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A Comparative Study of the Results of Natural Radioactivity and the Associated Radiation Hazards of Na(Tl) and HPGe Detectors

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Abstract **- The natural radioactivity of soil at Nineveh Province has been studied in this paper. The radioactivities of 19 soil samples have been measured with NaI(Tl) detector. The radioactivity concentrations of, ^{226}Ra , ^{232}Th ,^{214}Pb and ^{40}K ranged from, 17.02 to 40.98 Bq/kg, 11.22 to 32.65 Bq/kg,8.46 to 16.00 Bq/kg and from 206.51 to 509.56 Bq/kg respectively. In order to evaluate the radiological hazard of the natural radioactivity, the radium equivalent activity ,the absorbed dose rate, the annual effective dose rate, internal and external hazard indices , gamma index, alpha index, excess life time cancer risk and finally annual gonadal dose equivalent have been calculated. The study provides background radioactivity concentrations in Nineveh Province. Specific activity concentrations in ten soil samples of selected regions in Nineveh province were analyzed for the natural radioactivity of ^{226}Ra, ^{232}Th,^{214}Pb and ^{40}K using γ-spectroscopy based on high-purity germanium detector with an efficiency of 40%. The activity concentrations of natural radionuclides ^{226}Ra,^{232}Th ,^{214}Pb and ^{40}K were found to range from 16.21 Bq/kg in (Al-Medan district) (S9) to 38.83 Bq/kg in(Sinjar district) (S1)with an average value of value of 32.52±6.48 Bq/kg , 8.53 Bq/kg in (Al-Medan district) (S9) to 28.37Bq/kg in (Rabeaa district)(S2) with an average value of 20.30±5.36 Bq/kg, 8.13 Bq/kg in (Al-Medan district) (S9) to 18.22 Bq/kg in (Sinjar district) (S1) with an average value of 14.78± 2.97and 236.03 Bq/kg in (Telkaif district) (S5) to 613.11 Bq/kg in (Rabeaa district) (S2) with an average value of 378.93± 123.29 Bq/kg. The radium equivalent activity, absorbed gamma dose rate, annual effective dose equivalent , gamma index , alpha index ,internal and external hazard indices, excess life time cancer risk and annual gonadal dose equivalent associated with the natural radionuclides were calculated.**

Keywords**: Activity concentration, NaI(Tl) detector, HPGe detector.**

I. INTRODUCTION

Radiation is present everywhere and man is knowingly or unknowingly being continuously exposed to radiations present in environment (natural). The natural radiations surrounding the life on earth can either be terrestrial or extraterrestrial (cosmic) origin. The ionizing radiations a, b and c emitted from various terrestrial materials (soil, rocks, and etc.) coming from naturally occurring radionuclides such as uranium, thorium etc., their isotopes, their decay products and some singly occurring radionuclides such as ^{40}K, ^{87}Rb contribute to the terrestrial radiations [1]. Natural radioactivity can be found, in low concentrations, throughout the geology of the planet. It is naturally occurring in many rocks, soils, and waterways. Phosphate rocks are one of the matrices that contain higher levels of natural radioactivity than the background. As the world population continues to grow, so does the world's need for food. The increased demands of food production have led to a steady increase in the use of phosphate fertilizers [2-3].Natural radioactivity exists widely in the terrestrial environment. There are many sources of radiation and radioactivity in the environment.

Gamma radiation emitted from naturally occurring radionuclides, also called terrestrial background radiation, represent the main external source of irradiation of the human body. It is located in different geological formations such as the surface of the earth, rocks, water, plants and even the air. The

concentration of the natural radioactive materials depends on situation of geology and geography and appears at different level in soils of each different geological region [4],[5]. The exposure of human beings to ionizing radiation from natural sources is a continuing and inescapable feature of life on earth. For most individuals, this exposure exceeds that from all man-made sources combined. External exposures outdoors arise from terrestrial radionuclides present at trace levels in all soils. The specific levels are related to the types of rock from which the soils originate. Natural environmental radioactivity and the associated external exposure due to gamma radiation conditions, and appear at different levels in the soils which the soils originate [4],[6].

Natural sources are the largest contributor to the external dose of world population [7]. These doses vary depending upon the concentration of the natural radionuclide's ^{238}U and ^{232}Th,^{235}U their daughter products and ^{40}K, present in soil and rocks, which in turn depend upon the local geology of the region in the world [8-10].

II. MATERIALS AND METHODS

A. Study area

This study was carried out at Nineveh province , ten districts has been selected from the center of Mosul city[Al-Medan, Camp of Gazlany and Palace of Presidential(college of Agriculture in Univ. of Mosul)], and others from some small towns outside the center of Mosul city like(Sinjar, Rabeaa, Telfar, Al-Qoosh,Al-Hamdanea and Bacheeka) as shown in table I.

B. Collection and preparation of samples

After we selected the districts of samples, we collected ten soil samples from all the selected districts with a weight of about 1.5 kg. All the stones, organic matter were removed from these samples. Then the samples dried by placing the samples in oven of about 110 C° about 24 h, then the samples cursed to pass through 2 mm sieve to be homogenized in size and they were packaged in a marinelli beaker , the sealed marinelli beaker were kept for four weeks before measurements in order to achieve the secular equilibrium for ^{238}U and ^{232}Th with their respective progenies.

Table I

Names and codes of collected soil samples from Nineveh province

Sample no.	Sample code	Sample name
1	S1	Sinjar
2	S2	Rabeaa
3	S3	Telfar
4	S4	Al-Qoosh
5	S5	Telkaif
6	S6	Al-Hamdanea
7	S7	Bacheeka
8	S8	Camp of Gazlany
9	S9	Al-Medan
10	S10	Palace of Presidential

C. Gamma spectrometry

Gamma ray spectrometry analysis of the soil samples for natural radioactivity was carried out by using NaI(Tl) detector of radius (3.8cm) and thickness(2.5cm).The detector was interfaced to a PC-computer with a program installed for this purpose to make it equivalent to a multi-channel analyzer .The system also contains the usual electronic components of preamplifier, amplifier and power supply. The detector has resolution (FWHM) of (33.3keV) for the (1332 keV) γ-ray line of ^{60}Co. The γ-ray spectrometer energy calibration was performed using ^{137}Cs and ^{60}Co point source in a lead protected box ,then the concentration of natural radionuclides in these samples was determined from the peaks at 911 keV ^{228}Ac for ^{232}Th, the peak at 1765 keV(^{214}Bi) for ^{238}U, the peak at 1460 keV for ^{40}K and the peak at 609keV(^{214}Bi)for ^{226}Ra .

For HPGe detector system the gamma spectrometer (Canberra) used for performance this work which consists of a detector, preamplifier, and pulse-height analyzer (DSA2000), lead shield , using vertical high purity germanium (HPGe) detector of efficiency 40%, and resolution (2.0keV), normally based on the measurement of 1.332 MeV gamma ray photo peak of ^{60}Co source and cooled with liquid nitrogen , Multichannel analyzer(MCA) with 8192 channel is used , both high voltage supply and amplifier device are compact in one unit(DSA2000). A detector shield is with activity adequate to

accommodate large samples. Shield has walls 10 cm lead, thick lined inside with graded absorber of Cd ~ 1.6 mm, Cu~ 0.4mm. Calibration and efficiency of the system are carried out using multi- gamma ray standards sources (MGS-5, Canberra) of Marinelli beaker geometry. A library of radionuclides which contained the energy of characteristic gamma emission of each nuclide was analyzed and their corresponding emission probabilities was built from the data supplied in the software. The energy regions selected for the corresponding radionuclides were 609 keV, 11120 keV for ^{214}Bi for ^{226}Ra, 911keV and 969 keV of ^{228}Ac for ^{232}Th and 1460 keV for ^{40}K. The activity concentration of ^{226}Ra, ^{232}Th ,^{40}K and ^{137}Cs were calculated using the following relation [11]:

$$A = (CPS)\ net / I.\varepsilon .m.t \quad (1)$$

Where A is the activity concentration in Bq/kg (CPS) net is the (count per second) and equal [(CPS) sample –(CPS) background], I is the intensity of γ-line in a radionuclide, ε is the measured efficiency of each γ-line observed ,m is the weight of each sample and t is the sample counting time.

III. RESULTS AND DISSCUSION

A. Activity concentration in soil samples

The results of activity concentrations of radionuclides ^{226}Ra,^{232}Th ,^{40}K and ^{214}Pb obtained from gamma spectrometry techniques(Na(Tl) and HPGe) for 10 soil samples collected from districts of Nineveh province are shown in figs.1,2,3 and 4.

B. Gamma Radiation Parameters

B1. Radium equivalent activity (Ra_{eq})

The distribution of ^{226}Ra, ^{232}Th and ^{40}K in soil is not uniform . Uniformity with respect to exposure to radiation has been defined in terms of radium equivalent activity(R_{aeq}) in Bq/kg to compare the specific activity of the material containing different amounts of ^{226}Ra, ^{232}Th and ^{40}K.It is calculated through the following relation [12]:

$$Ra_{eq}\,(Bq/kg) = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad (2)$$

Where A_{Ra}, A_{Th} and A_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Bq/kg , respectively. While defining R_{aeq} activity, it has been assumed that 370 Bq/kg of ^{226}Ra or 259 Bq/kg of ^{232}Th or 4810 Bq/kg of ^{40}K produce the same gamma dose rate. The results of radium equivalent activity for both NaI(Tl) and both HPGe detectors shown graphically in fig.5

B2. Absorbed gamma dose rate(D)

The external outdoor absorbed gamma dose rate due to terrestrial gamma rays from the nuclides ^{226}Ra, ^{232}Th and ^{40}K at 1m above the ground level were calculated as follows outlined by [12]:

$$D(nGy/h) = 0.462\ A_{Ra} + 0.604A_{Th} + 0.0417\ A_K \quad (3)$$

Where A_{Ra}, A_{Th} and A_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Bq/kg. Fig.6 shows graphically the results of absorbed gamma dose rate for both NaI(Tl) and HPGe detectors.

B3. Annual Effective Dose Equivalent (AEDE)

The annual effective dose equivalent AEDE (μSv/ y) in air was calculated using the values of the absorbed dose rate by applying the dose conversion factor of 0.7 Sv/Gy and the outdoor occupancy factor of 0.2 (people spend about 20% of their life outdoor).The Annual Effective Dose (in μSv/y) received by population can be calculated by using equation [4] .

$$AEDE\ (\mu Sv/y) = D\ (nGy/h) \times 8{,}760\ h \times 0.7(Sv/Gy) \times 0.2 \times 10^{-3} \quad (4)$$

Where**:** D (nG/h) is the total air absorbed dose rate in the outdoor. 8,766 h is the number of hours in 1 year. 10^{-3} conversion factor to micro.

B4. Internal hazard index (H_{in})

Radon and its short-lived products are also hazardous to the respiratory organs. So internal exposure to radon and its short-lived products is quantified by internal hazard index and is expressed mathematically as [13]:

$$H_{in} = A_{Ra}/185 + A_{Th}/259 + A_K/4810 \leq 1 \quad (5)$$

The results of H_{in} for NaI(Tl) and HPGe detectors are shown in fig.8.

B5. External hazard index (H_{ex})

To limit the external gamma radiation dose, an extensively used hazard index, the external hazard index (H_{ex}) was calculated from the equation [14].

$$H_{ex} = A_{Ra}/370 + A_{Th}/259 + A_K/4810 \leq 1 \quad (6)$$

Fig.9 shows the results of H_{ex} for NaI(Tl) and HPGe system detectors.

B6. Gamma index (I_γ)

Another radiation hazard called the representative level index I_γ , is defend as follows [15,16]:

$$I_\gamma = A_{Ra}/150 + A_{Th}/100 + A_K/4810 \leq 1 \quad (7)$$

Where A_{Ra}, A_{Th} and A_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Bq/kg, respectively.

The results of gamma index from NaI(Tl) and HPGe detectors are shown graphically in fig.10.

B7. Alpha index (Iα)

Also several indexes dealing with the assessment of the excess alpha radiation due to the radon inhalation originating from building materials "called alpha indexes or internal-indexes" have been developed [17].In the present work ,alpha indexes were determined through the following formula [18] :

$$I\alpha = A_{Ra}/200\text{Bq/kg} \leq 1 \quad (8)$$

B8. Excess Lifetime Cancer Risk (ELCR)

This gives the probability of developing cancer over a lifetime at a given exposure level, It is presented as a value representing the number of extra cancers expected in a given number of people on exposure to a carcinogen at a given dose, and we can calculate (ELCR) by eq. (8) if considering 70 years as the average duration of life for human being [19].

$$ELCR = AEDE \times DL \times RF \quad (9)$$

Where, AEDE is the Annual Effective Dose Equivalent, DL is the average Duration of Life (estimated to be 70 years) and RF is the risk factor (Sv^{-1}), fatal cancer risk per Sievert. For low dose background radiations which are considered to produce stochastic effects, ICRP 60 uses values of 0.05 for the public exposure [19]. This value-free units because it represents the probability of cancer incidence through this we can deduce the equation above. The results of Excess lifetime cancer risk for Na(Tl) and HPGe detectors are shown in figure 12.

B9. Annual Gonadal Dose Equivalent (AGDE)

The annual gonadal dose equivalent (AGDE) in mSv /y due to the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K was calculated using the following formula [20-21]:

$$AGDE(\text{ mSv/ y}) = (3.09A_{Ra} + 4.19A_{Th} + 0.314A_K)/1000 \quad (10)$$

The results of Annual gonadal dose equivalent for Na(Tl) and HPGE detectors are shown in figure 13.

IV. CONCLUSIONS

The percentage for the agreement between the results from NaI(Tl) detector system and HPGe detector system in measure the activity concentrations of natural radioactivity are as follows: 97.99% for ^{226}Ra results in all selected studied districts , for ^{232}Th activity concentration the percentage agreement results is 96.9%, while percentage agreement is 79.60% for ^{214}Pb activity concentration and the percentage agreement results for ^{40}K is 86.20%.

The results of the radiological hazards of natural radioactivity from HPGe detector system present high agreement percentage with the results obtained from NaI(Tl) detector system as follow: For radium equivalent activity R_{aeq} (Bq/kg) the percentage of agreement results is 97.2%, for gamma absorbed dose rate D(nGy/h) results is 96.56%, also the percentage agreement for annual effective dose equivalent (outdoor) AEDE results is (96.57%), for the internal and external hazard indices (H_{in}&H_{ex}) results are 97.13% &97.59% respectively, while the percentage agreement of gamma index(Iγ)and alpha index(Iα)

results are 98.78% & 99.70% respectively and finally for excess life cancer risk(ELRC) and annual gonadal dose equivalent (AGDE) (mSv/y) are 96.70% & 96.05% respectively.

V. REFERNCES

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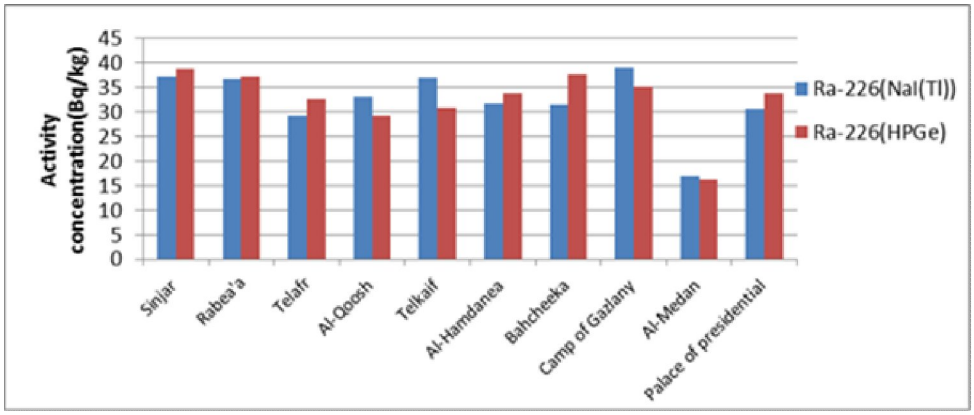

Fig. 1 The activity concentration of ^{226}Ra (Bq/kg) for both Na(Tl) and HPGe detectors system.

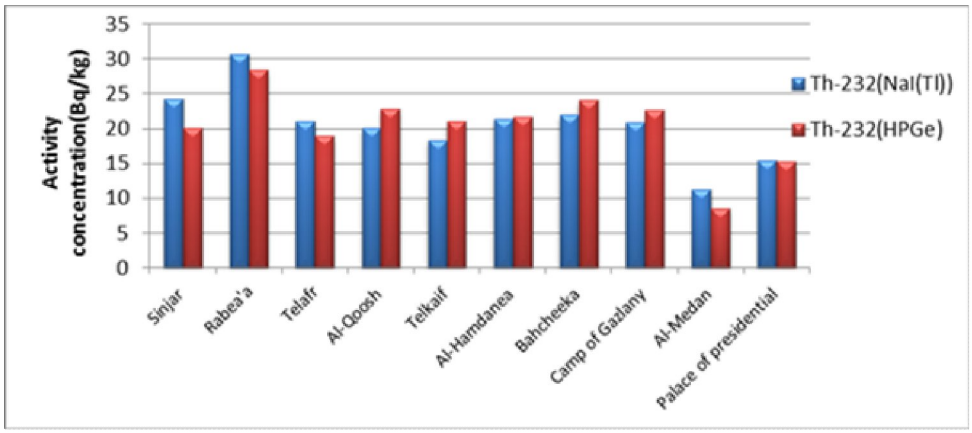

Fig.2 The activity concentration of ^{232}Th (Bq/kg) for both Na(Tl) and HPGe detectors system.

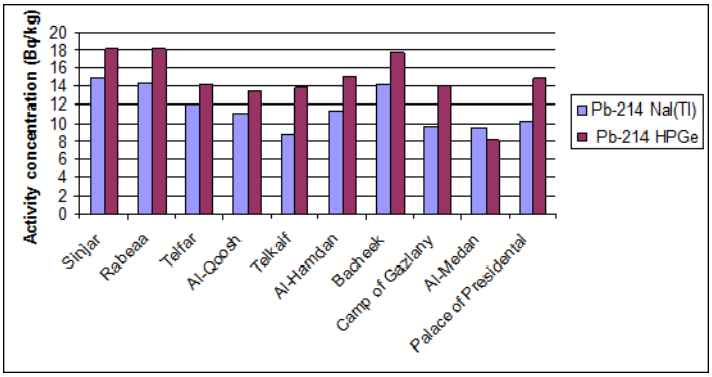

Fig.3 The activity concentration of ^{214}Pb (Bq/kg) for both Na(Tl) and HPGe detectors system.

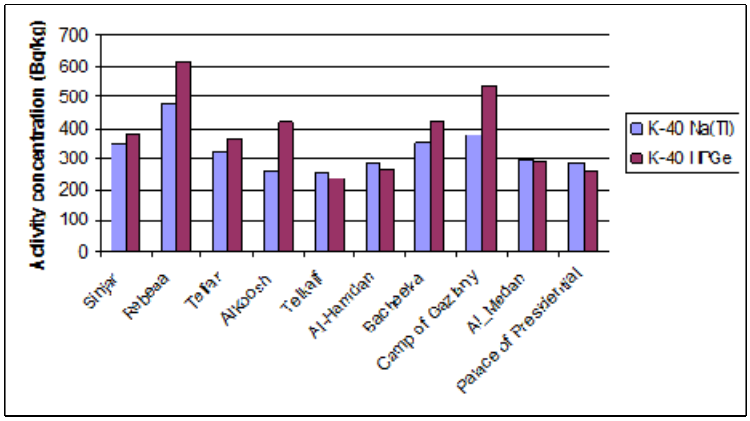

Fig.4 The activity concentration of ^{40}K (Bq/kg) for both Na(Tl) and HPGe

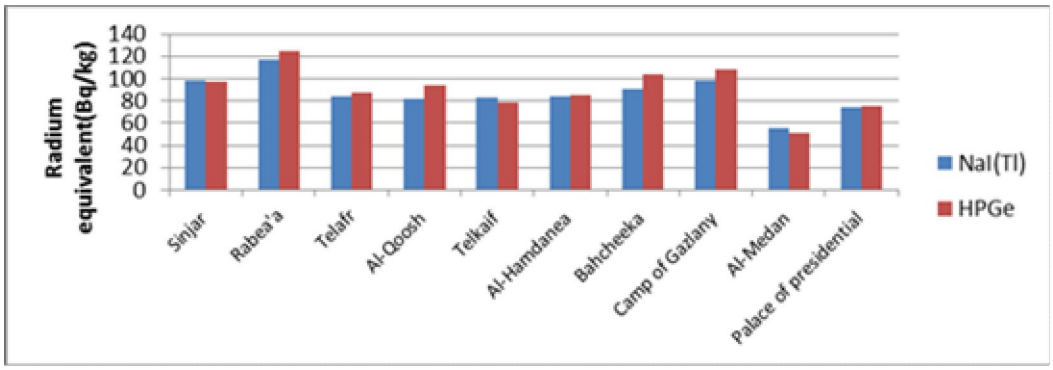

Fig.5 Radium equivalent activity R_{aeq} (Bq/kg) results for both NaI(Tl) and HPGe detectors system.

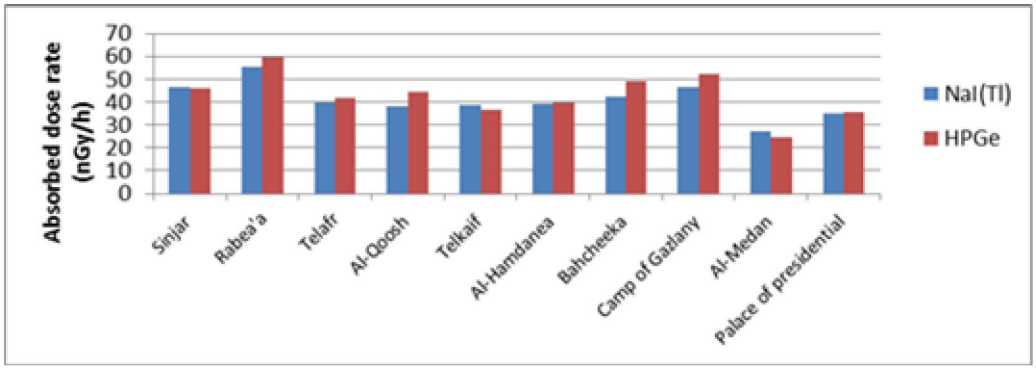

Fig.6 Absorbed gamma dose rate D(nGy/h) for both NaI(Tl) and HPGe detectors system.

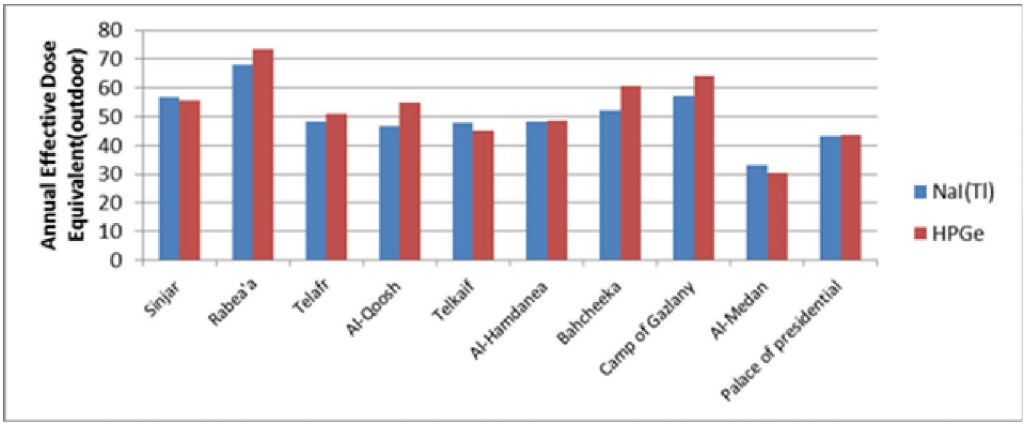

Fig.7 Annual effective dose equivalent (outdoor)((μSv/y) for both NaI(Tl) and HPGe detectors system.

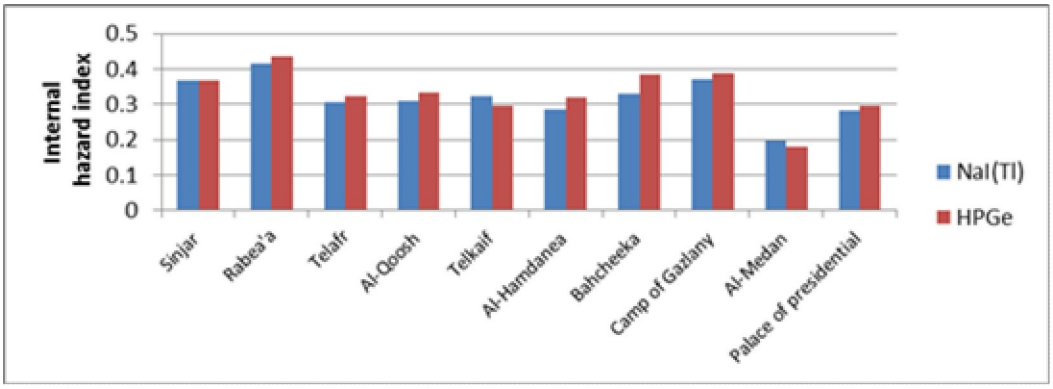

Fig.8 Internal hazard index for both NaI(Tl) and HPGe detectors system.

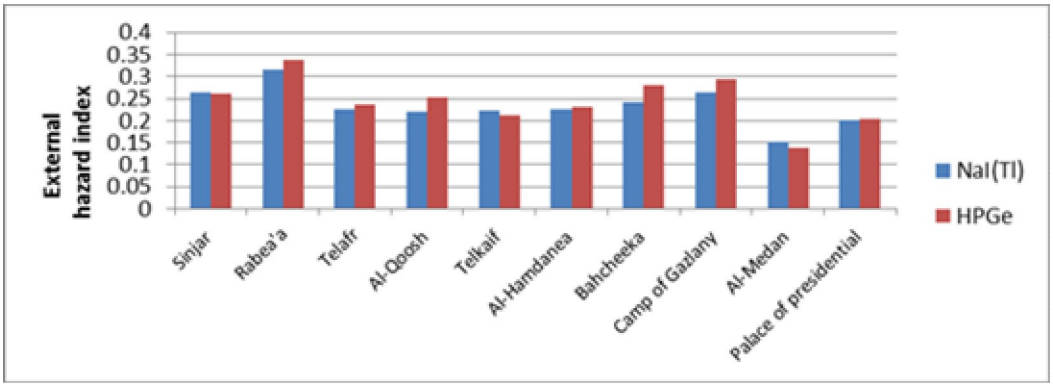

Fig.9 The results of External hazard index for NaI(Tl) and HPGe detectors system.

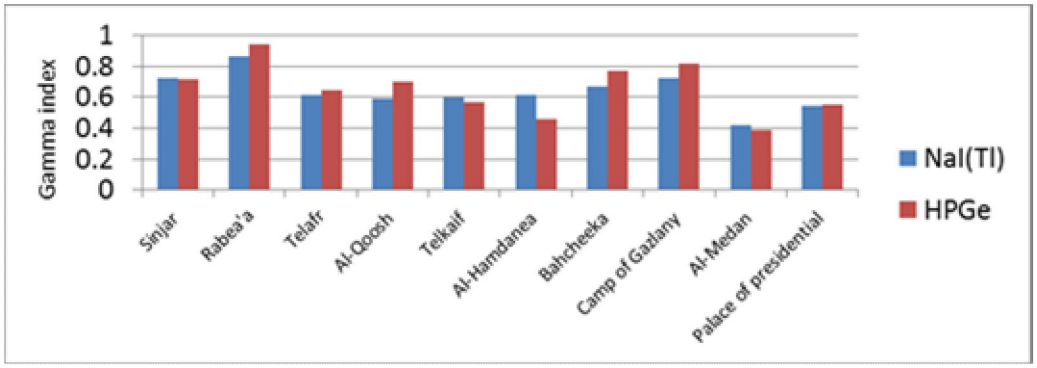

Fig.10 Gamma index(I_γ) results for NaI(Tl) and HPGe detectors system.

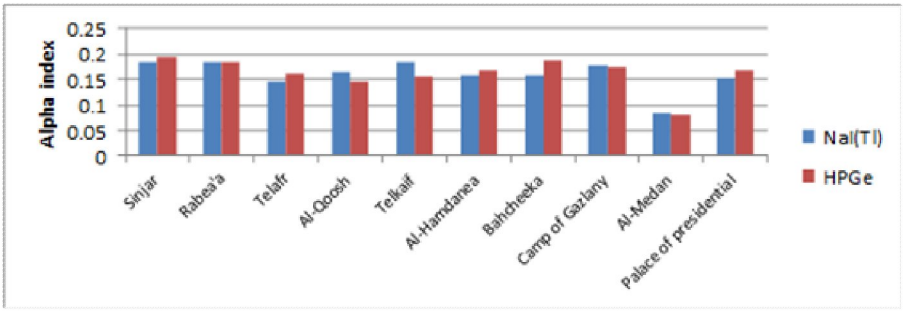

Fig.11 The alpha index (Iα) results for NaI(Tl) and HPGe detectors system.

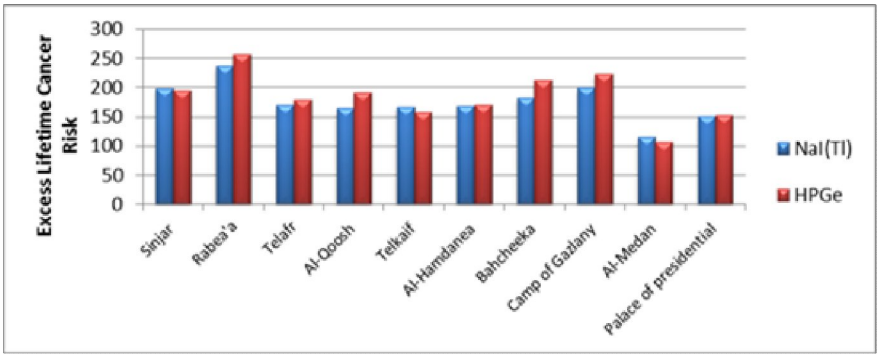

Fig.12 Excess lifetime cancer risk(ELR)($\times 10^{-6}$) results of NaI(Tl) and HPGe detectors system

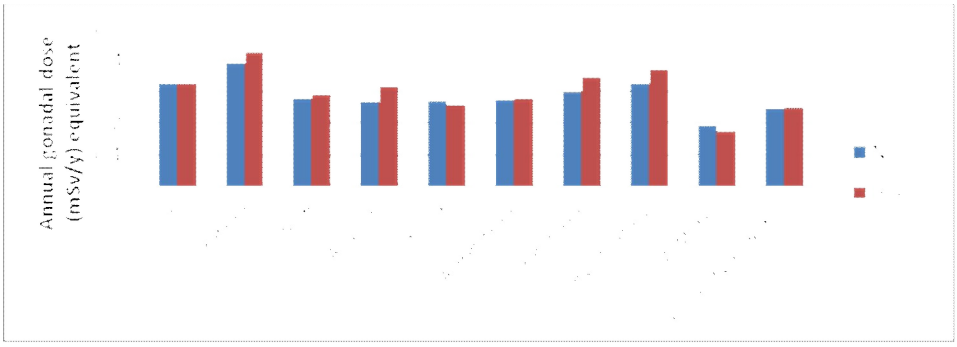

Fig.13. Annual gonadal dose equivalent (AGDE)(mSv/y) results for NaI(Tl) and HPGe detectors system.