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Integrating Radon monitoring activities into the ongoing quarterly monitoring program at the Newell County Facility

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Summary

This study explores the use of Radon, a rarely utilized noble gas, as a geogenic tracer to provide insights into major gas sources, transport rates, and the presence of preferential pathways in the shallow subsurface (<300m) at Carbon Management Canada Inc.'s Newell County Facility (NCF), a carbon storage and monitoring facility located in Alberta, Canada. While Radon commonly co-occurs with natural sources of CO_2, its short half-life (3.82 days) prevents its occurrence at detectable concentrations in injected CO_2, so CO_2 with detectable Radon can be an indication of geogenic CO_2. Radon's short half-life can obviate this benefit, but can offer valuable information on major and noble gas origins by serving as an indicator of relatively fast transport velocities via preferential pathways for migrating gases and providing an additional tool to distinguish between deeper and shallower gas sources. Radon concentrations were measured in both gas and groundwater samples collected at the NCF. Surface casing vent (SCV) samples collected from the injection and two observation (geochemical and geophysical) wells showed variable Radon concentrations, with the geochemical observation well exhibiting the highest (7,503 Bq/m^3), and the injection well (1,242 Bq/m^3) the lowest concentration. Groundwater samples collected from five shallow (<105 m) monitoring wells had dissolved Radon concentrations ranging from 494 to 7,323 Bq/m^3, with a distribution that suggests higher dissolved Radon concentrations may be related to specific strata. The composition of major and noble groundwater gas species will aid in more definitive interpretations. Finally, Radon concentrations in the soil zone (approximately 0.3 m depth), collected in a grid-like pattern, showed no notable spatial patterns. Long-term Radon monitoring, in concert with major and noble gas composition analysis, is expected to enhance the understanding of major and noble gas sources, migration pathways, and provide an additional tool to monitor subsurface containment at the NCF.

Introduction

The necessity for long-term monitoring of fugitive CO_2 migration and the potential risks for CH_4 displacement and migration around carbon storage sites has been clearly identified (Sekera & Lichtenberger, 2020). However, the understanding of the fate and transport of dissolved and free-phase gases requires different approaches complementary to aqueous geochemistry, particularly for gas-bearing aquifers (Roy and Ryan, 2013; Ryan et al., 2015) and long-term monitoring in the presence of free phase gases (Roy et al., 2022).

Noble gases are useful tracers since they are unreactive and have isotopic compositions that can be diagnostic with respect to their geogenic source(s) and transport (Ballantyne et al., 2002). Noble gas components in both SCV and groundwater have been previously characterized and monitored quarterly at the NCF in recent years (Utting et al., 2022; Utley et al., 2023). Further, the injected CO_2 contains a significant component of compositionally and isotopically specific noble gases that distinguishes between naturally occurring and injected gases. Although Radon is also a noble gas, it has not been widely used in tandem with other commonly analyzed noble gases (e.g., He and Ne) perhaps because its short half-life (3.82 day) requires minimal storage times before analysis. While the Radon's short half-life presents a challenge, it also presents an excellent opportunity since its relative concentrations can provide information about subsurface travel times.

Since the short half-life of Radon limits its ability to travel long distances by diffusion, Radon can be a valuable indicator of preferential pathways and transport mechanisms in the subsurface. Radon concentrations can reveal the presence of fractures and pathways along well casings, potentially providing information about the depth of the Radon source(s). Previous studies have indicated that buoyant, free-phase migration gas along fractures and fault zones can be rapid (i.e., m to km/day) and long-distances gas migration (Etiope and Martinelli, 2002; Stauffer et al., 2019, Chen et al., 2023). In contrast, groundwater transport of dissolved gases by advection and dispersion are typically orders of magnitude slower. Therefore, buoyant, free phase gas Radon transport is likely to occur along preferential pathways, with higher concentrations, and potentially deeper sources.

Therefore, this work aims to incorporate Radon into noble gas sampling to evaluate whether it could provide insights into the presence of preferential pathways for the gas species transport (i.e., major, noble, and fugitive gas species at the NCF). A secondary objective was to assess the Radon's utility to distinguish between natural and injected CO_2.

Methodology

Radon concentrations were measured in gas and water samples using a Durridge RAD7®. The RAD7® is equipped with a solid-state alpha detector that converts alpha radiation into an electrical signal for determining Radon concentrations (Durridge, 2021). Groundwater samples are analyzed using the RAD Aqua attachment to the RAD7® (Figure 1B). Radon concentrations were corrected for humidity and decay during sample storage based on the duration between sample collection and analysis. Soil gas and surface casing vent samples were collected using a 5-liter multi-layer gas sampling bag, enabling a comprehensive assessment of Radon concentrations in the gaseous phase (Figure 1A). Soil gas samples were collected by pumping soil gas gently through a ¼ inch diameter soil gas probe installed to a depth of approximately 0.3 m below the ground surface. Surface casing vent samples were collected via gas-impermeable tubing attached to the surface casing vent. In contrast, water samples were collected in 250 mL glass vials shortly after well purging using a submersible pump.

Preliminary Results and Discussion

Radon in Surface Casing Vent Gases

Significant variability in Radon concentration was observed between free gas samples collected from the surface casing vent of the injection well and the two observation wells (Figure 2). The geochemical well SCV exhibited the highest Radon concentration (7,503 Bq/m^3), followed by the geophysical well SCV (4,046 Bq/m^3), and the injection well SCV (1,242 Bq/m^3). The lowest Radon concentration (73 Bq/m^3) was found in samples collected at the geochemical well U-tube sampler, which samples the injection zone approximately 300 m below ground surface.

Despite their relatively low concentrations, the observed variations in Radon concentrations hold promise for combining insights with noble gas sources in the surface casing vent. While awaiting additional data on major gas composition and noble gases for further interpretations, preliminary observations suggest a shallow source of Radon at the site The identification of carrier gases for Radon should be considered in future investigations, with varying surface casing flow vent rates potentially influencing Radon concentrations. Although presenting a practical challenge, the short half-life of Radon also offers an excellent opportunity as its relative concentrations may provide valuable travel time information.

In addition, temporal variations in Radon concentration occurred between the last two quarterly sampling campaigns, with increasing Radon concentrations observed in both geochemical and geophysical well SCV. While these findings are preliminary, long-term monitoring is anticipated to validate these observations. Future considerations include more frequent sampling to assess how surface casing vent rates and the SCV shut-in time gap prior to sample collection might impact Radon concentrations. We expect that this approach could provide a better understanding of Radon dynamics in the shallow subsurface, emphasizing the importance of extended monitoring and detailed data collection for more robust interpretations.

Radon in Shallow Groundwater

Variable, and in some cases relatively low, Radon concentrations were observed in groundwater samples collected from five shallow groundwater monitoring wells. The conventional water well drilled to an intermediate depth (64 m) exhibited the highest average Radon concentration (7,323 Bq/m^3), while the shallow (27 m) and deep (103 m) conventional water wells showed significantly lower concentrations (899 Bq/m^3 and 494 Bq/m^3, respectively). Finally, the domestic water well (29 m) and the multilevel monitoring well (28 m) showed an average Radon concentration of (2,800 Bq/m^3 and 5,640 Bq/m^3, respectively.

The Radon distribution suggests that the Dinosaur Park Formation could be a source of Radon at the study site (Figure 2) although insufficient data are available to determine if there is a significant difference. More informed conclusions will be possible when dissolved gas and noble gas data from water samples collected on the same dates become available. It is expected that long-term monitoring of Radon, major gas species composition, and noble gases will refine our interpretations and inform us about the dynamics of Radon concentrations in shallow groundwater.

Radon in Soil Zone

The measurement of Radon concentrations in soil gas (0.3 m) at 26 locations has revealed its ubiquitous presence across the study site, with no significant anomalies detected. The average measured soil gas concentration at these 26 locations was 7,569 Bq/m^3 (minimum = 4,368 and maximum = 13,434 Bq/m^3), which is typical for soil gas concentrations. While some soil gas sampling locations exhibit relatively higher or lower Radon concentrations, the single largest soil Radon concentration (13,434 Bq/m^3) was observed one meter north of an old exploratory coal well suggesting in could be related to fugitive gas migration. However, it is important to consider the influence of factors such as atmospheric pressure, wind speed, and soil moisture on these variations in soil gas concentrations (Othman et al., 2021; Fleming et al., 2021). Therefore, we are currently conducting a more comprehensive evaluation.

Future Work

Long-term monitoring of Radon concentrations will be conducted in the SCV of the injection and the two observation wells to better evaluate whether the preliminary variations observed in Radon concentration could provide more data about the sources of Radon and other noble gases at the study site. Additionally, a comparative analysis between results presented here and noble gases samples collected at the same locations is expected to provide insights into the depths from which Radon and other noble gases are migrating from. The correlation between Radon concentrations and shut-in time will also be explored, aiming to understand its potential influences on sampling for Radon analyses. This investigation also seeks to address questions regarding the sources of potentially multiple Radon sources, and whether SCV Radon is allochthonous (i.e., migrating from deeper stratas) or autochthonous (i.e., formed in-situ).

Long-term monitoring of groundwater Radon concentrations will also be initiated in all groundwater monitoring wells installed at the study site. Furthermore, the deployment of sensors capable of measuring Radon and CO_2 concentrations in the headspace is planned in tandem with continuous groundwater monitoring to assess the occurrence of episodic releases of gas, as previously observed in the domestic well. The integration of these diverse datasets will contribute to a more comprehensive understanding of the source(s) and transport of Radon and noble gases in the shallow groundwater zone.

The long-term measurement of other noble gases, gas composition, along with the investigations mentioned above is expected to enhance the understanding of the major and noble gas sources and migration pathways in the subsurface. This approach aims to evaluate whether these noble gases (including Radon) can provide any information about potential risks to containment at the NCF.

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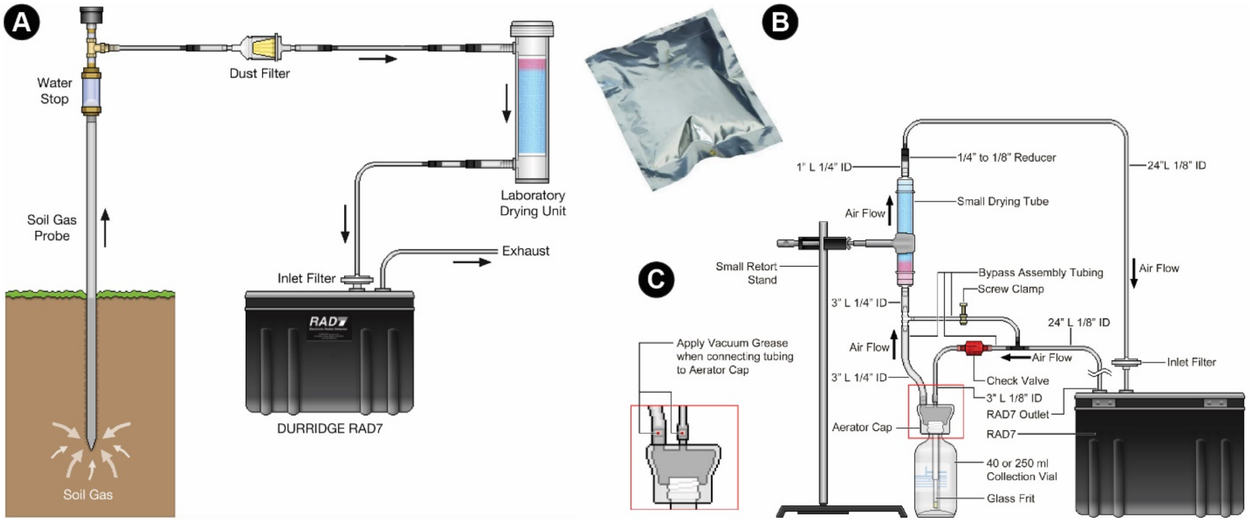

Figure 1. Schematics illustrating the set-up for measuring Radon concentrations from (A) soil gas samples, (B) surface casing vent samples, and (C) groundwater samples. Adapted from Durridge RAD7 User's Manual.

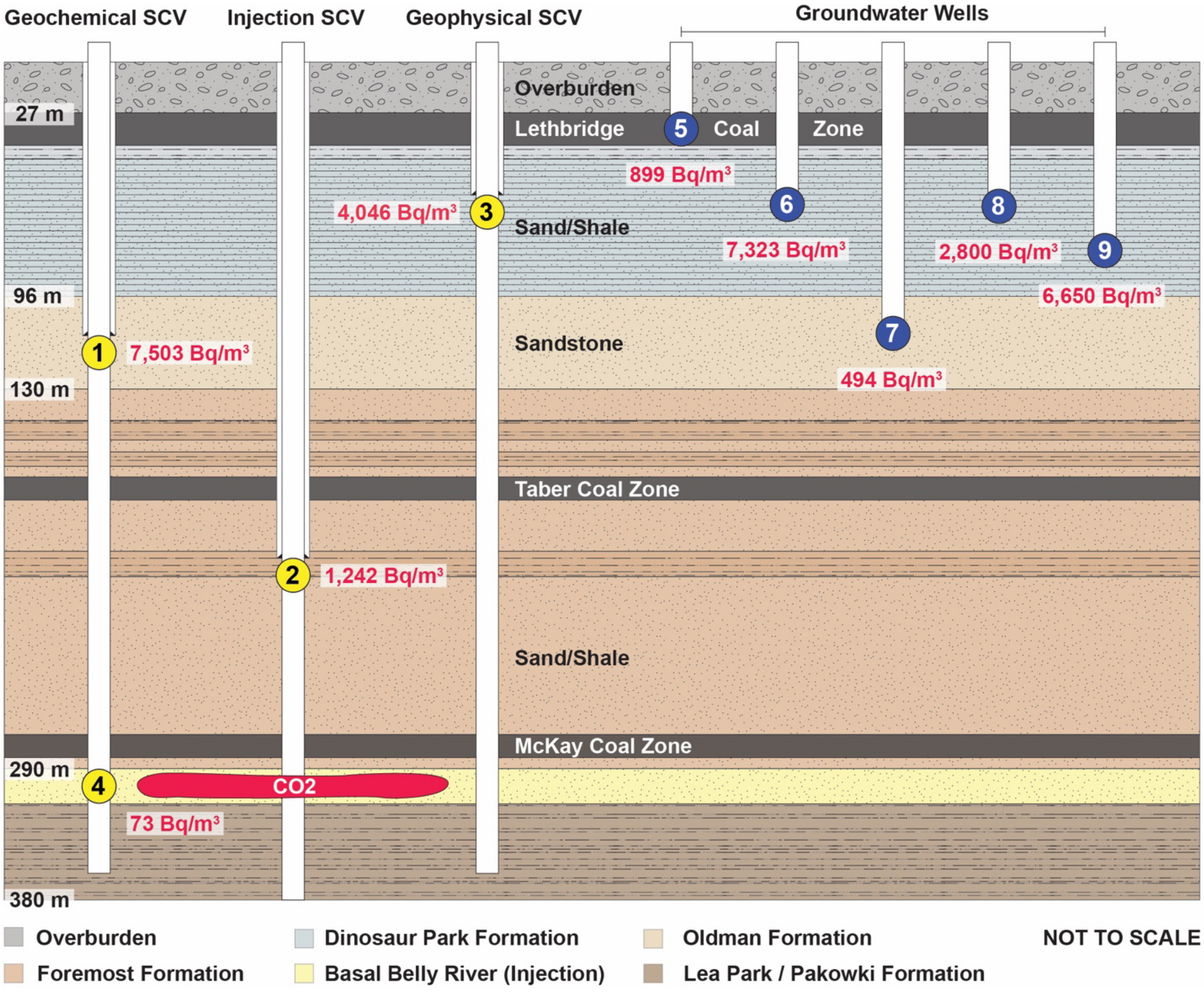

Figure 2. Schematics illustrating the surficial and geological units underlying the study site and all surface casing vent and groundwater sampling locations. Surface casing vent sampling locations (yellow): geochemical obs. well (1), CO_2 injection well (2), geophysical obs. well (3). Groundwater sampling locations (blue): shallow well (5), intermediate well (6), deep well (7), domestic well (8), and multilevel well (9). Adapted from Cheung (2019) and Riley (2023).