Radon Concentration in the Work Atmosphere of Cement Plants in the Sulaymaniyah Area, Iraq

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***Abstract*–This work reports the radon concentration level in the work environment of cement plants (CPs) located in the Sulaymaniyah city-North of Iraq. This survey for the radon concentration is performed in 24 sectors of three different CPs including Tasluja, Mass, and Bazian. The measurements were recorded using solid state nuclear track detector (CR-39 NTDs). The radon effective dose µSv/hr correlated weakly with the gamma effective dose µSv/hr to enhance the radon concentration measuring. The detector was fixed in different places of the plants such Crusher, Correction stores, Raw Mill (Grinding Mill), Preheater (Tower), Clinker, and Cement Storage. The arithmetic mean (AM) value of radon concentration (C_a) was found to be 98 ± 9, 101 ± 10, and 125 ± 10 Bq m^{-3} and the arithmetic mean value of annual effective dose (E) of radon was 0.767, 0.753, and 0.962 mSv y^{-1} for Tasluja, Mass, and Bazian CPs, respectively. The maximum values of about 222 ± 20 Bq m^{-3} and 1.402 mSv y^{-1}, respectively, in sector III (Grinding) at Bazian CP. The achieved results reveal that the maximum value of radon concentration in all sectors of the CPs is below the international standard value (300 Bq m^{-3}) of both the World Health Organization and International Commission on Radiological Protection.**

***Index Terms*–Annual effective dose, cement plants, CR-39 detector, Radon concentration.**

I. Introduction

Radon is an odorless noble natural radioactive gas directly produced by ^{226}Ra decay in the natural uranium series chain (^{238}U) which is distributed everywhere in the earth's crust. Its half-life (3.82 days) is long enough to permit the gas diffusion in the soil or groundwater and the successive transfer to the atmosphere or, through cracks or penetrations in the building foundations, into houses (Ciolini and Mazed, 2010). The level of radon in the air varies widely according to the geological nature of the ground, with low levels in areas of basalt and high levels in granite-rich areas (Bajwa and Virk, 1997). Radon is a primary radiation source, in which exposure risk duplicates in public places, workplaces, closed area, and underground places. In recent years, there has been an increased awareness of the exposure of radon and thoron in workplaces other than mines (IAEA, 2011). Many workplaces are often located above the ground, such as offices, schools, old bazaar, and factories. Recently, the normal limit of indoor radon concentration determined by International Commission on Radiological Protection (ICRP) to be 200 Bq m^{-3}, and ICRP recommended the maximum level of indoor radon concentration of 300 Bq m^{-3} in dwelling and workplace (ICRP, 2012; Lecomte, et al., 2014). In addition, the World Health Organization proposed a reference level of 100 Bq m^{-3} to minimize the health hazards of indoor exposure due to ^{222}Rn. They stated that "if this level cannot be reached under the prevailing country-specific conditions, the chosen reference level should not be exceeded than 300 Bq m^{-3}" (Kathleen, et al., 2009; Bochicchio, 2014).

^{222}Rn and ^{220}Rn get into the atmosphere mainly by crossing the ground-air or building material-air interfaces. Concentrations of ^{222}Rn and ^{220}Rn in soil and building materials are found to be up to 1E+04 times higher than in the atmosphere (Gurau, et al., 2014). Previous studies reported that the risk of stomach cancer increased among the workers of some Korean cement industry due to the dust exposure (dust carried radon) (Koh, et al., 2013). The direct exposure of workers to cement dust in the construction industry and the cement manufacturing industry is expected. This is due to the inhalation of short-lived decay productions of ^{222}Rn and ^{220}Rn (thoron) from the atmosphere and their subsequent deposit along the walls of the various airways of the bronchial tree. Radon emanates by two ways; first come from the walls and ceiling and the other from the raw materials (UNSCEAR, 2000). Therefore, it is the role of researchers and associations of environmental radioactivity in all countries to provide sufficient information to the workers in cement plant (CP) and construction industry to reduce the risk of cancer. On the other hand, cement is a crucial, economical, and high-quality construction material used in construction projects worldwide. Knowledge about the physics and chemistry of cement products is important since they are directly related to the people's life. Portland cement is the most prevalent one among other types of cement. The natural radionuclide in raw and processed materials can vary considerably depending on their

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geological source and geochemical characteristics (El-Taher, et al., 2010). The essential constituents of cements such as lime, silica, and alumina are derived from the earth's crust in which radioactive elements such as uranium and thorium are also present in varying amounts almost everywhere (Nain, 2006).

In this work, passive detection technique (CR-39 detector) was used for recording radon concentration. CR-39 detector offers several advantages over alternative charged particle detectors. It is resistant to electromagnetic radiation, especially X-rays. CR-39 detector is mainly used in the field of health physics (Jain, et al., 2013). Many studies have been performed on a local scale with passive detectors to determine the radon concentration value in homes and workplaces. According to Alsaedi, et al. (2013) recent study, the CR-39 detectors can be used successfully to measure the radon concentration in cement products of Iraq cement companies. They observed that the radon concentration values vary from 18 to 178 Bq m^{-3} and the highest radon exhalation rates were found in Bazian CP - Sulaymaniyah, Iraq. In general, raw materials used in Bazian and Tasluja regions for cement production are naturally more radioactive than other CPs. Moreover, a lot of information about the radioactivity of cement has been recorded in worldwide studies. The cement radioactivity in each sector of cement processing was studied by Turhan, 2008 in which he added one inorganic material such as blast furnace slag, natural pozzolanas (trass), silica fume, fly ash, burnt shale (schist), and limestone. The above fact encouraged us to assess the radon level in the mentioned CPs and to focus on the radon exposure to workers directly in each sector of cement processing. The main objective of the present work is to record the radon concentration in different sectors of CPs established in Sulaymaniyah city - Iraq, using the CR-39 technique. CP sectors are divided into two main categories, some of them are close storage and the other is open. Hence, the indoor and outdoor radiations were measured in the present work. The results of this work can identify the radon concentration level inhaled by workers in each operating sector of the CPs can be identified. In addition, the total effective dose was measured directly by a portable dosimeter (UltraRadiac - Canberra, model - MRAD111), at least to determine the terrestrial radium concentration which acts as a main source (parent) of the measured radon.

II. Materials and Methods

A. Studied area description

Experimental measurements were carried out in Tasluja, Mass, and Bazian CPs located 30–40 km west and south-west of Sulaymaniyah city. The area is characterized by the most suitable geological formation for cement production. Capacity of Tasluja, Mass, and Bazian CPs are about 2.3, 6.0, and 2.5 million t/annum, respectively. The CPs provide different types of cement (CEM I 42.5 R-OPC, high sulfate resistance-HSR, Al-Gesr, and CEM II/A-L 42.5 R) for many Iraqi and Kurdistan cities (Holcim, 2016; Mass Group Holding, 2016). In general, this area characterizes as a dense industrial zone. Each CP contains varies sectors, CR-39 chambers were hanged in open position of some of sectors but the other were hang in closed area such as (I) crusher is closed area, (II) proportioning equipment is closed area (correction storage for adding sand, iron, and gypsum), (III) grinding mill is closed area, (IV) preheater tower is open area, (V) clinker is open area, (VI) clinker cooler is open area, (VII) cement storage is closed area, and the last one is (VIII) background is open area as are shown in Fig. 1. Some of these sectors are big closed storage for raw and mixed material.

B. Experimental Method

In this work, the radon concentrations were measured in all sectors of the above mentioned CPs. For this purpose, the survey was performed from May to August 2016. Sufficient pieces of CR-39 (made by Track Analysis System Ltd., Bristol, United Kingdom) detectors are calibrated using standard alpha emitter source (^{241}Am). The detail of this procedure can be seen elsewhere (Abu-Jarad, 1988). The dimensions of CR-39 pieces were 1 × 1.5 cm^2 and placed in the upper part of a chamber. The alpha particles emitted in the radon decay inside the chamber leave tracks in the CR-39 detector. These dosimeter chambers were fixed at the height of 165 cm in each sector for the sake of simulating worker radon inhalation, especially at the location where workers have done their responsibility. A total of 24 dosimeters were suspended on the walls of each sector as shown in Fig. 2a and b.

After 90 days of exposure, the suspended dosimeters were collected and the track density recorded based on the method mentioned in Abdulla, 2013. The radon concentration is estimated from the following equation:

$$\rho = K \times C_a \times T, \tag{1}$$

where, ρ is track density (Tr/cm^2), K is calibration factor, C_a is ^{222}Rn concentration in airspace inside the dosimeter chamber which is measured by Bq m^{-3}, and T offers exposure time which that is 90 days in the present work. The K value is calculated for the cylindrical chamber as shown in Fig. 2, its value equal to 0.0582, $\frac{\mathrm{Tr\,cm^{-2}\,hr^{-1}}}{\mathrm{Bq\,m^{-3}}}$ which based on the method mentioned in Abdulla, 2013; Barillon, et al., 1993.

The ^{222}Rn emanate from the raw materials and its dose exposed to the workers in each sector of the CPs. The famous criteria for measuring radon risk are an annual effective dose (E in mSv y^{-1}) due to the inhalation of the decay products of ^{222}Rn as reported in UNSCEAR, 2000, which is given by:

$$E = C_a \times F \times H \times T \times D \tag{2}$$

Where, C_a is the ^{222}Rn concentration in Bq m^{-3}, F is indoor an equilibrium factor (0.4) and outdoor one is (0.6), H is the outdoor occupancy factor (0.2), T is hours of working in a year (8766 hr y^{-1}), and D is the dose conversion factor (9.0 * 10^{-6} mSv hr^{-1}/Bq m^{-3}) (Al-Saleh, 2007; UNSCEAR, 2000). Furthermore, one can calculate the radon dose of lung and soft tissue as reported in ICRP-1993 (Protection, 1993).

III. Results and Discussions

In this work, the radon concentration (C_a) in Tasluja, Mass, and Bazian CPs was recorded by CR-39 detector. It is clear

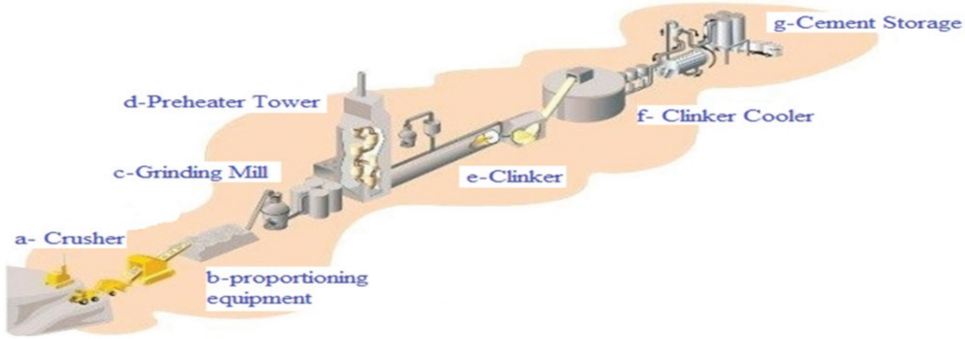

Fig. 1. Diagram of cement plant sectors of Lafarge association that established and reconstructed Bazian and Tasluja cement plants (CPs). The mass CP design is near to the other two plants (Holcim, 2016).

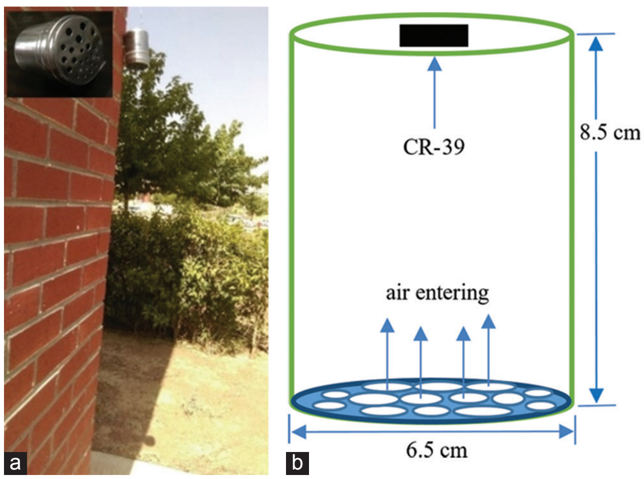

Fig. 2. Pinholes dosimeter containing CR-39 detector; (a) Dosimeter *in situ* (background) location and (b) diagram of the dosimeter.

from Table 1 that the AM values of C_a are 98, 101, and 125 Bq m^{-3}, for Tasluja, Mass, and Bazian CPs, respectively. Fig. 3 presents the frequency distribution of the radon concentration (Bq m^{-3}) in all sectors of the three CPs. Almost all the sectors aggregate in the range of the full width half maximum range, except of sector III of Bazian CP which deviates from the other. Most of the radon concentrations presented in Fig. 3 lay between 80 and 130 Bq m^{-3}. The details of the results are presented in Table 1. The AM value of radon concentration in Bazian CP is 125 Bq m^{-3} which is the highest radon concentration values recorded in all Iraqi CPs (Alsaedi, 2013). The high value of track density in cement of the Bazian CP is an evidence for the existence of high radon concentration compared to Mass and Tasluja CPs. The maximum value (222 Bq m^{-3}) of radon concentration was recorded in sector III of Bazian CP compare to the other sectors as shown in Fig. 4. This is related to the fact that the radon emanated from the soil and limestone slit come from the quarry (the mountain that is surrounding the CPs) to the crusher (first sector) and then transferred from one sector to another.

Many of CPs in Sulaymaniyah city were built near to the mountains; thus, a high radionuclides background is expected. Another main factor is the variation in soil used by CPs. Bazian and Tasluja CPs depend on the soil quarry located in the western field side of the Bazian plant. The soil is derived from weathered part of Gercus and Pilaspi formations from the adjacent surrounded high elevated area. Whereas, the Mass CP depends on the Fatha “Lower Fars” formation where the depositional environment is totally different and its enriched with sulfate mineral (Lawa, 2004). These results suggest that the CPs need to be established far away from the mountains. Obviously, this will be more cost-effective, but it will provide a healthier environment for the workers. It is clear from Table 1 that only two sectors (II and III) of Tasluja CP have radon concentrations above 100 Bq m^{-3}. Regarding the Mass CP, the high radon concentration (above 100 Bq m^{-3}) can be noted in sectors III and V. Unfortunately, five sectors of Bazian CP exhibit the existence of high radon concentration.

Another important radiological parameter is the radon annual effective dose E (mSv y^{-1}). It was calculated from Eq. 2 and tabulated in Table 1. The AM values of E (mSv y^{-1}) in all sectors of the CPs were less than the worldwide value 1.15 mSv y^{-1} as reported by UNSCEAR-2008 (UNSCEAR, 2008), except the sector III and IV of Bazian CP. The maximum values of E (mSv y^{-1}) were recorded by the sector III in each mentioned CPs.

Furthermore, the total effective dose was measured directly to enhance the passive radon measuring by CR-39. The direct total effective dose recorded in each sector of the three CPs using the UltraRadiac dosimeter with efficiency 30%. Table 2summarizes that the total effective dose rate ranged from 0.138 to 0.229 mSv hr^{-1} of Tasluja CP, in Mass CP ranged from 0.100 to 0.217 mSv hr^{-1}, and in Bazian CP ranged from 0.165 to 0.67 mSv hr^{-1}.

From Table II, it can be seen that the anomalies of total effective dose recorded in sector II of Bazian CP (correction storage for adding sand, iron, and gypsum) were 0.670 mSv hr^{-1}, which is 4 times larger than the other sectors. This can be attributed to the addition of iron and gypsum to the crushing raw materials.

In Table II and Fig. 5, it can be observed that the correlation between radon and total effective dose is low and it is about 0.085 plus a constant which is about 0.157. These factors are specified by this radon survey. The constant refers to the participation of other gamma

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TABLE I

Track Density, Dadon Concentrations (Ca), and Annual Effective Dose (E) for Different Sectors of Tasluja, Mass, and Bazian CPs

Sectors	Tasluja CP			Mass CP			Bazian CP		
	Track density	C_a (Bq m^{-3})	E (mSv y^{-1})	Track density	C_a (Bq m^{-3})	E (mSv y^{-1})	Track density	C_a (Bq m^{-3})	E (mSv y^{-1})
I	471.6	89±9	0.568	503.04	95±9	0.606	679.10	129±11	0.818
II	538.97	102±10	0.649	503.04	95±9	0.606	729.40	139±12	0.878
III	660.24	125±12	0.795	848.88	161±15	1.022	1164.4	222±20	1.402
IV	503.04	95±9	0.909	519.44	99±9	0.938	723.12	137±12	1.306
V	471.6	89±9	0.852	538.97	102±10	0.973	603.51	115±10	1.090
VI	471.6	89±9.	0.852	440.16	83±8	0.795	440.16	83±7	0.795
VII	503.04	95±9	0.606	419.16	79±7	0.505	411.97	78±7	0.496
VIII	503.04	95±9	0.909	465.97	88±6	0.580	503.04	95±8	0.909
AM±ε		98±9	0.767		101±10	0.753		125±10	0.962
Max.		125±12	0.909		161±15	1.022		222±20	1.402
Min.		89±9	0.568		79±7	0.505		78±7	0.496

CP: Cement plant

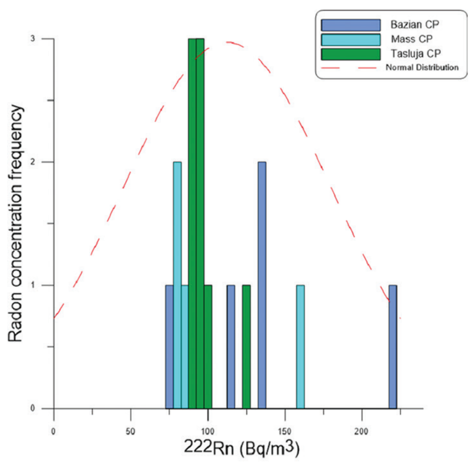

Fig. 3. Frequency distribution of the radon concentration in Bq m^{-3} for all sectors of the three cement plants

sources such as natural radionuclide ^{40}K and some isotopes out of natural series (^{238}U and ^{232}Th); Al, Fe, Mn, Cd, Co, Cr, Cu, Ni, Pb, V, and Zn (Al-Dadi, et al., 2014) due to the material mixing in sectors II, III, IV, and V. The unexpected result in this study is that the radon concentration value of the sector VIII (manager office) was close to the mean value in each cement factory, the researcher regarded the sector VIII as background level for all other sectors which recorded in Table II. Moreover, it is far 200 m from the other sectors.

IV. Conclusions

The concentrations of radon in various sectors of Tasluja, Mass, and Bazian CPs have been measured directly; using a CR-39 detector and the radon annual effective doses E (mSv y^{-1}) have been calculated. In this work, the measured radon concentration and its annual effective dose E in all sectors of Bazian CP were significantly higher than Mass and Tasluja CPs. These high recorded values in some sectors of the Bazian CP can be hazardous and increase the risk of cancer in the future. The finding of this study indicates that the highest value of radon concentration and annual effective dose E was recorded in grinding mill sectors (III). This can be ascribed to the radon emanation and the natural radionuclei emission ratio as a result of material mixing and resizing process. The data obtained show that the radon concentration is high in the closed sectors such as crusher sector I, proportioning equipment sector II, and the grind mill sector III in all plants compared to open sectors. Our suggestion is that workers in the grinding mill sector must have more permission hours compared to the other sectors. In addition, the ventilation process must be improved in the entire closed sector for all CPs.

A novel finding of the present study was that radon concentration level of manager office was found to be dependent on radon concentration mean value of all other sectors of the CP. Many European and North American countries established the radon reduction program. This program should include radon reduction, especially from the plants that have fly ash and dust such as CP. It is crucial to keep the work environment safe for the workers. Therefore, all sectors in CPs should installed radon monitoring system to detect the limit of radon concentration. Moreover, the anomalies of total effective dose recorded in sector II of Bazian CP make the researchers pay attention to assess the total dose in storage sectors of the CPs in the future work. In general, the researchers suggest that the quality control agency elsewhere should focus on the materials storage. Total effective dose correlates weakly with radon one linearly plus a constant. The constant could be useful in the interpretation of future radon surveys in the Bazian area.

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TABLE II
Total and Radon Effective Dose Rate (mSv hr−1) in the Tasluja, Mass, and Bazian CPs Sectors

Sectors	Tasluja CP		Mass CP		Bazian CP	
	Total effective dose	Radon effective dose	Total effective dose	Radon effective dose	Total effective dose	Radon effective dose
I	0.153	0.324	0.137	0.346	0.210	0.466
II	0.172	0.370	0.162	0.346	0.670	0.501
III	0.143	0.453	0.185	0.583	0.200	0.800
IV	0.172	0.518	0.171	0.535	0.195	0.745
V	0.138	0.486	0.182	0.555	0.181	0.622
VI	0.229	0.486	0.182	0.453	0.165	0.453
VII	0.228	0.346	0.100	0.288	0.210	0.283
VIII	0.150	0.518	0.217	0.331	0.180	0.518
AM	0.173	0.438	0.167	0.430	0.251	0.549
Max	0.229	0.518	0.217	0.583	0.670	0.800
Min	0.138	0.324	0.100	0.288	0.165	0.283

CP: Cement plant

Fig. 4. (a-c) Landscape map of the investigated area to define radon concentration level of the sectors. (a) Tasluja cement plant (CP), (b) Mass CP, (c) Bazian CP.

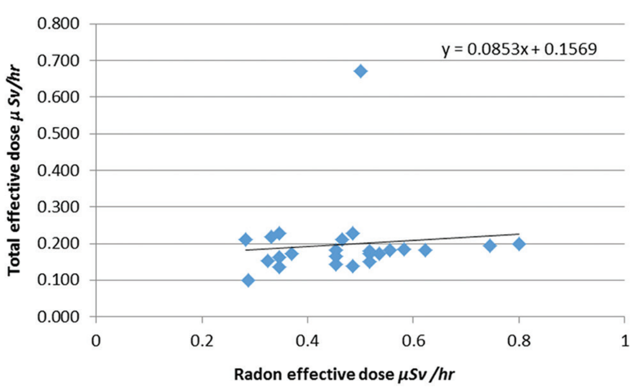

Fig. 5. Total and radon effective dose rate (mSv hr^{-1}) relation in all sectors of the Tasluja, Mass, and Bazian cement plants.

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