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Article

Coordinated indoor radon surveys in some Arab countries

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ABSTRACT Indoor radon surveys were carried out in some of the Arab countries through a Coordination Research Program (CRP) organized by the Arab Atomic Energy Agency (AAEA). The objectives of the program aim at establishing a database on indoor radon concentration levels in the region and investigating any anomalies, where they exist. The approach adopted by the survey teams to achieve public participation in accepting the radon detectors in dwellings is presented and discussed. Most of the participants in the CRP used the passive method (CR-39 plastic detectors) for long-term radon measurements, while others used charcoal detectors and E-Perm systems for short-term measurements. The results of the surveys showed that radon concentration levels in most of the dwellings were low, whilst in some old cities and in an area close to a phosphate mine the levels were found to be relatively high.

Keywords: Indoor radon survey / charcoal detector / E-Perm / CR-39 / Egypt / Jordan / Kuwait / Libya / Syria / Tunisia / Yemen / AAEA

1. Introduction (Radon problem)

The presence of radon and its progeny resulting from the natural radioactive decay of ^{238}U in the environment contributes to more than 50% of the total effective dose received by the public (UNSCEAR, 2000). Due to the exhalation of radon from building materials, the soil underneath the buildings and the domestic use of water, radon is found in dwellings. Radon gas may escape into houses through openings such as cracks in concrete floor-wall joints, small pores in hollow-block walls, and

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through sumps and drains. Consequently, radon levels are usually higher in confined places, such as basements, cellars or other structural areas in contact with soil. Depending on the types of building materials, the geological location and the rate of ventilation inside the dwellings, the indoor radon concentration may reach unacceptably high levels.

The main health hazard associated with exposure to high radon levels is an increase in lung cancer risk (Holiday, 1969). This has been substantiated in many studies of uranium miners. Based on these studies, the International Agency for Research on Cancer (IARC), a WHO agency specializing in cancer, and the US National Toxicology Program have classified radon as a human carcinogen (Belson *et al*., 2007).

In view of the recognized potential health hazard of radon and its descendents α-emitters as the probable cause of lung cancer among miners (Holiday, 1969), measurements of radon concentration levels became of great concern to authorities, health organizations and scientists in the field of environmental radiation protection.

The correlation between the high levels of radon in the uranium mines and the lung cancer mortality of the miners motivated scientists to investigate whether the levels of radon found in dwellings and other places are a significant hazard to health. During the 1980s, a large number of surveys of indoor radon levels were carried out in many countries. These surveys range in type from small localized short-term screening surveys to national surveys in which long-term (yearly-average) indoor radon concentrations were determined in randomly chosen population-weighted representative samples of national housing stock, which is the recommended methodology (UNSCEAR, 1993). National surveys which approximate in character to this latter description were carried out in many European countries; the UK (Wrixon *et al*. 1988), Ireland (McLaughlin and Wasiolek, 1988), Italy (Bochicchio *et al*. 1994), Finland (Castren, 1994) and Sweden (Swedgemark and Mjones 1984), and non-European countries, *e.g.* the United States of America (Marcinowski, 1992) and Australia (Langroo *et al*. 1991). UNSCEAR reports (UNSCEAR, 1993 and 2000) give a summary of the principal results from a number of national and regional surveys carried out in EU Member States, other European countries, North America, Japan and Australia. It is important to note that radon concentration levels greater than 100,000 Bq m^{-3} have also been detected in individual dwellings in some countries (Huber *et al*., 2001).

Therefore, with reference to the above surveys and the possibility of elevated radon concentration levels in dwellings, one can emphasize the importance of carrying out indoor radon measurements within the region of the Arab countries. This called for a coordinated research program to carry out the radon survey in realization that indoor radon concentrations and exposures to radon depend on people's way of life (or lifestyles); weather or climatic pattern; building styles, etc. And for a region sharing part or all of these factors, *e.g.* the Arab countries, the result of a coordinated survey in this region is expected to provide some new understanding of the influence of these factors (building designs, habits, etc.) on indoor radon. It will therefore provide the scientific basis on which, *e.g.*, a regional-level action may be established. Hence, this is another impetus for embarking on this regional survey.

2. Initiating coordinated indoor radon surveys within the Arab countries

The Arab Atomic Energy Agency (AAEA) is a regulatory agency located in Tunis (Tunisia). Arab countries that are member states of the agency are: Jordan, Tunisia, Saudi Arabia, Sudan, Syria, Iraq, Palestine, Kuwait, Lebanon, Libya, Egypt, Yemen and Bahrain.

In view of the role of the IAEA in supporting member states in developing their scientific capabilities and deriving benefits from the peaceful applications of atomic energy, the AAEA adopted coordination research programs on specific research topics that are of mutual interest to participating member states, one of which is the radon measurements in dwellings. The primary aim of the Coordination Research Program (CRP) is to establish a database on indoor radon levels in the Arab countries and to find out if there are any anomalies in the concentrations that require remedial actions.

Each individual survey team (from each country) presents a progress report on the survey's activity annually in the coordination meeting organized by the AAEA agency. During the meetings, results of the indoor radon measurements were presented and discussed. Cross-calibration measurements were planned and other problems associated with the progress of the surveys were also discussed.

All the surveys on indoor radon levels within the framework of the CRP were carried out at no cost to the owners of the dwellings (provided by individual governmental agencies). Primarily, the project started by screening measurements in the capitals and regions where radon concentrations were expected to be high (in some counties of member states) due to geological structures or any industrial activities, such as phosphate mining or oil and gas industries. The distribution methods of the detectors were decided to be as follows: ten detectors in each 1 km^2 in the old part of the capitals and one to two detectors in each 1 km^2 in the rest of the measuring places. In addition, it was decided that during this project the measurements would be focused on the locations (or dwellings) where radon gas shows relatively high values such as occupied basements and ground floors.

3. Radon detectors used in the surveys

Solid-state nuclear track detectors (CR-39) were selected as the radon detectors for the coordinated surveys within the Arab countries for long-term measurements of indoor radon. The track detector was kept inside a dosimeter that was fitted with a paper filter so that equilibrium could be achieved between the radon and its daughters within the dosimeter. The dosimeters were calibrated using a radon chamber of a volume of about 600 liters available at the Atomic Energy Commission in Damascus, Syria. The calibration process was examined with another international laboratory and the calibration curves were produced for different exposure times (Shweikani and Raja, 2005). Other radon detectors such as charcoal detectors (Pico Rad vials) and E-Perm chambers were used for short-term measurements in Kuwait and Jordan.

4. Difficulties in getting homeowners' consent

The main reasons for the difficulties in presenting the project to homeowners and getting their consent are related to the very nature of radon, *i.e.*, it is a gas with no smell or color. People identify air pollution through smell and appearance in the atmosphere (as commonly observed and associated with industry and exhaust gas from vehicles) and assess the outdoor and indoor air quality based on that. The other main reason was with regard to the radioactivity of the radon gas, as the majority of the people only attribute radioactivity in air or in any environmental sample to the existence of nuclear facilities (or nuclear accidents). Since there are virtually no nuclear facilities in the region, the people are unaware, and therefore found it difficult to accept that the survey teams were genuinely seeking to measure radioactivity in their dwellings.

During the surveys, when homeowners were approached to cooperate in the survey of their dwellings, some of them wondered about the survey and others were reluctant to agree to the survey. In general, most people accepted the survey due to its scientific importance in understanding the pollution factors that affect the environment.

Unlike the collection of samples from an open environment such as soil, water or similar samples, the measurements to be taken inside individual dwellings will necessitate the investigators entering living quarters. Distribution of radon detectors in the dwellings will lead to interference with the habits of the people in some way. Generally, only female personnel were preferred for surveys that required entrance to a dwelling, particularly in bedrooms.

Some of the country-specific experiences are described below:

4.1. Kuwait

It is worth mentioning here that the "Depleted Uranium Issue in Kuwait" (Bem and Bou-Rabee, 2004) has created a severe concern for the public in Kuwait. Most people thought that the indoor radon survey was related to such an issue. Therefore, it was decided at the beginning to avoid asking the homeowners about any health problems or medical history, in order not to cause any concern. It was mentioned to the homeowners that the survey was about the indoor air quality, with some hints that extremely high levels of indoor radon may cause lung cancer.

The survey team made good efforts and used a low profile approach in contacting their own relatives and the people they knew in order to have their agreement to participate in the survey. The small size of the country allowed such a personal approach to be effective. The return after two days (2-day exposure) to collect the charcoal radon detectors allowed a smooth process for the sampling (distribution and collection) of the radon detectors.

4.2. Jordan

The survey in Jordan was carried out in the living rooms in three cities: Zarka, Irbed, and the capital Amman. The problems the survey team faced, during the distribution of the detectors (plastic detectors for long-term measurements and E-perm chambers for short-term measurements), were mainly due to the lack of awareness of most of the homeowners about radon. The survey team had to explain to them in detail about the aim of the survey and the expected results. Nevertheless, some of them refused to allow their houses to be investigated. This led us to rely on our colleagues from our center as well as relatives to help in cooperating in this respect.

Other problems were noticed after the collection of the radon detectors for analysis. Some of the results had to be canceled because the homeowners did not follow our instructions on the way to distribute the detectors. They hung the detectors directly on the walls, which gave results with high values. Therefore, repeated measurements had to be performed.

4.3. Syria

The main problem was convincing people to accept the placing of the detectors in their bedrooms. They thought that the radon detectors might contain cameras or recorders and transmission devices (Rahman *et al*., 2006). This problem was overcome by:

1) using detector chambers made of transparent materials to allow the people to see inside the chamber clearly, and
2) by assembling the chamber in front of the people (placing the track detector with glue inside the chamber), so that they could observe the whole detector assembly and knew what it consisted of.

In this way, it was possible to gain the acceptance of the people to place the detectors in their bedrooms. Nevertheless, some of the people kept asking to have the detectors placed in the living room instead.

Other problems arose due to security measures, which prevented the working teams (or anyone) from entering the dwelling without some sort of document or a permit from the local authorities. This type of problem was overcome by sending an official letter to the Ministry of the Interior, requesting their support. The Ministry of the Interior then issued a formal letter to all its regional representatives in the country to assist the working teams in their duties. Therefore, an official escorted the team for this purpose. This approach, relying on official support from the government, ensured that the homeowners felt safe and dealt with the team freely.

4.4. Egypt

Based on some of our previous studies of indoor radon measurements carried out in the past, mainly for the purpose of pilot and short-term investigations, we noticed that some misuse might be caused by children.

Therefore, our efforts concentrated on approaching homeowners whom we could rely on with emphasis on this issue.

4.5. Libya

Initially, people were not approached in a random manner during the survey. The first number of detectors was distributed through personal contact with eighty homeowners. Then it was thought that instead of providing information and convincing each individual to accept installation of the detectors in his home, it was wise to select workplaces where a large group of people could be gathered for an instructive lecture on radon. During the lecture, the methods of measurements were pointed out, namely, the tools to be used, and the required period of exposure; and it was emphasized how important their cooperation was and that these measurements could not be achieved without their help.

The work started at Tajoura Nuclear Research Center (TNRC). In this way, it was possible to obtain the cooperation of most people who attended the lecture and allowed random distribution of the detectors throughout the city of Tripoli, the capital of Libya. In other cities, teachers and students in high schools were successfully approached, thus achieving smooth distribution of radon detectors in their houses and handing back to the research team.

4.6. Tunisia

During the time of performing the survey in the countryside in southern Tunisia, it was explained to the house occupants that the survey was being carried out by the Department of the Environment in order to study some indoor factors that could affect human health. The terms “radioactivity” and “radiation” were not explicitly mentioned at this stage in order not to generate unnecessary fears and phobia, which these terms often elicit from the general public.

In spite of the people's lack of scientific awareness about this subject, the rate of loss of detectors was relatively low (13.5%). The loss of some dosimeters was because some of the owners forgot them due to the long-term exposure which lasted for about three months.

4.7. Yemen

Although the survey team encountered friendly collaboration from the homeowners, some of the homeowners thought that the installation of the radon detectors in their dwellings might cause some diseases, particularly cancer. We had to discuss the details of the survey with each homeowner individually to have their approval for the installation of the radon detector. Nevertheless, we noticed that some of the installed detectors were misused and we had to cancel them from our survey, and others were lost.

Therefore, the work requires public awareness to explain the importance of the survey and its value to understand some of the indoor environmental factors.

5. Results from the indoor surveys

This study is based on a number of surveys carried out simultaneously in some cities within the region of the Arab counties. A short summary of some of the results of the indoor radon surveys by the member states is presented in Table I. In general, the results from the various countries show low concentration levels. We believe that the low levels indicate the low concentration of the source in the soil underneath, in addition to the fact that most houses in the region are naturally ventilated due to the moderate weather in the region, which may have a direct effect on the indoor concentration levels.

It is useful here to discuss some points regarding the relatively high concentrations of indoor radon in some regions. High radon concentration levels were detected in some old dwellings in a region near a phosphate mine in southern Tunisia and in Yemen as a result of cracks and gaps in the floor and wall joints.

The presence of radon in water was found to elevate the radon concentration levels in the area surveyed in Egypt where some houses were built on an area where dumped water wells exist. In Libya, the relatively high level in the bathrooms in comparison with other rooms in houses as presented in Table I would require further studies to be conducted on the radon concentration levels in water.

The results from Syria provided different and interesting information about other factors causing some relative increase in indoor radon findings which were not related to the common expected causes such as the types of building materials used in the construction or other deformation in buildings such as cracks; instead, china dishes kept as decorations in an old household were found to contribute to increased indoor radon concentration levels. This was observed in two different types of houses, one in the old city of Damascus (185.6 Bq m^{-3}) and the second in an apartment on the third floor of a multi-storey building (199.7 Bq m^{-3}) in the modern part of Damascus. Gamma-ray spectrometry measurements carried out for some of the china dishes collected from these dwellings showed a higher concentration of ^{238}U (3 times more) compared with some other dishes used as control. Similar findings were reported elsewhere (Roylance, 1994). However, the radon concentration levels were back to average values (around 50 Bq m^{-3}) after advising the owners to increase the natural ventilation rate in the measured places.

The relative increase in the radon concentration levels in the basements in Kuwait were found to be as expected (relatively higher than other floors), for which a further study is planned to continue.

6. Discussion

Unlike the collection of water, soil or any other types of environmental samples, the sampling for the indoor radon measurements requires a visit to each individual dwelling to distribute the radon detectors and then another visit to collect them for analysis. Repeated visits might be required in other seasons. This type of work relies on the cooperation of the homeowners with the survey teams. Sharing of experience and coordination among the various survey teams in different countries helped in preparing the individuals to overcome typical difficulties associated with distribution and collection of radon detectors and to allow the survey to be carried out successfully.

TABLE I
Results of the indoor radon surveys.

Country	Radon Detectors	Number of measured Locations	Indoor Radon Concentration Average (Range) (Bq m^{-3})	Remarks	Reference
Kuwait	Charcoal (Pico Rad Vials) Duplicate set (two vials) was used in each location. The average mean was considered	255 Living Rooms 260 Bedrooms 86 Basements	29.4 (4.2–83.2) Living Rooms 31.3 (4.0–164.5) Bedrooms 47.4 (4.4–241.8) Basements	Measurements in basements are planned to continue due to relative increase within this location	Al-Azmi *et al.*, 2008
Jordan	E-Perm and Nuclear Track Detectors, CR39	150 Living Rooms in three cities.	Average values for the 3 stages 41.3 (Amman) 48 (Zarka) 41.1 (Irbid)	Measurements were carried out in summer. The concentration in Zarka city is expected to be high during winter (less ventilation) due to its proximity to a phosphate mine. Previous results show high values of 70-90 Bq m^{-3}.	
Syria	Nuclear Track Detectors, CR39, One to two detectors in each location.	A total number of measurements in about 70 places in Damascus. Detectors were placed mainly in bedrooms and living rooms. A few measurements were also made in other parts of the measuring places.	35 Bedrooms. 30 Living rooms. 43 Guest rooms. 37 kitchens. 38 bathrooms.	Relatively high concentration levels of radon were measured in two locations where some old houses were decorated with Chinese dishes containing uranium. A value of 185.6 Bq/m^3 in the old part of Damascus, and 199.7 Bq/m^3 in the modern part were reported. Both were reduced to around 50 Bq m^{-3} by applying natural ventilation.	Shweikani, 2008 Othman *et al.*, 1997
Egypt		4 Living Rooms 36 Bedrooms 26 Basements 5 Kitchens	64 Living Rooms 67 Bedrooms 204 Basements 82 Kitchens	Houses built on areas of dumped water wells.	
Libya		73 Living Rooms 70 Bedrooms 66 Kitchens 59 Bathrooms	44.0 ± 6.0 (1–97.9) Living Rooms 45.8 ± 5.5 (9–174) Bedrooms 48.4 ± 5.6 (6–147) Kitchens 58.7 ± 6.3 (11–144) Bathrooms	The slight increase in radon levels in bathrooms were expected due to the use of well water. Measurements of radon in water are in progress.	

TABLE 1

Continued.

Country	Radon Detectors	Number of measured Locations	Indoor Radon Concentration Average (Range) Bq m^{-3}	Remarks	Reference
Tunisia		171 Living Rooms 171 Bedrooms	77.1 (21.2–368.5) Living Rooms 76.6 (35.8–282.3) Bedrooms	The high concentration level of radon of about 368.5 Bq m^{-3} was in an old house near to a mine industry area related to phosphate in the region of Moularés and Gafsa in southern Tunisia.	
Yemen		(Northern part of old city of Sana'a) 43 Living rooms 52 Bedrooms	45 (Living rooms) 50 (Bedrooms)	In the northern part of the old city of Sana'a, the highest concentration level of radon (890 Bq m^{-3}) was in an old house, in a bedroom in the ground floor without windows, and could be due to cracks in the floor-wall joints and gaps in the floor.	Al-Saeedi, 2009

Visits to dwellings required appointments with the homeowners. Such appointments were time-restricted in the case of using short-term measurements with charcoal detectors. Whereas, using nuclear track detectors for long-term measurements was more convenient because it allowed some flexibility in time without an effect on the readout. Ideally, one could avoid all the above-mentioned troubles associated with the distribution and collection of detectors if the detectors could be delivered to the homeowners by post. Such an alternative way would require public awareness about radon and the health risk associated with its existence as a component of indoor air. Most individuals or groups of people who were informed about radon gas, the nature of this survey and the importance of their cooperation, had never heard of radon or its effects on health. This is because of the lack of public information through the educational sector or the press and TV channels. Most disturbing to some of the people was when the survey teams talked about the nature of the health hazard because it is difficult to correlate the risk of lung cancer with radon exposure, especially when they have never heard of any case of a lung cancer patient due to radon exposure. In general, although the team intruding into their privacy was not appreciated, there was no mistrust and the scientific nature of the work was highly respected by all individuals. However, similar experience in other countries has been reported; for example, in Pakistan many of the homeowners who were approached to have their homes measured for radon were reluctant to allow the installation of the CR-39 dosimeters in their

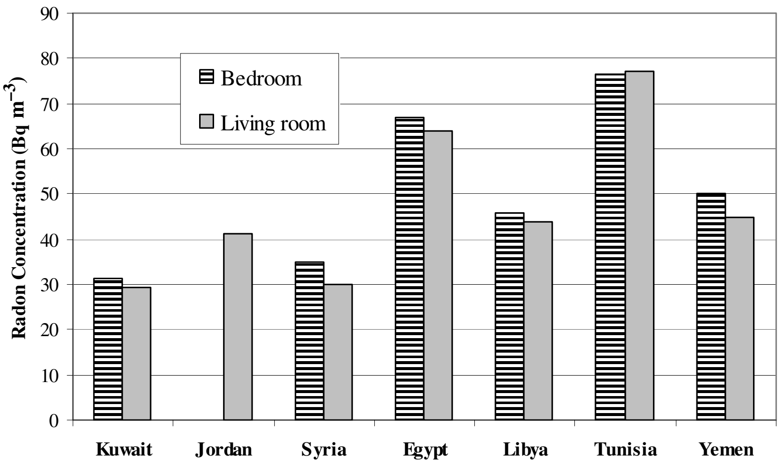

Figure 1 – Average radon concentration in some of the participating countries. Results for Jordan are for the capital city Amman (see Table I for additional data).

dwellings. They thought the dosimeters could be some type of spying equipment such as cameras. Most of the homeowners refused to participate in the survey as if their privacy would be at stake (Rahman *et al.*, 2006).

From all the results obtained from this coordinated project, it was easy to notice that indoor radon concentration varies from country to country, and the geological structure underneath and the construction design of the building contribute significantly to radon results. However, some high values were obtained during these screenings, which were mainly due either to the inhabitants' habits or to the design and structure of the measured place. The seasonal effect on the radon concentrations in houses was investigated in Kuwait (Al-Azmi *et al.*, 2008) and Libya and no significant effects were found. It is believed that the moderate climate in both countries, which allows natural ventilation of the houses, contributes to the non-significant effect of seasons on the indoor levels of radon in the area. Figure 1 shows the variation of radon in bedrooms and living rooms in the participating countries. It is quite clear that in hot countries (such as Kuwait and Libya) in which the use of air-conditioners as well as fresh-air ventilation are common, radon concentrations were quite comparable in those countries. Whereas in countries such as Syria, Jordan, Egypt and Tunisia where closing windows is essential to keep in heat in the cold seasons, the radon levels are relatively higher. In addition, there was almost no significant difference between radon in bedrooms and living rooms in all reported results. This is consistent with the fact that natural ventilation all year long in most Arab countries is a common practice.

7. Conclusion

The scientific literature is rich in publications dealing with inter-comparisons of radon measurements and calibrations among a number of collaborating laboratories worldwide, discussing the technical problems and limitations in their work and progress in order to obtain more accurate results. However, the work presented here deals with an important fundamental issue; namely, the distribution and collection of the radon detectors for which the personnel team need to make visits to living quarters.

The present work provides varied experiences of survey teams from different countries within a geographical region on how to cope with the situation when dealing with the distribution and collection of samples related to radioactivity. Such a situation requires not only home visits but there is also a need to convince the homeowners about the importance of the survey, as well as to avoid disturbing the public. The coordination among the member states of the AAEA allowed the chance to have an in-depth program for the measurements of the indoor radon in Arab cities. The organized annual meetings allowed an exchange of experiences to overcome the survey problems, further improve the measurement techniques and allow cross-comparison and discussion.

The indoor radon results obtained under these surveys show that the radon levels in the Arab countries are considered low. This is most likely due to the moderate climate conditions in the region. Such observed low indoor concentration levels do not cause concern about possible health hazards. However, additional surveys need to be carried out in old cities, phosphate areas, mountainous regions and workplaces.

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