Assessment of Radiological Status for the Destroyed Nuclear Fuel Fabrication Facility at AL-Tuwaitha Site

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Abstract

The fuel fabrication facility (FFF) is one of the destroyed nuclear facilities in AL-Tuwaitha site that requires remediation and decommissioning. The characterization of activities of FFF had been conducted in 2013 using hand-held radiation detection instruments for the structures and the surface of FFF for contaminations. The exposure dose rates and laboratory measurement was conducted for forty nine soil samples that collected for activity measurements and analysis using gamma spectrometry technique of high purity germanium detector. The surveys and laboratory results indicated that the FFF was contaminated with uranium-238 and uranium-235 nuclides in excess of the IAEA limits for exemption from regulatory control, and indicating that the decommissioning operations for the FFF must be subjected to regulatory control and safety surveillance to ensure adequate protection of the operators, public and the environment during implementation of the decommissioning operations, according to ALARA (As Low As Reasonable Achievable) principle as recommended by International Atomic Energy Agency (IAEA).

Key words: Radiological characterization, Fuel fabrication facility, Iraqi decommissioning program (IDP), Radiological safety.

تقييم الحالة الاشعاعية لمنشاة صناعة الوقود النووي المدمرة في موقع التويثة

الخلاصة

منشاة صناعة الوقود النووي هي احدى المنشات النووية في موقع التويثة التي تتطلب تنظيفها وتفكيكها. اجريت عمليات التوصيف الاشعاعي لهذه المنشاة خلال عام 2013 باستخدام الاجهزة المحمولة للتلوث الاشعاعي و التعرض الاشعاعي للأبنية وارضية المنشأة وكذلك بواسطة اجهزة التحليل المختبرية حيث تم جمع(49) نموذج تربة وجرى قياس النشاط الاشعاعي للنماذج باستخدام منظومة تحليل اطياف كاما المتكون من كاشف الجرمانيوم عالي النقاوة. بينت نتائج التوصيف الاشعاعي ان الموقع ملوث بنظائر اليورانيوم-238 واليورانيوم-235 بمستويات تتجاوز معايير الاعفاء من السيطرة الرقابية والمعتمدة من قبل الوكالة الدولية للطاقة الذرية، وأن عمليات تنظيف وتصفية هذه المنشاة يجب ان تخضع للسيطرة الرقابية لضمان صحة وسلامة العاملين وعامة السكان والبيئة خلال تنفيذ عمليات التصفية و تقليل مستويات التلوث والتعرض الاشعاعي الى اقل قدر ممكن وحسب مبدا (ALARA)الموصى به من قبل الوكالة الدولية للطاقة الذرية .

الكلمات المفتاحية: التوصيف الاشعاعي، منشاة صناعة الوقود، برنامج التصفية العراقي، السلامة الاشعاعية.

Introduction

Fuel Fabrication Facility (FFF) is one of nuclear facilities located within Al-Tuwaitha nuclear site,GPS Coordinates (North= 33°11.462˝, East= 44°30.723˝) (Figures 1 and 2). It was designed to manufacture nuclear fuel (natural UO_2) with the requirements of nuclear technology in laboratory scale [1-3]. The FFF wasused to prepare nuclear fuel pins of maximum length (4.1 m) and to assembly fuel element of maximum length (4.5 m), which irradiated at Iraqi nuclear research reactor IRT 5000 kW for the purpose of radiochemistry research. The Fuel Fabrication Facility was established by Italy in 1980 at Al-Tuwaitha Nuclear Site of the previous Iraqi Atomic Energy Commission (IAEC). It was operated in 1981 and destroyed in 1991 in the second gulf war. Now, only steel skeleton remains and large piles of concrete, rubbles, soil, steel, unsafe structure and the surroundings area were contaminated with Uranium compounds such as (UO3, UO2) as a result of operation and the dispersion of uranium due to facility bombarding by coalitionforces. The FFF covered ground area of about 32000 $m^2$and consists of the constructions as shown in Figure 3 and 4.

Fig. 1.Location of (FFF) inside Al-Tuwaitha site.Fig. 2. Shows the current condition of FFF

The purpose of study was to assess the radiological activity to be used as a basis for evaluating the radiological impact risk due to decommissioning operations on the operators, public and the environment.

Materials and Methods:

Typical methods were used to determine the radiological condition of areas, equipments, and systems, for destroyed fuel fabrication facility in radiological characterization process.

Instrumentation

The instruments were selected for the external exposure dose rates and contaminations of the destroyed FFF were determined using different types of portable instruments types:

- Ludlum model (2241-2) with model 44-10 Sodium Iodide (NaI) 2"×2" Detectorfor measuring gamma dose rate in (µSv/hr), with sensitivity of approximately 900 count per minute (cpm) per (µR/hr) for Cs-137.
- Radeye-sx with100cm^2 scintillation probe model DP6BD for measuring (α, β, and γ) contaminationin unit (Bq/cm^2), a zinc sulfide (ZnS(Ag)) scintillation detector ,with gamma sensitivityapproximately 15-20 cpm/µR/hr for Cs-137.

Measurements:

Background Measurements:

The background measurements for dose rates and contaminations were done at 150 m far from North of the FFF at coordinate(N 33 12,072. E 44 30, 721), because this location was free from any contamination and had the same components (soil, steel, rubble, concrete, etc.).Grid (10 m x 10 m) was chosen to perform background measurement [4-6]. The results of radiological background measurements are shown in Table-1:

Measurements ofthe destroyed Fuel Fabrication Facility (FFF)

The surface area of the facility was divided into 320 grids, each grid was divided to (10 m x10 m), initial point (0, 0) located at the left end of the entrance, y –axis represent the south of the facility, while X-axis represent the west. Number of grids on Y-axis is 16 grids while number of grids on X-axis was 20 grids. The dose rate measurements were done at 15 cm height above the ground levels, the average for each grid were determined for 20 number of measurements in (µSv/h), while the contamination measurements were done for measuring (α, β, and γ) contaminations at height 5 cm in Bq/cm^2 for 20 number of measurements at each grid and moved in a serpentine pattern to cover whole grid while walking at a speed that allows the investigator to detect the desired investigation level [7-10]. Figures (3, 4) show the contamination areas and construction of FFF.

Table 1. Background measurements

Type of material	Contaminations (Bγ) Bq/cm² By RadEye SX with DP6BD scintillation (100cm²) detector at height 5 cm above the ground surface			Dose rates µSv/h (γ) by Ludlum Sodium Iodide (NaI) 2"×2" Detector at height 15 cm above the ground surface		
	MIN.	MAX.	AVAR.±SD	MIN.	MAX.	AVAR..±SD
Concrete	0.090	0.140	0.108±0.013	0.046	0.063	0.057±0.004
Soil	0.090	0.150	0.128±0.019	0.063	0.081	0.070±0.006
Asphalt	0.090	0.140	0.113±0.014	0.049	0.058	0.053±0.002
Steel	0.090	0.140	0.102±0.014	0.045	0.059	0.051±0.004

SD= Standard deviation

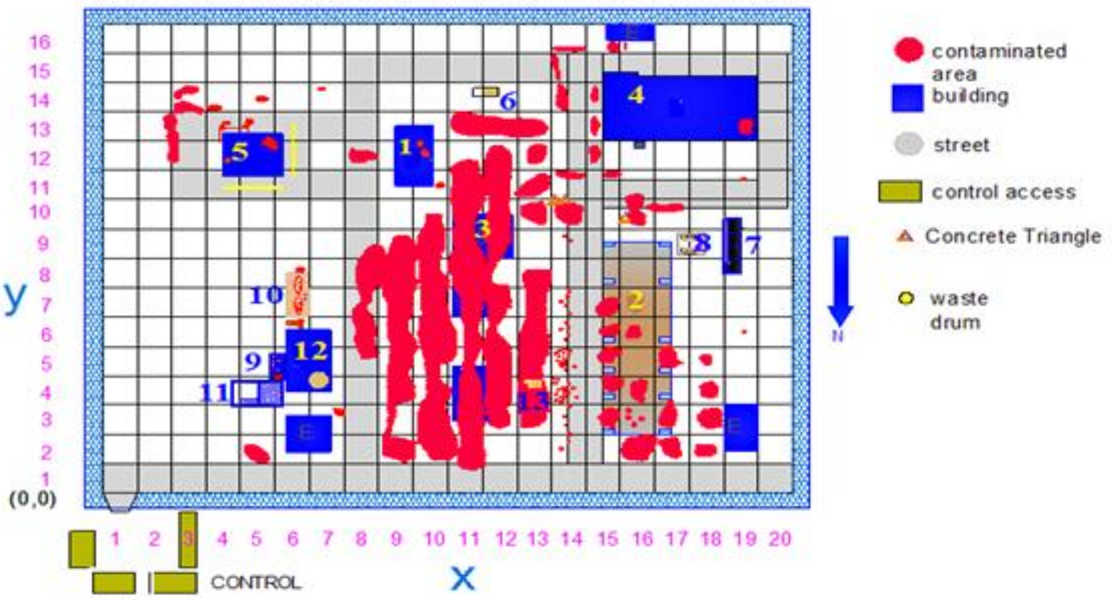

Fig 3: Ground Contamination area of FFF which is illustrated in red color.

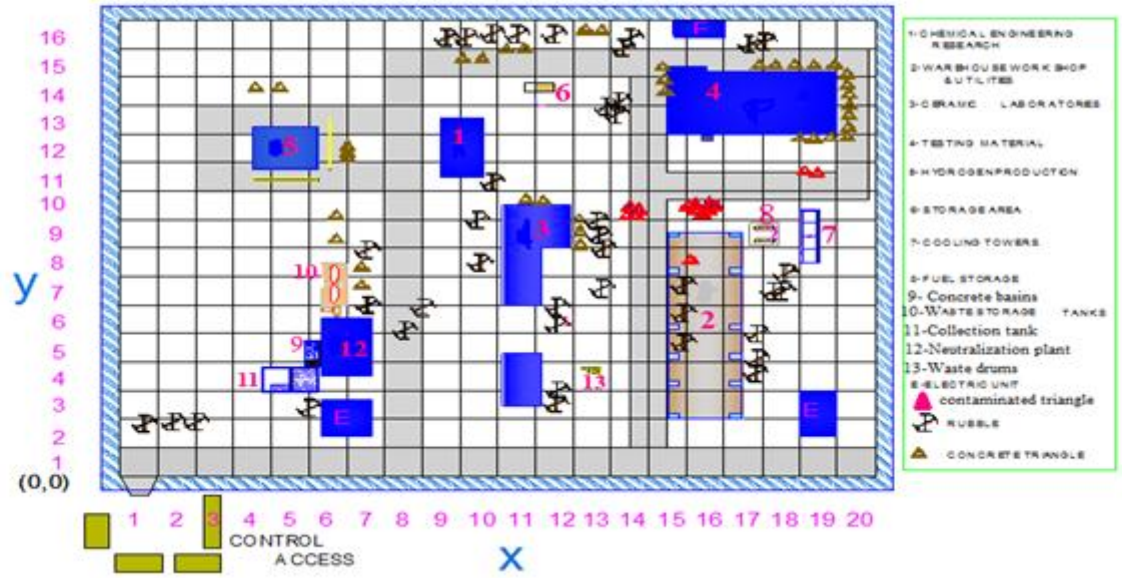

Fig. 4.The constructions and gridding of ground of (FFF).

Table 2. Measurement for dose rate and contaminations of FFF

No.	Measurement Location	Dose rate at 15cm by Ludlum µsv/h			Contamination measurements by radeyeBq/cm^2		
		Min.	Max.	Aver.±SD	Min.	Max.	Aver.±SD
1	Waste drums	0.236	1.867	0.702±0.352	3.700	54.710	29.300±17.708
2	Underground channels	0.043	0.372	0.056±0.084	0.090	6.030	0.510±1.534
3	Neutralization concrete basins	0.057	0.688	0.212±0.198	0.120	62.300	4.480±3.511
4	Radioactive liquid waste tank	4.605	30.000	16.681±3.667	0.150	492.300	89.380±49.5
5	Technological Hall	0.045	0.247	0.077±0.051	0.130	10.500	0.510±1.567
6	Ceramic laboratories	0.057	4.053	0.314±0.473	0.120	80.800	8.100±5.523
7	Hydrogen Production Building	0.065	0.154	0.094±0.091	0.110	1.480	0.230±0.150
8	Ware house, Work Shop and Utilities Building	0.052	6.492	0.454±0.269	0.110	420.000	32.100±28.834
9	Hall for Testing Material	0.051	0.062	0.058±0.018	0.090	9.130	0.240±0.328
10	concretes triangle	0.098	1.534	0.573±0.310	0.110	145.000	29.400±24.683
11	Chemical waste treatment and neutralization plant	0.057	0.082	0.062±0.011	0.100	0.180	0.140±0.021
12	Surrounding areas	0.061	4.543	0.213±0.475	0.360	84.600	5.300±9.538
13	Electric units	0.053	0.091	0.062±0.008	0.120	0.180	0.140±0.015
14	Cooling tower	0.052	0.069	0.058±0.005	0.110	0.140	0.120±0.012
15	Collection tank	0.062	0.088	0.068±0.006	0.120	0.350	0.190±0.025

Laboratory measurements

Forty-nine surface soil samples (45 from inside the FFF and 4 samples from outside the FFF as background) were collected from different location of the facility to cover approximately the whole area of the facility and focused on the elevated areas that have a potential contamination according to survey measurements. The samples collected at depth of 5 centimeters using hand augerand there are only three soil samples were taken at depth 20 -30 cm, each soil sample was packed into its own secure bag to prevent cross contamination and sent to the laboratory for measurements. Soil samples were crushed by grinding machine and sieved through a 1 mm mesh sieve, and then dried in an oven at 80 – 100 ^{0}C for 5 h. One kilogram was packed in marinelli beaker geometry, closed and tightly sealed using par film and store about one month to allow U-

238 and Th-232 decay series to reach radioactive equilibrium with it short live progeny. Gamma spectrometer (Canberra) system was used to measurement and analyze samples, which consists of a detector, preamplifier and pulse-height analyzer (DSA 2000), lead shield, using vertical high purity germanium (HpGe) detector of efficiency 40 %, and resolution (2.0 keV). Based on the measurement of 1.332 MeV gamma ray photo peak of Co-60 source and Multichannel analyzer (MCA) with 8192 channel was used, both high voltage supply and amplifier device are compact in one unit (DSA 2000), A detector shield with a cavity adequate to accommodate large samples. Shield has walls 10 cm lead, thick lined inside with graded absorber of Cd ~ 1.6 mm Cu ~ 0.4 mm [5-7],calibration and efficiency of the system were carried out using multi–gamma ray standard source (MGS-5, canberra) of Marinelli beaker geometry and the time of measurements about 1 h. A library of radionuclides contained the energy of the characteristic gamma emissions of each nuclide was analyzed and their corresponding emission probabilities were built from the data supplied in the software (Genie-2000) [11-14] .The activity concentrations of radionuclides in soil sample are given in table (3), where Figure (5) showed the location of these samples. The specific activity in terms of the activity concentration is defined as the activity per unit mass of the sample. The specific activity of individual radionuclides in soil samples is given by the following equation [7]:

$$A= \frac{N}{\varepsilon_f P_\gamma t_s m\ K}$$

Where *N* = the corrected net peak area of the corresponding full-energy peak
N = *NS* - *NB*
NS = the net peak area in the sample spectrum
NB = the corresponding net peak area in the background spectrum
ε_f = the efficiency at photo peak energy
ts= the live time of the sample spectrum collection in seconds
m = the mass (kg) of the measured sample
P_γ= the gamma-ray emission probability corresponding to the peak energy
K = the correction factor

Table 3. Activity concentrations of radionuclides in soil samples (Bq/Kg). BDL; Below Detection Limit.

No.	Code of sample	No. of grid	Radionuclide concentrations (Bq/Kg)					
			U-238		U-235	Th-232	K-40	Cs-137
			Bi-214	Pa-234M				
1	IFS-1	1-2	12.8±0.9	BDL	BDL	12.9±1.1	475.5±12	BDL
2	IFS-2	1-10	13±0.8	BDL	BDL	14.9±1.1	299.7±17.1	2.5±0.3
3	IFS-3	19-16	16.9±0.89	BDL	BDL	11.8±0.7	237.4±14.5	1.7±0.2
4	IFS-4	2-2	14.8±0.95	BDL	BDL	7±1.6	392±14.5	3.17±0.33
5	IFS-5	2-8	18.4±1.14	BDL	BDL	16.1±1	334.5±20.1	3.2±0.42
6	IFS-6	2-16	12.5±1.3	BDL	BDL	8.4±1.2	453±15	BDL
7	IFS-7	3-12	7.5±0.9	6211.6±249.6	149±8.9	8.6±1.3	258±11.3	7.3±0.85
8	IFS-8	3-13	53±9.6	975758±19167	21203±365.6	BDL	379.6±44.4	BDL
9	IFS-9	4-14	11.7±1.8	18952±500.5	404.4±16.9	13.8±2.8	281±10.5	10.2±1.2
10	IFS-10	3-10	16.6±1.3	BDL	BDL	15.3±1.7	312±26.7	BDL
11	IFS-11	3-5	9.1±1	BDL	BDL	13.5±1.8	346±11	3.2±0.5
12	IFS-12	4-3	14.1±1.3	BDL	BDL	9.9±1.5	259.4±21	2.4±0.5
13	IFS-13	4-7	11.5±1.2	BDL	BDL	11±1.5	268.9±20.9	3.9±0.5
14	IFS-14	4-13	9.4±1.2	11942±396.9	290.4±11.4	12.3±1.6	270.2±20.4	4.3±0.6
15	IFS-16	5-13	17.4±2.5	94525±2066.1	2153.5±47.1	BDL	335±11	BDL
16	IFS-17	11-7	60±11.2	749005±14634.	15592±266.1	BDL	363.6±33.7	BDL
17	IFS-18	14-5	26±2.5	153174±3181.1	3656±71.7	BDL	253.4±22.5	BDL
18	IFS-19	17-3	29±3.4	224630±4495.5	4161±50.5	BDL	325±10.6	BDL
19	IFS-20	12-13	78±14.7	1125495±2181	16820±288.9	BDL	264±26.9	BDL
20	IFS-21	11-10	36±18.7	377785±7454.2	6744±119.4	14.9±5	124±18.9	BDL
21	IFS-22	10-7	62±12.9	539612±10755	13083±232.5	BDL	332±35.7	BDL

22	IFS-23	12-10	42±19.2	342493±6868.5	8179±147.9	BDL	283.6±28.7	BDL
23	IFS-24	20-11	11±0.85	BDL	BDL	14.9±1.1	316.±12.1	3.4±0.3
24	IFS-25	20.2	14±0.8	BDL	BDL	15.9±1.1	273.7±17.1	BDL
25	Core 5-2	5-2 at depth 20cm	17±1.8	135.7±60.2	BDL	21.9±2.5	440±32.4	BDL
26	Surface 5-2	5-2	13.3±1.7	10820.6±354.2	209±11.8	15±2.3	290.2±25.1	5.7±0.9
27	Core 8-6	8-6 at depth 20 cm	47.4±29.4	BDL	BDL	12±2.5	246±29.3	BDL
28	FFFS 9-2	9-2	25.1±2	8608.6±267.1	87.8±8.5	15.7±2.2	356.6±27.6	4.4±0.8
29	FFFS 9-6	9-6	14.6±1.4	12176.5±413.9	226.9±8.5	17.1±2.1	331.2±25	2.2±0.6
30	FFFS 9-14	9-14	16.3±1.1	BDL	BDL	14.2±1.4	328.5±21.1	0.96±0.3
31	FFFS 11-13	11-13	42.7±17	193956±4517	4367±1.9	BDL	75.9±25.4	BDL
32	FFFS 13-7	13-7	18.3±1.4	4273.1±210.3	93.6±11	16.3±3.2	287.3±24.7	5±1.2
33	FFFS 13-13	13-13	21.9±1.8	66290±1022.7	1482.2±39.2	15.8±2.2	333.6±22.7	BDL
34	FFFS 14-3	14-3	19.8±1.6	5215±220.8	92±7.4	18.2±2.5	287.2±23.1	3.4±0.6
35	FFFS 15-6	15-6	38±19.1	201993±913.1	4061.5±83	BDL	241.7±18.4	BDL
36	FFFS 15-5	15-5	40±23.3	286542.5±3778	5466.3±107	BDL	404.6±34.8	BDL
37	FFFS 15-16	15-16	25.6±2.2	17834.6±459.7	385±15.7	21.2±2.5	495±24.6	15±1.3
38	FFFS 16-2	16-2	18.9±1.9	31428±637.1	559±137	21.8±2.8	339.3±24.7	7.1±1
39	FFFS 16-	16-11	20±1.7	5597.4±240.9	123.6±8.9	14.4±2.6	343.6±26.6	BDL

	11							
40	FFFS 18-4	18-4	5.2±1.4	2606.3±155.4	55.7±4	10.6±1.7	295.6±23.9	3.2±0.6
41	FFFS 18-10	18-10	15.6±1.4	1021±91.9	BDL	11.8±1.6	317.2±24	7.9±0.8
42	FFF 19-13	19-13	15.6±1.5	6908.4±292.6	141.9±6.3	11.9±1.7	203.8±19.4	12.9±1
43	Surface 18-3	18-3	9.6±1.2	16901.4±491.4	299±11.8	8.7±1.5	218.8±17.6	BDL
44	Core 18-3	18-3 at depth 20 cm	8.9±0.8	126.4±35.9	BDL	8.1±0.8	179.4±14.5	BDL
45	bFFFS	B.G	16.3±1.2	BDL	BDL	12.1±0.9	327.3±22.3	3.2±0.4
46	bFFFS-1	B.G	21±3.7	BDL	BDL	16±4.7	478±65	4.1±1.8
47	bFFFS-2	B.G	14±2.1	BDL	BDL	10.4±2.4	439±47	2.5±0.7
48	bFFFS-3	B.G	13.7±1.9	BDL	BDL	14.1±1.2	385±53.5	4.2±0.9
49	BT	Storage tank	86±19.7	2233061±5981	28077.6±418	BDL	351±47.5	BDL

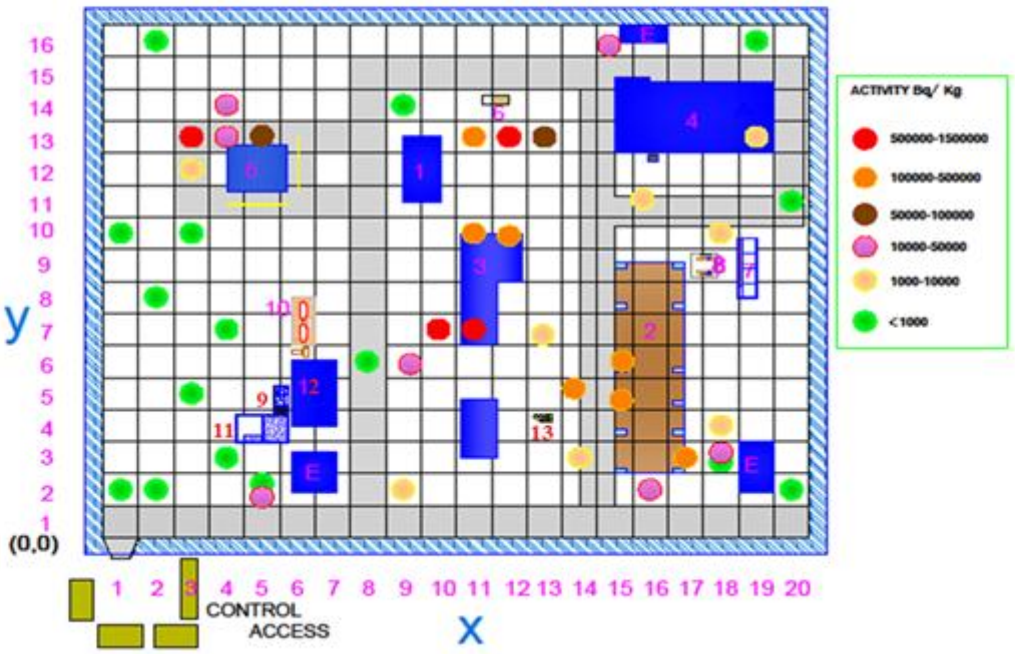

Fig. 5. Represents the soil samples location and the colors represent range of activities.

Results and Discussions

According to the field measurement and laboratory analysis, the FFF was contaminated with natural uranium with different level of activities. According to sample analysis, the maximum activity concentrations of surface soil sample was 1.125 MBq/Kg in grid 12-13 that was taken underneath the rubbles, while the dose rates and contaminations were 4.500µSv/h, 21.630 Bq/cm^2,respectively in the same grid, which were measured without removing the scrape and rubbles that can be considering as shielding for minimizing the exposure dose rates and contaminations also we found that the maximum dose rates, contaminations, and activity concentrations were 30.000 µSv/hr, 492.300 Bq/cm^2 , 2.233 MBq/Kg, respectively. In waste storage tank that located at depth -5 m of the FFF, the measurements were conducted directly without attenuation. The radiological survey and laboratory measurements and assessments, indicated that the FFF was contaminated with uranium-238 and uranium-235 nuclides in excess of the IAEA limits for exemption from regulatory control [4,9,10]. The ranges of activity concentrations of Cs-137 (0.96±0.3 ↔ 15±1.3), which considered as a background compared with the (IAEA) safety guide level was 100**Bq/Kg** [4]. The standard deviation of some readings were relatively high and that because high ranges in readings (minimum and maximum in same grid are high) and this variation in readings lead to high in standard deviation value. Radioactive waste that will be generated by the decommissioning operations are within low level waste (LLW) [13]. Therefore, the decommissioning operations for the FFF must be subjected to regulatory control and safety requirements to ensure adequate protection of the operators, environmental and public during the dismantling and decontamination operations, according to ALARA (As Low As Reasonable Achievable) principle as recommended by International Atomic Energy Agency (IAEA) [8, 12-14].

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