Radiological Risk Assessments for Occupational Exposure at Fuel Fabrication Facility in AlTuwaitha Site Baghdad – Iraq by using RESRAD Computer Code

Ziadoon H Ibrahim¹, S A Ibrahim², M K Mohammed¹, A H Shaban²
¹Central Laboratories Directorate Ministry of Science and Technology
²Department of Physics College of Education Ibn AlHaitham University of Baghdad

Abstract. The purpose of this study is to evaluate the radiological risks for workers for one year of their activities at Fuel Fabrication Facility (FFF) so as to make the necessary protection to prevent or minimize risks resulted from these activities this site now is under the Iraqi decommissioning program (40) Soil samples surface and subsurface were collected from different positions of this facility and analyzed by gamma rays spectroscopy technique High Purity Germanium detector (HPGe) was used It was found out admixture of radioactive isotopes (²³²Th, ⁴⁰K, ²³⁵U, ²³⁸U, ¹³⁷Cs) according to the laboratory results the highest values were (9.75758) for ²³⁸U (21203) for ²³⁵U (218) for ²³²Th (4046) for ⁴⁰K and (129) for ¹³⁷Cs in (Bqkg⁻¹) unit The annual total radiation dose and risks were estimated by using RESRAD (onsite) 70 computer code The highest total radiation dose was (5617µSv/year) in area that represented by soil sample (S7) and the radiological risks morbidity and mortality (118E02 8661E03) respectively in the same area

1 Introduction
Italian fuel fabrication facility (FFF) is located in AlTwaitha site at Iraq / Baghdad at 33°12'57 North and 44°31'82 East It was previously belong to the Iraqi Atomic Energy Commission (IAEC) The total area of this site was about (13 km²) the concern facility FFF area around (37400 m²) Each soil sample represent (100 m²) from this facility were as in 'figure 6' During the second Gulf war (1991) it was completely destroyed and now is subjected to the Iraqi decommissioning project (IDP) The facility was contaminated by Uranium radionuclides (238U235U) in soil concrete equipments and scrap materials

Dose and risk estimation managements were carried out according to single or numerous radionuclides and the radiation types (alpha beta gamma) to demonstrate compliance with regulations[12] Radiological dose and risk assessment done at the beginning of project during decommissioning or decontamination and after cleanup of a site[3] It was used pathway analysis and exposure scenarios

A radiological dose is afforded by a likely exposed individual because of a specific exposure[45]

- External doses happen when the body is exposed to radioactive material outside the body
- Internal doses take place from radioactive exposure to material entered into the body by inhalation or ingestion
- skinny absorption doses happen from skin absorption of radionuclides (Tritium or open wound)
The dose can be centralized to particular organs or spread across the whole body due to the radionuclide intake or organ exposed by the nature of work. The total dose is the sum of all pathways such as external exposure, inhalation, and ingestion [67]. The radiation dose and risk was evaluated by using ResRad (onsite) 70 computer code. The results of soil samples were regarded after analyzing in laboratory so as to characterize the radionuclides concentrations which represent the chosen zones. A radiological risk evaluation is a probability assessment of deadly cancer over the existence of an exposed. It can express the radiation cancer health risks through terms of death and incidence. A risk of $1 \times 10^6$ means the possible for an exposed individual having a deadly cancer is one in 10000 persons. The concept of risk constrain provide a basic level of protection for the individuals from a source and serves as an upper bound on the individual risk in optimization of protection for that source. According to International Atomic Energy Agency (IAEA) safety standards, the relation between dose and cancer risk development is well described for high doses of most radiation kinds. The exposure scenarios, pathways, and environmental parameters values should be identified to the workers.

The suitable radiological risk factor is $(1 \times 10^{6} \text{ to } 1 \times 10^{3})$ [89]. The radiological dose and risk evaluation can be helpful through:

- To support a lot of kinds of decisions like operational controls to make certain that the radiation exposures are safe and reasonable time limitations arrival controls personal protective equipment and storage requirements.
- Decisions to remediation and decontamination objectives (getting the site clean enough the effectiveness different in assessments actions in terms of limiting future radiation exposures and the possible future uses of the site).
- Storage treatment disposal facility operation and design The necessity in design and operation features for a facility workers protection public protection during operations and facility closure.

The information that needed to manage these assessments are the source material features physical regulations location and exposure scenarios (Workers’ activities environmental pathways onsite direct exposure surface water or groundwater contamination and soil contamination) [10].

2 ResRad computer code

In order to assess contaminated sites it can use a suite of software tools developed by the US Department of Energy to assessing radiation dose and risks from residual radioactive material under different scenarios using suitable parameters [810]. Four kinds of scenarios are being used Resident Farmer (RFS), Suburban Resident (SRS), Industrial Worker (IWS), and Recreationist (RS). RESRAD code Version 70 was used in the research and IW scenario was carried out for being benefited with decommissioning work. Table 1 shows the parameters that applied in this scenario.

Table 1: Factors values of the Industrial Workers scenario Dose Library

| Parameter | (Unit) | Quantity |
|-----------|--------|----------|
| Area      | square meters | 100      |
| Exposure time | Hour/year | 1250     |
| Inhalation rate | m³/year | 11400    |
| Indoor time fraction (occupancy factor) | | 005    |
| Outdoor time fraction (occupancy factor) | | 014     |
| Contaminated fraction of food (plant meet and aquatic food) | kg/year | 0        |
| The amount of the annual soil ingestion | g/year | 365      |
| Soil and dust density | g/cm³ | 15       |
| Wind speed | m/s | 02       |
| Contaminated zone erosion rate | m/year | 0001     |
| Contaminated zone total porosity | | 04       |
| Saturated zone effective porosity | | 02       |
3 Materials and methods

The equipment that are used are sampling tools core sample milling machine sieve of 750 μm mesh size drying oven weighting scale sample container global position system (GPS) as shown in 'figures 12' portable device for radiological survey(LUDLUM 2241 2RK) type 4410 sodium iodide scintillation detector and Gamma Spectroscopy system (Canberra) as shown in 'figures 45' Gamma spectroscopy system consists of a detector preamplifier pulseheight analyzer(DSA1000) lead shield multichannel analyzer (MCA) with 8192 channel and vertical high purity germanium (HPGe) detector with relative efficiency 40% and resolution (<18keV) based on measurements of 1332 MeV gamma ray at photo peak of 60Co source Both high voltage supply and amplifier device are compact in one unit (DSA1000) detector shield with a cavity adequate to 10 cm Lead absorbed grid from Cadmium 16mm and Copper 04mm to reduce radiological background as shown in 'figure 5'

3.1. Samples Collecting

The samples was collected (40) (surface and subsurface) from the Fuel Fabrication Facility at depth of 15cm and 6 samples at 40 cm depth each sample represent the studied area (100m²) from facility three samples were collected from outside AlTuwaitha site to determine the background levels Samples were labeled and coded in all locations by using (GPS) where the samples taken from the mass of the sample was one kilogram

3.2. Preparing samples method

By putting each soil sample in a drying oven at 100°C for one hour to make sure of removing any remaining of moisture samples preparation was managed then the dried samples was milled till to be a fine powder using grinder for pulverizing the soil sample A 750 μm mesh is used to sieve the soil samples to obtain uniform particle sizes The volume was (500ml) that was kept in sealed Marinelli Beaker with plastic strip to avoid the escaping of (222Rn) and (220Rn) from the samples as shown in 'figure 3' after that it was stored for one month so that the Uranium238 and Thorium 232 chains could reach to the radiological equilibrium

3.3. Samples analysis

Gamma Spectroscopy system (Canberra) was used to analyze soil samples A library of radionuclide’s which contained the energy of the characteristic gamma emissions of each radionuclide and their corresponding emissions probabilities were built from the date supplied in the software (Genie 2000)238U radioactivity concentration was determined by gamma energy (1001keV) that is belong to the Protactinium isotope (234mPa) for high radionuclide concentration samples and by (60932 keV) that is belong to the Bismuth (214Bi) to low concentration239U was determined at gamma energy (1438 keV 1633 keV 1857 keV and 2053 keV)which are belong to the same isotope the corrected activity in Genie 2000 software was depended whereas the thorium (232Th) was determined at (9117keV) gamma energy by energy is belong to 228Ac 40K and 137Cs isotopes which can be determined at 14608 and 662keV peak energy respectively it should be noticed that all concentrations were determined in (Bq /kg) unit
Figure 1. a milling machine for soil sample (b) sieve (c) oven (d) weighing scale.

Figure 2. Trowel tool used to collect sample, handheld GPS unit.

Figure 3. A prepared soil samples filling in 500 ml Marinelli beaker.

Figure 4. Gamma spectrometry system.

Figure 5. Ludlum dose rate meter.
### 3.4. Samples analysis results

Three samples were analyzed using gamma spectrometry system with consider that samples are as the radiation background in order to compare results with the selected areas. The (40) mentioned samples were analyzed the radiological activity concentration can be seen in Table 2 and figures 67. Table 3 shows the higher and lower radiological activity concentration in samples.

| Sample code | Coordinate North | East | Radionuclide concentration Bq/kg | 238U | 235U | 232Th | 40K |
|-------------|------------------|------|---------------------------------|------|------|-------|-----|
| S1          | 33° 12014        | 44° 30757 | 128±09  | BDL** | 129±11 | 4755±12 | BDL |
| S2          | 33° 11970        | 44° 30789 | 13±085  | BDL   | 149±112 | 2997±171 | 25±032 |
| S3 Sub*     | 33° 12013        | 44° 30755 | 148±095 | BDL   | 7±16   | 392±145 | BDL |
| S4 Sub      | 33° 11984        | 44° 30770 | 184±114 | BDL   | 161±1  | 3345±20 | BDL |
| S5 Sub      | 33° 11946        | 44° 30774 | 125±13  | BDL   | 84±12  | 453±15 | BDL |
| S6          | 33° 11962        | 44° 30776 | 62116   | 149±89 | 86±13  | 258±113 | 73±085 |
| S7          | 33° 11958        | 44° 30778 | 975758  | 21203 | BDL    | 3796±444 | BDL |
| S8          | 33° 11949        | 44° 30780 | 18952   | 4044  | 138±28 | 281±105 | BDL |
| S9          | 33° 11972        | 44° 30770 | 166±13  | BDL   | 153±17 | 3127   | BDL |
| S10         | 33° 11996        | 44° 30754 | 91±1    | BDL   | 135±18 | 346±11 | 32±05 |
| S11         | 33° 12003        | 44° 30744 | 141±13  | BDL   | 99±15  | 2594±21 | 24±05 |
| S12         | 33° 11985        | 44° 30745 | 115±12  | BDL   | 11±15  | 2683±209 | 39±05 |
| S13         | 33° 11952        | 44° 30776 | 11942   | 2904  | 123±16 | 2702   | 43±066 |
| S14         | 33° 11954        | 44° 30768 | 94525   | 21535 | BDL    | 335±11 | BDL |
| S15         | 33° 11964        | 44° 30719 | 749005  | 15592 | BDL    | 3636   | BDL |
| S16         | 33° 11971        | 44° 30962 | 153174  | 3656  | BDL    | 2534   | BDL |

| Sample code | Coordinate North | East | Radionuclide concentration Bq/kg | 238U | 235U | 232Th | 40K |
|-------------|------------------|------|---------------------------------|------|------|-------|-----|
| S17         | 33° 11967        | 44° 30964 | 224630  | 4161 | BDL   | BDL   | BDL |

Table 2 Activity concentration in soil samples
|     |     |     |     |     |     |     |     |
|-----|-----|-----|-----|-----|-----|-----|-----|
| S18 | 33° 11956 | 44° 30735 | 377785 | 6744 | BDL | BDL | BDL |
| S19 | 33° 11968 | 44° 30721 | 539612 | 13083 | BDL | 332 | BDL |
| S20 | 33° 11981 | 44° 30741 | 342493 | 8179 | BDL | 2836 | BDL |
| S21 Sub | 33° 11924 | 44° 30672 | 11±085 | BDL | 149±112 | 316±121 | BDL |
| S22 Sub | 33° 11996 | 44° 30647 | 14±084 | BDL | 159±112 | 2737±171 | BDL |
| S23 | 33° 12010 | 44° 30732 | 108206 | BDL | 15 | 2902 | 57 |
| S24 | 33° 11990 | 44° 30711 | 86086 | 878 | 157 | 3566 | 44 |
| S25 | 33° 11973 | 44° 30726 | 121765 | 2269 | 171 | 3312 | 22 |
| S26 Sub | 33° 11938 | 44° 30752 | 163 | BDL | 142 | 3285 | BDL |
| S27 | 33° 11939 | 44° 30736 | 193956 | 4367 | BDL | 2759 | BDL |
| S28 | 33° 11961 | 44° 30702 | 42731 | 936 | 163 | 2873 | 5 |
| S29 | 33° 11933 | 44° 30721 | 66290 | 14822 | 158 | 3336 | BDL |
| S30 | 33° 11980 | 44° 30686 | 5215 | 929 | 182 | 2872 | 34 |
| S31 | 33° 11960 | 44° 30691 | 201993 | 40615 | BDL | 2417 | BDL |
| S32 | 33° 11962 | 44° 30689 | 2865425 | 5466 | BDL | 4046 | BDL |
| S33 | 33° 11913 | 44° 30723 | 178346 | 35246 | 212 | 3952 | 15 |
| S34 | 33° 11980 | 44° 30670 | 31428 | 559 | 218 | 3393 | 71 |
| S35 | 33° 11932 | 44° 30703 | 55974 | 1236 | 144 | 3436 | BDL |
| S36 | 33° 11960 | 44° 30667 | 26063 | 557 | 106 | 2956 | 32 |
| S37 | 33° 11930 | 44° 30690 | 1021 | 2125 | 118 | 3172 | 79 |
| S38 | 33° 11914 | 44° 30692 | 69084 | 1419 | 119 | 2038 | 129 |
| S39 | 33° 11963 | 44° 30668 | 169014 | 299 | 877 | 2188 | BDL |
| S40 | 33° 11897 | 44° 30670 | 169±089 | BDL | 118±075 | 2374±145 | 17±025 |

S3 Sub soil sample sub surface BDL below detection limit
### Table 3 Summary of the activity concentration of soil sample

| Sample code | $^{238}$U Bq/kg | $^{235}$U Bq/kg | $^{232}$Th Bq/kg | $^{40}$K Bq/kg | $^{137}$Cs Bq/kg |
|-------------|-----------------|-----------------|------------------|--------------|-----------------|
| Highest sample | 975758 | 21203 | BDL | 3796±444 | BDL |
| Lowest sample | 91±1 | BDL | 135±18 | 346±11 | 32±05 |
| Average background | 878 | BDL | 1326 | 28398 | BDL |

**Figure 6** location of sampling in FFF and $^{238}$U concentration activity levels (Bq/kg)

**Figure 7** Radioactivity concentration in soil samples
The radiological dose and risks results

The radiation dose and risks was analyzed to workers by using RESRAD onsite computer code. The industrial scenario (IS) in RESRAD was applied with the limited exposure pathways because it is suitable with the workers in FFF to their activities in decommissioning project. The RESRAD code used a pathway analysis method in which the relation between radionuclides concentrations in soil with dose and risks to a member of workers that expressed as a pathways sum which is the sum of products of pathway factors correspond to pathways involving radionuclides that can be transported or from radiation that can be emitted. Table 1 shows the input values for RESRAD software parameters. Table 4 and figures 89 show the annual radiological dose and risk (morbidity and fatal mortality).

### Table 4 Total radiological dose and risk in FFF

| Sample code | Total annual dose µSv/yr | Radiological risk | Sample code | Total annual dose µSv/yr | Radiological risk |
|-------------|--------------------------|-------------------|-------------|--------------------------|-------------------|
| S6          | 4383                     | 9324E05           | S27         | 1102E+03                 | 2311E03           |
| S7          | 5617E+03                 | 118E02            | S28         | 3309E+01                 | 7078E05           |
| S8          | 1160E+02                 | 2444E04           | S29         | 3899E+02                 | 8184E04           |
| S13         | 7723E+01                 | 1632E04           | S30         | 3776E+01                 | 8051E05           |
| S14         | 5527E+02                 | 1160E03           | S31         | 1143E+03                 | 2396E03           |
| S15         | 4283E+03                 | 8973E03           | S32         | 1647E+03                 | 3451E03           |
| S16         | 8766E+02                 | 1838E03           | S33         | 1139E+02                 | 2407E04           |
| S17         | 1272E+03                 | 2665E03           | S34         | 1883E+02                 | 3965E04           |
| S18         | 2139E+03                 | 4480E03           | S35         | 4175E+01                 | 8909E05           |
| S19         | 3139E+03                 | 6579E03           | S36         | 2329E+01                 | 5032E05           |
| S20         | 1753E+03                 | 3668E03           | S37         | 1249E+01                 | 2727E05           |
| S23         | 6394E+01                 | 1353E04           | S38         | 4653E+01                 | 9865E05           |
| S24         | 5670E+01                 | 1205E04           | S39         | 1008E+02                 | 2122E04           |
| S25         | 7804E+01                 | 1651E04           |             |                          |                   |

**Figure 8** The annual effective dose for selected area
Figure 9 The annual radiological risk factor for selected area

Figure 10 The total radiological dose to highest area (S7) by pathways components

Figure 11 The total radiological dose to highest area (S7) by the radionuclides
Figure 12 The radiological risk factor for highest area (S7) by pathways components

5. Discussion
(40) soil samples were collected from the fuel fabrication facility according to the results obtained from laboratory analysis as in table 2 there were a presence of high concentrations of (\(^{238}\text{U}\) and \(^{235}\text{U}\)) radionuclides in (27) soil sample above background level the highest radiation dose for the chosen area of (S7) was (5617\(\mu\text{Sv/year}\)) and risk (118\(x10^{-8}\), 124\(x10^{-3}\)person/year) morbidity and mortality respectively. The total radiation dose and risk factor were conducted to (27) areas because of these areas have residual radioactive material depending on soil samples analysis results. In 'figure 10' it can see the contribution and participation of each by pathways components in the total radiation dose and risks such as external ingestion and inhalation. As shown in 'figure 11' the total radiological dose to highest area (S7) area along 100 years by contribution of the radionuclides \(^{238}\text{U}\) is the highest radionuclide that contribute in radiation dose and risk. In 'figures 10, 11, 12' there are decreasing in radiation dose and risks over the time integration from RESRAD program report (19) areas were determined over to the risk limit that illustrated in table 4 and 'figures 8, 9' these areas are (S7, S8, S13, S14, S15, S16, S17, S18, S19, S20, S23, S25, S27, S29, S31, S32, S33, S34, S39).

6. Conclusions and Recommendations
The radiological risk depend on total dose from the results of this research there are a rising in nineteen areas in FFF each area in this study represent 100 m\(^2\) that mean 1900 m\(^2\) from 37400 m\(^2\) (5%) from total FFF area over the risk limit 2700 m\(^2\) from 37400m\(^2\) are contaminated (72%) under this study Radiation protection program must conduct for workers in these areas by decreasing the working hours wearing protective clothing and suitable equipment's. From one area that represented by soil sample the external exposure of all radionuclides that dominant on the exposure pathways (inhalation and ingestion) therefore must focus on the precaution and protection workers from external dose by taking in to account the working time is the major factor from radiation exposure. Time factor can solve by reduce the daily number of working hours or use the alternative system for workers \(^{238}\text{U}\) is the highest radionuclide that contributes in radiation dose and risk because of the obviously high difference in concentration activity between \(^{238}\text{U}\) and another radionuclides by analyzed soil samples. Because of the long life \(^{238}\text{U}\) (about 45x10\(^9\) year) the radiological dose and risk reduce over the time but slightly by radioactive decay of all radionuclide but the second basis is environmental condition that play main role to reduce dose and risk from transport the contaminants by wind and leaching them underground that fine in 'figures 10, 11, 12'.
The highest areas (S7 S15 S17 S18 S19 S20 S27 S31 S32) must be controlled by surrounding with warning label to prevent anyone from reaching them and putting a plan to decontamination as well as other contaminated areas.

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