mike Benotto, Eric Pellerin

Radiation Protection Bureau of Health Canada, Ottawa, ON K1A 1C1 Canada

ARTICLE INFO

Keywords:
Fixed point surveillance network
FPS
Cosmic rays
Effective dose
Sodium iodide detector
NaI

ABSTRACT

This work explores the application of Health Canada's Fixed Point Surveillance (FPS) network for cosmic ray monitoring and dose estimation purposes. This network is comprised of RS250 3 inch by 3 inch Sodium Iodide (NaI) spectroscopic dosimeters distributed throughout Canada. The RS250's high channel count rate responds to the electromagnetic and muonic components of cosmic ray shower. These count rates are used to infer cosmic ray doses throughout FPS locations. The derived dose was found to have an accuracy within 6.5% deviation relative to theoretical calculation. The solar cycle effect and meteorologically induced fluctuation can be realistically reflected in the estimated dose. This work may serve as a basis to enable the FPS network to monitor and report both terrestrial and cosmic radiation in quasi-real time.

1. Introduction

For most individuals on Earth, the exposure to natural radiation background, comprised primarily of terrestrial and cosmic radiation, is much more significant than the exposure to man-made sources (UNSCEAR, 2000). On average, the annual exposure to these natural sources amounts to 2.4 mSv worldwide, of which the cosmic radiation contributes about 16% or equivalent to 0.39 mSv. The population-weighted cosmic dose over a 99% world population coverage was estimated to be 0.32 mSv/a and ranges from 0.23 to 0.70 mSv/a (Sato, 2016). Across Canada, the calculated cosmic ray dose varies from 0.30 mSv to 0.84 mSv annually, depending largely on the geographical latitude and altitude, while the population-weighted dose at ground level is estimated to 0.31 mSv/a (Chen et al., 2009).

At Health Canada, the Radiation Protection Bureau (RPB) has a long-standing commitment to protecting and promoting the health of Canadians from ionizing radiation exposure in daily living and working environments. For almost two decades, the RPB has been operating a national FPS network (FPS, 2017) for radiation monitoring purpose. The use of spectroscopic dosimeters in the FPS network supports health impact assessment arising from both Naturally Occurring Radiation Materials (NORM) and man-made sources.

In this work, the FPS network's potential as a cosmic dose monitoring system is explored and discussed. The count rate recorded in the highest-energy channel of the FPS detector, containing the detector's response to photons and directly ionizing components of cosmic radiation, is used for dose estimation. The study explores the possibility of the FPS network becoming a monitoring system reporting both terrestrial and cosmic radiation doses in quasi-real time from a single instrument type. The FPS network's terrestrial monitoring data has been incorporated into EURDEP (the European RadiIological Data Exchange Platform) of the European Commission (EURDEP, 2018). The data exchange effort empowers the emergency response capability at regional and global scales to nuclear events. Expanding the measurement functionality of the current system to include a cosmic dose contribution will further efforts and participation in the international collaboration on radiological data exchange by providing a complementary basis of inter-comparability with other contributing national networks. These latter typically record terrestrial and cosmic doses as a single unresolved value. The timely reporting the magnitude of the cosmic dose levels will provide a broad geographic and population representation of the magnitude of the cosmic ray dose exposure, including the real short term and long term variation in this dose level. The magnitude of the variation itself is often larger than routine local anthropogenic contributions (FPS, 2017) and contributions from distant nuclear accidents (HC, 2015). Thus, the measurement of this significant natural component of dose provides the public with an immediate scaling of different contributions to exposure as a basis of risk communication. Furthermore, it helps the public become familiar with the natural background radioactivity through freely accessible public maps (EURDEP map, 2018; Szegvary et al., 2007; Cinelli et al., 2017). Finally, the network measurement of a pure cosmic dose can provide an immediate characterization of the ground based influence of major space weather events with regional and temporal discrimination that complements the

---

* Corresponding author.
E-mail addresses: Chuanlei.Liu@canada.ca, chuanlei.liu@canada.ca (C. Liu).

https://doi.org/10.1016/j.jenvrad.2018.04.023
Received 27 March 2018; Received in revised form 27 April 2018; Accepted 27 April 2018

existing ground based systems explicitly designed for such environmental surveillance (Bartol Research Institute Neutron Monitor Program, 2017; Natural Resources Canada, 2017).

2. The FPS network and cosmic dose calculation

2.1. The FPS network

Beginning 2002, the FPS network was gradually built up, monitoring health risks in radiation exposure arising both from NORM and man-made sources. Anthropogenic radioisotopes of particular interest are the noble gases (i.e. ^{133}Xe, ^{135}Xe and ^{41}Ar) which are released from Nuclear Power Plants and some nuclear events. A stripping algorithm (Grasty et al., 2001a) has been developed to process data such that radioisotopes are identified and quantified. For dose estimation, the system was calibrated for Air Kerma (the Kinetic Energy Released per Unit Mass) and for Ambient Dose Equivalent, H*(10), and thus allows a measure of health impact from the external radiation sources presented (Grasty et al., 2001a; b).

To date, over seventy five gamma detectors, organized as several sub-networks, have been deployed in Canada's major population centres and areas in proximity to ports or nuclear power plants. A map of the FPS deployment locations is provided in Fig. 1. These stations cover a latitude range from the Canada-United States border to the Arctic region, and an elevation from a few to a thousand meters above sea level, as shown in Table 1.

The gamma detector used in the FPS is the RS250 (RS250, 2017), a 3 inch by 3 inch Sodium Iodide (NaI) detector. It was optimized to provide radiation measurement over a wide energy range from 15 keV to 3 MeV, and has a typical energy resolution of 7.5% at 662 keV. The monitoring data is collected, transmitted, and analyzed at a central server at a frequency from minutes to an hour. In the standard operation mode, data is integrated over a 15-min period and is processed immediately as available to the server. In this sense, FPS can serve as a (quasi-) real time radiation monitoring system, which is practically valuable in responding to nuclear events or potentially to extreme space weather. To overcome the impact of temperature variation, known gamma radiation from NORM was utilized to stabilize the instrument calibration from drift in instrument gain.

An example of a typical RS250 spectrum measured at the RPB station is given in Fig. 2. The terrestrial radiation background from potassium and from uranium and thorium progenies characterizes the full energy range from keV level up to 3 MeV. Above this region, the NORM contributions are nearly absent and cosmic rays dominate. To record RS250 response at 3.5 MeV and above, a dedicated Cosmic Channel (CC) was created at the high energy end of the spectrum. At the RPB station, the CC count rate is 2051 per 15-min period of time, equivalent to 2.28 counts per second, based on the monthly average in July 2016. By assuming Poisson statistics, the uncertainty solely from counting is thus 2.2% for each 15-min measurement. The count ratio between CC and all channels below approximately represents the detector's relative response to cosmic rays and NORM. This ratio varies to certain extent from location to location in the FPS network. At the RPB station, the ratio is about 1.3%.

2.2. Cosmic-ray spectrum above 3.5 MeV

An indoor experiment was conducted at RPB to study the RS250 response to cosmic rays, especially those registered with an energy above 3.5 MeV in the standard operation mode. As illustrated in Fig. 3, the experiment was configured to have two scintillator plates atop a RS250 detector such that the cosmic muon contribution could be discerned from other cosmic components using coincidence techniques. The measurement time for the indoor experiment was about 20.4 h.

The scintillator plates used were rectangular Saint-Gobain BC408 plates with a dimension of 66 × 91 × 5 cm. The plates are composed of a base material of polyvinyltoluence with a density of 1.032 g/cm^3. The use of two plates allowed confirmation and identification of the muon detection within BC408 plates through coincident detections. In addition, comparison between the BC408 individual and coincidence spectra suggests that an energy threshold at ∼3 MeV for the BC408 is optimal for performing coincidence measurement between the BC408 plate (the bottom one is used in this work) and the RS250. All spectra obtained in the experiment are shown in Fig. 5 and discussed in Section 3.2.

The RS250 deployed at the RPB station has a typical High Voltage Power Supply (HVPS) of ∼700 V and uses a 512-channel spectrum analyzer. Such configuration ensures adequate channels (∼8 channels)

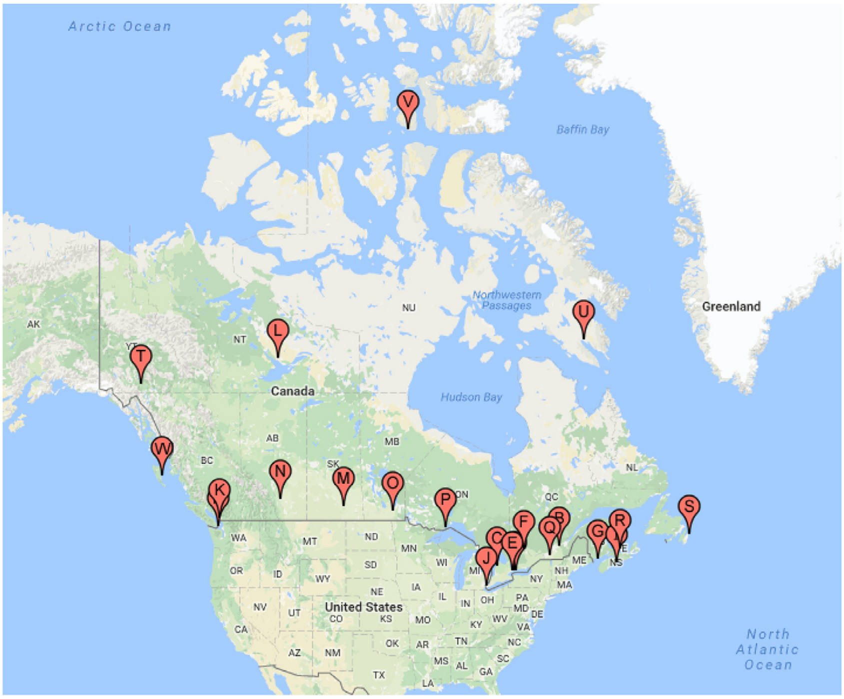


Fig. 1. The FPS network operated at RPB at Health Canada. A: Pickering system B: Gentilly system C: Bruce system D: Darlington system E: Toronto system F: Chalk River system G: Point Lepreau system H: Vancouver Island system I: Halifax system and the Regional system (J: Amherstburg K: Vancouver L: Yellowknife M: Regina N: Calgary O: Winnipeg P: Thunderbay Q: Montreal R: Charlottetown S: St. Johns T: Whitehorse U: Iqaluit V: Resolute W: Haida Gwaii). Markers A and D, I and H are hidden behind E, R and K respectively.