PVT and LaBr3(Ce)-based Radon Express Analyzers – 18164

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ABSTRACT

RadComm Systems has developed a new technology for quick, express analyzing (~ 5 minutes) of Radon concentration in the air by using low energy resolution plastic PVT **(**polyvinyl toluene**)** -based scintillator and high energy resolution Lanthanum Bromide inorganic scintillator as the gamma-detectors.

INTRODUCTION

Radon is the second most influential factor after smoking for lung cancer diagnosis in Canada, according to the Canadian Nuclear Safety Commission [1].
Widely used devices and approaches to determine the heavy radioactive gas Radon in the air are usually very time consuming, ranging from one day to one week. Such long term measurements may be irrelevant to actual Radon concentration due to gas fluctuations in specific environment, atmospheric changes, etc. – such factors obviously have an effect on the accuracy of measurement.

Radcomm's proposed approach is more in accordance with providing a quick determination of Radon concentration. However, to provide a relatively accurate measurement with a precision of +/- 30% or less the energy response of a gamma-spectrometer has to be consistent to allow the reliable separation of gamma-lines from radioisotopes which may overlap energetically with high energy Radon gamma lines (over 1,7 MeV).

Obviously, the influence of external sources like Radium or Uranium may substantially distort the Radon measurements. However, we assume that in the great majority of cases (e.g., measurements in homes, commercial buildings, etc) there will be no such influence and that a gamma-spectrum approach will definitely benefit the majority of users.

Since PVT-based spectrometry is not by itself accurate in terms of energy determination [2] we have explored the additional use of Lanthanum Bromide crystal ability to evaluate Radon concentration in air.
In the case of LaBr3(Ce) the major interference happens between Radon's 1.7 MeV and the Lanthanum crystal contaminating isotopes: five progenies of Ac- 227contaminantssuch as Th-227, Ra - 223, Rn-219, Po-215 and Bi-211 which contributes to internal background and energy spectrum [3]. As a result the evaluation of the concentration of Radon has a systematic shift. To resolve the systematic shift the internal LaBr3 crystal background has to be taken into account.

Due to the high energy contribution of the isotopes listed above the determination of Radon with LaBr3(Ce) is more problematic in comparison with PVT. In addition to that the PVT has higher sensitivity at high energies due to its larger volume and is therefore more cost effective for same type of hand-held detectors, which have more practicality as express Radon` analyzers.

METHOD

Radiation Detection Technique

Radiation detection, spectra acquisition and Radon analysis were introduced for two serial RadComm made hand-held gamma-spectrometers: "Syclone", with LaBr3(Ce) crystal and "RC2Plus" with PVT. The software and firmware of both spectrometers were modified to evaluate Radon concentration is air.

Since some fundamentals of Radon estimates to correct airborne geophysical data were well described and collected in International Atomic Energy Agency document [4], we would like first briefly consider some specifics of spectral analysis related with PVT and LaBr3(Ce) detectors to get appropriate energy windows for Radom analysis.

1. **PVT**

On figure below is a typical PVT- based 256 channel gamma spectrum, ambient background.

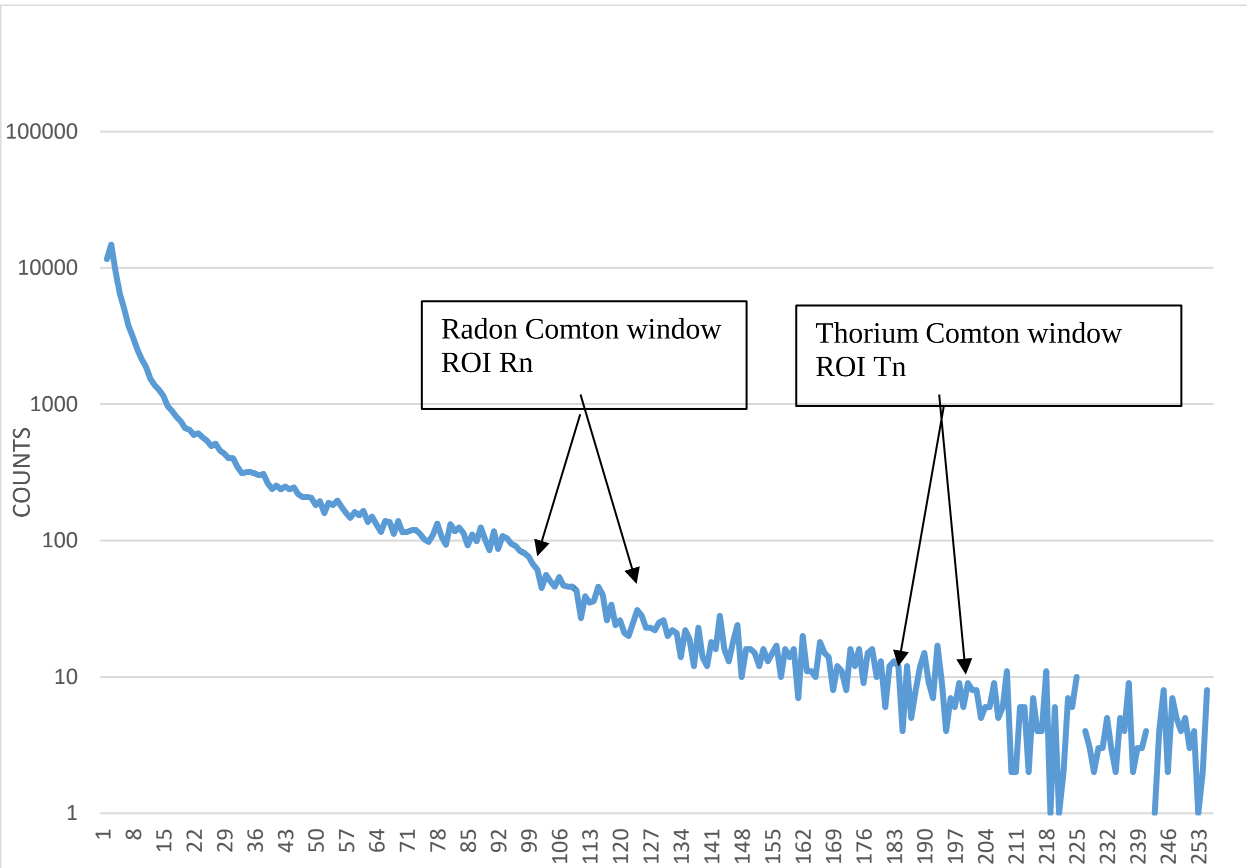

Figure 1. PVT 256 channel gamma-spectrum, with energy windows corresponded to Radon evaluation.

Since PVT has no gamma photo-peaks but Compton edges, we have to consider associated Compton energy windows - ROIs. There are two of them:

a) Radon (Radium), Compton: KeV: 1536, channels: 110 – 127

b) Th (Thorium), Compton: KeV: 2382, channels: 185 – 201

High energy Thorium contribution has measurable effect on Radon gamma-energies and, therefore we have to take it into account in the similar way as in IAEA report [4].

Default spectrum acquisition time was 3 minutes. To get net count in Radon Region of Interest (ROI Rn) we use the following:
Net Sum ROI Rn = Sum ROI Rn – 1.16 * Sum ROI Th (Eq.1)
Where 1.16 is empirical coefficient to extract Thorium-232 contribution to Radon ROI.
The specific activity of Radon in Bq/g in air A_{Rn} is derivative of several fundamental radiation detection parameters and evaluated as:

$$A_{Rn} = \frac{Net\ Sum\ ROI_{Rn} 2\mu(e)}{Eff(e)\gamma(e)\Delta SdetTacc} \qquad \text{(Eq. 2)}$$

Where μ(e) – mass attenuation coefficient of given gamma-line energy ‘e’ in cm2/g
for Radon: 0.048
Eff(e) – detector efficiency for gamma-energy ‘e’, for Rn: 0.06
γ(e) – photon yield for energy ‘e’, for Rn: 0.21
ΔS det – effective detector area (cross-section) in cm2, for RC2PLus we can use 60 cm2
Tacc – spectrum time accumulation in sec.

To convert specific activities of isotope into activity per cubic meter, Radon specific activity Bq per m3 (Bq/m^3):

$$C_{Rn} = A_{Rn} * 1225 \qquad \text{(Eq. 3)}$$

Where 1225 is a mass of one cubic meter of air in standard conditions in grams.

2. LaBr3(Ce)

On figure below is typical LaBr3(Ce) - based 1024 channel gamma spectrum, ambient background

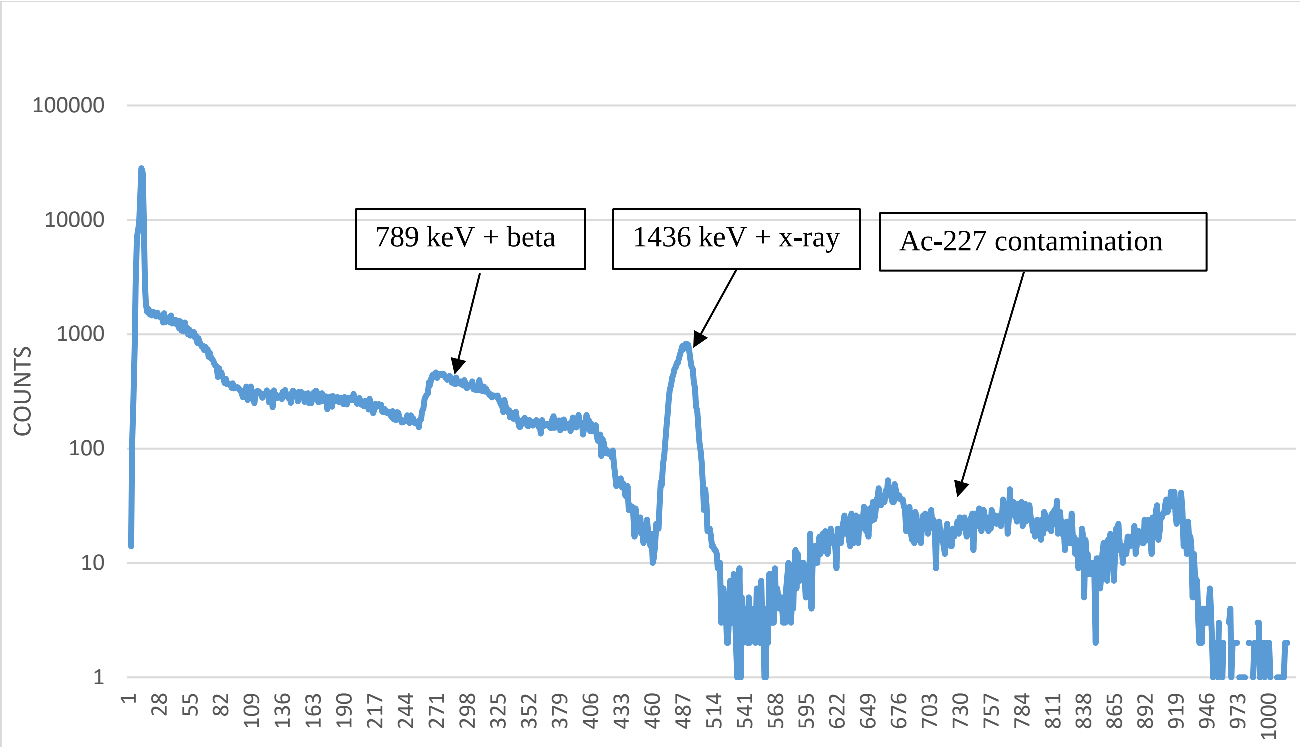

Figure 2. LaBr3(Ce) 1024 channel gamma-spectrum, with energy windows corresponded to Radon evaluation.

The ambient background is contaminated with detector material isotopes La-138 and Ac-227. Background La-138 is a naturally occurring radioisotope of La with 0.09% abundance. These two isotopes contaminate ambient background with 789 keV, 1436 keV gamma-lines emitted from La-138 decay and some higher energies with contribution from Ac-227 lines [3].

To eliminate the influence of internal LabBr3(Ce) radiation we collected internal background of the instrument in a cylindrical 38mm Lead shield, lined with 6mm of Copper to supress x-ray florescent Lead lines. See Picture 1. On the top and bottom of the cylinder the same shielding was applied.

Picture 1. Lead shield with Copper lining to collect internal LaBr3(Ce) background.

Upon subtraction of internal background the ambient background spectrum is as shown on Figure 3.

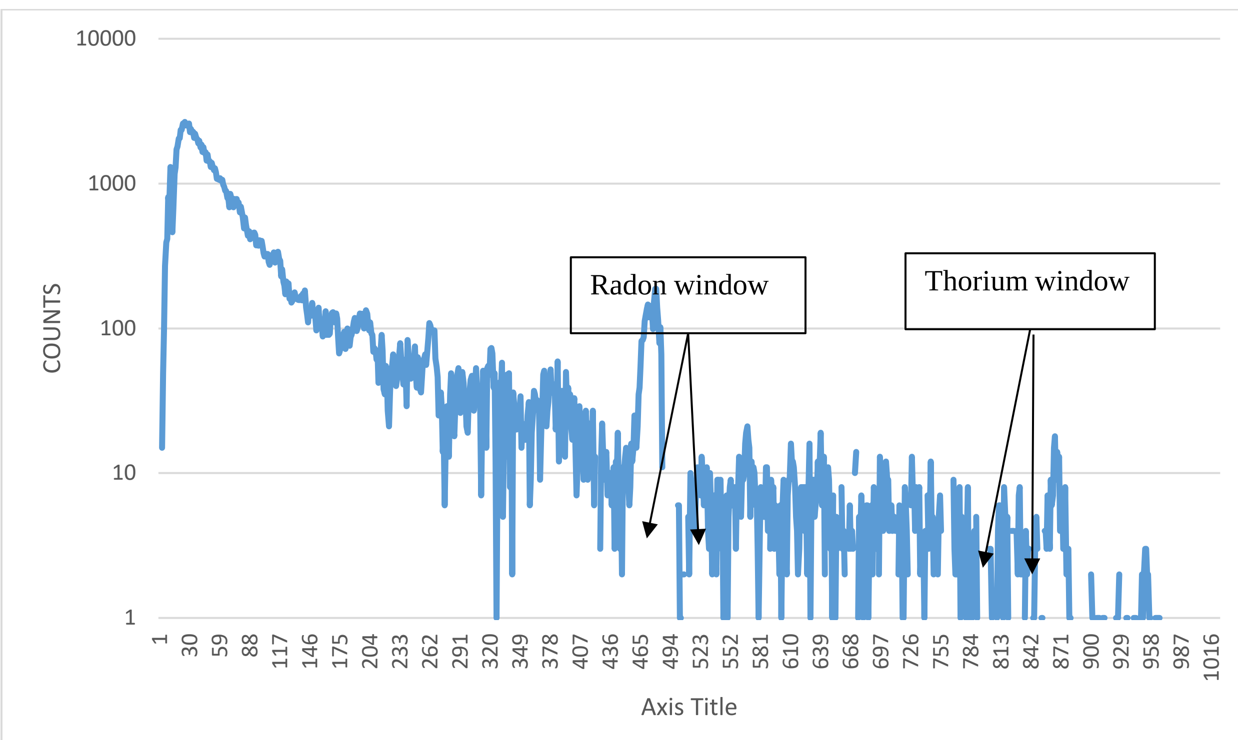

Figure 3. Ambient LaBr3(Ce) background with removed internal background removed.

Just as for PVT there are two Regions of Interest (ROI) relevant to determining Radon concentration, however, these ROIs are both related with the gamma photo-peaks of Rn-222 and Th-232

Radon (Radium), photo-peak: KeV: 1760, channels: 507 – 550

Th (Thorium), photo-peak: KeV: 2615, channels: 810 - 854

Default spectrum acquisition time was 3 minutes. To get the net count in Radon Region of Interest (ROI Rn) we use the following:
Net Sum ROI Rn = Sum ROI Rn – 1.08 * Sum ROI Th (Eq.1)
Where 1.08 is empirical coefficient to extract Thorium-232 contribution to Radon ROI.
The specific activity of Radon in Bq/g in air A_{Rn} is derivative of several fundamental radiation detection parameters and evaluated in the same way as above in Equation 2, however, the parameters are different:

$$A_{Rn} = \frac{Net\ Sum\ ROI_{Rn} 2\mu(e)}{Eff(e)\gamma(e)\Delta S det Tacc} \qquad \text{(Eq. 4)}$$

Where μ(e) – mass attenuation coefficient of given gamma-line energy ‘e’ in cm^2/g for Rn: 0.048
Eff(e) – detector efficiency for gamma-energy ‘e’, for Rn: 0.07
γ(e) – photon yield for energy ‘e’, for Rn: 0.21
ΔS det – effective detector area (cross-section) in cm2, for LaBr3 we can use 18 cm^2
Tacc – spectrum time accumulation in sec.

To convert specific activities of isotope into activity per cubic meter, Radon specific activity Bq per m3 (Bq/m^3):

$$C_{Rn} = A_{Rn} * 1225$$

Where 1225 is the mass of one cubic meter of air in standard conditions in grams.

RESULTS:

We have in hand a comparison of Radon concentrations in air between our express-analyzers and a commercially available (in hardware store) electronic Radon gas detector. This detector has (so-called) short-term reading which is 7 days average and long-term average.
The comparison table is given below for 7 days average. No error assessment was available for the commercial Radon detector.

Detector type	Radon concentration ± 1 st. deviation, Bq/m^3
PVT (Rc2Plus, RadComm)	41.3 ± 4.3
LaBr3Ce (Syclone, RadComm)	44.2 ± 2.2
Commercial electronic Radon analyzer	38 ± ?.?

To better understand express analysis opportunities we have measured Radon concentration in our office during thunderstorm on May 1st, 2017 hourly to observe the Radon change during the peak period of the event.

As it seen on figure below in the Radcomm ground level of the RadComm office at about 4 PM the Radon concentration has elevated almost to the health concern level of 200 Bq/m^3.

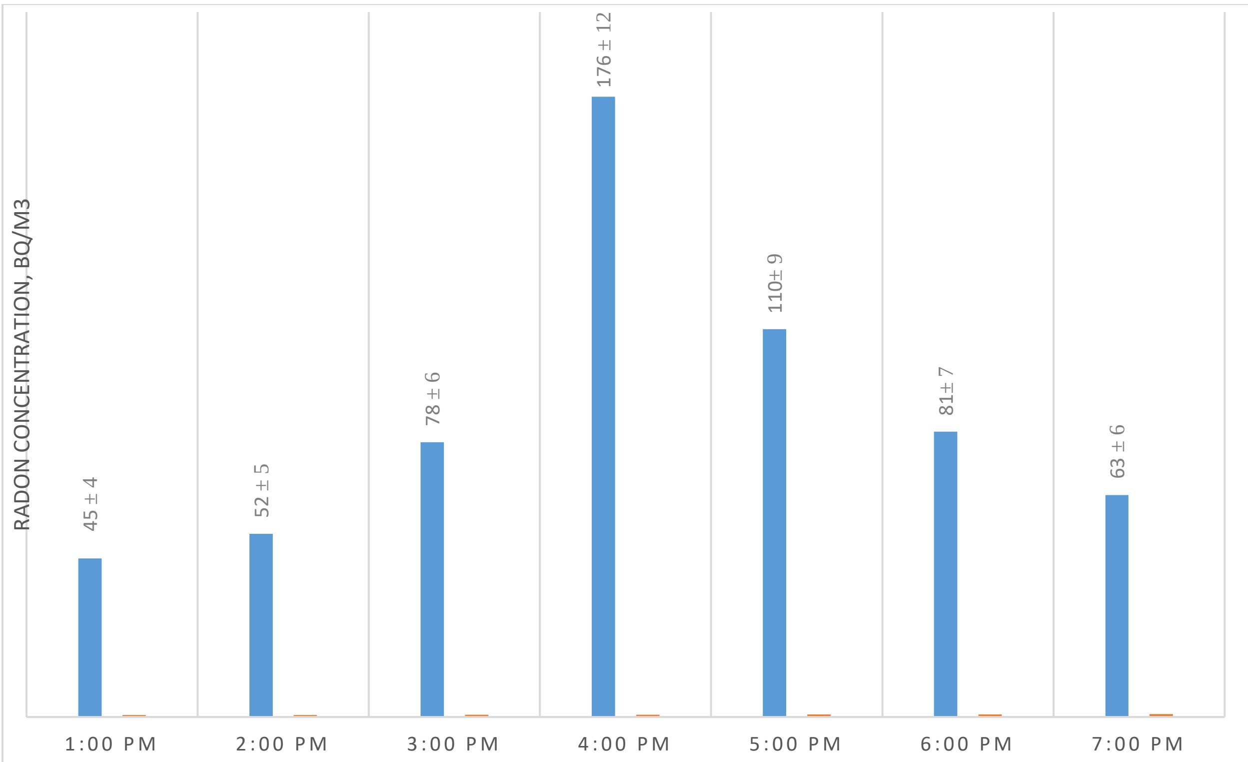

Figure 4. Radon concentration Bq/m^3 during thunderstorm May 1st, 2017, RadComm's location, Instrument: RC2Plus, Oakville, Canada

CONCLUSION:

The method described above is not a direct Radon evaluation because the Radon itself could be detected primarily by alpha-particle emission. Nevertheless, both Express Radon analyzers have demonstrated feasibility for far more timely Radon evaluation in situations where are no significant sources of Radium or Thorium presence, which is quite normal for majority of prospective applications or measurement scenarios. The Express Radon analyzers are effective tools for timely warning of excessive Radon presence for indoor or outdoor applications where are regularly used Radon detectors are too slow to produce the needed results.

REFERENCES:

1. Radon and Health, Canadian Nuclear Safety Commission, INFO-0813, Feb., 2011
2. Birks, J.B. The Theory and Practice of Scintillation Counting. London: Pergamon, 1964
3. Study of linearity and internal background for LaBr3(Ce) gamma-ray scintillation detector, INFN, Reprint, Italy, 2012
4. Guidelines for radioelement mapping using gamma ray spectrometry data, IAEA-TECDOC-1363, July, 2003