RESEARCH REPORT

Radon Mitigation Planning Inspection and Mitigation System Installation

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Radon Mitigation Planning Inspection and Mitigation System Installation

On behalf of

Health Canada - Radiological Impact Section

And

Canada Mortgage and Housing Corporation

ARTHUR SCOTT AND ASSOCIATES

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RESEARCH HIGHLIGHT

June 2008

Technical Series 08-105

Fixing Houses with High Radon—A Canadian Demonstration

INTRODUCTION

Radon is a radioactive gas. It has the potential to cause lung cancer amongst those people exposed to it.

In 2007, as a result of new scientific findings, Health Canada (HC) lowered the federal indoor radon guideline for dwellings to 200 Bq/m^3 after consultation with provincial and territorial officials. See http://hc-sc.gc.ca/ewh-semt/radiation/radon/guidelines_lignes_directric e_e.html.[1]

More Canadian houses will now be above the federal guideline and awareness of radon is likely to increase among Canadians over the next several years. Health Canada, Canada Mortgage and Housing Corporation (CMHC) and other agencies are starting to provide more information on how to test for radon, how to remediate houses that have high radon levels and what areas of the country are most at risk. For more information, see the joint CMHC/HC publication *Radon: A Guide for Canadian Homeowners* at http://www.cmhc-schl.gc.ca/odpub/pdf/61945.pdf.

The small research project, funded by Health Canada and managed by CMHC, described in this highlight demonstrates that the techniques described in *Radon: A Guide for Canadian Homeowners* can be applied to Canadian houses and that the remediation technique involved, active sub-slab depressurization, can effectively lower radon to concentrations below the guideline.

A homeowner in the community of Kanata in western Ottawa contacted CMHC and Health Canada for advice on high radon concentrations he had measured in his new house. Figure 1 shows almost a month of radon readings from his basement. Note that the concentration fluctuates due to house operation, climate factors, and so on. A short reading of two days duration could give a reading as low as 150 Bq/m^3 (for example, Oct. 28) or as high as 2,700 Bq/m^3 (Oct. 19). For that reason, *Radon: A Guide for Canadian Homeowners* recommends that houses be tested for at least one month.

Averaged over the test period, the homeowner's results were in the order of 1,400 Bq/m^3, considerably in excess of either the new or old guideline. The basement had a poured concrete floor and walls, and was not remarkably different from neighbouring houses. It had a slab poured on polyethylene sheeting, which should reduce the radon entry rate.

[1] English and French. Retrieved March, 2008.

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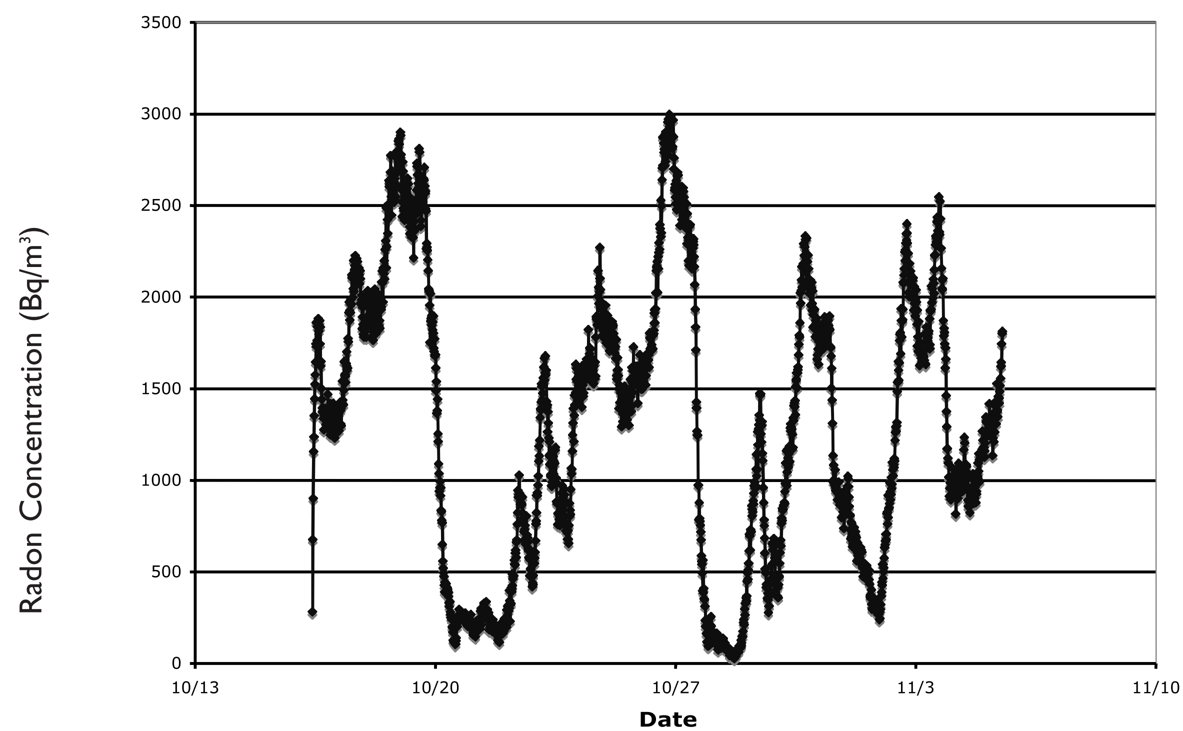

Figure 1 Continuous radon monitor trace, October–November, 2007

RESEARCH PROGRAM

The research program was quite simple: an experienced radon consultant visited the house with CMHC and HC scientists. The group reviewed the potential radon entry points and decided on a remediation strategy.

The recommended remediation, active soil depressurization (or sub-slab depressurization), involves having a fan draw air from underneath the concrete slab and exhaust it outside. This causes a pressure change. Air beneath the slab usually has a positive pressure during the heating season, so the radon moves from the soil, through cracks and holes in the slab, and into the house. A sub-slab depressurization system withdraws air from this space, making its pressure less than in the house above. Any air movement now is from the house, through the cracks, to the soil. This pressure change keeps radon out of the house air.

The consultant drilled several small holes in the floor to measure whether all the air contained in the gravel layer under the slab could be depressurized by an exhaust fan connected through the slab at a single entry point. A ventilation contractor installed the fan and ducting to the consultant's recommendations, and the system was activated.

The exhaust fan discharged the sub-slab air at grade and not at roof level, as recommended by the United States Environmental Protection Agency (EPA). This was due to concerns regarding the possible condensation and ice build-up problems within vertical vents on the outside of houses in cold Canadian climates. The project team felt that, if re-ingestion of the exhausted radon through windows, doors or other envelop leakage points in the vicinity of the exhaust fan discharge point was a large factor, the post-mitigation test would show high levels of radon inside the house. The radon concentrations were measured for a month in the winter following installation of the system. Figure 2 shows the basement, the location of the measurement holes (B, C), and the fan and ducting system.

RESULTS

The system was remarkably effective (see Figure 3). Radon concentrations dropped from an average of 1,400 Bq/m³ to about 40 Bq/m³ for the month following, significantly below the HC 200 Bq/m³ guideline. The homeowner was happy with the installation of the system and with the results. Re-ingestion of the exhausted radon was not a significant factor in this location during this period.

During the commissioning of the system, the fan flow was not quite high enough to make a consistent depressurization at the test holes B and C shown in Figure 2. This was cause for some concern, but it was decided to run the fan for a month and monitor its effectiveness before looking for a way to increase fan flow.

As the mitigation system proved effective, even in mid-winter with the highest competing pressures, there has been no adjustment to the fan flow. The homeowner has some flexibility in the future to do such modifications, as the fan speed can be modulated, and he is able to monitor the results of impact on radon concentrations with a continuous radon monitor. He could reduce the fan flow rates to save electricity (associated with fan motor operation) if he ascertained that the radon concentrations still remained low in the house. For homeowners who have not purchased their own radon monitors, this fan optimization would not be available to them.

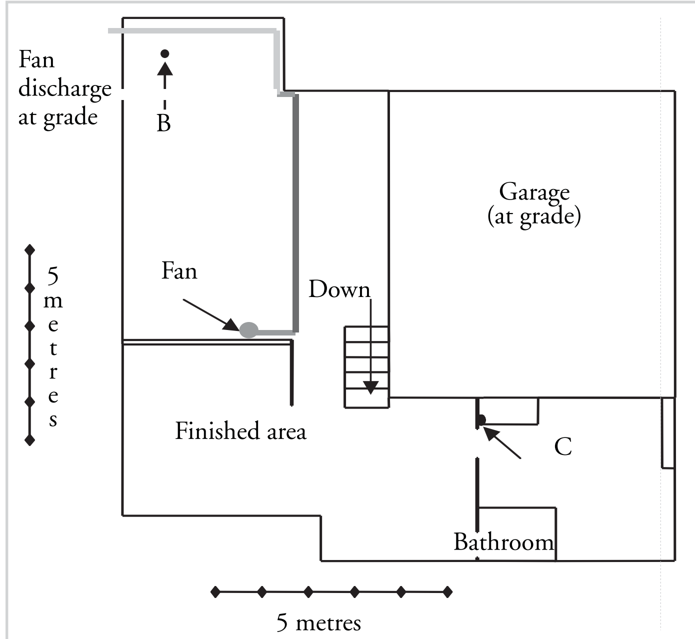

Figure 2 Installed fan and piping layout

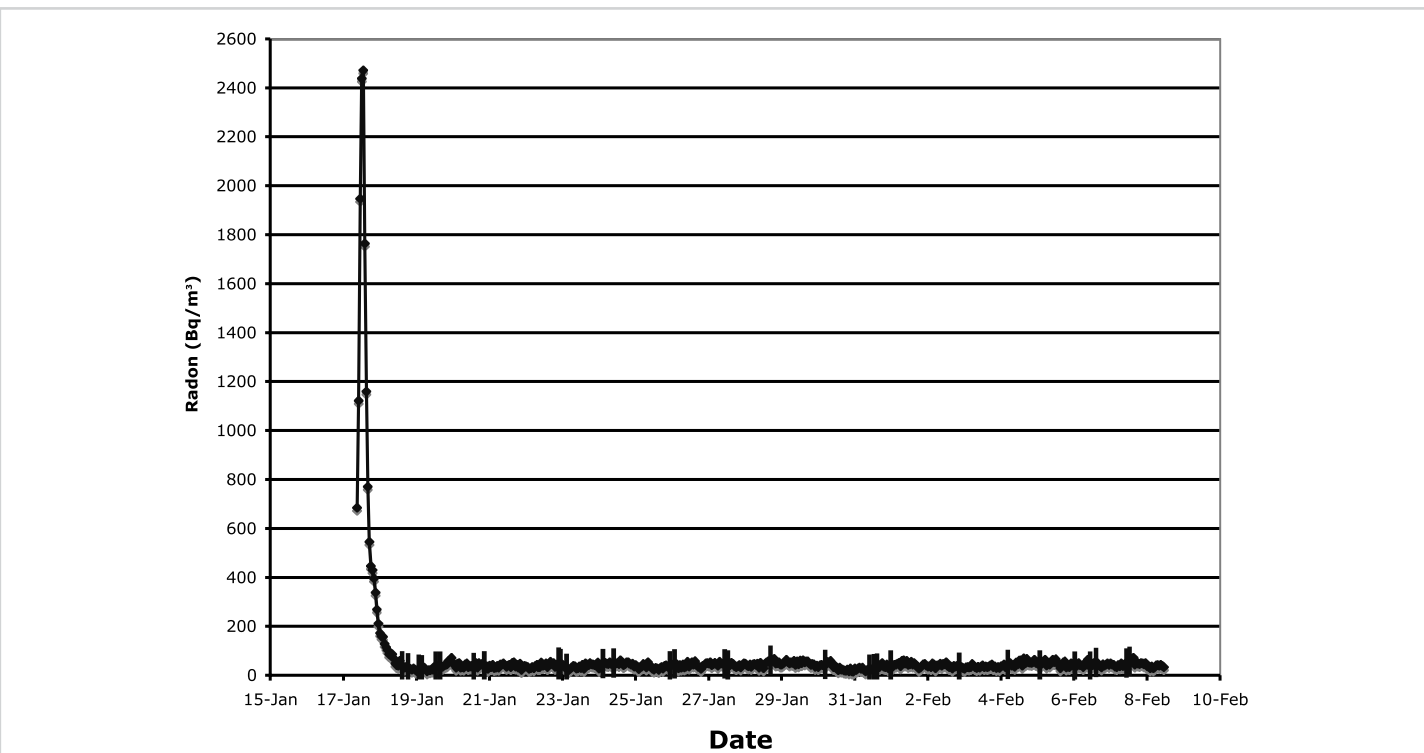

Figure 3 Continuous monitor trace during and after mitigation

CONCLUSIONS:

This small project showed that active soil depressurization, or sub-slab depressurization, as described in HC/CMHC publications, worked effectively at reducing radon concentrations in the indoor air of a house troubled by excessive radon levels.

A ventilation contractor, with no radon experience, installed an effective mitigation system following this advice. The results also illustrate the need for a month-long test (or longer) both before the work, for diagnosis, and following installation of the system, to measure the success.

CMHC Project Manager: Don Fugler

Research project consultant: Arthur Scott,
Arthur Scott and Associates

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Printed in Canada
Produced by CMHC 17-06-08

66063

LE POINT EN RECHERCHE

Juin 2007 Série technique 08-105

Réfection de maisons affichant une teneur élevée en radon — une démonstration canadienne

INTRODUCTION

Le radon est un gaz radioactif. Il peut entraîner l'apparition du cancer des poumons chez les personnes qui y sont exposées.

En 2007, à la suite de nouvelles découvertes scientifiques, Santé Canada (SC) a abaissé la ligne directrice fédérale visant le radon à 200 Bq/m^3 après avoir consulté les responsables provinciaux et territoriaux. Voir le http://hc-sc.gc.ca/ewh-semt/radiation/radon/guidelines_lignes_directrice_e.html[1].

Ainsi, davantage de maisons canadiennes se trouveront maintenant à excéder la ligne de conduite fédérale, et la sensibilisation au sujet du radon au sein de la population canadienne est susceptible de s'améliorer au cours des prochaines années. Santé Canada, la Société canadienne d'hypothèques et de logement (SCHL) et d'autres organismes ont commencé à fournir plus d'information sur la façon de dépister le radon, d'assainir les maisons dont la teneur en radon est élevée, et de déterminer quelles régions du pays sont les plus à risque. Pour obtenir de plus amples informations, consultez la publication conjointe SCHL-Statistique Canada intitulée Le Radon : *Guide à l'usage des propriétaires canadiens* au http://www.cmhc-schl.gc.ca/odpub/pdf/61328.pdf

L'étude de faible envergure, financée par Santé Canada et administrée par la SCHL, décrite dans le présent Point en recherche fait la démonstration que les techniques décrites dans le document Le Radon : *Guide à l'usage des propriétaires canadiens* peuvent être appliquées aux maisons canadiennes et que la technique d'assainissement dont il question, la dépressurisation sous la dalle, peut réellement abaisser la teneur en radon sous le seuil de la ligne directrice.

Un propriétaire-occupant de la collectivité de Kanata à l'ouest d'Ottawa a communiqué avec la SCHL et Santé Canada pour obtenir des conseils sur les teneurs élevées en radon qu'il avait mesurées dans sa maison. La figure 1 montre presque un mois de mesures de radon dans le sous-sol. Notez que la concentration fluctue selon l'exploitation de la maison, les facteurs climatiques, etc. Une courte période de mesure de deux jours peut donner des lectures aussi faibles que 150 Bq/m^3 (p. ex. le 28 octobre) et aussi élevées que 2 700 Bq/m^3 (le 19 octobre). C'est pour cette raison que le document Le Radon : *Guide à l'usage des propriétaires canadiens* recommande que les maisons soient mises à l'essai pour au moins un mois.

La teneur moyenne mesurée au cours de la période d'examen a été de l'ordre de 1 400 Bq/m^3, ce qui est considérablement plus élevée que la nouvelle ligne directrice et même l'ancienne. Le sous-sol était composé des murs de fondations et d'un plancher en béton, et n'était pas tellement différent des maisons avoisinantes. La dalle avait été mise en place sur une membrane de polyéthylène, ce qui aurait dû réduire le taux de pénétration du radon.

1 Versions française et anglaise consultées en mars 2008.

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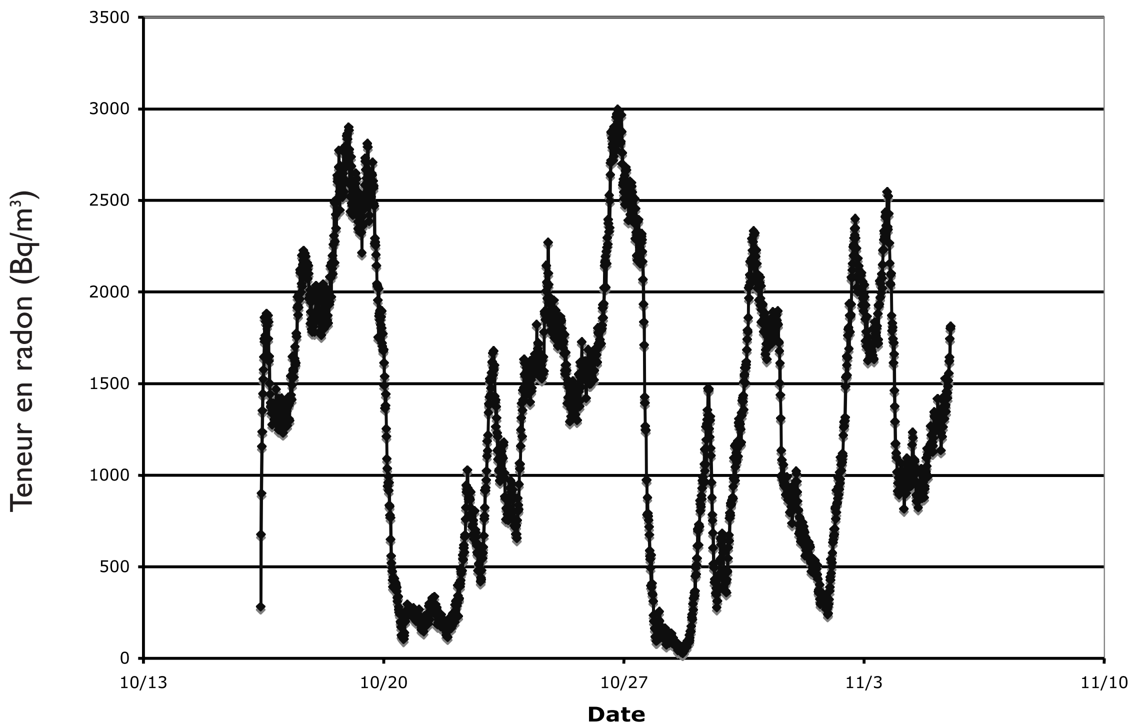

Figure 1 Suivi en continu de la teneur en radon, octobre et novembre 2007

PROGRAMME DE RECHERCHE

Le programme de recherche se révèle très simple : un consultant d'expérience en radon a visité la maison en compagnie de chercheurs de la SCHL et de Santé Canada. Le groupe a passé en revue les points de pénétration de radon possibles et a décidé d'une stratégie d'assainissement.

La mesure d'assainissement recommandée, la dépressurisation active du sol (ou dépressurisation sous la dalle), prévoit la mise en place d'un ventilateur d'extraction qui tire l'air sous la dalle de béton et l'évacue dehors, ce qui entraîne un changement de régime de pression. L'air sous la dalle présente habituellement une pression positive au cours de la période de chauffage, ce qui fait que le radon passe du sol, puis à travers les fissures et vides dans la dalle pour arriver dans la maison. Un système de dépressurisation sous la dalle retire l'air de cet espace, ce qui rend sa pression inférieure à celle de la maison au-dessus. Tout mouvement d'air se fait maintenant à partir de la maison, puis à travers les fissures jusqu'au sol. C'est ce nouveau régime de pression qui garde le radon hors de la maison.

Le consultant a percé des trous dans le plancher afin de mesurer si l'ensemble de l'air contenu dans le gravier sous la dalle pouvait être extrait par un ventilateur d'extraction raccordé à travers la dalle à un seul endroit. Un entrepreneur en ventilation a posé le ventilateur et les conduits suivant les recommandations du consultant et on a activé le système.

Le ventilateur d'extraction évacuait l'air (sous la dalle) au niveau du sol et non au niveau du toit, comme le recommande l'agence de protection de l'environnement des États-Unis (EPA). Cette technique a été retenue en raison des préoccupations ayant trait à des problèmes de condensation possible et d'accumulation de glace dans les évents verticaux à l'extérieur de la maison dans les conditions climatiques qui ont cours au Canada. L'équipe de projet était d'avis que si le radon évacué revenait dans la maison par les portes, fenêtres ou autres points de fuite de l'enveloppe dans les environs du point d'évacuation du ventilateur d'extraction, les essais après la mise en place des mesures d'assainissement indiqueraient des teneurs élevées en radon dans la maison. Les teneurs en radon ont été mesurées pendant un mois au cours de l'hiver qui a suivi la mise en place du système. La figure 2 montre le sous-sol, l'emplacement des ouvertures pour le mesurage (B, C), et le ventilateur et le système de conduits.

RÉSULTATS

Le système s'est avéré d'une remarquable efficacité (voir la figure 3). Les teneurs en radon sont passées d'une moyenne de 1 400 Bq/m³ à environ 40 Bq/m³ pendant le mois qui a suivi les travaux, ce qui est considérablement plus faible que la ligne directrice de 200 Bq/m³ de Santé Canada. Le propriétaire-occupant était satisfait de l'installation et des résultats. La réintroduction du radon évacué n'a pas constitué un facteur à cet endroit durant la période.

Pendant la mise en service de l'installation, le débit du ventilateur n'était pas tout à fait assez puissant pour créer une dépressurisation à l'endroit des ouvertures B et C montrées dans la figure 2. Cette situation a été la cause d'inquiétudes, mais on a décidé de faire fonctionner le ventilateur durant un mois tandis que l'on suivait son efficacité, avant de se pencher sur des façons d'augmenter le débit du ventilateur.

Comme l'installation d'assainissement s'est avérée efficace, même au milieu de l' hiver lorsque les pressions contraires sont les plus importantes, le débit du ventilateur n'a pas été augmenté. Le propriétaire-occupant possède une certaine souplesse quant à la possibilité de procéder à de telles modifications à l'avenir, puisque la vitesse du ventilateur peut être modulée, et qu'il est en mesure de suivre les résultats de son incidence sur la teneur en radon à l'aide d'un moniteur de radon en continu. Il pourrait réduire le débit du ventilateur pour économiser de l'électricité (associée au fonctionnement du

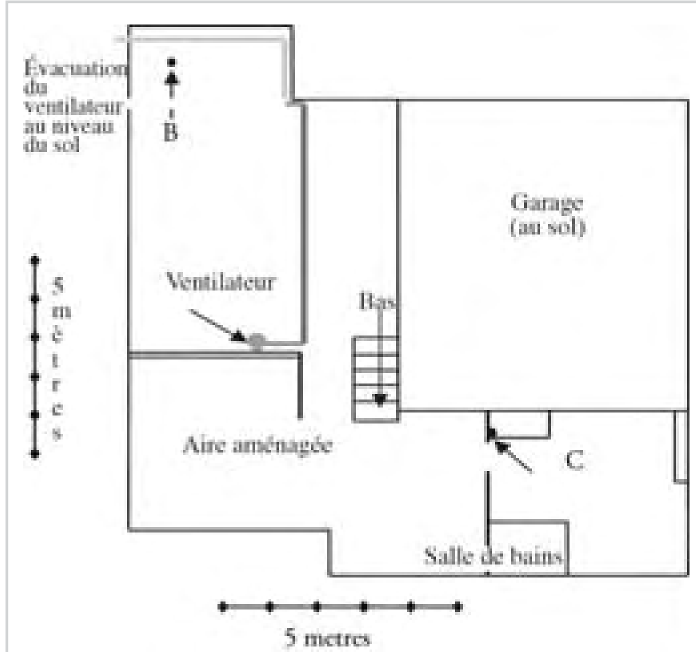

Figure 2 Schéma du système : ventilateur et conduits

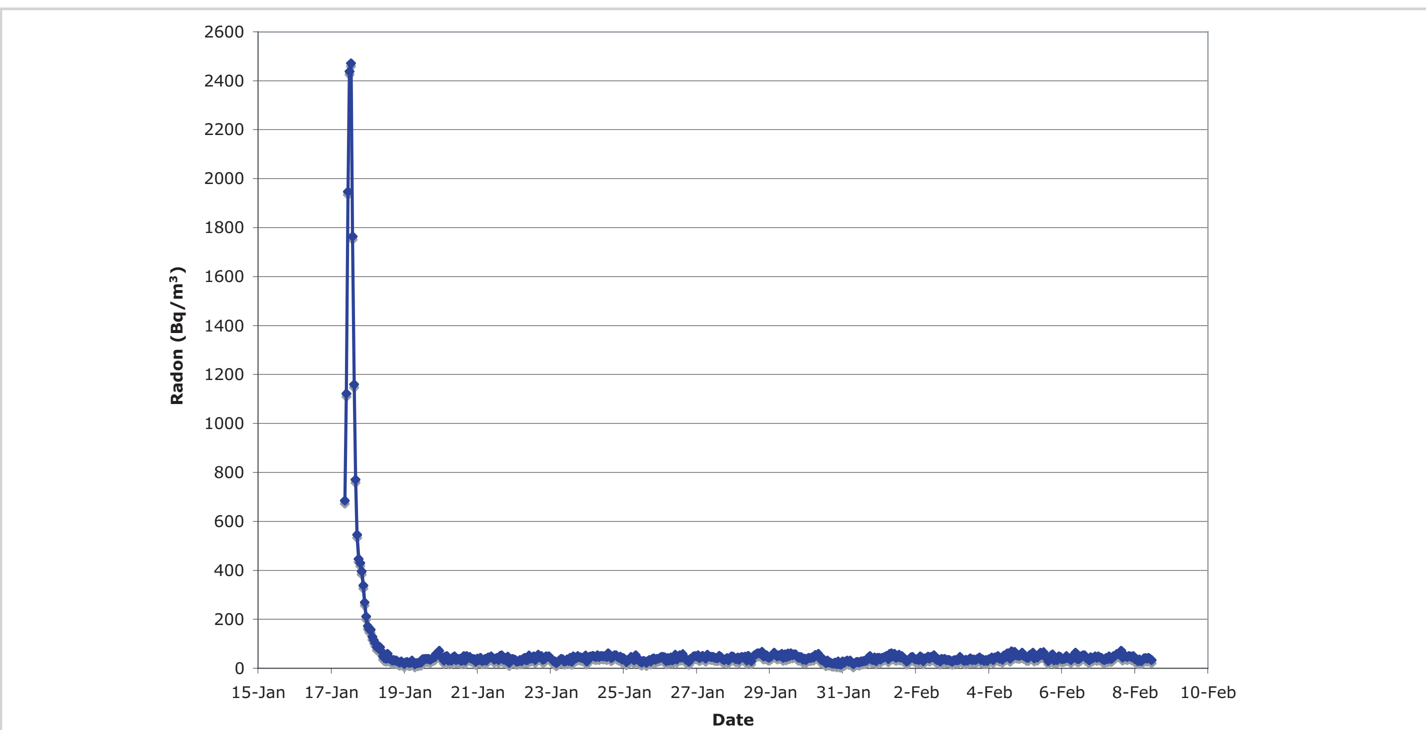

Figure 3 Suivi en continu du moniteur avant et après les améliorations

moteur du ventilateur) s'il était convaincu que les teneurs en radon dans la maison demeuraient faibles. Dans le cas des propriétaires-occupants qui n'auraient pas acheté leur propre moniteur de radon, cette option d'optimisation du ventilateur ne leur serait pas disponible.

CONCLUSIONS

Ces travaux de faible envergure indiquent que la technique de dépressurisation active du sol ou de dépressurisation sous la dalle, comme décrite dans les publications de Santé Canada et de la SCHL, se révèle efficace pour réduire les teneurs en radon dans l'air intérieur d'une maison dont les teneurs sont excessives.

Un entrepreneur en ventilation, sans expérience avec le radon, a mis en place une installation efficace d'assainissement en suivant ces conseils. Les résultats illustrent également la nécessité d'effectuer un suivi pendant un mois (ou plus) tant avant les travaux, durant la période de diagnostic, qu'après la mise en place de l'installation de ventilation, pour évaluer le succès de l'entreprise.

Gestionnaire de projet à la SCHL : Don Fugler

Consultant pour le projet de recherche : Arthur Scott, Arthur Scott and Associates

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Aux termes de la partie IX de la ***Loi nationale sur l'habitation,*** le gouvernement du Canada verse des fonds à la SCHL afin de lui permettre de faire de la recherche sur les aspects socio-économiques et techniques du logement et des domaines connexes, et d'en publier et d'en diffuser les résultats.

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Imprimé au Canada
Réalisation : SCHL 17-06-08

66064

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Introduction

Exposure to high levels of radon increases the risk of developing lung cancer. This relationship has prompted concern that radon levels in some Canadian homes may pose a health risk. Health Canada was interested in demonstrating how the sub-slab ventilation techniques proposed for use in Canada can effectively reduce indoor radon concentrations in houses with high levels of radon.

This report describes the identification and investigation of a house with high radon concentrations, measurements of the radon concentrations over time, and effective radon reduction to near-background levels by sub-slab ventilation. The work was managed by Canada Mortgage and Housing Corporation on behalf of Health Canada.

General

This is a detached house, less than two years old, in a new sub-division in Kanata, Ontario (an Ottawa suburb), with two storeys, a built-in garage, and a poured concrete basement. The footprint including the garage is approximately 15m deep by 12m wide.

The owner of this house purchased an electronic radon meter, and found elevated radon levels. He contacted Health Canada, who made further measurements with a continuous radon monitor, (Pylon AB4), and radon concentrations were found to vary between 500 to 2000 Bq/m^3 in February-March 2007, and from 50 to 3000 Bq/m^3 in October-November 2007. The average value was about 1400 Bq/m^3. The monitor traces are shown in the Appendix as Figure 1and Figure 2.

Review

The house was visited on October 16, 2007 for a Mitigation Planning inspection.

The northern part of the basement (street side) is a utility area, containing the furnace and water heater. A fresh–air duct runs between the floor joists from the west wall to near the furnace air-intake. The owner had the furnace fan set to continual run.

The utility area exterior walls are covered with framing with pink insulation batts running from the floor to the joists behind plastic vapour barrier. The wall-floor joint is not visible anywhere, as it is covered by the framing. The floor is bare concrete, with a major crack up to 5 mm wide running east-west at the approximate centre of the utility area. The rest of the basement area, including the stairs, has plasterboard wall and ceiling finish, with carpet on the floor.

There is a small bathroom with tub, toilet and sink at the south end of the basement. The plumbing stacks from upstairs are boxed in a chase on the south-east wall of the basement. The basement was measured, and a basement plan is shown as Figure 3 in the Appendix.

Measurements

The house is located near an area of elevated uranium that was discovered by airborne-gamma spectroscopy in the early 1970's. Investigations in the late 1970's found a few houses in this area with short-term radon concentrations as high as 2000 Bq/m^3.

Gamma radiation fields measured outside the house with a hand-held meter were:

Location	Gamma Field nGy/h
Road	45 – 55
Lot – front, back, sides	80 – 90
Front step (concrete)	95

These are typical radiation fields, and show that the radioactivity of the near-surface soil is "normal". Simple gamma survey measurements are unlikely to identify houses with potentially high radon concentrations.

A review of the basement layout suggested that a sub-slab exhaust fan in the unfinished utility room adjacent to the frame wall between the utility room and finished area might be able to effectively depressurise the entire basement slab. A possible fan location was about 50 cm from the frame wall and 100 cm from twin teleposts on the centreline corner. This would avoid the telepost footing. The location is shown as A on Figure 3.

A test with chemical smoke on the floor drains found no airflow into the house. A smoke test on the floor crack found no airflow into the house.

The radon concentration in the basement just before test drilling started at 9.30 h was measured with a scintillation cell as ~2200 Bq/m^3, comparable to the continuous monitor reading at that time.

A 9.5 mm diameter test hole was drilled at location A, and a scintillation cell measurement through the hole of the sub-slab air immediately after drilling gave a radon concentration of ~33.3 kBq/m^3. A probe down the hole found that the slab was ~10 cm thick, poured on a plastic sheet, with ~10 cm of coarse aggregate beneath. Smoke tests showed a marked flow of air into the house from the sub-slab. A micro-manometer measurement gave a pressure differential sub-slab to house of 1.4 Pa, i.e. the sub-slab pressure was higher than the house pressure by 1.4 Pa.

A 9.5 mm diameter "monitoring hole" M (not shown on figure 1) was drilled at ~40 cm from hole A. A 9.5 mm diameter test hole was drilled in the north-west corner of the basement, about 1.3 m from each wall, shown as location B on the figure. A probe down that hole found the slab was ~10 cm thick, poured on a plastic sheet, with ~10 cm of coarse aggregate beneath. A micro-manometer measurement there gave a pressure differential sub-slab to house of 1.4 Pa.

Suction was applied to hole A with the vacuum cleaner, but the change in pressure at B was too small to read. Hole A was enlarged to 12.5 mm diameter, and when suction was applied with the vacuum cleaner the pressure differential at B fell to from 1.4 Pa to 0.5 to 0.7 Pa, and the pressure differential at hole M fell to from 1.4 Pa to 0.4 Pa.

The similarity in pressure drop between the distant hole B and the monitoring hole M suggests that the connectivity beneath the slab is very good, with the sub-slab space acting like a plenum.

The carpet was peeled back in a corner of a closet in the finished area, and a 9.5 mm diameter test hole drilled there. This is shown as location C on Figure 3 Basement Layout. A probe down the hole found the slab was ~10 cm thick, poured on a plastic sheet, with ~10 cm of coarse aggregate beneath.

A scintillation cell measurement of the sub-slab air gave ~1400 Bq/m^3, comparable to the basement air concentration. Hole C is close to the slab perimeter, and the sub-slab air measurement was made after a number of suction tests, suggesting that the testing had drawn house air into the sub-slab space.

A micro-manometer measurement at hole C gave a pressure differential sub-slab to house of 1.2 Pa. Suction was applied to hole A with the vacuum cleaner, and the pressure differential fell to 0.4 to 0.6 Pa. The pressure differential at hole M was 1.3 Pa before the test, and decreased to 0.4 Pa with suction on.

The vacuum cleaner hose was sealed to the floor, and the exhaust flow velocity in a 5 cm diameter tube was measured at ~3.9 m/s – equivalent to 7.7 L/s, or 16.5 cfm. The pressure differential at test hole M was 0.4 Pa during this test.

The results of the vacuum cleaner test with 12.5 mm suction hole are summarised in Table 1 below.

Table 1 Test Measurement Summary

Hole Location	Slab Pressure Differential (Pa)		
	No Suction	Suction	Change
B Front of House	+1.4	+0.5 – +0.7	-0.8
C Closet	+1.2	+0.4 – +0.6	-0.7
M	+1.4	+0.4	-1.0

Interpretation

The long and wide floor crack suggests that there has been major slab shrinkage, and the (concealed) wall/floor joint may be several mm wide, and provide little resistance to airflow.

Airflow of 7.7 L/s from beneath the slab produced a near field pressure drop of ~1 Pa, and near-perimeter pressure drops of 0.6 – 0.7 Pa at the test holes. The small change in pressure drop over a distance of 6.5 to 7 m shows that the sub-slab fill has low resistance to airflow, and the sub-slab space is acting like a plenum.

The far side of the finished area, which includes the bathroom, is about 14 m from the proposed fan site, about double the distance to the test hole at C. There may be openings through the slab for the bath and toilet drain plumbing, so the estimated pressure drop in that area is half the measured drop at C. To produce a pressure drop of ~1.4 Pa in the bathroom area would require a pressure drop at C of 1.4/0.4 = 3.5 Pa, which would be produced by a flow at A of 7.7x3.5 = 27 L/s (57 cfm).

The temperature difference between the house interior (25° C) and outdoors (5° C) was 20° C. In mid-winter, exterior temperatures fall to -15° C or lower and the temperature difference will be 40° C. If the observed sub-slab pressure differential of 1.4 Pa was caused entirely by the 20° C temperature difference, we can expect a slab pressure differential in mid-winter as high as 2.8 Pa. For effective performance in mid-winter, a fan flow as high as 52 L/s (114 cfm) may be needed to reverse a 2.8 Pa difference over the entire floor slab perimeter. A flow of 52 L/s was taken as the Design Flow rate for the purpose of system design.

System Design

Figure 4 shows the route of the proposed sub-slab exhaust system.

The proposed design was:

Cut out a section of the floor-slab ~60 x 60 cm, centred on hole A, remove aggregate, and place an inverted 150 mm (6") schedule 40 plastic "T" with pipe stub to act as a soil gas collector. Fill open ends of T with low airflow-resistance material to prevent aggregate filling the openings (e.g. folded chicken wire), fill hole to slab level with aggregate, place barrier to prevent concrete entering aggregate, fill opening with quick-set concrete to floor level.

Join fan inlet to the 150 mm (6") stub pipe with a 150x150 mm (6"x6") rubber coupling Attach fan to the frame wall. Join fan outlet to the exhaust pipe of 100 mm (4") schedule 40 plastic pipe with a 150x100mm (6"x4") rubber coupling. Run exhaust pipe up the frame wall, over to the central steel joist, along the joist to the north end of the basement, and then in the joist space to the west wall, to pass through rim joist and exterior siding to discharge via a 45° down elbow.

The estimated resistance of this system is calculated in Table 2 below at the Design Flow rate of 52 L/s.

Table 2 System Resistance Calculation

Fitting	Loss Coefficient	Loss @52 L/s
150 mm (6") T	1.3	
150 mm (6") Stub Pipe	0	
150x150 mm (6"x6") boot	0.2	
150 mm (6") Total Loss	**1.5**	**7.4 Pa**

100 mm (4”) piping		
150x100 mm (6”x4”)boot	1	
2 x 45° fittings	0.75	
90° fitting	0.5	
2 x 45° fitting	0.75	
90 fitting	0.5	
90° fitting	0.5	
45° fitting	0.25	
45° fitting	0.25	
11.2 m 100mm (4”) pipe	0.28x11.2=3.2	
100 mm (4”) Total Loss	**7.7**	**190**
Total System Loss		**197.4**
Loss in sub-slab fill		**7**
Overall System Loss @52 L/s		**205 Pa**

The resistance is calculated based on smooth curve 45° and 90° fittings.

The pressure drop from slab edge to the fan suction pit is estimated as linearly proportional to the airflow. The test hole M is located at approximately the edge of the proposed fan suction pit. From Table 1, the pressure drop at M was 1 Pa at 7.7 L/s, the design flow is 52 L/s, 7 times higher. The estimate of pressure drop in the sub-slab fill from slab edge to the suction pit edge at design flow is therefore 7 Pa. This is a small amount compared with the other losses in the system.

The pressure drop in the system at other flows can be estimated on the basis that the pressure drop is proportional to the square of the airflow velocity. This was done for a range of airflows, to produce a system resistance curve (piping pressure loss versus airflow).

Figure 5 plots the system resistance curve and the fan pressure/flow curves provided by the manufacturer for two Fantech fans sold for radon mitigation, FR-150 and FR-160. The predicted flow rate in the system with a given fan is where the fan curve intersects the resistance curve. The FR-150 curve intersects at ~120 cfm (57 l/s), which is close to the estimated flow rate required for effective performance in winter. The FR-160 curve intersects at ~130 cfm (61 l/s), which provides a margin over the design flow to compensate for underestimates in the required system performance.

The selected fan was the FR-160 with an electronic speed control so that the flow, and resulting sub-slab suction, may be adjusted to the minimum required for effective operation in summer and winter.

Installation and Testing

A local contractor was engaged, and after an inspection of the basement, suggested that the exhaust layout be modified to discharge closer to the front corner of the house to avoid interference with air ducting and electrical services. The modified design layout is shown in Figure 6.

Installation of the system took place on 17 January 2008. Work started at ~8:15 am, when a 120 mm circular hole was cut through the exterior siding and the rim joist, and a 3.3 m length of pipe inserted from the outside. While this was in progress, the concrete coring contractor crew set up an electric coring machine to cut a 12” (30 cm) diameter opening in the floor slab. The current required by the machine was at the limit for a domestic electricity circuit, and after repeated breaker trips, a line was run outside to a generator in the coring contractor’s truck. Good progress was made with this supply, and coring was completed by 9:30 am.

A continuous radon monitor was started in the basement area at about 8:30 am. This monitor was left in the house until 8 February, and the trace is shown in Figure 7 and Figure 8.

When the core was removed, the slab thickness was measured at 8 cm. There was a polyethylene sheet beneath the floor. The exposed sub-slab fill layer was a coarse crushed stone ca.1- 2 cm diameter, about 10 cm thick, and was wet from the water used to suppress dust and cool the coring bit. The corner of the telepost footing was exposed at the side of the opening.

The fill material plus some sub-slab soil was removed into two 25 L (6.5 gallon) buckets, plus additional stone, which was stored on a plastic sheet. Material was removed from the opening to a depth of ~20 cm beneath the slab to give space for the 150 mm (6”) “T”.

The “T” was black Schedule 80 PVC, as the plastic pipe supplier did not have a Schedule 40 “T” in stock. The rest of the piping was also black Schedule 40 PVC. The supplier did not have white pipe in either ABS or PVC in stock. The pipe elbows were short radius elbows, as large radius elbows were not in stock.

To prevent sub-slab fill material from blocking the “T” openings, a perforated cap was attached to each end of the horizontal part of the “T” with a stub pipe. The caps originally had 28x6 mm holes drilled over half the cap. This was increased to about 50x6 mm holes per cap to reduce flow resistance.

The T was installed in the hole, a vertical length of 15 cm (6”) pipe cemented in, the fan attached to the vertical pipe with a rubber coupling, and secured to the frame wall by 10:50 am.

The 100 mm piping that ran down the central joist was installed while the T and fan were being placed, and the 45° leg to the fan was then cut to fit, and joined to the fan with a rubber coupling at 11:12. The rest of the discharge piping was then installed, starting from the fan end. All pipe joints were solvent welded.

While the piping installation was in progress, the reserved sub-slab fill material was returned to the hole to fill it to the underside of the slab. A piece of plastic was cut to fit the annular space between the vertical 150 mm (6") fan inlet pipe and the floor slab, placed over the fill, and caulked to the pipe. The annular space was then filled with a quick-set concrete bag mix, and finished level with the top of the slab. A small oil-filled manometer was attached to the 150 mm inlet pipe to monitor the fan operation.

Some of the heating ducts attached to the floor joists were removed to allow the discharge piping to be installed. These ducts were reconnected, and the installation was complete by ~11:45. An electrician had been scheduled to wire the fan with a speed control, but had been delayed. The fan was connected to a power supply via an extension cord, and started at 12:10. All waste, materials and tools were removed by 12:15.

Post-Installation Measurements

The continuous radon monitor reading had been increasing every hour since it had been started at 8:00, and read 2470 Bq/m^3 at 13:30. This reading represents the average radon concentration over the previous hour. This was the highest concentration measured in the basement, as readings fell steadily from that time on, reaching the average mitigated value of ~40 Bq/m^3 by 9:00 am the next day. This is shown in Figure 7.

The upper limb of the U-tube fan manometer read 0.4", equivalent to a suction of 1.2" of oil, or ~270 Pa if the oil has density 0.9 g/cm^3. (Both limbs of the manometer read –0.2" with no suction applied.) This is a high suction, considering the coarse crushed stone sub-slab fill and the large cavity excavated for the T.

Chemical smoke tests were carried out on the fan and piping, and no leakage from the system could be detected at any of the joints or connections. A smoke test on the major central floor crack found that there was a small airflow into the crack at several locations. Clearly the plastic sheet beneath the slab was not a compete seal. Filling the crack with grout might give a small increase in suction in the utility area.

The holes used for the original testing were drilled out, and measurements made of the pressure differentials across the slab with the fan on and off. The results are shown in Table 3.

The average natural pressure difference across the floor slab with the fan off was between 1.5 to 2.2 Pa depending on location, with short-term time variations of up to 0.3 Pa, probably due to varying wind pressures. The exterior temperature at this time was -5ºC, giving an inside-outside temperature difference of 30ºC, smaller than the 40ºC (and 2.8 Pa) assumed for the design extreme 2.8 Pa used for the design extreme.

The pressure decrease produced by the fan at hole B (at the front of the house) was 2.6 Pa, close to the design value. This was 0.4 Pa larger than the natural pressure differential, and effectively imposed an airflow from house to sub-slab. This was confirmed by a smoke test.

In contrast, the pressure decrease produced by the fan at hole C (in the closet), was only 1.3 Pa, too low to consistently reverse the local pressure differential of 1.5 Pa. This was confirmed by a smoke test, which showed a variable flow of air from sub-slab space to house.

The lower natural pressure differential and the lower fan pressure decrease at this location suggests that there may be some sub-slab obstruction in this area, plus larger concealed openings in the floor slab, or a larger perimeter joint. Larger openings will allow a freer flow of air into the sub-slab space, decreasing the slab pressure differential.

To verify the extent of the fan suction field, the carpet was peeled back near the wall edge of the slab by the bathroom door threshold, and a new hole drilled. The pressure decrease produced by the fan was 1.6 Pa, too low to consistently reverse the natural pressure differential of 1.8 Pa. This was confirmed by a smoke test, which showed a variable flow of air from sub-slab space to house. Despite this, the suction field extension from fan to this location was better than anticipated in the system design.

Table 3 Post-Installation Pressure Differentials.

Hole Location	Slab Pressure Differential (Pa)		
	Fan OFF	Fan ON	Change
B Front of House	+2.2	-0.4	-2.6
C Closet	+1.5	+0.2	-1.3
Bathroom door (New)	+1.8	+0.0 - 0.2	-1.6

Overall, the fan provides pressure reversal over the entire utility area floor slab, and has greatly reduced the pressure differential and radon inflow in the finished area.

A pitot tube measurement of the fan discharge rate was made on 8 February, 2008, after the sub-slab fill had a month of operation to dry out. The upper limb of the fan inlet manometer still read ~0.4”, so the flow had not changed greatly since installation. The average velocity in the 100 mm pipe was 6.4 m/s (1260 ft/min), giving a flow of 51.9 L/s (110 cfm). This is equivalent to the design flow of 52 L/s, but less than the expected 61 L/s flow for the FR-160 fan operating at full speed.

The performance during January-February 2008 was satisfactory, as shown in Figure 8. The average radon concentration is about 42 Bq/m^3, well below the mitigation guideline value of 200 Bq/m^3. The outside temperature during this period typically ranged from -10ºC to -5ºC, but fell to -20ºC on 20 – 21 January. This would be expected to increase the slab pressure differential, and increase the radon inflow, but the continuous radon monitor trace shows that range of house radon concentrations over these days were not higher than the average over the period. There was little correlation between house radon concentration and exterior temperature, “high” measurements of 50 to 70 Bq/m^3 on 5 - 6 February were associated with warmer temperatures of -5ºC to 0ºC.

Comments

The coring machine cut a neat circular hole with minimal dust generation, but the 30 cm diameter opening was only just large enough to install the "T". The smaller hole reduced the diameter of the sub-slab fill excavation below the design value of ~60 cm. The hire of the coring machine and crew plus the cost of the "T" was several hundred dollars, more than triple the cost of placing a roughed-in and capped "T" through the floor slab at the time of construction.

The installed system discharge differed from the design with fewer, but sharper bends and a longer pipe run. An estimate of the discharge resistance is given in Table 4.

Table 4 Installed System Resistance Calculation

Fitting	Loss Coefficient	Loss @52 L/s
150x100 mm (6"x4")boot	1	
1 x 45° fittings	0.4	
90° fitting	0.6	
3 x 45° fitting	1.2	
90 fitting	0.6	
13 m 100mm (4") pipe	0.28x13.0=3.7	
100 mm (4") Total Loss	**7.5**	**185 Pa**
Original Estimate 100 mm (4") Total Loss	**7.7**	**190 Pa**

The estimated flow resistance of the installed 100 mm discharge system is essentially the same as the estimated flow resistance of the original 100 mm discharge system design. There is no performance penalty associated with the changes from the original discharge system design.

Note that the design pressure drop across the entire system (fan inlet suction plus fan discharge pressure) as estimated in Table 2 was 205 Pa at 52 L/s. The measured system flow is 52 L/s (110 cfm), at which flow the FR-160 fan curve shown in Figure 5 indicates the fan produces a pressure differential of 340 Pa – 65% higher than estimated as necessary to produce the design flow. The choice of the larger fan (FR-160) to provide spare capacity is justified.

The fan inlet suction as measured by the oil manometer is about 275 Pa, so this suggests that the discharge pressure is about 65 Pa. This is less than half of the value estimated in

Table 4. The pressure loss in the long runs of smooth plastic pipe is probably less than the estimated value.

Conclusions

Installation of this sub-slab exhaust system demonstrated that radon concentrations in winter can be reduced to a fraction of the mitigation guideline value of 200 Bq/m^3 using a sealed fan inside the basement, solvent welded pipe joints, and near-ground-level discharge. These features have been proposed to reduce the anticipated problems of condensation and icing associated with discharge of warm, humid air to the outside during sub-zero conditions – as occur in Canada for several months of the year.

Even though the system did not completely reverse the soil gas flow into some parts of the basement house, performance was not affected even during -20ºC weather.

The fan selected for the system was about 10% larger than the sizing calculation suggested was needed to produce the design flow. The installed system had a higher resistance than calculated, and the larger fan only just achieved the design flow. A margin over design flow to allow for contingencies is good practice.

Although openings in concrete floors to install the soil gas collector can be cut rapidly with minimal mess, the cost of the hiring the equipment and crew is much higher than the cost of installing a capped collector during construction.

APPENDIX

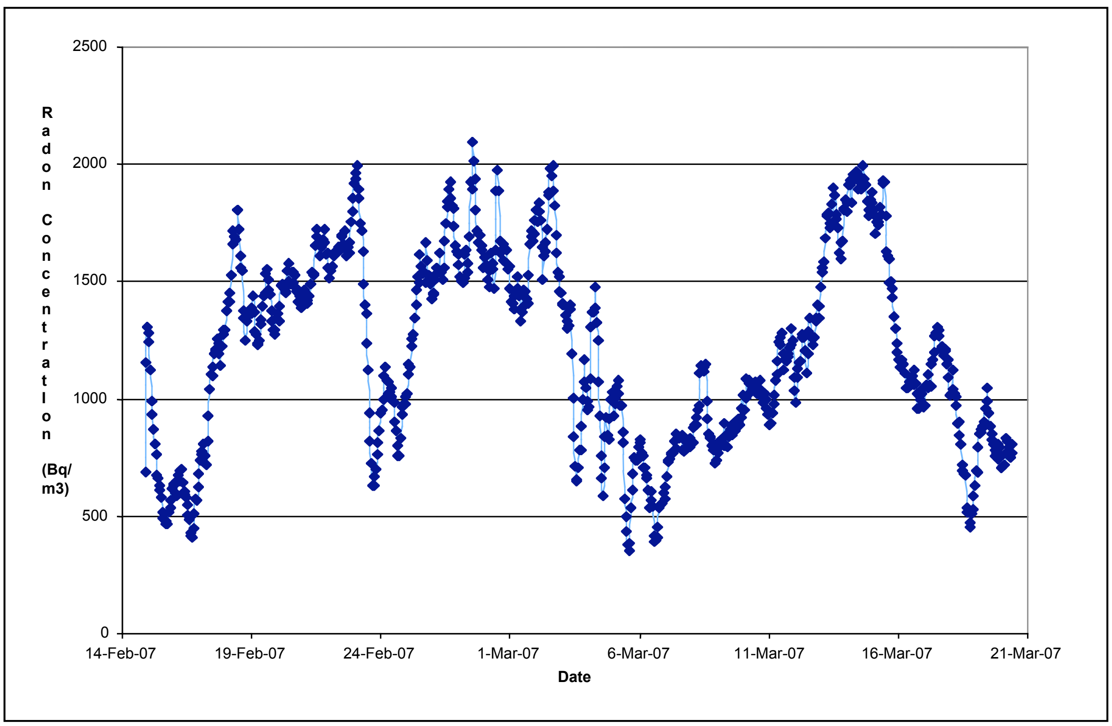

Figure 1 Continuous Radon Monitor trace February – March 2007

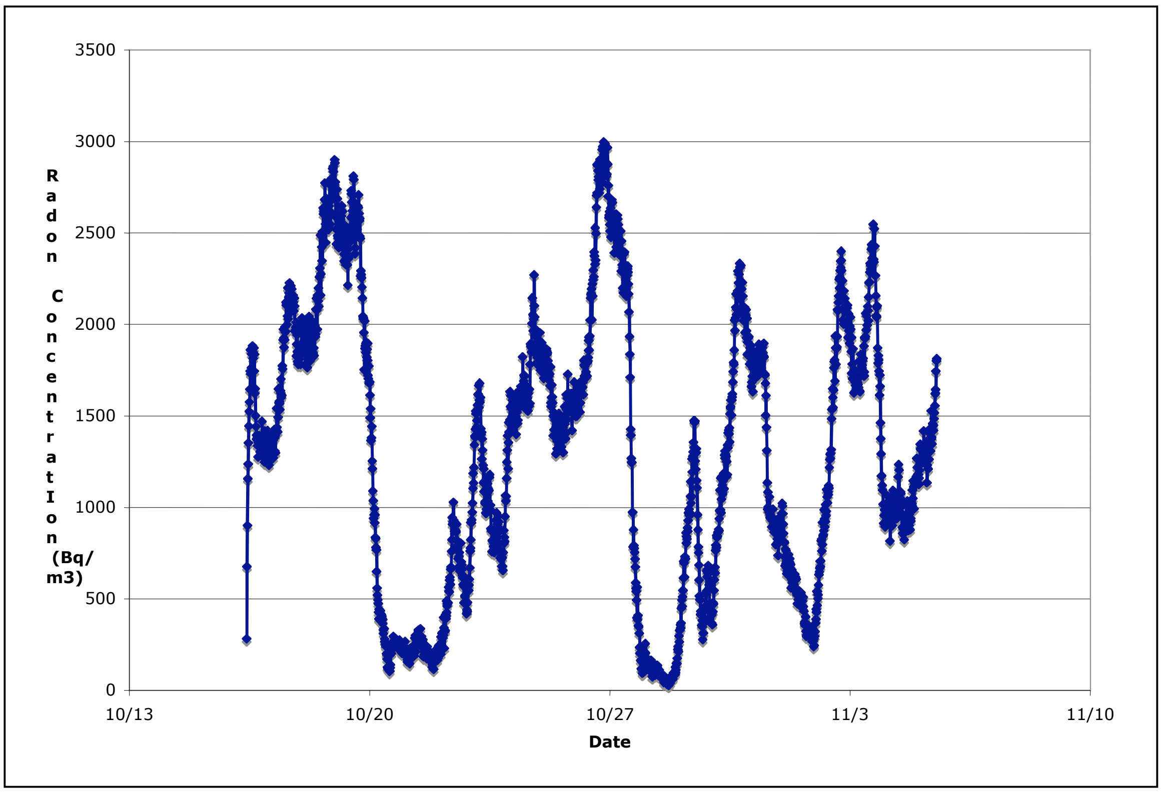

Figure 2 Continuous Radon Monitor trace October- November 2007

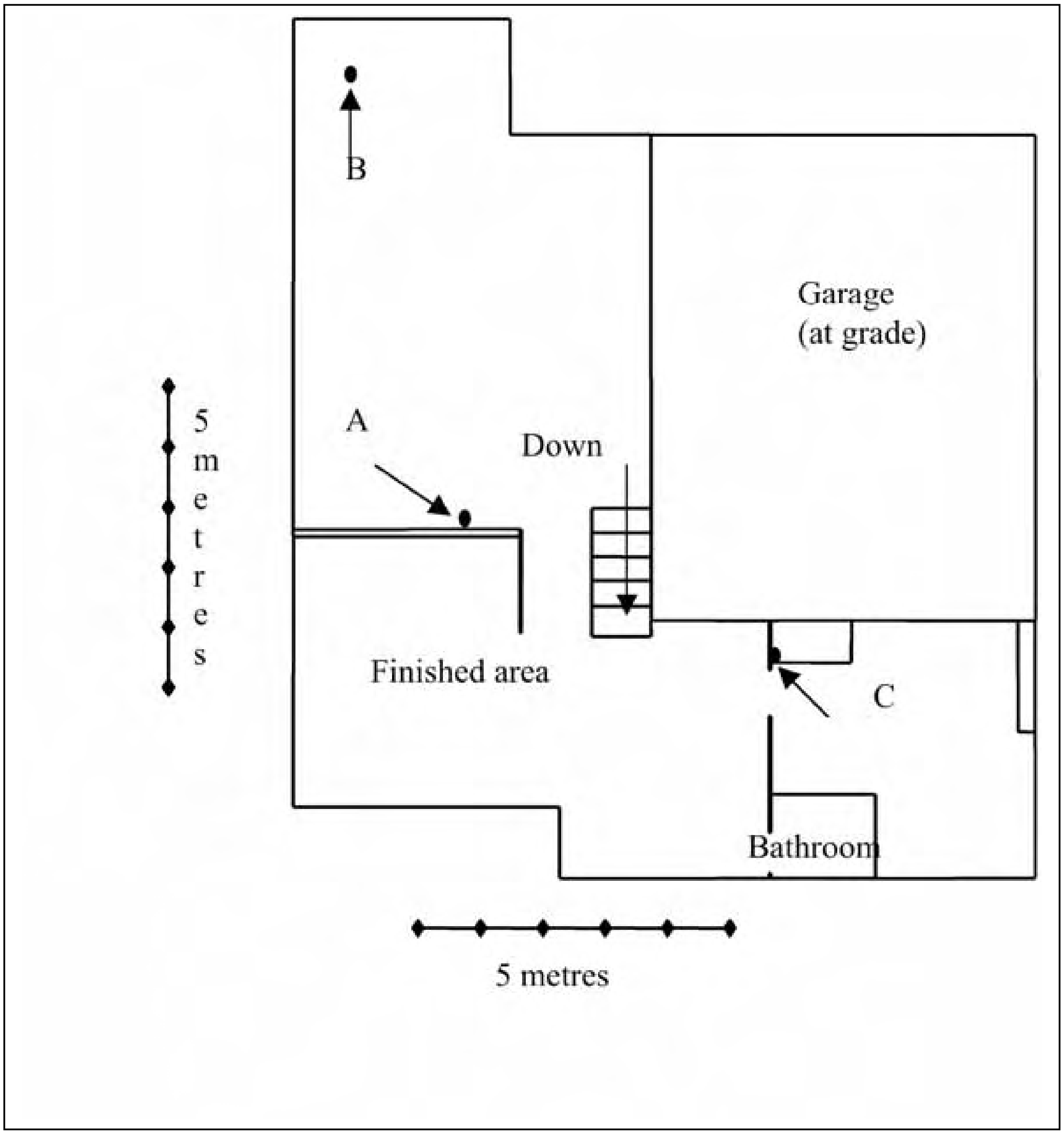

Figure 3 Basement Layout

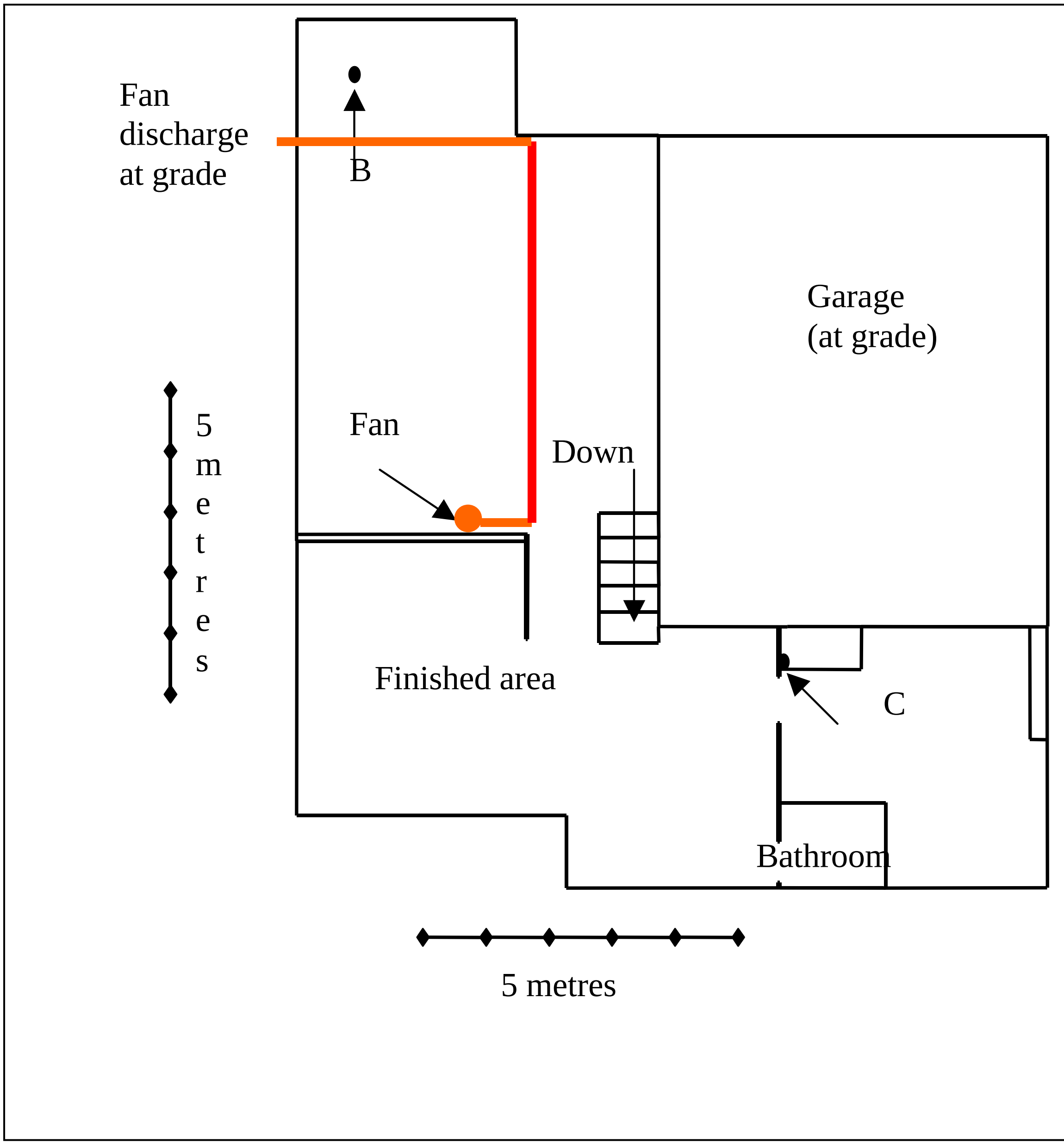

Figure 4 Proposed Fan and Piping Layout

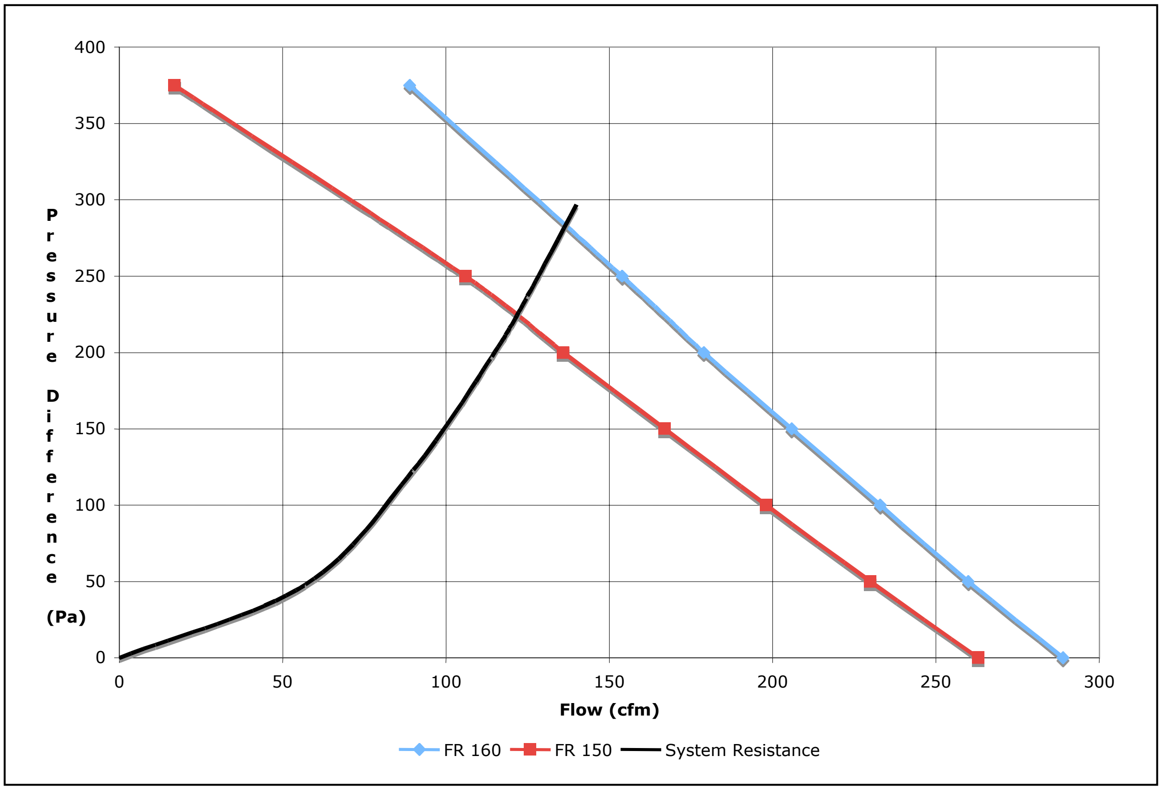

Figure 5 Fan and System Resistance Curves

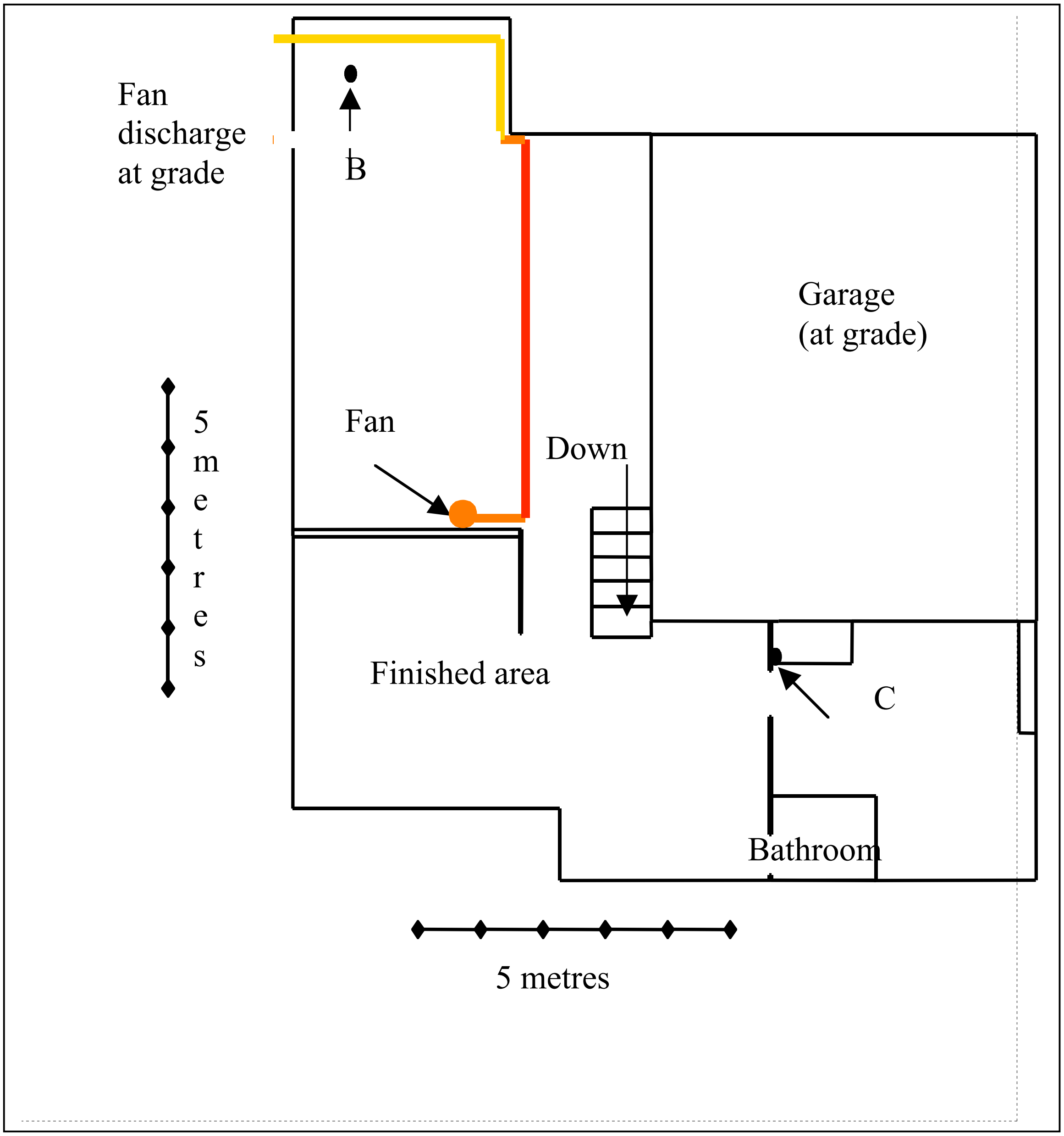

Figure 6 Installed Fan and Piping Layout

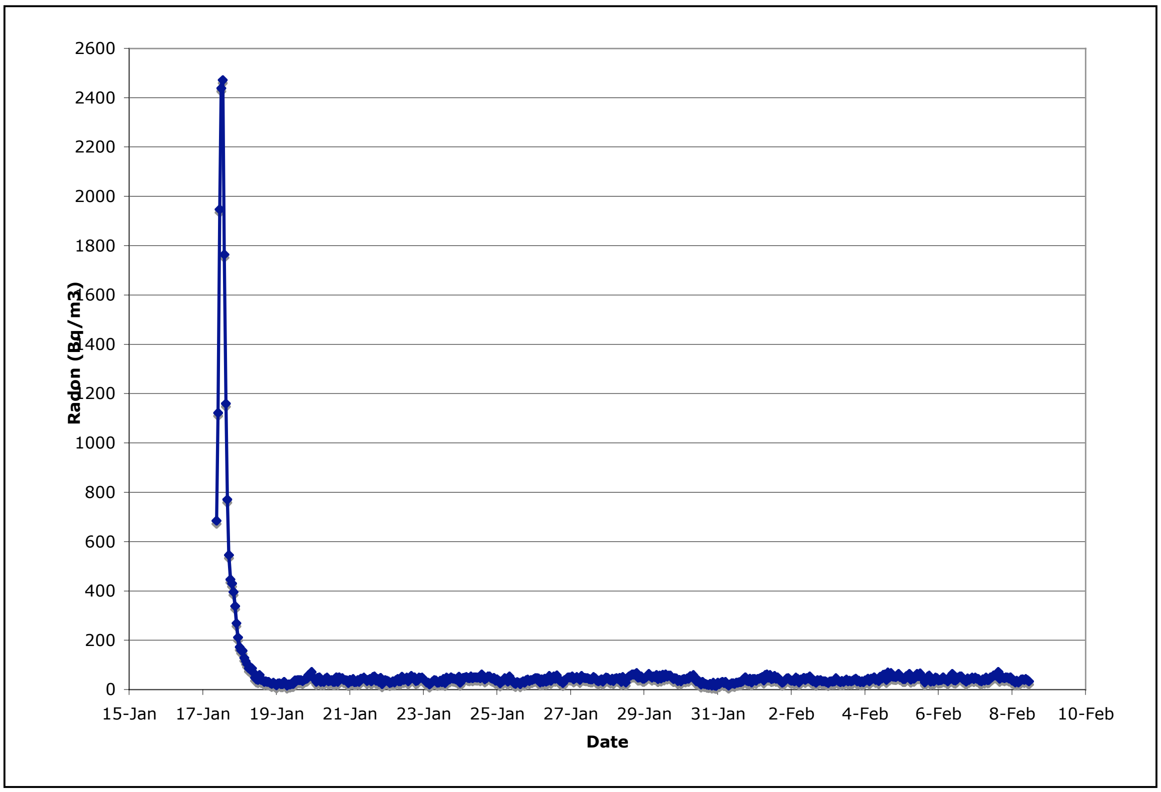

Figure 7 Continuous Monitor Trace During and Post Mitigation

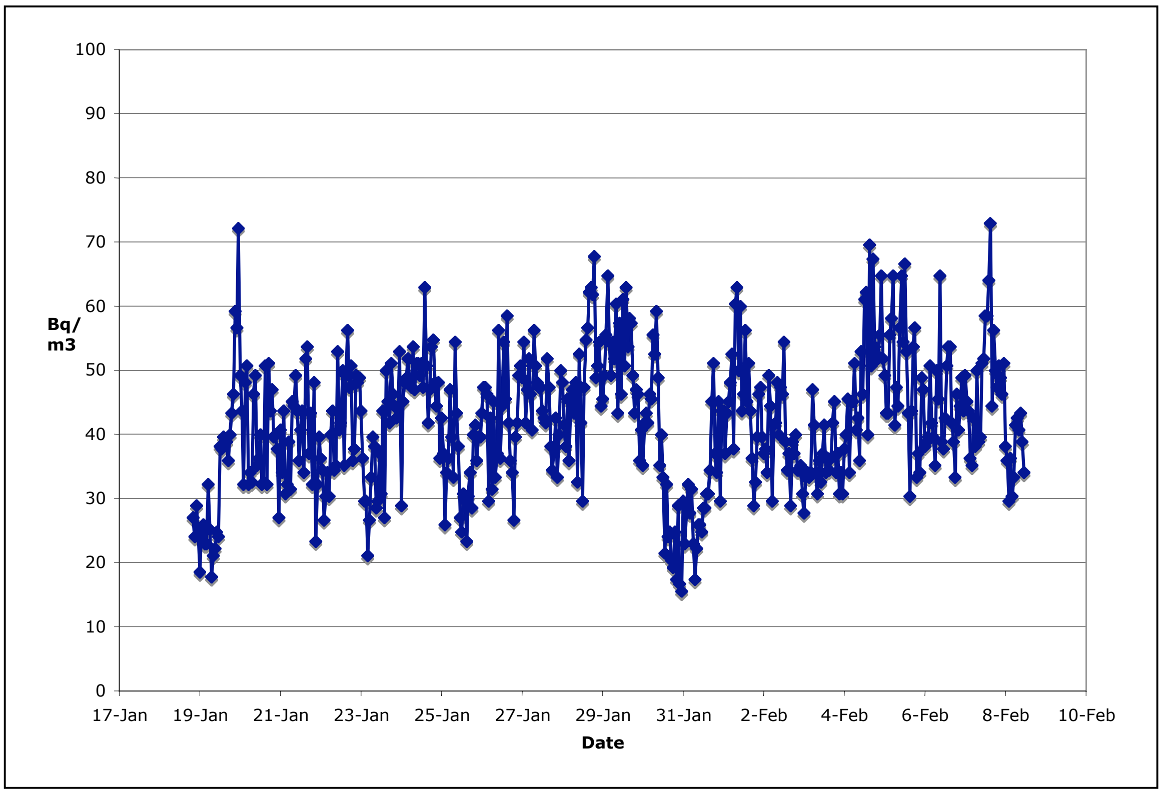

Figure 8 Continuous Radon Monitor Trace - Post Installation only

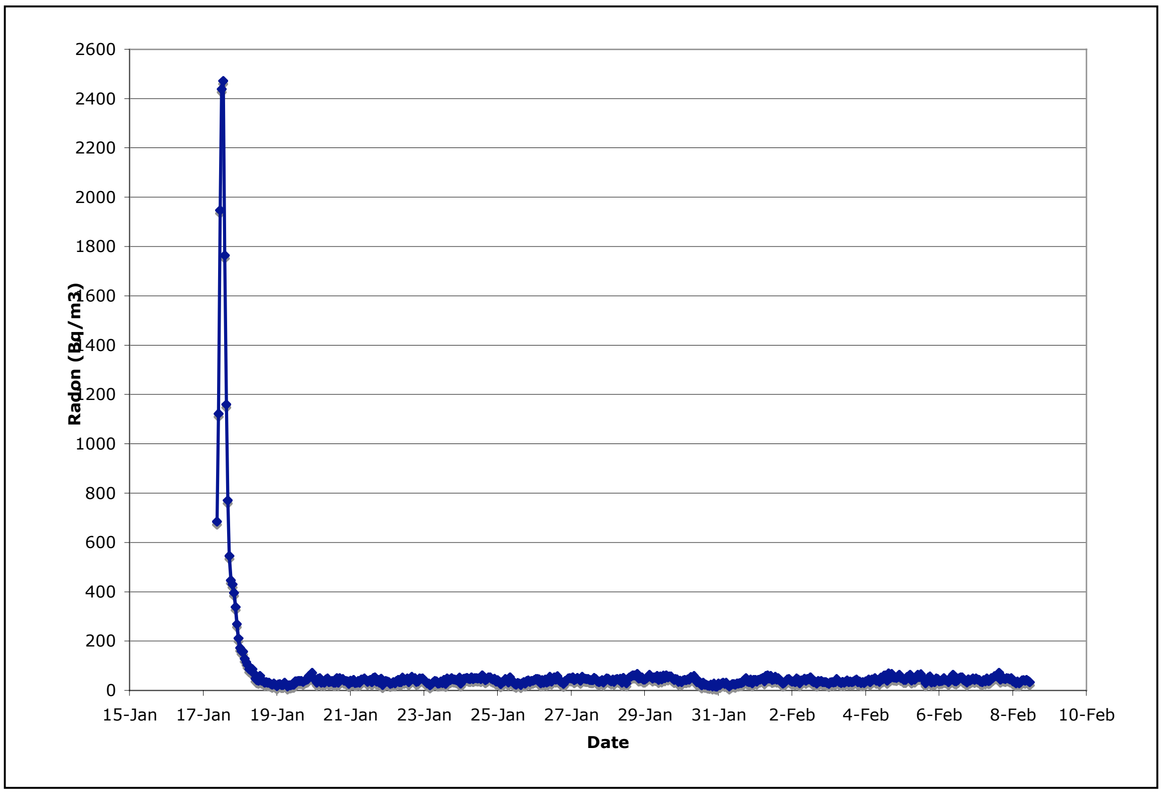

Figure 9 Continuous Monitor Trace During and Post Mitigation

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