

# Gamma Radiation Hazards and Risks Associated with Industrial Wastes Materials

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## Abstract

Solid wastes are generated from common manufacturing and industrial processes, and can also be caused by disposing commerce products. The natural radionuclide ( $^{238}\text{U}$ ,  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$ ) concentrations in various solid waste samples were determined by using a high pure germanium detector. The obtained average concentration values of  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$  in various solid wastes were: Iron (173.29, 141.99 and 32.68  $\text{Bq}\cdot\text{kg}^{-1}$ ), Copper (2.63, 0.60 and 30  $\text{Bq}\cdot\text{kg}^{-1}$ ), Aluminum (3.97, 4.89 and 41.67  $\text{Bq}\cdot\text{kg}^{-1}$ ) and in Wood (4.22, 3.11 and 30.20  $\text{Bq}\cdot\text{kg}^{-1}$ ), respectively. The total average values of radium equivalent and the absorbed dose rate were 95.87  $\text{Bq}\cdot\text{kg}^{-1}$  and 44.56  $\text{nGy}\cdot\text{h}^{-1}$ , respectively. The effective dose rates in outdoor and indoor average values were 0.05 and 0.20  $\text{mSv}\cdot\text{y}^{-1}$ , respectively. These health hazard parameters were considered to be below the safe limit of UNSCEAR 2000. The presented results show no significant radiological health risks for the workers in the industrial workshops and inhabitation health.

## Keywords

Gamma Ray spectrometry, Waste, Effective Dose, Risk

## 1. Introduction

“The occurrence of natural radionuclides  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  in industrial solid waste is the source of the radiation hazard to the population and the environment [1]”. Monitoring all sources of natural radiation in the workplace is essential to evaluate the potential environmental risk [2]. Some industrial activities produce a huge amount of wastes which might pollute the environment. In fact, “Industrial waste is the fastest growing materials which lead to doses of radiation exposure. If this waste is not organized and recycled, no areas will be available to store it [3]”. The industrial solid waste product of Iron, Aluminium, Cooper and

wood could be found as sharp pieces or as a powder. These products are formed either by filling the metals and woods, or by mending finished materials, or by several other methods, including automatic and manual ones. These waste materials may be the source of natural radiation for the workers at the workshops. In general, there is no control over the operation of these industrial workshops, and there is no specific approach to a guideline of natural radioactivity of industrial wastes. Thus, the first aim of this work is the measurement of the natural radionuclides ( $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$ ) in different samples of industrial solid wastes (Iron, Aluminium, Copper and wood). The second aim is the assessment of the radiological hazard to the environment and the workers at the workshops that produce materials with enhanced content of natural nuclides. The significance of this study is to supply basic safety standards for the sake of workers and public health against the danger arising from such industrial waste.

## 2. Materials and Methods

Twenty-five of solid waste samples were collected from several Industrial workshops in Saudi Arabia, Jeddah city. The collected samples were oven dried at  $110^\circ\text{C}$  for twelve hours and then packed in a Marinelli beaker and sealed for one month to reach secular equilibrium between  $^{226}\text{Ra}$  and  $^{232}\text{Th}$  with their decay products. The radionuclide activity concentrations in the prepared samples were measured using a high-purity germanium (HPGe) detector with an efficiency of about 25 %. A counting time of 36,000 s was used for measurements the Gamma-rays spectrum. The background concentration of the  $\gamma$ -rays was determined with an empty Marinelli beaker under the same measurement conditions.  $^{226}\text{Ra}$  activities were calculated from the activities of its short-lived daughters  $^{214}\text{Pb}$  at 295.2 keV & 351.9 keV and  $^{214}\text{Bi}$  at 609.3 keV.  $^{232}\text{Th}$  activities were measured by taking the mean activity of photo peaks of the daughter nuclides  $^{228}\text{Ac}$  (338.40 and 911.07 keV) and  $^{212}\text{Pb}$  (238.63 keV). Activities of  $^{40}\text{K}$  were determined directly from its gamma emission at 1460.83 keV.

The activity concentrations of the investigated samples were evaluated using the following equation [4] [5]:

$$Ac(\text{Bq/kg}) = Nc/\varepsilon\beta M \quad (1)$$

where  $Nc$  is the net gamma counting rate (counts per second),  $\varepsilon$  the detector efficiency of the specific  $\gamma$ -ray,  $\beta$  the absolute transition probability of Gamma-decay and  $M$  the mass of the sample (kg).

## 3. Assessment of Radiation Hazard

### 3.1. Radium Equivalent Activity ( $R_{eq}$ )

To assess the radiological hazard of the concerning samples, it is useful to use the radium equivalent activity ( $R_{eq}$ ) in  $\text{Bq}\cdot\text{Kg}^{-1}$  [5]:

$$R_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad (2)$$

where  $A_{Th}$ ,  $A_{Ra}$  and  $A_K$  represent the activity concentrations of  $^{232}\text{Th}$ ,  $^{226}\text{Ra}$  and

$^{40}\text{K}$  in  $\text{Bq}\cdot\text{kg}^{-1}$  respectively.  $R_{\text{eq}}$  is defined according to the estimation that 1  $\text{Bq}\cdot\text{kg}^{-1}$  of  $^{226}\text{Ra}$ , 0.7  $\text{Bq}\cdot\text{kg}^{-1}$  of  $^{232}\text{Th}$  and 13  $\text{Bq}\cdot\text{kg}^{-1}$  of  $^{40}\text{K}$  produce the same gamma-ray dose [6] the permissible dose limit for the public is  $1.5 \text{ mSv}\cdot\text{y}^{-1}$  [7].

### 3.2. Absorbed Gamma Dose Rate (D)

The absorbed gamma dose scale in air 1m above the ground surface for the uniform distribution of radionuclides ( $^{232}\text{Th}$ ,  $^{238}\text{U}$ , and  $^{40}\text{K}$ ) were computed by guidelines provided by [5]:

$$D(\text{nGy}\cdot\text{h}^{-1}) = (0.621A_{\text{Th}} + 0.462A_{\text{Ra}} + 0.0417A_{\text{K}}) \quad (3)$$

where  $A_{\text{Th}}$ ,  $A_{\text{Ra}}$  and  $A_{\text{K}}$  represent the activity concentrations of  $^{232}\text{Th}$ ,  $^{226}\text{Ra}$  and  $^{40}\text{K}$  in  $\text{Bq}\cdot\text{Kg}^{-1}$  respectively.

### 3.3. The Annual Effective Dose Equivalent ( $D_{\text{eff}}$ )

The annual effective dose equivalent received by a member has been calculated from the absorbed dose rate by applying dose conversion factor of  $0.7 \text{ Sv/Gy}$  and the occupancy factor for outdoor and indoor as 0.2 and 0.8, respectively, [5], using the following equations:

$$D_{\text{eff}}(\text{Outdoor})(\text{mSv/y}) = D(\text{nGy}\cdot\text{h}^{-1}) \times 7320 \text{ h} \times 0.7 \text{ Sv/Gy} \times 0.2 \times 10^{-6} \quad (4)$$

$$D_{\text{eff}}(\text{Indoor})(\text{mSv/y}) = D(\text{nGy}\cdot\text{h}^{-1}) \times 7320 \text{ h} \times 0.7 \text{ Sv/Gy} \times 0.8 \times 10^{-6}. \quad (5)$$

### 3.4. Excess Lifetime Cancer Risk (ELCR)

Excess Lifetime Cancer Risk (ELCR) was calculated by the equation below [4] [5]:

$$\text{ELCR} = D_{\text{eff}}(\text{outdoor}) \times D_L \times \text{RF} \quad (6)$$

where  $D_{\text{eff}}(\text{outdoor})$ ,  $D_L$  and  $\text{RF}$  are the outdoor annual effective dose equivalent, the duration of life (70 years) and the risk factor ( $\text{Sv}^{-1}$ ), fatal cancer risk per Sievert. For detriment-adjusted cancer risk of  $5.52 \times 10^{-2} \text{ Sv}^{-1}$  for the whole population [5].

## 4. Results and Discussion

### 4.1. Activity Concentration

The results of  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  concentrations in the waste samples were summarized in **Table 1**. From this Table, All samples under investigation, the average values of  $^{226}\text{Ra}$  ranged from  $2.6329 \text{ Bq}\cdot\text{Kg}^{-1}$  in (Copper) to  $173.29 \text{ Bq}\cdot\text{Kg}^{-1}$  in (Iron).  $^{232}\text{Th}$  average values ranged from  $0.60 \text{ Bq}\cdot\text{Kg}^{-1}$  in (Copper) to  $141.99 \text{ Bq}\cdot\text{Kg}^{-1}$  in (Iron) while the average values of  $^{40}\text{K}$  ranged from  $29.99 \text{ Bq}\cdot\text{Kg}^{-1}$  in (Copper) to  $41.99 \text{ Bq}\cdot\text{Kg}^{-1}$  in (Aluminum). Iron waste recorded the highest average values concentration of  $^{226}\text{Ra}$  and  $^{232}\text{Th}$ , and are much higher than the world average values 30, 35  $\text{Bq}\cdot\text{Kg}^{-1}$  for  $^{226}\text{Ra}$  and  $^{232}\text{Th}$  respectively, as reported by [5], which can be explained by adsorption on weathered ferromagnetic

**Table 1.** Results of natural radioactivity concentration ( $\text{Bq}\cdot\text{kg}^{-1}$ ) in the waste samples collected from different industrial workshops, Saudi Arabia.

Sample type	Sample code	Radioactivity concentration ( $\text{Bq}\cdot\text{kg}^{-1}$ )		
		$^{226}\text{Ra}$	$^{232}\text{Th}$	$^{40}\text{K}$
Iron	F1	$154.04 \pm 4.89$	$162.28 \pm 2.27$	$36.51 \pm 2.17$
	F2	$171.34 \pm 5.12$	$135.63 \pm 2.11$	$35.69 \pm 2.0$
	F3	$224.53 \pm 7.0$	$164.63 \pm 2.22$	$46.29 \pm 3.21$
	F4	$147.38 \pm 4.56$	$115.62 \pm 2.12$	$17.31 \pm 1.12$
	F5	$169.16 \pm 5.54$	$131.81 \pm 2.0$	$27.58 \pm 1.6$
	Average (range)	173.29 (147.38 - 22,453)	141.99 (115.62 - 164.63)	32.68 (17.31 - 46.29)
Cooper	Cu1	$1.23 \pm 0.22$	$0.34 \pm 0.02$	$11.94 \pm .28$
	Cu2	$3.26 \pm 0.56$	$0.82 \pm 0.03$	$45.82 \pm 1.78$
	Cu3	$1.31 \pm 0.08$	$0.98 \pm 0.04$	$67.37 \pm 2.28$
	Cu4	$5.58 \pm 0.42$	$0.60 \pm 0.03$	$16.37 \pm 0.16$
	Cu5	$1.79 \pm 0.42$	$0.26 \pm 0.02$	$8.43 \pm 0.42$
	Average (RANGE)	2.63 (1.23 - 5.58)	0.60 (0.26 - 0.98)	29.99 (8.43 - 67.37)
Aluminium	Al1	$2.76 \pm 0.76$	$0.54 \pm 0.04$	$23.36 \pm 1.14$
	Al2	$1.56 \pm 0.17$	$6.05 \pm 1.50$	$36.99 \pm 1.61$
	Al3	$3.08 \pm 0.61$	$2.64 \pm 0.86$	$27.91 \pm 1.31$
	Al4	$7.24 \pm 0.73$	$5.12 \pm 1.15$	$55.49 \pm 2.29$
	Al5	$5.23 \pm 0.74$	$10.12 \pm 2.22$	$64.58 \pm 2.65$
	Average (range)	3.97 (1.56 - 7.24)	4.89 (0.54 - 10.12)	41.67 (23.36 - 64.580)
Wood	Wo1	$1.30 \pm 0.22$	$0.27 \pm .03$	$10.81 \pm .28$
	Wo2	$10.75 \pm 2.31$	$2.46 \pm 0.04$	$7.79 \pm 0.41$
	Wo3	$2.46 \pm 0.65$	$3.51 \pm 1.33$	$44.57 \pm 2.01$
	Wo4	$5.56 \pm 0.92$	$4.06 \pm 0.34$	$72.26 \pm 3.13$
	Wo5	$1.03 \pm 0.03$	$5.25 \pm 0.58$	$15.58 \pm 0.81$
	Average (range)	4.22 (1.03 - 10.75)	3.11 (0.27 - 5.25)	30.20 (7.79 - 72.26)

minerals, also iron scrap were used in high percentage [8]. For all the studied samples, the average values of K were lower than the world average values of 400  $\text{Bq}/\text{kg}$  [5]. Different concentrations of radioactive nuclei in the samples refer to the sources and environmental acting on these samples. The average activity concentrations of  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  in the waste samples under study are given in **Figure 1**.

#### 4.2. Radiation Hazard from Waste Samples

The calculated average values of radium equivalent activity ( $R_{\text{eq}}$ ), absorbed Gamma Dose Rate (D) and the Annual Effective Dose Equivalent ( $D_{\text{eff}}$ ), for all

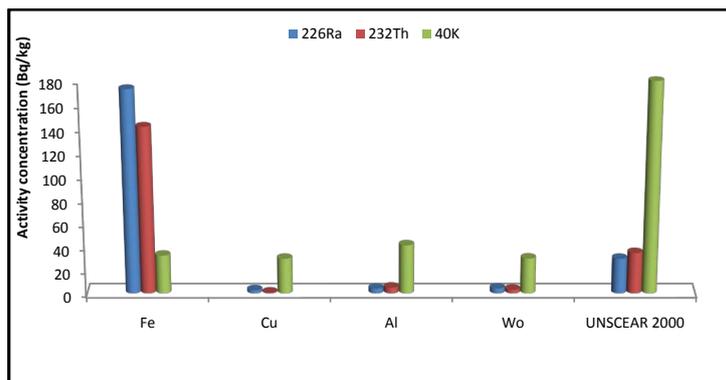
waste sample types and the total average values are shown in **Table 2**. The radiological hazards were compared with the recommended values by UNSCEAR 2000. From this table, we can establish the following:

1) Radium equivalent activity ( $R_{eq}$ )

The minimum average value of  $R_{eq}$  activity was  $1.12 \text{ Bq}\cdot\text{Kg}^{-1}$  for Copper waste while the maximum average value was  $378.86 \text{ Bq}\cdot\text{Kg}^{-1}$  for Iron waste, which is higher than the recommended maximum value of  $370 \text{ Bq}\cdot\text{Kg}^{-1}$  [5]. The highest value in Iron is attributed to the high activity concentration level of  $^{226}\text{Ra}$  and  $^{232}\text{Th}$  in Iron waste samples. The total average value of  $R_{eq}$  for all samples was  $95.87 \text{ Bq}\cdot\text{Kg}^{-1}$ , this value is lower than  $370 \text{ Bq}\cdot\text{Kg}^{-1}$ .

2) Absorbed gamma dose rate (D)

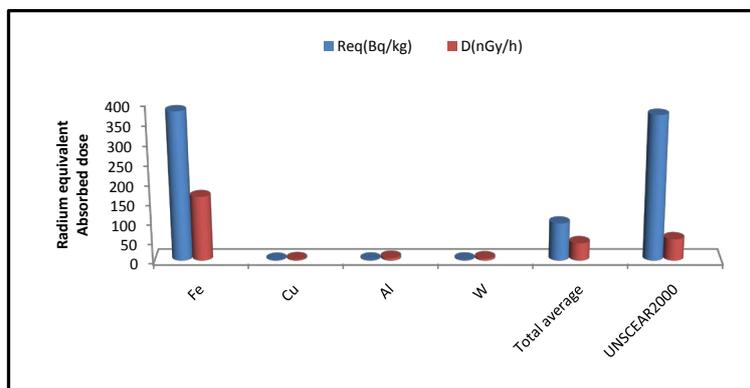
As shown in **Table 2**, the average value of the absorbed dose of all types of waste samples ranged from  $2.79 \text{ nGy}\cdot\text{h}^{-1}$  (Copper) to  $163.86 \text{ nGy}\cdot\text{h}^{-1}$  (Iron) with total average value  $44.56 \text{ nGy}\cdot\text{h}^{-1}$ . UNSCEAR 2000 reported that the world wild average value in an air of outdoor absorbed dose  $55 \text{ nGy}\cdot\text{h}^{-1}$  with atypical range from 10 to  $200 \text{ nGy}\cdot\text{h}^{-1}$ . The average values for Copper, Aluminium and Wood and the total average are lower than the recommended values by [5]. **Table 2** shows that only for Iron waste samples, its absorbed average value is 3 times higher than the world average value. **Figure 2** shows a comparison between the



**Figure 1.** Average activity concentrations of  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  for waste samples collected from different Industrial workshops, Saudi Arabia

**Table 2.** Comparison of the average radiological hazard of the studied waste samples.

Sample no.	Radium equivalent activity ( $\text{Bq}\cdot\text{kg}^{-1}$ )	Absorbed dose ( $\text{nGy}\cdot\text{h}^{-1}$ )	Deff (indoor) ( $\text{mSv}\cdot\text{y}^{-1}$ )	Deff (outdoor) ( $\text{mSv}\cdot\text{y}^{-1}$ )	Excess lifetime cancer risk outdoors ( $\text{CR})\times 10^{-3}$
Iron	378.86	163.86	0.73	0.18	2.54
Copper	1.12	2.79	0.012	0.003	0.04
Aluminium	1.70	6.54	0.029	0.007	0.10
Wood	1.80	5.04	0.022	0.006	0.08
Range of average	1.12 - 378.86	2.79 - 163.86	0.012 - 0.73	0.003 - 0.18	0.04 - 2.54
Total average	95.87	44.56	0.20	0.05	0.69
UNSCEAR 2000	<370	60	0.42	0.07	0.29



**Figure 2.** Comparing the average and the total average values of absorbed dose rate (nGy/h), and Radium equivalent (Bq/Kg) of the waste samples with UNSCEAR 2000.

average and total average values of radium equivalent (in Bq·Kg) and absorbed dose (in nGy $h^{-1}$ ) for the waste samples under investigation and the recommended values by UNSCEAR 2000.

### 3) The annual effective dose equivalent

The average annual effective dose of indoor and outdoor for all samples ranged from 0.012 mSv $y^{-1}$  (Copper) to 0.73 mSv $y^{-1}$  (Iron) and from 0.003 mSv $y^{-1}$  (Copper) to 0.18 mSv $y^{-1}$  (Iron) with the corresponding total average values of 0.20 mSv $y^{-1}$  and 0.05 mSv $y^{-1}$ , respectively. These average values are less than the world average annual effective dose indoor 0.42 mSv $y^{-1}$  and outdoor 0.07 mSv $y^{-1}$  as reported by [5]. The maximum average values for outdoor and indoor effective doses were observed in Iron are higher than the world average effective dose for outdoor and indoor. This indicates that there is a significant effect for the workers in Iron workshops.

### 4) Excess lifetime cancer risk (ELCR)

The average values of ELCR ranged from  $0.04 \times 10^{-3}$  in Copper to  $2.54 \times 10^{-3}$  in Iron, with a total average value of  $0.69 \times 10^{-3}$ . The average values of ELCR for all waste types are less than the world average ( $0.29 \times 10^{-3}$ ) reported by [5]. The ELCR for Iron exceeded this value; this indicates that there is no risk to the general public and the workers in the industrial workshops which produce wastes of Copper, Aluminium and Woods and the workplace are still in zone of normal radiation, but there is a threat to the workers' health in Iron workshops.

## 5. Conclusion

The activities of the natural radionuclides  $^{238}\text{U}$ ,  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  in the solid waste samples collected from various industrial workshops in Saudi Arabia were measured by using a gamma-ray spectroscopy with HPGe detector. The total average values of radium equivalent, external hazard, absorbed dose and effective dose of all studied samples are below the internationally accepted values. The measured samples are still in the zones of normal radiation level, causing no threat to the environment, the human health, and the workers at the workshops except the Iron waste may create some radiological complications. The results may be useful in the assessment of the exposures and the radiation doses due to

the natural radioactive content in industrial solid waste samples. They may provide a wide serve as a guideline for future measurement and assessment of possible radiological risks to human health.

### Recommendation

We recommend two major steps to be taken into account: first, reducing the hours of operation at the workshops of iron; second, using ventilation and respirators in the workplace at all industrial workshops. Finally, there must be the radiological control on the operation of such industrial workshops.

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