Journal of University of Babylon for Pure and Applied Sciences,Vol.(27), No.(4): 2019

Gamma Dose Measuring for the Rice Sample in Slemani City Markets, Kurdistan Region – Iraq

Adil M. Hussein

Advance Nuclear Laboratory, Physic Department, College of Science, University of Sulaimani, Slemani- Iraq

adel.hossien@univsul.edu.iq

Submission date:- 12/12/2018 Acceptance date:- 20/1/2019 Publication date:- 1/4/2019

Keywords: Rice Radioactivity, Gamma Measurement, Radium-226, Thoruim-232 and Potassuim-40 Activity Concentrations, Radium Equivalent, ingestion dose, intake annual effective dose of rice samples.

Abstract

In this study, the Radium-226, Thoruim-232 and Potassuim-40 in the selected fourteen types of rice samples were collected from local markets in Slemani city- Kurdistan region- Iraq. The concentrations were determined by using scintillation detector (NaI (Tl) -3x3). The results of the Radium-226, Thoruim-232 and Potassuim-40 specific activities in rice samples were ranged (0.55 – 5.7) Bq Kg^{-1}, (0.6 – 4.66) $BqKg^{-1}$ and (16.11 – 20.02) Bq Kg^{-1}, respectively. The average value of the radium equivalent activity ($Ra_{(eq)}$) was below the average worldwide values as reported by UNSCEAR. The values of total annual effective dose (E_t) of the rice samples, ranged from 64.66 to 355.62 $\mu Sv\, y^{-1}$. The E_t value of each of Thailand- Kallasher and Slemany_ Banikhellan samples were (355.62, 344.38) $\mu Sv\, y^{-1}$, which were higher than the the average worldwide value 290 $\mu Sv\, y^{-1}$ as reported by UNSCEAR. In general, the mean value of E_t was 196.20 $\mu Sv\, y^{-1}$. Therefore, the studied samples are safe in term of the radiological health hazards.

1. Introduction

Environmental pollution has various types; water pollution is a numerous permanent problem, but it has gained a non-controlled dimension lately because most of the pollution types transfer via the flowing water cause to increase problems of population; sewage disposal, industrial waste, radioactive waste, etc.. Terrestrial radionuclides transfer in a complex cyclic pathway (terrestrial- water- plant- animal - human). Terrestrial and aquatic food chains are capable to transfer the natural radionuclides to humans through ingestion of food [1]. In case of water pollute with a radiation causes to exposure humans and their foodstuffs to various types of radiation that are originated from primordial, Cosmo-genic, terrestrial, natural decay series. Radionuclides can enter our body through either ingestion of food and water or inhalation air. One of the water pollution with radiation case is public exposure to waterborne Radon-222 and its short-lived radioactive progenies/decay products (viz., such as Polonium-218, Lead-214, Bismuth-214 and Polonium-214), may occur directly by ingestion (drinking water containing Radon-222) posing a potential health risk [2], but indirectly by transfer the fractional of radiation dose to human in a cyclic closed pathway.

The meals are mainly based on rice, which contains an amount of radioactivity that deposes in human body organs. Uranium-238, Thorium-232 and their progeny besides Potassium-40 are available in food and water extremely [3]. Approximately, half the radioactivity detected in humans return to Potassium-40, when the Potassium-40 enters the body from the consuming vegetables and food. In addition, the ionization radiation coming from Potassium-40 causes cell damage and induce the cancer cells [4]. Potassium-40 ratio in soils based on chemical fertilizer (phosphate) ratio in agricultural land. In other side, food crops are contaminated in direct and indirect pathways by uranium-series radionuclides [5]. The previous studies about animal and human, showed the evidence data to indicate that a fraction of Strontium-90 and Radium-226, distributed instantaneously throughout the bone volume [6].

Natural radionuclides ingestion depends on the consumption rates of; food, water and their radionuclide concentrations. Long-term dose exposes to various organs of the body; this would be done extremely by ingestion of radionuclides through food intake [7].

The amount of local rice production is not sufficient to provide the Iraqi markets, especially in Slemani city, that causes to import the sufficient amount of rice from the different countries. The present work tries to collect the rice samples in the Slemani city markets that import from different countries. The previous studies concluded that different intake rate of natural radionuclides may vary considerably from one area to another because of radionuclides concentration differences among food types in the diet [8]. Based on this fact, the samples were measured by gamma measuring system, which was contain NaI (Tl)-3x3 detector, Digital Spectroscopy Analyser (DSA-1000) and Genie- 2000 software to determine the concentration rate of each natural radionuclide and then calculating the intake annual effective dose for each of natural radionuclides [9].

2. Methodology

2.1 Gamma measuring System

Fourteen types of rice samples were collected to determine radionuclides' activity concentration. Some of them were obtained from local markets of the Slemani city. The concentration distribution of Raduim-226, Thorium-232, and Potassium-40 in the rice samples found in $Bq\,kg^{-1}$ such as; Sevan - India, China, Italy, Argentina- Saman, Vietnam, India - Bwan, Iraqi- Ambar, Spain -Aura, Slemany- Banikhellan, Turkey- Hunkar, Thailand - Kallasher, USA - Lorance, Uruguay – Saman and Russia- Grda. The rice samples crashed into less than 0.650 μm as shown in Fig.1. Each sample was weighted (1 kg) without the weight of plastic tube (Marnelli beaker). The samples were sealed and kept one month in a Marnelli beaker to achieve secular equilibrium between Raduim-226, Radon-222 and their progenies [10].

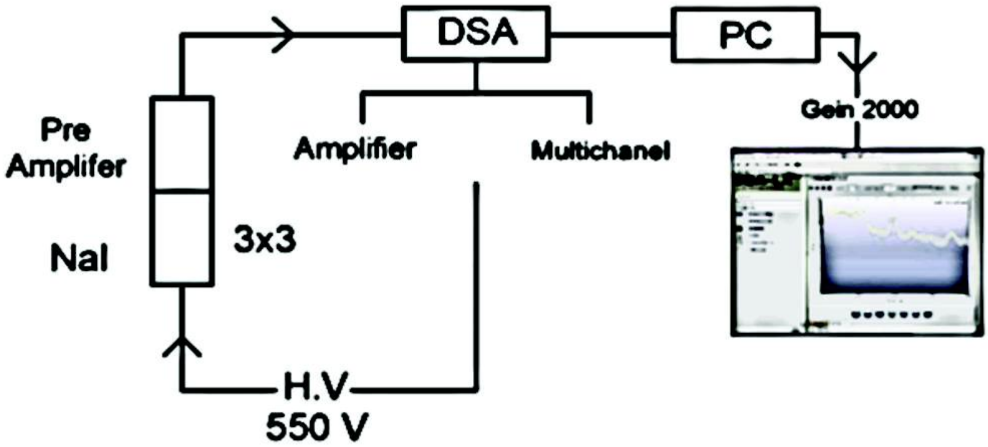

Fig.1. Sample containers and the gamma measuring system in the ANR Laboratory

After that, the natural radionuclides (Raduim-226, Thorium-232, and Potassium-40) of rice samples were detected using the NaI (Tl) $3_{in} \times 3_{in}$ detector with an energy resolution of about 7.5% at the 662 keV peak of Cesium-137, the detector was connected to the DSA-1000. Furthermore, the detector was enclosed with by a cylindrical lead shield (10.0 cm thick and 40 cm height) fixed on steel holder and covered by a thick (5cm) lead to reduce the background radiation [11].

These devices were connected to the PC that Genie- 2000 is installed on it. Genie- 2000 has some functions such as; MCA, spectral display, basic spectrum analysis, determining peak energy to alpha- gamma spectrum and reporting. In addition, Genie- 2000 capable reduces pile up of gamma energy peak to 2 keV as shown in Table 1 [9].

Table 1. Peak energy analysis report of China rice sample.

Peak Analysis Report 2/9/2018 9:06:43 AM Page 1

****
***** S T A N D A R D V M S P E A K A N A L Y S I S R E P O R T *****
****

Configuration Title:
Spectrum Title: Sample title.
Peak Analysis Performed on: 2/9/18 9:06:43 AM
Peak Analysis From Channel: 3 To Channel: 1024
Peak Search Sensitivity: 3.00 Gaussian Sensitivity: 10.00
Max Iterations: 10 Fit Singlets: Yes Critical Level Test: Yes
Use Fixed FWHM: Yes FWHM Reject: Yes FWHM Reject Ratio: 0.00
Peak Fit Engine Name: NDSTD Continuum Type: STEP

	Pk	IT	Energy	Area	Bkgnd	FWHM	Channel	Left	PW	Cts/Sec	%err	Fit
M	1	2	108.55	9539	60135	23.32	20.85	11	102	1.2E-001	5.6	57.5
m	2	2	138.29	67592	90524	26.55	32.12	11	102	8.8E-001	1.1	57.5
m	3	2	172.52	16686	109352	29.65	45.10	11	102	2.2E-001	5.0	57.5
m	4	2	194.41	19655	120224	32.04	53.39	11	102	2.6E-001	4.4	57.5
m	5	2	214.81	18922	131386	33.28	61.13	11	102	2.5E-001	4.8	57.5
m	6	2	238.94	19815	143632	34.85	70.28	11	102	2.6E-001	4.8	57.5
m	7	2	262.70	15745	152906	36.17	79.28	11	102	2.1E-001	6.2	57.5
m	8	2	299.86	18715	156595	38.68	93.37	11	102	2.4E-001	5.0	57.5
F	9	1	559.40	8910	71821	53.17	191.75	174	32	1.2E-001	6.2	5.4
F	10	1	643.94	13794	67449	57.23	223.80	205	39	1.8E-001	4.3	2.9
F	11	1	1125.12	6036	42623	75.60	406.21	378	58	7.9E-002	9.0	1.1
F	12	1	1443.44	37830	29294	85.56	526.87	480	85	4.9E-001	1.5	15.7
F	13	1	1729.69	4801	13313	93.69	635.39	595	78	6.3E-002	7.3	2.0
M	14	1	2072.91	2747	9602	102.0	765.49	713	137	3.6E-002	12.0	1.8
m	15	1	2155.88	707	8688	104.0	796.95	713	137	9.2E-003	47.4	1.8
m	16	1	2211.42	1652	4804	105.9	818.00	713	137	2.2E-002	12.6	1.8
M	17	10	2533.35	8686	3450	112.3	940.04	882	106	1.1E-001	2.5	181.3
m	18	10	2535.39	6952	3334	112.6	940.81	882	106	9.1E-002	3.0	181.3
m	19	10	2651.91	2142	113	114.1	984.98	882	106	2.8E-002	0.8	181.3

M = First peak in a multiplet region
m = Other peak in a multiplet region
F = Fitted singlet

Errors quoted at 1.000 sigma

All mentioned devices were prepared by Canberra industries INC. and arranged as a system as shown in Fig.2.

Fig.2. The gamma measuring system of the rice samples.

The energy calibration was fulfilled using multi-nuclide gamma-ray (Europium-155, Cobalt-57, Tin-113, Cesium-137, Manganese-54, Zinc-65) source, which prepared by (Canberra Industries, INC) to cover the low and high energy range from 122.1 to 1332.5 keV through 18000 second. The samples put into Marnelli beaker then placed on the top of the detector and were counted for 86,400 seconds to reduce the counting error that agree with [12]. The measurements of gamma ray for samples were done in the Advance Nuclear Laboratory- Physic Department- College of Science - University of Sulaimani- Iraq.

The obtained radionuclides spectrum of the rice samples based on the energy peaks of the progenies. The activity concentration of Radium-226 was calculated via energy peaks of its progynies as Bismuth-214 (1764.5, 2204) keV and Lead-214(295, 351 keV), while the specific activity of Thorium-232 has been calculated based on the energy peaks of Thalium-208 (2614.5) keV and Lead-212 (238 keV), Actinium-228 (911,969) keV, the last one is unique energy peak 1460 KeV identified Potassium-40. Selection of these enrgy peaks agreed with prious studies [13, 14].

2.2 Gamma radiological parameters calculation

The natural radionuclides activity concentrations of the rice samples were calculated by subtracting the area peak energy from the background, However the program sofware redmove the background radiation too, using an equation as [15,16].

$$A_c = \sum_{i=1}^{i=n} \frac{N_p(i)-N_B(i)}{T\ I_\gamma(i)\ \varepsilon(i)\ M} \qquad (1)$$

Where A_c is the activity concentrations of the samples in Bq Kg^{-1}, N_p is net area under peak, N_B is background area under peak, n is number of the decay product of natural series radionuclides, T is time of counting in sec, I_γ is the absolute transition probability, ε is detector efficiency for the corresponding peak and M is the weight of the rice samples in Kg.

The radium equivalent activity ($Ra_{(eq)}$) is derived from the three principal natural rdionuclides given as [17],

$$Ra_{(eq)} = A_{\mathrm{Ra}} + 1.43\,\mathrm{A_{Th}} + 0.077\mathrm{A_K} \qquad (2)$$

where A_{Ra} , A_{Th}, $\mathrm{A_{Ra}}$ are specific activities of Raduim-226, Thorium-232, and Potassium-40, respectively.

Intake dose

The annual effective dose of the individual intake of the natural radionuclides from the consumption of rice has been calculated by the following relation [18] and presented in Table2.

$$E_{ann} = A_c * A_{ing} * e_{ing} \qquad (3)$$

Where, E_{ann} is the annual effective dose ($\mu Sv\, y^{-1}$) of an ingestion radionuclides, A_c is the activity concentration of radionuclides ($Bq\ kg^{-1}$), A_{ing} is the average worldwide annual intake per capita consumption of rice is 140 $kg\ y^{-1}$, and e_{ing} is the ingestion dose conversion factor for the radionuclides (0.28 $\mu Sv\ Bq^{-1}$for ^{226}Ra, 0.23 $\mu Sv\ Bq^{-1}$ for ^{232}Th and 6.2 * 10^{-3} $\mu Sv\ Bq^{-1}$for Potassium-40) [19, 20]. The total ingestion dose (E_t) due to the intake of radionuclides via consumption of rice samples based on formula (3) is given as,

$$E_t = \sum_{n=1}^{n=3} E_{ann}(n) \qquad (4)$$

where n is the number of individual radionuclide.

3. Results and conclusions

This study focused on the pure activity of the radionuclides present in samples. Radioactivity distribution in rice samples used NaI (Tl) detector to determine the radioactive level of Raduim-226, Thorium-232, and Potassium-40 and thier intake doses. The radionuclides Raduim-226, Thorium-232, and Potassium-40 in 1Kg of rice are not exposure the radiation uniformly. The radium equivalent activity ($Ra_{(eq)}$) in Bq kg^{-1} presents all specific activities (Raduim-226, Thorium-232, and Potassium-40) of rice samples, it was calculated using Eq. 2. The activity concentration of Raduim-226, Thorium-232, and Potassium-40 in rice samples ranged as (0.55 – 5.7) Bq Kg^{-1}, (0.6 – 4.66) Bq Kg^{-1}, and (16.11 – 20.02) Bq Kg^{-1}, respectively.

Table 2 showed that the maximum value of activity concentrations for each of Thorium-232, and Potassium-40 recorded by Russia- Grda rice sample, while the minimum values of them return to China rice. The mean activity concentration observed, as any raw terrestrial materials, the highest value return to Potassium-40, followed by Raduim-226 which was close to Thorium-232 value (17.76 > 2.59 > 2.46). The Raduim-226 activity concentration values of; Italy, Urguay- Saman and USA – Lorance rice samples were recorded the lowest activity (0.55, 0.6, 0.64) Bq Kg^{-1}, respectively. The highest activity concentration value of Raduim-226 was found in Thailand- Kallasher_rice 5.7 Bq Kg^{-1}. Fortunately, the maximum values of the radionuclides activity concentration were lower than the average worldwide value (30 Bq kg^{-1}) [20]. In addition, Table 2 showed that the maximum value of the $Ra_{(eq)}$ was found in Thailand- Kallasher_rice, and the minimum vale return to China rice.

Table 2. The specific activity of Raduim-226, Thorium-232, and Potassium-40, the radium equivalent activity ($Ra_{(eq)}$) and their annual effective dose of the rice samples.

Rice Samples	Specific Activity o fA_c (Bq kg^{-1})			$Ra_{(eq)}$ (Bq kg^{-1})	Annual Effective Dose E_{ann} ($\mu Sv\ y^{-1}$)			Total annual effective dose
	^{226}Ra	^{232}Th	^{40}K		^{226}Ra	^{232}Th	^{40}K	E_t ($\mu Sv\ y^{-1}$)
India (Sevan)	2.89	1.90	19.48	7.11	113.28	61.29	16.91	191.48
China	0.80	0.60	16.11	2.90	31.36	19.32	13.98	64.66
Italy	0.55	1.82	17.90	4.53	21.56	58.60	15.54	95.70
Argentina (Saman)	4.06	0.92	17.20	6.70	159.15	29.62	14.93	203.70
Vietnam	2.46	3.58	16.79	8.87	96.43	115.28	14.57	226.28
India (Bwan)	2.56	2.30	18.66	7.29	100.35	74.06	16.20	190.61
Iraq (Ambar)	1.43	2.82	18.94	6.92	56.06	90.80	16.44	163.30
Spain (Aura)	4.78	1.87	18.32	8.86	187.38	60.21	15.90	263.49
Iraq-Slemany (Banikhellan)	5.12	3.98	17.60	12.18	200.79	128.32	15.28	344.38
Turkey (Hunkar)	2.18	1.94	17.44	6.30	85.56	62.47	15.13	163.17
Thailand (Kallasher)	5.70	3.66	16.52	12.21	223.43	117.85	14.34	355.62
USA (Lorance)	0.64	1.73	16.94	4.42	25.19	55.73	14.71	95.62
Uruguay (Saman)	0.60	2.65	16.65	5.67	23.52	85.33	14.45	123.30
Russia (Grda)	2.50	4.66	20.02	10.71	98.00	150.05	17.38	265.43
Mean	2.59	2.46	17.76	7.48	101.58	79.21	15.41	196.20
Max.	5.7	4.66	20.02	12.21	223.43	150.05	17.38	355.62
Min.	0.55	0.6	16.11	2.9	21.56	19.32	13.98	64.66

The annual effective dose (E_{ann}) value of both of Raduim-226 and Thorium-232 for each of (India-Sevan, Argentina- Saman, Vietnam, India- Bawan, Iraq- Ambar, Spain- Aura, Iraq- Slemany_ Banikhellan, Turkey- Hunkar, Thailand- Kallasher and Russia- Grda) rice samples were exceeded the average worldwide value 120 $\mu Sv\ y^{-1}$ and tabulated in Table 2. The total annual effective dose (E_t) value of each of Thailand- Kallasher and Slemany_ Banikhellan samples were (355.62, 344.38) $\mu Sv\ y^{-1}$, which were higher than the the average worldwide value 290 $\mu Sv\ y^{-1}$[20]. The minimum value of E_t recorded by China rice was (64.66 $\mu Sv\ y^{-1}$).

4.Conclusions

The study of natural radioactivity in the rice samples is usually done in order to gain information about the levels of radioactivity risk in the intake natural radionuclides. The highest radionuclide concentration value was found in Potassium-40 among the three natural radioactivity, because Potassium-40 is an essential element of the fertilizers for plant. The E_t values of most of the samples were under the average worldwide value 290 $\mu Sv\ y^{-1}$. Therefore, the use of these rice samples for eating is considered to be safe in general. The mean value of the E_t is (196.2 $\mu Sv\ y^{-1}$) lower than the average worldwide value, this fact caurages the author to suggest that the hapitant can use all type of rice. This type of work regards as the baseline data to make estimations of internal exposure for the inhabitance of the studied area.

CONFLICT OF INTERESTS

There are no conflicts of interest.

References

[1] A. Abid Abojassim, H. Hamad Al-Gazaly and S. Hade Kadhim," Estimated the radiation hazard indices and ingestion effective dose in wheat flour samples of Iraq markets", *International Journal of Food Contamination*, 1:6, 2014.

[2] Ravi kumar P. and Somashekar R. K., "Determination of the radiation dose due to radon ingestion and inhalation*", International Journal of Environment Science and Technology*, vol.11, pp.493–508, 2014.

[3] Asaduzzaman Kh., Khandaker M.U., Amin Y.M., Mahat R.," Uptake and distribution of natural radioactivity in rice from soil in north and west part of peninsular Malaysia for the estimation of ingestion dose to man", *Annals of Nuclear Energy*, vol. 76, pp. 85-93, 2015.

[4] Shafaei, M.A. Saion, E., Wood, K., Naghavi, K., Rezaee, Kh., 2011, Evaluation of 40K in vegetables collected Malaysia by determination total potassium using neutron activation analysis, Journal of Radioanalytical and Nuclear Chemistry , Vol. 288, pp.599–602, 2011.

[5] Ali H. A. and A. Ali Gafur, "Natural Radioactivity Measurements of Soil Samples from Soran District in Kurdistan Region- Iraq", *Solid State Science and Technology*, vol.22, no. (1 & 2), pp. 26-39, 2014.

[6] International Atomic Energy Agency (IAEA), "Assessment of Occupational Exposure due to Intakes of Radionuclides", *Safety Standards Series*, no. RS- G- 1.2, Vienna, 1999.

[7] Jibiri, N.N., Farai, I.P., Alausa, S.K., "Activity concentrations of 226Ra, 228Th, and 40K in different food crops from a high background radiation area in Bitsichi", *Jos Plateau, Nigeria, Radiation Environment Biophysics*, vol. 46, pp. 53–59, , 2007.

[8] Al-Masri, M.S., Mukallati, H., Al-Hamwi, A., Khalili, H., Hassan, M., Assaf, H., Amin, Y., Nashawati, A., "Natural radionuclides in Syrian diet and their daily intake", *Journal of Radioanalytical and Nuclear Chemistry*, vol. 260, pp.405- 412 , 2004.

[9] Adil M. Hussein, "Pulse Shape Processing to Correct Pile Up and Dead Time at high Count Rate by Using Digital Spectroscopy Analyser (DSA)", *Journal of Zankoy Sulaimani*, Part A, vol.10, no.1, pp. 113-123, 2007.

[10] Abdullah K. M-S and Ahmed M.T., "Environmental and Radiological Pollution in Creek Sediement and Water from Duhok, Iraq", *The Nucleus*, vol. 49, no.1, pp. 49-59, 2012.

[11] K. Omar Abdullah , "Natural Radioactivity Measurements of soil and water in Sulaimani Governorates", PhD thesis, Univ. of Sulaimani, Slemani, Iraq, 2013.

[12] K. K. Ali, S. M. Awadh, M. R. Al-Auweidy, "Assessment natural radioactivity of marl as raw material at Kufa Cement Quarry in Najaf Governorate", *Iraqi Journal of Science*, Part A,vol.55, no. 2, pp.454-462, 2014.

[13] H. Kayakökü, Ş. Karatepe, M. Doğru, "Measurements of radioactivity and dose assessments in some building materials in Bitlis, Turkey*", Applied Radiation and Isotopes*, vol. 115, pp.172-179, 2016.

[14] El-Taher, "Assessment of Natural Radioactivity Levels and Radiation Hazards for Building Materials Used in Qassim Area, Saudi Arabia", *Romanian Journal of Physics*, vol. 57, no. 3–4, pp.726–735, 2012.

[15] Hussain H. H and Ali A. S., "Natural Radioactive Survey around Kufa cement factory", *Journal of Kufa – Physics*, vol. 6, no. 1, 64-73, 2014.

[16] L. A. Najam, F. M. AL-Jomaily, "Natural radioactivity levels of limestone rocks in northern Iraq using gamma spectroscopy and nuclear track detector", *Journal of Radioanalytical and Nuclear Chemistry*, vol. 289, pp. 709–715, 2011.

[17] O.Baykara, S.Karatepe, M.Dogru, "Assessments of natural radioactivity and radiological hazards in construction materials used in Elazig, Turkey", *Radiation Measurements*, vol. 46, pp.153-158, 2011.

[18] IAEA, "Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards", *IAEA Safety standards series*, no. GSR Part 3 (Interim), STI / PUB / 1531, 190– 219, 2011.

[19] A. H. Ahmed and A. I. Samad, "Measurement of Radioactivity Levels in Daily Intake Foods of Erbil City Inhabitants", *Journal of Zankoy Sulaimani - Part A*, vol.16, no. 4, pp. 110-120, 2014.

[20] UNSCEAR, "Sources and effects of ionizing radiation", *Report to General Assembly, with Scientific Annexes*, United Nations, New York, 2000.

قياس جرعة كاما لنماذج الارز المتوفرة في الاسواق المدينة السليمانية، اقليم كردستان – العراق

الخلاصة

تم جمع ١٤ نموذجا لهذه الدراسة من الارز في اسواق مدينة السليمانية لتحديد مقدار كل من ^{226}Ra ، ^{232}Th و ^{40}K . ثم استخدمت مطياف اشعة كاما (NaI (Tl)) لتحديد تركيز النشاط الاشعاعي. النتائج لتركيز النشاط الاشعاعي للنويدات الطبيعية الثلاثة تقع ضمن المدى (٠.٥٥ – ٥.٧) و (٠.٦− ٤.٦٦) و (١٦.١١− ٢٠.٠٢)Bq Kg^{-1} بشكل متتالي. ان معدل قيمة النشاط الاشعاعي المكافيء للراديوم ($Ra_{(eq)}$) اقل من القيمة المقبولة عالميا ٣٧٠ Bq Kg^{-1} كما اشيرت اليه في تقرير UNSCEAR . ان القيمة الاجمالية للجرعة السنوية (E_t) تقع ضمن (٦٤.٦٦ – ٣٥٥.٦٢) $\mu Sv\, y^{-1}$, ولكن قيمة E_t لكل من النماذج الارز التايلندي و بانخيلان العراقي تجاوز القيمة العالمية (٢٩٠)$\mu Sv\, y^{-1}$. عموما, حددت معدل القيمة E_t بمقدار ١٩٦.٢$\mu Sv\, y^{-1}$, وهذه يشير الى ان النماذج من الارز صحي وبعيد من اضرار النشاط الاشعاعي.

الكلمات الدالة: النشاط الإشعاعي للأرز، قياس غاما، *Radium-226*، *Thorium-232* و تركيز نشاط البوتاسيوم ٤٠ ، مكافئ الراديوم ، جرعة الابتلاع ، جرعة فعالة سنوية من عينات الأرز.