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Comprehensive Personal Dose Assessment during Transportation of TENORM Contaminated Wastes

*YA.A. Ahmed, W.M.Abdellah
Radiation Protection Department Nuclear and Radiological Safety Research Center, Egyptian Atomic Energy Authority, Cairo, Egypt

Abstract:
Technologically Enhanced Naturally Occurring Radioactive Materials (TE-NORM) are by-products or wastes generated from various industrial processes, such as the oil and gas industry, which may contain radionuclides at radiologically significant concentrations. When these concentrations exceed regulatory thresholds, the transportation of such materials must be carefully managed to protect workers, the public, and the environment. This study evaluates radiation exposure during the transportation of TE-NORM contaminated wastes, including sludge, soil, and scale, under defined scenarios involving truck drivers and loading/unloading personnel. Radionuclide concentrations, specifically for the ^{238}U series (up to 42.75 Bq/g in sludge and 7.20 Bq/g in soil), ^{232}Th series (up to 8.41 Bq/g in sludge and 2.63 Bq/g in soil), and ^{40}K (up to 0.444 Bq/g in sludge and 0.122 Bq/g in soil), were measured using gamma spectrometry with a high-purity germanium detector. Annual Effective Doses were calculated for external gamma radiation, inhalation, and ingestion pathways based on IAEA and European Commission guidelines.
The results show that Annual Effective Doses for truck drivers range from 139.99 µSv/y to 3952.94 µSv/y, depending on working hours and material type. For loading/unloading workers, doses range from 139.99 µSv/y to 743.63 µSv/y. The IAEA recommended safety threshold values should be considered during the transport of technically increased natural radionuclides. The study also highlights the importance of conducting periodic risk assessments and strengthening safety protocols during the transport of materials contaminated with TE-NORM.
Keywords*: TENORM, Dose Assessment, Annual Effective Doses*

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I. Introduction:

Technologically Enhanced Naturally Occurring Radioactive Materials (TE-NORM) are naturally occurring radioactive materials (NORM) that have been concentrated or dispersed by human activities, such as oil and gas production, mining, and industrial processes. Many wastes may arise as a result of these activities. Transport of these radioactive contaminated wastes can lead to increased levels of occupational radiation exposure as well as contaminate the environment, including soil, water, and air. This can pose risks to human health and the environment [1]. The International Atomic Energy Agency (IAEA) assign sets the standards for safety of transport of radioactive materials (Regulations for the Safe Transport of Radioactive Material 2018 Edition) [2]. These standards defined the radioactive materials as materials that contains both the activity concentration and the total activity of the radioisotopes in the consignment exceed the respective exemption values for those radioisotopes, which are listed in the IAEA regulations. Therefore, if either value is not exceeded then such material is exempt from the transport regulations.

TE-NORM contaminated wastes can be found in various forms, including:

- **Solid wastes:** These include scales, sludge, and other solid materials that accumulate in pipes, tanks, and other equipment used in industrial processes.
- **Liquid wastes:** These include wastewater from industrial processes, such as oil and gas production and mining.
- **Gaseous wastes:** These include radon gas, which can be released from TENORM-contaminated materials [3].

In such wastes, the activity concentrations may be slightly higher than the exemption concentrations of uranium and thorium series, but do not exceed 10 times those values and therefore are outside the scope of the transport regulations. For those materials that are outside the scope of the transport regulations, a generic assessment was carried out to estimate the levels of potential radiation exposure of workers and members of the public during transport operations [4].

This study focuses on evaluating radiation doses associated with the transportation of-contaminated sludge and soil. It provides a detailed assessment of the radiological impact on workers and the public, offering valuable insights for improving safety requirements and regulatory compliance during TE-NORM waste transportation.

Experimental:

Sample collection:

TE-NORM contaminated sludge and soil samples were collected from one of a production oilfield at Ras Shukier area (western bank of Suez Gulf near to Ras Gharib) in Egypt. 5 TE-NORM contaminated sludge samples collected from storage tank and 10 TE-NORM contaminated soil samples collected from evaporation pond during desludging and cleaning process.

Sample preparation

The collected soil and sludge samples stored on plastic container to prevent cross-contamination and transferred to Lab for preparation. An accurate 100 cm^3 of the each samples were packed in a PVC cylindrical radon-tight Marinelli beaker (volume: 100 cm^3), sealed tightly by sealing tape for preventing radon escape and stored for four weeks before the radiometric measurements (allowing establishment of secular equilibrium between radium and its decay products) [5].

The specific activity of Ra (^{238}U series), ^{232}Th series, and ^{40}K were determined using gamma-spectrometry based on high-resolution hyper-pure germanium detector. The HPGe detector used in this study has a relative efficiency of 40% and full width at half maximum (FWHM) of 1.95 keV for ^{60}Co gamma energy line at 1332 keV and operated with Canberra Genie 2000 software for gamma acquisition and analysis. The gamma transmissions used for activity calculations were 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. The gamma-spectrometers were calibrated using both ^{226}Ra point source and potassium chloride standard solutions in the same samples geometry [6].

Estimation of Effective dose

The effective dose of external gamma radiation, inhalation, and ingestion exposure for driver as well as loading and unloading workers during TE-NORM contaminated sludge and soil in each exposure pathway was calculated by means of the following equations as described in the Radiation Protection 122 (RP 122) publications of the European Commission [7, 8]:

$$E_{ext} = D_{ext} * T_e * F_d * A \qquad (1)$$
$$E_{inh} = D_{inh} * T_e * F_d * B_r * C_{dust} * A \qquad (2)$$
$$E_{ing} = D_{in}g * T_e * F_d * R_{ing} * A \qquad (3)$$

Where:

E_{ext}, E_{inh}, and E_{ing} are effective doses due to external gamma radiation, inhalation, and ingestion exposures (Sv y^{-1});

D_{ext}, D_{inh}, and D_{ing} are dose coefficients for external gamma radiation, inhalation and ingestion exposures. [((Sv h^{-1})/(Bq g^{-1})) for D_{ext}] (Sv Bq^{-1} for D_{inh});

T_e is working hours (h y^{-1});

F_d is dilution factor;

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

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

C_{dust} is dust concentration during exposure time (gm^{-3}).

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

TE-NORM contaminated wastes contains mainly ^{238}U series, ^{232}Th series, and ^{40}K. Therefore, the total effective dose received by the driver as well as loading and unloading workers could be estimated by using the following equations [7, 8]:

$$E_{ext\,(total)} = E_{ext\,(U)} + E_{ext\,(Th)} + E_{ext\,(K)} \qquad (4)$$
$$E_{inh\,(total)} = E_{inh\,(U)} + E_{inh\,(Th)} + E_{inh\,(K)} \qquad (5)$$
$$E_{ing\,(total)} = E_{ing\,(U)} + E_{ing\,(Th)} + E_{ing\,(K)} \qquad (6)$$
$$E_{total} = E_{exe\,(total)} + E_{inh\,(total)} + E_{ing\,(total)} \qquad (7)$$

Where:

$E_{ext\,(U)}$, $E_{ext\,(Th)}$, and $E_{ext\,(K)}$ are the E_{ext} for ^{238}U series, ^{232}Th series, and ^{40}K, respectively (Sv/y).
$E_{inh\,(U)}$, $E_{inh\,(Th)}$, and $E_{inh\,(K)}$ are the E_{inh} for ^{238}U series, ^{232}Th series, and ^{40}K, respectively (Sv/y).
$E_{ing\,(U)}$, $E_{ing\,(Th)}$, and $E_{ing\,(K)}$ are the E_{ing} for ^{238}U series, ^{232}Th series, and ^{40}K, respectively. (Sv/y).
E_{total} is the total effective doses of amount of external gamma radiation, inhalation, and ingestion exposures due to ^{238}U series, ^{232}Th series, and ^{40}K (Sv/y).

II. Results and discussion

Activity concentrations of the transported wastes

There are notable differences in the specific activity between the contaminated sludge samples and the contaminated soil samples. The specific activity of the sludge samples is significantly higher than that of the soil samples, with both sample types exhibiting values well above the exemption criteria specified in IAEA GSR Part 3. These exemption values are 1 Bq/g for both the ^{238}U and ^{232}Th decay series, and 10 Bq/g for ^{40}K [9].

The specific activity of the ^{238}U series in the contaminated sludge samples ranged from 42.48 to 42.75 Bq/g, whereas the contaminated soil samples showed a range of 6.89 to 7.20 Bq/g, which is higher than the exemption threshold for the ^{238}U series in the IAEA.

For the ^{232}Th series, the specific activity of the sludge samples varied between 8.34 and 8.41 Bq/g, while the soil samples exhibited values ranging from 2.29 to 2.63 Bq/g. Both sets of samples have specific activities that exceed the exemption limit for the ^{232}Th series.

In the case of ^{40}K, the specific activity of the contaminated sludge samples ranged from 8.34 to 8.41 Bq/g, and the contaminated soil samples showed values between 2.29 and 2.63 Bq/g, which are below the IAEA exemption value for ^{40}K.

The specific activity values for the ^{238}U series, ^{232}Th series, and ^{40}K in the collected samples are presented in Table 1, Figure 1.

Table (1): The specific activity of ^{238}U series, ^{232}Th series and ^{40}K for the samples under the current study

Sample	Specific Activity A (Bq g^{-1})		
	U238	Th232	K40
Sludge 1	42.48 ± 1.51	8.36 ± 0.69	0.44 ± 0.01
Sludge 2	42.62 ± 1.50	8.35 ± 0.72	0.44 ± 0.01
Sludge 3	42.58 ± 1.50	8.34 ± 0.70	0.44 ± 0.01
Sludge 4	42.56 ± 1.52	8.35 ± 0.67	0.44 ± 0.01
Sludge 5	42.75 ± 1.53	8.41 ± 0.69	0.44 ± 0.01
Sludge Average	**42.60 ± 1.52**	**8.36 ± 0.69**	**0.44 ± 0.01**
Soil 1	7.20 ± 0.42	2.30 ± 0.23	0.12 ± 0.01
Soil 2	6.94 ± 0.73	2.63 ± 0.25	0.11 ± 0.01
Soil 3	6.94 ± 0.44	2.29 ± 0.28	0.12 ± 0.01
Soil 4	6.93 ± 0.49	2.29 ± 0.28	0.12 ± 0.01
Soil 5	6.95 ± 0.43	2.31 ± 0.30	0.12 ± 0.01
Soil 6	6.96 ± 0.63	2.29 ± 0.29	0.11± 0.01
Soil 7	7.11 ± 0.50	2.30 ± 0.70	0.11 ± 0.01
Soil 8	6.89 ± 0.56	2.51 ± 0.69	0.11 ± 0.01
Soil 9	7.10 ± 0.60	2.45 ± 0.69	0.12 ± 0.01
Soil 10	6.93 ± 0.65	2.35 ± 0.69	0.12 ± 0.01
Soil Average	**6.97 ± 0.60**	**2.37 ± 0.35**	**0.12 ± 0.01**

IAEA Exemption Values	1 Bq/g	1 Bq/g	10 Bq/g

Dose assessment

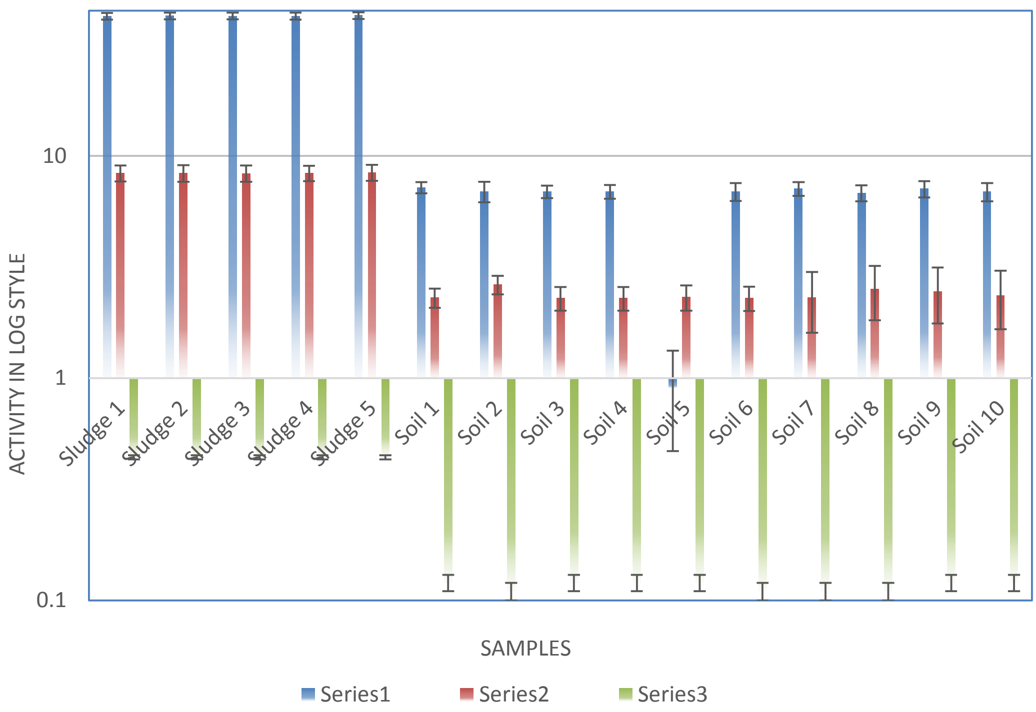
The annual effective doses received due to external exposure received by the vehicle driver and loading and unloading workers during TE-NORM contaminated sludge and soil transportation are calculated depending on the activity concentration of each radionuclide.

Different factors such as the dose conversion factor, dilution factor, working hours, breathing rate, dust concentration, and ingestion rate were used to estimate the annual effective doses [10, 11]. The values of those factors are shown in Table 2.

During transport scenario, time during loading – unloading procedure was assumed to be 100 hours a year and time during the driving was assumed to be 100 - 800 hours a year for dose assessment. External exposure was assumed to occur only during driving and loading–unloading procedures. Exposure by inhalation and ingestion were assumed to occur only during loading–unloading procedures [10, 11].

The calculated annual effective doses are shown in table 3. Annual Effective Doses for the vehicle driver in normal work are ranged from 3952.94 to 139.99 µSV/y depending on the driving hours. Annual Effective Doses for loading and unloading worker in normal work are ranged from 743.63 to 139.99 µSV/y.

Figure 1: The specific activity of ^{238}U series, ^{232}Th series and ^{40}K for the samples under the current study



Annual Effective Doses for both the vehicle driver and loading and unloading workers in normal work increases with increasing working hours and increasing the activity concentration of each radionuclide.

Annual Effective Doses for both the vehicle driver and loading and unloading workers for this study are higher than the recommended annual effective doses for safe transport of natural radionuclides that is 0.3 mSv According to IAEA SAFETY STANDARDS SERIES "Occupational Radiation Protection", General Safety Guide No. GSG-7) [12].

Table 2: values of used factors to estimate the annual effective doses

Factor	External	Inhalation	Ingestion
T_e (h y^{-1})	100 - 800	100	100
F_d	1	1	1
B_r (m^3 h^{-1})	1.2	1.2	1.2
C_{dust} (g m^{-3})	0.001	0.001	0.001
R_{ing} (g h^{-1})	0.01	0.01	0.01
D_{ext} (µSv h^{-1} Bq g^{-1}), D_{inh} (µSv g^{-1}), and D_{ing} (µSv g^{-1}) for ^{238}U series	0.077	29	2.6
D_{ext}, D_{inh}, and D_{ing} for ^{232}Th series	0.12	48	1.1
D_{ext}, D_{inh}, and D_{ing} for ^{40}K	0.0076	0	0

Table 3. Annual Effective Dose in µSV/y for Transport Scenario

Sample	E_{total} (µSv y^{-1})							
	800 h	700 h	600 h	500 h	400 h	300 h	200 h	100 h
Sludge 1	3952.94	3311.08	2883.17	2455.26	2027.35	1599.44	1171.54	743.63
Sludge 2	3961.55	3318.30	2889.47	2460.64	2031.81	1602.98	1174.15	745.32
Sludge 3	3958.04	3315.36	2886.91	2458.46	2030.01	1601.56	1173.11	744.66
Sludge 4	3957.51	3314.91	2886.52	2458.12	2029.72	1601.33	1172.93	744.54
Sludge 5	3976.61	3330.91	2900.44	2469.97	2039.51	1609.04	1178.57	748.10
Soil 1	766.45	641.70	558.54	475.38	392.22	309.06	225.89	142.73
Soil 2	784.00	656.29	571.14	486.00	400.85	315.71	230.56	145.42
Soil 3	747.21	625.57	544.48	463.40	382.31	301.22	220.13	139.04
Soil 4	747.18	625.55	544.46	463.38	382.29	301.20	220.12	139.03
Soil 5	749.73	627.68	546.31	464.95	383.58	302.22	220.85	139.49
Soil 6	747.92	626.17	545.01	463.84	382.68	301.52	220.35	139.19
Soil 7	759.93	636.24	553.78	471.32	388.86	306.40	223.94	141.48
Soil 8	767.60	642.58	559.24	475.89	392.55	309.20	225.86	142.51
Soil 9	776.19	649.81	565.55	481.30	397.05	312.79	228.54	144.28
Soil 10	752.81	630.25	548.54	466.83	385.12	303.41	221.70	139.99

III. Conclusion

The specific activity in TE-NORM contaminated soil and sludge wastes produced from some production oilfield at Egypt were investigated. The specific activity of ^{238}U series and ^{232}Th series for the investigated samples were found to be higher than the exemption levels assigned by IAEA.

The estimated Annual Effective Doses for both the vehicle driver and loading and unloading workers for the study conditions are higher than the recommended annual effective doses for safe transport of natural radionuclides assigned by IAEA so, The IAEA recommended safety threshold values should be considered during the transport of technically increased natural radionuclides. The study also highlights the importance of conducting periodic risk assessments and strengthening safety protocols during the transport of materials contaminated with TE-NORM

References:

[1]. IAEA (2003). Radiation protection and the management of radioactive waste in the oil and gas industry. Safety Reports Series No. 34. International Atomic Energy Agency, Vienna.

[2]. INTERNATIONAL ATOMIC ENERGY AGENCY, Regulations for the Safe Transport of Radioactive Material 2018 Edition, IAEA Specific Safety Requirements No. SSR-6 (Rev. 1), IAEA, Vienna (2018).

[3]. J S Hughes and M P Harvey, 2008. "A study on the transport of naturally occurring radioactive materials, ISBN 978-0-85951-615-0.

[4]. K.K. VARLEY, "The appropriate level of regulatory control for the safe transport of NORM", Proceedings of an International Symposium Marrakesh, Morocco, 22–26 March 2010.

[5]. Ahmed. YA. A, Mahmoud. R.M.M, Ezz El-Din. M.R and Khalil. M. M. H., 2019. Radiological Hazards of TE-NORM Contaminated Soil at Oil and Gas Fields. Arab J. Nucl. Sci. Appl. 52(3): 16-24.

[6]. Ahmed. YA. A, 2024. Measurement of TE-NORM Concentrations and Resulting Dose Assessment in Produced Water at Some Oil and Gas Sites, Arab J. Nucl. Sci. Appl., Vol. 57, 1, 91-99.

[7]. Iwaoka K., Keiko Tagami, Hidenori Yonehara, Short communication," Measurement of natural radioactive nuclide concentrations in various metal ores used as industrial raw materials in Japan and estimation of dose received by workers handling them", Journal of Environmental Radioactivity 100 (2009) 993–997.

[8]. EC, 2002. European Commission, Practical Use of the Concepts of Clearance and Exemption (Part II). EC, Belgium.

[9]. IAEA (2014). Radiation protection and safety of radiation sources: international basic safety standards. General Safety Requirements Part 3, GSR Part 3. International Atomic Energy Agency, Vienna.

[10]. INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Dose Coefficients for Intakes of Radionuclides by Workers, Publication 68, Pergamon, Oxford (1994).

[11]. **Calytrix. 2008,** Radiation Exposure in the Transport of Heavy Mineral Sands; Report for the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA). Calytrix Consulting Pty Ltd, September. http://www.arpansa.gov.au/pubs/rps/rps2_calytrix.pdf

[12]. IAEA SAFETY STANDARDS SERIES, "Occupational Radiation Protection", General Safety Guide No. GSG-7), IAEA, Vienna (2018).