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A Study on Protection Against the Radioactive Hazards During Transportation of Naturally Occurring Radioactive Materials

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In this work, radiation dosages and hazards emerging due to doses received by drivers and workers involved in transporting naturally occurring radioactive materials (NORM) in Egypt are assessed and compared with the accepted doses in many countries. Two cases were studied; the first case is of a truck driver and the other one was of the loading-unloading workers. The workers' case was studied to estimate the doses and hazards to workers in the field of recycling materials. The annual working hours for truck drivers were defined, according to normal, heavy and abnormal duties, as 200, 400 and 600 hours. Working hours for loading-unloading workers were also selected under various conditions of duties to be 50, 100 and 150 annual hours. External and internal exposure for drivers and workers were estimated according to the properties of materials. Zircon, phosphate and bauxite were the assumed cargos. The doses due to inhalation of contaminated dust were considered in addition to the external dose of g - radiation.

Keywords: *Radiation, Hazards, NORM, Exposure dose*

Introduction

Transport workers may face hazards due to certain radioactive materials that are contained in some goods. These include dealing with radioactive sources or handling materials containing high concentrations of naturally occurring radioactive materials (NORM) [1]. The International Atomic Energy Agency (IAEA) set the protocols of safety for the radioactive stuff's transportation [2, 3]. According to these protocols, the radioactive materials are defined as those materials which have radionuclides of both activity concentration and total activity, in the shipment, exceeding the exemption levels for those radionuclides. Permitive materials that have low values of radioactivity are imported and processed in many industries. Ilmenite and rutile contain radioactive Uranium-238 and Thorium-232 [4] is used to extract pigment titanium dioxide. These materials are shipped by marine tankers and railways in bulks. Also, production of refactory bricks, ceramic, glasses and the high temperature casting are utilizing zircon which is normally bagged during transport [5].These materials are outside the transport regulation scope because the radioactivity concentrations are not much higher than the exemption concentrations of uranium and thorium. Therefore, a common assessment was carried out to evaluate the levels of potential radiation exposure of workers involved in the transport operations. The transport of zircon flour was used as an example to calculate the dose rate. IAEA has introduced an international research program to examine the transport of NORM and this study is a contribution to that research [6]. Many NORM materials were studied [7]. Transport of zircon, phosphate and bauxite is examined in the current study. Valuation has been made of the radiological influence during the transport operations.

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Sample preparation

A database is built to collect information during the NORM investigation. It was possible to identify several firms that are importing stuffs containing NORM. Different types of raw material (zircon, phosphate and bauxite) with high activity concentrations were collected from factories. The samples were transferred to the Egyptian Nuclear and Radiological Regulatory Authority, Central Laboratory for Environmental Radioactivity Measurements Inter-comparison and Training (CLERMIT) for preparation and analysis. Ra (^{238}U series), Th-series, and K-40 activities were measured using γ-spectrometry based on hyper-pure germanium detectors (HPGe). HPGe detector are of 40% relative efficiency and 1.95 keV FWHM for ^{60}Co $\gamma -$ energy line at 1332 keV. $\gamma -$ acquisition and analysis were carried out using Canberra Genie 2000. Activity calculations were made using the following γ - transmissions: 351.9 (^{214}Pb), 609.3, 1120.3 and 1764.5 keV (^{214}Bi) for the ^{226}Ra-series, 338.4, 911.1 and 968.9 keV (^{228}Ac) for Th- series, and 1460.7 keV for ^{40}K. A point source of ^{226}Ra and a KCl-standard solutions were used to calibrate the $\gamma -$spectrometers [8].

Estimation of effective dose

$\gamma -$radiation external, inhalation, and exposure effective dose due to transporting of zircon, phosphate, and bauxite materials were calculated using the following equations [9]:

$$E_{ext} = A\ D_{ext}\ T_e\ F_d \quad (1)$$

$$E_{inh} = A\ D_{inh}\ T_e\ F_d\ B_r\ C_{dust} \quad (2)$$

$$E_{ing} = A\ D_{ing}\ T_e\ F_d\ R_{ing} \quad (3)$$

Where;

E_{ext} is the external γ-radiation effective dose (Sv y^{-1});

E_{inh} is the inhalation effective dose (Sv y^{-1});

E_{ing} is the ingestion effective dose (Sv y^{-1}) ;

A is the samples activity concentration in (Bq g^{-1});

D_{ext} is the dose coefficient for external γ-radiation (Sv h^{-1} Bq g^{-1});

D_{inh} is the dose coefficient for inhalation exposure (Sv g^{-1});

D_{ing} is the dose for ingestion exposures (Sv g^{-1});

T_e is the time of exposure (y^{-1});

F_d is the dilution factor;

B_r is the rate of breathing (m^3 h^{-1});

C_{dust} is the concentration of dust during exposure (g m^{-3});

R_{in} is the rate of ingestion rate (g h^{-1}).

Determination of transportation circumstances

These doses were evaluated according to the work rehearses set up. Driving periods, vehicles loading and distance from the material were taken into consideration to describe the transport operations and develop exposure circumstances. Doses were generally calculated for vehicle drivers transporting materials in a conveyance and for individuals involved in loading materials. For each of these materials, experts categorized the radionuclides, activity concentrations and the transported volumes, as well as other aspects of the process such as the typical loading and the types of shipment containing NORM.

a-External exposure for a vehicle driver

The following assumptions have been developed to deal with this case:

The shipment is assumed to be a parallelepiped of a 20 m^3 volume, of dimensions 2 x 2 x 5 m. The density of the material is assumed to be 1500 kg m^{-3}, therefore the mass is assumed to be 30 tons. The truck walls are assumed to be made of steel of 1 cm thickness of. The shipment is positioned to be 1 m from the driver.

As for the loading-unloading process, the following circumstances are considered:

(1) Loading, transport and unloading process takes about 4 hours.

(2) Annual exposure period of 200, 400, or 600 h, depending on the numbers of trips that are done by the driver. Where the 200 h is considered to be a normal duty, 400 h is for the heavy duty and the 600 h is taken in the case of abnormal working conditions.

b-External exposure for loading-unloading worker:

In case of the worker, it is assumed that the worker is exposed for 1, 2, and 3 hours per week with annual duty of 50 weeks which results in an annual exposure period of 50, 100, and 150 hours respectively. Also, exposure pathway inhalation must be considered because the worker is exposed to dust during handling bulk bags.

c-Internal exposure

To predict the rates of internal dose for dust inhalation and ingestion, the following assumptions are considered:

1- The concentration of the dust is 1 mg m^{-3};

2- The dust rate of ingestion is 1 mg h^{-1};

3- The worker's breathing rate is 1.2 $m^3 h^{-1}$ [10];
4- The inhaled particle size is 5 µm;
5- Radionuclides that are contained in the dust have activity concentration of 1 Bq g^{-1};
6-Exposure distance is 1 m without assuming shielding.
7-The lung clearance for uranium and thorium is of S-type [11];
8-The lung clearance type for other elements is as mentioned in a previous study [11].

Results and Discussion

Activity concentrations of the transported materials

Depending on the type of transported NORM, the effective dose per year is evaluated for both the driver and the worker. A wide range of ^{226}Ra (^{238}U series) and ^{232}Th activity concentrations in zirconium, bauxite and phosphate minerals were measured and reported as shown in Table (1).

Annual exposure effective dose

Table (2) shows the calculated annual effective doses, which are received to the driver and worker, depending on the concentration activity of each radionuclide. Annual effective doses in normal work range from 20.4 to 62.6, and from 5.3 to 16.2 µSv for vehicle driver and loading-unloading worker, respectively. In the case of hard work, annual effective doses are range from 40.7 to 125.2, and from 10.5 to 32.4 µSv for vehicle driver and loading-unloading worker respectively. Also, in abnormal work, the annual effective doses range from 61.1 to 187.8, and from 15.7 to 48.6 µSv for vehicle driver and loading-unloading worker, respectively. Figure 1 (a, b) presents the annual effective dose for vehicle driver at 200, 400, and 600 h and loading-unloading workers at 50, 100, and 150 h during transportation scenario of Zircon, Bauxite, and Phosphate. According to the IAEA safety guide TS-R-1 [12], and European Commission, practical use of the concepts of clearance and exemption (2002) (Part II) [13], the recommended annual effective doses for safe transport of NORM range from 0.005 to 10 mSvh^{-1}.

In NUREG-1717 [14], doses were estimated using a microshield and assuming that a 48 pallet (50 bags 41 kg per pallet) of 0.05% by weight uranium and thorium in zircon flour were transported with an exposure duration of 24 h to transport 1 load and 25 trips per year (600 hours per year) by the same driver. Based on these assumptions, the estimated annual dose to the truck driver was estimated to be 0.06 mSv. Doses were also estimated using a micro-shield by the Health Protection Agency, Radiation Protection

Table (1): Activity concentration (Bq gm^{-1}) of natural radioactive nuclides in raw materials

Sample type	Ra-226	Th-232	K-40
Zircon Bally	3914.1 ± 15.5	1205.7 ± 101.3	110.2 ± 12.3
Zircon flour	2400.4 ± 5	427.4 ± 8.5	7.6 ± 10.2
Zircon batch	2740.1 ± 21.6	521.4 ± 24.8	107.3 ± 4.6
Zirconia Ramming material	3354.4 ± 9.2	829.7 ± 0.3	68.4 ± 10.8
Zirconia Powder	3597.5 ± 8.5	872.1 ± 0.3	129.3 ± 9.8
Bauxite	2153.7 ± 11	372.7 ± 9.7	1336.4 ± 22.1
Phosphate Raw material	1180.6 ± 0.3	16 ± 20.1	1582 ± 0.6

Table (2): Annual Effective Dose in µSv y^{-1} for Transport Scenarios

NORM	Driver			Loading- Unloading Workers		
	200 h	400 h	600 h	50 h	100 h	150 h
Zircon(MAX)	62.6±0.5	125.2±0.9	187.8±1.5	16.2±0.1	32.4±0.37	48.6±0.4
Zircon(MIN)	37.6±0.1	75.1±0.2	112.7±0.3	9.72±0.03	19.4±0.1	29.2±0.1
Bauxite	35.7±0.2	71.4±0.4	107.1±0.7	9.22±0.1	18.4±0.1	27.7±0.2
Phosphate	20.±0.01	40.7±0.01	61.1±0.02	5.25±0.0014	10.5±0.01	15.8±0.01

Division [4]. It was assumed that 20 tons of zircon flour was transported with the following radionuclide concentrations: 3 Bq g^{-1} of ^{238}U, 0.15 Bq g^{-1} of ^{235}U and 0.6 Bq g^{-1} of ^{232}Th. The driver was assumed to be 1m away from the load surface and to have an annual driving time of 600 h, resulting in an annual dose of about 0.18 mSv (3 x 10^{-4} mSv h^{-1}). In the present study, the maximum total effective dose for zircon ore was 188 ± 1.5 µSv, which was the highest among other ores.

Table (3) shows a comparison of the annual effective dose between maximum result of the present study and different countries in mSv for zircon material transport scenarios. These results agree with the average values of worldwide for annual period of 600 h. Estimated doses based on 10 Bq g^{-1} exemption concentration [15], in transportation approach to evaluating the dose and actual activity concentration data is to determine the doses that would result if the activity concentration was10 Bq g^{-1}. Multiplying by a ratio of the normalized doses (annual exposure duration of 400 h) over the actual activity concentrations, the estimated doses associated with 10 Bq g^{-1} for the ores and products, ranged from 0.01 to 0.4 mSv. An average annual dose was estimated to be about 0.1 mSv. According to the International commission on radiological protection ICRP [17], the current assessed doses are considerably lower than the practical dose constraint of 1 mSv and within the range of the prudent dose constraint of 0.1 mSv.

Table (3): A comparison between the current results and the annual effective dose in some countries at the same exposure time and material

Country	Annual effective dose (µSv y^{-1})	Material	Annual exposure period (h)	Reference
NUREG 1717	60	Zircon flour	600	[14]
UK	180	Zircon flour	600	[4]
USA	59	Zircon	600	[15]
Australia	180	Zircon flour	600	[16]
Current study	188	Zircon	600	

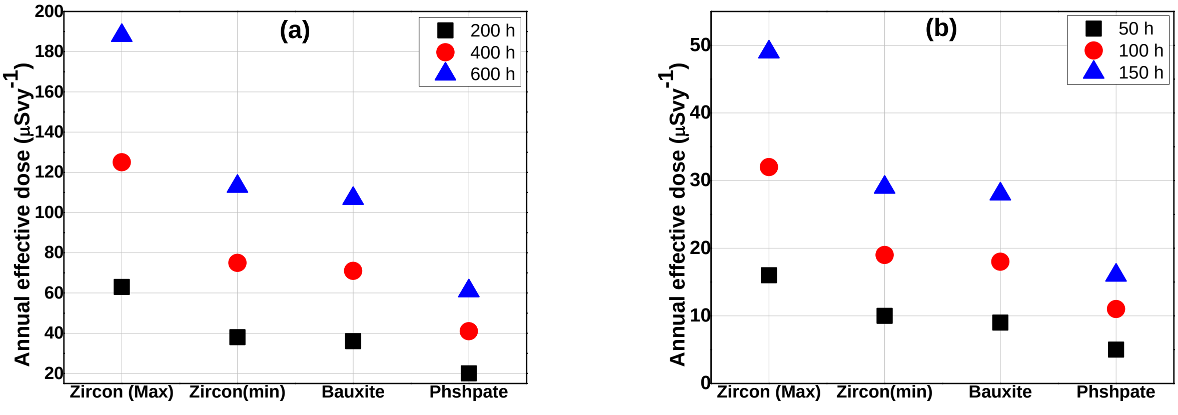

Fig. (1): Annual effective dose for the (a) truck driver and (b) loading-unloading worker according to the transport scenario

Conclusion

The aim of the current study is developing scenarios according to the working hours and materials type to determine the annual effective dose of external γ-radiation, inhalation, and exposure received by the driver in the case of working for 600 hours per year as maximum working hours. According to IAEA safety guide TS-R-1, the annual recommended dose ranges from 0.005 to 10 mSv h^{-1}. The calculated annual dose is 188 μSv (3.13 $x10^{-4}$ mSv h^{-1}). This value is suggested if 20 tons of zircon flour with 3 Bq g^{1} of ^{238}U and, 0.15 Bq g^{-1} of ^{235}U and 0.6 Bq g^{-1} of ^{232}Th is transported. This estimated value is the highest among all other ores. Therefore, the exposure of workers of all materials does not need to be controlled.

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