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Sub-daily periodic radon signals in a confined radon system

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ABSTRACT

Signals from radon in air enclosed in a tight canister are recorded by five gamma detectors located around the horizontal plane and along the vertical axis. At steady state conditions (diffusion input = radon decay) the primary variation is of daily radon (DR) signals with amplitudes of around 20–25%. The DR signal, with a rounded form, is characterized by periodicities of 24-, 12- and 8-h (i.e. 1, 2 & 3 CPD). Similar DR variation patterns occur in the east and west sensors whereas inverse DR patterns are recorded by the north and south sensors. Short term (ST) signals, having saw tooth form and periods of 2–3 h (frequencies in the range of 9–12 CPD) are observed at all five sensors and are superimposed on the DR signals with relative amplitudes of around 20%. They exhibit differing forms and phase at the different sensors, located at different directions around the canister. The latter is similar to the spatial manifestation of form and phase of the DR signal in such experiments, indicating a communality of the driving mechanism. At this stage a geophysical explanation cannot be presented for the ST signals. In this respect a peculiar observation is that their extraordinary occurrence coincides in time with the Tohoku Earthquake ($M_w = 9.0$; 11 March 2011).

1. Introduction

Radon (^{222}Rn) is a radioactive inert gas formed by disintegration from ^{226}Ra as part of the ^{238}U decay series. The combination of its noble gas character and its radioactive decay make it a unique ultra-trace component for tracking temporally varying natural processes. In the geological environments it occurs at varying concentrations and shows large and complex temporal variation patterns which exhibit periodic and non-periodic signals of annual to daily scale. The issue of its exceptional behavior was addressed in numerous works in the last decades reporting on observations from diverse environs and situations. Many different environmental, geodynamical and physical processes have been suggested as influencing the variability of radon. Despite the efforts of the scientific community, the nature of the physical processes driving the temporal patterns observed in ^{222}Rn time series remains elusive and interpretation of the observed phenomena on a physical basis is not straightforward. Suggested processes such as exhalation, diffusion, advection, and transport in porous media, stack effect, atmospheric influence (variation of pressure, temperature, and humidity) and solar tides sometimes even oppose each other.

Advance in the investigation of the radon system in air was achieved by the radon research group at the Geological Survey of Israel (GSI). Extensive monitoring measurements conducted since 1990 in subsurface geological sites are complemented in recent years by simulation experiments in the laboratory. In these radon signals in an enhanced confined mode (ECM) are investigated (Steinitz et al., 2011). In these experiments a relatively high level of radon is maintained inside a confined volume by diffusion (via tube) from a connected radon source. The nuclear radiation from the radon (and progeny) in the confined volume is monitored mainly with alpha sensors (inside volume) and gamma sensors (inside and outside the volume). Under such conditions where radon only diffuses into a closed volume it is expected that stable and uniform nuclear radiation will be observed determined by a balance between the diffusion controlled supply and the decay rate of radon (half-life of 3.82 days). In difference with the expected, nuclear radiation from the radon (progeny) shows (Steinitz et al., 2011, 2013: a) temporal variations (signals) spanning annual to daily scale; b) directionality of the nuclear radiation reflected as inverse signal patterns in the east–west versus north–south directions; c) patterns, periodicities and their characteristics which are similar to those observed on radon in the geological environment.

Previous observations derived from the subsurface geological environment indicated the unique temporal variations of nuclear radiation from radon (Steinitz et al., 2007; Steinitz and Piatibratova,

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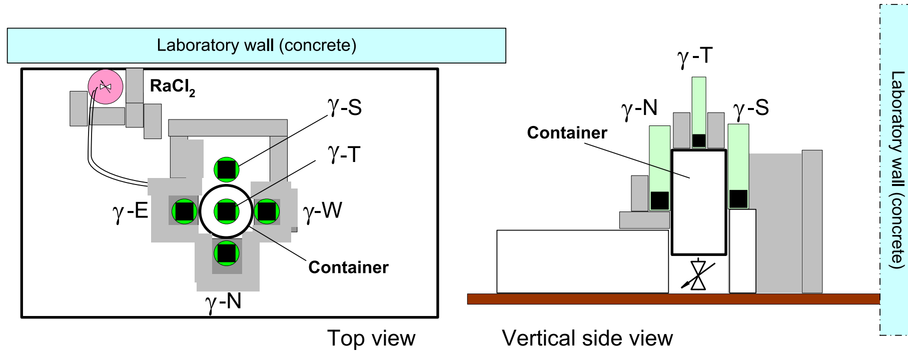

Fig. 1. The experiment comprised of a 3.53 L cylindrical SS canister and five gamma sensors in vertical orientation. ^{222}Rn diffuses from a commercial source to the experimental volume via a tube and valves. All components of the system – radon source and air – are enclosed within leak tight SS components (canisters, tube) which are connected using UHV flanges and valves. Four sensors (PM-11) are placed in four orientations (γ-E, γ-N, γ-W, γ-S) next to the middle of the canister. A further sensor (Scionix) is placed in the middle of the top of the canister (γ-T). Lead shielding minimized the effect of radiation from the source lowered environmental radiation. The laboratory wall is oriented E–W.

2010a,b), and raised the suggestion that an unrecognized geophysical driver influences the variations, primarily in the diurnal band. The outcome of the first experiments using the ECM configuration substantiated this assertion and led to the further suggestion that the prominent diurnal periodicity was associated with solar tide (Steinitz et al., 2011). Reanalysis of the long experimental radon time series by Sturrock et al. (2012) corroborated the results from Steinitz et al. (2011) and provided further evidence for the solar influence by identifying solar rotational frequencies (which are independent of Earth) in time series of the nuclear radiation and by showing a 24-h modulation of the gamma radiation of the radon system in the annual and in the solar rotational frequency bands. In conformity with the view in previous works Sturrock et al. (2012) suggested that the decay is influenced by solar radiation and solar neutrinos were considered as a possible particle involved.

Systematic radon signals of sub-daily duration have been observed in the geological environment (Steinitz and Piatibratova, 2010a,b). In this contribution an occurrence of sub-daily short-term (ST) signals in a simulation experiment are described.

2. Methods

Simulation experiments of radon signals (Steinitz et al., 2011, 2013) are performed using the Enhanced Confined Mode (ECM) principle, which is based on:

1. A tight container in which a high level of radon in air is maintained.
2. A radon source (commercial – $RaCl_2$) connected with a tube (and valves) supplies radon in a diffusion regime.
3. Nuclear radon detectors – alpha as internal or directly connected to the container volume, and/or gamma detectors which are either inserted into the volume (large volume) or placed outside next to the container. Our field and laboratory experience has shown that similar results in monitoring temporal variation of radon are obtained using alpha and gamma detectors. Furthermore, Zafrir et al. (2011) have shown that gamma sensors are advantageous due primarily to the higher count rates.
4. When using the gamma radiation a lead shield is added to minimize the effect of environmental gamma radiation and the eventual influence of the source on the detectors.

The radiation (α, γ) from the radon in the system is expected: a) to be proportional to concentration in the container air; b) to rise once the source is connected due to diffusion from the source, and c) to level-off once the rate of diffusion equals the rate of decay of radon. Experiments conducted using different configuration showed that in contradiction with the expected large temporal variations are encountered (Steinitz et al., 2011, 2013). The phenomenology of these variations and the characteristics of the signals resemble those encountered in the natural geological environs.

The specific experiment dealt with here is placed on a table, north of the east–west laboratory wall (Fig. 1). The experimental work is based on an enhanced confined module (ECM) in which an enhanced level of radon is maintained inside a confined volume by diffusion (via tube) from an attached commercial radon source. The nuclear radiation from the radon in the confined volume is monitored, basically, with gamma sensors placed outside the confined volume. The setup used (Fig. 1) is the setup used in EXP #1 described by Steinitz et al. (2011). It consists of a 3.53 L cylindrical (Ø = 15 cm) stainless steel (SS) canister, ultra-high vacuum tested, and equipped with a UHV valve. Radon is let in (diffusion) from a commercial ^{222}Rn source (103.2 kBq), placed within a leak tight SS enclosure, via a UHV valve on the source and a 60-cm-long SS pipe, resulting in a radon level in the order of 8400 kBq/m^3. In this specific experiment the atmosphere inside the ECM was of argon. Air was first evacuated from the canister and from the radon source to around 5×10^{-2} mbar. After evacuation the source valve was closed and argon was introduced to around 1 atm (controlled with a Pirani gauge). Once the system was isolated diffusion of radon was enabled by opening the source valve.

Detection of temporal variation of radiation is achieved by utilizing gamma detectors with NaI(Tl) scintillation detectors. The utilization of gamma detectors for monitoring radon in air has been described in detail by Zafrir et al. (2011). Five gamma detectors were placed around the canister. Four sensors (PM-11; Rotem Industries Inc.) are based on 2 × 2″ crystals tuned to the energy range of 50–3000 keV. These gamma sensors (PM-11) are set vertically around the central horizontal plane of the canister. They are placed, relative to the canister, according to the global directions. The orientation of these sensors is estimated to deviate not more than 5° from the true geographic directions. To allow comparison among them these sensors were adjusted (inter-calibrated) during the experiment using the radon in the canister. This was done by placing each sensor at position north and recording the radiation from radon in the canister (relative adjustment: North = 1, East = 1.65, West = 1.8, South = 1.78). A further gamma sensor (Scionix Ltd.) is based on a 36 × 76 mm crystal and is tuned to the energy range of 475–3000 keV. It was placed on top of the canister, in a vertical position along the axis of the canister. The