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(E S N S A)

Radiological Impact Assessment of TE-NORM Generating from Combustion of Fuel in Thermal Power Plant Using RESRAD Model

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ABSTRACT

Industrial practices involving natural resources often concentrate radionuclides to a degree that may pose a risk to humans and the environment. In the present study, Tchnically Enhanced Naturally Occuring Radioactive Materials TE-NORM are generated from the combustion of natural gas and fuel oil in a typical thermal power plant in Egypt. They were accumulated in the form of sludge or scales inside pipes, separators, heaters, storage tanks, and any other plant equipment or deposited in the soil surface land of the thermal power plant. The average measurements of the radioactivity of radionuclides in the contaminated soil of the thermal power plant were used as input data for the RESRAD computer code to estimate the radiological doses and health risks to the workers. In this assessment, the exposure source parameters were adjusted a period of 100 years. The predicted maximum total effective doses equivalent (TEDE) for the external exposure and soil ingestion of the contaminated area received by workers were 17.4and 0.106 µSv/y, also their annual total cancer risk for the external exposure and soil ingestion were 2.9 x10^{-5} and 2.68 x 10^{-8} respectively. It is found that the estimated doses and risks received by workers were below the international limits.

INTRODUCTION

The NORM are found in a wide range of applications, from residential to industrial, and their activity concentration can be increased as a result of human activities and industrial processes. The geologic formations that contain oil and gas deposits contain naturally occurring radionuclides. The radioactive materials are transported with the water formation from the oil fields to the surface of the earth during the extraction of petroleum[1-2]. The two most common NORM decay series are the uranium-238 and the thorium-232 series which the radioisotopes associated with their decay series as shown in Figure (1).

The long-lived radioactive elements in NORM can be a source of radiation that emits alpha, beta, and gamma radiation [3- 6]. Combustion of natural gas and oil fuel in thermal power plants generates NORM waste such as ash and sludge which may accumulate inside processing equipment or be deposited over the land surface of the plant. During routine operations of the thermal power plant, workers are exposed to NORM deposits in the contaminated area of the power plant [7].

Hazardous radiation may enter the workers' body through various ways of exposure that are classified as either internal or external, such as absorption, wounds, inhalation and ingestion [8]. The exposure of workers to radioactivity in NORM waste through internal pollution by absorbing contaminated soil NORM can take place as their hands may become dirty with contaminated soil, or by transferring the material into their food [9].

The uncontrolled release of radioactivity related to TENORM levels may pollute the environment and endanger human health. The health effects associated with exposure to ionizing radiation vary depending on the total amount of energy absorbed, time period, dose rate, and body exposed to radiation. Many studies have concluded that exposure to low doses of ionizing radiation may still cause a risk [10]. A variety of

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cancers, including leukemia, lung cancer, stomach, esophagus, bone, thyroid, brain, and nervous system, have been associated with exposure to ionizing radiation.

The accumulation of NORM waste from thermal power plant operation could constitute a radiological danger, and should be submitted to dose assessment to ensure that the workers are not exposed to uncontrolled radiation [11]. Controls have been adopted by measurement and evaluation of radioactivity of TENORM to avoid the risk of these wastes. Among the computational codes that have been adopted to assess the dose to the workers, the public, and the environment for the cases of NORM is the RESRAD computer code. RESRAD (onsite) version 6.5 has been used in the present study to estimate the potential radiological impact of an operation of thermal power plant at the site on the workers depending on the land use scenario and potential exposure pathways.

MATERIAL AND METHOD

Study area

The radiation survey in the current study was conducted in a typical thermal power plant north Helwan City, Egypt. Combustion of fuel oil and gas during operation of the thermal power plant was generated amounts of NORM waste that may be deposited on the soil land of the power plant as shown in Figure (2).

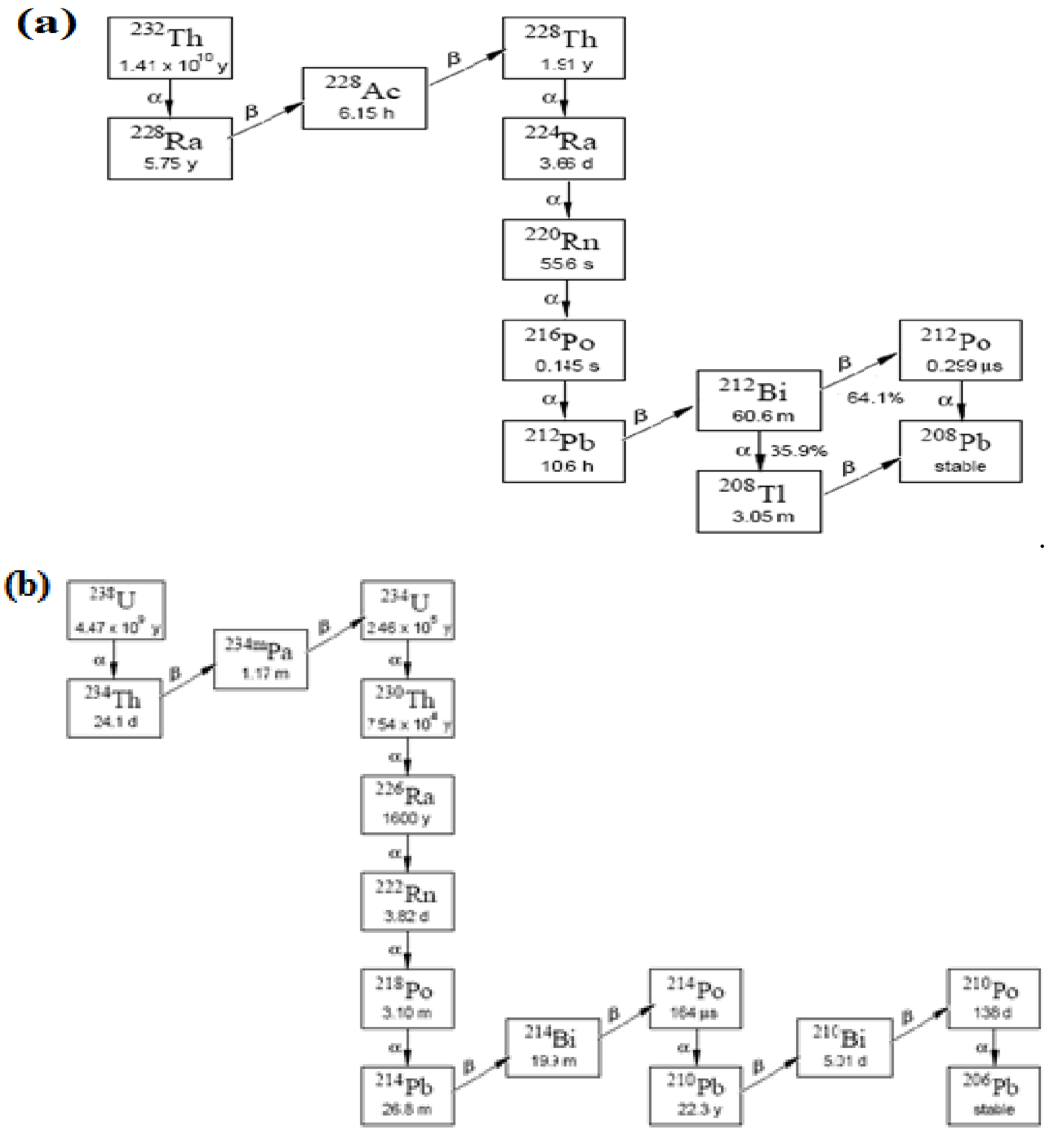

Fig. (1): Radioactive decay in (a) Thorium and (b)Uranium series

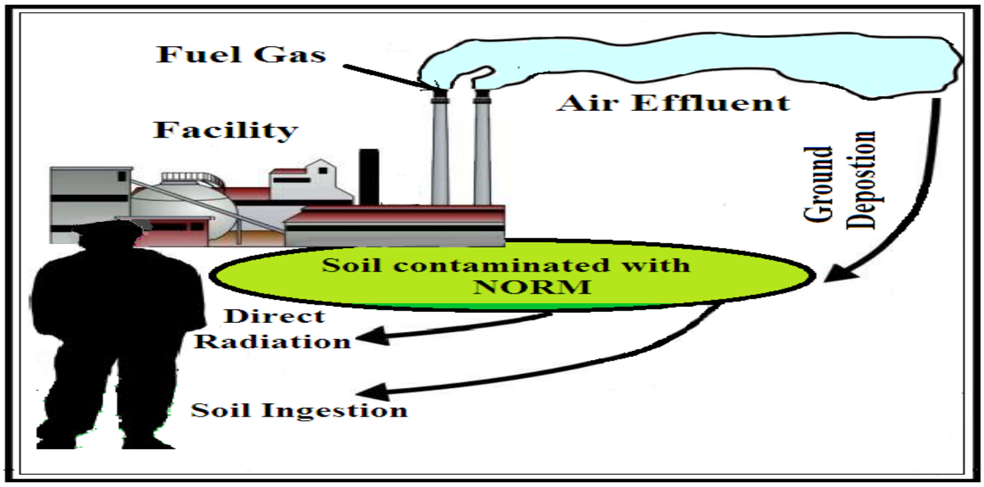

Fig. (2): Exposure pathways of radioactivity to workers in the study area

The measured activity concentrations of ^{226}Ra, ^{232}Th, ^{40}K of the soil contaminated samples of the power plant was used as input data in the RESRAD model to evaluate the radiological doses and health risks to the workers.

RESRAD MODEL

RESRAD was developed by Argonne National Laboratory in the 1980s and has been widely used to perform assessments of contaminated sites since its release in 1989. The RESRAD (onsite) computer code evaluates the radiological dose and excess cancer risk to an individual who is exposed while residing or working in an area where the soil is contaminated with radionuclides. RESRAD numerically evaluates the analytical expressions for concentration, dose, and risk at any desired time.

The exposure models in RESRAD such as direct external radiation and ingestion of soil were used in the present study. The RESRAD model was used to calculate the total effective dose equivalent of the workers for the external exposure pathway of deposited radionuclides of ^{226}Ra, ^{232}Th, ^{40}K on the contaminated soil with NORM of the thermal power plant. The expected estimation of the amount of effective doses of the external gamma radiation due to ^{226}Ra, ^{232}Th, ^{40}K is calculated according to the following equation [12].

$$M(t) = \sum_i S_i(0)/G_i(t) \leq 1 \qquad (1)$$

$$= HE(t)/HEL \quad tr \leq t \leq th$$

Where:

***M* (*t*) =** fraction of the basic dose limit received by an average a member of the critical population group at time *t* following the radiological survey (dimensionless),

***Si*(0)** = initial concentration of the *i*th principal radionuclide averaged, and

Gi(t) = single-radionuclide soil concentration guideline for the *i*th principal radionuclide in a uniformly contaminated zone at time *t* (Bq/g [pCi/g])

***HE*(*t*) =** average annual TEDE received by a member of the critical population group at time *t* following the radiological survey of the site (mSv/yr [mrem/yr]),

***HEL* =** basic dose limit (0.25 mSv/yr [25 mrem/yr]),

tr = time at which the site is released for use without radiological restrictions following the radiological survey (1 yr), and

***th* =** time horizon (1,000 yr).

The estimation of effective doses of the amount of gamma radiation is calculated for workers from ingested radionuclides in soil using the average concentration of radioactivity of^{226}Ra, ^{232}Th, ^{40}K in contaminated soil (Bq g^{-1}) according to equation (2)[13].

$$SoiI = Csoil * Isoil * ED * DF \qquad (2)$$

Where:

Dsoi, = effective committed dose from ingestion ofradioactively contaminated soil (Sv);

Csoil =average concentration in soil of a single

Isoil= average daily ingestion rate of soil during

ED= exposure duration (d); and

DF= dose factor **(Sv** Bq^{-1}).

Input parameters for RESRAD code

The area of the thermal power plant is 10200 m^2. The average radionuclides concentration of ^{226}Ra, ^{232}Th and ^{40}K of the collected contaminated soil with NORM from the power plant were 24.5, 14.5, 205.3 Bq/Kg respectively. The Exposure duration for the workers was considered to be 30 years. The outdoor time fraction is 0.25, and the indoor time fraction is 0.5 [14]. The pathways of greatest concern for workers are exposed to external gamma ray and soil ingestion.

The radiological risk to workers at the thermal power plant was estimated according to equation (1) the calculation of the external and internal (soil ingestion) doses for the workers exposed to NORM contaminated soil was carried out as equation(2) The associated health risks for the workers from external and internal exposure to contaminated soil were estimated.

RESULTS AND DISCUSSION

A radiological risk assessment is required for the workers in order to demonstrate that the exposure to the contaminated area meets safety regulations for workers. The RESRAD analysis was used to predict the maximum total dose received by workers exposed to the contaminated area inside the thermal power plant. The exposure pathways include direct exposure to external radiation from the contaminated soil material and internal dose from ingestion of the contaminated soil [15]. An average activity concentration of ^{226}Ra, $^{232}Th$and^{40}K of contaminated soil samples collected from the thermal power plant was used as the input data for RESRAD model.

Total effective dose equivalent

The scenario of a contaminated site depends on numerous factors, including the area of the contaminated soil, cover depth, erosion rate, and the ingestion rate and exposure pathways [16]. To estimate the total effective dose equivalent and total cancer risk for^{226}Ra, $^{232}Th$and^{40}K and their decay products, computer simulations were made using the RESRAD program in two scenarios external exposure and soil ingestion pathways of the contaminated soil with NORM at 1, 10, and 100 years.

Scenario 1

TEDE and the dose contributions of the individual radionuclides ^{226}Ra, ^{232}Th, $^{40}K$and their progenies to the workers who were exposed to contaminated zone using RESRAD program were calculated at 1, 10 and 100 years and as presented in Figure (3).

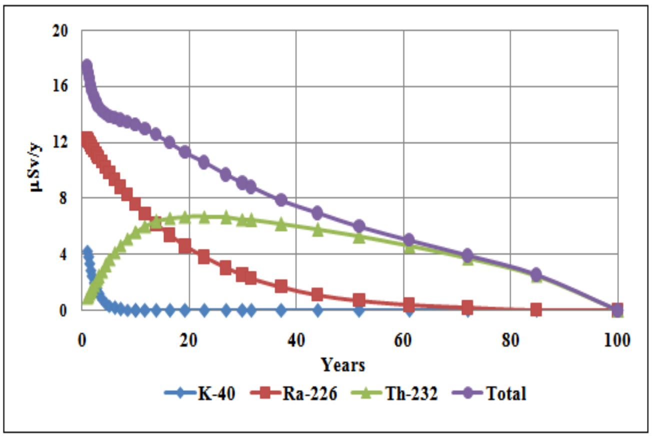

Fig. (3): Total effective doses equivalent via exposure pathway

The TEDE values of NORM waste according to Table (1) are 17.4, 13.3 and 0.0 µSv/y for 1, 10 and 100 years respectively.

Table (1): Total effective doses equivalent (µSv/y) of exposure to contaminated soil

Years	K-40	Ra-226	Th-232	Total
1.0	4.2	12.2	0.9	17.4
3.0	1.3	11.0	2.3	14.7
10.0	0.0	7.6	5.6	13.3
11.8	0.007	6.9	6.1	13.0
13.9	0.002	6.2	6.4	12.6
16.4	0.0005	5.4	6.6	12.0
30.0	1.59E-07	2.6	6.5	9.1
37.3	2.13E-09	1.7	6.2	7.9
43.9	4.09E-11	1.2	5.8	7.0
51.8	3.81E-13	0.7	5.3	6.0
61.1	1.49E-15	0.4	4.6	5.0
72.0	2.06E-18	0.2	3.7	3.9
84.8	7.61E-22	0.1	2.5	2.6
100.0	0.0	0.0	0.0	0.0

As shown in Table (1) the total annual dose is 17.4µSv/year during the year 1 and decreased to a minimal value after 100 years. The maximum total annual dose is below the dose limit for the workers and the public (20 and 1mSv/year respectively) [17].

Scenario 2

Workers inadvertently ingest some radionuclides arise as a result of direct contact with the contaminated soil in the thermal power plant [18]. There are many factors that may significantly impact the estimated dose and risk from the ingestion pathway such as time-dependent exposure time, the size of the contaminated area, the amount of soil ingested and the soil ingestion rate. The results of TEDE of the activity concentrations of radionuclides ^{26}Ra, ^{232}Thand^{40}K for ingestion of contaminated soil at (1, 10 and 100) years using 36.5 g/years the soil ingestion rate are presented in Figure (4) [19, 12].

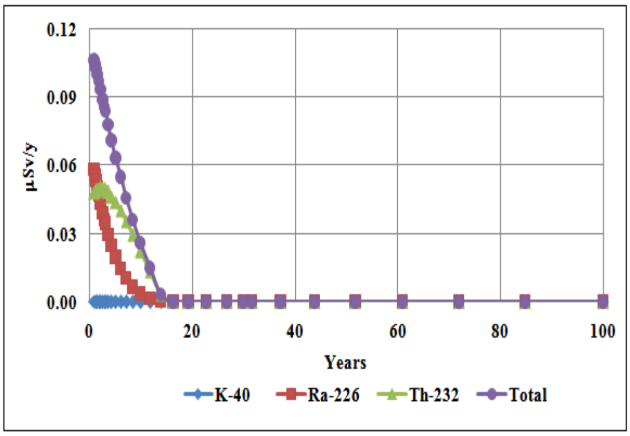

Fig. (4): Total effective doses equivalent via ingestion pathway

The maximum values of TEDE of contaminated soil according to Table (2) are 0.106, 0.0257and 0.0µSv/y for 1, 10 and 100 years respectively.

Table (2): Total effective doses equivalent (µSv/y) of ingestion of contaminated soil

Years	K-40	Ra-226	Th-232	Total
1.0	6.79E-05	0.0580	0.0480	0.1061
3.0	2.43E-08	0.0360	0.0496	0.0855
10.0	1.48E-20	0.0035	0.0223	0.0258
11.8	8.84E-24	0.0014	0.0135	0.0149
13.9	7.12E-28	0.0002	0.0030	0.0032
16.4	0.0	0.0	0.0	0.0
30.0	0.0	0.0	0.0	0.0
37.3	0.0	0.0	0.0	0.0
43.9	0.0	0.0	0.0	0.0
51.8	0.0	0.0	0.0	0.0
61.1	0.0	0.0	0.0	0.0
72.0	0.0	0.0	0.0	0.0
84.8	0.0	0.0	0.0	0.0
100.0	0.0	0.0	0.0	0.0

The obtained results were compared with the effective annual dose received by individuals as a result of natural radioactivity in the soil surrounding Assiut Thermal Power Plant (ATPP), where the plant uses heavy fuels to operate. The annual effective dose rate received by the local residents outdoor due to natural radioactivity in soil ranges from 0.05 to 15.6 mSv yr-1 with an average of 2.2 mSv yr^{-1}. The dose rate was higher than that of the studied thermal power plant and the global average for outdoor exposure [20].

Risk assessment

The RESRAD computer code is used extensively to calculate carcinogenic risk from exposure to radiological contaminants in the environment including a soil ingestion pathway. The assessment of carcinogenic risk to workers from exposure to radiological contaminants originating in contaminated soil was performed in addition to the estimated dose absorbed by the body. The simulation results using RESRAD which estimated the excess cancer risk after 100 for each individual radionuclide namely, ^{226}Ra, ^{232}Th and ^{40}K for workers exposed to contaminated soil in the thermal power plant is illustrated in Fig. (5). The annual total cancer risk was 2.9 x10^{-5} and decreased to a minimal value after 100 years.

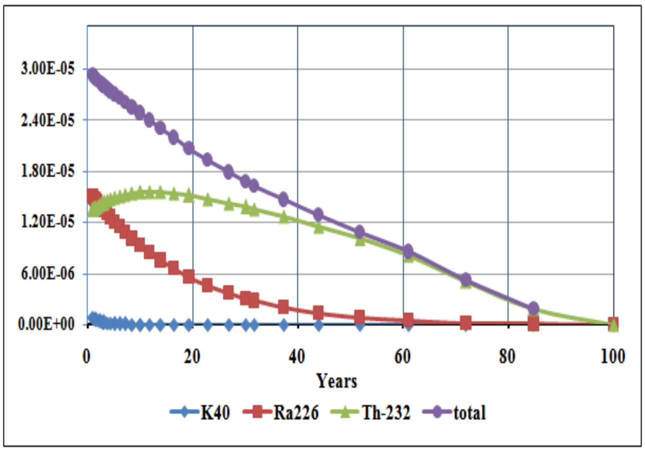

Fig. (5): Excess cancer risk from exposure to contaminated soil

The RESRAD code estimates the excess lifetime cancer risk to workers exposed to soil ingestion from the contaminated soil with radiological contamination. The excess cancer risk for each individual radionuclide namely,^{226}Ra, ^{232}Th and ^{40}K for workers through of soil ingestion pathway of the contaminated soil is shown in Figure (6).

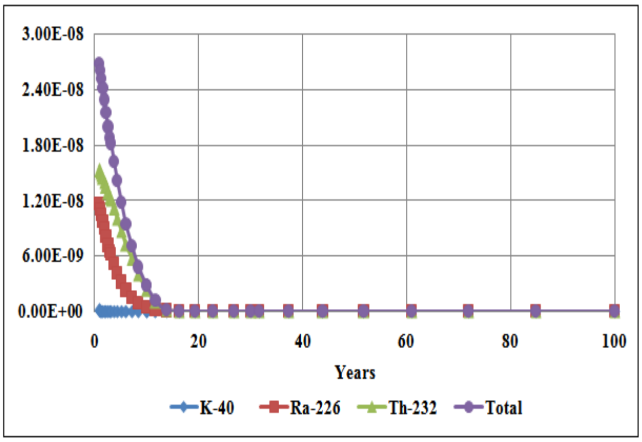

Fig. (6): Excess cancer risk from ingestion of contaminated soil

The maximum total cancer risk in the first year for soil ingestion exposure to contaminated soil was 2.68 x 10^{-8} . Risks are expressed as the increased probability of fatal cancer over a lifetime. The US Environmental Protection Agency considers in its acceptable regulatory a cancer risk is in the range of 1 × 10^{-6} to 1 × 10^{-4}[21]. The estimated values of the maximum total cancer risk to workers in the study area for both the **e**xposure to contaminated soil and soil ingestion pathways are significantly less than the the International Commission on Radiological Protection**(**ICRP) cancer risk of 2.5 × 10^{-3}. This is based on the annual dose limit of 1 mSv for the general public, which gives an annual death probability of 10^{-5}i.e. 1 in 100,000 [22, 21].

CONCLUSION

The calculated annual total effective doses equivalent to contaminated soil received by the workers of the thermal power plant are found to be 17.4and 0.106µSv/yr respectively. These are still within the recommended value According to IAEA [23]. The currently accepted dose limit recommended is 1 msv/yr (100 mrem/yr) which is the main aim to achieve (as low as reasonably achievable, ALARA) optimization for the general public to decrease radiological hazards.

The acceptable total absorbed dose rate by the workers in areas containing gamma-radiations from ^{238}U and ^{232}Th series and their respective decay progenies, as well as ^{40}K, was recommended not to exceed 0.055 mGy/h [24]. It is obvious that the calculated total absorbed dose rates in the study area are less than the acceptable recommended dose levels.

Radiation doses were converted to carcinogenic risks using risk factors recommended by the International Commission on Radiological Protection [25]. The probability of annual total cancer risk for the workers for external and internal exposure to contaminated soil in a thermal power plant was 2.9 x10^{-5} and 2.68 x 10^{-8}respectively. These limits are applicable to the workers and risks are lower than International limits.

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