ABSTRACT- Radon calibration chamber was designed and constructed for promoting the NIS facilities for radon gas measurements with high precision. The factors affecting the calibration process for radon monitors and sources, such as a good sealing, temperature controlling, ventilation ...etc., were taken into account. The experimental half life time of radon inside the chamber was measured during fan operation and over normal pressure and it was found to be $90 \pm 1.62$ h. The temperature has been controlled inside the chamber from 0 to 70 °C with a maximum fluctuation of $\pm 0.3$ °C. The verification of the calibration inside constructed chamber evaluated a good results. All sources of uncertainty in the calibration were evaluated.

1. INTRODUCTION

For assessing the quality of radon measurements at environmental levels, it requires an instrument whose response to radon is determined from measurements of a certified or standard $^{226}$Ra source and a calibration chamber with a known radon concentration. These two elements compose a secondary standard system which must be traceable to the international standard. This can be realized with defensible technical expenditure by integrating the radon source together with a continuous radon monitor into an airtight chamber. For such chamber there are high requirements in terms of tightness in order to exclude an uncontrolled exchange of gas between the measuring volume and the environment. If this condition is granted as well as controlling temperature of the calibrating chamber then, the radon concentration of the standard can be accurately determined.

This investigation was performed for constructing a radon calibration chamber to fit the best performance for radon calibrations and evaluating a secondary standard system for radon quality control in NIS.

2. CONSTRUCTION OF THE RADON CALIBRATION CHAMBER

The radon calibration chamber was constructed from a firm corrosion-resisting container of 1 mm stainless steel with a removable lid and volume of 50 liters. The removable lid of the chamber was equipped with two gas valves, which allow a controlled gas exchange. Moreover, the lid was equipped with three tight electric ducts for controlling the operation of the monitor and a small fan as well as a RS-232 interface to install a communication between the monitor inside the chamber and a PC set up outside the chamber.

A temperature control system was built in NIS to control the temperature inside the calibration chamber. It was constructed from a temperature isolated housing with a removable lid. The inner and outer walls of the housing were made from stainless steel of 1mm thickness. The space between the inner and the outer walls had a thickness of 10 cm, which was filled with polyurethane foam. According to this construction, the heat transmission coefficient $k$ is smaller than 0.2 W m$^{-2}$ K$^{-1}$ (Honig et al, 1998). Moreover, all the functions of the system can be fully controlled by a PC software support with numerical and graphic presentation tools. The controlling process occurs using two
temperature sensors, S_1 and S_2 which mounted inside the housing to control and measure the temperature distribution. In case of cooling, a compressor transfers the cooling temperature to the housing by a compressed gas which passes through a copper tube surrounding the inner wall of the housing. In the heating mode, the temperature was adjusted by three heaters which were distributed inside the housing wall. This leads to fast uniformity and homogeneity for the heat transfer inside the housing. Figure (1) illustrates a side view for the chamber and the temperature control system. Using such system, the temperature inside the chamber can be controlled from 0 to 70 ± 0.3 °C.

![Diagram](image)

**Fig. (1) Side view for the calibration chamber inside its temperature control system.**

**Determination of Radon \((T_{1/2})_{exp}\) Inside the calibration chamber**

The calculation of the experimental half life time of radon \((T_{1/2})_{exp}\) during each experiment is necessary to calculate the accurate integrated radon concentration inside the chamber, which will be very helpful to get information about the radon gas leakage loss. For determining the loss of the original radon concentration in the constructed calibration chamber, the radon was injected from a Pylon flow through radon gas generator model RN-1025 into the chamber. The radon concentration was measured using the Alpha Guard radon monitor during a period of 9 days at room temperature. The pressure was increased by pumping free radon air into the chamber to increase the pressure to 1080 mbar which was stable during the experiment period. Also, the fan was operated to increase the motion of the air inside the chamber. The monitor readings were registered each 10 minute, plotted and fitted as exponential fitting. The experimental decay constant of radon \((\lambda_{Rn})_{exp}\) was calculated. Consequently, \((T_{1/2})_{exp}\) was deduced to be 90 hours with expanded uncertainty ± 1.8%. This uncertainty is estimated at a level of confidence of 95% (Taylor and Kuyatt, 1994) with a coverage factor k of 2.13. The obtained value of \((T_{1/2})_{exp}\) is approximately equal to the half life time of \(^{222}\)Rn in a closed system (91.75 hours). Consequently, about 98% of the radon concentration injected inside the chamber can be measured by the monitor even in case of over normal pressure and fan operation inside the calibration chamber. The difference, between the experimental value and the theoretical value of radon half life time, may be due to the loss of \(^{222}\)Rn that diffused into the monitor detector through the radon diffusing barrier, which mounted before the monitor detector to diffuse only radon rather than its progenies.
3. CALIBRATION OF RADON MONITORS IN THE CONSTRUCTED CHAMBER

The use of NIST (National Institute for Standards and Technology U.S.A.) encapsulated \(^{222}\)Rn emanation standard source gives an elegant method for calibrating continuous radon monitors in a single experiment over a wide range of radon concentrations (Kotrappa & Stieff, 1994; Colle, et. al, 1995). This application is based on the fact that, the radon concentration \(R_s\) can be given at any accumulation time in the calibration chamber by:

\[
R_s = \frac{f A_{Ra} e^{-\lambda_{Ra} T_D (1-e^{-\lambda_{Rn} T_A})}}{V}
\]

where \(f\) is \(^{222}\)Rn emanation fraction from the source, \(A_{Ra}\) is the \(^{226}\)Rn source activity, \(\lambda_{Ra}\) is the \(^{226}\)Ra decay constant, \(\lambda_{Rn}\) is the \(^{222}\)Rn decay constant, \(T_D\) is the time interval from the certified \(^{226}\)Ra activity reference time \(t_r\) to the start time \(t = 0\) of the accumulation period \((T_D = t_0 - t_r)\), \(T_A\) is the time interval for the total duration of accumulation (NIST, 1994) and \(V\) is the air volume inside the chamber that corrected for volume \(V_{stp}\) at standard pressure and temperature (1013.25 mbar; 273.15 K):

\[
V_{stp} = V \times \frac{p \times 273.15}{1013.25 \times T}
\]

where \(p\) is the pressure in mbar and \(T\) is temperature in Kelvin for the air volume inside the accumulation chamber.

After adjusting the temperature inside the chamber to be 21°C, which is the recommended temperature value for the calibration using the NIST radon emanation standard source (NIST, 1994), the monitor under calibration was inserted inside the chamber with the source, then the chamber was sealed for build-up of radon.

**a- Determination of the calibration factor of the Alpha Guard radon monitor**

Since the Alpha Guard is based on a pulse-ionization chamber detector, all the reading of the monitor should be corrected for the standard pressure and temperature. The correction was performed using alpha expert software correction formulas for pressure and temperature, which are based exclusively on the general level-equation of ideal gases (Genetron, 1995). Figure (2) shows that, the ratio between the measured value \(R\) by the monitor and the standard calculated value using the source \(R_s\) do not fluctuate about unity with a large statistical variation, but rather exhibit a definite systematic bias trend. \(R\) is systematically approximately equal \(R_s\) with a range of \(0.87 \leq R/R_s \leq 1.15\).

![Fig.(2) The fluctuation of the calibration factor R/Rs of the Alpha Guard radon monitor around unity with low statistical variation.](image-url)
b- Uncertainty analysis

The comparison ratio \( (R/R_s) \) can barely exclude the possibility of their equivalence on consideration of their respective total uncertainties. The two-sides uncertainty intervals \( (R/R_s) \pm k \sqrt{\frac{2}{u_R^2 + u_{Rs}^2}} \), obtained by propagating \( u_R \) and \( u_{Rs} \), overlaps unity at confidence level 95% with a coverage factor \( k \geq 2 \).

The standard combined uncertainty in measuring radon concentration \( u_R \) (2.08 %) depends on:
- The standard uncertainty due to the repeatability in monitor readings (0.2%),
- The uncertainty in the Alpha Guard reading according to its specification is 3%. Assuming rectangular distribution, the standard uncertainty of the monitor is 1.73%.

The standard combined uncertainty in the theoretical calculation is calculated as follows:

\[
u_{A_{Ra}}^2 = \left( \frac{1}{V_{stp}} \right)^2 u_{A_{Ra}}^2 + \left( \frac{A_{Ra} V_{stp}}{V_{stp}} \right) u_{V_{stp}}^2\]

(3)

Where \( u_{A_{Ra}} \) is the combined uncertainty in the theoretical calculation of the radon activity \( A_{Ra} \) which is calculated as follows:

\[
u_{A_{Ra}}^2 = \left( A_{Ra} (1-e^{-\lambda Rn T}) \right)^2 u_f^2 + \left( f (1-e^{-\lambda Rn T}) \right)^2 u_{A_{Ra}}^2
+ \left[ f A_{Ra} \lambda Rn e^{-\lambda Rn T} \right]^2 u_{A_{Ra}}^2
+ \left[ f A_{Ra} T_A e^{-\lambda Rn T} \right]^2 u_{A_{Ra}}^2
\]

(4)

- The standard uncertainty \( u_f \) of radon emanation fraction \( f \) which certified at 21°C (2%),
- The standard uncertainty \( u_{A_{Ra}} \) of \( A_{Ra} \) according to NIST standard source certification (0.465%),
- The standard uncertainty \( u_{A_{Ra}} \) in the time \( T_A \) is negligible,
- The standard uncertainty \( u_{A_{Ra}} \) in determining \( A_{Ra} \) for radon inside the calibration chamber (0.88%).

The standard uncertainty \( u_{V_{stp}} \) in the measurement of air volume inside the chamber (0.46%), which depends on the standard uncertainties in measuring the air volume, pressure and temperature \( (V,p,T) \) inside the accumulation chamber.

Consequently, the Alpha Guard calibration factor was measured to be 0.998 with an expanded uncertainty of ± 5.52% at a level of confidence of approximately 95% with a coverage factor \( k \) equal 2.

c- Determination of the RM3-B radon monitor calibration factor

In case of the RM3-B radon monitor, there is no need to correct the reading of the monitor for the standard pressure and temperature since, the monitor detector is based on solid state alpha surface barrier detector. Figure (3) clearly shows that, the calibration factor for the monitor is always fluctuate less than unity with an average of 0.746. This is in agreement with the previous calibration of the monitor, which was performed in the Swedish Radiation Protection Institute’s radon room with controlled NIST traceability activity (Studsvik, 1997).
The major source of uncertainty in the calibration of RM3-B is due to the monitor manufacturing uncertainty specification (15%). The RM3-B radon monitor calibration factor was measured to be 0.75 with expanded uncertainty of ± 17.86% at a level of confidence of approximately 95% with a coverage factor k equal 2.

4. PASSIVE TRACK DETECTORS CALIBRATION

As a result of the calibration of the Alpha Guard, it will be used as a secondary standard for the NIS radon measurements quality control. This experiment was carried out to test the feasibility of using this secondary standard in the calibration of integrated passive radon detectors. Six diffusion chambers containing CR-39 track detectors were placed inside the calibration chamber together with the Alpha Guard. The diffusion chambers are cylindrical in shape with internal diameter of 3cm and length of 2 cm, which were made from a polypropylene mixed with carbon particles to make it electrically conductive. This design, with similar material, is commonly used by other different laboratories. Radon was injected inside the calibration chamber from the Pylon radon generator then, the monitor and detectors were exposed for 138 hours.

At the end of exposure, the CR-39 detectors were immediately separated from the chamber to avoid overexposure for radon absorbed on their diffusion chambers (More and Hubbard, 1997). A standard procedure for etching and counting was performed for evaluating the track density in the CR-39 detectors. The detectors were etched in a 6.25 N-NaOH at 70 °C for 6 hours with stirring by 50 rev/min (Mansy et al., 1998). After etching, the detectors were washed in distilled water, dipped for a few seconds in 3% acetic acid solution, washed again in a distilled water and allowed to dry in air. Using an optical microscope at 400X a number of 150 fields were scanned for each detector to determine the track density per cm².

Results

For this calibration, the activity concentration of radon $C_{\text{max}}$ at the starting of the experiment was calculated from the exponential decay curve of the monitor readings. After calculating $\lambda_{\text{Rn}}$ experimentally as previously described, the integrated radon concentration $I$ during the exposure time $t$ was calculated as follows:

$$I = \frac{C_{\text{max}}}{\lambda_{\text{Rn}}} - \frac{C_{\text{max}}}{\lambda_{\text{Rn}}} e^{-\lambda_{\text{Rn}}t}$$

(5)

$I$ was found to be 6674.5 k Bq h m⁻³. The standard uncertainty $u_I$ related to this value was calculated as follows:
\[ u_I^2 = \left[ C_{\text{max}} e^{-\lambda_{\text{Rn}} t} \left( \frac{\lambda_{\text{Rn}} + 1}{\lambda_{\text{Rn}}^2} \right) \right]^2 u_{\lambda_{\text{Rn}}}^2 \]

\[ + \left[ C_{\text{max}} e^{-\lambda_{\text{Rn}} t} \right]^2 u_{\lambda_{\text{Rn}}}^2 + \left[ \frac{1}{\lambda_{\text{Rn}}} (1 - e^{-\lambda_{\text{Rn}} t}) \right]^2 u_{C_{\text{max}}}^2 \]

(6)

\( u_{\lambda_{\text{Rn}}} \) is the standard uncertainty in the determination of \( \lambda_{\text{Rn}} \) (0.88%).

\( u_t \) is the standard uncertainty for the exposure time which is negligible.

\( u_{C_{\text{max}}} \) is the standard uncertainty due to the calculation of the starting of the experiment which is the combined standard uncertainty of:

- The standard uncertainty in the calibration factor of the Alpha Guard monitor (2.75%),
- The standard uncertainty in monitor readings (0.17%),
- The standard uncertainty in the fitting equation for calculating \( C_{\text{max}} \), was negligible.

Thus, the combined standard uncertainty in the integrated activity concentration \( u_I \) is 2.83%.

The Calibration factors \( C_F \) for CR-39 in the used diffusion chambers were calculated as \( C_F = \frac{n_{tr}}{I} \), where \( n_{tr} \) is the area track density. The standard uncertainty \( u_{n_{tr}} \) is calculated to be 0.38%.

The standard combined uncertainty of \( u_{C_F} \) is calculated as follows:

\[ u_{C_F}^2 = \left( \frac{1}{I} \right)^2 u_{n_{tr}}^2 + \left( \frac{n_{tr}}{I^2} \right)^2 u_I^2 \]

(7)

Fig (4) shows the individual \( C_F \) of the diffusion chambers. The average \( C_F \) is equal to 2.37 track. cm\(^2\) / kBq.h.m\(^{-3}\) with associated combined uncertainty of 2.83%. As a result, the expanded uncertainty was ± 5.74% at a approximately 95% confidence level with a coverage factor \( k \) of 2.03.

![Fig. (4) The calibration factor (C_f) for each diffusion chamber](image)

5. CONCLUSION

The radon calibration chamber constructed with its good sealing specification and temperature controlling have verified one of NIS goal for assessing the quality of radon gas measurements at environmental levels. The built system is a good achievement in the introduction to the NIST international traceability in radon gas measurement. The calibration factor of the Alpha Guard radon monitor was reasonably good indicator for the performance of the Alpha Guard radon monitor compared to the NIST radon standard source when satisfying the best calibration conditions. Consequently, the monitor will be used as a secondary standards in for the NIS radon measurements and calibration.
REFERENCES


