SURVEYING AND REMEDIATION OF CONTAMINATED SMALL-SCALE RESIDENTIAL SITES IN PORT HOPE

D. Elion
SNC-Lavalin Inc.
Oakville, Ontario, Canada

A. Husain and Y. Verzilov
Kinectrics Inc.
Toronto, Ontario, Canada

ABSTRACT

There are approximately 4500 small-scale properties in Port Hope, Ontario, Canada, a town in which there were historic radium refining operations. It is expected that 200-400 of these properties are contaminated at levels above the Port Hope Area Initiative Clean-up Criteria (PHAI CC) and will need to be remediated.

In 2010, an initiative was implemented to (1) resurvey a representative number of the 4500 properties and (2) remediate up to six of the properties where the presence of historic Low Level Radioactive Waste (LLRW) contamination was confirmed. Information from the resurvey and remediation field work was intended to be used as the basis for developing procedures feasible for the overall resurvey and remediation work to be done as part of Phase 2 of the Port Hope Project.

Thirty-five small-scale properties, selected based on historical data, were resurveyed for the presence of interior radon gas and for exterior as well as interior gamma radiation levels. Objects and surfaces were surveyed for the presence of fixed and loose contamination at various locations including those with elevated gamma radiation levels. Boreholes and hand-augered holes were drilled to obtain soil samples for analysis of PHAI CC parameters; in addition, radiation profiles were recorded as a function of depth in the drilled boreholes. Based on the results obtained, the presence of LLRW was confirmed on several properties and deemed likely on several others. One of the more extensively contaminated properties was chosen for remediation.

This paper presents an overview of the techniques employed and results obtained during the SRCA field work as well as an account of the remediation work carried out. Overall conclusions are presented and recommendations drawn for the next phase of the work.

1. INTRODUCTION AND BACKGROUND

Contaminated waste originating from uranium ore refining activities in the early 1930s at Port Hope, Ontario, Canada, was used as backfill material resulting in radioactive contamination of a number of properties in Port Hope. As well, contaminated materials and artifacts were incorporated into some building structures resulting in contamination indoors. Of the approximately 4500 small-scale properties within Ward 1 of the Municipality of Port Hope, it is estimated that 200-400 properties are likely to be contaminated with historic Low-Level Radioactive Waste (LLRW). These properties include residential, industrial / commercial, institutional, woodlot and park properties.

Part of the mandate of the Port Hope Area Initiative (PHAI) is to resurvey all small scale properties and to remediate and restore properties where the contamination levels are found to exceed the PHAI Clean-up Criteria (CC). Depending on the location and extent of the contamination present, properties can be categorized as shown in Table 1. Contaminated soils are expected to be primarily contaminated with Ra-226, Th-230, Th-232, uranium, antimony, arsenic, cobalt, copper, lead and nickel. Their cleanup criteria are shown in Table 2 which also includes radon (Rn-222), a short-lived gaseous decay product of Ra-226[1]. Criteria for contaminated objects and materials are summarized in Table 3.

Table 1: Types of Properties

Type	Location of Waste on Property
A	Property with survey results less than PHAICC*
B	Property with survey results above PHAICC*, but not from historical LLRW
C	Property with contaminated soils not exceeding 25% of the area of the property
D	Property with contaminated soils exceeding 25% of the area of the property
E	Property with contaminated materials in unique conditions requiring site-specific remediation plans and cost estimates

* PHAICC – Port Hope Area Initiative Cleanup Criteria

Table 2: Current Selected PHAI Clean-up Criteria

Contaminant	Criteria
Ra-226	0.29 Bq/g*
Th-230	1.16 Bq/g*
Th-232	0.158 Bq/g*
Rn-222	125 Bq/m^3
Arsenic	20 ppm
Antimony	13 ppm
Cobalt	40 ppm
Copper	225 ppm
Nickel	150 ppm
Uranium	35 ppm
Lead	200 ppm

*Includes natural background

[1] Radon may migrate from the ground and accumulate in enclosed spaces such as houses and buildings.

Table 3: PHAI Clean-up Criteria for Contaminated Objects and Materials

Criterion	Limiting Value
Fixed surface contamination averaged over 100 cm^2	1 Bq/cm^2
Loose alpha surface activity averaged over 300 cm^2	0.04 Bq/cm^2

The PHAI Management Office (PHAI MO) is responsible for resurveying all small-scale sites and remediating those found to be contaminated. In 2010, an initiative was undertaken to resurvey a representative number (35) of the 4500 properties and to further remediate up to six of the contaminated properties. Information from the actual field work would provide the basis for developing procedures for the overall resurvey and remediation project. PHAI MO engaged AECL's Low Level Radioactive Waste Management Office (LLRWMO) to manage the work. Services for the Project Management and Cost Estimating and Trials Contractor components of the work were provided by SNC-Lavalin Inc. (SLI). SLI in turn contracted with Kinectrics, Inc. for all the radiological re-survey work as well as analysis of soil samples. Most of the resurvey work was undertaken from June through August 2010 and then some follow-up work was done for a few days in March and April 2011.

2. DETAILED SCOPE OF SRCA WORK

As stated above, scope of the work was to resurvey 35 properties and further to remediate up to six of the contaminated properties. To achieve the objectives of the work, each property was surveyed for the following:

- Indoor Radon-222 levels: Detection of elevated radon levels in conjunction with the presence of a characteristic LLRW soil signature would indicate that the radon originates from the LLRW and hence PHAI would be obliged to remediate this condition.

- Interior and exterior surface contamination: Incorporation of contaminated artifacts or materials from the historical refining operations may cause the surface contamination levels both inside and outside the properties to exceed the PHAI CC. Such locations would require decontamination and /or remediation.

- Interior and exterior gamma radiation: External gamma radiation at levels significantly above background is indicative of the presence of Ra-226 and daughter products in the soil. Mapping of the external gamma radiation levels was required to assess the distribution of Ra-226 and other associated contaminants across the front and backyards of each property and to identify preferred locations for placing boreholes and sampling of the soil cores. Similarly, interior gamma surveys were required to identify the location of elevated gamma radiation and the location of contaminated artifacts or building materials.

- Gamma surveys as a function of depth in bore holes: Activity profile along the depth of a borehole was required to assess the depth to which LLRW signature contaminants may be present in the soil. The activity profile information was intended to be used to decide how the extracted soil core was to be sub-sampled for analysis of various PHAI CC parameters.

- Concentrations of radiological and non-radiological contaminants in soil: Selected soil sub-samples were required to be rapidly analyzed for various radioactive and non-radioactive contaminants to compare with the PHAI CC and, where, the presence of LLRW was found, to determine the estimated excavation volume. The detection limits for PHAI CC parameters were required to be consistent with the values shown in Table 2.

Plans, procedures and processes were developed for both the resurvey as well as the remediation work. The project was carried out in two stages.

Stage 1: Radiation surveys, including surface contamination measurements and soil sampling on all selected sites to identify those requiring to be remediated.

Stage 2: Radiation surveys and soil sampling in support of remediation and verification activities.

Stage 1 itself was comprised of 3 sub-stages:

Stage 1A: Site Screening designed to identify buildings containing elevated radon gas and possibly locate LLRW based on gamma radiation levels, and surface contamination.

Stage 1B: Initial Intrusive Investigation involved drilling boreholes and hand-augered holes, in-hole gamma radiation monitoring, collection and analyses of soil samples. Results were expected to enable the elimination of all Type A & B sites from further consideration and identify Type C & D sites requiring remediation.

Stage 1C: Contaminant Delineation involved drilling additional boreholes and collection and analyses of sub-surface soil samples on sites requiring remediation. Results helped to delineate the area and depth of the remediation zone and, therefore, determine the volume of contaminated soil to be removed.

3. FIELD MEASUREMENTS - METHODOLOGY AND INSTRUMENTATION

The previous section provided the rationale for the various surveys required to detect and delineate the zone of contaminated soil and for identifying materials and items with surface contamination which would need to be decontaminated or removed as part of the remediation work. This section provides a description of the survey techniques employed.

3.1 Exterior and interior gamma surveys

Background gamma radiation fields at Port Hope arising from cosmic radiation and natural radioactivity in the soil typically range from 30 to 60 μSv/h. Based on past radiation surveys at

Port Hope, the presence of LLRW contamination in the soil may result in gamma fields of up to 300 µSv/h. The increase results principally from gamma emitters like Bi-214 and Pb-214, which are decay products of Ra-226. Because of soil attenuation, only LLRW located within about 1 m from the surface contributes to increased gamma radiation levels.

Kinectrics selected Thermo Scientific Model FH 40 G NBR survey meters (see Figure 1) to map out radiation fields at the levels indicated above. The instrument is a combination of the Model FHZ 672 E-10 detector and the Model FH 40 G digital rate meter. The detector is a combination of sodium iodide and plastic scintillators coupled to a photo multiplier. The sodium iodide scintillator improves the detector's sensitivity to low-energy photons. Unique features of the system include:

- Ability to automatically discriminate between natural cosmic radiation and radiation from other sources based on Natural Background Rejection (NBR) technology which differentiates between natural radioactive material (NORM) and artificial, man-made sources;

- High gamma sensitivity (2800 cps/µSv/h) - 1000 times more sensitive than normal gas filled detectors;

- Measurement range of 1 nSv/h up to 100 µSv/h; and

- Rapid response - a signal of 10 nSv/h can be detected within a few seconds even in fluctuating background radiation fields of 50-100 nSv/h.

Figure 1 FH 40G NBR Survey Meter

In keeping with the eventual need to efficiently survey over 4000 properties, a target of completing a minimum of two property surveys per day using a crew of two was considered to be desirable and readily achievable. For both exterior as well as interior surveys, the survey data must be recorded as a function of spatial co-ordinates in order that any subsequent remediation can be carried out expeditiously. For interior surveys, measurements were manually recorded on a coarse grid for each room within a house. For external gamma surveys, a manual approach was considered impractical and hence a mobile system was developed which consisted of two

FH 40G survey meters integrated with a Trimble™ GPS unit (see Figure 2) mounted on a wheeled cart. Features of this system included the following:

- One survey detector was positioned about 15 cm above ground level while the other about 1 m above it; the former provided a local response while the latter a general response from the immediate surroundings.
- A tablet computer (Yuma) continuously recorded radiation levels along with GPS location and time. The location co-ordinates (longitude and latitude) were determined in real time with a precision ~ 2 m. Post-processing increased the precision of the GPS data to about 30 cm.
- The GPS receiver located on a telescopic pole was raised as needed to obtain improved satellite response when surveying in the shadow of the building or other obstructions.
- Survey data were displayed on an ortho-rectified air photo of the property map and the radiation levels were colour-coded for display and further assessment.

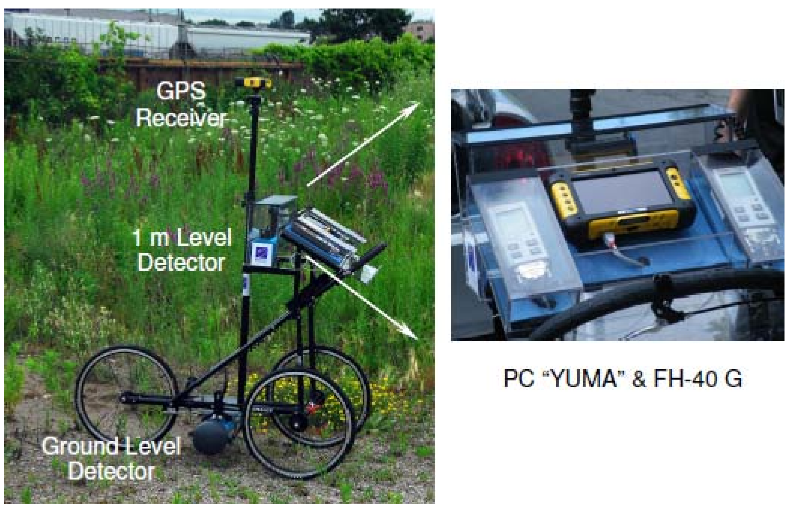

Figure 2: Mobile, GPS-Integrated, Exterior Gamma Radiation Mapping System

3.2 Exterior and interior surface contamination surveys

Both gamma as well as alpha/beta contamination surveys were performed. While gamma surveys were performed using the FH 40 G-10 survey meter, alpha/beta surveys were conducted using a Thermo Scientific Model FHZ 742 zinc sulfide scintillation detector (see Figure 3) coupled to the FH 40 G-10 Rate Meter. The FHZ 742 detector has a sensitive area of approximately 125 cm^2. It can be used in an alpha/beta/gamma mode where the detector responds to all three types of radiation or in an alpha mode where it responds only to alpha radiation. In the first mode, two measurements are required, first, a measurement using a thin shield plate placed between the source and the detector to screen out alpha/beta radiation and a second measurement without the shield plate. The difference between the two responses represents the alpha/beta signal.

Contaminated surfaces were further smeared to determine the presence of loose contamination. The smears were counted using a laboratory gross alpha/beta proportional counter.

Figure 3: FHZ 742 Zinc Sulfide Scintillation Detector

3.3 Down-hole gamma radiation surveys

Down-hole gamma radiation measurements were performed using the Thermo Scientific FHZ 512A sodium iodide probe connected to the FH 40 G-10 rate meter. The detector size was 1 x 1 inch while its overall housing length and diameter were 12 and 1.6 inch, respectively. Nominally, the detector responds to radiation as follows: 3400 cps per µSv/h for Am-241, 1000 cps per µSv/h for Cs-137and 550 cps per µSv/h for Co-60. The probe was mounted on a pole to take readings as a function of depth in a borehole (see Figure 4).

Figure 4: Recording Gamma Radiation in a Bore-Hole

3.4 Radon measurements

Radon measurements were performed using the passive E-PERM (Radelec Inc) electret ion chamber method by NEHA[2] certified technicians. The ion chamber contains an electro-statically charged disk detector (electret). During measurement, radon diffuses into the ion chamber through a filter-covered opening which prevents entry of any charged aerosols present in the air. Ionization from the alpha decay of radon produces a reduction in the charge on the electrets, which is read using a specially-designed voltage reader and related to the radon concentration.

Short-term radon measurements (duration of 5-7 days) were performed using Health Canada guidance for selection of test locations, detectors being placed in the breathing zone of the normal occupancy area at the lowest lived-in levels of a house. Typically, measurements were done in the basement and on the first floor of the house or building. Two E-PERM detectors were placed side-by-side at each test location. Gamma dose rate measurements were taken at each location in order to compensate for any voltage loss due to gamma radiation.

Figure 5: E-PERM Electret Detectors with Voltage Reader

4. ANALYSIS OF SOIL SAMPLES

Soil cores extracted from the boreholes during Stage 1were further sub-sampled based on the recorded activity depth profile and a visual assessment of its physical characteristics. Stage 2 soil samples, obtained from the excavation zone, were analyzed to demonstrate compliance with clean-up criteria. In addition to various inactive elements, the analytes of interest included the radionuclides Th-230, Th-232 and Ra-226 (see Table 2 for the list of primary contaminants).

[2] National Environmental Health Association - National Radon Proficiency Program (NEHA-NRPP)

Inductively Coupled Plasma - Mass Spectrometer (ICP-MS) was selected as the method of choice for all contaminants[3] based on the following considerations:

- Use of a single technique minimized sample handling, making it easier to achieve the required turnaround requirements of 24-48 hours. This was particularly important because of the large expected sample throughput of up to 40 samples per day.

- Gamma spectrometry was an alternate option considered for the analysis of Ra-226. However, the Ra-226 gamma emission line at 186 keV could not be used because of the significant presence of uranium in many samples. As a result, analysis would have to be based on the emission line for Bi-214, a daughter product. This, however, requires a 30-day in-growth period in sealed sample containers to achieve equilibrium conditions. The need for an extended equilibration period (without equilibration, results would be biased low) was inconsistent with the required 24-48 hour turnaround time for analysis.

- Achievable detection limits using ICP-MS were consistent with the clean-up criteria for the analytes and thus results obtained could be assessed against PHAI CC and to establish the end point for any remediation undertaken.

In preparation for analysis, soil samples were oven-dried for several hours, pulverized and homogenized and finally sieved (50 mesh). The samples were then microwave digested using a mixture of nitric, hydrochloric and hydrofluoric acids and then bulked up using distilled water. Appropriate quality control samples were included in the digestion, including blanks, duplicates, and certified reference materials.

In general, samples were unlike typical soil matrices and contained elevated concentrations of several elements. Interference in Ra-226 measurement due to elevated lead content (presence of $^{208}Pb^{18}O$ interference) was minimized by optimizing instrument conditions. However, interference from the formation of $^{207}Pb^{19}F$ due to use of hydrofluoric acid necessitated the development of a correction factor. Application of the correction factor to the ICP-MS data yielded results which compared favorably with those based on gamma spectroscopy. Any residual inaccuracy was determined to result in false positives, although limited in magnitude.

5. SURVEY RESULTS

This section presents selected results from the survey work carried out at the 35 selected Port Hope residential properties. Table 4 shows the initial classification of these sites.

- Interior and exterior dose rate surveys as well as surface contamination surveys were carried out at each site.

[3] Samples were analyzed for Th-232 and various in-active elements using the Perkin Elmer SCIEX Elan 6100 DRC ICP-MS. Th-230 and Ra-226 were analyzed using the more sensitive Varian 820-MS ICP-MS.

- The number of boreholes on the selected Type A and B properties were generally limited to 1 and 2, respectively while those on Types C, D and E properties varied up to 13. In-ground gamma radiation surveys were carried out down each borehole.

- Radon surveys were carried out in duplicate at two levels (basement and the main level) within each home. These measurements were carried out during July and August 2010 without the usual board-up stipulations.

- Each extracted soil core was sub-sampled. Selected sub-samples were analyzed for radiological and non-radiological contaminants per the PHAI CC. The number of sub-samples analyzed for Type A and B soil cores were generally limited to 1 and 4, respectively. The corresponding sub-samples analyzed from C, D and E sites varied according to site conditions with 47 Stage 1 soil samples taken for the property which ultimately was remediated.

Table 4. Classification of the 35 Sites Selected for Surveying

Type	Number of properties
A	20
B	3
C	5
D	5
E	2

5.1 Exterior and interior gamma radiation surveys

Exterior gamma radiation measurements were obtained on approximately a 1 x 1 m grid at 15 cm and 1 m above ground level using the cart mounted system shown in Figure 2. Data for both detectors as well as the GPS location were automatically logged and finally displayed on a property map for further evaluation. Where site features (such as porches, decks, ponds, pools, vegetation) interfered with access of the cart, readings were taken as close to the grid location as possible, using one of the detachable cart-mounted gamma survey probes. Data collected during site screening were transferred for overlay onto base maps. This geo-referenced data was used to identify areas with elevated gamma radiation readings which were then considered for further investigation.

Figure 6 shows a typical exterior dose rate map obtained. It is evident that the excellent positional accuracy achieved after post-processing of the GPS data led to good quality data maps where the cluster of data points aligned well within the boundary and various features of the property. As shown, the exterior gamma radiation readings 1m above the ground typically ranged from 33 to 70 nSv/h . The front yard exhibited gamma radiation readings below 60 nSv/h. There was an area with elevated readings (60-90 nSv/h) at the south east corner (garage) along the driveway. The backyard exhibited readings between 70 to 110 nSv/h interspersed amidst general readings less than 70 nSv/h. Localized areas of elevated gamma radiation were noted near the shed, north of the gazebo and near the northeast property line. Slightly elevated gamma readings were measured along the exterior brick cladding of the house.

Interior gamma radiation surveys were obtained by strapping the Thermo NBR detector (coupled to rate meter) to a shoulder harness and taking readings at hip level on an approximately 1 x 1 m grid. Measurements were taken in individual rooms on both levels of the house. Further assessment was carried out if elevated gamma readings were observed and to locate areas with potential surface contamination. Results for a typical interior gamma radiation survey are presented in Figure 7. The readings were generally uniform (40-60 nSv/h). The elevated readings along some of the walls were due to the radioactivity associated with the brickwork.

Figure 6. Example of Exterior Gamma Dose Rate Map of a Residential Site

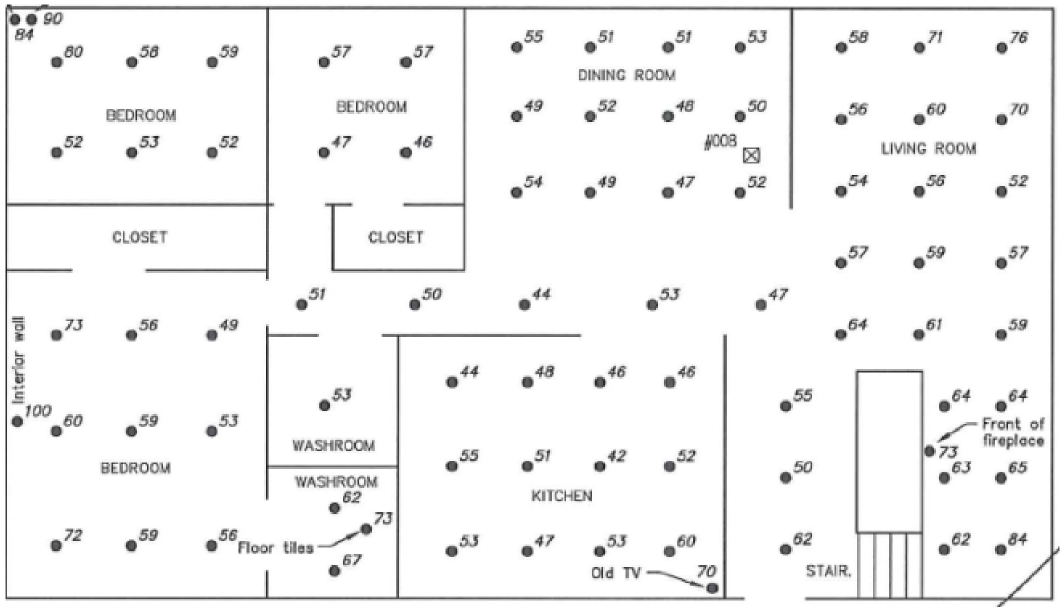

Figure 7. Gamma Survey Results Recorded on the Main Floor of a House

Down-hole gamma radiation readings within a borehole were taken at 15 cm increments using a FHZ 512 sodium iodide detector equipped with a telescoping adapter. The readings yielded a measure of the activity depth profile within the bore hole. Figure 8 presents an example of the type of response obtained. Uniform activity in the soil, up to a depth of about 125 cm, would give rise to the observed profile. Also shown in Figure 8 is a response recorded along the length of the extracted core. Unlike the down-hole measurements, where the detector receives a response from the surrounding soil, measurements of the extracted core have poor sensitivity because the signal arises only from the limited activity present in the core. Nevertheless, this response obtained appears to be consistent with the presence of uniform activity in the soil. The depth profile information was used to select sub-samples for analysis, recognizing that the activity profile does not necessarily represent the profiles of non-radiological constituents.

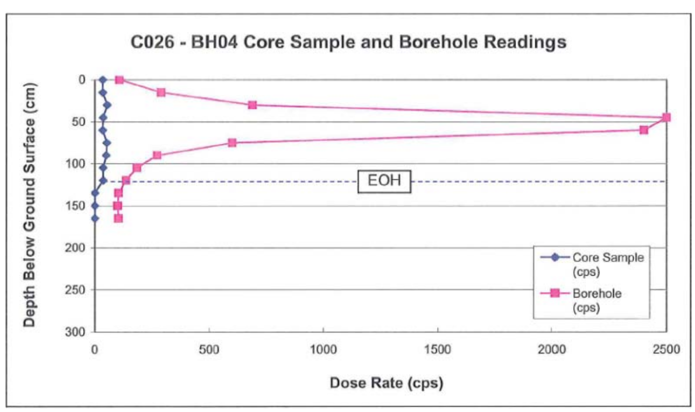

Figure 8. Example of a Depth Profile Obtained from Down-hole Gamma Measurements

5.2 Exterior and interior surface contamination surveys

Surface contamination surveys were conducted to establish the levels of total surface contamination and loose alpha activity. Their limiting values are given in Table 3.

Interior high traffic locations were surveyed because of the potential for contamination to be trekked in from outside the home. Typical locations included the threshold, door handles, wall and floor by both the front and side doors. Additional locations were selected based on elevated readings obtained during the interior gamma survey.

Exterior locations surveyed included vertical and horizontal surfaces (excluded soil surfaces) having a reasonable likelihood to be contaminated. Surfaces of any contaminated artifacts installed on the premises were included in the survey scope. Typical locations included the following: back yard deck, house bricks, front door threshold, front door handle, garage floor, garage door frame, down spout run off, front porch surface, house flashing, concrete patio, front stairs, front porch hand railing.

As discussed in Section 3.2, determination of the total surface contamination involved two separate measurements, one with a shield plate and one without the shield plate to yield by difference the net response due to impinging alpha and beta emissions. These arise from the various members of the Ra-226 decay chain (see Table 5). To interpret the net detector response, calibration efficiency data obtained using alpha (Am-241) and beta (Cs-137 and Sr-90) sources were worked up considering the decay chain characteristics shown in Table 5 and assuming suitable values for the radon emanation and alpha & beta attenuation factors.

Table 5. Characteristics of Ra-226 Decay Chain

Radionuclide	Decay Mode	Emission Energy (MeV)	Abundance (%)
Ra-226	Alpha	4.7	100
Rn-222	Alpha	5.5	100
Po-218	Alpha	6	100
Pb-214	Beta	0.67	97
Bi-214	Beta	1.5	67
Po-214	Alpha	7.7	100
Pb-210	Beta	0.063	16
Bi-210	Beta	1.2	100
Po-210	Alpha	5.3	100

Smears were collected at all interior and exterior surface contamination survey locations unless the measured total surface contamination was less than 0.04 Bq/cm^2, the criterion for loose alpha activity in which case a measurement was, therefore, not required. In general, where possible, smears were collected over an area of 300 cm^2. Measured activity data were interpreted based on the area smeared and corrected using a collection efficiency of 10% to obtain an estimate of the loose alpha surface contamination level.

Table 6 summarizes the overall findings at the 35 properties surveyed in Port Hope.

Table 6. Overall Findings of Surface Contamination Levels

Total surface contamination - interior surfaces	Levels were generally less than 1 Bq/cm^2 except at • One location each on two properties where levels were 1.2 Bq/cm^2, • One location (painted I-beam) where levels were up to 8.4 Bq/cm^2 and • One location (crawl space) where levels were up to 3.8 Bq/cm^2.
Total surface contamination - exterior surfaces	Levels were generally less than 1 Bq/cm^2 except at • Three locations where levels were 1.9, 1.3 and 2.8 Bq/cm^2, respectively. • One site where a tool was located with surface activity of 5,900 Bq/cm^2. • One site where levels of 16 Bq/cm^2 were observed on fire pit blocks.
Loose alpha activity - interior surfaces	Levels were generally less than 0.04 Bq/cm^2
Loose alpha activity - exterior surfaces	Levels were generally less than 0.04 Bq/cm^2 except on a hand tool found on one site where the level was 1.0 Bq/cm^2

5.3 Radon surveys

Radon surveys were generally carried out in the basement and at the main level in each house. Measurements were recorded in duplicate over 5-8 days. Home owners were not specifically instructed to board up doors and windows to avoid inconveniencing them. Because of greater isolation, radon levels measured in the basement are likely to be more representative than those recorded at the main floor.

Radon levels ranged from 20 to 260 Bq/m^3 in the basement and from 10 to135 Bq/m^3 at the main floor. Levels in the basement, as expected, exceeded those on the main floor at 26 of the 30 sites surveyed (a factor of 1.0-1.6 for 17 sites, 2.8-4.8 for 7 sites and 7-12 for 2 sites). At the remaining 4 sites, the basement radon levels were unexpectedly lower (factor of 0.8-1.0).

Figure 9 presents a histogram of the overall results. The basement radon levels exceeded the 125 Bq/m^3 criterion at 8 of the surveyed sites. In comparison, the radon levels on the main floor exceeded the criterion in only one instance. Subject to confirmation by more reliable winter radon test results and confirmation that LLRW is the likely source of the gas, the eight sites may need to be remediated to lower their radon levels below the PHAI CC criterion.

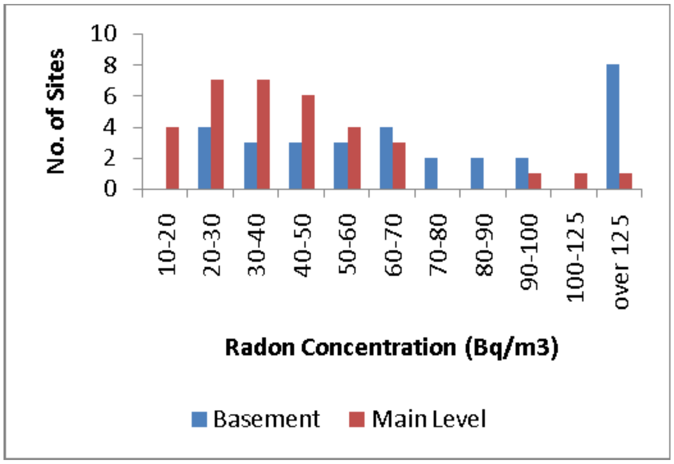

Figure 9. Distribution of Radon Levels at the Surveyed Sites

5.4 Summary of soil sampling results

During the project, over 1,000 soil samples were taken and about 300 were analyzed for the PHAI CC. Results of the analyses of soil samples taken during Stage 1A and 1B showed the following key findings:

- Fourteen (14) of the sites fully met the PHAI CC and radon criterion.
- Presence of LLRW was confirmed or likely on fourteen (14) of the sites.
- Of the four signature parameters of LLRW, arsenic was the most commonly found, at 13 of the 14 sites. The least commonly found signature parameter was Th-230, at only 2 of the sites.
- For other Contaminants of Potential Concern (COPC), there were twelve properties where PHAI CC were exceeded.
- Barium, a secondary COPC, was found above its PHAI CC at 6 of these 12 sites. Also, barium above its background concentration limit was found on many of the sites. It is possible that some of the Port Hope soils contain barium at higher than its background level of 210 µg/g stated for Ontario soils.

For properties where the presence of LLRW was confirmed or deemed likely, further (Stage 1C) subsurface investigations were conducted to delineate the areal extent and depth of contamination in soils. The two Type E properties, which were not to be considered for remediation, had evidence of LLRW in soil samples and radon was measured in buildings above the 125 Bq/g clean-up criterion. Consequently, Stage 1C investigations were conducted on twelve properties.

Eighty-nine boreholes, 58 hand-augered (shallow) holes and 928 soil samples were taken for the delineation of contamination on these 12 properties. Two hundred and twenty-seven (227) soil samples were analyzed for the PHAI CC. Based on this analytical information and the property plans, an estimate of the quantity of contaminated soil requiring removal was determined for each of the 6 properties ultimately considered for remediation (see section 6 below). Arsenic was present typically deeper (at 40-50 cm) than the other signature parameters. Consequently, excavation plans were largely based on meeting the PHAI CC for arsenic which is 20 µg/g. This was certainly the case for the property remediated (see section 6.0), where 25 of the 47 soil samples analyzed contained arsenic above 20 µg/g. For Ra-226 and Th-230 measured above their PHAI CC of 0.29 Bq/g and 1.16 Bq/g, respectively, contamination was typically found in the topsoil at depths of 10-30 cm.

Contaminants other than radioactive elements are likely to define clean-up volumes based on their proposed criteria. This is because arsenic and uranium are more mobile and leachable in soils than radium and have tended to migrate beyond the initial volumes of contaminated soils. In a practical sense, excavations will likely be characterized by soil radioactivity levels that are significantly below criteria for radioactive contaminants because of the need to remove soils contaminated by non-radioactive contaminants. Arsenic or uranium is likely to determine the boundaries for removal of soil contaminated by LLRW.

6. REMEDIATION

Up to six properties found to be contaminated by LLRW were to be remediated under the work programme. Therefore, six of the twelve properties for which waste delineation investigations were conducted were selected for possible remediation.

Of these six, one property was finally selected for remediation. Considerations in this selection included the large areal extent of contamination and therefore an expected large volume of contaminated soil to be removed (there was a limit to the amount of contaminated soil that could be received at the designated temporary storage site), the variation in terrain (sloped), the presence of constraining existing features such as wooden decks and a retaining wall which needed to be removed and replaced and consent and support of the property owner for the use of the property as a demonstration site for remediation and restoration.

A detailed Remediation Plan was prepared for the property. This plan included the approach to be taken to accomplish the following:

- Conduct the pre-remediation site visit and survey of conditions
- Identify the location of underground utilities and all constraining features
- Prepare the site e.g. install construction fencing, signage, etc.
- Delineate contamination control and work zones
- Delineate access / egress routes including construction of temporary haulage road
- Collection, control and disposal of accumulated water

- Environmental monitoring
- Remediation verification sampling
- Property restoration activities

Reference was made in the Remediation Plan to the Health & Safety Plan, Radiation Protection Plan and Environmental Protection Plan. Specific operational and monitoring procedures under these overall plans were developed for the remediation / restoration work.

Of particular importance was the development of the remediation plan and procedures to prevent the spread of contamination both inside and outside the work zone into uncontaminated areas via spillage of contaminated soil, blowing of dust, movement of contaminated soil on personnel and mobile equipment and a transportation accident.

A Remediation Verification Standard Operating Procedure (RVSOP) [2] for the Port Hope Project was used. This RVSOP is intended to confirm that the PHAI CC have been achieved as a result of remediation or to confirm that a property already achieves the PHAI CC (without remediation).

Based on previous survey and remedial work undertaken in 1978 and the results of the resurvey work done in the summer of 2010, contamination was expected to be found at a depth of approximately 0.5 m over a wide area of the property's backyard. During the excavation and verification work, additional contamination was discovered in some areas to greater depths, even to bedrock, and also below clean fill which had been placed in 1978 around the house on the property. Consequently, the volume of contaminated soil removed and replaced with clean fill was considerably higher than expected.

To facilitate loading of trucks with contaminated materials and delivery of clean fill, topsoil, sod, etc., a temporary road was constructed from the backyard, across municipal property to the municipal road. During excavation, a zone for loading and monitoring of trucks for loose contamination was delineated and fenced and all vehicle and personnel movement made through this zone. In this way, control of the potential for the spread of contamination was maintained.

Control of dust generated during the excavation of the contaminated soil was done by wetting dry soil when needed. Hi-Vol samplers were deployed at both upwind and downwind locations at the property fence lines to determine potential off-site impacts as well as help determine the need for the wearing of respirators by site workers. Personal dosimeters were also worn by at least 3 of the workers every day that the remediation work was being done. Results of this monitoring showed no off-site impact and no radiation doses to workers beyond expected and administrative control levels. The wearing of respirators was not required.

Loading of contaminated materials into the haulage trucks was done very carefully and the level of material in the truck boxes was kept well below the tops of the boxes. Plastic tarpaulins anchored with elastic cords were placed over the top of the truck box and tail gate to prevent possible loss of material during transport to the Pine Street Extension Temporary Storage Site.

Transport was accomplished without incident, although one of the elastic cords failed on one trip and was immediately replaced.

Excavation work was conducted in the fall of 2010 and higher than normal rainfall and runoff into the excavation resulted in the accumulation of a significant amount of water. Sampling nd analysis of this water showed a slightly elevated level of uranium. Consequently, approximately 14,600 litres of contaminated water was vacuumed out of the excavation and disposed of via a licensed hazardous waste haulage / disposal company.

Verification sampling and analyses were performed to confirm that all contaminated soil had been removed. Since bedrock was located less than 1.5 m below grade at the west end of the property and contamination was found at some locations to bedrock, verification samples could not be taken at bedrock and the RVSOP could be used in this circumstance. However, removal of contaminated soil was deemed by the PHAI MO to be complete if excavation was done to bedrock.

Restoration of the property began in December 2010. A new retaining wall was constructed and clean fill, topsoil and sod was placed; however, cold weather did not allow completion of the landscape restoration work until the spring of 2011.

7. KEY LESSONS LEARNED AND RECOMMENDATIONS

As the work was intended to provide an opportunity for "piloting" the expected resurvey and remediation of all small-scale sites, a number of expected and unexpected lessons were learned during the execution of the resurvey and remediation work. Some of these lessons learned could have significant impact on the level of effort and cost required for the implementation of the Phase 2 Port Hope Project and so recommendations were made for consideration in adjusting, modifying or even completely changing some of the anticipated approaches and procedures. Also the approach taken for the resurveying and remediating individual properties representative of all properties in Ward 1 of the Municipality of Port Hope would be different. For example, resurveying and remediation of small-scale sites for the Phase 2 Port Hope Project will likely be done by areas, streets or other grouping of sites rather than based on individual properties as was done.

7.1 Resurvey Stage

Gamma radiation surveys to detect radiation levels above background were intended to be used to identify likely areas of LLRW contamination, both above and below ground, and to guide further and more intrusive investigation by sampling and analysis of soil.

While useful, these gamma radiation surveys were not able to fully define locations of LLRW contamination, particularly when arsenic was the defining signature parameter. Rather, more extensive soil sampling and analysis than originally planned was required. This combined with the detection of arsenic alone above the PHAI CC on 5 of the 35 SRCA properties leads to the conclusion that the remediation efforts would require a more traditional engineered excavation approach based on characterization of sub-surface conditions and delineation of the extent of

LLRW contamination based on many more boreholes and test pits than the gamma radiation surveys indicated.

Using the 1m x 1m grid for the exterior gamma radiation measurements took quite a long time at each property. It was felt that a survey using a grid of 3m x 3m would yield acceptable results and take much less time. However, a trial should be conducted to demonstrate the time saved without compromising the quality and usefulness of data.

The use of down-hole gamma radiation measurements to determine the depth at which soil samples should be taken for analysis was of limited use. The down-hole gamma profiles did not correlate well with the radiological PHAI clean-up criteria parameters as analyzed in soil samples. Before completely discarding down-hole gamma radiation measurements, further studies are required to develop a correlation between down-hole gamma radiation and the PHAI CC radiological parameters.

A more intensive sub-surface sampling regime is recommended for Type A and B sites to provide increased confidence in confirming "uncontaminated" status. Furthermore, on sites where contamination by LLRW is demonstrated or known, intrusive investigations need to be done more extensively on a grid pattern, not necessarily dictated by the surface gamma radiation data, with increased soil sampling and analysis to provide stratigraphic contamination profiles. Methods and procedures to be used for soil sampling and laboratory analysis must be determined in advance and documented in the form of a manual for use in the field and by the certified laboratory conducting analysis of samples.

7.2 The Verification Process

Several constraints, arising from the application of the Remediation Verification Standard Operating Procedure (RVSOP), were identified for both contaminated and uncontaminated properties.

For properties where Stage 1 investigations involved only a single borehole and composited soil sample was taken, the RVSOP could not be applied and therefore verification of "uncontaminated" status could not be made. A minimum number of multiple boreholes and soil samples need to be established for every property to be resurveyed.

As noted in section 5.4, the widespread presence of barium in soil above its background concentration limit resulted in failure of verification using the RVSOP. The current PHAI CC and background concentration limit for barium should be re-evaluated in light of the relatively high barium concentrations found in some of the Port Hope soils.

7.3 Remediation Stage

The remediation work, while challenging for a number of reasons, not all technical in nature, demonstrated that removal of contaminated soils and restoration by placing of clean materials could be done in a safe and environmentally acceptable way in compliance with applicable regulatory requirements. Radiation protection and monitoring of the local environment especially the air showed compliance with remediation criteria set out in the Radiation Protection Plan, the

Health and Safety Plan and the Environmental Monitoring Plan. Key to successful remediation work is the control of the generation and possible migration of dust. An engineered system for fogging or misting areas is recommended where soil excavation and replacement is being conducted.

8. CONCLUSIONS

The work carried out provided an excellent opportunity to establish methods and procedures required for the resurvey of small-scale sites and for the remediation/ restoration work required for LLRW contaminated properties. While many of the methods and procedures worked well, some needed adjustments or significant changes. A resurvey procedures manual was prepared for consideration by the PHAI MO for application to Phase 2 of the Port Hope Project.

The use of an integrated GPS and gamma radiation measurement system was successful in being able to produce good geo-referenced mapping of properties.

Based on the remediation of the property selected, the delineation and excavation of contaminated soil was driven more by the PHAI CC than by the exterior gamma radiation surveys. The benefit of using down-hole gamma radiation monitoring was inconclusive at best as the measured radiation levels did not match well with the actual concentrations of the radiological parameters of concern.

The procedures used for soil sampling were effective; however, because of the large number of soil samples taken, the level of effort in managing the sampling and analytical results was considerably more than anticipated. For Phase 2 of the Port Hope Project, the very high number of soil samples anticipated to be taken, prepared for analysis (e.g. compositing, grinding, screening, dissolution, etc.), analyzed for PHAI CC and reported will require dedicated facilities and personnel. Rapid turnaround of laboratory results is essential particularly at the remediation verification stage so that excavations are left open for the minimum length of time.

The Remediation Verification Standard Operating Procedure requires revision to address a number of difficulties identified. In general, more stream-lined and field-friendly procedures are required.

REFERENCES

[1.] EcoMetrix Incorporated, "Port Hope Area Initiative Clean-up Criteria", LLRWMO-01611-TE-11004, Revision 5, 2006

[2.] Marshall Macklin Monaghan, "Remediation Verification Standard Operating Procedure – Port Hope Project", prepared for Atomic Energy of Canada Limited, 14-09824-001, Revision 0, May 2010

ACKNOWLEDGEMENTS

The authors wish to acknowledge the technical support of Atomic Energy of Canada and specifically the Low-level Radioactive Waste Management Office (Mark Gardiner) and the Port Hope Area Initiative Management Office (John Benson) during the resurvey and remediation work conducted by SNC-Lavalin Inc. and Kinectrics Inc.. The authors acknowledge the valuable contributions made by several members of the project team: Eve Casavant from SNC-Lavalin Inc. and Christina Wu, Glen Corben, Yevgenia Kravtsova, Mark Hooper and Clive Morton from Kinectrics Inc.