Estimation the annual dose for residents in the area around the berms of Al-Tuwaitha nuclear site using RESRAD software

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Abstract
RESRAD is a computer model designed to estimate risks and radiation doses from residual radioactive materials in soil. Thirty seven soil samples were collected from the area around the berms of Al-Tuwaitha site and two samples as background taken from an area about 3 km north of the site. The samples were measured by gamma-ray spectrometry system using high purity germanium (HPGe) detector. The results of samples measurements showed that three contaminated area with $^{238}\text{U}$ and $^{235}\text{U}$ found in the study area. Two scenarios were applied for each contaminated area to estimate the dose using RESRAD (onsite) version 7.0 code. The total dose of resident farmer scenario for area A, B and C are 0.854, 0.033 and $2.15\times10^{-3}\text{ mSv.yr}^{-1}$, respectively. While suburban resident scenario for area A, B and C are 0.807, 0.031 and $2.04\times10^{-3}\text{ mSv.yr}^{-1}$, respectively.

Key words
Annual dose, RESRAD, Al-Tuwaitha nuclear site.

Introduction
One of the most important steps in protecting human health in the contamination areas with radioactive material is to determine how these radionuclides may eventually reach people and thus cause them harm [1]. Evaluation of the impact of radionuclide releases on humans and on the environment is important, both to quantify the risks which arise from radionuclides present in the environment due to past human activities and to predict the possible future risks. The risks from these releases arise as a result of the
transport of radionuclides in air, water, soils, or food from their release point to human [2]. Given that calculations for risk and dose assessments are complex, they are best done on a computer. RESRAD is a computer model designed to estimate risks and radiation doses from residual radioactive materials. RESRAD (short for residual radioactivity) was first released in 1989 and developed by Argonne national laboratory. It is a multifunctional tool to assist in developing cleanup criteria and assessing the risk and dose associated with residual radioactive material in soil [3]. The exposure pathways considered by RESRAD include (1) external radiation, (2) inhalation of radon or other gaseous radionuclides and contaminated dirt, (3) ingestion of contaminated plants, meat, aquatic foods, and soil, and (4) drinking contaminated water and milk [1].

**The studied area**

Al-Tuwaitha nuclear research center is considered the biggest and most complex nuclear facility in Iraq. It is located about 1 km east of the Tigris River and 3 km south of the southern edge of Baghdad. The facilities in Al-Tuwaitha cover approximately 1.2 km² and surrounding by earthen security berm with an approximately 4.6 km long and 30 m high and contain three gaps which allow for vehicle access. In 1991 and during the Gulf War, most of these facilities were extensively destroyed [4]. The area around the berms of Al-Tuwaitha site involved an area approximately 12 km². It is contained Ishtar village, military barracks, farms and a wide area not occupied by people. Therefore, it is important to evaluate the annual dose for those populations who resident in present time and those will resident in future. The dose for this area should not exceed the limits for public which recommendation by regulatory control.

**Collection samples**

Two soil samples were taken from the area located approximately 3 km north of the site in order to establish background level. 37 soil samples were collected from the area around the berms of Al-Tuwaitha site. Fig.1 shows the location of samples in the area around the berms of Al-Tuwaitha site and background samples. The samples were taken at 15 cm depth from the top surface soil layer to make approximately 1.5 kg weight per sample, using trowel tool. Each soil sample is filled into secure polyethylene bag with sealable tops to prevent cross contamination and sent to the laboratory. The soil sample is contained label recorded in it the information about the sample such as code, sample type, data of collected, location and GPS coordinates. The samples dried, grinded, sieved, filled into 500 ml Marinelli beakers and stored for about one month to obtain the radioactive secular equilibrium between parent and their daughter radionuclides. Samples were measured by gamma-ray spectrometry system using high purity germanium (HPGe) detector with relative efficiency 65%. To determine the radionuclides in soil samples, the energy 1001.03 keV (\(^{234}\text{m} \text{Pa}\)) used for \(^{238}\text{U}\), 911.20 keV (\(^{228}\text{Ac}\)) for \(^{232}\text{Th}\), 609.31 keV(\(^{214}\text{Bi}\)) for \(^{226}\text{Ra}\), 163.76 and 205.31 keV used for (\(^{235}\text{U}\)), 40K at 1460.81 keV and \(^{137}\text{Cs}\) at 661.65 keV were used.
The radionuclide concentration in the soil sample

The specific activity of $^{238}\text{U}$, $^{235}\text{U}$, $^{232}\text{Th}$, $^{226}\text{Ra}$, $^{40}\text{K}$ and $^{137}\text{Cs}$ for all soil samples are given in Table 1. According to results of the samples measured in gamma spectrometer.

There are three areas contaminated with uranium component ($^{238}\text{U}$ and $^{235}\text{U}$) which considered clearly above background concentrations were found in the area around the berms and divided according to their location to area A, B and C. Fig. 2 shows the location of contamination areas.
Table 1: The measurements of radionuclides activity in the soil samples.

| N  | Sample code | Activity Concentration (Bq.kg⁻¹) |
|----|-------------|----------------------------------|
|    |             | ²³⁵U (²³⁴mPa) | ²³⁴U   | ²²⁴Th (²²⁸Ac) | ²²⁶Ra (²¹⁴Bi) | ⁴⁰K      | ¹³⁷Cs     |
|----|-------------|----------------|--------|----------------|----------------|---------|----------|
| 1  | S-1         | <MDA           | <MDA   | 19.95±1.75     | 18.16±2.63     | 383.44±10.35 | 3.84±0.49 |
| 2  | S-2         | <MDA           | <MDA   | 15.52±1.63     | 18.12±2.5      | 372.39±10.49 | <MDA      |
| 3  | S-3         | <MDA           | <MDA   | 16.74±1.5      | 16.54±2.28     | 348.6±9.5   | <MDA      |
| 4  | S-4         | <MDA           | <MDA   | 18.67±1.67     | 18.26±1.54     | 341.4±9.62  | 5.92±0.49 |
| 5  | S-5         | <MDA           | <MDA   | 18.62±2.81     | 19.11±2.41     | 409.65±21.53 | <MDA      |
| 6  | S-6         | <MDA           | <MDA   | 17.65±1.71     | 17.5±1.7       | 402.9±9.94  | <MDA      |
| 7  | S-7         | <MDA           | <MDA   | 15.5±1.49      | 19.59±1.82     | 364.56±10.08 | 1.35±0.34 |
| 8  | S-8         | 50674±847.5    | 1959.5±29.2 | 19.19±5.65     | 19.02±1.74     | 345.63±24.9 | <MDA      |
| 9  | S-9         | 7523.6±152.25  | 272.5±5.23 | 15.9±1.67      | 17.24±1.5      | 289.9±8.95  | <MDA      |
| 10 | S-10        | <MDA           | <MDA   | 15.05±1.63     | 17.6±1.4       | 357.6±9.85  | 1.29±0.3  |
| 11 | S-11        | <MDA           | <MDA   | 16.22±1.65     | 18.7±1.2       | 326.7±9.7   | 2.95±0.4  |
| 12 | S-12        | <MDA           | <MDA   | 18.2±3.9       | 16.32±2.11     | 339.5±20.8  | <MDA      |
| 13 | S-13        | <MDA           | <MDA   | 19.14±3.6      | 16.82±1.9      | 398.9±22.5  | 3.24±1.09 |
| 14 | S-14        | <MDA           | <MDA   | 11.4±2.44      | 12.78±2.75     | 261.1±16.7  | 1.11±0.5  |
| 15 | S-15        | <MDA           | <MDA   | 16.87±3.5      | 18.12±1.4      | 299.67±19.32| <MDA      |
| 16 | S-16        | <MDA           | <MDA   | 18.4±4.1       | 18.4±2.5       | 414±23.07   | <MDA      |
| 17 | S-17        | <MDA           | <MDA   | 23.2±3.85      | 16.69±2.3      | 392.22±23.6 | 2.86±1.04 |
| 18 | S-18        | <MDA           | <MDA   | 14.8±3.61      | 17.46±2.1      | 343.75±20.5 | <MDA      |
| 19 | S-19        | <MDA           | <MDA   | 16.6±3.2       | 16.13±2.3      | 332.7±20.6  | <MDA      |
| 20 | S-20        | <MDA           | <MDA   | 16.15±3.6      | 16.35±1.95     | 371.49±22.1 | <MDA      |
| 21 | S-21        | <MDA           | <MDA   | 16.69±1.63     | 19.84±1.32     | 380.95±10.2 | 1.62±0.41 |
| 22 | S-22        | <MDA           | <MDA   | 11.26±0.7      | 17.53±1.32     | 365.4±10.49 | 10.7±0.63 |
| 23 | S-23        | <MDA           | <MDA   | 15.72±1.66     | 16.08±1.2      | 339.8±10.41 | <MDA      |
| 24 | S-24        | 196.6±14.37    | 9.34±0.68 | 16.37±1.7      | 19.39±1.7      | 406.09±10.54 | <MDA      |
| 25 | S-25        | 1931.3±79.19   | 71.03±3.2 | 19.26±1.8      | 23.05±1.8      | 378.4±10.2  | 1.84±0.3  |
| 26 | S-26        | 1428.2±167.3   | 54.4±2.7 | 19.1±3.9       | 16.26±2.8      | 389.24±21.4 | 2.05±0.84 |
| 27 | S-27        | <MDA           | <MDA   | 20.15±2.1      | 18.19±1.1      | 412.2±10.96 | <MDA      |
| 28 | S-28        | <MDA           | <MDA   | 19.13±1.6      | 19.49±1.5      | 393.5±9.88  | 1.48±0.3  |
| 29 | S-29        | 28.4±3.8       | 3.2±0.3 | 19.07±1.7      | 18.74±1.4      | 381.49±10.15 | 6.35±0.5  |
| 30 | S-30        | 78.8±34.8      | 5.7±0.9 | 17.12±1.6      | 18.69±1.7      | 341.96±10.6 | <MDA      |
| 31 | S-31        | 80.04±25.02    | 7.1±0.8 | 17.24±1.7      | 16.32±2.3      | 368.2±9.8  | 0.65±0.2  |
| 32 | S-32        | <MDA           | <MDA   | 16.48±3.4      | 18.5±4.1       | 370.28±21.7 | <MDA      |
| 33 | S-33        | <MDA           | <MDA   | 16.19±3.7      | 17.39±2.6      | 410.33±22.39 | 2.2±0.7   |
| 34 | S-34        | <MDA           | <MDA   | 19.5±3.3       | 19.02±2.1      | 422.3±22.9  | 4.28±0.96 |
| 35 | S-35        | <MDA           | <MDA   | 21.02±3.7      | 18.52±2.2      | 393.9±22.3  | 2.66±0.91 |
| 36 | S-36        | <MDA           | <MDA   | 20.9±3.6       | 16.35±1.9      | 359.34±21.7 | <MDA      |
| 37 | S-37        | <MDA           | <MDA   | 17.56±3.6      | 16.63±2.1      | 359.8±22.12 | 2.25±0.8  |
| 38 | BG-1        | <MDA           | <MDA   | 17.75±1.3      | 19.7±2.6       | 395.48±25.3 | 2.35      |
| 39 | BG-2        | <MDA           | <MDA   | 15.48±1.4      | 17.97±2.3      | 323.7±19.5  | <MDA      |
The input parameters of RESRAD
Resident farmer and suburban resident scenario applied for each contaminated area to evaluate the dose using RESRAD (onsite) version 7.0 codes created in 2014. The Table 2 showed the input parameters values of RESRAD which used to calculate the annual dose of these areas for two scenarios.

Table 2: The input parameters for RESRAD used to calculate the dose of contaminated area.

| parameters                              | unit         | Area(A) | Area(B) | Area(C) |
|-----------------------------------------|--------------|---------|---------|---------|
|                                        |              | Resident Farmer | Suburban Resident | Resident Farmer | Suburban Resident | Resident Farmer | Suburban Resident |
| Mean radionuclide concentration @ Bq/g m |              | 29.098 for ²³⁸U  | 1.115 for ²³⁵U | 1.185 for ²³⁸U  | 0.044 for ²³⁵U | 0.06256 for ²³⁸U | 0.0053 for ²³⁵U |
| Contaminated area @ m²                  |              | 1250     | 1250    | 500     | 500     | 1000     | 1000     |
| Thickness of contaminated @ m           |              | 0.15     | 0.15    | 0.15    | 0.15    | 0.15     | 0.15     |
| Cover depth @ m                        |              | 0        | 0       | 0       | 0       | 0        | 0        |
| Average annual wind speed [7] m/s       |              | 3.1      | 3.1     | 3.1     | 3.1     | 3.1      | 3.1      |
| Precipitation[8] m/yr                  |              | 0.152    | 0.152   | 0.152   | 0.152   | 0.152    | 0.152    |
| Fraction of time indoors[3] _           |              | 0.50     | 0.50    | 0.50    | 0.50    | 0.50     | 0.50     |
| Fraction of time outdoors[3] _          |              | 0.25     | 0.25    | 0.25    | 0.25    | 0.25     | 0.25     |
| Plant food[3] _                        |              | 0.5      | 0.1     | 0.5     | 0.1     | 0.5      | 0.1      |
| Milk[3] _                              |              | 0.1      | Not used | 0.1     | Not used | 0.1     | Not used |
| Meat[3] _                              |              | 0.1      | Not used | 0.1     | Not used | 0.1     | Not used |
| Aquatic food[3] _                      |              | 0.5      | Not used | 0.5     | Not used | 0.5     | Not used |
| Soil ingestion[3] g/yr                  |              | 36.5     | 36.5    | 36.5    | 36.5    | 36.5     | 36.5     |
| Drinking water intake[3] L/yr           |              | 510      | Not used | 510     | Not used | 510     | Not used |
| Duration exposure[3] yr                 |              | 30       | 30      | 30      | 30      | 30       | 30       |
| Inhalation rate[3] m³/yr                |              | 8400     | 8400    | 8400    | 8400    | 8400     | 8400     |

@ Current study

Results and discussions
Table 3 shows the results of RESRAD calculations. The total dose of resident farmer scenario for area A, B and C are 0.854, 0.033 and 2.15×10⁻³ mSv.yr⁻¹, respectively. The large contribution of total dose comes from external, plant and soil ingest dose with 88, 6 and 4 %, respectively.
The total dose for suburban resident scenario for area A, B and C are 0.807, 0.031 and 2.04×10⁻³ mSv.yr⁻¹, respectively. The large contribution of total dose comes from external, soil ingestion and plant dose with 93.7, 3.87 and 1.25%, respectively. According to IAEA safety standard [5, 6], the total dose of area A for resident farmer scenario and suburban resident scenario were exceed the dose constraint for soil cleanup or site decontamination from all pathways which is 0.3 mSv.yr⁻¹ above background. The total dose of area B for resident farmer scenario and suburban resident scenario were below the dose constraint but is still above of the dose for clearance material of order 10 µSv.yr⁻¹, which means that the optimization less than 10 µSv.yr⁻¹ might not be warranted on radiological protection grounds. The total dose of area C for both scenarios were below the dose for clearance material 10 µSv.yr⁻¹, which means that, the dose of area C is unwarranted on radiological protection grounds and can be release from regulatory control [6]. Figs.3-6 showed the total dose over the time and the contributions pathways of all nuclides to total dose of area A for both scenarios. From Figs.3-6, the dose appears reduction over the time until reach the zero value, but in resident farmer scenario (Figs. 3-4) the value arises slightly after many years and then back reduces again. The reason of the dose reduction attributed to the dilution of the activity concentrations of radionuclide in the soil contaminated. This dilution may come from some factors such as change in thickness of cover contaminated area, leaching and also radionuclide decay, but in case of uranium contaminated which has long half-life 4.5×10¹⁰ year, the reduction belong to decay is negligible in comparison to the other two. After hundreds years, when radionuclides adsorbed in soil leached by infiltrating water (precipitation water or irrigation water) from the contaminated zone and reached to groundwater used from public, the total dose is starting rise slightly with time (as in Figs.3-4). This behavior only appears in resident farmer scenario because the groundwater contamination used from public and the dose of drink water will be large contribution to total dose.

| Area  | Scenario          | Total dose (mSv.yr⁻¹) | Contributions pathways to total dose (mSv.yr⁻¹) | Soil Ingest |
|-------|-------------------|-----------------------|-----------------------------------------------|------------|
|       |                   | External | Inhalation | Plant | Meat | Milk | Soil Ingest |
| (A)   | Resident Farmer   | 0.854    | 0.747      | 1.032×10⁻² | 0.05156 | 1.608×10⁻³ | 4.096×10⁻⁴ | 3.883×10⁻² |
|       | Suburban Resident | 0.807    | 0.747      | 1.032×10⁻² | 1.033×10⁻² | - | - | 3.883×10⁻² |
| (B)   | Resident Farmer   | 0.033    | 0.029433   | 3.81×10⁻⁴ | 2.097×10⁻⁵ | 6.54×10⁻⁵ | 1.663×10⁻⁣ | 7.897×10⁻⁴ |
|       | Suburban Resident | 0.031    | 0.029433   | 3.81×10⁻⁴ | 4.194×10⁻⁴ | - | - | 7.897×10⁻⁴ |
| (C)   | Resident Farmer   | 2.15×10⁻³ | 1.912×10⁻³ | 2.27×10⁻³ | 1.16×10⁻⁴ | 3.61×10⁻⁶ | 9.19×10⁻⁶ | 8.71×10⁻⁵ |
|       | Suburban Resident | 2.04×10⁻³ | 1.912×10⁻³ | 2.27×10⁻³ | 2.31×10⁻⁵ | - | - | 8.71×10⁻⁵ |
Fig. 3: Annual dose over the time of area (A) for resident farmer scenario.

Fig. 4: The contribution pathways of all nuclide to total dose of area (A) for resident farmer scenario.
Fig. 5: Annual dose over the time of area (A) for suburban resident scenario.

Conclusions

The total dose of resident farmer scenario is higher than suburban resident scenario because it includes all environmental pathways. The early major pathway is external and the later major pathway is drink water. The total dose of area A for both scenarios was exceeded the dose constraint which is 0.3 mSv.yr\(^{-1}\), the total dose of area B for both scenarios was below the dose constraint but it is still above the dose for clearance material which is 10 \(\mu\)Sv.yr\(^{-1}\), while the total dose of area C for both scenarios were below the dose for clearance material, that means the dose of area C is unwarranted on radiological protection grounds and can be released from regulatory control.
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