

## Environmental assessment of natural radioactivity in Mahamid phosphorite and the related phosphatic fertilizers

Ibrahim H. Zidan

*Nuclear Materials Authority, P.O. Box 530 El Maadi, Cairo, Egypt.*

*Received: 20 July 2019 / Accepted 19 August 2019 / Publication date: 15 Sept. 2019*

### ABSTRACT

The natural radioactivity sourced from Mahamid phosphorite and the related fertilizer, single super phosphate (SSP), was measured hence, some radiation indices were calculated to assess the environmental impact of these materials. The activity concentrations were measured in  $\text{Bqkg}^{-1}$  based on the recorded activities of the  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  radioactive nuclides using the High-Purity Germanium detector (HPGe). The calculated radiation indices included; Radium equivalent activity ( $\text{Ra}_{\text{eq}}$ ), the absorbed dose rate (D), the annual effective dose (Eff. D.), the internal hazard index ( $\text{H}_{\text{in}}$ ), the external hazard index ( $\text{H}_{\text{ex}}$ ), gamma index ( $\text{I}_{\gamma}$ ), alpha index ( $\text{I}_{\alpha}$ ) and Excess lifetime cancer risk (ELCR). All the resulted values were compared with the permissible limits of the corresponding indices as internationally recommended. Although the fabrication process of the SSP fertilizer caused significant reduction in the activity concentration relative to the phosphate source, but both materials commonly appeared as probable additional source for radiation risks for both the surrounding environment and the public. Accordingly, some recommendations were delivered to enhance the radiation protection issue.

**Keywords:** environmental assessment, radioactivity, phosphorite, fertilizer, radiation indices

### Introduction

Uranium and thorium are traditionally found in rocks, soils, ores and even in some water bodies particularly the sea water. Although their concentrations, mostly, are in trace and ultra-trace amounts but cause the natural radioactivity phenomenon of their hosts. In particular, the radio-daughters  $^{226}\text{Ra}$  and  $^{222}\text{Rn}$  (resulted as decay products of  $^{238}\text{U}$  series) and the radioactive isotope of potassium ( $^{40}\text{K}$ ) are the main source of radiation due to their  $\gamma$ -ray emission. However, the decay chain segment in the  $^{238}\text{U}$  series starts from radium ( $^{226}\text{Ra}$ ) is radiologically the most important, so reference is often made to  $^{226}\text{Ra}$  instead of  $^{238}\text{U}$  (UNSCEAR, 1993). The internal and external radiation-exposure is due to these radionuclides where breathing of radon gas causes the internal exposure while the outflow of  $\gamma$ -rays from the radioactive sources is the source of external exposure (El-Taher, 2010). The natural materials and ores that contain sensible radioelements concentrations are known as naturally occurring radioactive materials (NORM). Exploitation and milling of the different NORMs yield what are known by technologically enhanced-NORM (TE-NORM). Using such materials in the industrial, agricultural and other civilian activities could impose hazards risks from the radioactivity point of view, consequently an intensive attention was pointed to measure the radioactivity of those materials and estimate their hazard indices (Sroor *et al.*, 2001, El-Taher and Makhluaf, 2010, El-Taher and Madkour, 2011, Shams *et al.*, 2013, Ndontchueng *et al.*, 2014 and Ce'bastien *et al.*, 2017).

The phosphorites are considered NORM and generally containing variable concentrations of uranium which either encountered in the major forming minerals (e.g. the apatite) or adsorbed onto the phosphatic grains. Sea water is the essential source of uranium in marine sediments in the form of dissolved  $\text{U}^{+6}$  linked to a carbonate complex. The main uranium forms in phosphorites are  $\text{U}^{+4}$  and/ or  $\text{U}^{+6}$ . The tetravalent form replaces partially  $\text{Ca}^{+2}$  in apatite because their similar ionic radii, while the hexavalent one is enriched in the ore by adsorption onto mineral surface (Slansky, 1986). In average, the phosphate ores contain about 1500  $\text{Bq/kg}$  activity concentration of uranium and radium (Paschoa and Godoy, 2002).

Phosphates are extensively used for fertilizers and phosphoric acid manufacturing where the majority of original uranium content is delivered into the fertilizers while lesser concentrations of

**Corresponding Author:** Ibrahim H. Zidan, Nuclear Materials Authority, P.O. Box 530 El Maadi, Cairo, Egypt.  
E-mail: Dr.01097960113@yahoo.com

$^{226}\text{Ra}$  and  $^{232}\text{Th}$  are also received by the fertilizers (UNSCEAR, 2008). So, using of phosphatic fertilizers in agriculture is a further source of possible public exposure to radiation (Paschoa and Godoy, 2002).

Average of the uranium content in the Egyptian phosphorites were estimated as 85, 68 and 24 ppm for Sibaiya, Red Sea and Abu-Tartur phosphate deposits respectively (Zidan, 2012 and Amin & Zidan, 2014). Although the phosphorite reserves in these localities are not clearly indicated but the estimated geological reserves point to about 50 million tons at Red Sea Coast, 70 million tons at Sibaiya (Nile Valley) and 7000 million tons at Abu Tartur area (NMA, 2010). About 6 million tons of phosphorite ores were mined in Egypt during 2018, half of them were manufactured as phosphatic fertilizers (single super phosphate, SSP), 90,000 tons were used for tri-super phosphate production and 75,000 tons for phosphoric acid manufacturing, while the rest was exported (AFA, 2018).

Zidan (2014) pointed to that the average U content in the phosphatic fertilizers (SSP) is 72 ppm that represents a highly probable pollution source for agricultural soil hence, for water and plants. Some plants absorb much more U than others, may reach up to 100 ppm, while the normal absorbed uranium by plants usually ranged from 0.2 to 1 ppm (Vandenhove *et al.*, 2006). Increasing and accumulation of the radioelements and heavy metals concentrations in the soil, fruit, and vegetables is highly engaged in causes of the upper gastrointestinal cancer and other serious health problems (Oliver, 1997 and Turkdogan *et al.*, 2002).

The current work was designed to evaluate the radiation hazard indices for either Mahamid phosphorite or and manufactured single super phosphate (SSP). Also, the study will investigate the effect of fertilizer's manufacturing on reduction of the activity levels which encountered in the original phosphorite ore. Finally, the study has to deliver the appropriate recommendations and/or cautions have to be followed to avoid dangerous consequences.

### **Sampling and analytical techniques**

The current work was carried out using 10 collected representative phosphorite samples from Mahamid mine as well as other 10 SSP samples of different production batches from Abu Zaable Superphosphate Factory.

The minerals constituents of the phosphorite samples was identified using the X-ray diffraction (XRD) instrument model; Philips PW 3710/31 diffractometer with scintillation counter, (Cu- target tube and Ni filter at 40 Kv and 30 mA) attached with a computer system using APD program and PDF-2 data base for the minerals identification. The scan program covers  $2\theta$  at the range from 5 to 65 with a step size of 0.02 degree and 0.5 second as count time /step.

The major elemental composition of the phosphorite samples was chemically estimated according to the wet chemical analysis after Shapiro and Brannock (1962). Before the chemical analysis, the solid samples were firstly converted to the soluble phase where 10 grams of each sample were ground to less than 0.063 mm (-200 mesh) in size. After the well homogenization, 0.5 gram was accurately weighted and subjected to either acid or alkaline attack (based on the kind of the required measured element) under aggressive heating conditions. Finally, the attacked samples were diluted by the de-ionized water and up to volume of 250 ml using the same water. The analytical precision for the measured elements was found as  $\pm 2\%$ .

For measuring the radioactivity concentrations, the phosphorite and SSP samples were ground well to less than 0.1 mm size then dried at 105 C° in the dryness oven for moisture removal. After cooling, homogenization and quartering the proper weight of each sample was placed in a polyethylene cup of 350 Cm<sup>3</sup> volume and the cups were tightly sealed for 4 weeks to reach the secular equilibrium. Finally, all the samples were measured using the high-purity germanium (HPGe) system model No. GEM-15190, coaxial type detector with a serial NO. 27-p-1876A recommended operating bias, negative 3 kV. The used HPGe is installed in Faculty of Girls, Ain Shams University, Cairo.

The concerned  $\gamma$ -ray emitting radionuclides are  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$ . While the  $^{40}\text{K}$  activity concentration (Bqkg<sup>-1</sup>) was directly measured from its 1460 kV  $\gamma$ - ray line, the activity concentrations of both  $^{226}\text{Ra}$  and  $^{232}\text{Th}$  were assessed from the photo-peaks of  $^{214}\text{Pb}$  (351 kV) and  $^{208}\text{Tl}$  (2615 kV) respectively (IAEA, 1989).

### Geological, mineralogical and geochemical characteristics

The Egyptian phosphorites belong to the Duwi Formation which is conformably overlain by Dakhla Formation and assigned as Upper Campanian to Early Maastrichtian age (Hermina, 1972 and Issawi *et al.*, 1978 & 1999). These phosphorites are exposed in three belts extend in the East-West trend (Hermina, 1972) where the economic occurrences are restricted to the central belt confining to the Red Sea coast (Safaga – Quseir), the Nile Valley (Idfu – Qena) and the Western Desert (Kharga - Dakhla Oases). Mahamid phosphorite is a part from the Nile Valley phosphorite deposits locates at the northern tip of El-Sibaiya area between latitudes  $25^{\circ} 08' 21'' - 25^{\circ} 17' 15''$  N and longitudes  $32^{\circ} 46' 12'' - 33^{\circ} 08' 22''$  E (Fig. 1). It based by Qusseir shale Member of the Nubia Formation while overlain by the Dakhla Formation. The thickness of the productive phosphorite bed ranges from 1.8m to 3.5m with an average of 2.5m and composed of yellowish brown colored phosphorite intercalated with oyster limestone, marl and grey shale lenses. Zidan (2002) reported that the Duwi Formation is unconformably overlying the Qusseir shale member with an undulating surface.

The XRD investigation for the sampled Mahamid phosphorite revealed the apatite as the main phosphorite mineral while other non-phosphatic minerals were identified as anhydrite, quartz and hematite (Fig.2). Although the francolite was assigned as the only apatite mineral composes the Egyptian sedimentary phosphorite (El-Kammar, 1974) but other minerals and solid states of “uncommon” phosphate were also recognized in minor constituent (El-Kammar and El-Kammar, 2002). Presence of both hematite and anhydrite minerals is reasonably reflect the oxidation of pyrite mineral under the effect of the chemical weathering (Zidan, 2014).

On the other hand, the chemical analysis of the studied phosphorite samples illustrated that the average concentrations of major constituents are 38.4% (CaO), 26.4% ( $P_2O_5$ ) and the  $SiO_2$  content was 11.6% while the other components were estimated in much lesser concentrations (Table1). The interesting remark is related to the  $P_2O_5$  content where this phosphorite is reasonably to be categorized as medium-grade ore (Zidan, 2017).

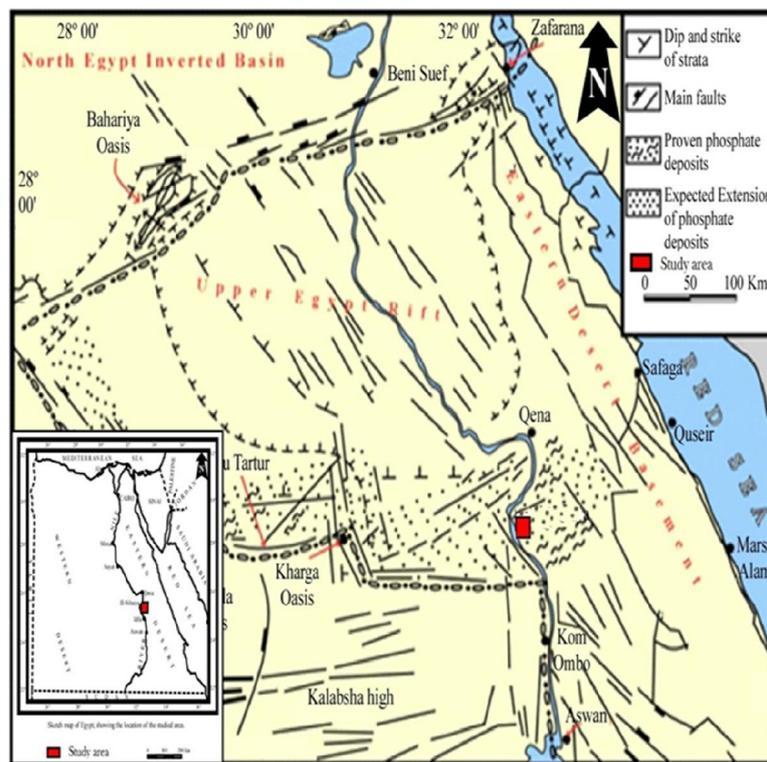


Fig. 1: Location map of Mahamid phosphorite mine.

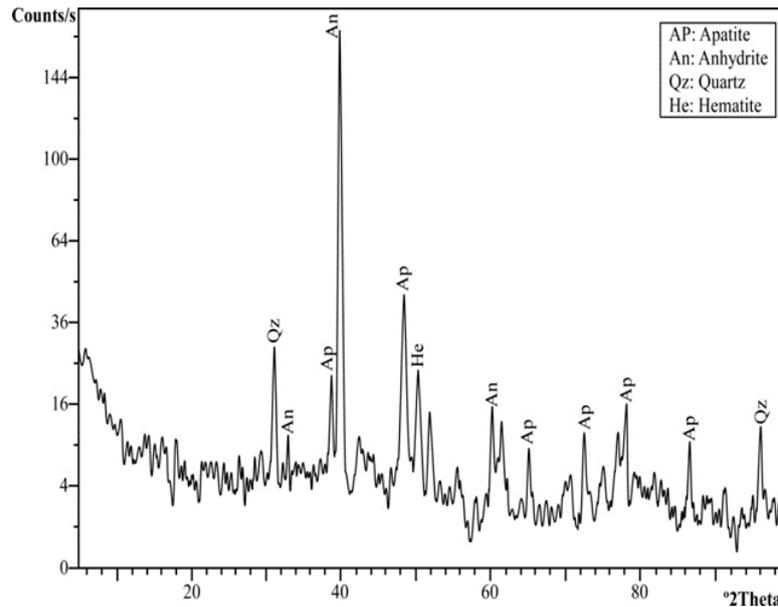


Fig. 2: X-ray diffraction pattern of composite whole-rock Mahamid phosphorite.

Table 1: Major elemental composition (%) in their oxide forms of Mahamid phosphorite.

S.NO.	P <sub>2</sub> O <sub>5</sub>	CaO	MgO	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	Na <sub>2</sub> O	K <sub>2</sub> O	F	L.O.I	Total
M1	26.20	37.30	04.50	11.20	03.50	01.60	01.20	00.20	02.20	11.60	99.50
M2	27.30	38.50	04.20	10.80	03.10	01.50	01.20	00.30	01.10	11.50	99.50
M3	25.20	36.40	04.60	12.90	04.30	01.90	01.10	00.30	02.30	10.40	99.40
M4	24.20	35.70	05.30	13.20	05.40	02.20	01.20	00.10	02.20	10.80	100.3
M5	26.90	39.20	04.10	10.70	03.40	01.50	01.20	00.20	00.90	11.90	100.0
M6	24.50	35.60	05.40	12.70	05.20	02.10	01.20	00.10	02.20	10.60	99.60
M7	29.20	40.80	03.50	10.40	02.50	01.40	01.60	00.40	03.00	07.80	100.6
M8	24.20	38.40	04.50	12.70	05.30	02.30	01.20	00.20	01.80	09.50	100.1
M9	28.50	41.20	03.70	10.70	02.90	01.50	01.20	00.20	03.00	07.30	100.2
M10	27.30	39.60	04.20	10.60	03.20	01.60	01.10	00.20	01.00	11.40	100.2
Min.	24.20	35.60	03.50	10.40	02.50	01.40	01.10	00.10	00.90	07.30	
Max.	29.20	41.20	05.40	13.20	05.40	02.30	01.60	00.40	03.00	11.90	
Aver.	26.40	38.40	04.40	11.60	03.90	01.80	01.20	00.20	02.00	10.30	

### The radiometric specifications

#### The activity concentration

The activity concentration “A” in Bqkg<sup>-1</sup> of <sup>226</sup>Ra (A<sub>Ra</sub>), <sup>232</sup>Th (A<sub>Th</sub>) and <sup>40</sup>K (A<sub>K</sub>) are calculated by the following equation (Shams *et al.*, 2013):

$$A = N_p / (e \times \eta \times m) \dots \dots \dots (1)$$

where **N<sub>p</sub>** = the (cps) sample - (cps) background, “**e**” is the abundance of the  $\gamma$ -line in a radionuclide, “ **$\eta$** ” is the measured efficiency for each gamma-line observed for the same number of channels either for the sample or the calibration source and “**m**” is the mass of the sample in kilogram.

#### The environmental radiation indices

- **Radium equivalent activity (Bqkg<sup>-1</sup>)**

Radium equivalent activity (Ra<sub>eq</sub>) means the collected activity concentrations of <sup>226</sup>Ra, <sup>232</sup>Th and <sup>40</sup>K found in the material and can be estimated by this equation (Ibrahiem, 1999):

$$Ra_{eq} = 370 \times [(A_{Ra}/370) + (A_{Th}/259) + (A_K/4810)] \dots \dots \dots (2)$$

where A<sub>Ra</sub>, A<sub>Th</sub> and A<sub>K</sub> represent the activity concentrations of <sup>226</sup>Ra, <sup>232</sup>Th and <sup>40</sup>K as (Bq kg<sup>-1</sup>) and the factors 370, 259 and 4810 were assumed to get the same  $\gamma$ -radiation dose rate by the three radionuclides respectively (OECD, 1979).

• **The absorbed dose rate (D) (nGy h<sup>-1</sup>)**

The absorbed dose rate expresses the total absorbed gamma dose rate in air at 1m above the ground level for the uniform distribution of the naturally occurring radionuclides. It can be calculated by multiplying the activity concentrations (Bqkg<sup>-1</sup>) of <sup>226</sup>Ra (A<sub>Ra</sub>), <sup>232</sup>Th (A<sub>Th</sub>) and <sup>40</sup>K (A<sub>K</sub>) in the factors 0.462, 0.604 and 0.0417 respectively to convert them into radiation doses (nGyh<sup>-1</sup>Bq<sup>-1</sup>kg<sup>-1</sup>) (UNSCEAR, 2000) then go through the following equation (Shams *et al.*, 2013):

$$D \text{ (nGyh}^{-1}\text{)} = 0.462A_{Ra} + 0.604A_{Th} + 0.0417A_K \dots\dots\dots(3)$$

• **The annual effective dose(Eff. D)**

In General, The annual effective dose equals summation of the annual outdoor effective dose (E<sub>out</sub>) and the annual indoor effective dose (E<sub>in</sub>). The average annual effective dose received by a person is calculated using a conversion coefficient of 0.7 Sv Gy<sup>-1</sup>, to convert the absorbed rate (D) to annual effective dose with considering outdoor occupancy 20% and indoor occupancy 80% from the total hours per year (8760 h). However, in this work there is no consideration for the indoor occupancy based on the investigated materials so the annual effective dose will be calculated depending only on the outdoor occupancy by the following equation (UNSCEAR, 2000):

$$\text{Annual effective dose (mSvy}^{-1}\text{)} = D \times 0.7 \times 0.2 \times 8760 \times 10^{-6} \dots\dots\dots(4)$$

• **Internal hazard index (H<sub>in</sub>.) and external hazard index (H<sub>ex</sub>.)**

The exposure level due to radon inhalation originating from natural materials can be assessed by calculating the internal hazard index (H<sub>in</sub>.) according to the following equation:

$$H_{in} = (A_{Ra}/185) + (A_{Th}/259) + (A_K/4810) \dots(5)$$

On the other hand, the external hazard index (H<sub>ex</sub>.) proves the exposure level due to the emitted gamma rays from the investigated materials hence examines their validity for public using and is calculated by the following equation (UNSCEAR, 1988):

$$H_{ex} = (A_{Ra}/370) + (A_{Th}/259) + (A_K/4810) \dots(6)$$

where A<sub>Ra</sub>, A<sub>Th</sub> and A<sub>K</sub> are the activity concentration (Bqkg<sup>-1</sup>) of <sup>226</sup>Ra, <sup>232</sup>Th and <sup>40</sup>K respectively.

• **Gamma index (I<sub>γ</sub>) and alpha index (I<sub>α</sub>)**

To verify whether the natural building materials could/couldn't be an additional source of exposure to the population, two radiological parameters called the gamma index (I<sub>γ</sub>) and alpha index (I<sub>α</sub>) were proposed (European Commission, 1999) where;

$$I_{\gamma} = (A_{Ra}/300) + (A_{Th}/200) + (A_K/3000) \leq 1 \dots\dots\dots(7)$$

$$I_{\alpha} = A_{Ra}/200 \leq 0.5 \dots\dots\dots(8)$$

• **Excess lifetime cancer risk (ELCR)**

The lifetime cancer risk (ELCR) index depends mainly on the estimated annual effective dose value with other factors and can be calculated from this equation:

$$ELCR = E_{total} \times LE \times RF \dots\dots\dots(9)$$

where E<sub>total</sub> is the annual effective dose, LE is the life expectancy (70 years) and RF (Sv<sup>-1</sup>) is the fatal risk factor per sievert, which is 0.05 (Raymond *et al.*, 2016).

**Results and Discussion**

The calculated activity concentrations of the measured samples (Table 2) pointed to extremely high <sup>226</sup>Ra activity concentration (either in Mahamid phosphrite or the SSP) relative to the world average (UNSCEAR, 2008), while the activity concentrations revealed by both <sup>232</sup>Th and <sup>40</sup>K are lesser than or very close to the world averages. The high <sup>226</sup>Ra - activity is reasonably expected due to the elevated uranium concentration in the studied phosphrite ore hence in the derivative fertilizer where most of the uranium content in the ore transferred into the manufactured fertilizer.

On the other hand, the estimated radiation indices values of the radium equivalent activity (Ra<sub>eq</sub>), absorbed dose rate (D), annual effective dose (Eff. D), internal hazard index (H<sub>in</sub>), external hazard index (H<sub>ex</sub>), gamma index (I<sub>γ</sub>), alpha index (I<sub>α</sub>) and the Excess lifetime cancer risk (ELCR) are listed in (Table 3).

The achieved  $Ra_{cq}$  values in most of Mahamid phosphorite samples are higher than the world's average of  $370 \text{ Bq kg}^{-1}$  (Al-Trabulsy *et al.*, 2011) and the same behavior was given by the SSP samples although the observed decreasing comparing to the phosphorite ore.

The absorbed dose rates (D) in the measured samples ranged from 137 to 740 with an average value  $338 \text{ nGyh}^{-1}$  in Mahamid phosphorites and from 104 to 485 with an average value  $222 \text{ nGyh}^{-1}$  in the SSP samples. This means obvious high absorbed dose rate by the investigated samples relative to global range of  $18\text{-}93 \text{ nGyh}^{-1}$  (UNSCEAR, 2008).

**Table 2:** Activity concentration of radionuclides (in  $\text{Bq/kg}^{-1}$ ) of phosphate and SSP samples.

Sample type	S. No.	Activity concentration ( $\text{Bq/kg}^{-1}$ )		
		$^{226}\text{Ra}$ ( $A_{\text{Ra}}$ )	$^{232}\text{Th}$ ( $A_{\text{Th}}$ )	$^{40}\text{K}$ ( $A_{\text{K}}$ )
Mahamid phosphorite	M1	454	46	229
	M2	618	58	470
	M3	205	38	472
	M4	1121	52	939
	M5	854	60	469
	M6	1483	75	226
	M7	300	45	229
	M8	456	45	939
	M9	449	44	563
	M10	269	40	471
	Min.	205	38	226
	Max.	1483	75	939
Av.	621	50	500	
Single super phosphate (SSP)	SSP-1	159	35	229
	SSP-2	297	35	336
	SSP-3	268	41	226
	SSP-4	483	63	337
	SSP-5	448	34	227
	SSP-6	753	62	939
	SSP-7	206	28	315
	SSP-8	221	42	228
	SSP-9	968	41	313
	SSP-10	162	35	226
	Min.	159	28	226
Max.	968	63	939	
Av.	397	42	378	
<b>World Average (UNSCEAR, 2008)</b>		32	45	412

Referring to the estimated values of the annual effective dose (Eff. D), the calculated averages were  $0.42$  and  $0.27 \text{ mSvy}^{-1}$  for Mahamid phosphorite and SSP respectively, while no samples exceed the unity value which means that all the conducted values lower than the safety criterion limit of  $1 \text{ mSv y}^{-1}$  as a recommended safety limit for general public (ICRP, 1991).

On the other hand, the calculated values of both  $H_{in}$  and  $H_{ex}$  for the studied phosphorite and fertilizer showed their all values are greater than 1 (for the Hint) and the majority of samples are also more than 1 in the case of the Hext. Such values do not support the applicability of the examined materials where they exceed the unity value which the recommended value for both indices (UNSCEAR, 2008).

Furthermore, the gamma index ( $I_{\gamma}$ ) and alpha index ( $I_{\alpha}$ ), most countries applied their own control on the upper limit. The Europe commission (EC) introduced two dose criteria for the gamma dose of materials: an exception basic of  $0.3 \text{ mSvy}^{-1}$  and a maximum cut-off of  $1 \text{ mSvy}^{-1}$  (European Commission, 1999). In the event that the exclusion level of  $0.3 \text{ mSvy}^{-1}$  is viewed, the estimates values of  $I_{\gamma}$  ought to be beneath  $0.5$  for materials used in bulk like granite, cement, sand...etc. while if the upper level of  $1 \text{ mSvy}^{-1}$  is observed, the values of  $I_{\gamma}$  ought to be underneath  $1$  for such materials. Generally, the advisable values of  $I_{\alpha}$  and  $I_{\gamma}$  are beneath  $0.5$  and  $1$ , respectively (European Commission, 1999). In the concerned samples, the calculated values of  $I_{\gamma}$  were found to be more than  $1$  for the phosphorite samples with an average value equals  $2.49$  while three samples of the SSP

showed lower values than 1 and the remaining samples were greater with general average value equals 1.64. On the other hand, all investigated samples had  $I_{\alpha}$  over the advisable value (0.5). Such results mean that both Mahamid phosphorite and the SSP have potentiality to cause additional source of radioactive exposure for the public.

Regarding calculated ELCR values, all the examined samples (except three phosphorite samples and one SSP sample) gave values lesser than the world's average of  $1.45 \times 10^{-3}$  (Taskin *et al.*, 2009).

**Table 3:** The calculated radiation indices for Mahamid phosphorite and SSP samples.

Sample type	S. No.	The environmental radiation indices							ELCR x (10 <sup>-3</sup> )
		R <sub>aeq</sub> (Bqkg <sup>-1</sup> )	(D) (nGy h <sup>-1</sup> )	Eff. D (mSvy <sup>-1</sup> )	H <sub>in</sub>	H <sub>ex</sub>	I <sub>γ</sub>	I <sub>α</sub>	
Mahamid phosphorite	M1	537	247	0.30	2.68	1.45	1.82	2.27	1.05
	M2	737	340	0.42	3.66	1.99	2.51	3.09	1.47
	M3	295	137	0.17	1.35	0.80	1.03	1.03	0.60
	M4	1267	586	0.72	6.46	3.43	4.31	5.60	2.52
	M5	976	450	0.55	4.95	2.64	3.30	4.27	1.93
	M6	1607	740	0.91	8.38	4.34	5.39	7.41	3.19
	M7	381	175	0.21	1.84	1.03	1.30	1.50	0.74
	M8	592	277	0.34	2.83	1.60	2.06	2.28	1.19
	M9	555	257	0.32	2.71	1.50	1.90	2.25	1.12
	M10	362	168	0.21	1.71	0.98	1.25	1.35	0.74
	Min.	295	137	0.17	1.35	0.80	1.03	1.03	0.60
Max.	1607	740	0.91	8.38	4.34	5.39	7.41	3.19	
Av.	731	338	0.42	3.66	1.98	2.49	3.11	1.45	
Single super phosphate (SSP)	SSP-1	226	104	0.13	1.04	0.61	0.78	0.80	0.46
	SSP-2	372	172	0.21	1.81	1.01	1.28	1.84	0.74
	SSP-3	343	158	0.19	1.65	0.93	1.17	1.34	0.67
	SSP-4	598	275	0.34	2.92	1.62	2.04	2.41	1.19
	SSP-5	514	237	0.29	2.60	1.39	1.74	2.24	1.02
	SSP-6	865	424	0.52	4.50	2.47	3.13	3.76	1.82
	SSP-7	270	125	0.15	1.29	0.73	0.93	1.03	0.53
	SSP-8	298	137	0.17	1.40	0.81	1.02	1.11	0.60
	SSP-9	1050	485	0.59	5.45	2.84	3.53	4.84	2.07
	SSP-10	229	105	0.13	1.06	0.62	0.79	0.81	0.46
	Min.	226	104	0.13	1.04	0.61	0.78	0.80	0.46
Max.	1050	485	0.59	5.45	2.84	3.53	4.84	2.07	
Av.	476	222	0.27	2.37	1.30	1.64	2.02	0.96	

**Conclusions and recommendations**

Based on the above illustration and discussion some conclusions can be formulated in the following points:

- Mahamid phosphorite is characterized by elevated radioactivity concentration due to its relative high uranium concentration which yielded considerable gamma-emitters decay products along its life time.
- Although the relative reduction of the activity concentration in the single super phosphate fertilizer but it still has undesirable radioactive contents that means transforming of the majority of radioelements from the phosphorite ore into the fertilizer during the manufacturing process.
- Either the phosphorite ore or the manufactured fertilizer can impose radioactive risks for the environment and users.

**Accordingly, some recommendations are put in place;**

- 1- Mahamid phsphorite is recommended for the production of the wet processed phosphoric acid more than the phosphatic fertilizers, where the majority of <sup>226</sup>Ra passes to the by-product phosphogypsum (Moahammaden, 2011).

- 2- Appropriate radiation protection should be consider for workers in phosphate mines and phosphatic fertilizer factories, periodical check of absorbed dose for workers should be taken in consideration and reducing the working hours.

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