

## Estimating the Radioactive Waste from Decontamination of Fuel Fabrication Facility Floors

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### Abstract

Is Radioactive Waste (RW) is main Issue of Decommissioning Fuel Fabrication Facility (FFF). The whole FFF floor area is 32000m<sup>2</sup> with 2520m<sup>2</sup> area of contaminated floors with Uranium Oxides. There are three types of floor surfaces concrete, soil and asphalt paved. Volumes, weights and activity of RW were estimated through detailed radiological characterization for FFF floors , The surface free releases limit is 0.4Bq/cm<sup>2</sup> .Total estimated RW weight in tons were 307.9, 159.1 and 50.7 for surface contamination of (>0.4), (>1.0) and (>4.0) limits in Bq/cm<sup>2</sup> unit respectively. Limits of 0.4, 1.0, 4.0 and 32.0 in Bq/cm<sup>2</sup>, made 3 layers of contaminated floors, which generate three types of RW. RW activity concentration in Bq/g, for each layer, were 27.0, 3.75 and 1.05 for soil, then 43.2, 6.0 and 1.68 for concrete. Total RW activity in MBq were 223.536, 204.234 and 155.471 for surface contamination criteria (>0.4), (>1.0) and (>4.0) limits respectively in Bq/cm<sup>2</sup>. Estimation results show that, using Surface contamination of limit 4.0 Bq/cm<sup>2</sup> will minimize RW weight to 16.5% with total activity of 70% than RW generated by 0.4 limit. Other free release and restricted limits could be adopted with relevant scenario to estimate accumulated annual Dose-rate.

**Key Word:** Decommissioning; Contamination; Uranium; Radioactive and Waste.

### تخمين النفايات المشعة من ازالة التلوث الاشعاعي عن ارضيات منشأة انتاج الوقود

نضال غازي صالح قصي عبد الوهاب عبد الهادي حسين جبار الشموسي رائد عيسى جعفر،  
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بغداد - العراق

### الخلاصة

تعد النفايات المشعة من أهم المشاكل التي تنتج من تصفية مواقع منشآت انتاج الوقود. المساحة الكلية للأرضيات الملوثة بأكاسيد اليورانيوم 32000m<sup>2</sup> من اصل مساحة قدرها 2520m<sup>2</sup> الكونكريتية والترابية والمعبدة بالأسفلت. تم تخمين حجم ووزن ومقدار النشاط الاشعاعي للنفايات المشعة الناتجة من ارضيات الموقع تحت الدراسة من خلال توصيف اشعاعي تفصيلي. معيار الأطلاق الحر للمواقع هو 0.4Bq/cm<sup>2</sup>. كان وزن النفايات المشعة المخزن الكلي بوحدات الطن يساوي 307.9 و159.1 و50.7 لمقياس التلوث السطحي (>0.4) و(>1.0) و(>4.0) على التوالي بوحدات Bq/cm<sup>2</sup>. تم تحديد ثلاثة طبقات من النفايات المشعة للأرضيات محصورة بالقيم 0.4 و 1.0 و 4.0 و 32.0 بوحدات Bq/cm<sup>2</sup>. كان تركيز النشاط الاشعاعي لهذه الطبقات هو 27.0 و 3.75 و 1.05 للترية، ثم 43.2 و 6.0 و 1.68 للكونكريت، بوحدات Bq/g. النشاط الاشعاعي الكلي للنفايات المشعة بوحدات MBq كان 223.536 و 204.234 و 155.471 لحدود التلوث السطحي 0.4 و 1.0 و 4.0 على التوالي بوحدات Bq/cm<sup>2</sup>. اظهرت نتائج التخمين ان استخدام الحد >4.0 Bq/cm<sup>2</sup> للتلوث السطحي سيقوم بتقليص وزن النفايات المشعة الناتجة بمقدار 16.5% والنشاط الاشعاعي الكلي 70% من النفايات الناتجة من استخدام الحد >0.4. يمكن اعتماد حدود اخرى للأطلاق الحر والمشروط مع السيناريو الملانم وتخمين الجرعة السنوية المتراكمة.

**الكلمات مفتاحية:** - تصفية، تلوث، يورانيوم، اشعاعي و نفايات.

## Introduction

Fuel Fabrication Facility (FFF) is one of the former Iraqi Atomic Energy Commission (IAEC) facilities at Al-Tuwaitha. It is located 20 km south east Baghdad center; the capital of Iraq. It has many constructions like, steel structure buildings, brick building, underground tunnels, and concrete pools. Most of these structures are totally destroyed during the 2<sup>nd</sup> Gulf war bombing. This Italian-supplied facility was on operation since 1981 and destroyed in 1991. It was used to purify yellow cake, UF<sub>4</sub> and metallic uranium. Modern yellowcake typically contains 70% to 90% triuranium octoxide (U<sub>3</sub>O<sub>8</sub>) by weight and amounts of other oxides such as uranium dioxide (UO<sub>2</sub>) and uranium trioxide (UO<sub>3</sub>) (Abdulhadi, 2013). Contamination with yellow cake is spread all over FFF floors, walls, metallic scrap and pools, according to surface radiological scan and Laboratory sample analysis (Al-Bakhat, 2013). Qualitative and quantitative estimation of Radioactive Waste is one of main issues of any nuclear facility decommissioning. The owner of FFF is Ministry of Science and Technology (MoST). Iraqi Decommissioning Directorate (IDD) is one of moST directorates, and is responsible of all Decommissioning and Decontamination (D&D) activities for FFF. Ministry of Environment (MoEn) is the national regulator of IDD by Radiation Protection Center (RPC). RPC has recommended criteria and limits for free released material from FFF site. These limits were, 0.4 Bq/cm<sup>2</sup> for  $\beta$ ,  $\gamma$  and 0.04 Bq/cm<sup>2</sup> for  $\alpha$ , for surface contamination. Activity concentration limits were; 1Bq/g for each U-238 and U-235 for free released weights of materials (IAEA, RS-G-1.7, 2004). FFF floors will have higher release limits according to reuse scenario of restriction.

Main concern of nuclear facility decommissioning is, ensuring radiation protection for public and environment. Iraqi Decommissioning Directorate is responsible of all Decommissioning and Decontamination activities for FFF.

### Objectives

Radioactive Waste (RW) is main issue of Nuclear Industry, and specifically decommissioning nuclear facility or site. Many western countries and huge companies with enormous budget, and very advanced technological background, spend much time and efforts to estimate RW, which may consume great part of project budget (Boing, 2013). Decommissioning projects may be halted several of years, till funds could be provided. Estimation of RW should be done through cleared and detailed evaluation of radiological contamination, which is main requirement to make proper remediation and cleanup plan for FFF to achieve the objectives below.

1. Ensuring radiation protection for public and environment.
2. Ensuring radiation protection for workers of FFF decommissioning activities.
3. Minimizing generated Radioactive Waste (RW).
4. Safely releasing location and recycling cleared equipments.
5. Gaining experience for further decommissioning or remediation projects.

Evaluation of radiological contamination would make the basis of cleaning criteria and limits, then estimating volumes, weights, and activity concentration of generated RW (IAEA, 2006).

## Materials and Methods

### Site Description

FFF location is surrounded by more than 30 m height of artificially erected soil dam. All FFF buildings and remains are located in an area of 32000 m<sup>2</sup> with length of 200m and width of 160m. This area has been fenced then divided to (10x10) m<sup>2</sup> grids for radiological scan. Rubble and metallic scrap are distributed over some areas of FFF ground as piles and single pieces. FFF has different types of floors surfaces mainly, concrete, asphalt paved and soil. Figure No.(1), shows an aerial and ground photos of FFF. FFF consists of the following remains of buildings, that most of them are just concrete floors:-

- 1- Technical hall for chemical engineering research.
  - 2- Workshop and utilities building.
  - 3- Ceramic laboratories.
  - 4- Testing material hall.
  - 5- Hydrogen production building.
  - 6- Storage area.
  - 7- Cooling towers.
  - 8- Combustion fuel storage tanks.
  - 9- Radioactive liquid waste tank.
  - 10- Neutralization concrete tanks.
  - 11- Chemical waste treatment plant.
  - 12- Liquid collecting concrete tanks.
- E- Electric units.



**Fig. (1) Aerial and ground photos of FFF at Al-Tuwiatha site, IAEC.**

### Instruments

Radiological evaluation for FFF ground were done by using portable field instrument detector and a laboratory detector as followed .

1. Portable radEye SX multi purpose meter connected to surface scintillator detector, were implemented to measure surface contamination with activity concentration per area unit (Bq/cm<sup>2</sup>).

2. High Purity Germanium (HPGe) detector, with relative efficiency 30% and

resolution 2keV for Co-60 at energy 1.33MeV, was the main and the only laboratory instrument used to measure activity concentration per weight unit (Bq/kg).

### Methodology

Contact radiological survey conducted over FFF floors with portable survey meter. Surface contamination detector with reference mean background of 0.12 Bq/cm<sup>2</sup>, were implemented. Laboratory measurements indicate ground

contamination with Uranium-238, which mainly an emitting isotope, hence it is hard to detect and investigate. Field and laboratory detection for U-238 was mainly conducted through its daughter product, Pa-234m at  $\gamma$  energy line 1001keV (Ebaid, 2009) d. Most highly contaminated floors could be seen with bare eyes; light yellow colored as shown in figure No. (2). Different types of contaminated ground surfaces have been marked like, concrete, paved asphalt and soil. Uranium was detected at 20cm maximum depth for soil and 4cm for concrete. Uranium was

detected only on soil dust cover over asphalt paved surface, because asphalt is not porous material. There were 84 of 320 FFF grids with (10x10) m<sup>2</sup> area each, have been marked as contaminated spots and about 30% of its total area, which means 30 m<sup>2</sup> each. Total contaminated area of FFF is approximately 2520 m<sup>2</sup>. These grids were classified to 4 categories according to surface contamination as shown in figure No.(3). Categories were selected to available data; starts with free release limit (0.4Bq/cm<sup>2</sup>) and ends with measured maximum limit (32.0Bq/cm<sup>2</sup>).



Fig. (2) Photos of Measured and Seen with Bare Eyes, Contaminated Soil and Concrete Surfaces.

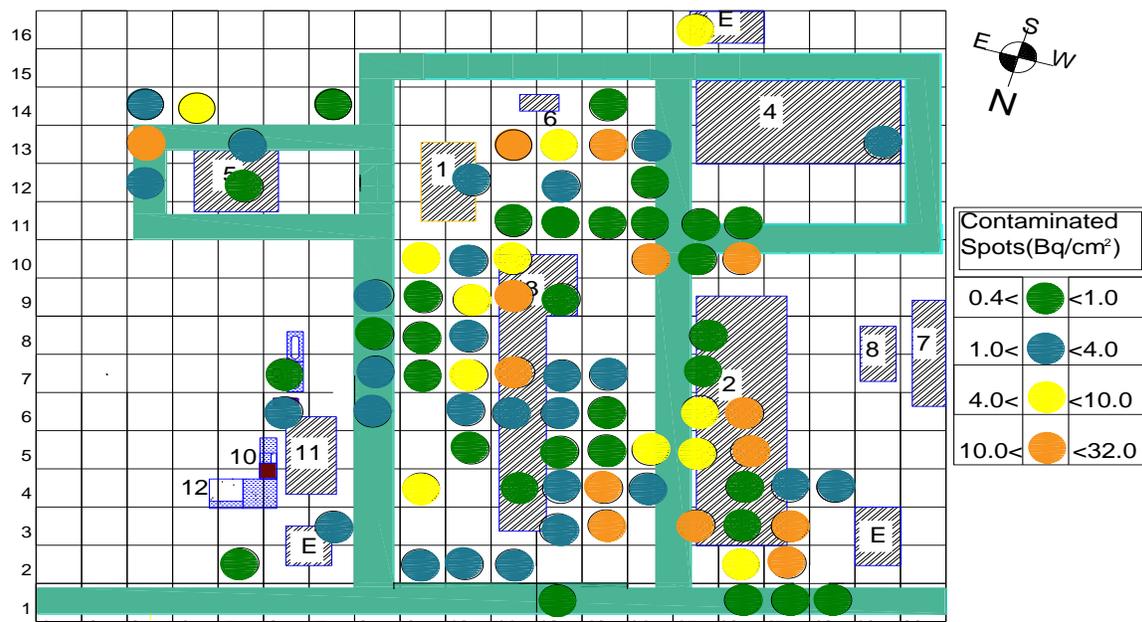
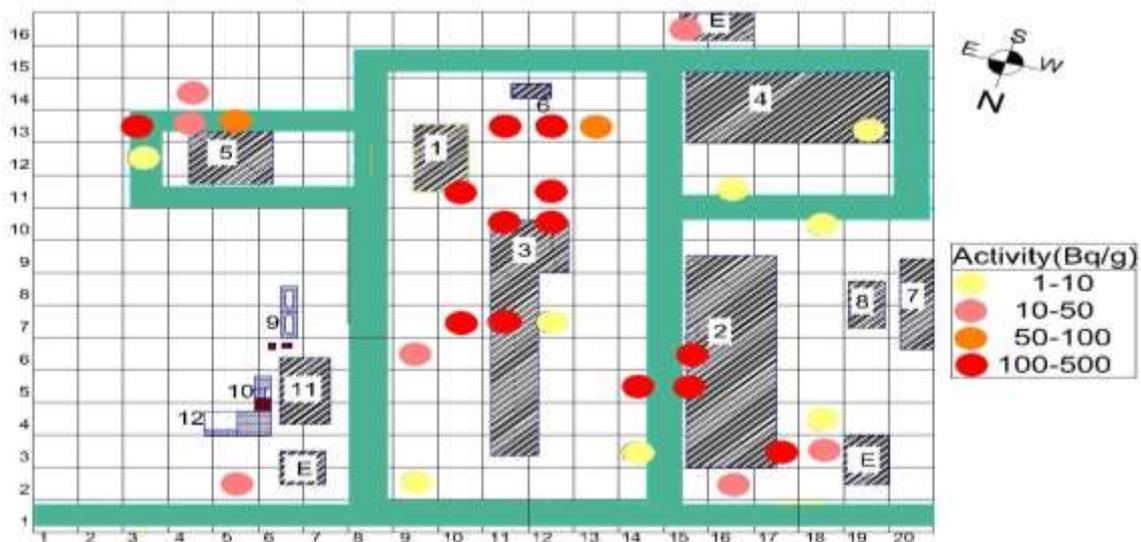


Fig. (3) Layout of FFF floors and radioactivity scan (Bq/cm<sup>2</sup>), using portable detector.

Soil samples from some selected FFF grids of approximately 1Kg weight, were taken to laboratory and proper sampling procedure was implemented; Vegetation and organic debris were removed from soil samples, then dried by slow-airflow at 50°C temperature. Soil was grinded and passed through a mesh size of 2mm (IAEA, 1989). Soil was filled in

Marinelli beaker for Uranium activity detection, using gamma spectroscopy technique with HPGe detector at mean time of 2000 seconds, (IAEA, 2008). Each sample was taken from surface ground area of (30cm x 30cm) at spots of maximum activity, hence it is not represent the whole 30m<sup>2</sup> area of each selected grid, as shown in Figure No. (4).



**Fig. (4) Activity Concentration of U-238 by HPGe Detector for Selected Surface Samples.**

**Results and Discussion**

1- Total RW volumes and weights calculation:-

Volumes and weights of RW were calculated according to surface contamination criteria and thickness. Three limits were adopted for surface contamination; 0.4, 1.0 and 4.0 Bq/cm<sup>2</sup>. Contamination thickness was adopted according to former projects D&D activities of contaminated surface with Uranium (IAEA, 1999). Contaminated thickness for concrete surface was 3cm, 2cm and 1cm, then for soil surface were; 15cm, 10cm and 5cm. Mean thickness of

contaminated soil over asphalt paved floors was 0.5cm. Each contaminated grid area has an average contaminated surface of 30%. Most contaminated concrete surfaces covered with an averaged of 2cm soil layer, hence calculated RW volumes for each concrete surface will have 2 types; soil and concrete dust. Volumes of RW were calculated illustrated in Tables (1, 2 and 3) Soil and concrete specific weight were considered as 1.5 and 2.4 g/ cm<sup>3</sup> / respectively

**Table (1) Volumes of RW Generated from Surface Contamination Greater than 0.4Bq/cm<sup>2</sup>.**

Surface	No. of grids	Area (m <sup>2</sup> )	Thickness (cm)	Soil volume (m <sup>3</sup> )	Thickness (cm)	Concrete volume (m <sup>3</sup> )
Concrete	49	1470	2	29.4	3	44.1
Soil	23	690	15	103.5		
Asphalt	12	360	0.5	1.8		

**Table (2) Volumes of RW Generated from Surface Contamination Greater than 1.0Bq/cm<sup>2</sup>.**

Surface	No. of grids	Area (m <sup>2</sup> )	Thickness (cm)	Soil volume (m <sup>3</sup> )	Thickness (cm)	Concrete volume (m <sup>3</sup> )
Concrete	33	990	2	19.8	2	19.8
Soil	18	540	10	54.0		
Asphalt	4	120	5.0	0.6		

There were no asphalt paved floors with contamination higher than 4.0Bq/cm<sup>2</sup>, so Table (3) will have just two types of contaminated surfaces.

**Table (3) Volumes of RW Generated from Surface Contamination Greater than 4.0Bq/cm<sup>2</sup>.**

Surface	No. of grids	Area (m <sup>2</sup> )	Thickness (cm)	Soil volume (m <sup>3</sup> )	Thickness (cm)	Concrete volume (m <sup>3</sup> )
Concrete	16	480	2	9.6	1	4.8
Soil	11	330	5	16.5		

**Table (4) Total Weights of RW for Each Selected Criteria for Surface Contamination.**

Criteria (Bq/cm <sup>2</sup> )	Volume (m <sup>3</sup> )		Weight (Ton)		Total weight (Tons)
	Soil	Concrete	Soil	Concrete	
>0.4	134.7	44.1	202.05	105.84	307.89
>1.0	74.4	19.8	111.60	47.51	159.11
>4.0	26.1	4.8	39.15	11.52	50.67

## 2- Calculation of RW activity concentration:-

Activity concentration of RW was estimated according to surface thickness and contamination limits using activity concentration per unit area; Bq/cm<sup>2</sup>. The averaged of all high surface contamination measurements of each grid was 32.0Bq/cm<sup>2</sup> and site free release limit was 0.4Bq/cm<sup>2</sup>. Limits like 1.0 and 4.0 could be considered as restricted release limits, so three surface contamination

Intervals in Bq/cm<sup>2</sup>, were chosen; (32-4.0), (4.0-1.0) and (1.0-0.4). These three intervals were name as RW types according to activity concentration. The activity concentration per unit volume of each RW type is the average of higher and lower limit intervals multiply with depth unit in centimeters (cm). Table (5) explains activity concentration for each RW interval or type for surface, volume, and weight.

**Table (5) Activity Concentration by Weight for Soil and Concrete.**

RW class	Activity interval (Bq/cm <sup>2</sup> )	Activity per volume (Bq/cm <sup>3</sup> )	Activity concentration (Bq/g)	
			Soil	Concrete
1 <sup>st</sup>	32.0 - 4.0	18.0	27.00	43.20
2 <sup>nd</sup>	4.0 - 1.0	2.5	3.75	6.00
3 <sup>rd</sup>	1.0 - 0.4	0.7	1.05	1.68

Total weights of RW for each selected criteria of surface contamination as shown in Table (4), will provide each RW type of total weight for activity calculations. RW of 3<sup>rd</sup> type will be obtained by subtracting total weight of limit >1.0 Bq/cm<sup>2</sup> from total weight of limit >0.4 Bq/cm<sup>2</sup>. RW of 2<sup>nd</sup> class will

be obtained by subtracting total weight of limit >4.0Bq/cm<sup>2</sup> from total weight of limit >1.0Bq/cm<sup>2</sup>. RW of 1<sup>st</sup> type will be the same total weight of limit >4.0Bq/cm<sup>2</sup>. Total radioactivity generated on FFF floors, through decontamination activities were estimated as shown in Table (6).

**Table (6) Total Estimated Radioactivity for Each RW Class of Concrete and Soil.**

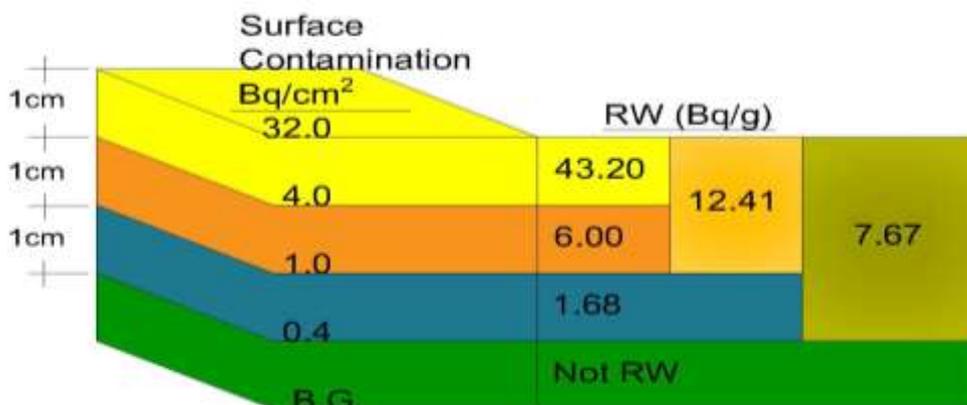
RW class	Weight (tons)		Activity (Bqx10 <sup>6</sup> )		Total Activity (Bqx10 <sup>6</sup> )
	Soil	Concrete	Soil	Concrete	
1 <sup>st</sup>	39.15	11.52	1057.05	497.66	1554.71
2 <sup>nd</sup>	72.45	35.99	271.69	215.94	487.63
3 <sup>rd</sup>	90.45	58.33	94.97	97.99	192.96

Total RW activity of decontamination FFF floors with criteria limit of more than 0.4 Bq/cm<sup>2</sup>, means total amount of all RW types. The generated RW with

limit more than 1.0 Bq/cm<sup>2</sup> is the total activity of 1<sup>st</sup> and 2<sup>nd</sup> type. Total RW Activity of 1<sup>st</sup> type will be generated using 4.0 limit, as shown in Table (7).

**Table (7) Total Weight, Activity and Activity Concentration of RW for Each Criteria.**

Criteria (Bq/cm <sup>2</sup> )	Total weight (Tons)		Total Activity (MBq)		activity concentration (Bq/g)	
	Soil	Concrete	Soil	Concrete	Soil	Concrete
>0.4	202.05	105.84	1423.71	811.59	7.05	7.67
>1.0	111.60	47.51	1328.74	713.60	11.91	12.41
>4.0	39.15	11.52	1057.05	497.66	27.00	43.20



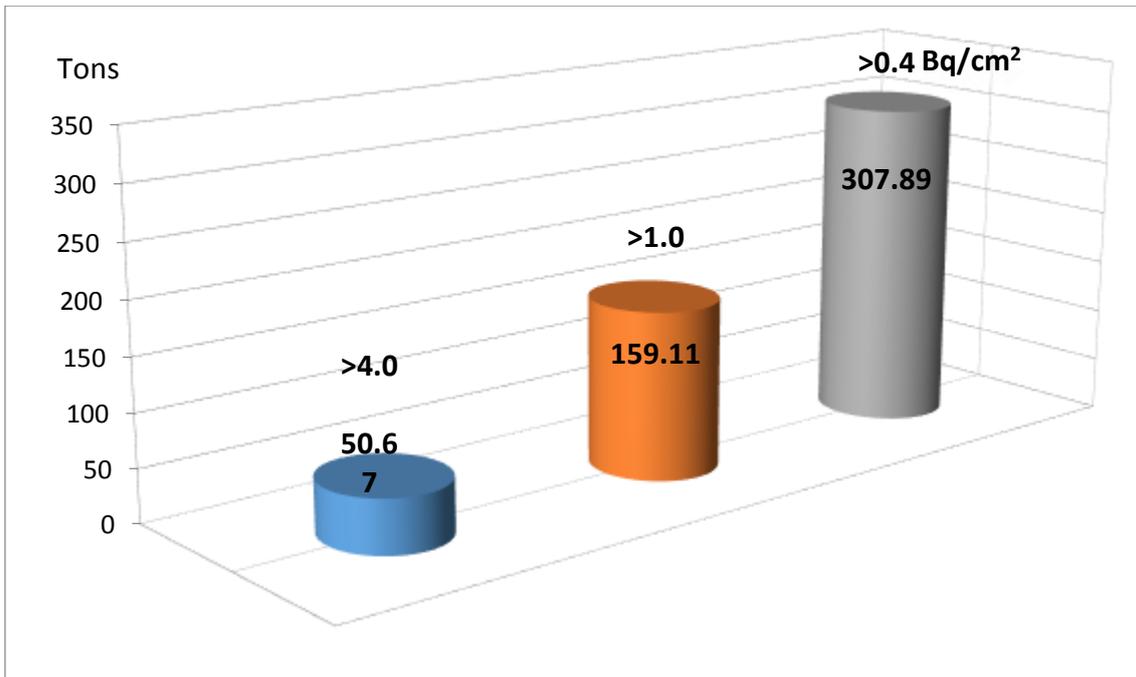
**Fig. (5) Illustration for Concrete Surface Contamination Intervals and Generated RW Activity Concentration.**

### Results and Discussion

1- Qualitative and quantitative estimation of RW by gamma spectroscopy in laboratory is not practically available, because FFF contaminated floor area is 2520m<sup>2</sup>, so we need 2520 samples, needed plus

most of that area surface is concrete with fixed contamination.

2- Choosing surface contamination limit >4.0 Bq/cm<sup>2</sup>, means minimizing RW weight from 307.89 Tons to 50.67 Tons, as shown in Figure . (6).

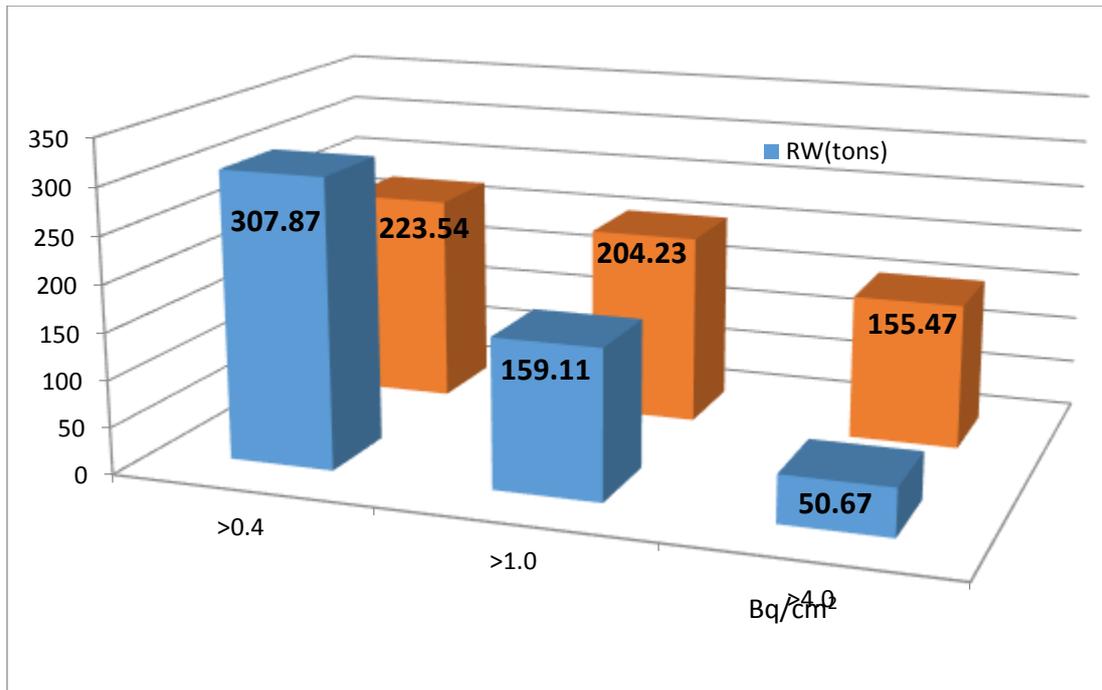


**Fig. (6) RW (Tons) for Surface Contamination (Bq/cm<sup>2</sup>) of Three Different Limits.**

3- Choosing surface contamination limit  $>4.0$  Bq/cm<sup>2</sup>, means minimizing RW weight of 16.5%, with total activity of 70%, than RW generated by limit  $>0.4$ , as illustrated in Table (8) and Figure. (7).

**Table (8) Total Weight and Total Activity Concentration of RW for Each Surface Criteria**

.Criteria (Bq/cm <sup>2</sup> )	Total weight (Tons)	Total Activity (MBq)
$>0.4$	307.89	223.536
$>1.0$	159.11	204.234
$>4.0$	50.67	155.471



**Fig. (7) Total RW Weight and Activity for Three Selected Surface Contamination Limits.**

4- Yellow cake is usually not an immigrant isotope through porous material such as concrete; but long time period of atmospheric influence like rain, will surely made some fixed contaminated surface area with maximum depth of 4cm.

5- Contaminated ground cracks and holes will generate more RW, due to deep and irregular contaminated concrete surfaces, but mostly that RW is exempted due to unintended dilution within decontamination process.

6- ALARA (As Low As Reasonably Achievable) principal requires Justification for such Optimized and dose limitation site release scenario, hence choosing 1.0 Bq/g limit for U-238 and U-235, should be justified (IAEA, 2004). 7- Los Alamos National Labs and Sandia National Labs in USA, have adopted 4 and 2 Bq/g respectively, as free release limits for U-238 (Boing, 2013).

### Conclusion

It is most challenging issue to balance cost against Safety. Different types of clearance level could be established for restricted and free released nuclear sites. Different scenarios could be adopted to achieve proper clearance level. Surface contamination level of more than 4.0 Bq/cm<sup>2</sup>, would generate less RW by weight of 16.5%, than RW generated by limit greater than 0.4, with total activity of 70% of whole activity required to achieve free release limit. Other release limits may be adopted according to data above with relevant scenario to estimate accumulated annual Dose-rate.

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