Materials Science Forum
ISSN: 1662-9752, Vol. 1021, pp 191-199

Submitted: 2020-06-20
Revised: 2020-09-16
Accepted: 2020-10-05
Online: 2021-02-09

Estimation of Radionuclide Concentration in Medical Waste

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Keywords: Radionuclides, Medical waste, Pollution.

Abstract. Almost all hospitals use radioisotopes for different purposes, as their applications grow, so their concentration in the waste of those hospitals does. To address this issue, twenty-nine samples were collected from (9) sites, these samples were collected from the incinerators of medical areas and the waste collection chambers. After collecting the samples, they were prepared for the examination, where a high-purity Germanium detector (HPGe) was used to detect radioactive elements. The element lead (Pb-214) of the uranium chain (U-238), the actinium element (Ac-228), and the element lead (Pb-212) of the thorium chain (Th-246) as well as, the potassium element (K-40) appeared in some medical areas. Some regions showed high concentrations of these elements compared to some sites, Iodine (I-131) appeared in high rates in some hospitals specialized in treating cancerous diseases. The equivalent efficacy of radium, the annual equivalent internal and external dose, and the internal and external risk factors were calculated and the results obtained were compared with the global limits.

Introduction

The natural and industrial sources of radiation continuously affect humans, as radiation surrounds us from almost every aspect, whether natural or industrial [1]. Radiation activity is one of the main influencers on environmental safety, it has an impact that lasts for several years and affects the health and safety of living organisms in addition to its effect on air, water, and soil [2]. Waste is one of the most important environmental pollutants; it is classified according to our study to medical and industrial waste. Waste in Iraq is a problem that affects human health and safety [3]. The definition of medical waste can be put as the waste generated by health centers, facilities, and institutions, including laboratories, research centers, and clinics. The resulting waste is classified into non-hazardous waste, this represents the largest percentage of the waste generated, while the second type of waste is the hazardous waste, which is considered to be less in quantity than the non-hazardous waste, it is produced by the residues of surgical operations, laboratories, etc., but this type causes a greater pollution rate than the non-hazardous waste [4, 5]. On the other hand, industrial waste is the waste that results from industrial activity whether it was light or heavy, a large amount of waste is generated from industrial activity according to the quantity and type of production, construction, textile, chemical, or food industries. This type of waste has negative effects on the health of humans and the environment as well [6].

Given the importance of the subject of radiation and its impact on the environment in terms of increasing the proportion of radioactive contamination, whether it is from natural or industrial sources, it was necessary to detect it. Many studies were done aiming to measure the concentrations of radioactive materials in water, air, soil, plants and many materials as building materials, aiming to help provide a better life for the living organisms and also to show the extent of the influence of radioactive elements on the life cycle of the organisms [7].

Aim of this Research

The research aims to measure the extent of pollution with radioactive elements, whether natural or industrial, with measuring (U^{238}), (Th^{232}), (K^{40}) and (Cs^{137}) in medical waste, and also to detect Iodine (I-131) which we expect to find in these areas using the HPGe detector, and then reveal the effects of gamma radiation on humans.

The Theoretical Side

Calibration of the Detector

Calibration of the HPGe detector was performed by (Stander Sources multi-gamma CNF) as shown in Figure 1.

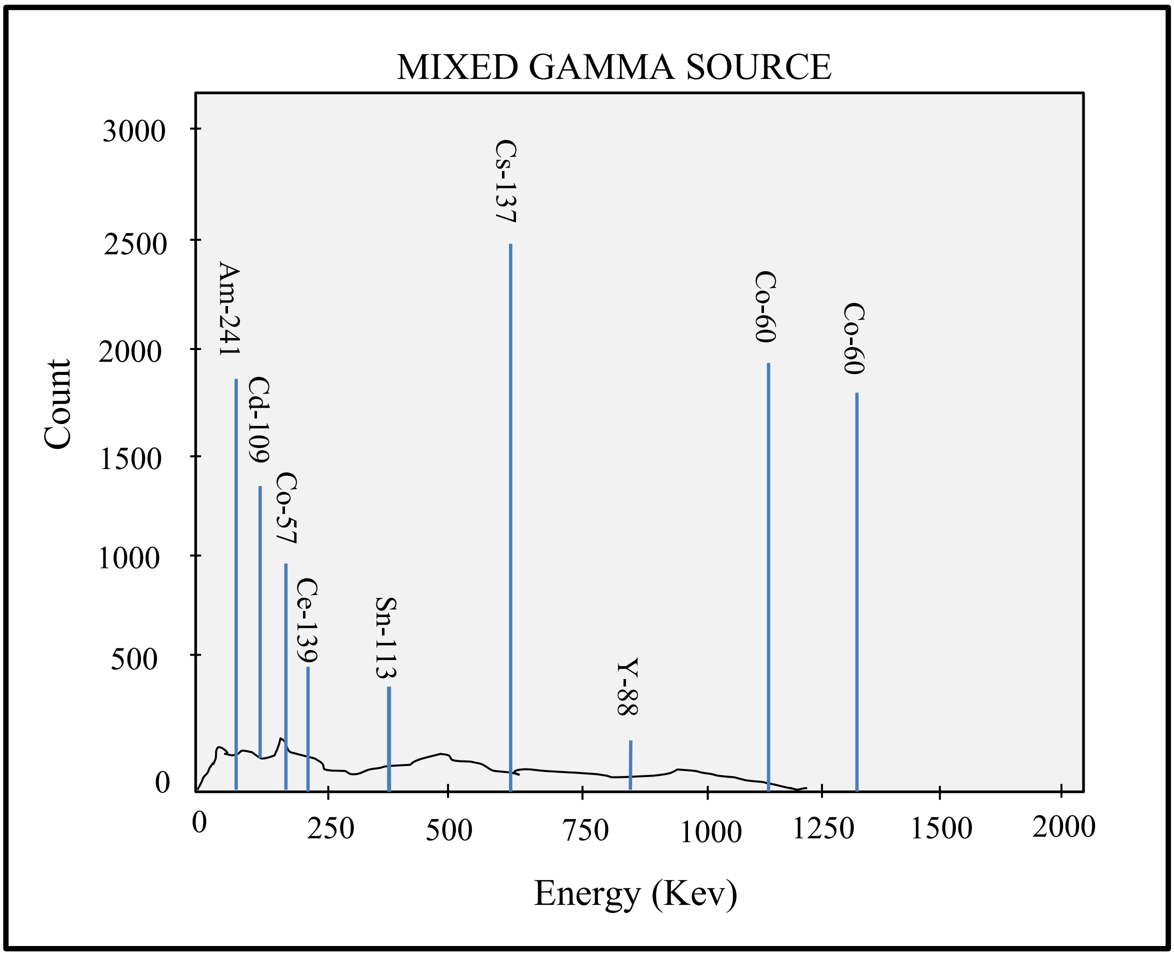

Figure 1 shows the calibration of the HPGe detector.

Calculating the Separation Capacity

To calculate the separation capacity of this device, we use equation 1

$$R= \frac{\Delta E}{\Delta Ch} \text{ x FWHM.} \quad \text{(Eq.1)}$$

where:
R: analytical capacity (separation capacity).
ΔE: the difference between two energies of the same element in the unit (Kev).
ΔCh: the difference between the peak and the calibration element is estimated by the channel unit
FWHM: width of the midline gamma line for peak height.

If we are to calculate the separation capacity for any of the radioactive elements and let it be (Co^{60}) according to equation 1

$$\Delta E = E_2 - E_2 = 1332.5\text{-}1173.2 = 159.3$$

$$\Delta Ch = Ch2 - Ch1 = 6195 - 5435 = 760 \text{ ch}$$

$$R = \frac{\Delta E}{\Delta Ch} \text{ x FWHM} = \frac{159.3}{760} \text{ x } 5.5 = 2.2 \text{ (Kev)}$$

The result that we obtained shows that the separation capacity of this device is very high, which means that the elements that appear in the measured samples can be adopted even if their energy reaches 2.2 (Kev).

Calculating the Efficacy of the Radioactive Source

To calculate the effectiveness of the radioactive source (A), we use equation (2).

$$A = A_0 e^{(-\lambda\, td)} \qquad \text{(Eq.2)}$$

where:
A 0: the activity of the radioactive source when it is made.
λ: the radioactive source of nuclear decay constant.
td: the time between the date of manufacture and the date of measurement
The decay constant (λ) can be calculated from equation (3)

$$\lambda = Ln(2)/t_{1/2}. \qquad \text{(Eq.3)}$$

Calculation of the Dose Absorbed in the Air from Gamma Rays (D_{γ})

The average absorbed dose in the air from gamma rays can be calculated at a height of one meter from earth's surface in (nGy / h) using the isotope efficacy which is thorium (Th^{232}), potassium (K^{40})and uranium (U^{238}) using equation 4 [8].

$$D_{\gamma} \text{ (nGy/h)} = 0.462A_U + 0.604A_{Th} + 0.0417A_K \qquad \text{(Eq.4)}$$

Calculating the Annual Effective Dose (AED)

The annual rate of the effective dose received by a person was calculated using the conversion factor of (0.7 Sv / Gy), where it was used to convert the rate absorbed in the air to the effective dose rate using the external (20%) and internal factor (80%), according to equations 3 and 4 [9].

$$(AED)_{in} \text{ (mSv/y)} = D_{\gamma} \text{ (nGy/h)} \times 10^{-6} \times 8760 \text{ h/y} \times 0.80 \times 0.7 \text{Sv/Gy} \qquad \text{(Eq.5)}$$

$$(AED)_{out} \text{ (mSv/y)} = D_{\gamma} \text{ (nGy/h)} \times 10^{-6} \times 8760 \text{ h/y} \times 0.20 \times 0.7 \text{Sv/Gy} \qquad \text{(Eq.6)}$$

Calculating the Radioactivity Concentration (I_{γ})

The radioactivity index (I_{γ}) of the samples is calculated from equation 7. [10]

$$I_{\gamma} = \frac{A_U}{150} + \frac{A_{Th}}{100} + \frac{A_K}{1500} \qquad \text{(Eq.7)}$$

where: A is the activity concentration of the radioactive element.

Calculating the Internal Hazards of Radioactivity (Hin)

Two indicators were identified by Mathew and Beretka in 1985 representing internal and external risks, with the aim of these indicators to reduce the radiation dose, knowingly the maximum value of radiation should be less than (1 mSv / y). The internal hazard index (H_{in}) is calculated using the equation 8. [10]

$$H_{in} = \frac{A_U}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \qquad \text{(Eq.8)}$$

Calculating the External Hazards of Radioactivity (Hex)

To calculate the external risk index (Hex) of radionuclides, the equation below was used [11]

$$H_{ex} = \frac{A_U}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad \text{(Eq.9)}$$

Calculating the Equivalent Dose for Radium (Ra Eq)

The equivalent value of this element is used to determine the risks of radium, thorium, and potassium. The element's concentration value can be estimated by the equation (10).

Ra eq=CRa+1.43CTh+0.077CK (Eq.10)

where:
(CRa): the concentration of radium or the resulting nuclide
(CTh): the concentration of thorium or the resulting nuclide
(CK): Potassium concentration.

The Practical Side

Nine sites were selected for sampling, which was conducted between 16/12/2019 to 13/01/2020, twenty-nine samples were collected from all study areas, samples collected from medical areas were from waste collection rooms, and incinerators of medical centers, with the weight of each sample being 100 grams. Table 1 shows the regions from which the samples were taken and the coordinates of each region.

After the collection, the samples were prepared and dried for examination. And for this purpose, an American high-purity Germanium detector (HPGe) was used. Tests were conducted at the Radiation Protection Center of the Iraqi Ministry of Health and Environment. This examination center was chosen because the device in this center holds an international examination certificate, which is the ISO certificate. Figure 2 shows the HPGe detector system.

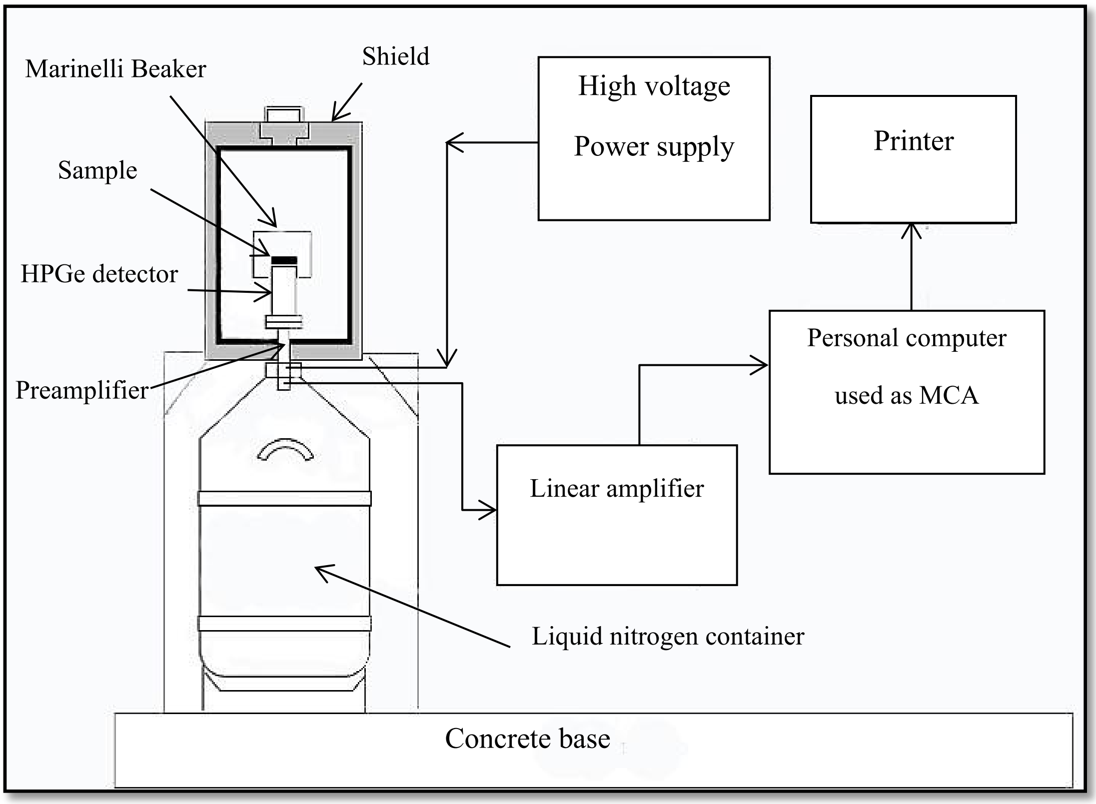

Figure 2 shows the system of high-purity germanium detector.

Table 1 shows study areas and their coordinates.

Location Name	Symbol	Coordinates	
		longitude	Latitude
Al Ramadi General Hospital	B	43,308709	33,435668
Medical City	H	44,375673	33.349511
Al Fallujah Women's and Children's Hospital	W	43,756041	33,351762
Al Ramadi Women's and Children's Hospital	L	43,284058	33.423671
Al Anbar Cancer Center	K	43,353303	33,453715
Al Amal Cancer Hospital	S	44,430607	33,316659
Baghdad Nuclear Medicine Center	J	44,375660	33.346555
Medical City Grinder	r	44,375679	33,349544
Al Fallujah General Hospital	O	43,793530	33,355039

Table 2 shows the average radioactive elements measured for several countries.

country	U-238 (Bq/kg)	Th-232 (Bq/kg)	K-40 (Bq/kg)	Reference
Egypt	7.68	8.07	27.20	[12]
Yemen	1.44	1.2	18.34	[13]
Iran	0.674	8.07	4.716	[14]
Saudi Arabia	0.17	3.3	339.2	[15]
Nigeria	7.75	19.09	-	[16]
India	56.74	87.42	143.04	[17]
Iraq	47.85	8.59	152.9	Current Study

Table 3 shows the concentration of radioactive elements in medical areas.

Region	**Sym**	**U-238 chain (Bq/kg)**		**TH-232 chain (Bq/kg)**		**K-40 (Bq/kg)**	**I-131 (Bq/kg)**	**CS-137 (Bq/kg)**
		Ra-226	**Pb-214**	**Ac-228**	**Pb-212**			
Al Ramadi General Hospital	**B1**	44±6	18.8±4.1	11.6±5	17±3	237.9±17	NF	**NF**
	B2	19.8±4	15.1±3	25.8±6	15.6±47	265.3±12	NF	**NF**
	B3	73.3±11	14.8±4	22.6±4.1	18.8±4	173.8±13	NF	**NF**
	B4	NF w	NF w	NF w	NF w	31.3±8	35.3±5	**NF**
Medical City	**H1**	NF	NF	2.8±0.7	NF	211.4±21.8	NF	**NF**
	H2	25.8±29	9.7±2.7	NF	9.9±1.7	14.9±4	NF	**NF**
	H3	57.3±7.4	14.6±3.6	6.1±0.9	7.6±1.4	165±14	NF	**NF**
	H4	29.4±3.9	10±2.5	NF w	7.1±0.9	144±12	NF	**NF**
Al Fallujah Women's Children's Hospital	**W1**	NF	NF	NF	8.1±1.9	154±14	NF	**NF**
	W2	37.5±9	14.6±4	NF	11.1±2.4	158.3±14	NF	**NF**
	W3	NF	15.4±3	NF	12.1±3.4	276±17	NF	**NF**
Al Ramadi Women's and Children's Hospital	**L1**	NF	41.1±9.1	NF	10.1±1.9	272.9±14	NF	**NF**
	L2	66.3±11	74.7±6	32.2±7	38.1±9	482.2±17	NF	**NF**
	L3	40.9±9	18±3	21.2±6	8.7±1.1	233±11	NF	**NF**
	L4	NF	NF w	NF w	NF w	34.3±5	NF	**NF**
Al Anbar Cancer Center	**K1**	NF	38.9±6	NF	10.2±1.9	339.7±17	NF	**NF**
	K2	NF w	NF w	NF w	NF w	25±4	NF	**NF**
	K3	NF w	NF w	NF w	NF w	NF w	312±14	**NF**

Al Amal Cancer Hospital	**S1**	31.7±9	23.8±7	16±3	14.6±3.9	NF	10.3±4	**NF**
	S2	NF	32.7±4.9	NF	23.5±4	309.3±27	66.8±13.3	**7.1±0.7**
	S3	NF w	NF w	NF	NF w	NF w	8440.2±414	**NF**
Baghdad Nuclear Medicine Center	**J1**	NF	412.5±13	NF	23.9±7	414±25	NF	**NF**
	J2	NF w	NF w	NF w	NF w	37.3±7	18.6±3	**NF**
	J3	NF w	NF w	NF w	NF w	NF w	3830±144	**NF**
Medical City Grinder	**r1**	65±4.9	14±3	13±2.4	7±1.5	180±11	NF	**2±0.4**
	r2	NF w	NF w	NF w	NF w	32.3±5	NF	**NF**
	r3	NF w	NF w	NF w	NF w	25.3±4	NF	**NF**
Al Fallujah General Hospital	**O1**	NF	15.2±3	NF	6.6±1.4	203±12	NF	**NF**
	O2	46±7.4	12±1.9	NF	5±0.8	15.2±4.1	NF	**NF**
Average		23.3±4.85	72.4±2.88	8.40±1.95	8.79±3.50	152.9±68.7	977.9±45.9	1.5±0.18

Table 4 shows the rate of radioactive elements obtained from the examination of samples for each region.

Location Name	U^{238} (Bq/kg)	Th^{232} (Bq/kg)	K^{40} (Bq/kg)	Cs^{137} (Bq/kg)	I-131 (Bq/kg)
Al Ramadi General Hospital	30.95±5.3	18.55±9.3	177.07±12.5	NF	35.3±5
Medical City	24.46±8.15	6.32±1.05	133.8±12.9	NF	NF
Al Fallujah Women's and Children's Hospital	26.25±6.2	10.53±2.56	162.7±15	NF	NF
Al Ramadi Women's and Children's Hospital	49.1±8.01	22.8±5.2	255.6±11.7	NF	NF
Al Anbar Cancer Center	38.9±6	10.2±1.9	182.3±10.5	NF	312±14
Al Amal Cancer Hospital	27.7±8	17.5±4.7	309.3±27	7.1±0.7	2839.1±143.7
Baghdad Nuclear Medicine Center	412.5±13	23.9±7	225.6±16	NF	1924.3±73.5
Medical City Grinder	39.5±3.9	9.5±1.9	79.2±6.6	2±0.4	NF
Al Fallujah General Hospital	29.8±4.9	5.8±1.2	109.1±8.05	NF	NF
Average	75.46±7.05	13.9±3.86	181.63±13.3	4.55±0.55	1277.6±59.05
Global limit [18]	35	30	400	14.8[9]	-

Calculation of Radiation Hazard Indicators

The hazard indicators for radioactive elements were calculated for each study area as shown in Table 5.

Table 5 shows the hazard factor for medical areas.

NO	Sym.	Ra_{eq} (Bq/kg)	D (nGy/h)	Hazard index		A.E.D (mSv/y)		I^{γ}
				H_{ex}	H_{in}	E_{in}	E_{out}	
1	B	71.11	33.20	0.192	0.275	0.126	0.040	0.509
2	H	43.80	19.69	0.117	0.184	0.096	0.024	0.315
3	W	53.83	25.44	0.145	0.216	0.124	0.031	0.388
4	L	101.38	47.49	0.273	0.406	0.232	0.058	0.725
5	K	67.52	31.88	0.182	0.287	0.156	0.039	0.482
6	S	76.54	36.57	0.206	0.281	0.179	0.044	0.565
7	J	465.04	215.69	1.254	2.368	1.058	0.264	3.139
8	r	59.18	27.43	0.159	0.266	0.134	0.033	0.411
9	O	46.49	21.90	0.125	0.206	0.107	0.026	0.329
Global limit [18]		370	55	1	1	1	1	1

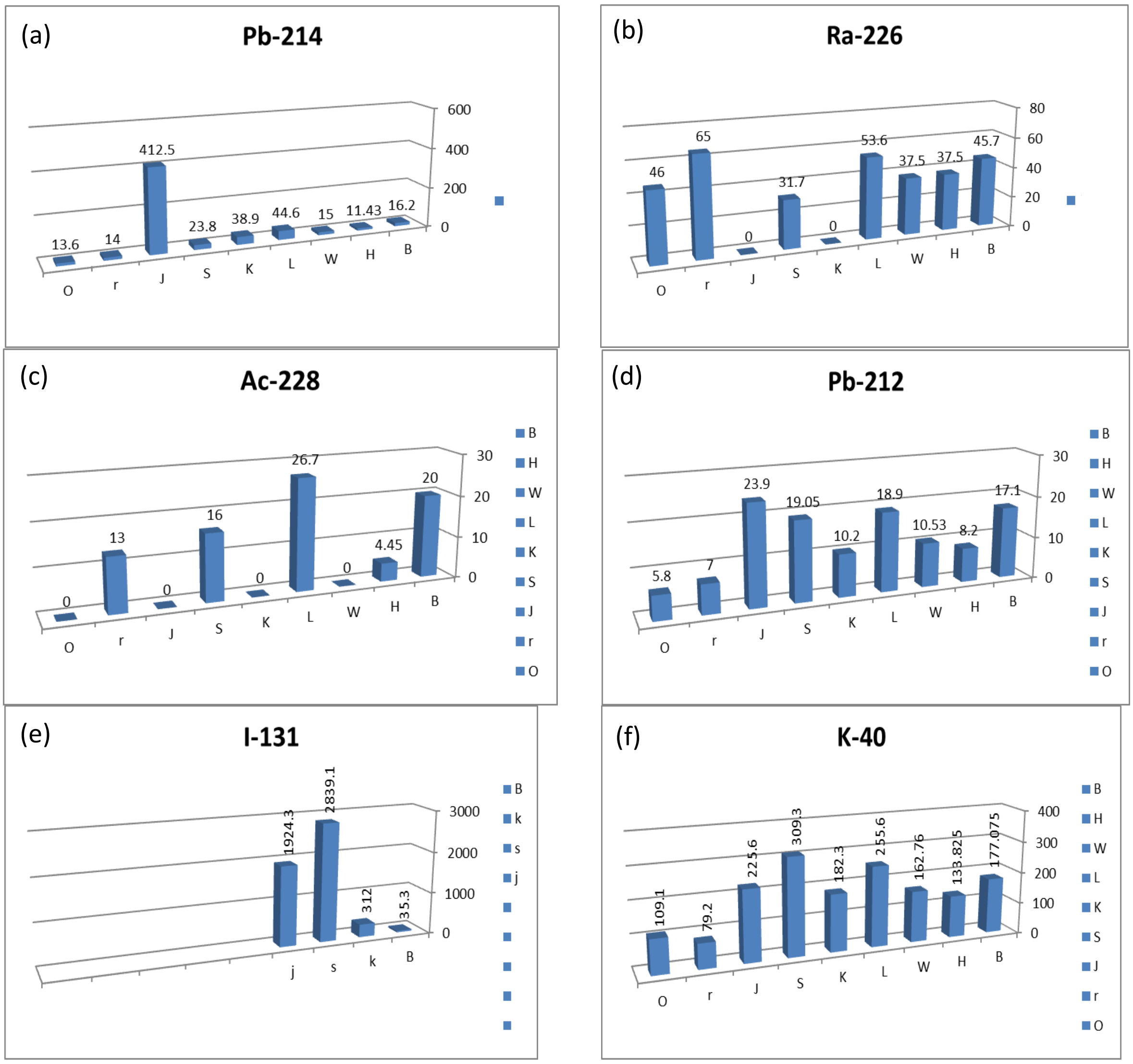

Figure 3 Charts of radionuclides concentration in the medical regions.

Results

After examining the samples, obtaining the results, and taking the rate of examination for each of the study areas, it was found that the radium (Ra-226) element of the uranium chain (U-238) had been shown at a high rate in the waste section of Medical City at a rate of (65 ± 4.9 Bq / kg). It was followed by the Ramadi Hospital for Women and Children with a rate of (53.6 ± 10 Bq / kg), while the rate of ratios in other locations ranged between (46 ± 7.4 Bq / kg) in the Fallujah General Hospital to (31.7 ± 9 Bq / kg) in Al Amal Hospital for Oncology, however, it did not appear in some locations, such as the Baghdad Center for Nuclear Medicine and the Anbar Cancer Center. As for the lead element (Pb-212), which is also related to uranium chain (U-238), it appeared in all study sites, with the highest being at the Baghdad Center for Nuclear Medicine at a rate of (412.5 ± 13Bq / kg), Ramadi Hospital for Women and Children came as (44.6 ± 6.03Bq / kg), then the Anbar Cancer Center at a rate of (38.9 ± 6 Bq / kg), while the average rate in other locations ranged between (23.8 ± 6 Bq / kg) in Al Amal Cancer Hospital to (13.6 ± 2.45 Bq / kg) in Fallujah General Hospital.

As for the actinium component (Ac-228) of the thorium chain (Th-232), it appeared at the highest percentage in Ramadi Hospital for Women and Children compared to other sites at a rate of (26.7 ± 6.5Bq / kg), followed by Ramadi General Hospital with a rate of (20 ± 5.07 Bq / kg) While its average prevalence in other sites ranged from (16 ± 3 Bq / kg) in Al Amal Cancer Hospital to (4.45 ± 0.8 Bq / kg), while it did not appear in four sites, which are the Fallujah General Hospital, the Baghdad Center for Nuclear Medicine, the Anbar Cancer Center, and the Fallujah Women's and Children's Hospital.

The lead component (Pb-212) of the thorium chain (Th-232), it appeared in all locations and recorded the highest rate in the Baghdad Center for Nuclear Medicine compared to other sites at a rate of (23.9 ± 7 Bq / kg), next is Al Amal Cancer Hospital at a rate of (19.05 ± 6.5 Bq / kg), then the Ramadi Hospital for Women and Children with a rate of (18.9 ± 4 Bq / kg), the Ramadi General Hospital at a rate of (17.1 ± 18 Bq / kg) being the least of these four sites, whereas the incidence of this component in other sites ranged between (10.53 ± 2.56 Bq / kg) In Fallujah Women's and Children's Hospital to (5.8 ± 1.1 Bq / kg) at the Fallujah General Hospital.

As for potassium (K-40), it appeared in all the sites, where it was shown at a high rate in Al Amal Cancer Hospital compared to other sites at a rate of (309.3 ± 27 Bq / kg), Al Ramadi Hospital for Women and Children at a rate of (255.6 ± 11.75 Bq / kg), Baghdad center for Nuclear Medicine at a rate of (225.6 ± 16 Bq / kg), then the Anbar Cancer Center at a rate of (182.3 ± 10.5Bq / kg), whereas the incidence of this component in the rest of the locations ranged between (177.075 ± 12.5Bq / kg) in Ramadi General Hospital to (79.2 ± 6.66 Bq / kg) in the Medical City waste. Cesium (Cs-137) has appeared in small proportions in only two locations, which are Al Amal Cancer Hospital at a rate of (7.1 ± 0.7 Bq / kg) and the waste grinder of the Medical City at a rate of (2 ± 0.4 Bq / kg). As for Iodine (I-131), it appeared in only four sites, it appeared at a very high rate in Al Amal Cancer Hospital (2839.1 ± 143.7Bq / kg), next is the Baghdad Center for Nuclear Medicine at a rate of (1924.3 ± 73.5Bq / kg), then the Anbar cancer Center with a rate of (312 ± 14Bq / kg), and the least was of Ramadi General Hospital at a rate of (35.3 ± 5Bq / kg).

Conclusions

Radioisotopes are used extensively nowadays in hospitals, their use is essential in diagnosing various diseases and conditions. This inevitably led to an increase in their concentration in the medical waste, it has appeared as per our results in Table 4, that Uranium (U^{238}) has passed the Global limit (35q/kg) in the samples of Baghdad Center of Nuclear medicine, Ramadi Women's and Children's Hospital, Medical City grinder, and Anbar Cancers Center. As for Thorium (Th^{232}), it was found that it is below the global limit (30Bq/kg) in all samples, Potassium (K^{40}) was found to be below the global limit too (400Bq/kg) in all samples. Cesium (Cs^{137}) is found in two regions which are; Al Amal Cancers Hospital and Medical City grinder, and it was below the global limit

(14.8 Bq/kg). Iodine (I^{131}) has appeared in a very high concentration in Al Amal Cancers Hospital, it also appeared in a lesser concentration in Baghdad Nuclear Medicine Center and Anbar Cancers Center too, it also appeared in a very small concentration in Ramadi General Hospital.

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