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Assessment of Radon-222 Concentrations in Buildings, Building Materials, Water and Soil in Jordan

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ABSTRACT

Monitoring of radon gas (^{222}Rn) in Jordan was started in early 1990. Since then our radon group at Yarmouk University and others have carried out tens of studies that include measurements of indoor radon, radon in water, radon in soil and radon emanating from building materials. All major cities of Jordan had been surveyed, from the northern city of Irbid down to the southern port city of Aqaba. Most of these studies were carried out by using time-integrated passive radon dosimeters containing CR-39 solid state nuclear track detectors. In addition to that, an active radon monitor was used to study the seasonal variation of ^{222}Rn in Al-Ruseifa that lies near abandoned phosphate mines and in Amman area. During such a study passive dosimeters were also used. The average radon concentrations in dwellings in Jordanian cities ranged from about 20 Bq/m^3 to 386 Bq/m^3 with the highest readings exhibited during the winter season around the town of Al-Ruseifa.

INTRODUCTION

In the last two decades, there has been a great deal of awareness about the health risks from exposure to radon radioactive gas and its decay products. In fact, the Surgeon General of the United States has warned that radon is the second leading cause of lung cancer in the United States today. Only smoking causes more lung cancer deaths (BEIR VI report, 1999).

Large-scale radon surveys have been carried out in Europe and in the United states, many more than have been conducted in the Third World countries. However, the study of radon has been steadily expanding throughout the world. The main issue was the monitoring of radon gas in air inside dwellings. However, over the last decade more emphasis has been placed on measuring radon-222 levels in soils and attempting to correlate the resultant concentrations to local geology. This due to the fact that most of the radon in dwellings comes from the underground soil. (Durrani, 1999).

A radon surveillance program in Jordan (Fig. 1) was started early in the 1990's. Since then, many scientists had measured radon concentrations in air inside dwellings (Al-Kofahi et al., 1992, Abumurad et al., 1994, 1997a, Kullab et al., 1997, Khatibeh et al., 1997) and its levels in soil (Abumurad et al., 1997b) and water (Al-Bataina et al., 1997). In addition to that, radon exhalation rates from building material were also measured (Ismail et al., 1994, 2002). Up to the end of the 20th century our group was mainly the only group in Jordan. These studies tested few thousands sites of homes, private and public buildings, schools and kindergartens. These surveys cover almost every major town in Jordan, from the northern city of Irbid down to the southern port city of Aqaba. Most of these works were carried out by using time-integrated passive dosimeters containing solid state nuclear track detectors (SSNTD) like CR-39.

By the end of the 20th century we studied the seasonal variation of ^{222}Rn in Al-Ruseifa City (about 15 km northeast of Amman) that lies near abandoned phosphate mines and also in Amman area (Kullab et al., 2001). In such a study, we used another technique besides that of time-integrated passive dosimeters, namely, an active radon monitor. Later on, we theoretically estimated the radon concentration level in some Jordanian building materials from the direct measurement of ^{226}Ra by using gamma ray spectroscopy.

EXPERIMENTAL TECHNIQUE

In our works on radon monitoring in Jordan, we mainly used two technical methods, passive and active dosimeters. In addition to that, a theoretical estimation of radon concentration in building materials was carried out through direct measurement of ^{226}Ra specific activity using a computerized gamma-ray spectrometer with a high purity germanium detector (HPGe) of high resolution.

Passive dosimeters

This type of technique was found to be the most appropriate one and most widely used because of the simplicity as well as the economy of the technique, besides the ability of such monitors to average out –by virtue of integration over a period- the effects of seasonal and environmental-related variations in radon levels in the dwellings (Durrani and Ilić, 1997, Nikolaev and Ilić, 1999, Durrani, 2001). The CR-39 detectors are more sensitive to alpha particles. They can detect alpha particles with energies from about 0.1 MeV to about 20 MeV.

In this method, time-integrated passive radon dosimeters containing SSNTDs CR-39 of super grade quality based on the closed can technique were used (Fig. 2). The structure of such dosimeters was similar to those used by Abu-Jarad (1980) and Majborn (1986). These dosimeters composed of plastic cups, 7.0 cm in diameter and 4.6 cm in depth. A circular hole of radius 0.75

cm was made at the center of the lid. The hole was covered by a piece of sponge of 5 cm × 5 cm and of thickness of 0.5 cm, glued onto the interior surface of the lid. A small piece of CR-39 with an area of about 2 cm^2 was put inside the cup and fixed to its bottom. This configuration was necessary to make sure that thoron (^{220}Rn; $T_{1/2} = 55.6$ s) cannot reach the detector.

To correlate the density of the recorded tracks on the detectors to radon concentration, some of these dosimeters (in our early works) were sent to the National Radiological Protection Board (NRPB), in England, for calibration, where they exposed to a known dose of radon (400 $kBqh/m^3$). Later on, in 1995, the dosimeters were recalibrated in the School of Physics and Space Research at Birmingham University, England, where they exposed to radon activity density of 90 kBq/m^3 for 48 hours.

On the average, about 500 dosimeters were usually distributed inside the dwellings of the selected sites in each survey. In each dwelling, at least four dosimeters were placed in different rooms at a height of about 2 m above the floor, where one dwelling has been normally selected from each level of high buildings. On the other hand, monitoring radon in subsoil was conducted by putting the dosimeters upside-down in the bottom of hole in the soil at a depth of 50 cm, protected by PVC tubes inserted in the cavities. .

For the purpose of monitoring radon in air inside the buildings, the dosimeters were usually exposed for three months. While for monitoring radon gas in soil the dosimeters were left up to two months, but we found that an exposure time of 15 days is much more appropriate for such purpose.

The collected dosimeters were then chemically etched, using a 30% solution of KOH at a temperature of 70° C ± 0.1° C for nine hours. An optical microscope with a magnification of

150x up to 400x was used to count the number of tracks per cm^2 recorded on each detector. The radon activity density C, in units of Bq/m^3, is then calculated using the following relation:

$$C = \frac{C_o\, t_o\, \rho}{\rho_o\, t} \tag{1}$$

where C_0 is the activity density of the calibration chamber in kBq/m^3, t_0 is the calibration exposure time, ρ is the measured number of tracks per cm^2 on the CR-39 detectors that were inside our dosimeters used in the studies, ρ_0 is the measured number of tracks per cm^2 on the calibrated CR-39 detectors and t is the exposure time of the distributed dosimeters.

Active dosimeters

A calibrated active radon device called Radon Monitor RM3 (Studsvik Instrument, Sweden) was used for fast measurements of indoor radon activity levels on sites. Usually, we set the monitoring time for three consecutive days in each location. RM3 is designed to present a fast measurement of radon concentration in air and in soil in the range from 1 to 10^6 Bq/m^3 using electrostatic deposition of radon progeny ^{218}Po and ^{214}Po with high-resolution α-ray surface barrier detector. The monitor has an internal pump, printer, RS232 output and can also be used for long-term radon monitoring, for radon leak detection or for the determination of emanation coefficients of materials. Either ^{218}Po-based "fast" or ^{218}Po + ^{214}Po-based "slow" recording options are selectable. Measurement intervals can be chosen from 5 minutes up to 24 hours. It was calibrated in the Radon Chamber of the Swedish Radiation Protection Institute.

Gamma-ray spectrometry

In this method, we used a γ-ray spectrometer (pre-calibrated for energy and efficiency in our laboratory) with high purity germanium detector (HPGe) of high resolution (1.73 keV at 1.33 MeV) to measure the specific activity of ^{226}Ra in 35 samples of seven different types of Jordanian building materials (1 kg each). The system also includes a Spectrum Master from

EG&G connected to the detector and a multichannel analyzer card installed in a PC computer. The Spectrum Master included a high voltage power supply of positive bias, a computer-controlled amplifier with triangular shaping and an automatic pole-zero adjustment. Also, the spectrum master had 16 K analogue to digital converter (ADC) with a software-controlled conversion gain, and a 16 K memory with up to $2x10^9$ counts/channel. The detector is shielded from background radiation by cylindrical lead walls. The samples were dried and crushed into a powder with a particle size of less than 500 μm except the samples of paint. Then the samples were sealed into a Marinelli beaker. The measurements were done after enough time (two weeks) to be sure that secular equilibrium between ^{226}Ra, ^{222}Rn and their daughters has been reached. The data acquiring time for each sample was 24 hours of live time. Spectrum analysis software called Gamma Vision that runs under windows is used in the analysis.

Concurrently, other sets of the samples (100g each) were placed in plastic cups that are similar to our radon passive dosimeters. Each cup was tightly covered by an inverted dosimeter and kept for 60 days. Then the CR-39 detectors were analyzed as usual and the radon concentrations in building materials were measured.

RESULTS AND DISCUSSION

The results of our studies for radon levels indoors are presented in Tables 1-3, radon levels in water are given in Table 4, while the Tables 5-8 contain our results for the seasonal variation of radon concentrations indoors and in soil and finally Table 9 shows the measured and the calculated values of radon levels in building materials.

Radon levels Indoors

Table 1 shows the indoor radon concentrations in Irbid metropolitan area during a summer season. The radon level in each location was normal and around 31 Bq/m^3. However, the big variation between the minimum and maximum values of radon concentration can be attributed to different ventilation conditions during the hot summer and to the difference in the dwelling heights. But in the Yarmouk University (YU) storehouses the radon level was higher by nearly a factor of 3. This is mainly due to the fact that these storehouses had some cracks in their floors and their windows are closed most of the time and poorly ventilated and consequently the radon concentration inside these storehouses builds up to a high value.

Table 2 presents a large-scale study that covered almost all major cities of Jordan during an autumn season. It shows that the dwellings in Northern Jordan Valley had the lowest radon concentration (16.21 Bq/m^3), which is mainly due to very good ventilation where all the windows of each dwelling are open most of the time due to hot weather. On the other hand, the southern cities of Karak, Madaba and Ma'an showed relatively high radon concentrations compared to those of other cities (> 90 Bq/m^3). This high concentration is reasonable because most of their dwellings are very close to each other and such a style allows only poor ventilation. Also, the inhabitants of Ma'an and Karak are very conservatives and their houses are crowded and surrounded by relatively high concrete walls (≥2 m). Although the Tafila city, lies in the south of Jordan, shares its geological structure with the other southern cities, nevertheless, the mean value of radon concentration there is about half of those. This is because Tafila during the period of study is usually windy with wind speed around 4 m/s, which may dilute radon in the atmosphere. In addition to that, it is also characterized by large houses with many openings, occupied by big families. These factors may induce good air circulation, which reduce the indoor radon concentrations. While Aqaba (lies at the south edge of Jordan on the Red Sea) that has a geological structure similar to that of southern cities showed a much lower value of radon concentration (29.36 Bq/m^3). Aqaba is an area of high pressure (~ 1011 mb) most of the time, that may depress the radon flux from the earth and as a result the indoor radon levels may be decreased. Also, it is a modern, well-organized city; most of the houses are newly built (< 30 years) and are carefully designed and constructed to permit excellent ventilation factors to moderate the atmosphere hot periods.

Table 3 shows the measurements of radon levels in 74 kindergartens in Amman during winter, where 10 passive dosimeters were distributed in each one. We found that the radon concentrations in units of Bq/m^3 were below 50 in 16 kindergartens (21.6%), 50-99 in 42 kindergartens (56.8%), 100-149 in 13 kindergartens (17.6%) and 150-199 in just 3 of them (4%). Comparing these results with that of Amman dwellings during the autumn season, we found that the average value of radon concentrations in kindergartens (76.8 Bq/m3) was twice that of Amman houses. This mainly due to the fact that the studied kindergartens are closed most of the time (>75%) for children's safety and conservation of heating energy, which allow radon level to build up. The variation of radon concentrations among the kindergartens can be attributed to many factors like geological structure of the sites, the heating systems and ventilation rates besides the aging effect on the buildings. We found that the schools of over 10 years old (48 out of 74) had slightly higher radon concentrations than the new ones (79.4 and 71.7 Bq/m^3 respectively). However, we expected that the radon concentrations in the old kindergartens to be much higher for different reasons, such as, their classrooms are relatively small with ventilation rates ranging from poor to moderate and the presence of cracks in the floors and walls of the classrooms may allow radon gas to emanate easily from soil, ground and building materials into indoors. On the contrary to that, the classrooms of the new kindergartens are spacious and well ventilated. Besides that, their walls and ceilings are properly painted without almost any cracks. But, the heating systems had a crucial impact on the radon concentration levels inside the kindergartens. Where 12 kindergartens from the old group were not using any heating system, and so all their doors and windows kept closed all day long, which allow radon level to build up inside to an average value of 86.5 Bq/m^3. While the rest of the old kindergartens were using kerosene portable heaters, and consequently, the average value of radon level inside them decreased to 72.9 Bq/m^3 because a higher ventilation rate was exercised during the daytime, in order to refresh the indoor air and to get rid of the kerosene's smell. On the other hand, most of the new kindergartens (24 out of 26) used central heating systems that cost very much in Jordan. Therefore, the ventilation rates of their classrooms were minimized to conserve energy, which in turn let the radon level to rise inside the classrooms.

Radon levels in water

The results of radon concentration levels in different types of natural water in Jordan are presented in Table 4. There were no significant variations in radon levels among the different resources of water. The cold spring water was characterized by the highest mean value of radon concentration (5.4 Bq/l) while the drinking tap water was characterized by the lowest one (3.7 Bq/l). It is worth mentioning that the hot mineral spring water had a relatively low radon concentration (3.8 Bq/l), which may be due to the decrease of radon solubility as temperature increases and/or due to the high sulfate content in hot water that cause precipitation of radium before emerging into these hot springs. Therefore, the radon levels in Jordanian water supplies are comparatively low since the recommended maximum contaminant level (MCL) of U.S. Environmental Protection Agency is 300 pCi/l, which is equivalent to 11.1 Bq/l.

Seasonal variation of radon levels indoors and in soil

Tables 5-8 show the seasonal variation of ^{222}Rn concentration indoors and in soil in Al-Ruseifa City (about 15-km northeast of Amman), which lies nearby abandoned phosphate mines (seven sites). The other three sites were selected from Amman district area in such a way that one of them is close to the phosphate mine tail, while the other two are far away from it and lie in the western suburbs of Amman. In that study, an active radon device called Radon Monitor RM3 from Studsvik Instrument, Sweden was used along with the passive radon dosimeters of closed can technique. It was used for measuring the radon concentration in air only inside the ground floors of these dwellings. We set the monitoring time for three consecutive days in each location. From these data, we found that the maximum value of radon concentration in air inside the dwellings, as measured by the passive dosimeters, was 1532.9 Bq/m^3 during the winter season, and the minimum one was 87.3 Bq/m^3 during fall season. While the highest and lowest readings of the active monitor were 892 Bq/m^3 and 4 Bq/m^3 during fall and summer seasons, respectively. Overall, the mean value of radon concentrations inside the ground floors of the dwellings, using CR-39, during the whole year was 273.7 Bq/m^3. Also, the mean values of radon concentration in the ground floors from both types of measurements were highest in winter and lowest in summer. These values are much higher than the average radon concentrations in the Jordanian dwellings (Abumurad et al., 1997a). The reason for that might be due to the fact that these dwellings in Al-Ruseifa were built on grounds that used to be phosphate mines. The seasonal variation of radon levels could be attributed to the meteorological conditions, since in winter, these dwellings were poorly ventilated to save energy but they had good ventilation in summer time. Both types of measurements yield the same trend in radon levels. But, there is still a difference between the results of CR-39 detectors and that of the active radon detector, which might be due to a poor calibration of the monitor and due to the weather conditions of those days during which the monitor was operated. However, we trust the results of CR-39 detectors because the collected data were integrated and averaged over a long period of time.

Also, it is obviously clear, that throughout the year the radon levels were higher in the ground floors than in the first ones. This is because the radon gas that emanated from the soil would have a better chance of entering the ground floors rather than the first ones through common pass ways such as cracks and pipes entering the dwellings.

The results of radon concentration in soil at a depth of 50 cm are shown in Table 7. The lowest average concentration was 2.53 kBq/m^3 during the winter season and the highest one was 10.9 kBq/m^3 during the fall. Although all the measurements were carried out at the same depth, the soil radon level varied from one season to another for the same site. The level of radon soil during winter was very low. This is because the soil is wet, humid and of lower porosity that may decrease the diffusion of radon gas (Shweikani, et al., 1997). While in spring, the humidity of the soil is lower than that of winter so the radon concentration increases due to the increase of porosity and the better ventilation caused by the presence of plants' roots. In summer, the soil becomes less humid and the porosity increases but the ventilation throughout soil granules decreases slightly due to drying of plants, which makes the radon level decrease. Whereas in fall, the soil becomes very dry after a long hot summer and the dehydration of plants increases the porosity even higher, so the radon diffusion flow is getting better. Therefore the radon soil concentration has the highest value in fall. However, comparing these results with earlier studies (Abumurad et al., 1997b) shows that the levels of radon soil in this study are moderate.

Radon levels in building materials

From the measured values of the specific activities of ^{226}Ra, shown in Table 9, the radon exhalation rates E_x (Bqm^{-2}h^{-1}) were theoretically calculated by using the following formula (Man and Yeung, 1999):

$$E_x = \frac{1}{2} C_{Ra}\, \lambda_{Rn}\, \rho\, \sigma\, d \tag{2}$$

where C_{Ra} is the ^{226}Ra specific activity, λ_{Rn} is the decay constant of radon, ρ is the material density, σ is the emanation coefficient and d is the wall thickness. Consequently, the radon concentrations were estimated by using the relation (Diano and Bellecci, 1998):

$$C_{Rn} = \frac{E_x\, S}{\phi} \tag{3}$$

where C_{Rn} is the concentration of radon-222, S is the surface wall area and ϕ is the air ventilation flux.

From Table 9, we found that the theoretically estimated values of radon concentrations in building material were in good agreement with the experimentally measured ones. Also, it is clear that quartz has the highest radon concentration while paint has the lowest one.

Estimate of the lung cancer risk due to inhaled and ingested radon

The value of the risk of lung cancer associated with lifetime inhalation of radon in air at a concentration of 1 Bq/m^3 was adopted to be the rounded average derived from the two BEIR-VI model results and equals to 1.6×10^{-4} per Bq/ m^3. The lung-cancer risk to smokers is, statistically, significantly higher than the risk to nonsmokers. While the cancer death risk from lifetime ingestion of radon dissolved in drinking water at a concentration of 1 Bq/m^3 is 0.2×10^{-8} (National Research Council, 1999). Therefore, the estimation of the individual's radon induced lung cancer risk in Jordan during a lifetime ranges from 2.59×10^{-3} to 1.59×10^{-2} with an average of 8.5×10^{-3}, while that due to ingested radon from drinking water, on the average, is 7.4×10^{-6}.

CONCLUSION

In conclusion, we found that the radon levels in Jordanian dwellings, water, soil and building materials are within the internationally acceptable values. Where the indoor radon concentration level is on the average equals to about 52 Bq/m^3 as measured in autumn, which is about 1/3 of the EPA recommended value. Only the small city of Al-Ruseifa showed high radon levels in every season, especially in winter where it was up to 386 Bq/m^3. Finally, the mean value of the risk of lung cancer in Jordan was 8.5×10^{-3}, which is considered to be a relatively low risk factor.

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Table 1: Range, median, mean and standard deviation (SD) of radon level In Irbid metropolitan area during summer season.

City	Range (Bq/m^3)	Median (Bq/m^3)	Mean (Bq/m^3)	SD (Bq/m^3)
Irbid	8-51	25.00	27.38	8.78
Irbid refugee camp	9-116	33.00	35.65	16.73
Hatim village	22-54	34.00	36.14	9.27
YU offices	3-164	31.00	38.56	22.60
YU housing 1	19-41	26.00	27.52	5.53
YU housing 2	17-59	27.00	28.71	6.72
YU housing 3	7-55	20.00	23.71	11.94
YU storehouses	66-145	99.00	102.02	32.81

Table 2: Range, median, mean and standard deviation (SD) of radon level In Jordanian cities during an autumn season.

City	Range (Bq/m^3)	Median (Bq/m^3)	Mean (Bq/m^3)	SD (Bq/m^3)
Mafraq	28-80	48.00	50.64	13.80
Jerash	24-116	44.00	48.64	18.18
Ajlun	12-160	36.00	40.08	27.00
Madaba	28-212	86.00	92.64	41.79
Amman	20-84	36.00	39.52	13.17
Zarqa	12-56	26.00	27.25	8.80
Northern Jordan valley	8-41	15.00	16.21	7.20
Salt	24-128	44.00	46.08	15.14
Tafila	24-180	40.00	47.28	28.67
Karak	24-556	78.00	99.68	91.78
Ma'an	40-440	72.00	96.48	70.01
Aqaba	12-64	28.00	29.36	8.90

Table 3: The mean values of radon concentrations (C) in Bq/m^3 for kindergartens in the sub-regions (SR) and the average (Ave.) of each major area in Amman during winter season.

Area A		**Area B**		**Area C**		**Area D**		**Area E**		**Area F**	
SR	**C**	**SR**	**C**	**SR**	**C**	**SR**	**C**	**SR**	**C**	**SR**	**C**
MS	87.1	WN	63.9	TA	121.1	NO	69.5	DR	61.6	SH	89.4
HS	60.1	JN	70.4	JO	46.3	QU	143.2	OS	73.9	D3	68.3
MJ	48.5	HH	71.4	AS	69.0	JH	80.5	HR	77.5	AB	94.2
MA	46.0	MN	69.5	WA	111.0	TQ	75.9	SW	82.5	SF	90.8
TB	55.5	AL	55.5	AA	50.9			TY	48.5	JA	113.9
				QW	54.3					BY	66.5
				FN	104.0					LU	69.6
Ave.	59.4		66.1		79.5		92.3		68.8		84.7

Table 4: Radon concentration levels in different types of natural water in Jordan.

Type of water	**Ground water basin**	**Range (Bq/l)**	**Average radon level (Bq/l)**	**Average Temperature (°C)**
Cold spring water	Irbid	3.3-10.7	5.4 ± 0.8	23
Hot spring water	Irbid, Madaba & Dead Sea	3.2-5.5	3.8 ± 0.5	40
Wells' water	Irbid	3.1-5.7	4.5 ± 0.8	31
Sea water	Dead Sea & Gulf of Aqaba	4.3-6.3	5.1 ± 0.9	28
Drinking tap water	Various basins	2.5-4.7	3.7 ± 0.8	22

Table 5: The radon concentrations in the ground floors using CR-39 detectors.

Location	**Radon Concentration (Bq/m^3)**				
	Fall	**Winter**	**Spring**	**Summer**	**Yearly Average**
S1	---	904.1	311.4	144.3	453.3
S2	97.2	112.7	197.6	214.5	155.5
S3	---	---	96.7	213.4	155.1
S4	95.2	111.3	108.4	139.1	113.5
S5	173.8	89.1	319.4	150.9	183.3
S6	180.1	102.9	453.9	242.9	245.0
S7	976.1	1532.9	510.5	322.4	835.5
S8	87.3	228.1	130.9	167.4	153.4
S9	---	217.0	254.6	282.9	251.5
S10	---	178.0	117.9	115.5	137.1
Seasonal Average	268.3	386.2	251.1	199.3	

Table 6: The radon concentrations in the first floors using CR-39 detectors.

Location	**Radon Concentration (Bq/m^3)**				
	Fall	**Winter**	**Spring**	**Summer**	**Yearly Average**
S1	---	86.2	143.8	116.9	115.6
S2	46.3	122.4	121.4	125.0	103.8
S3	123.8	112.7	234.6	169.8	160.2
S4	51.5	133.5	125.0	101.4	102.9
S5	95.4	130.8	256.9	128.5	152.9
S6	54.2	69.6	130.9	103.7	89.6
S7	107.5	239.3	271.1	178.0	199.0
S8	80.3	208.7	126.1	126.1	135.3
S9	---	228.7	270.0	249.9	249.5
S10	---	141.9	153.3	82.5	125.9
Seasonal Average	79.9	147.4	183.3	138.2	

Table 7: The radon concentrations in soil using CR-39 detectors.

Location	**Radon concentration (kBq/m^3)**				
	Fall	**Winter**	**Spring**	**Summer**	**Yearly Average**
S1	21.7	1.2	15.1	---	12.7
S2	37.8	0.5	21.2	24.1	20.9
S3	9.0	0.5	0.2	2.4	3.0
S4	10.6	0.4	0.8	3.5	3.8
S5	3.2	0.7	26.3	1.8	8.0
S6	3.4	0.9	5.6	0.5	2.6
S7	10.0	3.8	6.6	11.2	8.1
S8	1.7	2.2	---	0.6	1.5
S9	---	13.5	---	8.9	11.2
S10	0.6	1.6	1.9	1.4	1.4
Seasonal Average	10.9	2.53	9.7	6.0	

Table 8: Summary of data for radon seasonal variation.

Season	**Conc. In Ground Floor (Bq/m^3)**		**Conc. In First Floor (Bq/m^3)**		**Conc. In Soil (kBq/m^3)**		**Active Monitor Results (Bq/m^3)**	
	Max.	**Min.**	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**	**Min.**
Fall	976.1	87.3	123.8	46.3	37.8	0.6	892	19
Winter	1532.9	89.1	239.3	69.6	13.5	0.4	657	10
Spring	510.5	96.7	271.1	121.4	26.3	0.2	501	7
Summer	322.4	115.5	249.9	82.5	24.1	0.5	120	4

Table 9: The calculated and measured values of radon levels in building materials.

Building Material	**C_{Ra} (Bq/kg)**	**E_x (Bq/m^{2}h)**	**C_{Rn} (Theoretical) (Bq/m^3)**	**C_{Rn} (Experimental) (Bq/m^3)**
Sandstone	14.6	5.07	40.56	47.34
Rocks	1.7	0.73	5.84	7.88
Gypsum	5.5	0.91	7.28	11.54
Quartz	12.52	5.92	47.36	51.65
Cement	5.71	1.33	10.68	15.30
Glass	10.1	4.91	39.28	36.38
Paint	4.6	0.43	3.44	6.42

Fig. 1: Map of Jordan showing the locations of the surveyed cities for radon level.

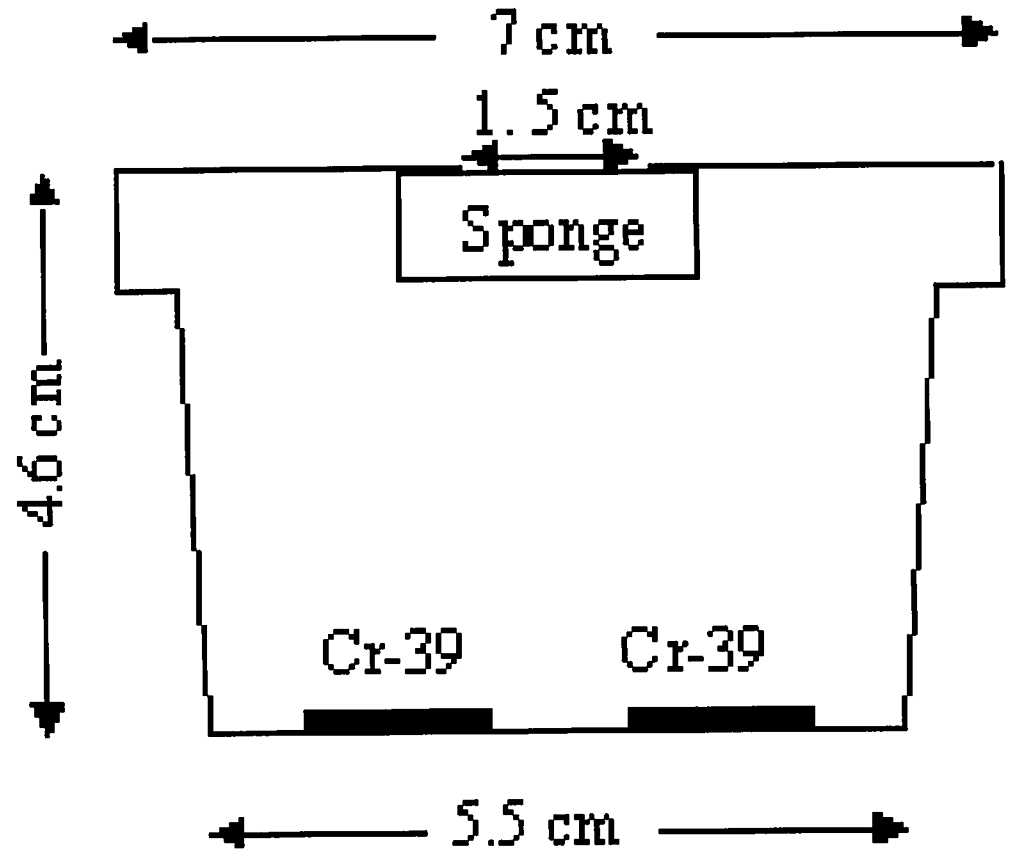

Fig. 2: CR-39 Passive dosimeter cup.