# Radon Soil Gas Associated With the C2 Zone, Millet Brook Uranium District (NTS 21A/16)

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## Introduction

Radon soil gas samples were collected as part of the North American Soil Geochemical Landscape Project (NASGLP), which began during the 2007 field season (Goodwin, 2008) and continued into the 2008 field season (Goodwin *et al*., 2009a). The radon soil gas sampling component of the NASGLP included a more detailed survey in the Halifax Regional Municipality during the later part of the 2008 field season (Goodwin *et al*., 2009b). A preliminary radon sampling study was also completed in 2008 above known uranium-rich rocks associated with the C2 Zone at the Millet Brook uranium district (Goodwin *et al*., 2009a). The 2008 sampling program was designed to test: (1) radon soil gas response within a uranium-mineralized zone; (2) assess optimum sampling depth; and (3) test the dilution rate of radon emanating from a mineralized bedrock source in ambient air immediately above the mineralized zone.

During the 2009 field season, a northwest-trending flagged line approximately 260 m in length across the C2 Zone was sampled for radon soil gas and *in situ* radioactivity (eU eTh, and K). Additional ambient air testing, similar to the preliminary study completed in 2008, above mineralized rocks was also carried out with different instrumentation in order to determine radon concentrations in ambient air.

Results of the 2009 sampling program are discussed below.

## Economic Geology of the Millet Brook Uranium District

The Millet Brook uranium district is located approximately 5 km northwest of Vaughan, Hants County (Fig. 1). Aquitaine Canada Limited discovered Millet Brook in 1978 by following up airborne (helicopter) radiometric anomalies (Interdepartmental Uranium Committee, 1994). Detailed geochemical and geophysical surveys combined with trenching and diamond drilling lead to the discovery of numerous uranium occurrences. Three main mineralized zones (C1 Zone, C2 Zone and the A9 Zone) constitute the Millet Brook deposit (Fig. 1). Non 43-101 compliant reserves for the three zones were estimated to be approximately 1.0 million tons of $U_3O_8$ at an average grade of 0.15% to 0.20% $U_3O_8$ using a cut-off of 0.10% over 2.0 m width (Chatterjee *et al*., 1982).

Uranium at Millet Brook is confined to a series of northeast–trending shear zones hosted in biotite granodiorite of the Salmontail Lake Pluton of the Devono-Carboniferous South Mountain Batholith (Ham, 1991). Uranium occurs as autunite and torbernite in the near-surface oxidized zones transitional to primary pitchblende at depths greater than 20 m (Robertson and Duncan, 1981; MacDonald, 2001). Alteration consists of hematization, kaolinization, saussuritization, minor chloritization and the presence of smokey quartz (Robertson and Duncan, 1981). Texturally, mineralogically and lithologically, the overlying and locally derived granite till is relatively thin

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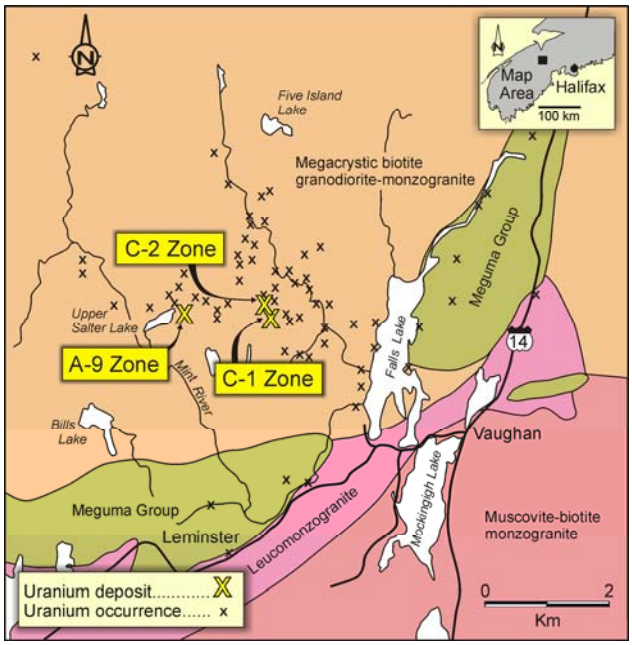


**Figure 1.** Location map and geological setting of the Millet Brook uranium district. Geology modified after Ham (1991).

(<2 m) and strongly reflects the underlying granodiorite bedrock.

The Millet Brook deposit has never been mined and all exploratory work effectively ceased on the property (and all other uranium-held claims in the province) on September 22, 1981, when the government imposed a moratorium on the issuing of new Special Uranium Exploration Licences and the renewal of existing licences due to safety concerns (Interdepartmental Uranium Committee, 1994). No exploration activity for uranium has taken place on the Millet Brook property (or anywhere else in Nova Scotia) since the announcement of the moratorium on uranium exploration and mining in 1981.

## Sampling Program

The 2009 sampling program consisted of two separate studies: (1) the acquisition of soil gas radon concentrations and *in situ* gamma spectrometric readings of Total Count (reported as counts per second - cps) and (2) radon in ambient air determinations from air samples collected directly over the C2 Zone.

Soil gas radon concentrations and *in situ* gamma spectrometric readings were collected along a 260 m long flagged traverse line bearing 340° that was centred over the C2 Zone (Fig. 2). Radon soil gas concentrations were collected approximately every 20 m from a single probe driven to a consistent 60 cm depth along the length of the traverse line. All sample stations were geo-referenced (UTM 20T, NAD83) with a GARMIN GPSmap 76Cx.

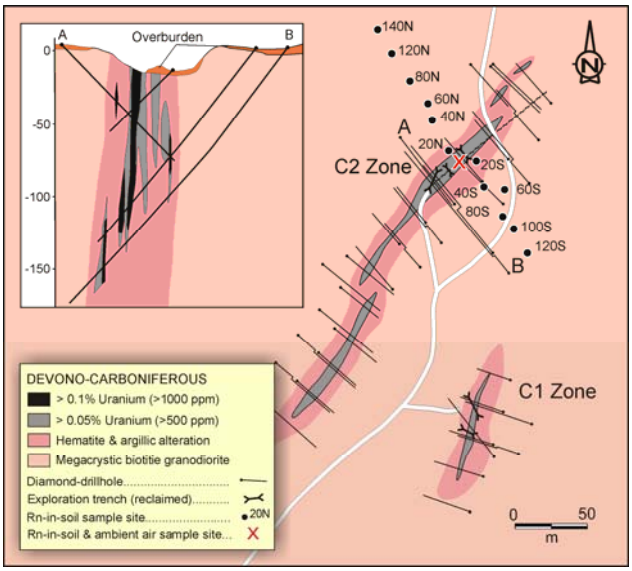


**Figure 2.** Plan view of sample stations across the C2 Zone, Millet Brook (refer to Table 1 for results).

At each 20 m station along the line, 150 mL of soil gas was extracted and a single radon soil gas determination was made with an ERM-3 electrometer. Detailed descriptions of the field sampling protocols and methodologies for radon soil gas have been previously described in Goodwin *et al*. (2009a, 2009b, 2010). Also at each 20 m station, a SAIC GR-135 PLUS spectrometer was used to acquire *in situ* radiometric determinations for Total Count recorded in counts per second (cps). *In situ* soil permeability measurements were not collected as part of this study.

A Durridge RAD 7 was used to determine radon concentrations in ambient air in samples collected at varying heights directly above the C2 Zone. The focus of this part of the study was to determine the

concentration of radon present in ambient air directly above the C2 Zone using the RAD 7 and compare these results to those reported by Goodwin *et al.* (2009a) using an ERM-3 electrometer.

The RAD 7 determinations of radon in ambient air were the average of four 5-minute sampling intervals (20 minute total sampling time) for samples collected at the ground/air interface and then for ambient air samples collected at 10 cm, 25 cm, 50 cm, 75 cm and 100 cm above the ground/air interface.

# Results

Results for radon in soil gas collected from the line across the C2 Zone indicated a minimum concentration of 43.1 kBq/$m^3$ and a maximum concentration of 1491.0 kBq/$m^3$ (upper detection limit of the instrumentation) with a mean concentration of 386.0 kBq/$m^3$ (Table 1). The mean radon soil gas concentration for the C2 Zone is significantly elevated relative to the mean of 25.3 kBq/$m^3$ from the Goodwin *et al.* (2009a) province-wide survey and the mean of 32.2 kBq/$m^3$ reported for the Halifax Regional Municipality survey of Goodwin *et al.* (2009b). A cross section of the radon soil gas results across the C2 Zone is presented in Figure 3.

*In situ* gamma spectrometric readings were also collected at each radon soil gas sampling site and results are presented in Table 1. Total count gamma spectrometric readings ranged from a low of 170 cps at the northern end of the line to a high of 14 997 cps directly over the C2 Zone (Fig. 3).

Radon concentrations in ambient air samples collected from a stationary test site immediately above the C2 Zone were (generally) very similar to results reported by Goodwin *et al.* (2009a). With the improved accuracy of the RAD 7, however, particularly at very low concentration ranges of radon in ambient air, detailed quantitative results from the 2009 sampling program were achieved.

In 2008, Goodwin *et al.* (2009a) measured a radon soil gas concentration at 60 cm of depth directly over the C2 Zone of 1491.0 kBq/$m^3$. At surface, however, radon was effectively non-detectable in ambient air. Radon in ambient air was re-tested in 2009 with the RAD 7 in order to measure very low concentration levels. Results are presented in Table 2.

At the ground/air interface, radon in ambient air decreased significantly to only 1.220 kBq/$m^3$ and clearly demonstrates the rapid dilution of elevated radon concentrations in soil gas as it is mixed with ambient air (Table 2). Radon concentrations in ambient air continued to decrease with increasing height above the ground/air interface. For example, at 10 cm above the ground, radon decreased to 0.231 kBq/$m^3$. At 25 cm above the ground, radon deceased further to 0.124 kBq/$m^3$. Radon continued to drop until the final sampling point, 100 cm above the ground, where the lowest concentration of 0.033 kBq/$m^3$ was measured.

# Discussion

The results of the 2009 sampling program show significantly elevated radon soil gas concentrations and Total Count radiometric responses are spatially associated with uranium enrichment within the C2 Zone of the granodiorite-hosted Millet Brook uranium deposit.

Figure 2 shows anomalous radon soil gas concentrations at several stations (i.e. 100 S, 40 S, 40 N and 80 N), in relation to the highest concentration associated with the C2 Zone found at station 0. The C2 Zone is located in a northeast-trending topographic low. Interpretation of other anomalous peaks in the radon in soil gas concentration suggests that additional uranium enrichment may exist in (unmapped) shear zones parallel to the C2 Zone. Several of the other anomalous stations are (similarly) associated with topographic lows. If uranium enrichment does indeed exist at depth below these stations, the amplitude of the radon soil gas response may be inversely proportional to the overlying till thickness.

In contrast, the Total Count anomaly (measured in cps) is a discrete anomaly situated directly over the C2 Zone. Brooks *et al.* (1982) identified a similar radiometric response directly over the bedrock

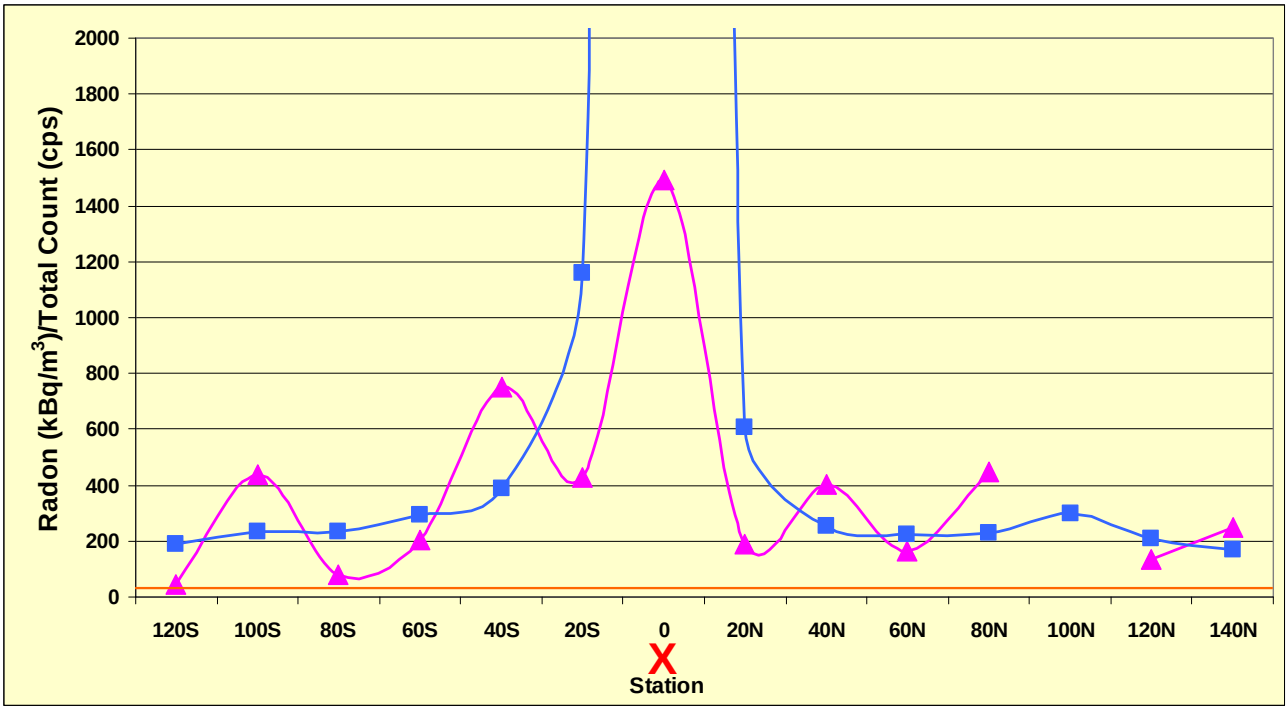


**Figure 3**. Soil gas radon (magenta triangles/line) and Total Count (blue squares/line) measurements across the C2 Zone, Millet Brook. Maximum Total Count measurement is 14 997 cps. The C2 Zone occurs at station 0 (represented by the red X). Radon soil gas concentrations were not determined for station 100 N because of excessively wet ground. The orange solid line represents the mean radon soil gas concentration (25.3 kBq/m$^3$) for the Province of Nova Scotia (Goodwin *et al.,* 2009a).

**Table 1.** Tabulated results for radon soil gas concentrations (kBq/m$^3$) and Total Count gamma spectrometric readings (cps) across the C2 Zone, Millet Brook (refer to Figure 2 for sample locations). Testing of radon concentrations in ambient air occurred at station 0 only.

| Station | Utm E83 | Utm N83 | Radon (kBq/m3) | Radiometrics (cps) | Comments |
|---|---|---|---|---|---|
| 120 S | 399640 | 4968031 | 43.1 | 189 | South end |
| 100 S | 399629 | 4968051 | 437.3 | 234 | |
| 80 S | 399624 | 4968065 | 79.2 | 233 | |
| 60 S | 399632 | 4968088 | 202.1 | 292 | |
| 40 S | 399608 | 4968093 | 749.1 | 390 | |
| 20 S | 399600 | 4968101 | 427.2 | 1157 | |
| 0 | 399588 | 4968115 | >1 491.0 | 14 997 | C2 Zone |
| 20 N | 399582 | 4968132 | 190.0 | 607 | |
| 40 N | 399569 | 4968149 | 401.0 | 255 | |
| 60 N | 399566 | 4968167 | 163.8 | 223 | |
| 80 N | 399552 | 4968188 | 447.7 | 231 | |
| 100 N | 399545 | 4968199 | not taken | 300 | Wet |
| 120 N | 399538 | 4968213 | 135.7 | 210 | |
| 140 N | 399528 | 4968234 | 250.5 | 170 | North end |

**Table 2.** Radon soil gas concentration at 60 cm depth (-60) and radon concentrations in ambient air for samples collected at 0, 10, 25, 50, 75 and 100 cm above the ground/air interface. All readings measured directly over the C2 Zone, Millet Brook (1 kBq/$m^3$ = 1000 Bq/$m^3$, note that radon in indoor air is measured in Bq/$m^3$). Health Canada's guideline for exposure to radon in indoor air is 200 Bq/$m^3$.

| Depth (cm) | Rn (kBq/m3) | Rn (Bq/m3) |
|---|---|---|
| 100 | 0.033 | 33 |
| 75 | 0.074 | 74 |
| 50 | 0.107 | 107 |
| 25 | 0.124 | 124 |
| 10 | 0.231 | 231 |
| 0 | 1.220 | 1 220 |
| -60 | 1 491.000 | 1 491 000 |

source of the A9 Zone, located approximately 1 km to the west of the C2 Zone (Fig. 1).

# Conclusions

Radon soil gas samples and *in situ* gamma spectrometric readings were collected across known uranium enrichment associated with the C2 Zone at the Millet Brook uranium district. Ambient air samples were also collected at varying intervals directly above the C2 Zone in order to quantify the rate of dilution of radon soil gas as it comes in contact with ambient air.

The highest radon concentration in soil gas (1491 0 kBq/$m^3$) occurred directly over the C2 Zone. The mean radon soil gas concentration for 13 stations was 386.0 kBq/$m^3$, which is significantly higher than the provincial mean of 25.3 kBq/$m^3$. The presence of anomalous radon soil gas concentrations at a number of sample sites suggests additional uranium enrichment, likely associated with unmapped shear zones parallel to the C2 Zone. The maximum *in situ* gamma spectrometric reading (14 997 cps) was also encountered directly over the C2 Zone.

Although radon soil gas concentrations at a sampling depth of 60 cm below the air/ground interface were extremely high (1491.0 kBq/$m^3$) and spatially associated with the C2 Zone, radon concentrations measured in ambient air decreased rapidly to only 1.220 kBq/$m^3$ at the ground/air interface directly above the C2 Zone. Radon concentrations in ambient air continued to decrease above the C2 Zone with increasing distance from the ground/air interface. The lowest concentration of radon in ambient air was 0.033 kBq/$m^3$ at 1 m above the ground.

# Acknowledgments

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