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## **IN SITU AIRBORNE RADON MONITORING FOR STANDARDS COMPLIANCE WITH OSHA-NRC-EPA**

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### **ABSTRACT**

*In situ* radon monitoring is necessary to characterize and qualify workplace and other environments in order to determine the need for occupational exposure assessments, to demonstrate compliance with standards and to verify the effectiveness of mitigation efforts. A web-based, energy sensitive electrostatic chamber radon monitoring system, developed at the University of Guelph, can be used to accomplish such occupational and environmental monitoring needs. This presentation illustrates the application of this monitoring system to radon monitoring challenges such as dynamic surveillance to define restricted “airborne radioactive areas”, assessing the need for radon exposure monitoring of workers via real-time radon concentration measurements, and performing this monitoring

### **INTRODUCTION**

Exposure to high concentrations of radon and radon decay products correlated with the incidence of lung cancer in several groups. In the United States of America (USA), National Research Council’s report of the sixth Committee on Biological Effects of Ionizing Radiations (BEIR VI) addresses the risk of lung cancer associated with exposure to radon and its radioactive progeny [1]. Many countries around the world adopted the limits of exposure recommended by the International Commission on Radiological Protection (ICRP) [2] at the national and regional level. Accordingly, in USA the regulations and guidelines are provided by Nuclear Regulatory Commission (NRC), and federal agencies such as Occupational Safety and Health Administration (OSHA), Environmental Protection Agency (EPA), Department of Energy (DOE), and Agency for Toxic Substances and Disease Registry (ATSDR) [3-6].

Seasonal variations were reported at above ground locations around the world with maximums occurring at different times of the year at different locations. Since radon concentration in air is dependent on the ventilation parameters, variations can be readily

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detected in the surface buildings as well as at underground sites. Depending on the ventilation at the underground location, the measured radon concentrations and working level values fell in different ranges stated by the regulatory authorities. Different monitoring schedules are then required in the different ranges of measured values in order to meet the recommendations of ICRP, and the regulations issued by the national and the regional regulatory agencies.

The Environmental Protection Agency (EPA) in USA identified that the continuous monitoring of radon is the most accurate method of measuring the actual radon exposures. Continuous monitoring of radon and radon decay products aids in optimization of compliance efforts, and in recording actual occupational exposure levels. Remedial actions can then be justified based on recorded data and compliance can be demonstrated in real-time.

For the purpose of developing policy for the radiation protection of the public, there is a need to measure and characterize the possible risks across the range of exposures received by the population. The higher end of that range of exposures is comparable to those exposures that caused lung cancer in underground miners. The lower end of that range includes exposures received from an average indoor lifetime exposure, which is at least one order of magnitude lower.

For many years in USA, radiation, even at low levels, was considered to present some risk to health. This risk model is referred to as the “linear, no-threshold (LNT)” hypothesis. Over the years, successive scientific studies have been done resulting in publication of the Biological Effects of Ionizing Radiation (BEIR) reports. Recent studies have led to an increasing debate whether the LNT model is appropriate.

In this context, high sensitivity continuous monitoring of radon aids in optimization of compliance efforts and in recording actual exposure levels at the low end of the exposure range. The present work reports on the use of the *Sabre-system* developed at the University of Guelph for the continuous monitoring of radon concentrations in air simultaneously with the working level values for the radiation protection of the workers and the public from the point of view of compliance with ICRP Recommendations.

## REGULATIONS AND GUIDELINES

ICRP Publication 35 [7] discussed the general principles of monitoring for radiation protection of workers. ICRP Publication 37 [8] examined the same from the point of view of a cost-benefit analysis in the optimization of radiation protection. The radiation protection standards for all DOE workers are described in 10 CFR 835. The Occupational Safety and Health Administration’s (OSHA) standard for ionizing radiation can be found in 29 CFR 1910.1096. The permissible radiation exposure levels are contained in Table G-18 of the standard. Some pertinent regulations are quoted below in Tables 1 and 2 for the sake of illustrating the salient points in the present work.

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Table 1. Occupational Standards and Regulations for Radon [6]

| Organization  | Pertinence            | Level                               | Notes                        |
|---|-----------------------|-------------------------------------|------------------------------|
| National Institute for Occupational Safety and Health     | Occupational (mining) | 1 WLM */year and ALARA <sup>†</sup> | Advisory; exposure limit     |
| Occupational Safety and Health Administration             | Occupational          | 4 WLM/year                          | Regulation                   |
| Mine Safety and Health Administration                     | Mining                | 4 WLM/year                          | Regulation                   |
| American Conference of Governmental Industrial Hygienists | Occupational          | 4 WLM/year                          | Advisory for radon daughters |

\*WLM (Working Level Month): a unit of measure commonly used in occupational environments. <sup>†</sup>ALARA: As Low As Reasonably Achievable.

Table 2. Radon-222 [9]

| Radionuclide | Category               | Occupational Values      |                                     |                                 |
|--------------|------------------------|--------------------------|-------------------------------------|---------------------------------|
|              |                        | 1                        | 2                                   | 3                               |
|              |                        | Oral Ingestion ALI (μCi) | Inhalation                          |                                 |
|              |                        | ALI (μCi)                | DAC (μCi/ml)                        |                                 |
| Radon-222    | With daughters removed | -                        | 1E+4                                | 4E-6                            |
|              | With daughters present | -                        | 1E+2<br>(or 4 working level months) | 3E-8<br>(or 0.33 working level) |

ALI: Annual Limit on Intake  
DAC: Derived Air Concentration

### HIGH SENSITIVITY CONTINUOUS MONITORING WITH SABRE SYSTEM

The *Sabre* detector system was designed for continuous monitoring of radon and radon progeny in the ambient room air with high sensitivity and high precision, and display the results on the Internet based World Wide Web (web) automatically in real time. The high sensitivity design was based on the earlier design of a Guelph Electrostatic Chamber (ESC) reported by Wang et al [10]. Jagam and Simpson [11] reported the early results obtained with the *Sabre-system* for the continuous monitoring of radon at a typical workplace.

Alpha-ray energy spectrometry of the decay products of radon (Radon  $^{222}\text{Rn}$  and Thoron  $^{220}\text{Rn}$ ) from the ambient air by electrostatic precipitation on to a PiN diode is the basic principle by which radon concentrations and working level (WL) values were determined by this system. Air was continuously monitored in a well-defined sensitive volume of the detector. The sensitive volume of the detector was not isolated from the room in any way, and was an integral part of the room because of diffusion. Digital data were sent at preset time intervals over the Internet to a server. The server displayed the time variation of the data as an X-Y plot available on the World Wide Web (Web). The data were also stored locally on the personal computer.

The focus in the continuous monitoring of radon was on the variations in the concentration of radon with time. When all other conditions remained the same, the radon concentration measured by the *Sabre-system* remained the same. The time variation of radon concentration should be zero under these conditions in ambient air as monitored by the system.

### RADON CHARACTERIZATION OF WORK ENVIRONMENTS

Variation in the measured concentration of radon at an above ground location in Sudbury ON, Canada, is shown in Figure 1 over a period of approximately three years. The breaks in the data collection resulted from equipment down time and / or changes in the priorities assigned to the data collection at that time.

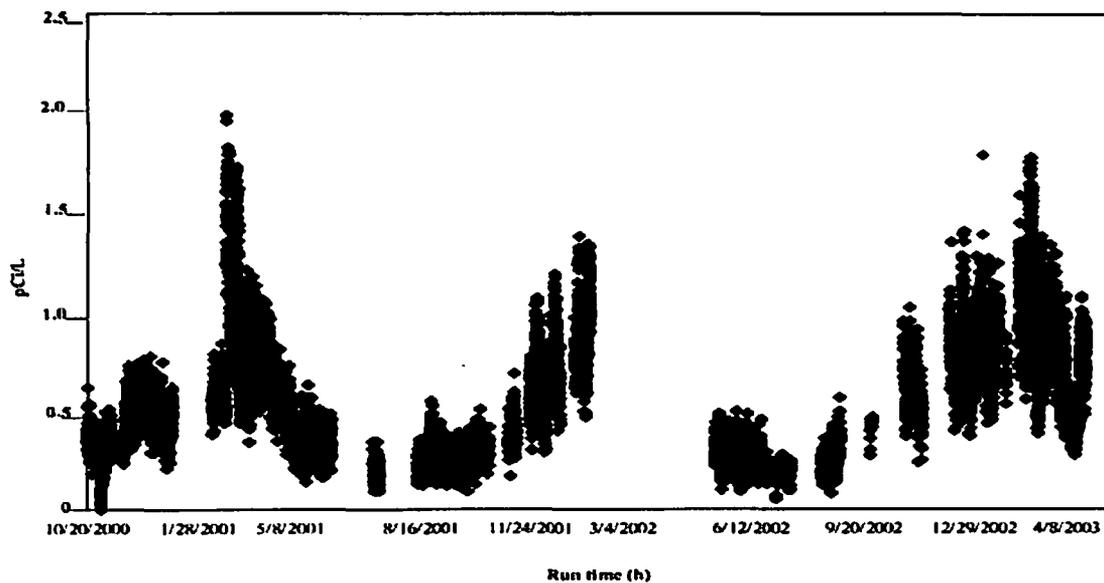


Figure 1. Variation of the concentration of radon over a period of three years at an above ground location in Sudbury, ON, Canada.

Variations of nearly an order of magnitude can be clearly seen in Figure 1. The maximums in the variation of the concentration of radon occur in the spring in each year at this location. Also, because of the energy spectrometry capability of the *Sabre-system*, the two polonium progeny ( $^{218}\text{Po}$  and  $^{214}\text{Po}$ ) of  $^{222}\text{Rn}$  were monitored independently of each other. The variation of the ratio of  $^{218}\text{Po}$  and  $^{214}\text{Po}$  was found to be constant within experimental errors, and confirms the variation in time independently at this above ground location.

Variation in the measured concentration of radon at an underground industrial location is shown in Figure 2 over a period of one year. The breaks in the data collection resulted from equipment downtime and / or changes in the priorities assigned to the data collection at that time. The variation in the concentration of radon was found to be a lot less than at the above ground location over the period of one year except for a systematic shift over a one month period. The shift was caused by changes in the ventilation due to changes in operational parameters of the ventilation system. The ratio of the two polonium progeny ( $^{218}\text{Po}$  and  $^{214}\text{Po}$ ) was found to be much more variable underground than above ground. The variations in humidity and temperature were found to be constant to within 5% over the entire period, and were not sufficient to produce the observed variations in the ratio of  $^{218}\text{Po}$  and  $^{214}\text{Po}$ . Also, the ratio of the polonium progeny detected at this location was larger than at the above ground location and much more variable in time. This sensitivity of the *Sabre-system* leads to a much more precise measurement of the actual exposure of the workers in real time.

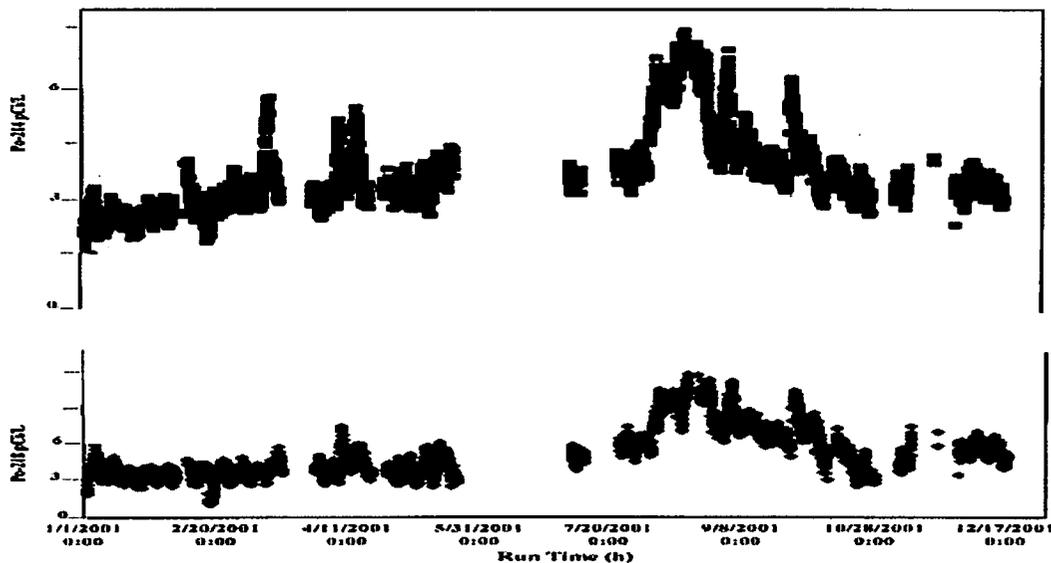


Figure 2. Variation of the concentration of radon progeny over a period of one year at an underground location in Sudbury, ON, Canada. The upper distribution is from  $^{214}\text{Po}$  and the lower distribution is from  $^{218}\text{Po}$ . Notice that the scaling factor is different for the two isotopes.

The time variation of the relative ratio of the two progeny in Figure 2, demonstrates the effect of the changes in the concentration of the ambient trace gases at the detector location. The calibration is determined dynamically from the continuous monitoring of ambient air at this location in order to account for these variations in the concentration of the individual progeny.

The above two examples demonstrate the need for dynamic surveillance to define restricted “airborne radioactive areas” as required by the regulatory agencies. In essence, the regulations require that more frequent monitoring is done under changing operating conditions. Continuous monitoring with energy sensitive spectrometry fulfills this need as shown above with high sensitivity.

## DISCUSSION

The *Sabre-system* is a WEB-enabled Internet based system capable of operating *unattended for prolonged periods* of time. The time variation of the raw data obtained from the radon monitor may be presented as equilibrium equivalent radon concentration or as working level values depending on the relevant calibration factors as needed. The calibration factors are determined dynamically as a function of time from the relative ratio of the  $^{218}\text{Po}$  and  $^{214}\text{Po}$ .

Calibration of the radon measurements with the *Sabre-system* was based on a methodology developed by Kiko [12] for  $^{222}\text{Rn}$  measurements in air at  $1\text{mBq/m}^3$  level and above. This methodology allowed for the dynamic self-calibration of the *Sabre-system* under varying ambient conditions in air at any given location. The *dynamic self-calibration* capability allowed for the reporting of radon concentration values in ambient air without assuming an arbitrary equilibrium ratio for the radon progeny at a measured location. The Working Level (WL) values were measured with high sensitivity in real-time because of the large volume of air continuously sampled with the *Sabre-system*. The self-calibration capability and the high sensitivity of the *Sabre-system* make it a unique radon monitoring system for demonstrating compliance with regulations in real-time.

The data in Figure 1 show the variation of the concentration of radon over a 3 y period at an above ground location in Sudbury, ON, Canada. The observed seasonal variations at this location with maximum radon levels occurring in the spring indicate a range of radon concentration values from 0.2 pCi/L to 2 pCi/L. The variation of the two polonium progeny tracked each other indicating that the relative ratio of the unattached fractions of the radon progeny at the detector location was quite stable over the measurement period. Working level values indicated that this location was compliant with the regulatory guideline for monitoring in the lowest range of permissible exposure  $< 0.06$  WL for Ontario.

The data in Figure 2 demonstrate the need for continuous monitoring in the assessment of the actual exposure received both at the above ground and underground locations. When the operating conditions were changed in the ventilation provided at this location, the

radon concentration levels and the working level values measured at this location fell into different regulatory requirements for monitoring radon at different times during the monitoring period. The required monitoring schedules were more frequent than the low radon environment above ground as per regulations. This is a demonstration of the continuous radon monitoring in real-time for the characterization of the ambient radon levels as discussed below, and for assessing the actual exposures received by the workers.

Compliance with the ICRP recommendations on the exposure requires in Ontario, Canada, that a different schedule for monitoring is required at different ranges of WL values as quoted below:

- “(3) The air to which workers may be exposed in an underground mine shall be retested,  
(a) at least monthly, if the concentration of radon daughters in a sample exceeds 0.1 WL; and  
(b) at least quarterly, if the concentration of radon daughters in a sample is greater than 0.06 WL up to and including 0.1 WL.  
(4) If the concentration of radon daughters in a sample is less than or equal to 0.06 WL, a competent person shall assess once a year whether to retest the air in the work area in the underground mine and in making the assessment shall consider previous test results and changes in the mine or its operations.” [13]

Because of the high cost of providing the ventilation in underground locations, ventilation may be cut back for operational reasons. At such times, the ambient concentration of radon seems to go above the recommended action level for significant periods of time. Therefore, the minimum that is required to be done under the ICRP guidelines is to characterize the radon levels and their progeny concentrations simultaneously in order to identify what the actual WL values are, on an ongoing basis. This can be done with a continuous radon monitor such as the *Sabre-system* demonstrated in the present work.

## CONCLUSIONS

The data presented above demonstrate the versatility and utility of the Web-based *Sabre-system* for the continuous monitoring of radon in the workplace and elsewhere with high sensitivity. *Sabre-system* fills the need for the characterization and identification of compliance with the ICRP recommendations for the radiation protection in a workplace and of the public in real-time.

The capabilities of the system presented in this work, and the results presented above demonstrate the need for continuous monitoring for the characterization of the workplace. The added capability of energy spectrometry demonstrates that the actual exposures can be determined with greater precision with real-time measurements as identified by EPA. The results obtained in the present work could stimulate discussion about radon

monitoring compliance in the mining industry and other high occupancy underground sites for the enforcement of OSHA and NRC regulations in real-time.

In their debate five years ago, Thomas and Lindell [14] pointed out that the protection quantities in radiological protection should be expressed in terms of measurable physical quantities. The present work demonstrates that this ideal can be achieved in real-time beyond the compliance requirements, with well-designed continuous radon monitors and working level devices. Determination of the required parameters in a cost effective manner on an ongoing basis will be pursued as part of the next phase of these investigations.

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