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Application of ^{222}Rn technique to locate subsurface coal heatings in Australian coal mines

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Abstract

Subsurface coal heating poses a significant problem in many coal mines. The identification of the exact location of the heatings that occur in often inaccessible locations several hundred meters deep in goaf areas is a key to allowing effective control measures to be taken. Detailed investigations were carried out to apply the surface-based ^{222}Rn technique to locate subsurface coal heatings in Australia. The results of two field trials indicated that subsurface coal heatings, at depths up to 450 m, lead to isolated ^{222}Rn anomalies on the surface vertically above the heating zones. The geogas microbubble model for ^{222}Rn transport through strata appears to be most in accord with the results of the field trials.

Keywords: Coal mining; Coal mine fires; Subsurface coal heating; Radon; Radon detection technique

1. Introduction

Subsurface coal heating is a significant hazard in coal mines worldwide and seriously threatens safe production in some coal mines. If not located accurately and appropriate control measures promptly undertaken, it can lead to fires, asphyxiation, explosions, and loss of life, equipment and resources, resulting in very high social, economic and environmental costs to mining communities in particular.

The broad principles of how subsurface coal heatings occur are reasonably known (Cliff et al., 1996; Walker, 1999), however locating the heatings which occur most often in inaccessible subsurface goaf areas has been very difficult. A ^{222}Rn technique appears to be a promising surface-based technique for locating subsurface coal heatings. A series of recent incidents of subsurface coal heatings in some Australian coal mines have highlighted the need to thoroughly investigate the application of this technique to locate subsurface coal heatings.

The ^{222}Rn technique was initially applied to locate subsurface coal heatings by Taiyuan University of Technology, China in 1992 and it has been used in the Chinese coal mines since then (Wu et al., 1998; Wu and Wu, 1998). Since 2002, the Commonwealth Scientific and Industrial Research Organization (CSIRO) has carried out detailed studies of this technique under the Australian Coal Association Research Program (ACARP). The studies include a review of the ^{222}Rn technique to gain a detailed understanding of its principle, operation and applications; field trials of the technique in Australian coal mines; laboratory investigation of temperature dependence of radon emission from coal; a detailed review of the radon transport mechanism through subsurface strata; and evaluation of the effect of subsurface coal heatings on radon movement. Some of the main findings of the studies are presented in this paper.

2. The ^{222}Rn technique

Because of its radioactivity (that makes it detectable in small concentrations), inert gas geochemical properties (that allows it

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to accumulate and to be transported in the pore fluid), and relative abundance and long half-life (half-life = 3.82 days), ^{222}Rn has been widely used as a precursor or event indicator for earthquakes and volcanic activity (King, 1986; Toutain and Baubron, 1999). Like any other nuclear-based techniques, the fundamental principle of the ^{222}Rn technique is based on detecting and measuring the energy emitted in the radioactive decay and using the detected and measured information and other relevant data to locate subsurface heatings.

^{222}Rn is a gas, but its short-lived daughters are all solid. It has a quite strong diffusion ability, and its diffusion coefficient is 0.12 $cm^2\ s^{-1}$ in air and 1.37×10^{-5} $cm^2\ s^{-1}$ in water at 25 °C (Nazaroff, 1992; Etiope and Martinelli, 2002). The mole solubility of ^{222}Rn in water at 298.15 K and 101.325 kPa partial pressure is 16.75, compared to 0.71 for helium and 61.88 for carbon dioxide (Scharlin et al., 1998). ^{222}Rn and its daughters are easily adsorbed by activated carbon, silica gel, polyethylene and some other materials. This property enables ^{222}Rn and its daughters to be easily collected from the surface of a container coated with these adsorbents and analyzed.

Since ^{222}Rn and its short-lived daughters are alpha-emitting nuclides, the alpha cup method described by Fang and Jia (1998) is used for on-site measurements. The method employs an alpha counter and sample cups. The counter detects the alpha radiation of ^{222}Rn and its daughters and is portable and battery powered. The sample cup is an open-end plastic cup with coating of a sorbent on its internal surface.

The application of the ^{222}Rn technique includes the six steps as follows:

(1) Selection of a surface area vertically above the subsurface area to be surveyed. There is no specific requirement to the shape of the surface area although it is normally rectangular, square or L-shaped.
(2) Determination of the location and spacing of measurement points in the surface area. The measurement points can be spaced between 5 and 20 m.
(3) Use of a hole-digging machine to dig the holes at these points. Each hole is about 30 cm in diameter and 30 to 40 cm in depth.
(4) Once the hole is dug, a sample cup is placed in the hole upside down. The hole is then refilled with the soil removed in hole-digging. The hole is numbered and the time the cup is buried is recorded.
(5) The cup placed in the hole is left buried for at least 4 h before it is retrieved for testing. The four-hour period is required for the ^{222}Rn gas to reestablish equilibrium with its short-lived daughter isotopes after the disturbance of surface soil. The retrieved cup is then inserted into the alpha counter to measure alpha-emitting counts per minute (CPM). The measurement for each retrieved cup takes about 3 to 5 min and the CPM readings are recorded manually.
(6) After the CPM readings at all measurement points are obtained, data are then processed. Any zones of elevated CPM are mapped and these indicate zones of subsurface coal heating. It should be noted that the data process was realized through statistical methods. The very common practice of considering the mean value plus n standard deviation as being anomalous is generally accepted in soil gas (including Rn) interpretation (McCarty and Reimer, 1986; Duddridge et al., 1991; Klusman, 1993; Guerra and Lombardi, 2001; Tansi et al., 2005). In this application, the statistical threshold for anomalous values was fixed at "mean value + 1/2 standard deviation".

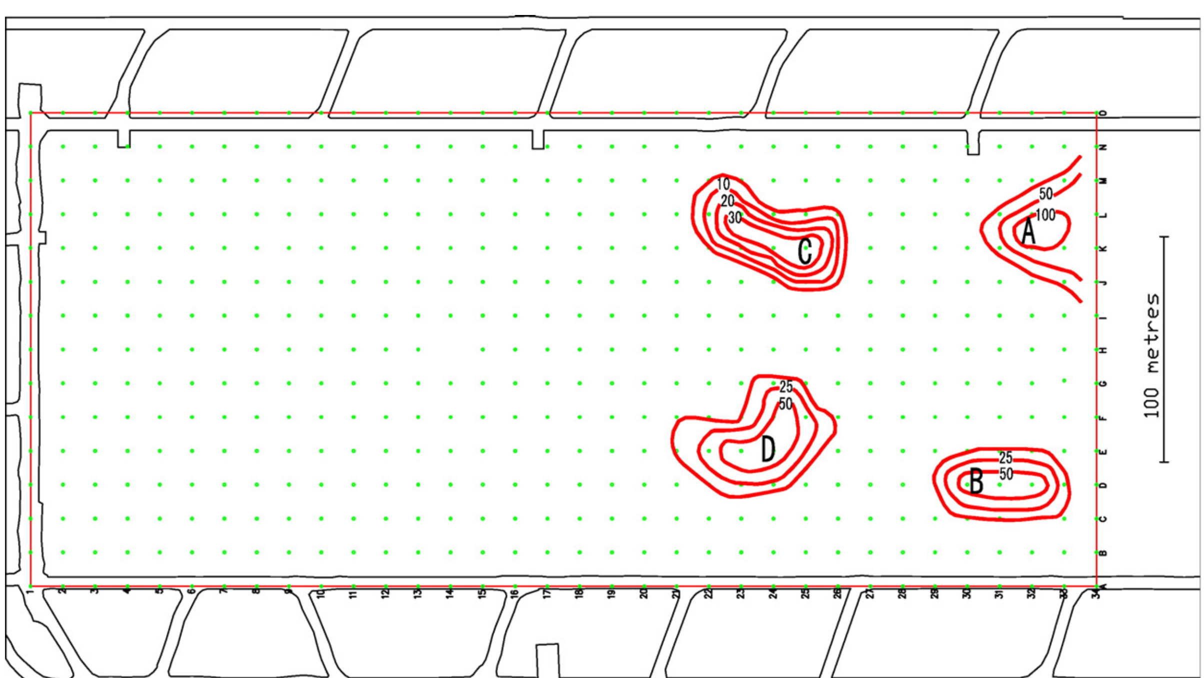

Fig. 1. Zones of elevated temperature in the trial region of Dartbrook mine (numbers in the figure refer to the elevated CPM readings).