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Estimating the Toxicity of Radionuclides in Soil Stored in Drums in the Tuwaitha Area for Determining the Harmful Effects on Humans and Environment

Saad M. Abd, Asia H. Al-Mashhadani, Naseer A. Ahmed, Rana M. Yas
Department of Physics, College of Science, University of Baghdad, Baghdad, Iraq

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Abstract

Radioactive waste management is a fundamental issue when using nuclear energy. Therefore, it is necessary to study the health and biological effects on human and environment that these radionuclides cause. The aim of the present study is to estimate the radiotoxicity for radioactive waste in stocked soil in Al-Twaitha city. The radiotoxicity was calculated for each radionuclide, present in the waste, using their dose factor due to ingestion, which is given by the International Commission on Radiological Protection (ICRP) compendium.

For the purpose of calculating radiation toxicity, a scenario was built that 20% of the radioactivity during radioactive waste handling processes is in the form of dust that can be inhaled or entered through the mouth or eyes. Drums Characterization System (DCS) provided with portable HPGe hand-held radioisotope identifier was used for the characterization and identification of the radionuclides in the drums and the dose rate was measured by Ludlum radiation detector. The absorbed dose rate ranged from 134.904nGy h^{-1} to 788400 nGy.h^{-1}, the internal hazard index (H_{in}) from 0 to 0.035, representative gamma index (I_{γ}) from 0 to 0.068, representative alpha index (I_{α}) from 0 to 0.017, excess lifetime cancer risk (ELCR) value ranged from 0.66×10^{-6} to 3.86×10^{-3} and the range of AEDE from 0.19 mSv to 1103.76 mSv.

Keywords: AEDE, Internal Hazard Index, Representative Alpha Index, Representative Gamma Index and Excess Lifetime Cancer Risk.

تقدير سمية النويدات المشعة في ترب مخزونة في براميل الطمر في التويثة في تحديد الآثار الضارة للإنسان والبيئة

سعد محمد عبد، اسيا حميد حمد، رنا محي ياس، نصير عارف احمد
قسم الفيزياء ، كلية العلوم ، جامعة بغداد، العراق

الخلاصة

تعد إدارة النفايات المشعة قضية أساسية ومهمة عند استخدام الطاقة النووية. ولذلك فمن الضروري دراسة التأثيرات الصحية والبيولوجية على الإنسان والبيئة التي تسببها هذه النويدات المشعة. الهدف من هذه الدراسة هو تقدير السمية الإشعاعية للنفايات المشعة في التربة المخزونة براميل خاصة في مدينة التويثة. تم حساب

*Email: asia.hammad@sc.uobaghdad.edu.iq

السمية الإشعاعية لكل نويدة مشعة موجودة في النفايات، باستخدام عامل الجرعة الخاص بها والذي نشرته اللجنة الدولية للحماية من الإشعاع (ICRP) في خلاصة عوامل الجرعة الناتجة عن الابتلاع.
ولغرض حساب السمية الإشعاعية أثناء عمليات التعامل مع النفايات المشعة، تم بناء سيناريو مفاده أن 20% من النشاط الإشعاعي سيكون على شكل غبار يمكن استنشاقه أو دخوله عن طريق الفم أو العينين. استخدم نظام توصيف البراميل (DCS) المزود بكاشف النظائر المشعة المحمول HPGe نوع MICRO–DET–HX (PKG–1)) لتوصيف وتحديد النويدات المشعة في البراميل وتم قياس معدل الجرعة بواسطة كاشف الإشعاع Ludlum. يتراوح معدل الجرعة الممتصة من $134.904\ nGyh^{-1}$ إلى $788400\ nGy.h^{-1}$، ومؤشر المخاطر الداخلية (H_{in}) من 0 إلى 0.035، ومؤشر جاما التمثيلي ($I\gamma$) من 0 إلى 0.068، ومؤشر ألفا التمثيلي ($I\alpha$) من 0 إلى 0.017، ومخاطر السرطان الزائدة مدى الحياة (ELCR) من 0.66×10^{-6} إلى 3.86×10^{-3} ومدى AEDE من 0.19 ملي سيفرت إلى 1103.76 ملي سيفرت

1.Introduction

Radioactivity is part of everyday life. It is present all around us and cannot be detected by our senses. According to the typology of the source, it is divided into natural and artificial. Natural radiation sources are cosmic rays and the radioactive content of soil and rocks. The most common of those belongs to the uranium and thorium radioactive series. Artificial radioactivity, so-called man-made radioactivity, is induced by man.

The importance of studying the effects of radiation is related to the lives of people, especially those working in the field of radiation, in addition to their understanding of the macroscopic manifestations of ionizing radiation. Exposure to natural or artificial radiation affects biological systems and the environment. Radioecology deals with the effect of radioactivity on the environment. While radiotoxicology investigates the effects of radiation on biological systems.

Toxicity is the ability of a chemical molecule or compound to cause injury once it reaches a sensitive site in or on the body. Toxicity risk is the possibility that injury may be caused by how the substance is used. However, the possibility of the substance entering the body is related to the mass of the substance used and the conditions of its use. In most cases, the focus is on the acute effects of chemical toxins, however, the effect of radionuclides entering the body, whose effect does not appear until after several years, is more severe, so the degree of infection and the time of its appearance in the two cases are generally different.

Different types of radiation deposit energy in biological tissues in different ways, which affects the amount of cellular damage. Relative biological effectiveness (RBE) is a relative measure of the damage done by a given type of radiation per unit energy deposited in biological tissues. Factors other than RBE were considered and presented in ICRP publication no. 30[2]. This publication provides guidance on the selection of critical organs and tissues for monitoring radiation exposure in occupational settings. Many factors determine the selection of the critical organ for a given radionuclide, such as the organ's importance and sensitivity to radiation, but usually, RBE is the dominant consideration[1].

Alpha and beta emitters possess the potential to inflict harm or pose a threat to cells or tissues within the body, particularly in tissues resembling the density of water, due to the radiation they emit. Despite alpha particles having a short path, typically up to a few hundred microns (5 MeV in energy) they can still induce damage. When alpha particles are deposited within delicate bone cells, they can contribute to the development of osteosarcoma.

Conversely, beta emitters like Sr-90 traverse longer paths. While their activity may be lower, they can still reach the bone marrow and potentially lead to the onset of leukemia.

The severity of damage caused by radionuclides to health, as well as the degree of radiotoxicity, can be assessed by considering factors such as the type and energy of radiation emitted, the absorption within living organisms, the impact of the absorbed dose, and the duration of time the radiation persists within the body. These parameters collectively determine the extent of harm inflicted by radionuclides on living systems.

The term "radiotoxicity hazard" is used more often in radiation protection, which is the potential of a particular radioactive substance entering the body to produce a health effect. It is related to the mass of the radioactive substance that may enter the body through inhalation, ingestion, or transfer from surrounding places to the skin. There is a wide hierarchy in radiotoxicity where tritium is considered the least radiotoxic isotope. On the other hand, heavier nuclei, uranium, plutonium, and small actinides are highly radiotoxic because they emit short-range alpha particles. Thus, plutonium-239 is 14,000 times more radiotoxic than tritium[1].

The above considerations are extended to radioecology, where physics links between radionuclides in the environment and their sources. The above concepts apply in every situation where radionuclides emit radiation causing transmutations and they are, in fact, sufficient for understanding the meaning of the result of a measurement relevant to radioecology and radiotoxicology. However, understanding the mechanisms behind such results is also often necessary, which requires a deeper insight into the physics of radioactive decay [2].
Effective dose is another factor that characterizes the exposure of an individual to both internal and external radiation sources independently of the individual's body-related parameters, such as sex, age (for adults), anatomy, physiology, race, and other factors [3].

These analyses furnish the necessary data for estimating the radiological dose impacts and risks to humans and the environment during the course of work. An itemized understanding of the radionuclide composition at this site is indispensable for ensuring safety. assessment [4].

The program of waste management or dealing with radioactive waste must ensure that the work output does not pose any radioactive risk to human health or the environment. Most approaches to radioactive waste safety assessments have included primary safety indicators (dose and risks). However, the assessment of worker safety based on these primary indicators has been deemed insufficient because dose and risks are calculated based of several assumptions [1].

Assessment of radiotoxicity of radioactive waste is the main objective of this study. This was achieved taking into consideration the radioactive decay rate of the radionuclides and the dose factors of each radionuclide present in the International Commission on Radiological Protection (ICRP)[5] compendium of dose factors due to ingestion.
The research paper centers on constructing a scenario based on the premise that 20% of the radioactivity present during the handling of radioactive waste exists in the form of dust, which could potentially be inhaled or enter the body through the mouth or eyes. The radioactive waste in the soil stocked in drums in Al-Twaitha city, where the Iraqi nuclear plant was situated, which contains different radioactive waste in stocked soil, are the object of this study.

1. Materials and Methods

Radiotoxicity is associated with internal exposure to radioactive material (through inhalation, ingestion, or wounds or the eyes), which is more harmful because our bodies are not protected from beta and alpha emitters. They can permanently settle in our bodies regardless of external exposures (gamma emitters or X-rays). Radiotoxicity is considered a criterion for classifying the danger resulting from radioactive materials. It is also considered an indicator for determining the radioactive risks when dealing with radioactive waste (characterization, removal, treatment, transportation, storage until the final landfill). Dealing with radioactive waste requires accuracy and safety of employees and environment. Radiological impacts may arise from gradual processes which may cause the facility and its components (e.g. barriers) to degrade and from discrete events that may affect the isolation of the waste (e.g. earthquakes, tsunamis, floods, fire, accidental human intrusion) [6].

The reference value for the radiotoxicity flux from radioactive waste at a certain waste site has been determined from the total radiotoxicity in a repository as given by following equation [7]:

$$J = \sum_n S_n \times D_n = \sum_n C_n \times Q \times D_n \quad (1)$$

where: J is the reference value for radiotoxicity flux (Sv/y), S_n is the activity flux of nuclide *n* (Bq/y), D_n is the ingestion dose conversion factor of nuclide n (Sv/Bq) and Q is volumetric groundwater flow rate in m^3/yr.

The effects of radioactivity and radiation dose were studied while handling radioactive waste and placing it in new drums.

The radioisotopes of the radioactive waste (RW) in twenty drums (D-1 - D-20) in Al-Twitha city and their specific activity were identified with portable HPGe hand-held radioisotope identifier (Ortec-type MICRO-DET-PKG-1 (HX)), which is provided with neutron and gamma detectors, GPS and gamma vision version (6.8) software for gamma spectrum analysis. Energy calibration of HPGe detector was done. The dose rate at the surface of the drums was measured using Ludlum Model 19 micro meter [8]. It ranged between 15.4 and 9000μR/h. The dose rate was measured on several points on the surface of the drums, and the average of these measurements was calculated to determine safety assessment for workers.

3- Results and discussions

High purity germanium (HPGe) hand held (HX) detector (ORTEC, International Inc.) was used for the characterization of the radioactive waste (RW) in the drums [9]. The relative efficiency of this instrument was 40% (as stated in detector worksheet). The detector efficiency calibration for different measurement geometries was performed using several standard radionuclides, of well-defined energies within the energy range of interest from 60 keV to 2000 keV, as presented in Table 1[10].

Table 1: The radioactive standard sources

Radionuclide	Energy keV	Efficiency
Am-241	59.5	0.031096
Cd-109	88	0.023606
Co-57	122	0.018691
Cs-137	661.6	0.0055875
Co-60	1332.3	0.0033904

3.1 Measurements of specific activity

The specific activity (A) of a radioactive waste of mass (m) is given by [11]:

$$A\ (Bq/kg) = \sum N / \xi\ I\ T_c\ m$$

where: ξ is the calibration efficiency, ∑N is the total measurement under the photoelectric peak, T_c is the measurement time, m is the mass of the soil sample from each drum and I is the relative intensity of each of the energies of the radioactive source.
The specific activity of each radionuclides of the samples was measured using HPGe detector and the results are tabulated in Table 2. The measured specific activity of nuclides varies from 3.3525Bq/kg to 2220146 kBq/kg. The highest specific activity was of Co-60 in D-3 sample while D-05 sample has the lowest activities for Sr-91 isotope.

3.2. External gamma dose rates

The external gamma exposure rates from the drums were directly measured using NaI gamma detector (Ludlum Model 19 Micro R Meter) 1m above the ground. It ranged from 15.4 µR/h to 90000 µR/h**.** The absorbed dose rate was calculated by multiplying the exposure rate by 0.00876. The absorbed dose rate ranged from 134.904nGy h^{-1} to 788400nGy.h^{-1}. The values are listed in Table 3.

3.3 The Internal Hazard Index (H_{in})

Radon gas and its short-lived daughters are sources of danger to the respiratory organs of humans, so the internal exposure of radon gas and its daughters constitutes an important part in calculating the level of internal hazard (H_{in}), which can be expressed mathematically as follows [12]:

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where A is the specific activity of the specified radionuclides.
The value of the total H_{in} from the twelve drums was calculated to be 0.1725

3.4 Representative Gamma Index (I_γ)

The other indicator of the gamma-ray hazard is expressed by the gamma index (I_γ), which is used to express the gamma-ray hazard associated with natural radionuclides, and it can be expressed mathematically by the following formula [13]:

$$I_\gamma = \frac{A_{Ra}}{150} + \frac{A_{Th}}{100} + \frac{A_K}{1500} \leq 1 \quad (3)$$

The value of the total I_γ from all the drums was calculated to be 0.302

3.5 Representative Alpha Index (I_α)

To calculate the I_α index, the following equation was used [14]:

$$I_\alpha = \frac{A_{Ra}}{200Bq/kg} \leq 1 \quad (4)$$

The value of the total I_α for all the drums was calculated to be 0.1004.

3.6. Annual Effective Dose Equivalent (AEDE)

The annual effective dose equivalent (AEDE) was used to evaluate the effect of external radiation dose (radiological health risks). The relationship below was used to calculate AEDE for workers in the radiation field [15]:

$$\text{AEDE (nSv/y)} = \text{D (nGy/h)} \times 2000\text{(h/y)} \times 0.7\text{ (Sv/Gy)} \quad (5)$$

where: D (nGy/h) is the absorbed dose rate, 0.7 Sv Gy^{-1} is the conversion factor, and 2000 is the number of working hours per year.
The calculation of the equivalent annual effective dose per drum was based on the calculated gamma dose rate. The results were in the range from 0.19 mSv/y to 1103.76 mSv/y, as shown in Table 3 and Figures. 1 and 2.

3.7. Excess Lifetime Cancer Risk (ELCR)

Excess Lifetime Cancer Risk (ELCR) is a term used in the field of risk assessment, particularly in the context of exposure to radiation. It refers to the additional risk of developing cancer that an individual incurs as a result of exposure to a particular agent or activity, above and beyond the baseline risk of developing cancer from all other causes.
This indicator can be calculated through the following equation, assuming that the average human lifespan is approximately 70 years [16]:

$$ELCR = AEDE_{outdoor}\ (mSv/y) \times DL(y) \times RF\ (Sv^{-1}) \qquad (6)$$

where: AEDE $_{(outdoor)}$ is the outdoor Annual Effective Dose Equivalent, DL is the average person's age estimated to be 70 years, and RF is the risk factor, measured as Sv^{-1} (fatal cancer risk per Sv). ICRP 60 has chosen a value of 0.05 for the risk factor for the mean radiation exposure values [17]. It is noted that this indicator is without a unit because it represents the possibility of the spread of cancer during a specific period. Table 3 gives the values of the ELCR for the different drums, where it can be noted that the values for several drums exceed the ELCR value recommended by ICRP-60 of 0.29×10^{-3} [19].

Table 2 : The calculated radiotoxicity (J) values for workers via ingesting and inhaling radioactive waste stored in drum.

Drum No.	Type of radionuclides	Specific Activity in Bq/kg	Ingestion		Inhalation	
			DCF (Sv/Bq)10^{-9}	Radiotoxicity (J) in Sv	DCF (Sv/Bq)$\times10^{-8}$	Radiotoxicity (J) in Sv
D-01	Th-234	4654.8	3.40	1.58×10^{-5}	0.66	3.07×10^{-5}
	Ra-226	3227.46	280.00	9.04×10^{-4}	380.00	1.23×10^{-2}
	Cs-137	175.472	0.025	4.39×10^{-9}	0.04	7.72×10^{-8}
	Pa-234M	6772.2	0.51	3.45×10^{-6}	0.038	2.57×10^{-6}
	Co-60	4691.46	3.40	1.60×10^{-5}	0.240	1.13×10^{-5}
	Bi-214	525.157	0.110	5.78×10^{-8}	1.40	7.35×10^{-6}
	K-40	152.48	6.20	9.45×10^{-7}	0.21	3.20×10^{-7}
D-02	Th-234	4080.91	3.40	1.39×10^{-5}	0.66	2.69×10^{-5}
	Ra-226	3384.08	280.00	9.48×10^{-4}	380.00	1.29×10^{-2}
	Cs-137	406.932	0.0250	1.02×10^{-8}	0.04	1.79×10^{-7}
	Co-60	214.087	3.40	7.28×10^{-7}	0.24	5.14×10^{-7}
	Bi-214	722.072	0.11	7.94×10^{-8}	1.40	1.01×10^{-5}
	Pa-234M	20988.7	0.51	1.07×10^{-5}	0.04	7.98×10^{-6}
	Eu-154	208.287	1.40	2.92×10^{-7}	0.02	4.37×10^{-8}
	Ra-226	990.707	280.00	2.77×10^{-4}	380.00	3.76×10^{-3}
	Pb-214	512.77	0.14	7.18×10^{-8}	1.40	7.18×10^{-6}

D-03	Co-60	2220146	3.40	7.55×10^{-3}	0.240	5.33×10^{-3}
	Ac-228	71.4706	0.43	3.07×10^{-8}	1.70	1.22×10^{-6}
	Bi-214	108.972	0.011	1.20×10^{-8}	1.40	1.53×10^{-6}
	Cs-137	6346.14	0.0025	1.59×10^{-7}	0.044	2.79×10^{-6}
	Ac-228	1668.75	0.011	1.84×10^{-7}	1.70	2.84×10^{-5}
	Eu-154	101.97	1.40	1.43×10^{-7}	0.021	2.14×10^{-8}
	Pa-234M	5602.67	0.51	2.86×10^{-6}	0.038	2.13×10^{-6}
	Ra-226	1140.08	280.00	3.19×10^{-4}	380.0	4.33×10^{-3}
D-04	Cs-137	724.982	0.0025	1.81×10^{-8}	0.044	3.19×10^{-7}
	Eu-154	1646.19	1.40	2.30×10^{-6}	0.021	3.46×10^{-7}
	Ac-228	1045.62	0.430	4.50×10^{-7}	1.70	3.46×10^{-7}
	Co-60	8144.43	3.40	2.77×10^{-5}	24.00	1.95×10^{-5}
	Bi-214	2807.18	0.11	3.09×10^{-7}	1.40	3.93×10^{-5}
	Th-234	50.4175	3.40	1.71×10^{-7}	0.66	3.33×10^{-7}
	Ra-226	188.597	0.028	5.28×10^{-5}	380.00	7.17×10^{-4}
D-05	Cs-137	33.955	0.025	8.49×10^{-10}	0.044	1.49×10^{-8}
	Pa-234M	795.177	0. 51	4.06×10^{-7}	0.038	3.02×10^{-7}
	Sr-91	3.3525	28.00	9.39×10^{-8}	0. 088	2.95×10^{-9}
	Co-60	26.24	3.40	8.92×10^{-8}	0.24	6.30×10^{-8}
D-06	Th-234	4469.08	3.40	1.52×10^{-5}	0.66	2.95×10^{-5}
	Eu-154	115.795	1.40	1.62×10^{-7}	0.021	2.43×10^{-8}
	Ra-226	2793.84	280.00	7.82×10^{-4}	380.00	1.06×10^{-2}
	Co-60	773318	3.40	2.63×10^{-3}	0.24	1.86×10^{-3}
	Cs-137	1094.91	0.025	2.74×10^{-8}	4.04	4.82×10^{-7}
	Ac-228	610.475	0.43	2.63×10^{-7}	1.70	1.03×10^{-5}
	Pa-234M	5932.09	0.51	3.03×10^{-6}	0.038	2.25×10^{-6}
	Bi-214	2235.99	0.11	2.46×10^{-7}	1.40	3.13×10^{-5}
D-07	Pa-234M	82216.5	0.51	4.19×10^{-5}	0.038	3.12×10^{-5}
	Ra-226	2752.65	0.11	3.03×10^{-7}	380.00	1.05×10^{-2}
	Co-60	307654	3.40	1.05×10^{-3}	0.24	7.38×10^{-4}
	Cs-137	711.025	0.025	1.78×10^{-8}	0.044	3.13×10^{-7}
	Ac-228	964.812	0.43	4.15×10^{-7}	1.70	1.64×10^{-5}
	Bi-214	2190.6	0.11	2.41×10^{-7}	1.40	3.07×10^{-5}
	Eu-154	345.41	1.40	4.84×10^{-7}	0.021	7.25×10^{-8}
	Pa-234M	63366.2	0.51	3.23×10^{-5}	0.038	2.41×10^{-5}
	Ra-226	2731.99	28.00	7.65×10^{-4}	380.00	1.04×10^{-2}
D-08	Cs-137	1688.86	0.025	4.22×10^{-8}	0.044	7.43×10^{-7}
	Co-60	1573.96	3.40	5.35×10^{-6}	0.24	3.78×10^{-6}
D-09	Co-60	4900.46	3.40	1.67×10^{-5}	0.240	1.18×10^{-5}
	Bi-214	5304.9	0.11	5.84×10^{-7}	1.00	5.30×10^{-5}
	Eu-154	257.185	1.40	3.60×10^{-7}	0.20	5.14×10^{-8}
	Th-234	254.302	3.40	8.65×10^{-7}	0.66	1.68×10^{-6}
	Ra-226	708.652	28.00	1.98×10^{-4}	380.00	2.69×10^{-3}
	Cs-137	224.692	0.025	5.62×10^{-9}	0.044	9.89×10^{-8}

D-10	Pa-234M	1770.25	0.51	9.03×10^{-7}	0.038	6.73×10^{-7}
	Co-60	154.22	3.40	5.24×10^{-7}	0.24	3.70×10^{-7}
	Bi-214	728.085	0.11	8.01×10^{-8}	1.40	1.02×10^{-5}
	Pa-234M	2088.53	0.51	1.07×10^{-6}	0.038	7.94×10^{-7}
	Ra-226	404.685	280.00	1.13×10^{-4}	380.00	1.54×10^{-3}
	Co-60	266015	3.40	9.04×10^{-4}	0.24	6.38×10^{-4}
	Cs-137	1067.42	0. 025	2.67×10^{-8}	0.044	4.70×10^{-7}
	Ac-228	565.165	0.43	2.43×10^{-7}	1.70	9.61×10^{-6}
D-11	Bi-214	2027.67	0.11	2.23×10^{-7}	1.40	2.84×10^{-5}
	Eu-154	37.185	1.40	5.21×10^{-8}	0.021	7.81×10^{-9}
	Eu-154	231.47	1.40	3.24×10^{-7}	210.00	4.86×10^{-8}
	Ra-226	1598.59	280.00	4.48×10^{-4}	380.00	6.07×10^{-3}
	Co-60	18383.3	3.40	6.25×10^{-5}	0.24	4.41×10^{-5}
D-12	Cs-137	24514.4	0.0250	6.13×10^{-7}	0.044	1.08×10^{-5}
	Ac-228	2126.86	0.43	9.15×10^{-7}	1.70	3.62×10^{-5}
	Co-60	1011.3	3.40	3.44×10^{-6}	0.24	2.43×10^{-6}
	Bi-214	5207	0.11	5.73×10^{-7}	1.00	5.21×10^{-5}
D-13	Eu-154	260.797	1.40	3.65×10^{-7}	0 .021	5.48×10^{-8}
	Cs-137	3786.09	0.025	9.47×10^{-8}	0.044	1.67×10^{-6}
	Ac-228	180.46	0.43	7.76×10^{-8}	1.70	3.07×10^{-6}
D-14	Co-60	271.22	3.40	9.22×10^{-7}	0.24	6.51×10^{-7}
	Bi-214	696.33	0.11	7.66×10^{-8}	1.40	9.75×10^{-6}
	Cs-137	169.045	0.025	4.23×10^{-9}	0.044	7.44×10^{-8}
D-15	K-40	36.365	6.20	0	0.21	7.64×10^{-8}
	Cs-137	5847.89	0. 025	1.46×10^{-7}	0. 044	2.57×10^{-6}
D-16	Co-60	509.067	3.40	1.73×10^{-6}	0.24	1.22×10^{-6}
	Bi-214	1464.31	0.11	1.61×10^{-7}	1.40	2.05×10^{-5}
	Pa-234M	9958.6	0.51	5.08×10^{-6}	0.038	3.78×10^{-6}
	Cs-137	4689.62	0.025	1.17×10^{-7}	0.044	2.06×10^{-6}
	Co-60	18.27	3.40	6.21×10^{-8}	0.24	4.38×10^{-8}
D-17	K-40	131.607	6.20	8.16×10^{-7}	0.21	2.76×10^{-7}
	Co-60	445715	3.40	1.52×10^{-3}	0.24	1.07×10^{-3}
D-18	Cs-137	2786.14	0.025	6.97×10^{-8}	0.044	1.23×10^{-6}
	Cs-137	1548.97	0.02.5	3.87×10^{-8}	0.044	6.82×10^{-7}
D-19	Co-60	1032.25	3.40	3.51×10^{-6}	0.24	2.48×10^{-6}
	Ra-226	893.722	280.00	2.50×10^{-4}	380.00	3.40×10^{-3}
	Cs-137	179.387	0. 025	4.48×10^{-9}	0.044	7.89×10^{-8}
D-20	Bi-214	9.2075	0.11	1.01×10^{-9}	1.40	1.29×10^{-7}
	Pa-234M	2185.85	0.51	1.11×10^{-6}	0.038	8.31×10^{-7}

Table 3: The exposure rate, absorbed dose, AEDE, ELCR, I_α, I_γ and H_{in} values of radioactivity waste.

Drum No	Exposure rate µR/h	Absorbed dose rate nGy/h	AEDE (mSv/y)	ELCR ×10^{-3}	I_α	I_γ	H_{in}
D-01	80	700.8	0.98	3.43	0.016	0.068	0.035
D-02	70	613.2	0.86	3.00	0.017	0.063	0.034
D-03	56	490.56	0.69	2.40	0.005	0.023	0.011
D-04	15.4	134.904	0.19	0.66	0.006	0.018	0.010
D-05	9000	78840	110.38	3.86	0.0009	0.007	0.003
D-06	100	876	1.23	4.29	0.013	0.024	0.017
D-07	74	648.24	0.91	3.18	0.013	0.027	0.018
D-08	90	788.4	1.10	3.86	0.013	0.018	0.014
D-09	60	525.6	0.74	2.58	0	0	0
D-10	50	438	0.61	2.15	0.0035	0.007	0.004
D-11	72	630.72	0.88	3.09	0.002	0.008	0.004
D-12	88	770.88	1.08	3.78	0.007	0.031	0.016
D-13	90000	788400	1103.76	3860.00	0	0	0
D-14	7500	65700	91.98	322.00	0	0.002	0.0006
D-15	9000	78840	110.38	386.00	0	0.00002	0.000007
D-16	80	700.8	0.98	3.43	0	0	0
D-17	7600	66576	93.21	326.00	0	0.00008	0
D-18	8400	73584	103.02	361.00	0	0	0
D-19	660	5781.6	8.09	28.31	0	0	0
D-20	760	6657.6	9.32	32.61	0.004	0.0059	0.0059
Total	**133755.4**	1171697			**0.1004**	**0.30197**	**0.1725**

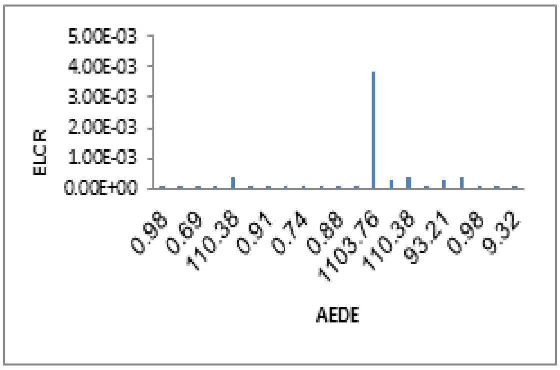

Figure 1: The relation between AEDE rate and ELCR

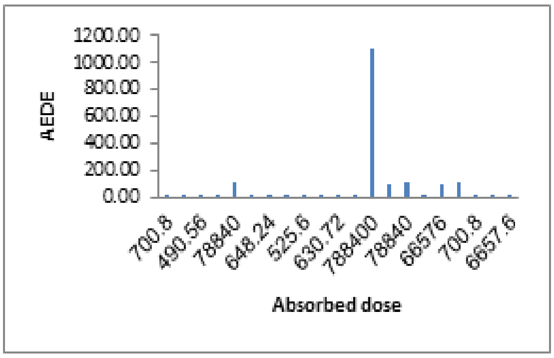

Figure 2: The relation between absorbed dose rate and AEDE rate

Figure 1 shows the high rate of ELCR of (3.86×10^{-3}) in (D-13) that is considered a high value compared to the global cancer risk rate of (0.29×10^{-3}) [18].
Figure (2) shows that the maximum absorbed dose rate was of the soil samples of D-13 which was 788400nGy/h = (1576.8 mSv/y) which is higher than the global dose rate of 20mSv/y [20].

The results of the study indicated various parameters related to radiation exposure and toxicity. The absorbed dose rate ranged from 134.904 nGy/h to 788400 nGy/h, reflecting the intensity of radiation exposure. The internal hazard index, representative gamma index, and representative alpha index are provided as measures of the potential hazard posed by internal radiation exposure. Furthermore, the excess lifetime cancer risk (ELCR) value was calculated, indicating the potential risk of developing cancer due to radiation exposure over a lifetime.

The range of Annual Effective Dose Equivalent (AEDE) was also provided, representing the estimated radiation dose received by individuals annually.

Overall, the study aimed to assess the radiotoxicity of the radioactive waste in the soil stored in drums at Al-Twaitha site, which provided valuable information for understanding the potential health and environmental impacts associated with nuclear energy and radioactive waste management.

4. Conclusions

The ingestion and inhalation of radioactive elements or materials generates a radiation dose called the committed dose whose effects are imminent and spread over long periods of time, which may reach an entire life. Therefore, those working in the field of radiation or those who are in contact with radioactive materials should take into account how radioactive materials are disposed of [21], and study ways to repair the damage generated by them in their bodies (type of radiation, half-life, radioactive decay, etc.).
The specific criteria for the extent of the activity of the radioactive source must be adhered to, and the value indicated in these criteria should not be exceeded. Must be to establishing a quality control program is essential and must be run in every activity or event where radioactive materials are handled.

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