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EVALUATION OF RADON MEASUREMENT IN A RESEARCH BUILDING IN CAIRO, EGYPT

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ABSTRACT

This paper presented the results of experimental measurements carried out by E-PERM technique to evaluate Radon concentration in ENRRA research building in Cairo, Egypt to assure that the indoor air quality has no pollutants from Radon gas and in the acceptable international level for work places. .

The radon concentrations are measured in 89 locations distributed in the building, and different factors which may influence the Radon concentration are studied; such as human behavior, floor location, orientation, opening size, type of ventilation, function of spaces, and finishing materials.

The results has shown that the concentration of Radon gas ranged from less than 0.4 to 37.9 Bqm-3 which is less than the upper reference level by ICRP. Radon concentration is not dependent on the finishing materials and orientation of the spaces but depends on the type of ventilation (naturally or mechanically) and the size of the windows. Finally, the human behavior of the occupants for ventilating the spaces is very significant.

INTRODUCTION

Indoor Air Quality (IAQ) can be defined as the air quality inside a building that will lead to the comfort and health of the occupants. IAQ is influenced by gases, microbial contaminants or particulates that bring to poor health conditions. A poor IAQ can be the major factor that leads to Sick Building Syndrome (SBS). In fact, good IAQ is required for a healthy indoor work environment. Poor IAQ can cause a variety of short-term and long-term health problems including allergic reactions, respiratory problems, eye irritation, sinusitis, bronchitis and pneumonia. IAQ problems can be due to indoor air pollutants or to inadequate ventilation [1].

Radon is a naturally occurring radioactive gas that can seep out of the ground and build up in buildings and indoor workplaces. The highest levels are usually found in underground spaces such as basements, caves and mines. High concentrations are also found in ground floors buildings, because they allow Radon from the sub-soil underneath buildings to enter through cracks and gaps in the floor [2].

For occupied underground workplaces (for example occupied greater than an average of an hour per week/ 52 hours per year), or those containing an open water source, the risk assessment should include Radon measurements, [3]. The EPA ranks indoor Radon among the most serious environmental health problems facing us today. After smoking, it is the second leading cause of lung cancer in the United States causing an estimated twenty one thousand (21,000) lung cancer deaths a year [4].

After Radon is a recognized as lung carcinogen. Regulations exist in the UK that limit the exposure to Radon at work and require employers to take action if levels exceed certain thresholds. Both Public Health England (PHE) and the Health and Safety Executive organizations advise employers to test routinely occupied basement workplaces for Radon, irrespective of geographical location, and to test ground floor workplace premises located in Radon affected areas as part of the employers' requirements to assess health and safety risks to their employees [5].

From a health assessment perspective, short-term measurements of Radon for the duration of some days may be of use in Radon screening surveys to identify locations with a potential for high Radon concentrations or when remediating a dwelling with a Radon problem, [6].

A national reference level does of Radon not specify a rigid boundary between safety and danger, but defines a level of risk from indoor Radon. In view of the latest scientific data. WHO proposes a reference level of 100 Bqm-3 to minimize health hazards due to indoor Radon exposure. However, if this level cannot be reached under the prevailing country-specific conditions, the chosen reference level should not exceed 300 Bqm-3 which represents approximately 10 mSv per year according to recent calculations by the International Commission on Radiation Protection (ICRP), [7].

There are a lot of papers discussed the Radon concentration in dwellings in Egypt [8], [9], [10], but we do not find any published data about Radon concentration in work places in Egypt. In this present research, the passive technique using the Electret Ion Chambers passive detectors has been used for the short term measurement (7 days) of Radon gas study in the research laboratory building of Egyptian Nuclear and Radiological Authority (ENRRA) in Cairo, Egypt. The overall objectives are: 1) to determine if the Radon concentration in the building is within the acceptable limits determined by international organization for work places, 2) to assess if further measurements are necessary or not.

METHODOLOGY

In this research, the Egyptian National Radiological and Radiation Authority (ENRRA) research laboratory building is the case study. The building is located in Nasr City, Cairo, Egypt. It has a rectangle shape and it consists of nine floors (basement, ground and 7 typical floors). The area of the typical floor is about 1200 m2. The building has about 230 rooms some of them are laboratories and the others are offices. It has also some service facilities such as library, large meeting room, training center, administration offices and storage areas. Figure (1) shows a schematic design of ENRRA building.

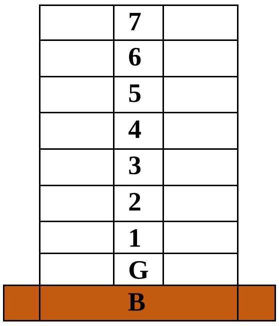

Figure (1): Schematic Design of ENRRA Building

Measurement Protocol in ENRRA Building

Radon exposure patterns in large buildings such as schools, research laboratories, commercial buildings and multiunit residential structures may differ from exposure in detached houses due to differences in building architecture, structure, occupancy and heating, ventilation and air conditioning (HVAC) operation. Measurement protocols should reflect these differences by defining multiple sampling locations in highly occupied locations for buildings with large floor areas, multiple floors, and multiple compartments with separate HVAC systems. Generally, lower floors should be sampled at a higher rate, because of the potential for increased Radon concentrations on ground-contact floors, when Radon from soil gas is the main source, [7].

Some publications are discussed the Radon measurements in large buildings and they defined some places for measurements as follows:

- Measurement for Radon in workplaces could be for spaces above ground level and the measurement have to cover at least 20% of rooms used for work place situated on the basement and ground floor, in upper floors one measurement per floor has to be made and at least one per 500 m2, and more

measurements are recommended for buildings constructed from material with enhanced uranium and radium level, such as blue lightweight concrete, [11].
- Measurements should be made in each occupied room in a basement or, if no basement exists, on the ground floor or the lowest floor having occupied rooms within the building. They defined "occupied room" is one in which an individual spends more than 4 hours per day. The EPA recognized that measurement and mitigation resources should be concentrated on areas in which occupancy is at least 2 hours per week or more.

In ENRRA building, different criteria had been taken into considerations for draw the protocol and for selection the locations of the measurement and these include:
- The measurement had been performed in all type of spaces of the building in all levels starting from the basement to the seventh floor and in all orientation. The measurements covered over 40% of spaces which is double of the recommended values which is 20% for Radon measurements in workplaces.
- Spaces had been chosen to test the most areas where occupants spend much of their time on it and these include offices, laboratories and meeting rooms.
- Measurements had not made in public toilets because little time is spent in a toilets.
- The measurement devices had been allocated inside the spaces to allow no disturbance of the measurement devices during the measurement period, [8]. Also the measurement devices were allocated far from the interior wall at a height of 1 m from the floor in the typical breathing zone and at the center of the spaces to allow normal airflow around the detector and to be far from any electrical equipment disturbance.

Methodology of Radon Measurement
There are a variety of test devices available to measure the level of Radon, and there are advantages and disadvantages to each type of these devices. One of the most widely used tests available for short-term measurement is the E-PERM Electret ion chamber which was selected to be used in this research.

For over fifteen years, Rad Elec's E-PERM System has been recognized in the U.S. and around the world for its highly accurate, very durable, cost-effective Radon detection equipment that is simple to use. Electret ion chamber technology consistently outperformed all other Radon testing methods in the US-EPA Radon Measurement Proficiency Program, [11]. Also, this device has been used in various countries and has displayed excellent accuracy and precision if standard operating procedures are followed [12].

Electret ion chambers (EIC) is a passive devices that function as integrating detectors for measuring the average Radon gas concentration during the measurement period. The electret serves both as the source of an electric field and as a sensor in the ion chamber. Radon gas enters the chamber by passive diffusion through a filtered inlet. Radiation emitted by Radon and its decay products formed inside the chamber ionizes the air within the chamber volume. The negative ions are collected by the positive electret located at the bottom of the chamber. The discharge of the electret over a known time interval is a measure of time-integrated ionization during the interval. This in turn is related to the Radon concentration. The electret discharge in volts is measured using a noncontact battery-operated volt reader. This value, in conjunction with a duration and calibration factor, yields the Radon concentration in desired units.

In ENRRA building the measurement had conducted in two months (November and December 2016) which is winter time in Egypt, the building is occupied during the daytime from 9 am to 4 pm and the work is running five days a week. The initial volt were measured (VI) of the electret then placed for one week and then closed, collected, and measured by volt reader to have the final volt (VF), also the Gamma dose rate (µs.h-1) was measured by Eberline survey meter. The Radon concentration calculated according to equation (1), [13]:

$$RnC = \frac{(VI-VF)}{(T)(CF)} - BG \qquad (1)$$

Where, RnC is the Rn concentration in Bq m^{-3}; T is the exposure period in days; VI, and VF are the measured initial and final electret voltages, respectively; CF is the calibration factor in units of V per Bq m^{-3} d^{-1}, and BG is the Rn concentration equivalent of natural gamma radiation background. A BG of 0.1 pGy h^{-1} (10 p rad h^{-1}) was measured to be equivalent to 32 Bqm^{-3}. A linear correction can be made to accommodate other BG values.

RESULTS AND DISCUSSIONS

The measurements of Radon concentrations in all floors of ENRRA building are shown in Table (1).

Table (1): Radon concentrations in ENRRA Building

Floor Number	Sample Number	Room Number	Orientation Wall-Floor Finish	Radon (Bqm^{-3})	Err %
Basement	1	B03	S-1C-C	5.4	11.33
	2	B04	S-1C-C	11.7	10.62
	3	B05	S-1C-C	17	8.62
	4	B07	N-1C-C	15.2	9.27
	5	B10	N-1C-C	37.9	7.51
	6	B17	N-1/2C-C	23.6	8.34
	7	B22	S-1C-C	11.2	8.38
	8	B25	S-1/2C-BG	31.5	8.61
Ground	9	004	S-1C-C	18.1	9.65
	10	006	S-1C-C	7.0	11.27
	11	007	N-1C-C	12.2	11.9
	12	012	N-1C-C	< 0.4	16.4
	13	015	N-1C-SR	20.2	9.65
	14	017	N-1C-SR	14.9	10.61
	15	018	N-1C-C	9.00	10.65
	16	024	S-1C-C	15.1	10.10
First	17	102	S-P-C	11.7	13.7
	18	108	N-P-C	< 0.4	12.86
	19	112	N-P-C	10.6	13.71
	20	114	N-P-C	14.3	10.10
	21	117	N-P-C	< 0.4	15.44
	22	119	S-P-C	< 0.4	20.92
	23	120	S-P-C	< 0.4	27.04
	24	124	S-P-C	< 0.4	14.95
Second	25	Library	E-P-M	8.9	11.93
	26	206	N-P-C	10.5	7.93
	27	210	N-P-C	6.9	13.75
	28	212	N-P-C	< 0.4	18.26
	29	215	N-P-C	9.2	6.15
	30	217	S-1C-C	0.9	16.87
	31	218	S-1C-C	< 0.4	13.84
	32	302	S-1C-C	20.2	8.92
	33	305	S-P-C	1.9	21.28
	34	306	S-1/2C-C	15.9	13.69

	35	309	N-P-C	15.6	11.20
	36	311	N-P-C	9.0	11.42
	37	312	N-P-C	< 0.4	10.7
	38	313	N-1C-C	< 0.4	11.21
	39	316	N-P-C	9.0	9.31
	40	317	N-P-C	< 0.4	12.72
	41	319	N-1C-C	7.3	10.68
	42	320	N-P-C	< 0.4	36.50
	43	321	N-P-C	16.00	10.61
	44	323	N-P-C	12.1	10.62
	45	326	S-P-C	2.2	12.07
	46	327	S-P-C	5.7	11.32
Fourth	47	402	S-P-C	9.0	9.7
	48	411	N-P-C	< 0.4	13.07
	49	415	N-P-C	3.3	10.52
	50	416	N-P-C	1.1	13.25
	51	418	N-1C-C	18.8	11.19
	52	420	N-1C-C	22.2	9.64
	53	421	N-P-C	1.9	12.36
	54	423	N-P-C	< 0.4	11.52
	55	427	S-P-C	3.3	13.05
Fifth	56	502	S-P-C	< 0.4	12.00
	57	505	S-P-C	1.7	12.63
	58	506	S-1/2C-C	10.6	10.12
	59	509	N-P-C	< 0.4	14.10
	60	510	N-P-C	2.7	12.44
	61	512	N-P-C	10.00	11.22
	62	515	N-P-C	11.00	10.63
	63	516	N-P-C	4.6	10.81
	64	517	N-P-C	18.5	10.6
	65	518	N-P-C	2.5	9.76
	66	520	N-P-C	7.4	9.73
	67	522	N-P-C	6.2	11.98
	68	523	N-P-C	17.00	9.26
	69	526	S-P-C	17.6	8.35
	70	527	S-P-C	< 0.4	16.79
Sixth	71	602	S-P-C	7.8	10.67
	72	605	S-P-C	8.4	9.71
	73	606	S-P-C	12.2	9.28
	74	609	N-P-C	< 0.4	9.7
	75	610	N-P-C	8.8	10.65
	76	612	N-P-C	16.3	10.61
	77	616	N-P-C	12.10	12.72
	78	617	N-P-C	10.1	6.81
	79	619	N-P-C	7.9	11.25
	80	621	N-P-C	< 0.4	13.86
	81	626	S-P-C	10.00	10.64
	82	630	S-P-C	13.70	11.20

Seventh	83	705	N-P-CA	10.7	11.91
	84	706EXT. A	N-P-CA	5.1	12.03
	85	706EXT. B	N-P-CA	< 0.4	12.74
	86	Entrance of Lecture room	N-P-CA	< 0.4	28.04
	87	Lecture room	N-P-CA	18.8	9.65
	88	Small Lecture room	S-G-G	8.5	11.24
	89	Restaurant	S-G-G	9.1	8.67

* The N, and S letters represent the North and South directions respectively.
** The C, 1/2 C, P, G, and CA represents Ceramics finishing of walls, half Ceramics of walls, Painted walls, Granite floor, and Carpet respectively.

The Radon concentration was measured in 89 spaces which distributed along the nine floors of the building as follows 8, 8, 8, 7, 15, 9, 15, 12, and 7 spaces starting from the basement to the seventh floor respectively.

The Radon concentration in (Bqm^{-3}) in the spaces of the building are ranged from <0.4 to 37 Bqm^{-3}. The concentration results are ranged from (5.4 to 37.9), (<0.4 to 20.2), (<0.4 to 14.3), (<0.4 to 10.5), (<0.4 to 20.2), (<0.4-22.2), (<0.4-18.5), (<0.4-16.3), and (<0.4-18.8) from the basement to the seventh floors respectively. The measurement showed also that about 23.59 % of spaces (21 space) have Radon concentrations below the lower limit of detection (0.4 B.qm^{-3}). No spaces in the basement floor had Radon concentration below the lower limit of detection (0.4 Bqm^{-3}). On the other hand, the basement floor had the maximum Radon concentration (37 Bqm^{-3}) which is normal because it is the most floor buried in the soil. Finally, the results in all spaces had shown Radon concentrations lower than the reference levels determined by ICRP and EPA.

Effect of Human Behavior (opening and closing windows and doors)
The results showed that all spaces which had Radon concentrations lower than the limit of detection (0.4 Bqm^{-3}) are well ventilated and they opened daily by the occupants. This happened because of the human behavior of opening the windows daily to let the fresh air enters the spaces. On the other hand, all spaces which have maximum Radon concentrations in all floors are not well ventilated because they are not working daily according to their function.

Effect of Function of Spaces
The results showed the effect of different function in all spaces, the basement floor which has different laboratories and storage areas and they are not working regularly showed higher values. On the other hand, the ground and first floors which have different laboratories and administration offices and working daily have lower values.

So, we can conclude that the human behavior and functions of spaces have significant effect on Radon concentration in ENRRA building.

Effect of Floors Location
The relation between mean Radon concentrations in all spaces starting from basement to the seventh floor are shown in the figure (2).

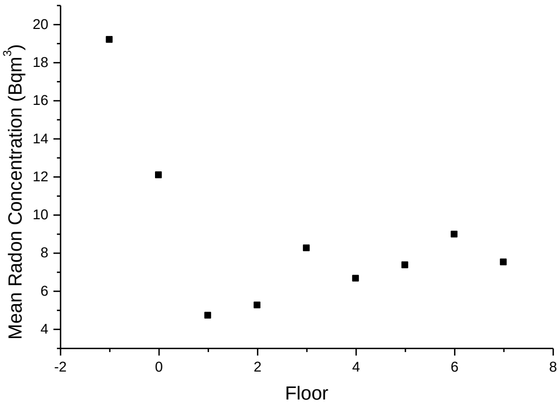

Figure (2): Relation between mean Radon concentrations of floors and location of floors

The relation between the mean Radon concentration and the floor level is an exact linear correlation with a strong negative regression (r= - 0.999) from basement floor to the first floor as shown in figure (2). On the other hand, the mean Radon concentration has a positive linear correlation (r = 0.749) for the first to the seventh floors. So, the results concluded that the floor level inversely proportional with Radon concentration from basement floor to the first floor and vice versa from the first to the seventh floor. Also the mean Radon concentrations of the floors from the second to the seventh are higher than the first floor and lower than the ground floor as shown in figure (2).

Effect of Orientation of Spaces
The building is rectangle shape and the long sides are facing North and South directions. The prevailing wind comes from North West direction. Most rooms of the building has a cross natural ventilation which had been reflected to the measurement of Radon to be in acceptable values. The results shown that no relation was found between the Radon concentration in the spaces in all orientation and in all floors except some small cases such as: all spaces have maximum Radon concentration located at the North direction for all floors except one floor (the third floor) which has the maximum Radon concentration at the South direction. So, it is concluded that the orientation of spaces have no effect on Radon concentration in ENRRA building.

Effect of Opening Size and Type of Ventilation
The ENRRA building design is modular in shape and it has windows in all spaces with the same size in all rooms in the typical floors with about 120 cm height which are providing good lighting and natural ventilation. On the other hand, basement floor has only elevated windows with height about 40 cm and most of the time they are closed, also the lecture room in the seventh floor had no windows and it is mechanically ventilated.

The result showed that the basement floor which has the small windows has the maximum mean concentration of Radon. On the other hand, the other floors which have wider windows have mean Radon concentrations less than the basement floor. Also, there are areas in the other floors which have Radon concentration lower than the lower limit of detection. Also, the results showed that the lecture room has the maximum Radon concentration in the seventh floor. So we can conclude that the size of windows and type of ventilation system has a clear direct effect on Radon concentration in the building.

Effect of Finishing Materials
The effect of the finishing materials on Radon concentration was studied, and the results showed the followings:
- The basement floor which its walls and floors finished with ceramic has a higher concentration of Radon compared to spaces which have ceramic floor and half height ceramic walls. This value can be noticed in room number B10 in the basement which has the highest Radon concentration in the ENRRA building

(37.9 Bqm^{-3}). On the other hand, there are spaces such as (B03, B04, B05, B07, and B22) in the basement with the same finishing materials but have small concentrations (5.4 to 17 Bqm^{-3}).

- In the ground floor, all spaces have the same finishing materials; the walls and floors are completely from ceramic, except for room number 007 and 012 which have a rubber floor. The results shown that room number 012 has the maximum Radon concentration in the floor 20.2 Bqm^{-3} and this is unexpected according to its materials.
- In the second floor, most of the spaces have painted walls and ceramic floors except the library which has wood cladding in the walls and carpet in the floor and the 2 spaces number 217, and 218 have walls and floor from ceramic. The room number 218 has Radon concentration lower than the lower limit of detection (0.4 Bqm^{-3}) in addition to the room number 217 which has the lowest Radon concentration (0.9 Bqm^{-3}) and this is unexpected according to its materials.
- In the seventh floor the walls are painted and ground from carpet except the restaurant and the small lecture room which has walls and ground from granite, and the lecture room which have carpet in floor and wood cladding in walls. It is expected that these 2 spaces have the maximum Radon concentration according to use the granite, but it is found that the lecture room has the maximum Radon concentration which is 18.8 Bqm^{-3}.
- Also the spaces which have the same materials have a wide range of Radon concentration for example in the first floor (painted walls and floors from ceramic) Radon concentration ranged from < 0.4 to 14.3 Bqm^{-3}, this difference had indicated that the maximum value is 35 times greater than the smaller value in the floor.

The final results showed that the finishing materials have no clear effects on Radon concentrations.

CONCLUSION

To date, and after this measurements in ENRRA building the results have not shown any significant increase in Radon at any spaces of the ENRRA building. Also, the measurements are less than the measurement which were taken in houses in Egypt by other researchers.

The Radon concentration in the different areas of ENRRA building had showed that Radon concentration are not depends on the finishing materials, orientation of the locations but depends on the type of ventilation (naturally or mechanically), function of space and also on the size of the windows. Finally, the human behavior of the occupants for ventilating the spaces is very significant.

According to the Guide for Radon Measurements in Public Buildings developed by Health Canada, January 2016, it is recommended that if the measurement results are below 200 Bqm^{-3}, further measurements are not necessary. So, Radon concentrations in ENRRA building was very low and had no significant levels comparing to the international limit levels in public buildings, it is strongly recommended that the result of this short-term measurement is sufficient and no need for any long term measurements and also no mitigation is needed.

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