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Full Length Research Paper

Effective Dose Safety Requirements and Risk Assessment in Petroleum Industries

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Abstract
The aim of this study was to assess the exposure of workers to naturally occurring radioactive materials (NORMs) in some of Egyptian petroleum industries. It was intended to provide a better knowledge of working practices and to provide sufficient meaningful information regarding the estimated exposures to workers in this industry due to NORM contaminated area, focusing in particular on the regulatory aspects relating to naturally occurring radioactive materials. The workers involved in the oil and gas production are subjected to radiation exposure either during decontamination of the used equipment or dealing with mixture of chemicals so the complexities of the problems that occur for them should be considered. The main harmful for the workers in these industries is the increase of cancer risk. Different samples from different NORM contaminated areas were collected and measured using gamma spectroscopic analysis. The data obtained were computed using Decontamination and Decommissioning computer code (D&D). 90% of the 100 calculated the Total Effective Dose Equivalent TEDE values from 2m² NORM contaminated areas is < 7.91E+02 mrem/year.
Comparing the results obtained with the IAEA safety standard and the Egyptian requirements it was found that the doses received from the exposure of workers to (NORMs) were lower than the national and international standard values.

Keywords: *NORM, Decontamination, D&D computer code, Effective Dose Equivalent.*

Introduction

Naturally Occurring Radioactive Materials (NORM) (uranium, thorium and their decay products such as radium-226, radium-228 and radon gas) are present in all geological materials. Oil and gas are formed in reservoirs within Formations of many types of geological and are often present together with water. During the oil and gas production, water is brought to the surface. Some sludge containing radioactive materials may be carried over to refinery installations and collected during tank cleaning. A small quantity of sludge containing traces of radioactive materials may also be produced in the gas processing plant. This operation of oil and gas facilities involving NORM can result in the formation of Technologically Enhanced Naturally Occurring Radioactive Material, known by the acronym TENORM. The presence of TENORM at the oil and gas facilities could lead to radiation exposure to workers through external radiation from radium daughters and internal exposure through inhalation (airborne dust and gas) and possible ingestion of radioactive materials at work sites (Selangor, March 2009).

NORM in Sludge

Radioactive molecules containing radium which were not incorporated into scale can be found in sludge, produced sands and produced waters. Other radionuclides such as Lead-210 and Polonium-210 can also be found in pipelines scrapings as well as sludge accumulating in tank bottoms, gas/oil separators, dehydration vessels, liquid natural gas, storage tanks and in waste pits as well as in crude oil pipeline scrapings (OGP, 2008).

NORM in Gas Processing Facilities

Radon is a radioactive gas, which is present in varying degrees in natural gas in oil and gas formations. In the absence of natural gas, radon dissolves in the (light) hydrocarbon and aqueous phase. When produced with the oil and gas, radon will usually follow the gas stream. If the natural gas is fractionated, a disproportionately high percentage of radon can concentrate in the propane streams and to a lesser degree in the ethane streams. Radon-222 produces, through natural decay, several radioactive nuclides (also known as radon progeny). Most radon progeny are short-lived, with the exception of Lead-210 and Polonium-210, which have relatively long half-lives of 22.6 years and 138 days respectively. Most of the radon decay products (90-99%) are attached to ambient aerosols, airborne particulates or surfaces. This can result in forming thin radioactive films on the inner surfaces of gas processing equipment such a scrubbers, compressors, reflux pumps, control valves and product lines (Selangor, March 2009).

Health Hazards of NORM

There are two ways in which personnel can be exposed to NORM, namely:

- Irradiation – external exposure where the source remains outside the body
- Contamination – internal exposure where radioactive material is taken into the body via inhalation, ingestion or absorption.

There is a large body of scientific research and literature on the health effects of ionizing radiation exposure. The health effects associated with exposure to ionizing irradiation vary depending on the total amount of energy absorbed, the time period, the dose rate and the particular organ exposed. A key consideration related to NORM is that exposures are generally quite low and below established regulatory action levels (International Labour Conference, 2003).

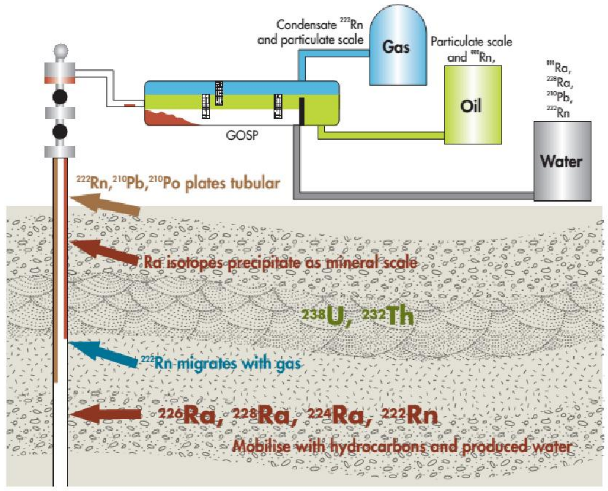


Figure 1. The origins of NORM, indicating where NORM may accumulate in the recovery process. (OGP, 2008)

In some situations, exposure to low-level ionizing radiation may not result in any adverse health effects; hence the basis for developing regulatory health-based action levels. Exposure to NORM will not result in acute and severe effects similar to those effects associated with exposure to high radiation levels from man-made sources. Chronic exposure to NORM above exposure limits for the general public or following inadequate safety precautions are typically delayed effects such as the development of certain forms of cancer. A variety of cancers has been associated with exposure to ionizing radiation including leukemia, and cancers of the lung, stomach, oesophagus, bone, thyroid, and the brain and nervous system. It is important to understand that the potential health effects are strongly dose-related. In addition, based on extensive scientific study over many decades, radiation exposure is not associated with all forms of cancer. Medical surveillance for low-level radiation exposures is typically triggered by exceedance of an established regulatory action level. However, medical surveillance is an imperfect and non-specific tool. It is difficult to find medical tests that detect meaningful abnormal changes in a timely fashion. Most medical tests do not have high sensitivity or specificity, i.e. the ability to correctly identify who has a problem (sensitivity-true positive) and who does not have a problem (specificity- true negative). All medical tests have various levels of sensitivity (false positive) and specificity (false negative). There is no perfect set of tests for every potential health concern. Therefore, while medical surveillance is a standard strategy that is often used, it must be emphasized that source control, exposure monitoring, worker education and safe operating practices are the most important strategies for preventing significant worker exposures (AEA, 2003).

Occupational Health Hazards

Occupational health hazards refer to the potential risks to health and safety for those who work outside the home. According to the World Health Organization (WHO), this represents about 70% of adult men and up to 30% of adult women throughout the world. In addition, an estimated additional 40 million adults enter the global workforce each year (International Labor Conference, 2003). Of course, the specific occupational health hazards faced by this large and growing number of people depend on the region and its economic standing. However, the following are some of the most common occupational health hazards faced by workers worldwide. Topping the list of occupational health hazards internationally are structural failures and mechanical accidents. This includes structures vulnerable to adverse weather (HAMM, 1998).

Risk Assessment

Modern occupational safety and health legislation usually demands that a risk assessment be carried out prior to making an intervention. It should be kept in mind that risk management requires risk to be managed to a level which is as low as is reasonably practical. Therefore the assessment should be to;

1. Identify the hazards;
2. Identify all affected by the hazard;
3. Evaluate the risk and
4. Identify and prioritize appropriate control measures.

The calculation of risk is based on the likelihood or probability of the harm being realized and the severity of the consequences. This can be expressed mathematically as a quantitative assessment (by assigning low, medium and high likelihood and severity with integers and multiplying them to obtain a risk factor), or qualitatively as a description of the circumstances by which the harm could arise. The assessment should be recorded and reviewed periodically whenever there is significant change to work practices. The assessment should include practical recommendations to control the risk. Once recommended controls are implemented, the risk should be re-calculated to determine if it has been lowered to an acceptable level. Generally speaking, newly introduced controls should lower risk by one level, i.e., from high to medium or from medium to low. Thus the risk of the occupational health hazard can be controlled if cannot be zeroed by a sincere and effective managerial effort for the hazard and risk management, but it is found for various reasons the management of the industrial unit are not taking effective measure to curb the potential risk areas causing danger to the workmen . Further the Government is also not ensuring that the industries are maintained the safety norms and standards aspen law (U.S. EPA 1998, Saul et al, 2009)

Materials and Methods

Sample Preparation

Samples of NORM were taken from contaminated area associated with oil and natural gas production. This area contained some sludge and scale was produced during the maintenance process. For measuring activity concentration, 250g of NORM waste sample was packed in a plastic container (typical use for calibration purposes), sealed and stored for 4 weeks to establish the secular equilibrium between the parent radionuclides and their respective daughters (between 226Ra and 222Rn, 214Pb and 214Bi).

Gamma Ray Spectrometry

The gamma ray measurements on samples were carried out using High Purity Germanium (HPGe) detector (model Canberra) with relative efficiency of 25%, the correlation between energy to channel number was 0.5 keV/ch. The gamma ray spectra were analyzed by using a software program (ABACOS) which calculates the activity concentration of the samples. The natural background level was subtracted from recorded spectrum.

D&D Computer Code

A dose calculation in petroleum industries is an essential task either for public or for workers (Smith et al 1996, 1997,1998). The aim of this work is to introduce a tool for calculating doses to workers that may exposed to ionizing radiation via inhalation, external exposure and secondary ingestion. Decontamination and Decommissioning (D&D) version 2.0 computer code was used to calculate these doses. D&D code (United States Department of Energy Waste Isolation Pilot Plant Carlsbad Area Office Carlsbad, New Mexico Appendix D&D, January 1995) deals with two different scenarios; building occupancy scenario for assessing unrestricted release of buildings having residual contamination on building surfaces. For unrestricted release of land having soil contamination residential scenario which considers the residential use of the property, including the use of groundwater for drinking and irrigation of farm products. For each scenario, a set of potential exposure pathways have been identified based on the assumed location of residual contamination and receptor behavior. Mathematical models are also defined for each of these pathways, as well as provisional values for the model parameters.

For the building occupancy scenario, the screening group consists of full-time adult male workers in light industry. For the residential scenario, the screening group is adult males who live and work on a farm, producing and consuming a fraction of their diet from the site. They obtain all water required for drinking, domestic and agricultural use from an on-site well. In this work we choose the building occupancy scenario which is suitable and easier to calculate the total effective dose equivalent (TEDE). D&D computer code was used to calculate total effective dose and find out cancer risk to workers.

Results and Discussion

Five samples from different locations of about 2 m^2 NORM contaminated area are collected and measured using HPGe detector. The mean average value of radionuclides activity concentrations is given in table (1). From the results in this table it is clear that the concentration of Ra-226 (3.79E + 00 pCi/g) is lower than Ra-228 (6.90E + 01 pCi/g) in this contaminated area this may be due to presence of U-238 lower than Th-232. The daughter of Th-232 is Ra-228 while the daughter of U-238 is Ra-226. The doses received from different concentrations for all pathways, external, inhalation and ingestion are represented in table 1. From this table it is clear that the doses are in the following order: all pathways > external >inhalation > ingestion.

Table 1. Dose from 2 m^2 NORM contaminated area.

Exposure	Dose (mrem)
All pathways	8.18E+02
External	3.51E+02
Inhalation	4.76E+00
Ingestion	1.96E+00

Doses received from each radionuclide through each active pathway for 2 m^2 NORM contaminated area is shown in table 2. From this table it is clear that the internal dose (inhalation and ingestion) higher than external dose for all radionuclides. Ra-228 plays an important role in external dose rather than other radionuclides.

Table 2. Concentration of radionuclides present in 2m^2 NORM contaminated area

Nuclide	Soil Concentration (pCi/g)
226Ra	3.79E+00
222Rn	3.73E+00
218Po	3.73E+00
214Pb	3.73E+00
218At	1.46E-04
214Bi	3.73E+00
214Po	3.73E+00
210Pb	8.55E-01
210Bi	8.53E-01
210Po	8.04E-01
228Ra	6.90E+01
228Ac	6.90E+01
228Th	3.90E+01
224Ra	3.88E+01
220Rn	3.88E+01
216Po	3.88E+01
212Pb	3.88E+01
212Bi	3.88E+01
212Po	2.49E+01
208Tl	1.39E+01

Table 3. Dose from Each Nuclide Through Each and all Active Pathway (mrem).

Nuclide	External	Inhalation	Ingestion	All Pathways (mrem)
226Ra	5.68E-02	1.03E-02	7.10E-02	1.77E+01
222Rn	3.92E-03	0.00E+00	0.00E+00	3.92E-03
218Po	9.08E-05	0.00E+00	0.00E+00	9.08E-05
214Pb	2.31E+00	9.38E-06	3.35E-05	2.32E+00
218At	0.00E+00	0.00E+00	0.00E+00	0.00E+00
214Bi	1.51E+01	7.91E-06	1.52E-05	1.51E+01
214Po	8.28E-04	0.00E+00	0.00E+00	8.28E-04
210Pb	9.37E-08	1.07E-03	3.82E-03	2.12E+01
210Bi	1.53E-03	5.50E-05	8.14E-05	2.62E-02
210Po	1.89E-05	2.50E-03	2.29E-02	7.77E+00
228Ra	0.00E+00	9.79E-02	1.32E+00	3.12E+02
228Ac	1.63E+02	6.32E-03	1.99E-03	1.64E+02
228Th	1.64E-01	4.60E+00	2.42E-01	5.80E+01
224Ra	1.03E+00	4.24E-02	2.23E-01	5.55E+01
220Rn	4.32E-02	0.00E+00	0.00E+00	4.32E-02
216Po	1.91E-03	0.00E+00	0.00E+00	1.91E-03
212Pb	1.42E+01	2.26E-03	2.77E-02	2.06E+01
212Bi	2.10E+01	2.89E-04	6.47E-04	2.11E+01
212Po	0.00E+00	0.00E+00	0.00E+00	0.00E+00
208Tl	1.36E+02	0.00E+00	0.00E+00	1.36E+02

The excess cancer risk from exposure to Ra-226 and Ra-228 with concentration 1.12E+01 and 3.09E+02 that present in $2m^2$ NORM contaminated area is shown in Figures 1 to 8. The excess cancer risk decreases with time increase this may be due to the decay time of these radionuclides. The excess cancer risk from external exposure, inhalation and ingestion for Ra-226 after 1 year was 5.11E-04, 2.75E-07 and 5.1E-06 respectively, while for Ra-228 it was 3.25E-03, 6.2E-06 and 2.51E-05 respectively. Figures 4 to 8 show that the external exposure plays an important role in the excess cancer risk for both Ra-226 and Ra-228 that present in the NORM contaminated area.

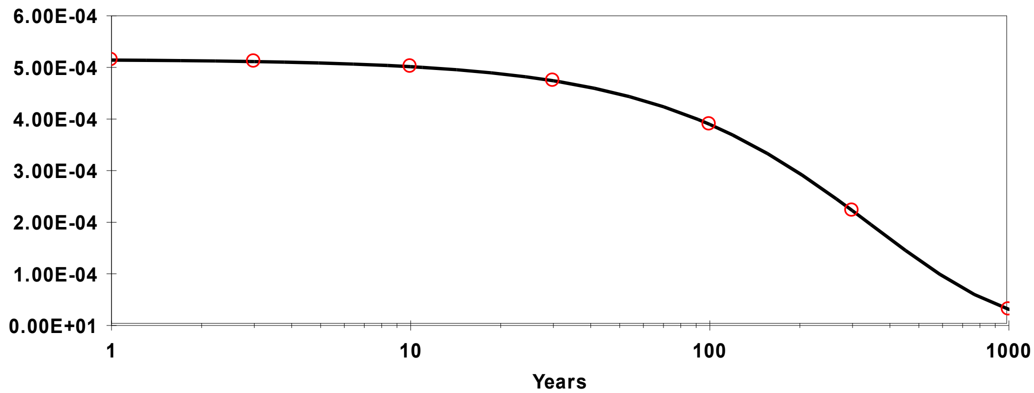


Fig.(1) Excess cancer risk from external exosure to 3.79 pCi/g Ra-226 present in 2m2 NORM contaminated area.

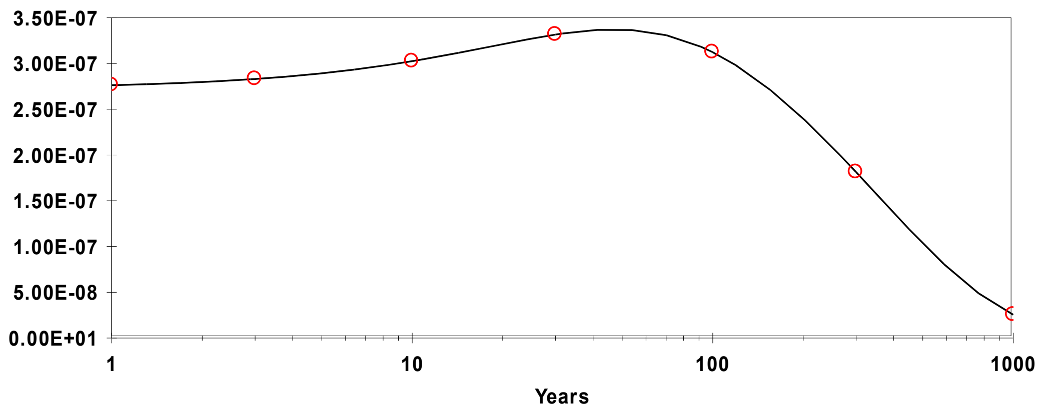


Fig.(2) Excess cancer risk from inhalation of 3.79 pCi/g Ra-226 present in 2m2 NORM contaminated area.

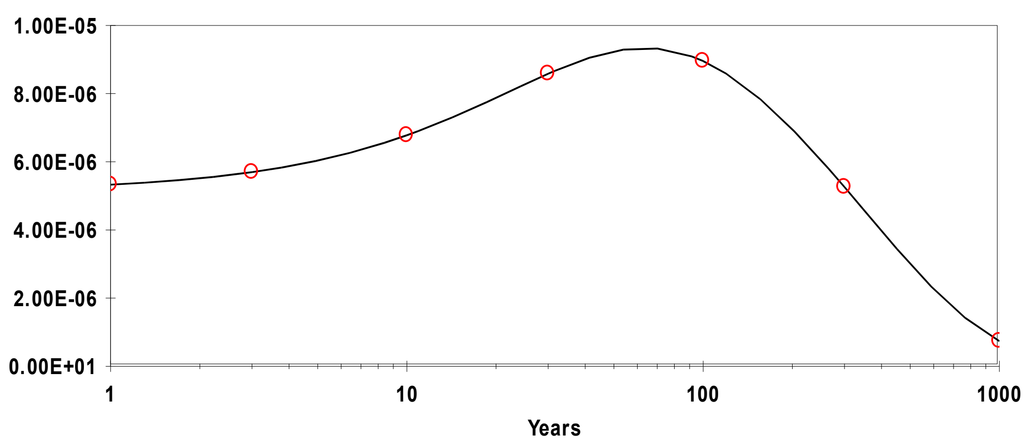


Fig.(3) Excess cancer risk from soil ingestion of 3.79 pCi/g Ra-226 present in 2m2 NORM contaminated area.

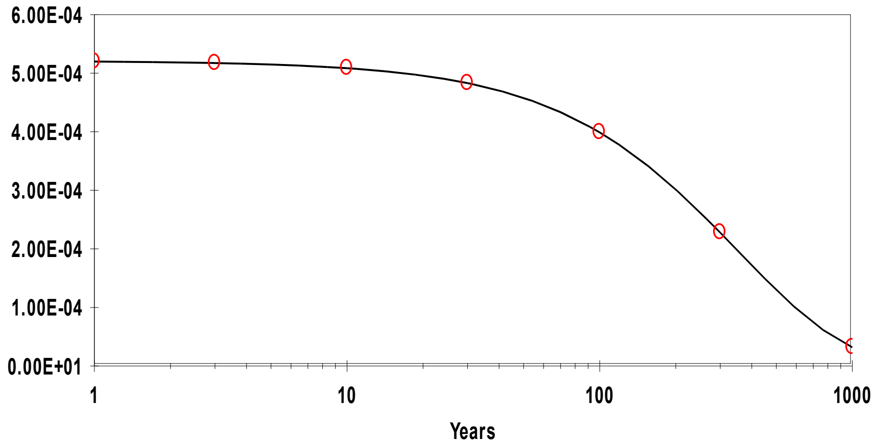


Fig.(4) Excess cancer risk from 3.79 pCi/g Ra-226 present in 2m2 NORM contaminate area and from all pathways (external exposure, inhalation, ingestion).

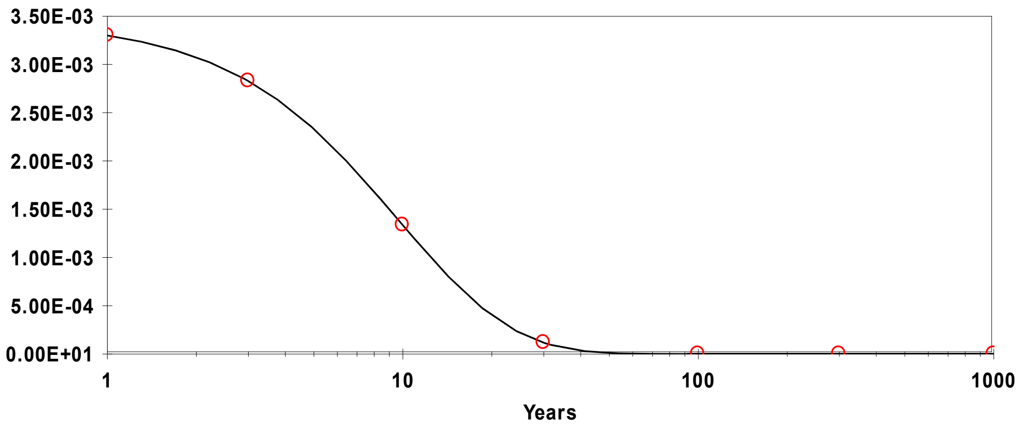


Fig.(5) Excess cancer risk from external exposure to 69 pCi/g Ra-228 present in 2m2 NORM contaminated area.

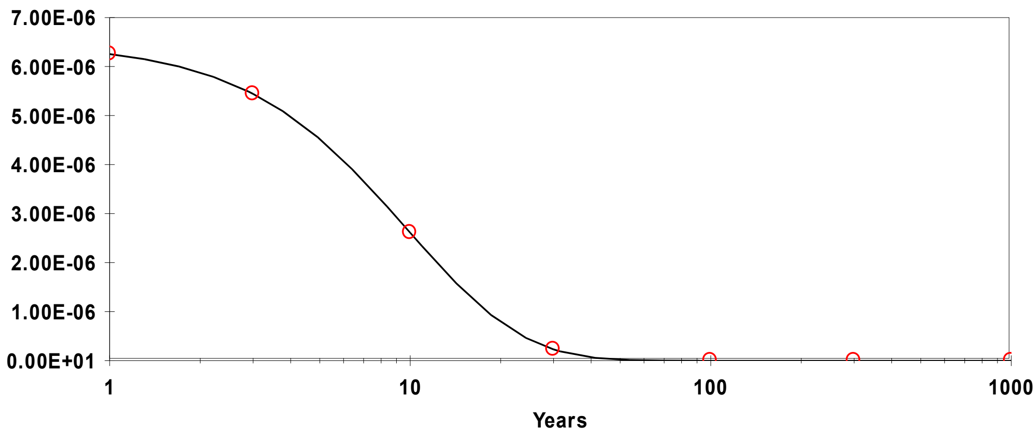


Fig.(6) Excess cancer risk from inhalation of 69 pCi/g Ra-228 present in 2m2 NORM contaminated area.

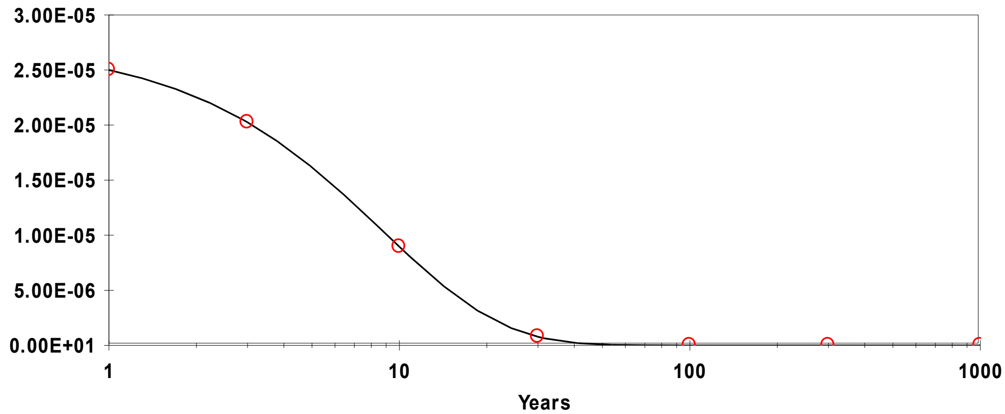
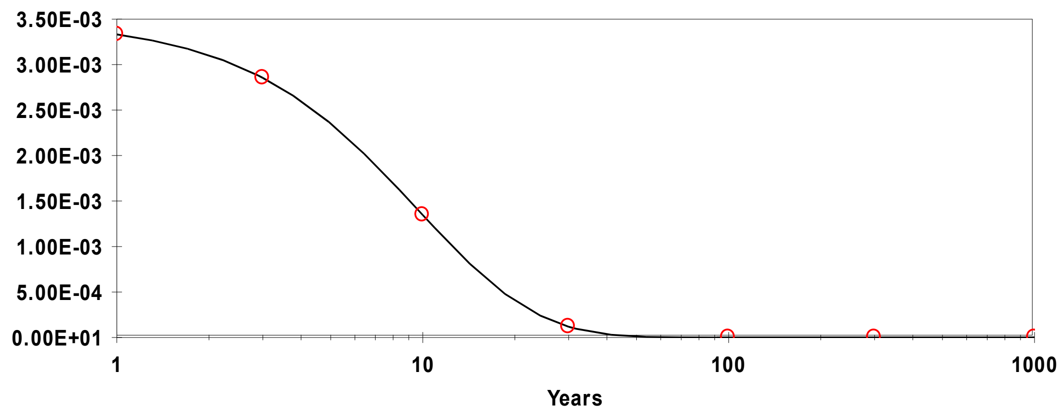


Fig.(7) Excess cancer risk from soil ingesion of 69 pCi/g Ra-228 present in 2m2 NORM contaminated area.



ig.(8) Excess cancer risk from 69 pCi/g Ra-228 present in 2m2 NORM contaminatec area and from all pathways (external exosure, inhalation, ingestion).

Worker Protection Requirements

Regulatory bodies are required to keep pace with the operational and technological developments in order to retain control with respect to national interests relevant to safety, health and the environment (IAEA, 2010). Workers entering NORM-contaminated vessels or conducting intrusive work on NORM-contaminated equipment should adhere to the following guidelines:

•Personnel required to work with NORM should be trained in the associated hazards.

•All NORM operations shall be covered by a safe system of work which should identify the hazards and highlight the precautions to be taken.

•Any item or area with detectable levels of loose NORM contamination should be subject to radiological controls.

•Appropriate Personal Protective Equipment (PPE) should be worn (which may include but not be restricted to):

– 'Tyvek' style coveralls

–Neoprene, PVC, or NBR gloves

–Half-face respirators with HEPA cartridges; these should be tested for fit

–Quarter-face HEPA disposable respirators.

•Eating, drinking, smoking and chewing are not allowed in work areas where there is potential NORM contamination.

•Only essential personnel should be allowed in the work areas of potential NORM contamination.

•Personnel should wash up thoroughly with copious quantities of soap and water, after working with contaminated equipment, and before eating, drinking, or smoking, and at the end of the workday.

•Use systems of work that minimize the generation of waste PPE (i.e use PPE that can be cleaned, inspected and re-used). (Kumuda 2012, Elena et al 2003).

Conclusion

With the oil and gas industry growing each year, the need for workers in this field is also rising. The obtained results for workers during maintenance and radiation decontamination of the petroleum equipment's resulting from the disposal of NORM wastes showed that the external radiation dose rate was less than the annual dose limits (2000 mrem or 20 mSv) according to the latest ICRP publication. The doses received from 3.79E+00 pCi/g Ra-226 for all pathways, external, inhalation and ingestion are 1.77E+01, 5.68E-02, 1.03E-02 and 7.10E-02 mrem respectively. The doses received from 6.9E+01 pCi/g Ra-228 for all pathways, external, inhalation and ingestion are 3.12E+02, 0.00E+00,9.79E-02 and 1.32E+00 mrem respectively. The excess cancer risk from 2m2 NORM contaminated area, when Ra-226 concentration is 3.79 pCi/g and Ra-228 concentration is 6.9E+1 pCi/g after 1 year was 5.31E-04 and 3.4E-03 respectively.

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