Development of Online Radon and Thoron Monitoring Systems for Occupational and General Environments

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Abstract

Online radon and thoron monitors have been developed using ZnS(Ag) detector for continuous monitoring of concentrations in occupational and general environments. Their performance has been tested successfully both in laboratory and field conditions. Special features of these monitors include low cost, high sensitivity and non-interference of humidity and trace gases. The capability of these radon monitors for networked radon monitoring in U mines and in the U-tailings pond has been demonstrated. The thoron monitor is designed for stack monitoring of thoron release in a thorium processing facility. Being highly sensitive, these monitors can also be used for radon/thoron monitoring in dwellings, radon exhalation measurements, radon concentration in water samples and thoron emission measurements from monazite sands in High Background Radiation Areas.

Introduction

Unlike time-integrated monitoring of radon and thoron which is mainly limited to dosimetric applications, continuous online monitoring yields insight into spatio-temporal correlations, build-up in confined spaces, hourly variations induced by pressure and temperature variations, atmospheric transport, extreme excursions, duration of specific highs and lows etc. While the increased computational capabilities on environmental modeling have given rise to greater needs for real time data, the corresponding developments in networking and data transmissions have made it possible to achieve large scale simultaneous measurements. Such facilities are being increasingly developed as part of systems for earthquake predictions, in uranium mining, environmental monitoring and geophysical research. Apart from these general applications, monitoring radon concentrations in Uranium mining and thorium processing facilities is important to evolve effective strategies to reduce radiation doses to occupational workers. With this in view, automatic radon and thoron monitors have been developed as described below.

Description of systems

Online Radon Monitor

Traditionally, the Lucas scintillation cell is used for one point sampling of radon (Lucas, 1957; Abbady et.al., 2004). The counting is carried out after a delay of 3 hrs, allowing for the decay products to achieve radioactive equilibrium with radon. The same Lucas cell may be used for continuous radon measurements with the help of an algorithm for calculation of radon concentration for each sampling time interval. The algorithm accounts for the...
fractions of radon decay products contributing to the total counts formed by radon in the current interval and in its preceding intervals. This innovative algorithm for correlating the counts with the radon concentration has been developed in-house, based on the theoretical growth and decay equations of radon decay products. Using this algorithm, two versions of radon monitor have been developed. The portable version called SRM (Scintillation Radon Monitor), utilizes a ZnS:Ag based scintillation cell for measurement of alpha from radon and its decay products. The other version named as ECAS (Electrostatic Collection and Alpha Scintillation) is developed using an electrostatic chamber for collection of charged decay products of radon on the ZnS:Ag surface. The details of these two versions are described below.

**Portable Radon Monitor - SRM**

The schematic of the microprocessor based SRM and its photograph are shown in Figs.1a & 1b respectively. Radon is sampled into the scintillation cell (150 cc) through a “progeny filter” and “thoron discriminator” eliminating radon progenies and thoron. The thoron discriminator based on “diffusion-time delay” does not allow the short lived thoron 220Rn (half life 55.6 sec) to pass thorough. The alpha scintillations from radon and its decay products formed inside the cell are continuously counted for a user-programmable counting period by the PMT and the associated counting electronics. The alpha counts obtained are processed by a microprocessor unit as per the developed algorithm to display the concentration of radon.

Considering the limitations on the range of the alpha particles (~6 cm), the dimensions of the scintillation cell were optimized to achieve high sensitivity (1.2 cph/Bqm⁻³) with lower detector volume (150 cc). The low detector volume, delivering very high sensitivity per unit activity of radon (6000 cph/Bq), is very useful for measurements of mass exhalation and surface exhalation of radon from various naturally occurring radioactive materials.

**High Sensitivity Radon Monitor - ECAS**

The low range of the alpha particles (~6 cm), makes it difficult to enhance the sensitivity of the SRM monitor just by increasing the dimensions (or volume) of the scintillation cell. Hence, an electrostatic collection technique for charged decay products of radon, namely ²¹⁸Po⁺ and ²¹⁴Pb⁺ ions, on the ZnS:Ag scintillator has been used. The schematic and the photograph of ECAS are shown in Figs.2a & 2b respectively. As in SRM, the sampling of radon into the
detector volume (1000 cc) is carried out by diffusion through “progeny filter” and “thoron discriminator” in succession. The electric field for various detector geometries and dimensions were modeled using commercial software and the optimal field with this simple-to-fabricate cathode and anode design was obtained. Accordingly, an electrical potential of –2 KV is applied to an aluminized mylar (12µm thickness) covering the ZnS:Ag scintillator coated on the cathode which is a solid perpex cylindrical block with a hemispherical head. The alpha scintillations produced by $^{222}$Rn, $^{218}$Po and $^{214}$Po are detected by the PMT and the associated counting electronics. The alpha counts obtained are processed by a microprocessor unit to display the concentration of radon.

**Online Thoron Monitor**

The indigenously developed microprocessor based thoron monitor consists of two Lucas scintillation cells (LSCs) which are coupled to a separate photomultiplier tube with associated pulse preamplifier and scalar. Its schematic diagram and photograph are shown in Figs.3a & 3b respectively. The LSC is a 2” dia and 3” height cell built in S.S. 316 material with inbuilt two levels of radon-thoron progeny pre-filters for reducing the background contamination. The flow to either LSC is switched by microprocessor.
at the intervals specified through programmable parameters. During each interval, while one cell counts the background, the other cell measures counts due to both thoron and the background activity. The unit automatically calculates and logs the thoron concentration data in the memory.

**Performance evaluation**

Various tests were carried out under controlled conditions in a chamber to evaluate the performance of the monitors. The first set of experiments was carried out to compare the measurements of online radon monitors against the commercially available system AlphaGUARD. A fair agreement was seen between ECAS, SRM and AlphaGUARD as shown in Fig. 4. Similarly, the measurements with the indigenous thoron gas monitor was compared with that obtained with the commercial unit RAD-7 (Fig. 5). Since the background is high at higher thoron concentrations, the thoron monitor is tested upto 2 MBq/m³. For both the monitors, the variations were within 3%.

To evaluate the response time of SRM radon monitor and also to study the effectiveness of algorithm based calculation, the measurements of radon counts and concentration for sudden rise and fall of radon was carried out which is shown in Fig. 6. The radon concentration of the order of 10 KBq m⁻³ was suddenly introduced inside a closed chamber and after 3 hrs, it was suddenly brought down to 100 Bq m⁻³ (a factor of 100). The gross counts show a slow rise due to time taken to build-up and a slow fall due to the presence of residue activity. However, the algorithm used for the estimation of radon concentration as measured by SRM corrects for these delays and depicts the sharp changes in the concentration as expected. To demonstrate the capability of ECAS to operate in high humidity conditions measurements were carried out by varying the humidity as shown in Fig. 7. As may be seen, the effect of humidity does not arise as the electrostatic voltage is not utilized for collection of radon progenies.
To assess the long term measurement capability of SRM and ECAS radon monitor, they were operated continuously in a room for about two weeks without any manual attendance. Both the instruments performed successfully with agreements in radon concentration as seen by the trends given in Fig. 8.

Additional tests were also carried out in controlled conditions to obtain technical specifications of radon and thoron monitors. These specifications are summarized in Table 1.

Table 1: Technical Specifications of online radon/thoron monitor

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Online Radon Monitor</th>
<th>Online Thoron monitor</th>
</tr>
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<tbody>
<tr>
<td>Sensitivity</td>
<td>ECAS: 2.8 cph/(Bq/m³) SRM: 1.2 cph/(Bq/m³)</td>
<td>0.7 cph/(Bq/m³)</td>
</tr>
<tr>
<td>MDL</td>
<td>ECAS: 8 Bq/m³ at 95% confidence, 1 hr counting</td>
<td>15 Bq/m³ at 95% confidence, 1 hr counting</td>
</tr>
<tr>
<td></td>
<td>SRM: 14 Bq/m³ at 95% confidence, 1 hr counting</td>
<td></td>
</tr>
<tr>
<td>Upper Detection Limit</td>
<td>50 MBq/m³</td>
<td>50 MBq/m³</td>
</tr>
<tr>
<td>Cycle time</td>
<td>15 / 30 / 60 min – Fast mode 1 / 2 / 3 h – Sensitive mode</td>
<td>10 / 30 / 60 min</td>
</tr>
<tr>
<td>Radon Response time</td>
<td>20 min for 95% of radon in air</td>
<td>10 min for 95% of thoron in air</td>
</tr>
<tr>
<td>Thoron Interference</td>
<td>&lt; 5% using thoron discriminator</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Humidity and Trace gas</td>
<td>&lt; 5% in ambient environment (20% to 60% RH) and &lt; 10% in</td>
<td>Negligible</td>
</tr>
<tr>
<td>effect</td>
<td>highly humid environment (60% to 95% RH) for ECAS.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Negligible for SRM</td>
<td></td>
</tr>
</tbody>
</table>
Applications of radon monitors

The features such as uninterrupted online operation, high sensitivity and free from humidity / trace gas interference open up diverse applications in radon and thoron studies. These include calibration of passive detector systems, indoor/outdoor radon monitoring, network based online radon monitoring in workplaces such as underground uranium mines, radon emission studies from soil/water/building materials, field survey and site monitoring such as uranium tailings pond. Some of the potential applications have been demonstrated below.

**Measurement of radon emission from soil and building materials.**

Soil in the earth’s crust is the major source of radon emission into the environment. We have demonstrated the use of ECAS for measuring the rate of radon emission from soil. The “accumulator” technique has been used for this. The soil area of interest is covered with the accumulator and the radon build up in it monitored using ECAS connected in a closed loop fashion with an external pump. The buildup data is fitted to an appropriate model to extract the radon emission rate from soil. The experiment was conducted in an open ground (Fig. 9). The accumulator technique of Sahoo and Mayya (2010) was followed to measure the radon emission rate from soil which was found to be 80 Bq m$^{-2}$ h$^{-1}$. This was close to the value obtained using RAD-7. Knowing that building materials are the second most importance source of radon, we used ECAS to measure the radon emission from cement samples (Fig. 10) using the mass exhalation measurement procedure of Sahoo et. al. (2007). The emission rate was found to be 7.2 mBq kg$^{-1}$ h$^{-1}$ which falls within the range reported by Sahoo et al., 2007.
Networking in Uranium mines at Turamdih - field trial

The networking capability with fast response of ECAS is useful for monitoring uranium mines and tailings pond, with multiple such units networked to give real-time spatial profiles of radon. In this context, few online monitors were installed inside the uranium mines (Fig. 11) at the locations where the concentration of radon is expected to be high. Results of the measurements are shown in Fig. 12.

indigenous monitors will serve as import substitutes for the Indian radon/thoron research programmes.

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References


