Application of RESRAD Model to Assess Radiation Doses due to TE- NORM Accumulation in Evaporation Pond during Petroleum Production

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ABSTRACT

TE- Naturally Occurring Radioactive Materials (TE- NORM) is the potential radiation source in the petroleum industry which needs to be identified and controlled to maintain safe working conditions and protection of the environment. In this study radioactive contamination of produced water by NORM has been modeled by using RESRAD (version 6.5) computer code to evaluate potential radiological doses and health risks to workers at several oil field locations. The presence of NORM in produced water unlikely to cause external exposures which may be exceeded dose limits for workers. In this assessment the exposure source parameters were adjusted a period of 100 years and area of evaporation pond was 1300 m² and 10 m depth. The predicted maximum total effective doses equivalent received by workers from produced water in evaporation pond are (1.5x10⁻⁵ mSv/yr) and for soil (categories I, II and III) are (0.732, 0.244 and 0.150 mSv/yr). Also its annual total cancer risk for produced water is (1.25x10⁻⁹) and for soil (categories I, II and III) are (6.0x10⁻⁵, 2.0x10⁻⁵, 1.25x10⁻⁵) respectively.

Key word: Radiation Protection / Risk Assessment/ RESRAD Model.

INTRODUCTION

The TE- NORM accumulation in oil production facilities contains mainly Radium- 226 and Radium -228. This is decay into various radioactive progeny, before becoming stable lead. The two principles radioactive decay is uranium -238 and thorium -232 series associated with NORM in the oil & gas industry is dilated in figure (1).

Fig. (1): Uranium- 238 and Thorium – 232 decay series
NORM is an inherent part of many geologic materials. Natural radioactive such as materials uranium and thorium were incorporated in the earth crust with different concentrations in rock formations. Decay of these radioactive elements produce other radionuclides that under certain condition in the subsurface environment are mobile and can be transported from the reservoir to the surface with formation water, oil and gas products being recovered. During the production process, NORM flows with the accumulation can vary substantially from one facility to another depending on geological formation, operational and other factors.

In this study radiation survey was done in a typical petroleum production facility. Oil and gas production streams pass through a separator where oil, gas, and water are divided into their different fluid densities. Most of the solids removed in the separator accumulate there. The product may also be treated to separate oil from produced water and sluge. The produced water discharged directly into an evaporation pond in the surrounding land in oil field as shown in Figure (2).

![Fig. (2): NORM of evaporation pond.](image)

**RESRAD MODEL**

The RESRAD computer code was used to calculate the total effective dose equivalent for external exposure pathway of radionuclides U238 and Th232 and excess cancer risk to industrial workers exposed to evaporation pond. Radioactive sources used in RESRAD calculations were values of radionuclides concentration of U-238 and Th-232 dissolved in produced water in evaporation pond. The estimation of effective doses of amount of external gamma radiation $E_{\text{ext}}$ (total) due to U238 plus Th232 dissolved in produced water in evaporating pond as according to equation (1).

$$E_{\text{ext}} = E_{\text{ext} (U)} + E_{\text{ext} (Th)}$$

Where, $E_{\text{ext} (total)}$ is total effective doses of amount of external gamma radiation of U238 plus Th232, $E_{\text{ext} (U)}$ is effective doses of amount of external gamma radiation of U238 and $E_{\text{ext} (Th)}$ is effective doses of amount of external gamma radiation of Th232.

**Input RESRAD parameters**

The evaporation pond was dimensions 26 m length x 50 m width x 10 m depth. The average radionuclides concentration U238 and Th232 series of NORM of produced water in this evaporation pond were (12 and 8.5 Bq/L) respectively. Evaporation pond soil was divided into three categories.
(categories I, II and III), the category (I) was defined with radiation level higher than 10 μSv/h, the category (II) was defined with radiation level between 5 to 10 μSv/h and the category (III) was defined with radiation level lower than 5 μSv/h. The average concentration radionuclides U238 of soil (I, II and III) were (42322.6, 13578 and 9236 Bq/Kg) and for Th232 were (36100, 12180 and 8289.5 Bq/Kg) respectively. TE-NORM activity in soil layer reaches to 0.5 m and radionuclides concentration background of U238 and Th232 below this layer. Duration of scenario is estimated at total exposure time of workers at evaporation pond about 1 h/week (4).

RESULT AND DISCUSSION

In this study computer simulations was made using the RESRAD program in two scenarios to estimate total effective dose equivalent and total cancer risk for U238 and Th232 and their decay products due to external exposure pathway of the evaporation ponds at (1, 10, 30, 50 and 100) years.

Scenario 1: Produced water in evaporation pond

Total effective dose equivalent TEDE from U238 and Th 232 radionuclides for external exposure of produced water in evaporation pond using RESRAD program for (1, 10, 30, 50 and 100) years which estimated according to equation (1) are represented in Figure (3).

Fig. (3): TEDE of produced water in evaporation pond

The maximum values of TEDE of produced water according to Figure (3) are (1.5x10^-5, 2.4 x 10^-5, 1.6x10^-6, 7.5 x10^-8 and 3.1 x10^-11 mSv/y) for (1, 10, 30, 50 and 100) years respectively.

The reasons for elevated radium and uranium series disequilibrium as shown in figure (3) are very complex. Ra\(^{2+}\) is commonly present in oil field brines but at such low levels that the oil field brines themselves do not pose a radiation safety risks or precipitate pure RaSO\(_4\) scale or sluge (5). RaSO\(_4\) sluge which are produced from oil and gas production controls Ra\(^{2+}\) concentrations in the produced water (6). The dissolved Ra\(^{2+}\) is favorably portioned into scale or sludge with respect to the aqueous phase and is scavenged into a solid solution. So it leads to self enrichment process (7).
Scenario 2: Soil in different NORM concentrations in evaporation pond

In this scenario the soil contaminated layer resulting from passage of produced water through it reached to 0.5 m thickness below the soil surface. The transfer of radionuclides from the liquid to the soil matrix controlled by adsorption and precipitation or versa Vera depending on radionuclides. The distribution coefficient Kd is the ratio of the mass of solute species absorbed or precipitated on the solids per unit of dry mass of the soil to the solute concentration in the liquid. Soil properties affecting the distribution coefficient include the texture of soil (sand, clay or organic soils). The particle size distribution of evaporation pond soil was coarse sand ≥ 500 μm (68.3%), medium sand ≤ 300 (27.5%) and silt and clay ≤ 75 μm (4.2%) which confirm this sand soil. The distribution coefficient Kd are (35, 500, 270 and 0.1 L/Kg) of uranium, radium, lead and technetium respectively, (8) in evaporation pond sand soil.

Total effective dose equivalent TEDE from U238 and Th232 radionuclides for external exposure of soil in different categories (I, II and III) according to degree of its radiation levels in evaporation pond using RESRAD program for (1,10, 30,50 and 100) years are shown in figures (4,5 and 6).

Fig. (4): TEDE of soil (category I) in evaporation pond

Fig (5): TEDE of soil (category II) in evaporation pond
Values of total effective dose equivalent TEDE (mSv/yr) of soil categories I, II and III are represented in table (1).

Table (1): Total effective dose equivalent TEDE (mSv/yr) of soil categories (I, II and III)

<table>
<thead>
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<th>year</th>
<th>1</th>
<th>10</th>
<th>30</th>
<th>50</th>
<th>100</th>
<th>1000</th>
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<td>External exposure mSv/yr</td>
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<td>0.722</td>
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<td>0.665</td>
<td>0.609</td>
<td>0</td>
</tr>
<tr>
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<td>0.201</td>
<td>0.171</td>
<td>0</td>
</tr>
<tr>
<td>III</td>
<td>0.153</td>
<td>0.149</td>
<td>0.143</td>
<td>0.139</td>
<td>0.127</td>
<td>0</td>
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</tbody>
</table>

**RISK ASSESSMENT**

The estimated doses and associated health risks for industrial workers exposed to produced water and contaminated soil in evaporation pond are shown in figures (7, 8, 9 and 10).
The values of annual total cancer risk of produced water in evaporation pond are \((1.25 \times 10^{-9})\) and for soil (categories I, II and III) are \((6 \times 10^{-5}, 2 \times 10^{-5}, 1.25 \times 10^{-5})\) respectively.

**Comparison between measured data and results from RESRAD program**

Gamma dose rate was measured by dose rate meters for the evaporation pond to drawing radiation map for this pond from the deposited radioactive materials (TE-NORM). According to the radiation map of pond, the evaporation pond could be classified into three (categories I, II and III) with different radiation levels as shown in Figure (11). The category (I) was defined with radiation...
level higher than 10 μSv/h (500 μSv/yr), the category (II) was defined with radiation level between 5 to 10 μSv/h (250 to 500 μSv/yr), and the category (III) was defined with radiation level lower than 5 μSv/h (250 μSv/yr), (Taha, A. A.2011). Assessments results by RESRAD program for soil (categories I, II and III) are (738, 244 and 153 μSv/yr) which are in good agreement with measured data.

CONCLUSION AND RECOMMENDATION

According to the (9) safety series publication No. 115 the currently accepted dose limit recommended is 1 msv/yr (100 mrem/yr) which is the main aim to achieve (ALARA) optimization for general public to decrease radiological hazard and this limit is applicable to the workers in the disposal of TE-NORM. The calculated annual total effective doses equivalent received by workers from produced water in evaporation pond are (1.5x10⁻⁵ mSv/yr) and for soil (categories I, II and III) are (0.73, 0.244 and 0.153 mSv/yr). Also its annual total cancer risk for produced water is (1.25 x10⁻⁹) and for soil (categories I, II and III) are (6.0 x10⁻⁵, 2.0 x10⁻⁵, 1.25 x10⁻⁵) respectively which still under the recommended value. Radiation doses were converted to carcinogenic risks by using risk factors recommended by the International Commission on Radiological Protection (10). The ICPR risk factor is 1.25 x10⁻⁹ per mSv (5.0 x10⁻⁵ mSv⁻¹) for the public and (4.0 x10⁻⁷ per mSv⁻¹) for workers. Risks are expressed as the increased probability of fatal cancer over a lifetime. The calculated doses and risks are lower than International limits.

The RESRAD mathematical modeling was used to estimate the contamination from the evaporation pond and the resulting doses received by the critical group. The regulatory body will then have to make a decision regarding the disposal method. Soil evaporation pond contaminated can be treated by the drawn ward migration of radionuclides which will have to be collected package and disposal in specific manner or transported in bulk to a burial site will isolate the waste more effectively than the seepage evaporation pond area.

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REFERENCES

(4) A. A. Taha; Ph.D. thesis, Faculty of Science, Zagazig University (2011).