

Estimation of indoor radiological hazard on worker and public health in atomic energy centre Dhaka campus, Bangladesh

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ABSTRACT

Introduction: Radiation gives tremendous benefit to mankind but unnecessary radiation may pose harm to worker and public. The purpose of the study is to continuous indoor radiation monitoring of Atomic Energy Centre Dhaka (AECD) campus to minimize the radiological risk on worker and public health in and around the campus.

Materials and methods: Continuous indoor radiation monitoring was conducted in the AECD campus from November 2018-April 2019 using the Thermoluminescent dosimeters. The excess life-time cancer risk on worker and public health were estimated based on the continuous indoor radiation monitoring data.

Results: The annual effective doses to the worker and public from indoor radiation were ranged from 0.28 ± 0.11 mSv to 0.67 ± 0.25 mSv and the mean was found to be 0.43 ± 0.10 mSv. The excess life-time cancer risk (ELCR) on the radiation worker & public health were estimated based on the annual effective dose and ranged from 1.13×10^{-3} to 2.65×10^{-3} with an average of 1.72×10^{-3} . The average annual effective dose and ELCR on worker and public health were lower than those of the worldwide average values.

Conclusion: The radiological hazard on worker and public health in and around the AECD campus is not significant because those values are lower than the recommended values of the international commission on radiological protection. Monitoring of these indoor places would help in keeping a record of safe working practices during the handling of the radioactive substances and radiation generating equipments in a radiological facility.

Introduction

Atomic Energy Centre Dhaka (AECD) is a radiological facility which has one radioactive wastes storage room and different types of radioactive material and radiation generating equipments are being used for service, training and research and development (R&D) purposes. Two largest hospitals (Bangabandhu Sheikh Mujib Medical Uni-

versity and Dhaka Medical College Hospital) of Bangladesh are situated around the AECD campus, where various kinds of radioactive material and radiation generating equipments are being used for diagnostic and therapeutic purposes to patients. Human being is exposing natural and man-made radioactive sources. Human being is getting radiation exposure from man-made source-

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es, such as nuclear and radiological facilities. Continuous radiation monitoring at the indoor and outdoor environments of the radiological facility like AECD is very important for the detection of unnecessary radiation exposure to worker and public arise from the man-made radioactive substances as well as radiation generating equipments. Through the radiation monitoring, the effective radiation dose to the radiation worker and public in and around of the radiological facility can be minimized which ensure the safety of radiation worker and public as well as the environment. Gamma radiation has enough energy to ionize the atoms of a material because it is the most energetic radiation in the electromagnetic spectrum that is 10,000 times higher than that of visible light [1, 2]. Gamma radiation contributes to the most of the public exposure that emitting from the naturally occurring radioisotopes. The main naturally occurring radioisotopes are the primordial radionuclides, namely ^{238}U and ^{232}Th and their decay products and ^{40}K which exists at trace level in all earth formation. The greater part of public exposure to ionizing radiation contributes from the naturally occurring radioisotopes, including cosmic rays and terrestrial radiation [3]. Public exposure from the terrestrial gamma radiation depends mainly on geological features of the location, e.g., altitude, latitude and planetary movement [4, 5]. Normally, public radiation exposure at indoor places is higher than those of the outdoor radiation exposure because of the construction materials of the buildings. In fact, building materials namely concrete, brick, sand, aggregate, marble, granite, limestone, gypsum, rod, etc., contain mostly naturally occurring primordial radioisotopes including ^{238}U and ^{232}Th and their decay products and the ^{40}K . The understanding of the natural radionuclides of the building materials is essential in order to estimate the public exposure to radiation because the majority of the people spend approximately 80% of their time at indoor place and the remaining 20% of their time at outdoor place [5-8]. Gamma radiation contributes to the greater part of the external public radiation exposures from all the ionizing

radiation sources because of its greater penetration capability [9]. Gamma radiation exists everywhere. High differences have been observed for radiation dose rates in the environment and a number of international studies have been reported the gamma dose rates at the outdoor and the indoor environments [10-18].

The existence of the naturally occurring radioisotopes in the environment may contribute an external and internal radiation effective dose to the public exposing directly or indirectly (through the ingestion and inhalation pathways). Evaluation of the annual effective dose from the indoor gamma radiation of a radiological facility is needed, because it is related to the probability of getting cancer of radiation worker and public from the low-level ionizing radiation. The estimation of the radiological hazard on worker and public health resulting from the radiation released by the natural and man-made radionuclides is crucial because those contribute to the collective dose of the public [19]. AECD usage different type of radioactive substances and radiation generating equipments for the peaceful applications including high activity industrial radiography source (Ir-192) for non-destructive testing, Co-60, Cs-137 etc. for research, education and training and service purposes, Ra-226, Co-60, Cs-137, etc. in the radioactive waste storage rooms. The objective of the study is to estimate the radiological hazard on worker and public health based on the radiation monitoring data from the radiological facility.

Materials and methods

Thermoluminescent dosimeter (TLD)

The material of the thermoluminescent dosimeter (TLD) is LiF:Mg,Ti (TLD-100) which has the effective atomic number of 8.2, almost equivalent to that of the soft tissue of a human body. TLD chip 3 mm (1/8 inch) square put between two sheets of Teflon 0.003 inch (10 mg/cm²) thick and supported on an aluminum substrate. TLD card (two chips) put in a holder that protects the TLD card in the environment for long time.

TLD reader and read out of TLD card

The Harshaw manual TLD Reader (Model 4500) is very popular for measurement of the TLD card. The Harshaw manual TLD reader is widely used for several thermoluminescence (TL) materials in different compositions and dimensions [20]. The reader has two photomultiplier tube (PMT) in a sliding position for manual read out of the TLD card and TL chip for whole-body, extremity and environmental radiation monitoring. Two PMTs and connecting electronics facilitate it for reading out card in two positions at the same time. PMT forms of photocathode which has the capacity to change the incident light into amplified current which is proportional to the number of produced photons and consequently proportional to the absorbed dose. The TLD card is read out through the nitrogen gas heating system by Harshaw TLD reader (Model 4500). The nitrogen gas heating system provides a flow of hot nitrogen gas at accurately controlled, linearly increased temperature up to 300°C. The nitrogen gas heating to the TLD chip under close loop feedback and the advanced electronic system gives steady and repeatable glow curves. The Harshaw TLD reader is connected with a personal computer and is operated by WinREMS. The effective dose to public and radiation worker is evaluated through the WinREMS.

Calibration of TLD card

The TLD card was calibrated using the standard radiation sources at the Secondary Standard Dosimetry Laboratory (SSDL) of Bangladesh Atomic Energy Commission (BAEC). Different types of standard source, namely ^{137}Cs , ^{60}Co , etc. and X-ray Unit available at SSDL, BAEC. The SSDL, BAEC has been available since 1991 and it is traceable to the Primary Standard Dosimetry Laboratory (PSDL) of National Physical Laboratory (NPL), UK. The SSDL, BAEC has X-ray Unit (30 kV-225 kV) for radiation generating equipments and TLD card calibration. The accuracy of SSDL, BAEC is retained as per requirements of the International Atomic Energy Agency (IAEA)/World Health Organization (WHO) network of SSDLs. Hence, the estimated effective

dose is traceable to the international radiation monitoring system. Moreover, the TLD laboratory on a regular basis takes part at inter-laboratory radiation monitoring comparison program organized by the IAEA. In previous inter-comparison, satisfactory performance was acquired as per the standards trumpet curve criteria [21, 22].

The TLD card output after reading out by Harshaw TLD reader is the charges generated by electrons because of the annealing process.

The following equation is applied to change the output reading of TLD card from charge (nC) to absorbed dose (Gy):

$$\text{absorbed dose} = \frac{\text{equivalent dose}}{\text{quality factor}} \quad (1)$$

The time between irradiation and readout need to be the same to maintain the equal fading from one set of TLD cards calibration to those of another set. The calibration factor ($f_{\text{calibration}}$) is given below:

$$f_{\text{calibration}} = \frac{D_{\text{ionization chamber (mGy)}}}{\text{TLD}_{\text{reading (nC)}}} \quad (2)$$

Absorbed dose due to irradiation is found after subtracting background using the following equation:

$$D_{\text{TLD}} = D_{\text{av}} - BG \quad (3)$$

After that absorbed dose is calculated for each TLD card using the equation below:

$$D_{\text{TLD}} (\text{mGy}) = f_{\text{cal}} \left(\frac{\text{mGy}}{\text{nC}} \right) \times \text{TLD}_{\text{reading}} (\text{nC}) \quad (4)$$

Estimation of excess life-time cancer risk (ELCR) Effective dose is the mostly used parameter for the estimation of the radiation worker and public exposure and the probable biological effects related with public exposure, which is calculated as the equation below:

$$\text{AED} = (D_{\text{out}} \times OF_{\text{out}} + D_{\text{in}} \times OF_{\text{in}}) \times T \quad (5)$$

Where, AED is the annual effective dose, D_{in} and D_{out} are the average absorbed dose rates in air at

indoor and outdoor places respectively, T is the time in hour, OF_{in} and OF_{out} is the indoor and outdoor occupancy factor which is the fraction of time spent of an individual. The values OF_{in} and OF_{out} are 0.8 and 0.2, respectively.

The excess life-time cancer risk (ELCR) is estimated using the following equation:

$$ELCR = AED \times DL \times RF \quad (6)$$

Where AED is the annual effective dose to radiation worker and public, DL is the duration of life of Bangladeshi people [23] and RF is risk factor (Sv^{-1}), it is a fatal cancer risk per Sievert. For stochastic effects from low dose radiation, ICRP 103 suggested the value of 0.057 per Sievert for the public exposure [24].

Results and discussion

Annual effective dose

Taking into account the international reports [5, 25-29], considering that public in Bangladesh spends about 20% of their time outdoor and the remaining 80% of their time indoor, the annual effective dose to radiation worker and public in AECD campus was calculated. Table 1 shows the annual effective dose received by worker and public during the period of November 2018-April 2019. The annual effective dose to the worker and public from indoor radiation in AECD campus was ranged from $0.280.11 \pm mSv$ to $0.670.25 \pm mSv$ and the mean was found to be $0.430.10 \pm mSv$. The mean annual effective dose of the radiation worker and public due to indoor radiation in AECD campus is comparable to those of the worldwide average value of 0.48 mSv [24]. The mean annual effective doses were found to be higher at the indoor locations that are nearer to the radioactive waste storage rooms and high activity industrial radiography source room and ranged from $0.470.17 \pm mSv$ to $0.670.25 \pm mSv$ with an average of $0.540.07 \pm mSv$. Although the mean annual effective doses to worker and public at indoor locations nearer to the radioactive waste storage rooms and industrial radiography source

room were found to be slightly higher than those of the worldwide average value of 0.48 mSv, but those values are below the acceptable limit of 1 mSv for public [24]. Furthermore, the acceptable limit for public (1 mSv/y) is to be considered from planned exposure situation and is not considered from the existing exposure situation. The lowest annual effective dose to radiation worker and public was observed at indoor location far from the radioactive waste storage rooms and industrial radiography source room which is $0.280.11 \pm mSv$.

Fig. 1 shows the indoor mean annual effective dose values normalized to the minimum annual effective dose value for each location. It is observed from Fig. 1 that mean annual effective dose for two locations (location number 3 and 6) are relatively higher than those of the other locations. The reason is that location number 3 and 6 are the nearest to the radioactive waste storage rooms and industrial radiography source room.

Fig. 2 shows the background dose rate ($\mu Sv/month$) at indoor locations of AECD campus contributes mainly from the construction materials of the building, natural radionuclides containing in soil and possible small amount of man-made sources (if any). The variation of the monthly background dose rate at indoor locations in AECD campus was found due to the weather conditions. From Fig. 2, it is observed that the indoor background dose rate ($\mu Sv/month$) in winter was higher than those in spring (March-April). It is found in the international literature [30], that the outdoor background gamma absorbed dose rate in spring and autumn are higher than those of other seasons. From Fig. 2, it can be seen that the late autumn (November-December) indoor absorbed dose rate is the highest which is consistent with the outdoor gamma absorbed dose rate [30], but inconsistent in case of indoor gamma absorbed dose rate for spring (March-April). Addition to radon gas near ground level at outdoor during the winter and spring seasons contribute to more gamma absorbed dose rate during the winter and spring seasons. On the other hand, in rainy season, the radon exhalation rate from soil

Table 1. Continuous indoor radiation monitoring at AECD campus in Dhaka city from November 2018-April 2019

Sl.No.	Dosimeter ID	Gamma dose rate ($\mu\text{Sv}/\text{month}$)			Annual effective dose due to gamma radiation (mSv) \pm SD
		Range	Mean	SD	
1.	16215	175.90-406.60	297.74	87.62	0.51 \pm 0.15
	16209	163.20-460.00	299.64	123.62	0.51 \pm 0.21
3.	16210	152.70-555.00	392.84	148.70	0.67 \pm 0.25
4.	16220	166.80-442.50	310.50	128.82	0.53 \pm 0.22
5.	16214	185.00-438.00	306.66	119.23	0.52 \pm 0.20
6.	16203	176.50-528.90	357.86	148.58	0.61 \pm 0.25
7.	16202	164.90-391.60	293.82	94.43	0.50 \pm 0.16
8.	16208	152.00-382.00	274.66	98.02	0.47 \pm 0.17
9.	16205	146.80-332.70	243.78	67.52	0.41 \pm 0.11
10.	16207	136.00-307.40	240.02	79.05	0.41 \pm 0.13
11.	16206	146.00-317.50	238.98	69.51	0.40 \pm 0.12
12.	16213	137.80-353.90	249.76	84.59	0.42 \pm 0.14
13.	16216	134.80-512.90	268.30	159.85	0.39 \pm 0.27
14.	16204	164.80-532.90	317.20	144.12	0.38 \pm 0.24
15.	16217	147.10-486.10	282.48	134.29	0.36 \pm 0.23
16.	16218	171.30-443.70	325.66	115.03	0.35 \pm 0.19
17.	16211	153.40-331.30	246.92	76.63	0.33 \pm 0.13
18.	16219	182.40-529.80	313.34	133.72	0.32 \pm 0.23
19.	16212	152.80-584.00	347.46	192.63	0.30 \pm 0.33
20.	16201	164.70-505.40	329.84	154.51	0.28 \pm 0.11

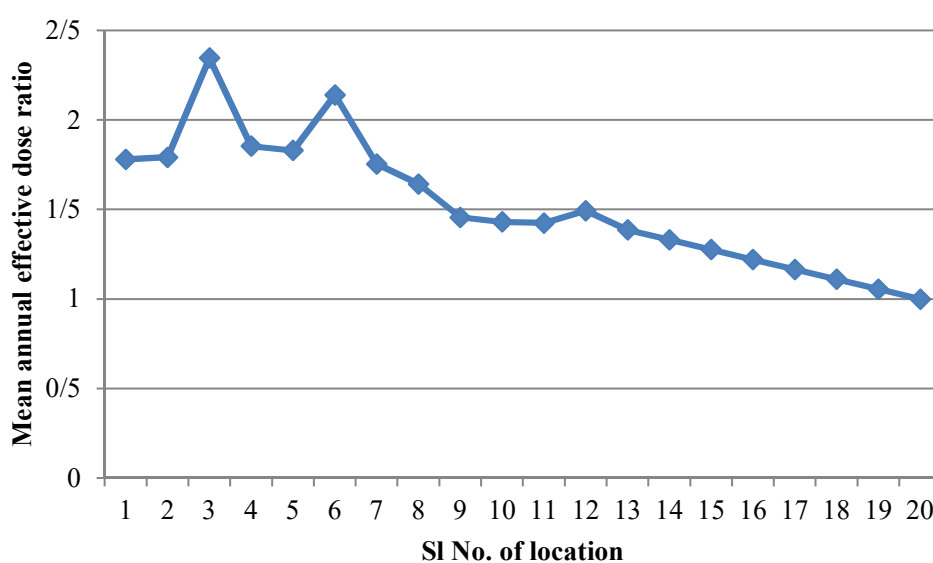


Fig. 1. Indoor mean annual effective dose values normalized to the minimum annual effective dose for each location

surface is decreased due to the filling up of pore spaces in the soil. In addition to that, in rainy season radon and its daughter products will be rinsed directing to reduce of its concentration in the

lower atmosphere [31, 32].

The frequency distribution of the indoor gamma absorbed dose rates at AECD campus is shown in Fig. 2.

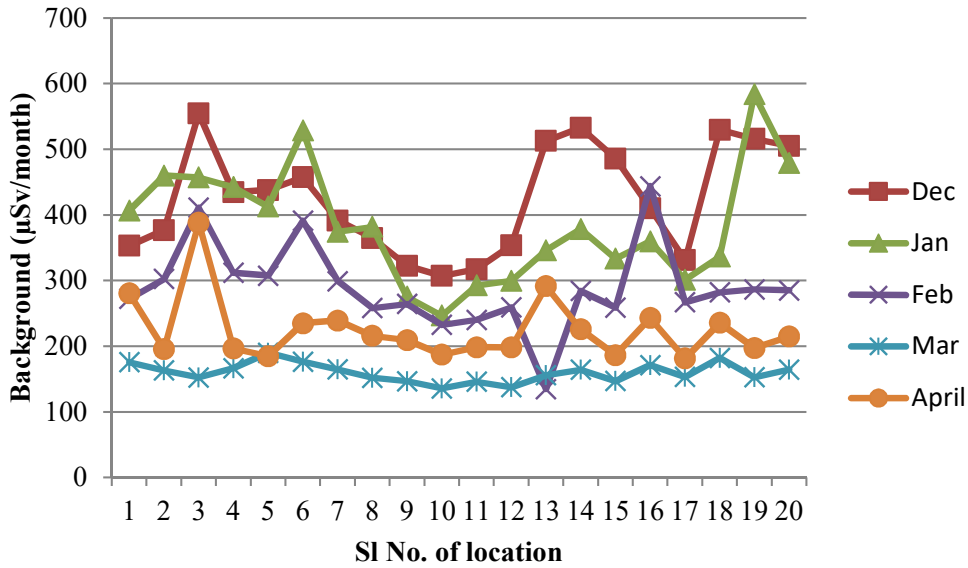


Fig. 2. Background radiation level (µSv/month) at indoor locations in AECD campus

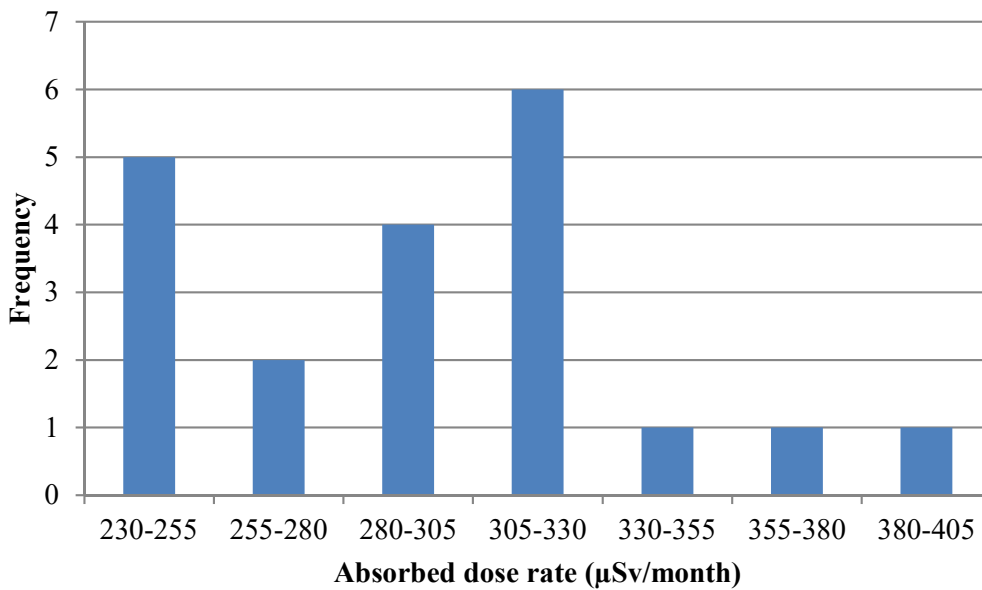


Fig. 3. Frequency distribution of the absorbed dose rates (µSv/month) at AECD campus in Shahbag Thana under Dhaka city

Excess life-time cancer risk (ELCR)

The radiological risk on worker and public health which may occur from the natural as well as man-made sources should be assessed for estimation of hazard. It was observed that the calculation of the annual effective dose and the corresponding ELCR at indoor places of a radiological facility is very few comparing to those found in the outdoor places. It is depicted in Table 2 that the estimated ELCR on worker and public health at indoor places of AECD campus is comparable to that of the worldwide average value. It is observed from Table 2 that the mean ELCR value in some areas of Iran, Malaysia, Nigeria, India and Pakistan are significantly higher than that of the AECD campus. However, the mean ELCR value in some areas of Iran, Iraq, India, Pakistan and Morocco are comparable to that of the AECD campus. The higher ELCR value at indoor places in some re-

gion of a country are mainly due to the usage of rocks and construction materials of the building that contains higher level of natural radionuclides, namely ^{226}Ra , ^{232}Th , and ^{40}K . In addition, the higher ELCR value at indoor places of a building exist because of the laboratory equipments, soil and other decorative stones for the construction of walls and floors and due to the poor ventilation situation in the rooms of the buildings that increase the radon concentration.

The estimated mean annual effective dose of 0.43 mSv is not predicted to contribute considerable more hazards on radiation worker & public health from the radiological risk observation. The reason is that the annual dose limit for the public as per ICRP 103 [24] is 1 mSv and the limit is applicable to the planned exposure situations and is not applicable to doses contributing from the existing exposure situations.

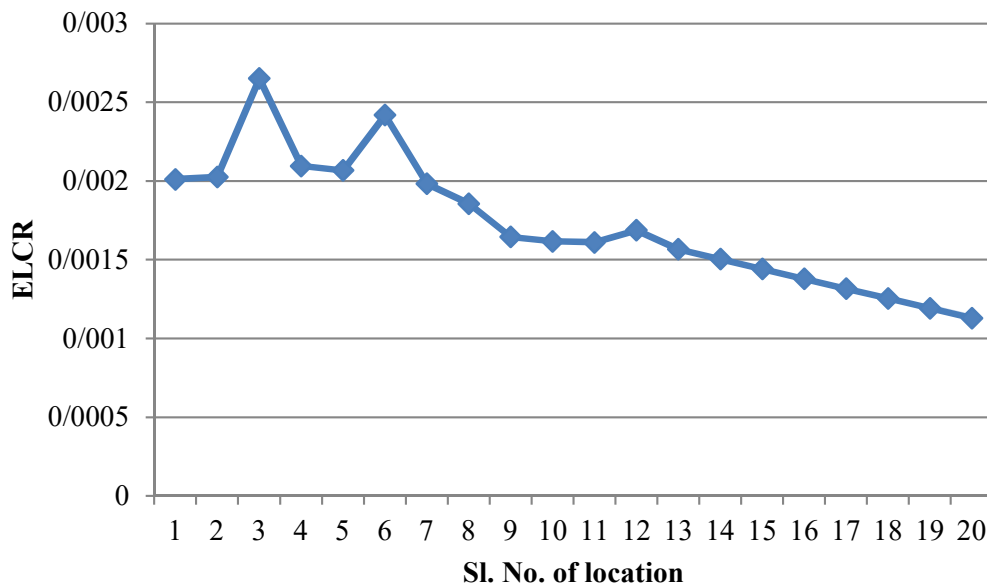


Fig. 4. Excess life-time cancer risk (ELCR) on radiation worker and public health at AECD campus in Shahbag Thana under Dhaka city

Table 2. Indoor annual effective dose and ELCR values of selected countries are compared with this study

Country	Annual effective dose range (mean) in mSv	ELCR	Reference
Iran	1.68	10.7×10^{-3}	[25]
Malaysia	0.782	3.22×10^{-3}	[28]
Nigeria	0.54-0.949 (1.06)	3.71×10^{-3}	[33]
Nigeria	0.645	2.26×10^{-3}	[34]
India	7.56	20.56×10^{-3}	[29]
Iran	0.49	1.715×10^{-3}	[27]
Pakistan	0.92	3.21×10^{-3}	[35]
Iraq	0.56	1.64×10^{-3}	[36]
Pakistan	0.49	1.629×10^{-3}	[37]
India	0.522	1.83×10^{-3}	[38]
Nigeria	0.14-0.19 (0.16)	0.56×10^{-3}	[39]
Pakistan	1.0	3.4×10^{-3}	[40]
Morocco	0.05-0.56	$0.19-1.96 \times 10^{-3}$	[41]
World	0.3-0.6 (0.48)	1.16×10^{-3}	[5, 38, 25]
Bangladesh	0.28-0.67 (0.43)	1.72×10^{-3}	This study

Conclusion

Continuous indoor radiation monitoring of a radiological facility like AECD is much needed in order to record the dose level of the radiation worker during their daily work while handling radioactive substances and radiation generating equipments. The radiation monitoring of a radiological facility is also important to estimate the radiological risk to the radiation worker and public health. The mean annual effective dose and the mean ELCR value on radiation worker and public health are comparable to those of the worldwide average values. This kind of study should be carried out regularly in a radiological facility to reduce the effective dose of the worker as well as public that ensure the safety of the radiation worker and public. The estimated mean annual effective dose of 0.43 mSv is not predicted to contribute considerable more hazards on radiation worker & public health from the radiological risk observation. However, radiation worker should be handled the radioactive substances and the radiation generating equipments as per national regulations as well as international recommendations in order to minimize the radiological hazard on worker and public health.

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Competing interests

The authors declare that there is no competing interest.

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Ethical considerations

“Ethical issues (Including plagiarism, Informed Consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors.”

References

- Eslami A, Shahsavani A, Saghi MH, Akhoondi L, Goorani A. Outdoor gamma radiation measurement in order to estimate the annual effective dose and excess lifetime cancer risk for residents of Tehran, Iran. *J. Air Pollut. Health.* 2017; 1(4):243-250.
- Eslami A, Saghi MH, Raštegar A. Assessment of background gamma radiation and determination of excess lifetime cancer risk in Sabzebar city, Iran in 2014. *Tehran Univ. Med. J.* 2016;73(10):751-755.
- Charles M, UNSCEAR Report, "Sources and Effects of Ionizing Radiation," *J. Radiol. Prot.* 2000;21:83-86.
- Agency for Toxic Substances and Disease Registry (ATSDR): Toxicological profile for ionizing radiation. Atlanta, GA: US, Department of Health and Human Services, Public Health Service. 1999.
- United Nations Scientific Committee on the effects of atomic radiation (UNSCEAR) Report, "Sources and Effects of Ionizing Radiation," Annex A: Dose assessment methodologies, New York, USA, Vol.1. 2000.
- United Nations Scientific Committee on the effects of atomic radiation (UNSCEAR) Report to the General Assembly, Volume 1, pp.260, New York, USA. 2008.
- United Nations Scientific Committee on the effects of atomic radiation (UNSCEAR) Report to the General Assembly. Ionizing radiation: sources and biological effects, New York, USA. 1982.
- Taskin H, Karavus M, Ay P, Topuzoglu A, Hidiroglu S, Karahan G. Radionuclides concentrations in soil and lifetime cancer risk due to gamma radioactivity in Kirklareli, Turkey. *J. Environ. Radioact.* 2009;100(1):49-53.
- Al-Saleh FS. Measurement of indoor gamma radiation and radon concentrations in dwellings of Riyadh City, Saudi Arabia. *Appl. Radiat. Isot.* 2007; 65:843-848.
- Al-Ghorable FH. Measurement of environmental terrestrial gamma radiation dose rate in three mountainous locations in the western region of Saudi Arabia. *Environ. Res.* 2005; 98:160-166.
- Arvela H. Population distribution of doses from natural radiation in Finland. *Int. Congr. Ser.* 2002;1225:9-14.
- Rybach L, Bachler D, Bucher B, Schwarz G. Radiation doses of Swiss population from external sources. *J. Environ. Radiat.* 2002; 62:277-286.
- Sagnatchi F, Salouti M, Eslami A. Assessment of annual effective dose due to natural gamma radiation in Zanjan (Iran). *Radiat. Prot. Dosim.* 2008;132:346-349.
- Tavakoli MB. Annual background radiation in the city of Isfahan. *Med. Sci. Monit.* 2003;9:7-10.
- Svoukis E, Tsertos H. Indoor and outdoor In situ high-resolution gamma radiation measurements in urban area of Cyprus. *Radiat. Prot. Dosim.* 2007;123(3):384-390.
- Rangaswamy R, Srinivasa E, Srilatha MC, Sannappa J. Measurement of terrestrial gamma radiation dose and evaluation of annual effective dose in Shimoga District of Karnataka State, India. *Radiation Protection and Environment.* 2005;38(4):154-159.
- Ononugbo CP, Avwiri GO, Tutumeni G. Estimation of indoor and outdoor effective doses from gamma dose rates of residential building in emelogu village in rivers state, Nigeria. *International Research Journal of Pure and Applied Physics.* 2015;3(2):18-27.
- Alasadi AH, Alaboodi AS, Alasadi LA, Abojassim AA. Survey of absorbed dose rates in air of Buildings Agriculture and Sciences in University of Kufa at Al-Najaf Governorate, Iraq. *Journal of Chemical and Pharmaceutical Research.* 2016;8(4):1388-1392.
- United Nation Scientific Committee on the Effects of Atomic Radiation, "Sources and Biological Effects of Ionizing Radiation," (Report to the General Assembly) New York, United Nations. 2008.
- Harshaw Model 4500, Manual TLD Workstation Operator's Manual (Cochran Road, Solon, Ohio) (Pub. No. 4500-0-O-0598-002, 6801); 2007.
- IAEA-International Atomic Energy Agency. Assessment of occupational exposures due to external sources of radiation. Safety Guides Series No. RS-G-1.3, (Vienna, IAEA);1999.
- ICRP-International Commission on Radiological Protection. General Principles for the radiation protection of workers, First edn. *Annals of the ICRP 27 (1)*, Pergamon Press, Oxford and New York;1997.
- <http://en.worldstat.info/Asia/Bangladesh> (accessed date: 15 June 2020).
- ICRP. Recommendations of the ICRP: *Annals of the ICRP (International Commission on Radiological Protection) (Vol. 37, pp.2-4)*; 2007.
- Hashemi M, Akhoondi L, Saghi MH, Eslami A. Assessment of indoor gamma radiation and determination of excess lifetime cancer risk in Tehran in winter and spring 2017. *Radiat. Prot. Dosim.* 2019;184(2):148-154.
- James IU, Moses IF, Vandi JN, Ikoh UE. Measurement of indoor and outdoor background ionising radiation levels of Kwali General Hospital, Abuja. *J. Appl. Sci. Environ. Manage.* 2015;19(1):89-93.
- Zarghani H, Jafari R. Assessment of outdoor and indoor background gamma radiation, the annual effective dose and excess lifetime cancer risk in Birjand, Iran. *Jundishapur J. Health. Sci.* 2017;9(3):1-4. doi: 10.5812/jjhs.40791
- Abdullahi S, Ismail AF, Samat S. Determination of indoor doses and excess lifetime cancer risks caused by building materials containing natural radionuclides in Malaysia. *Nuclear Engineering and Technology.* 2019; 51: 325-336. <https://doi.org/10.1016/j.net.2018.09.017>
- Monica S, Visnu PAK, Soniya SR, Jojo PJ. Estimation of indoor and outdoor effective doses and lifetime cancer risk from gamma dose rates along the coastal regions of Kollam District, Kerala. *Radiat. Prot. Environ.* 2016;39:38-43. doi: 10.4103/0972-0464.185180
- Bellia S, Basile S, Brai M, Hauser S, Puccio P, Rizzio S. Seasonal variation of air karma in the Vulcano Porto area (Aeolian Islands, Italy). *Appl. Radiat. Isot.*

- 2001;54:701-706. doi: 10.1016/s0969-8043(00)00306-7
31. Strandén E, Kolstad AK, Lind B. The influence of moisture and temperature on radon exhalation. *Radiat. Prot. Dosim.* 1985;7:55-58.
 32. Chandrashekara MS, Sannappa J, Paramesh I. Studies on atmospheric electrical conductivity related to radon its progeny in the lower atmosphere at Mysore. *Atoms Environ.* 2006;40:87-95. doi:10.1016/j.atmosenv.2005.09.026
 33. Ononugbo CP, Avwiri GO, Tutumeni G. Estimation of indoor and outdoor effective doses from gamma dose rates of residential buildings in emelogu village in Rivers State, Nigeria. *International Research Journal of Pure and Applied Physics.* 2015; 3(2):18-27.
 34. Etuk S E, Antia A D, Agbasi OE. Assessment and evaluation of excess lifetime cancer risk for occupants of university of Uyo permanent campus, Nigeria. *International Journal of Physical Research.* 2017; 5(1):28-35. doi: 10.14419/ijpr.v5i1.7564
 35. Qureshi AA, Tariq S, Din KU, Manzoor S, Calligaris C, Waheed A. Evaluation of excess lifetime cancer risk due to natural radioactivity in the rivers sediments of northern Pakistan. *J. Radiat. Res. and Appl. Sci.* 2014;7:438-447. <https://doi.org/10.1016/j.jrras.2014.07.008>
 36. Mohammed RS, Ahmed RS. Estimation of excess lifetime cancer risk and radiation hazard indices in Southern Iraq. *Environ. Earth. Sci.* 2017;76:303. DOI 10.1007/s12665-017-6616-7
 37. Rafique M, Rahman S, Basharat M, Aziz W, Ahmad I, Lone K A, Ahmad K, Matiullah. Evaluation of excess lifetime cancer risk from gamma dose rates Jhelum Valley. *J. Radiat. Res. and Appl. Sci.* 2014;7:29-35. <https://doi.org/10.1016/j.jrras.2013.11.005>
 38. Murugesan S, Mullainathan S, Ramasamy V, Meenakshisundaram V. Environmental radioactivity, magnetic measurements and mineral analysis of major south Indian river sediments. *J. Mater. Environ. Sci.* 2016;7(7):2375-2388.
 39. Avwiri GO, Ekpo J, Chad-Umoren YE. Occupational hazards from outdoor and indoor radiation in oil fields facilities in Rivers State, Nigeria. *Asian of Physical and Chemical Sciences.* 2019; 7(4):1-7. DOI: 10.9734/AJOPACS/2019/v7i430099
 40. Ali M, Bano S, Qureshi JA, Wasim M, Khan G, Begum F, Alam M. Indoor and outdoor gamma radiation level in mud and concrete houses and the annual effective dose and excess lifetime cancer risk in Gahkuch Ghizer valley of Hindukush Range. *Journal of Himalayan Earth Sciences.* 2019; 52(2):177-184.
 41. Kassi B, Boukhaïr A, Azkour K, Fahad M, Benjelloun M, Nourreddine AM. Assessment of exposure due to technologically enhanced natural radioactivity in various samples of Moroccan building materials. *World Journal of Nuclear Science and Technology.* 2018; 8:176-189. DOI: 10.4236/wjnst.2018.84015