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# Environmental Radiation: Natural Radioactivity Monitoring

*Isam Salih Mohamed Musa*

## Abstract

People are continuously exposed to ionizing radiation from many sources, including natural radioactive substances that are produced in the atmosphere and on Earth, in addition to radionuclides manufactured for various applications. Exposures vary among different places depending on many parameters. There are regions with considerably high natural background radiation while most places classified as low to medium levels. This noticeable interest pronounced worldwide is radioactivity monitoring and wide surveys by many countries. This is useful for the assessment of public as well as creating baseline if changes in the levels due to activities and practices take place. Good management of protecting the environment is to establish baseline data of high quality with efficient measurements. Natural radioactivity monitoring in view of radiation and environmental protection is presented in this chapter. It will shed the light on rapid methods describing the measurement of radionuclides and assessment of exposure to human. It presents a summary of methods of radiation dose calculations that individual may be exposed with some numerical examples. The chapter also presents methods for predicting the spatial distribution of radiological quantities using geographical information system. Environmental measurements may be costly and time-consuming practices; hence, thoughts to reduce time force itself in this chapter.

**Keywords:** environmental radioactivity, monitoring, gamma spectrometry, ambient dose, absorbed dose, GIS, geostatistics

## 1. Introduction

Our planet, the earth, is a wonderful place and has been suitable to live on its surface for thousands of years; it obliges us to preserve and nurture it. As investment volumes continue to grow in the globalized economy, environmental shadows are intersecting more and more on this planet. The concept of sustainable development, which generally means meeting the needs of the present without assaulting the rights of future generations, is addressed and implemented by many countries to manage the environment in an equal manner. However, there are some nations that achieve growth for their economies without regard to the adverse effects on the open environment. Nuclear and related applications became available everywhere to solve many problems of humanity. These applications, if not managed correctly, may lead to adverse effects of contaminating our environment by adding radioactive materials to already existing radioactivity of natural origin. So that our future generations and we will not be the victims of the various contaminations with

hazards, we must preserve our environment. Many models arise when large companies offer their products without paying attention to long-term effects on human health or environmental stability. Some states allow the export of banned products or remainders inside the country because they are not safe in domestic use. In that regard, there are some talk about agreements to bury dangerous waste (e.g., radioactive waste in deserts). We recognize this by developing appropriate solutions and standards to perform the required tasks. These procedures often require the availability of accurate information and must be much easier to facilitate making decisions. The environmental radiation monitoring, for example, requires a variety of measurements, so it needs development of equipment capable of performing fast and accurate measurements on demand in addition to training of people that deals with radioactive materials.

## **2. Natural radioactivity**

In nature, there are important components that cast a shadow over the existing development of humankind such as uranium, which contributed greatly to the generation of electricity around the world. This element, in addition to other natural radionuclides, believed to be originated during the supernova explosion millions of years ago and/or alien to the earth where it was formed in the fusion of neutron stars, eventually makes its way into the earth crust. Natural radioactivity is a term used to describe the levels of naturally occurring radionuclides in different environmental compartments, originated either from cosmic (e.g.,  $^{14}\text{C}$  and  $^3\text{H}$ ) or terrestrial radiation. In addition to radioactive potassium ( $^{40}\text{K}$ ), the terrestrial radionuclides include those contained in four known decays series, namely, uranium, thorium, actinium, and neptunium, which start with  $^{238}\text{U}$ ,  $^{232}\text{Th}$ ,  $^{235}\text{U}$ , and  $^{237}\text{Np}$ , respectively. They comprise 18, 11, 16, and 12 radionuclides, respectively. The most abundant in significant levels in our environment are those from  $^{238}\text{U}$  and  $^{232}\text{Th}$  series. It is believed that in the history of the earth, the crust was enriched in uranium in the beginning; then, the rise of oxygen had oxidized uranium leading to the transfer of huge amount to the oceans and by some natural processes back to the mantle [1, 2]. The processes involved led to spatial distribution of uranium and its decay products. No matter how these theories and assumptions are exact, they give a picture of the approach we can only prove their validity by experiments.

Natural environmental radioactivity arises primarily not only from uranium, as mentioned above, but includes also other nuclides, such as thorium series and potassium, which occur at trace levels in all formations. These radionuclides are believed to be formed by the process of nucleosynthesis in stars and are characterized by half-lives that are comparable to the age of the earth.

It has been recognized that there are some places with large inhabitants that encompass high levels of background radiation in environmental compartments. Great interest given worldwide for the study of naturally occurring radionuclides has led to the performance of broad investigations in many countries [3–10]. Investigators attempted to correlate the distributions of natural radionuclides with some settings such as geology, soil characteristics, etc. Such surveys can be useful for both the assessment of dose rates and the exploit of epidemiological studies, as well as to keep reference-data histories and to determine possible changes in the environmental radioactivity due to nuclear, industrial, or any other practices. What matters to us is to deal with the current reality of taking advantage of natural resources without disruption and tampering with our environment. The accurate determination of isotopes in environmental media presents a significant contest. Thanks to the technology that offered today many nuclear and related techniques

for evaluating isotopes in the environment in efficient manner. Depending on the isotope, the analytical technique is selected (alpha, beta, or gamma emitter).

Gamma radiation emitted from naturally occurring radioisotopes, also called terrestrial background radiation, represents the main external source of irradiation of the human body. Natural environmental radioactivity and the associated external exposure due to gamma radiation depend primarily on the geological and geographical conditions, as reported at different levels in the soils of different regions around the world [11–13]. The specific levels of terrestrial environmental radiation are related to the geological composition of each lithologically separated area and to the content in thorium (Th), uranium (U), and potassium (K) of the rock from which the soils originate in each area.

## **2.1 Radiation protection from natural sources**

This topic received some interests by many researchers in the field. Regardless of the general situation of safety and exposures, there are a number of conceptual issues, which remain open. That may include better revision of the protection concepts to cope with conditions of long-term chronic exposure resulting from natural sources. Developing real-world methodologies for the assessment and regulation of situations where there is a potential of exposure and addressing long-term safety aspects of radioactive waste of natural origin deem necessary. For decades, several studies have been conducted on the behavior of radionuclides in the environment and their transfer to humans through ecological and food chains. Most research focused on the contamination of the food chain release to the environment and development of mathematical models to describe environmental transport and assessment of general exposure. Continuing basic biological research is of particular importance to progress in protecting human, animal, and the environment from the hazards of radiation, so it should be strongly supported. However, it is also important to allow epidemiology, especially studies of low-dose populations, and to improve understanding of environmental phenomena as they relate to radiation protection, so as not to throw our hands at risk.

Many practices nowadays may increase the risk of surface contamination by radioactivity which needs control, such as oil exploration leading to NORMs, phosphate fertilizers, and illegal disposal of radioactive wastes in remote areas. Environmental monitoring can afford valuable means for understanding the distribution of natural worries of the ecological system. It is therefore importantly needed to increase our knowledge of the system by better means and offer adequate information to regulators, decision-makers, and the public. Authorities and investigators make baseline data such as risk maps to identify areas with low or high concentrations of certain radioactive and nonradioactive elements.

## **2.2 Environmental samples and sampling**

Environmental sample includes anything on the earth (soil, rocks, plants, water, sediments, air, etc.). It is important that samples taken from any place have to be representative to that place and care necessity be taken not to cross-contaminate samples. These precautions include also storing samples in a safe place to prevent conditions that could change the properties of the sample. Samples shall be kept sealed during long-term storing or transport. Before sampling a protocol, sampling strategy has to be set and all records of field sampling are written in a certain logbook. Simple logbook contains basic information of samples and sampling (date/time, coordinates, climate conditions, dose rate readings, etc.) It may contain additional information such as where and how samples are taken. As an example, soil

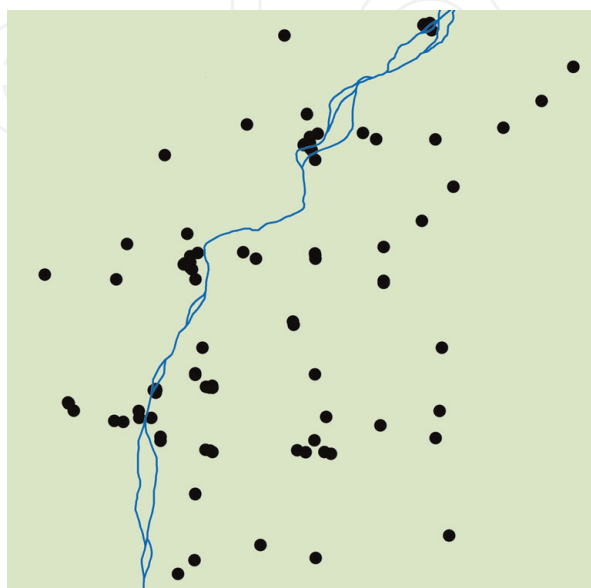
samples can be taken using auger with depths up to 20 cm (after removing the top 2–3 cm). Locations of samples have to be pre-defined on approximate map, and from each location, a set of triplicate samples (as shown in **Figure 1**) could be taken. Samples are then prepared for measurements in standard procedures (drying, grinding, sieving, etc.). Details about sample preparation are described elsewhere such as the IAEA Technical Report Series No. 295 [14].

### 2.3 Gamma radiation monitoring

Among other types of radiation, gamma rays are the most penetrating radiation that are emitted from natural and manufactured sources. This property made gamma rays easy to detect and measure. Measurements can be made in two manners: total measurements that record gamma rays emitted at different energies from various sources. These modes are generally used to evaluate the gross levels of the gamma radiation in fields and to detect the presence of abnormalities in the environment. Laboratory analyses, on the other hand, measure both the intensity and energy of radiation, which enables identification of the source of the radiation.

Gamma radiation monitoring is applied in several fields of science including geological, geochemical, and mineral exploration, related epidemiological studies, and environmental science. It allows the interpretation of regional features over large areas. The monitoring is useful to estimate and assess the terrestrial radiation dose to the human population and to recognize regions of probable natural radiation hazard. Radioactive potassium and the uranium and thorium decay series are relatively abundant in the natural environment. They produce gamma rays of sufficient energies and intensities to be detected by a simple gamma ray spectrometry. Average crustal abundances of these elements quoted in the literature are in the range 2–2.5%, 2–3 ppm, and 8–12 ppm for potassium, uranium, and thorium, respectively [12].

Regional monitoring provides a base against which contamination from artificial sources be estimated. For example, regular measurements are conducted around nuclear facilities such as power plants, hospitals, and mining, industrial, and even radiowaste sites to provide a baseline against which any unintentional release of radioactive material can be detected. The gamma ray techniques have been fruitfully applied to mapping the fallout from nuclear accidents [15].



**Figure 1.**  
*Part of soil sampling area where triplicate samples are found from each location in the area.*

## 2.4 Gamma ray laboratory

Gamma spectrometry is a system that is equipped with various types of detectors (HPGe, BEGe, LEGe, NaI, etc.), which characterized its specifications for radioactivity measurements. Germanium detectors are powerful systems used to measure the radioactivity in environmental samples. They have many advantages compared to other techniques as, for example, they distinguish many radionuclides in one single measurement without destruction or chemical modification of the sample. Simultaneous identification of many radionuclides with specific gamma energy and high-energy resolution of the germanium detectors allows measurements of complex combinations of gamma emitters. **Figure 2** shows typical gamma spectrum taken for environmental sample.

It is important to know what counting statistics is used to optimize counting times in view of the influence of background. Depending on detector characteristics, the minimum detectable activity (MDA) at specific energy  $E$  is an important parameter to be calculated for field measurements; this may be given using Eq. (1):

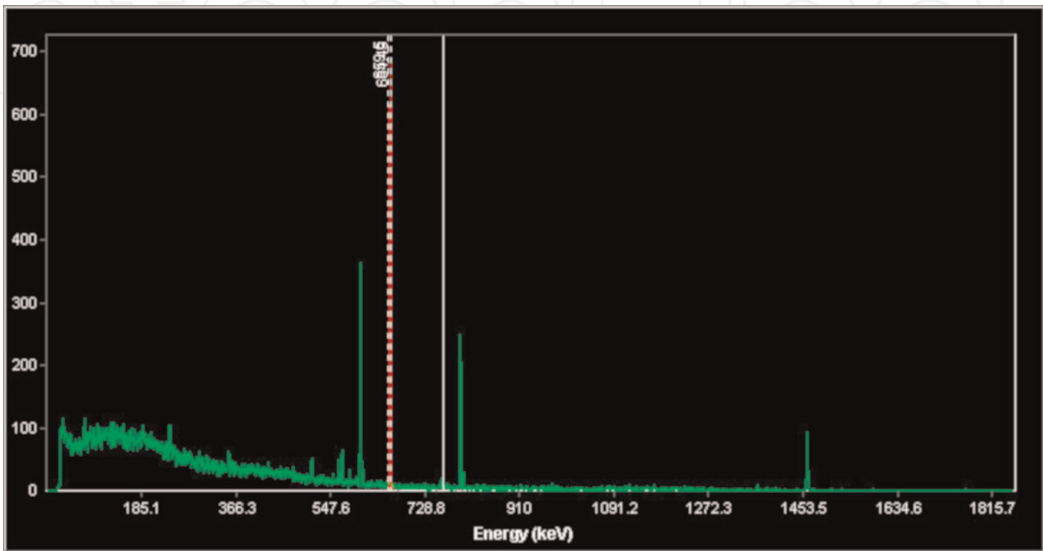
$$MDA = \frac{\sqrt{R(E)B(E)}}{\epsilon(E)}, \tag{1}$$

where  $R(E)$ ,  $B(E)$ , and  $\epsilon(E)$  are resolution of the detector (keV), background (counts/keV), and total efficiency at the specific energy  $E$ , respectively.

## 2.5 In situ ambient dose measurement

Measurements are generally carried out using various radiation survey meters that can have different detection abilities. The choice of field measuring devices usually depends on how sensitive these devices are to different energies of different concentrations of radionuclides in the environment. Quality control has to be conducted by researcher and investigators to make sure these devices are reliable, accurate, and precise.

An example of the reliability of field, compared to the laboratory measurements, will be given here. In a recent survey, a portable dose rate meter device (Radiogem2000 with probe [16]) was set to measure dose rates,  $D_F$  ( $\mu\text{Sv/h}$ ) at 1 meter above the ground while at the same time taking soil samples from the same



**Figure 2.**  
*A typical gamma measurement spectrum obtained using HPGe system.*

locations for laboratory analyses of  $^{238}\text{U}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$  in the collected samples. Ambient dose rates ( $D_C$ ) are calculated from the measurements using Eq. (2):

$$D(\text{nGy/h}) = 0.461A_U + 0.623A_{Th} + 0.0414A_K \quad (2)$$

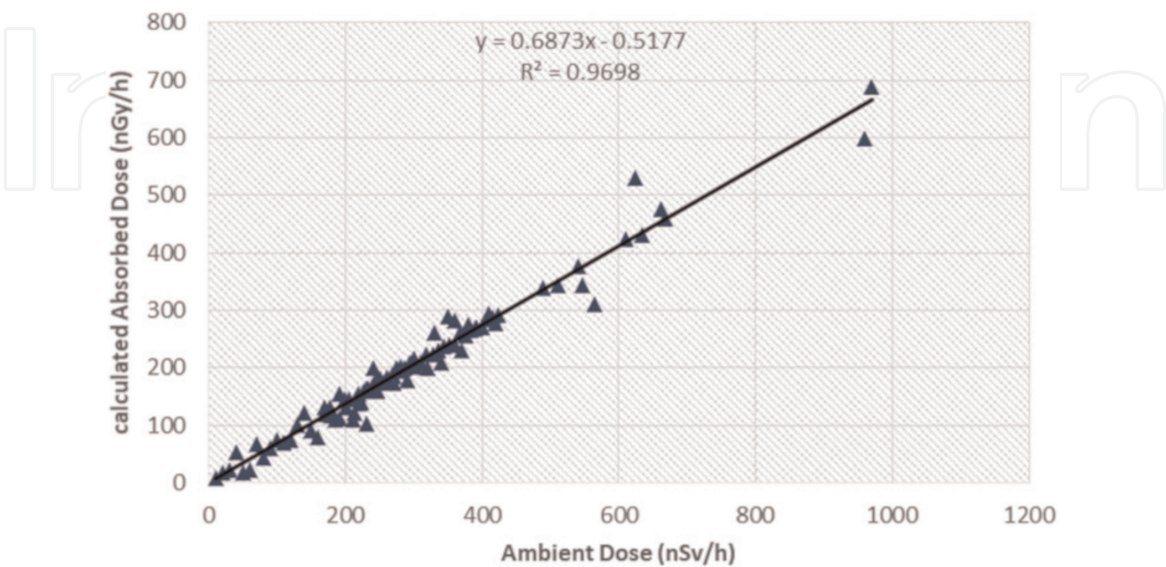
where  $A_U$ ,  $A_{Th}$ , and  $A_K$  are the activity concentrations (Bq/kg) of  $^{238}\text{U}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$ , respectively [11].

As shown in **Figure 3**, a very good linear relationship between field and laboratory measurements (calculated absorbed dose) was clearly perceived for about 100 data points with moderate dose rates ( $D_C \approx 0.7D_F$ ,  $R^2 = 0.97$ ). Of course, this result could be validated with more measurements. The most important outcome of that investigation is that at normal situations where the absorbed dose is up to 300 nGy/h, the field measurements have good agreement with laboratory measurements. It is therefore safe to rely on the portable devices for routine monitoring. The implication of that is that many measurements could be performed in a field mission (as the measurement takes only few minutes long). If levels are high, then sampling and laboratory measurements force itself.

## 2.6 Real-time radiation monitoring in the environment

The level of background radiation can be used as a consideration in remedial actions if contamination occurs. If measured constantly, it gives info about the trends with time and impact of man-made activities. Hence, it is important to carry out systematic investigations on ambient gamma dose throughout to establish a baseline database for future control assessment where it acts as early warning system.

The early warning system is composed of detectors installed at different locations and connected to central server over available communication system. Any type of detector or survey meters could be installed and used to fulfill the requirements. The advantage of this system is that the authority can create a national radiation map, showing environmental radiation levels (gross count of the radioactivity) throughout certain area updated in real time. It allows the citizen (or anyone) to see what radiation levels are within that specific area at any instance.



**Figure 3.**  
*Relationship between field (ambient dose) and laboratory measurements (absorbed dose).*

## 2.7 Geographical information system (GIS) for radioactivity monitoring

In a simple form, GIS is defined as a set of computer hardware and software designed to acquire, store, manipulate, display, and report geographically referenced information for a particular purpose in space. The space is presented by geographic coordinate systems. Therefore, GIS defines the relationships between various database information and geographical locations within the location system. Together with geostatistical tools, GIS is useful to interpolate scatter data by converting measured points into continuous surfaces. There are several methods available, the choice of which depends on the data itself. Among these methods it is worth to mention two methods, namely, inverse distance weighting (IDW) and kriging.

### 2.7.1 Inverse distance weighting (IDW)

In this interpolator, the data points are weighted during process so that the impact of points relative to each other is a function of inverse distance. Weighting is calculated to data via the use of a weighting power and the radius object. Larger power means that the adjacent points have the larger influence. Searching radius could be fixed or variable (with typical values of power around two). This flexibility allows controlling the interpolation, which may depend on the number of samples and how they are spatially distributed. One of the drawbacks using this method is that maxima and minima are always among data points since the inverse distance weighted interpolation is a smoothing technique by definition. On the other hand, it is a powerful interpolation technique which leads to reasonable predictions with no problem with results exceeding the range of meaningful values. Simple or advance GIS software could be employed to interpolate and validate the results. Validations are normally expressed as root mean squares error in the correlation between the predicted and actual values.

### 2.7.2 Kriging method

This is an advance method that makes a surface from scattered points. It is sometimes called weighted moving averaging method because it is derived from regionalized variable theory. It assumes that the variation of a parameter is statistically correlated all over the area. Kriging derives weights from semivariogram functions that depict the degree of spatial correlation between data points as a function of distance and directions between points. The semivariogram adjusts the way kriging weights are allocated to each data point during interpolation. The semivariogram  $\gamma(h)$  function is given by Eq. (3):

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^N \sqrt{[Z(x_i + h) - Z(x_i)]^2} \quad (3)$$

where  $x_i + h$  and  $x_i$  are sampling position separated by a vector  $h$ ,  $Z(x_i)$  is a random variable at fixed position  $x_i$ , and  $N(h)$  is the number of data pairs separated by a vector  $h$ . Ordinary kriging is a type of kriging that uses the sampled main variable to estimate values at unsampled locations. Cokriging, on the other hand, allows secondary variables to be incorporated in the model assuming that both primary and secondary variables are correlated [17, 18].

### 2.7.3 Example of prediction

**Figure 4** shows a typical example to predict unsampled places from randomly scattered data points of measured ambient dose (figure to the left). Both interpolator methods IDW and kriging were used to create continuous surface of this parameter as shown in middle and right figures, respectively. These maps (easy to visualize if there are trends) could be used as a guide for any future studies; it can be improved and updated.

## 2.8 Radon monitoring

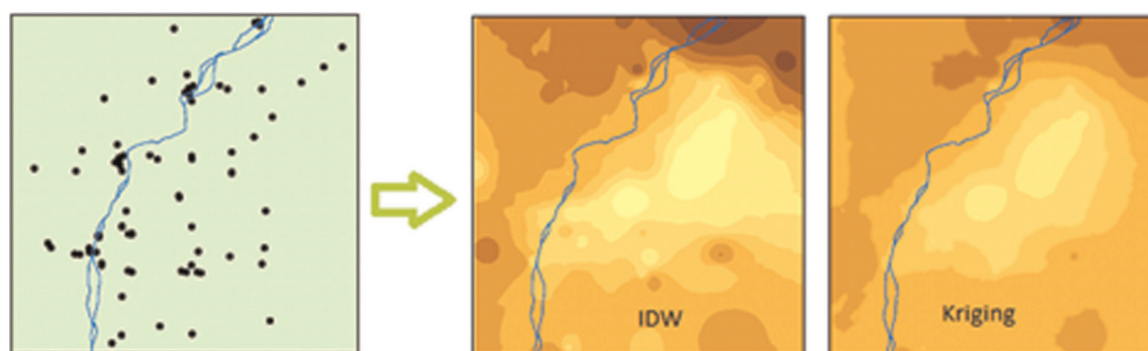
Radon is a naturally occurring radionuclide that is found in the environment as a member of the natural decay series of uranium. The  $^{222}\text{Rn}$ , including its progeny, is one of the most significant natural sources from a viewpoint of human radiation exposure to the population. Exposure to high concentrations of radon has been correlated to lung cancers, although the effect of low radiation doses is not well defined. The importance of environmental  $^{222}\text{Rn}$  data were pointed out in the UNSCEAR reports [11–13]. As an alpha emitter, the indoor  $^{222}\text{Rn}$  can be measured using detectors that estimate alpha particles or via its decay products that emit alpha, beta, or gamma rays. Many techniques have been developed to measure radon in the environment. Charcoal canister technique and solid-state nuclear track detector (SSNTD) are common methods in use to evaluate radon in passive mode. The radiation doses due to radon inhalation are calculated according to the ICRP assumption of equilibrium factor (the quotient of the equilibrium equivalent concentration to the  $^{222}\text{Rn}$  concentration) of 0.4 and assuming 5700 h spent indoors annually.

## 2.9 Assessment of external hazards

In addition to absorbed dose calculated from Eq. (2), the following additional hazard index parameters are, generally, evaluated using field or laboratory measurements to assess the risk of exposure due to natural radioactivity.

### 2.9.1 Annual effective dose ( $E$ )

The annual effective dose is a quantity that is introduced in the field of radiation protection for dose limitation, defined as organ or tissue weighted sum of equivalent dose in 1 year (averaged for the whole body) considering type of radiation. It represents the stochastic risk (probability of getting cancer [estimated as  $5 \times 10^{-2}$



**Figure 4.** Converting scattered measured ambient dose to continuous surface using inverse distance weighting (IDW) and kriging geostatistical methods.

per sievert] and genetic defects). For people living in a certain area, the annual effective dose could be calculated using Eq. (4) [12]:

$$E(\text{mSv/y}) = D(\text{nGy/h}) \times 24 \text{ h} \times 365.25 \text{ d} \times 0.2 \times 0.7 \text{ (Sv/Gy)} \tag{4}$$

where 0.7 is the absorbed/ambient dose conversion factor and 0.2 is the outdoor occupancy.

Example 1: About 100 soil samples were collected from an area, measured by gamma spectrometry which showed the following average results:  $80 \pm 7$ ,  $91 \pm 21$ , and  $573 \pm 89$  (Bq/kg) for  $^{238}\text{U}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$ , respectively. Estimate the annual effective dose for people living in this area spending 60% of their time indoor.  
Solution: First we calculate the absorbed dose using Eq. (2):  
$$D = 0.461 \times 80 + 0.623 \times 91 + 0.0414 \times 573 = 117 \text{ nGy/h}$$
  
This can then be converted into annual effective dose using Eq. (4):  
$$E \approx 0.3 \text{ mSv/y}$$

2.9.2 External hazard index (*hex*)

This index is calculated using Eq. (5) [19]:

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \tag{5}$$

Example 2: In example 1 above, calculate the external hazard index.  
Solution:  
$$H_{ex} = \frac{80}{370} + \frac{91}{259} + \frac{573}{4810} = 0.69,$$
  
less than unity (the recommended limit for external exposure).

2.9.3 Excess lifetime cancer risk (*ELCR*)

Cancer risk can be estimated using Eq. (6) [12, 20]:

$$ELCR = E \times DL \times RF \tag{6}$$

where DL is the life expectancy (in years) and RF is the cancer risk factor for each sievert [21], which is of order 0.05 for the public.

Example 3: In example 1 above, estimate cancer risk for a person living in that area.  
Solution:  
Assuming the average life expectancy of people in this area is 65 years, then using Eq. (6) the lifetime cancer risk is calculated as  
$$ELCR = 0.3 \times 10^{-3} \times 65 \times 5 \times 10^{-2} = 9.8 \times 10^{-4} \approx 10^{-3}$$

3. Conclusion

The chapter describes the importance of radioactivity monitoring to preserve our environment. It sheds the light on methods designated for the measurement of

natural radionuclides in the environment and assessment of radiation exposure to human in different situations. In addition to measurements and surveys, the chapter presents a summary of some methods of radiation dose calculations that the individual may be exposed to. As is difficult to measure everywhere, the chapter also presents methods for estimating and predicting the spatial distribution of radiological quantities. The use of a geographical information system, GIS, and geostatistical methods to create maps facilitates the evaluation and assessment of radioactivity in the environment. Environmental measurements may be costly and time-consuming practices; hence, thoughts to reduce time and efforts are given in this chapter where at normal levels portable simple equipment proved useful.

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## **Conflict of interest**

The author discloses no potential conflicts of interest.

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