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Automated Software for Gamma-ray Spectrum Analysis and Natural Radioactivity Estimation in Environmental Samples

By

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Abstract This work introduces modern software for finally Estimation Natural Radionuclides Concentrations in Environmental Samples called SLCONS. Q. Basic64 compiler was used for programing method. The output of SLCONS was confirmed with previous studies on soil samples taken from different Libyan sites. The program can calculate also all the radiological indices. A good agreement was obtained with the experimental results. The program can be used for sequential gamma spectrum analysis and fast output productions.

Keywords: Natural Radioactivity SLCONS software,Q.Basic64 compiler, Different Libyan cites

Introduction

FIGURE.1 represents the main functions of the SLCONS program. In literature one can find some authors interesting in these titles [1-3]. The program can run easy in automated mode to calculate a set of group of measurements. The produced results can summarize in different output mode. The output of the program can be compared with others [4-10].

Hardware requirements for the computer to run SLCONS are IPM computable PC, main processor 586 or higher. SLCONS can be run under 32 bit operating system such as Microsoft Windows 2007. Disk space is approximately 4.5MB for executable models. To run SLCONS just click its icon in start Windows menus.

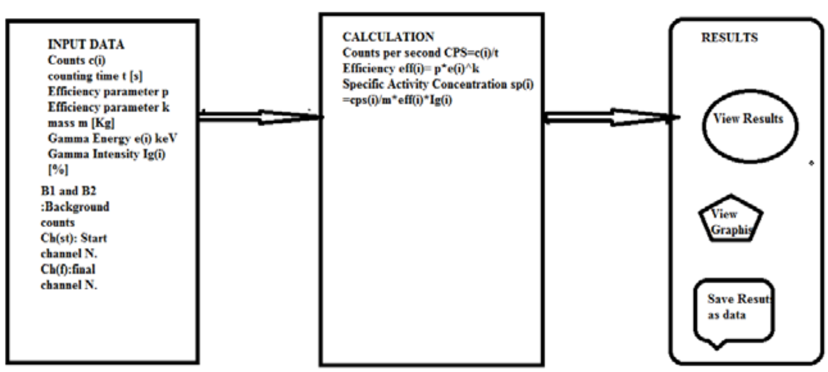

Fig.1. **Structure of SLCONS program**

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Computer Language

SLCONS software has been creat d using Q-Basic 64.

Operating Mode

All the operation modes are intended for calculating radionuclide concentration in soil for different samples momentary contamination of different localities. The user's operation session consists of three phases:

• inputting initial data, choosing required databases;
• Calculation;
• Results presentation.

All parameters necessary for calculations are specified by default.

Interactive Mode

The Input initial data allows the user to choose several parameters for subsequent concentration calculation Radionuclide. The necessary radionuclide must be chosen from the radionuclide list box. The list includes all radionuclides from the NAME field of the RAD_CAT.dbf database.

gamma-Ray Energy

The value is chosen from the GAMMA_ENERGY field of the (RAD_G.E.slcons) model database to suit the nuclide chosen.

Soil type will to be chosen from the soil type list box. The list includes all soil types from the SOIL_TYPE field of the SOIL.SLCONS model database.

Soil Parameters

In accordance with the soil type chosen, the values of mass, mean, depth, location are found in the SOIL.SLCONS model database.

Initial Surface Contamination

The user is offered to input the initial surface contamination value in possible units displayed in the window: [kBq/m].

Representation of Results Graphic Option

only for the Package Mode:

The graphic dialogue box allows to view results in graphic form in the user's results form.

Database - File

Interactive mode, Site Selection mode

For Interactive mode, Site Selection mode the text file has the following structure.

1) File name; 2) contamination field name; 3) radionuclide; 4) sample depth (cm).

The database contains only a results array. Note that in the Interactive and Site selection modes calculation results are written to a file with a constant structure, i.e. that with a constant number of definite fields, which are INTERVAL [cm] - Soil samples, Radionuclide concentrations in soil layers, [Bq/kg].

Initial input data of samples specifications can be summarized in the next table [1];

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Table [1] Parameters of samples

S.ID	*Region*	*Weight (gm)*	*Type of sample*	*Sample Location*	
				Latitude	Longitude
01	Qarabulli	330	Coast	32^0 44\	15^0 14\
02	Bu-njim	350	Sand (desert)	30^0 35\	15^0 24\
03	Zawia	480	Mountain(stones)	32^0 45\	12^0 44\
04	Qaddahea	510	Near the coast	31^0 22\	15^0 14\
05	Orban	450	Sand(Oises)	Near Ghrian	Near Ghrian
06	Tajoura	300	Sand (desert)	32^0 53\	13^0 23\
07	Sokna	530	Coast (near sea)	29^0 10\	16^0 10\
08	Ghrian	315	Coast	32^0 21\	15^0 o8\
09	Misurata	450	Mountain stones	32^0 25\	15^0 05\
10	Qaser Akhiar	240	Desert	Near Qarabulli	Near Qarabulli

Radionuclides spectra:

The spectra were evaluated with the computer software program SLCONS to calculate the natural radioactivity. ^{226}Ra activity of the samples was determined via its daughters (^{214}Pb and ^{214}Bi) through the intensity of the 351.93 keV, for ^{214}Pb and 1120, 1764.49 keV for ^{214}Bi gamma-line. ^{232}Th activity of the sample was determined from the daughters (^{228}Ac), (^{212}Pb) and (^{208}Tl) through the intensity of 911.2 keV gamma -line for (^{228}Ac), and (^{208}Tl) emission at 2614 keV gamma line. ^{40}K activity was determined from the 1460.7 keV emission gamma-lines.

Analysis of Gamma Spectra

Data collected in N channels of an analyzer take the form of a histogram of a continuous energy spectrum within a range of minimum (E_0) and maximum(E) energy. The area of a peak is the difference between its entire area and the respective background. The background comprises all pulses that do not belong to the photo peak but have been registered by the multichannel analyzer in the channels of the peak. The main reasons for the background are:

- Natural radiation at the place of measurement (e.g. cosmic radiation, terrestrial radiation),
- Artificial radiation at the place of measurement (e.g. operation of the reactor, storage of radiation sources close to the place of measurement),
- Background of Compton scattering originating from higher gamma energies of the sample being analyzed.

The first two components of the background can be minimized by shielding the gamma detector (e.g. with lead) and/or by storing other gamma sources as far as possible from the place of measurement. If the sample being analyzed has more than one gamma line, the third background component is often dominating and cannot be avoided.

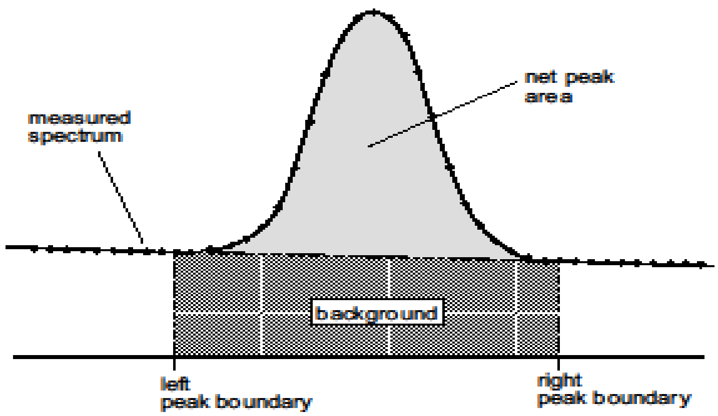

Fig. 2, Principle of net peak area determination

For correcting the background which is determined from Fig.2 [11]

$$B = \frac{(C_1 + C_n)}{2} n \qquad (1)$$

$$P = \sum_{i=1}^{n} C_i \qquad (2)$$

$$N.A = P - B \qquad (3)$$

B=area of the background

P=gross peak area

N.A= net peak area

C_1 = content of the channel at the left boundary of the peak

C_i = content of i^{th} channel

C_n = content of the channel the right left boundary of the peak

n = number of channel between left and right boundary

The software of the multichannel analyzer can calculate automatically the gross and net peak areas as well as the respective standard deviations, which are due to the counting statistics. For these calculations, the following keyboard commands are necessary:

1. Shift the measured spectrum to the buffer Alt-5
2. Display the content of the buffer Alt-6
3. Place the cursor at the left boundary of the peak
4. Mark the left boundary of the peak Alt-R, then Alt-B
5. Place the cursor at the right boundary of the peak
6. Mark the right boundary of the peak Alt-R, then Alt-E

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(peak sector is in red color, now)

7. Move the cursor inside the peak range

8. Calculate net peak area Alt-C, then Alt-A

The net peak area is calculated by the PC program according to following method. For balancing statistic errors at the lower and upper limits of the chosen peak range, the calculation of the background B averages both, the first and the last three channels inside the peak range and uses them for calculating net peak area as following[12] :-

$$B = \left\{ \sum_{1=1}^{l+2} C_i + \sum_{i=r-2}^{r} C_i \right\} \frac{r-l+1}{6} \quad (4)$$

$$P_b = \sum_{i=l}^{rn} C_i \quad (5)$$

$$N.A = P_{ib} - B \quad (6)$$

B = area of the background

l= channel number at the left boundary of the ROI (region of interest)

r = channel number at the right boundary of the ROI

C = content of the i-th channel i

P = gross peak area b

P_b = inner gross area (without both, the first three and the last three channels) ib

N.A = net peak area n

σ= statistical error of the calculated net peak area **$=\sqrt{P_{ib}} - B$**

Calculation

Peak area determination

The simplest way to determine the area of a gamma-ray peak is simply to add up the counts from each of the channels in the peak range; where the number of channels is difference between final channel and start channel n= c_1-c_n as discussed in above section.

The contribution of the continuum background is usually determined by averaging on one or two "clean" regions nearby B_1 and B_2 and then subtracted from the result counts sum c(i). In this approach, the net of the peak area assumed to be simply N.A= p-[c_1-c_n](B_1+B_2)/2

MEASUREMENT OF NATURAL RADIOACTIVITY

Through calculating the area under the peak (net area) and by means of the detector efficiency curve, $\varepsilon = pE_{\lambda}^{k}$ where p and k are constants can be determined from efficiency curve of detector the specific activity (activity concentration) A_c was determined using the formula[3].

$$A_c = \frac{N.A}{\varepsilon . I_{\gamma} T_c M} \quad (7)$$

Where N.A is the number of count in a given peak area corrected for background peaks of a peak at energy E, ε the detection efficiency at energy E, Tc is the counting lifetime, Iγ the number of gammas per disintegration of this nuclide for a transition at energy E, and M the mass in kg of the measured sample [4,5and 6].

CALCULATION OF AIR-ABSORBED DOSE RATE

The external, terrestrial γ-radiation, absorbed dose rate in air at a height of about 1 m above the ground is calculated by using the conversion factor of 0.042 nGy h^{-1}/ Bq kg^{-1} for 40K, 0.455 nGy h^{-1}/Bq kg^{-1} for ^{226}Ra, and 0.583 nGy h^{-1}/Bq kg^{-1} for ^{232}Th (assuming that the ^{235}U decay series can be neglected) [7].

$$D\ (nGy.^{h^{-1}}) = (0.4551)\ A_U + (0.583)\ A_{Th} + (0.042)\ A_K \qquad (8)$$

Calculation of Annual Effective dose

To estimate annual effective doses, the following must be considered: (a) the conversion coefficient from absorbed dose in air to effective dose and (b) the indoor occupancy factor. The annual, estimated, average, effective- dose equivalent received by a member is calculated using a conversion factor of 0.7 Sv Gy^{-1}, The annual effective doses are determined as follows [8,9 and 10]: which is used to convert the absorbed rate to human effective-dose equivalent with an outdoor occupancy of 20% and 80% for indoors.

$$\text{Effective dose rate } (mSvy^{-1}) = \text{Absorbed dose } (nGy\ h^{-1}) \times 8760\ h.y^{-1} \times 0.7 \times (10^3\ mSv/10^9) \times 0.2\ (nGy^{-1}) \qquad (9)$$

External Hazard index

External hazard index due to the emitted gamma-rays of the samples are calculated and examined according to the following criterion

$$Hex = A_{Ra}/370 + A_{Th}/259 + A_K/4810 \leq 1 \qquad (10)$$

Hex must be less than unity for the radiation hazard to be negligible

Results

The output results of the proposed software can be summarized in table [2, 3]. The activity was given in Bq/kg. The comparison ration between the experimental calculations (manually done) and the program are also given. This program is applied on ten regions (A,B) of investigated sites (SA1 –SB10)because the difference among Samples is signified. The results of program output have been done and compared with experimental calculation from Genie2000. Tabs(2,3) and figs(3-10) illustrate these results.

Tab.2. Activity concentration of Natural Radionuclides in soil samples coma red with calculated value (with decimal places: 2)

S.N	$^{235}U_{EX}$	$^{235}U_{Q}$	*Dev%*	$^{226}Ra_{EX}$	$^{226}Ra_{Q}$	*Dev%*	$^{232}Th_{EX}$	$^{232}Th_{Q}$	*Dev%*	K_{EX}	$^{40}K_{Q}$	*Dev%*
S1A	160.50	158.30	1.37	74.00	74.34	0.46	63.00	63.38	0.60	146.20	146.20	0.00
S2A	290.50	289.45	0.36	56.80	56.86	0.11	42.96	46.58	8.43	131.00	131.00	0.00
S3A	122.30	121.60	0.57	33.00	33.33	1.00	40.74	41.67	2.28	146.40	146.40	0.00
S4A	93.79	92.98	0.86	55.59	52.48	5.59	153.50	157.23	2.43	168.50	168.50	0.00
S5A	202.84	198.98	1.90	29.12	27.57	5.32	165.87	172.44	3.96	108.50	108.12	0.09
S6A	231.00	222.64	3.62	30.00	26.26	12.47	102.30	102.26	0.04	116.00	116.10	0.09
S7A				26.70	26.00	2.62	47.62	49.88	4.75	103.40	247.33	0.05
S8A				33.20	34.57	4.13	46.92	48.60	3.58	100.30	100.35	4.28
S9A				71.60	63.19	11.75	47.70	46.30	2.94	140.30	146.30	0.00
S10A				103.80	105.50	1.64	118.30	119.89	1.34	0.00	N.D	0.01
S1B				80.40	80.44	0.05	62.20	62.12	0.13	145.90	145.88	0.00
S2B				60.00	60.86	1.43	43.00	42.98	0.05	130.32	130.32	0.01
S3B				36.10	33.44	7.37	40.77	43.65	7.06	147.30	147.29	0.03

S4B				60.10	60.78	1.13	154.02	152.78	0.81	169.60	169.55	0.01
S5B				29.90	29.26	2.14	91.90	89.99	2.08	110.10	110.11	0.09
S6B				36.00	38.98	8.28	102.80	102.77	0.03	115.90	115.79	0.02
S7B				26.20	26.19	0.04	46.90	46.79	0.23	100.80	100.78	0.04
S8B				33.40	32.45	2.84	46.50	46.48	0.04	101.50	101.46	0.02
S9B				70.80	68.88	2.71	47.40	47.68	0.59	138.90	138.87	0.02
S10B				108.00	105.45	2.36	116.40	120.68	3.68	138.90	138.87	0.00
Avg.	183.49	180.66	1.45	52.74	51.84	3.67	79.04	80.21	2.25	122.99	137.33	0.24
MAX	290.50	289.45	3.62	108.00	108.00	12.47	165.87	172.44	8.43	169.60	247.33	4.28
MIN	93.79	92.98	0.36	26.20	26.00	0.04	40.74	41.67	0.03	0.00	100.35	0.00

Tab.3A, Part from radiological indices estimation in soil samples of western Lib (with decimal places:2)

S.N	Ra_{eq}	*RaeqQ*	*Dev%*	*A.Dose*	*A.DoseQ*	*Dev%*	H_{ex}	H_{exQ}	*Dev%*
SA1	175.35	170.40	2.82	77.00	77.04	3.48	0.44	0.47	6.31
SA2	128.32	129.41	0.85	56.33	56.34	2.78	0.35	0.34	1.79
SA3.	102.53	108.89	6.20	45.44	45.36	0.68	0.26	0.27	5.24
SA4	288.07	310.89	7.92	127.44	127.36	2.78	0.78	0.77	1.50
SA5	274.67	283.70	3.29	124.66	124.62	0.09	0.75	0.73	2.53
SA6	185.22	185.61	0.21	82.44	82.44	1.51	0.48	0.49	2.81
SA7	102.76	100.89	1.82	45.66	45.56	1.91	0.29	0.27	5.63
SA8	108.02	100.35	7.10	47.88	47.76	1.47	0.27	0.29	6.51
SA9	150.61	157.65	4.67	69.55	69.54	4.46	0.43	0.40	6.50
SA10	272.97	270.66	0.85	127.00	126.98	4.67	0.74	0.73	1.40
SB1	180.58	178.36	1.23	78.00	78.03	2.38	0.46	0.48	4.92
SB2	131.52	128.32	2.44	58.44	58.42	2.93	0.33	0.35	6.38
SB3	105.74	102.76	2.82	46.77	46.73	1.87	0.28	0.28	2.13
SB4	293.41	287.77	1.92	128.22	128.24	5.67	0.76	0.78	2.92
SB5	169.79	170.67	0.52	79.99	79.88	1.30	0.43	0.45	5.05
SB6	191.93	188.65	1.71	84.33	84.33	2.24	0.48	0.51	6.24
SB7	101.03	100.68	0.35	44.55	44.45	2.08	0.27	0.27	1.08
SB8	107.71	106.73	0.91	47.66	47.56	1.52	0.27	0.29	6.25
SB9	149.28	150.33	0.71	66.99	66.89	4.56	0.40	0.40	0.04

SB10	285.15	283.78	0.48	133.99	133.89	2.57	0.80	0.76	4.88
Aveg	175.23	175.83	2.44	78.66	78.57	5.67	0.46	0.47	4.00
Max.	293.41	310.89	2.82	133.99	133.89	0.1	0.80	0.78	6.51
Min.	175.35	170.40	0.85	44.55	44.5	3.48	0.44	0.47	0.0

Tab.3B, Part from radiological indices estimation in soil samples of western Libya (with decimal places: 2)

S.N	*$ANED_{EXP}$*	*$ANED_Q$*	*Dev%*	*I_γ*	*$I\gamma_Q$*	*Dev%*
SA1	79.99	79.33	0.83	1.22	1.24	1.61
SA2	70.88	71.55	0.94	0.90	0.91	1.50
SA3	54.55	57.22	4.67	0.76	0.74	3.40
SA4	158.00	157.22	0.50	2.34	2.24	4.46
SA5	152.00	148.77	2.17	1.98	1.93	2.37
SA6	100.00	101.00	0.99	1.42	1.31	8.43
SA7	59.10	56.77	4.10	0.75	0.73	2.55
SA8	56.11	59.77	6.12	0.72	0.77	6.23
SA9	86.88	84.00	3.43	1.05	1.07	1.94
SA10	147.00	149.00	1.34	1.89	1.91	1.03
SB1	79.33	98.00	19.05	1.27	1.28	0.87
SB2	98.44	100.33	1.88	0.94	0.94	0.43
SB3	72.4	73.33	1.27	0.74	0.76	2.33
SB4	57.00	59.00	3.39	1.98	2.07	4.48
SB5	158.22	160.22	1.25	1.18	1.20	1.75
SB6	91.88	92.77	0.96	1.40	1.36	3.21
SB7	100.88	104.77	3.71	0.72	0.72	0.15
SB8	56.66	55.77	1.60	0.77	0.77	0.55
SB9	58.55	59.55	1.68	1.04	1.06	2.00
SB10	82.33	83.22	1.07	2.03	2.01	0.9
Aveg	155.00	157.00	1.27	1.26	1.25	2.51
Max.	158.33	160.22	1.25	2.34	2.24	8.43
Min.	56.11	96.44	2.19	0.72	2.2	0.1

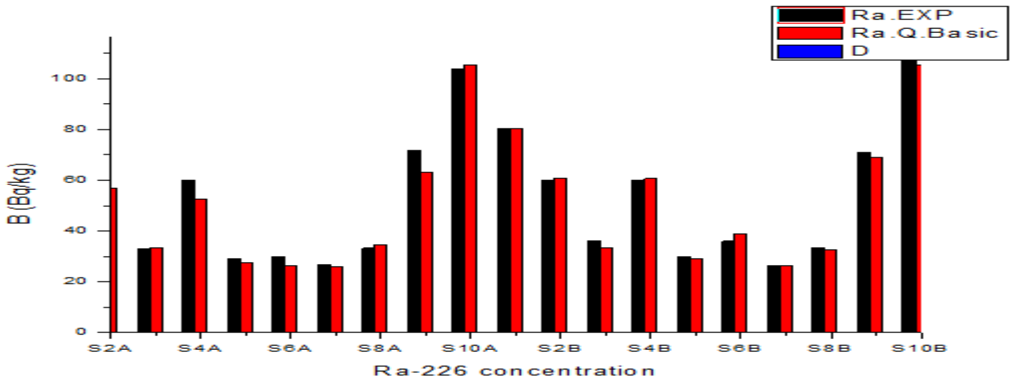

Fig.3 Concentration Uranium Chain in Samples soil as Comparison Experimental with Automated software program

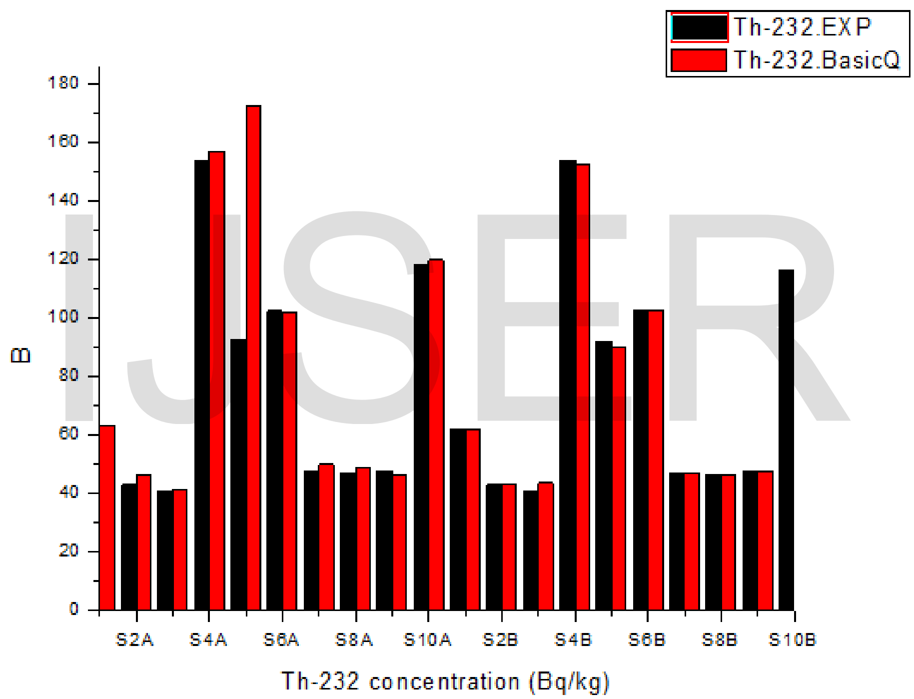

Fig.4 Concentration Thorium Chain in Samples soil as Comparison Experimental with Automated software program

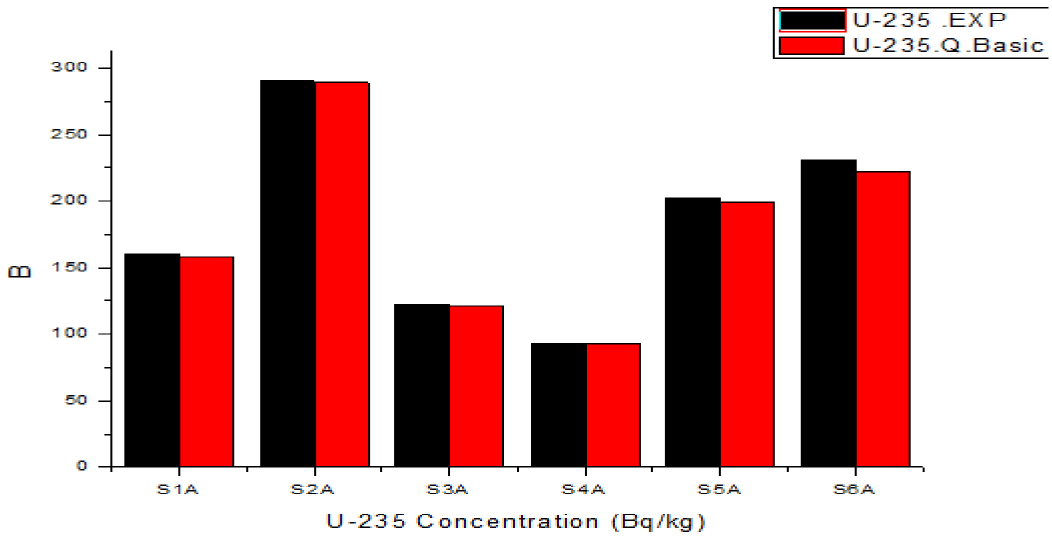

Fig.5 Concentration ^{235}U in Samples soil as Comparison Experimental with Automated software program

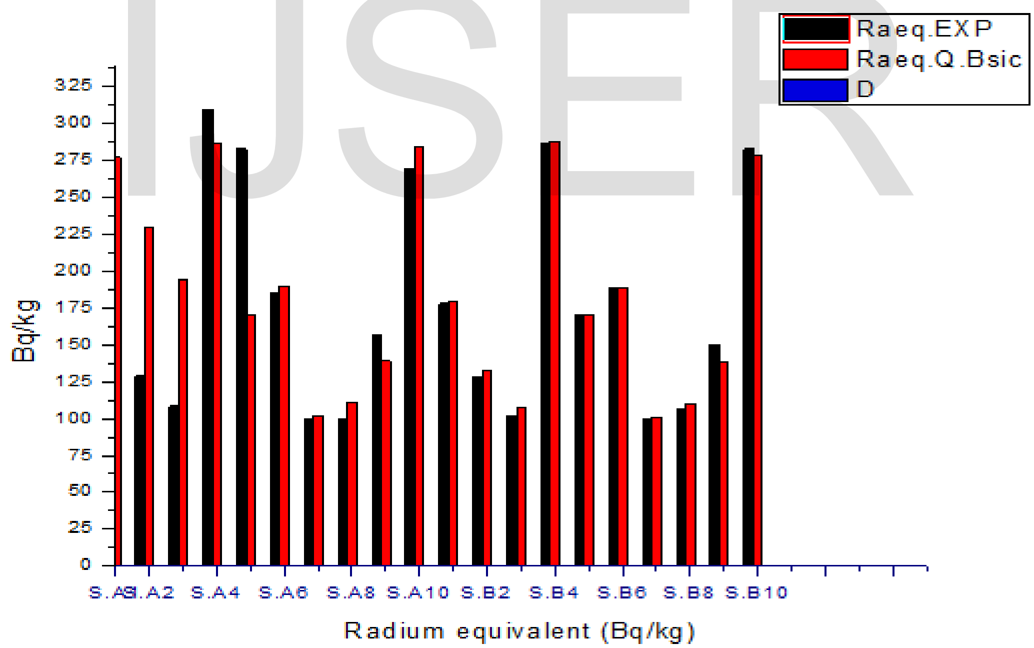

Fig.6 Radium Equivalent in Samples soil as Comparison Experimental with Autorotation program

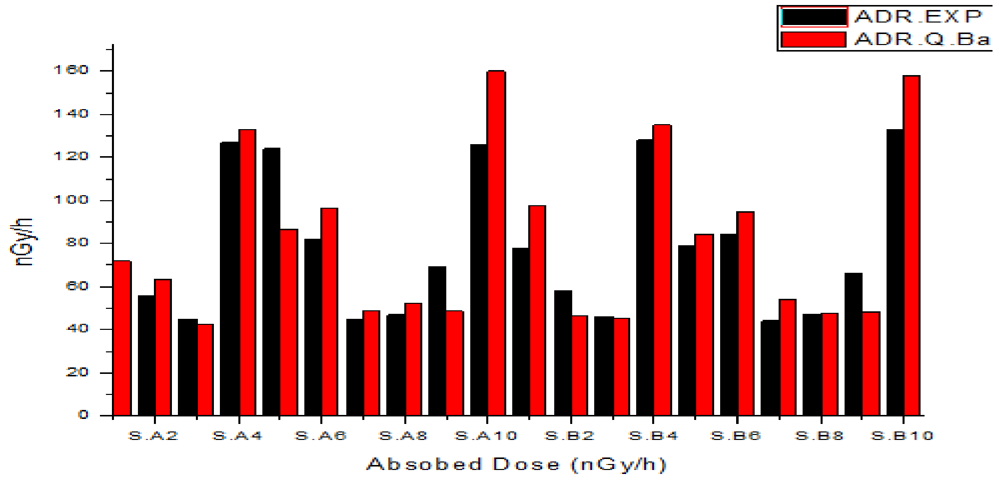

Fig.7 Absorbed Dose Rate in Samples soil as Comparison Experimental with Automated software program

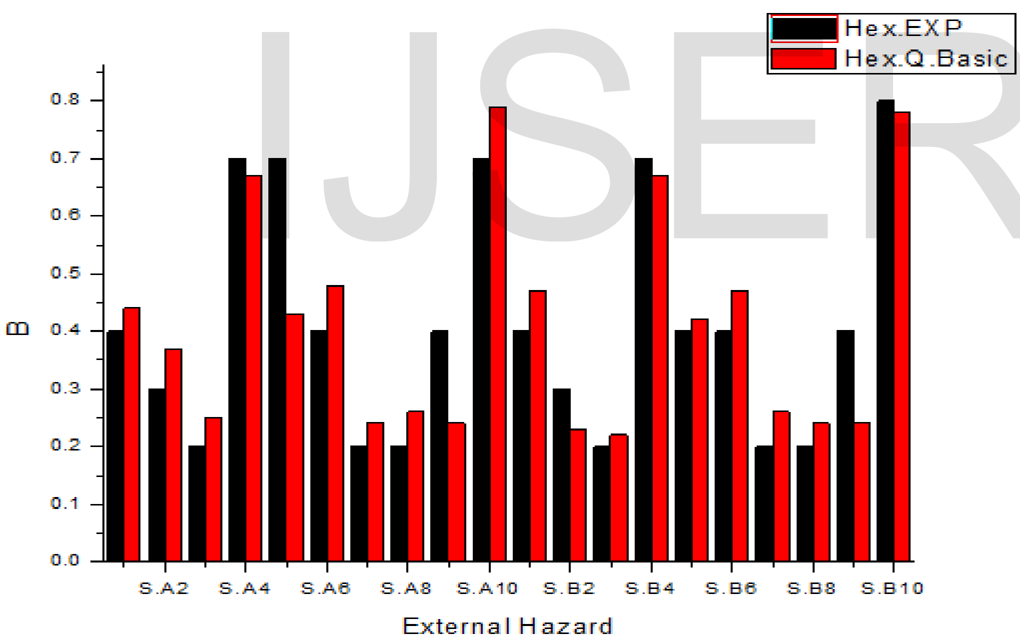

Fig. 8 External hazard in Samples soil as Comparison Experimental with Automated software program

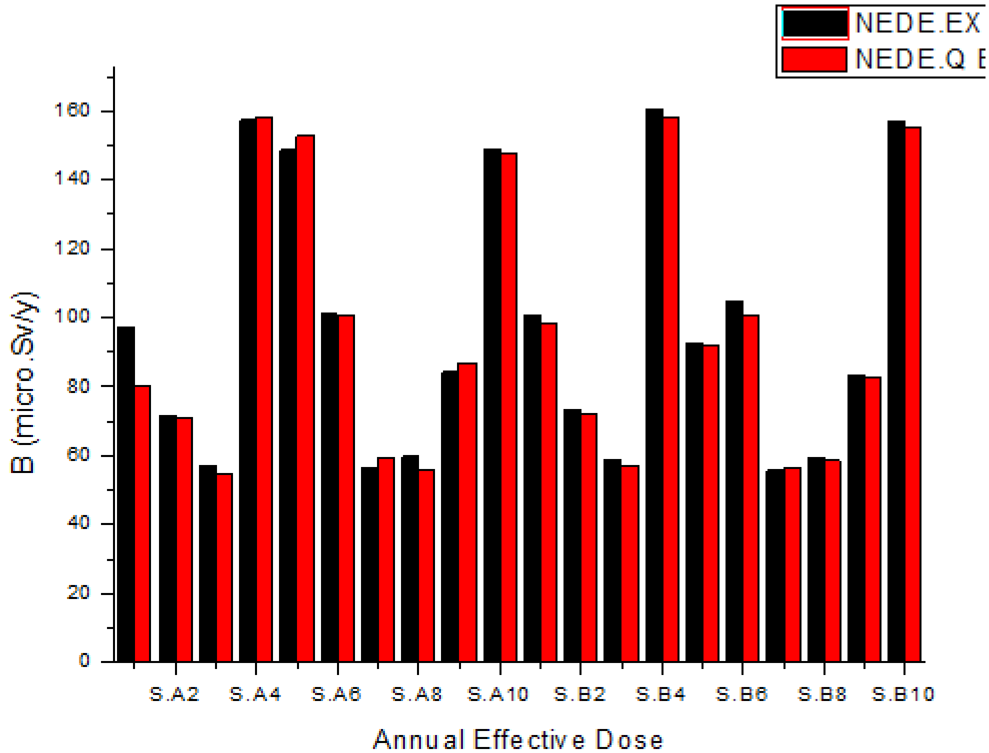

Fig.9Annual Effective Dosein Samples soil as Comparison Experimental with Autorotation program

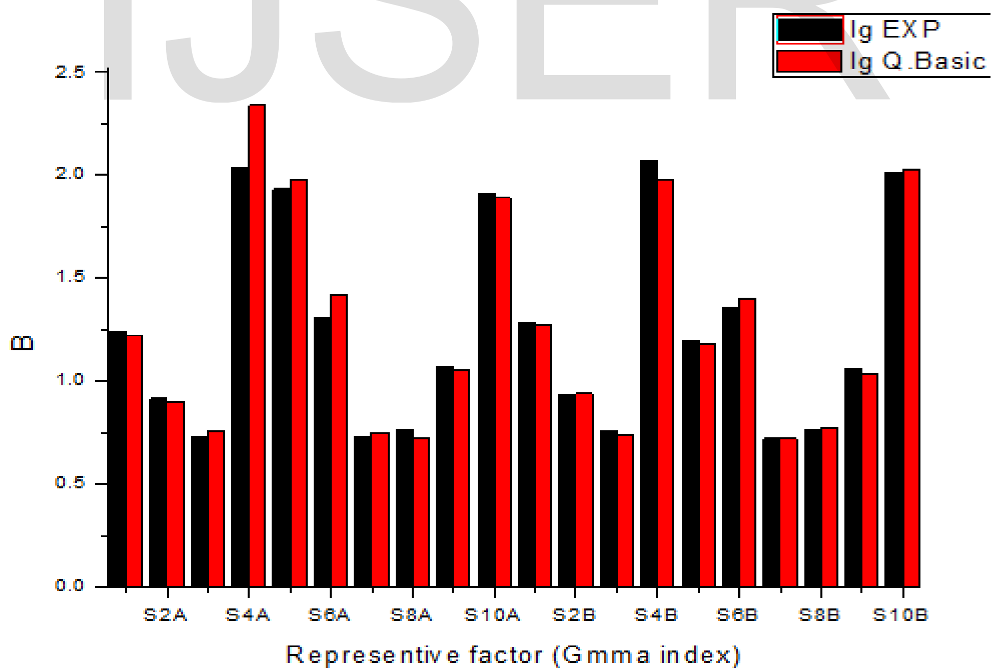

Fig.10 Reprehensive factor (Gamma index) Samples soil as Comparison Experimental with Automated software program

DISCUSSION

From Tab.2, it shows that the radium equivalent (Ra_{eq}) is found in the range 101-288/kg, as a result of average value for all concentrated radionuclides in soil .The average value of radium equivalent is less than the safe limits 370Bq/kg[2]. The range value of external radiation hazard index is (0.22-0.7) which is less than 1 and confirm it as safe to carry out the activities for the human in that region . The outdoor air absorbed dose rate due terrestrial gamma rays at 1m above the ground were calculated for ^{226}Ra ,^{232}Th and ^{40}K and the range is (44.7-133) nGy/h which is higher than the world average of 60 nGy/h[2] in SA4 (Qaddahie) where this region is located at cost surrounded by mountain and cultured land. The annual effective dose rates are found in the range of 56.1-158.3µSv/y with an average which is higher slightly near the world average of 80µSv/y[2] in the sample A5(Orban). The representative level index $I_{\gamma r}$ must be less than 1. For the investigated samples this index is in range 0.7-2.3Bq/kg, but higher than unity in five samples as shown in Tab.3 where these regions are located more than 100 km from coast and Chain Mountains passing through it. Figs (3-10) illustrated good fitting of experimental Genei2000 calculation and Q.Basic program

Conclusion

The need of software in gamma spectrometer to give flexible calculation can correct experimental calculation. Where this software has two parts: - Standard library –Simulation of spectrum. One of these soft wares is Genei2000 that can be used in analysis spectrum, reading results and processes them. Although there are many advantages of using Genei2000, but it has limitations in the automated software, this requires user to build program for developing software to determine all radioactive calculationIn this work, Quick-Basic (Q.Basic64) was used according to simple flowchart Fig.1; where the data were taken from MCA as output spectra in Genei2000, the net area was calculated using peaks analysis [2, 3], and therefore this software computes the specific activity and all important radiological factors. Furthermore, this software includes lots of important features like:Runs with any operation system like Windows and Real time remote control with any spectrum Analyzer

Typically; the results of samples under comparison between Genei2000 software and Q-Basic64 were in good agreement for activity concentration as shown in Tab.1 [13]. While the results were more fitting in S3, S4, S6, S8 and S10 for radiological analysis as tabulated in Tab.3 and Figs. (3-10).

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