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Determination of Excessive Lifetime Cancer Risk for Workers Exposed to Natural Radioactive Materials in Various Equipment in Oil and Gas Sector

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Abstract

In the oil and gas sector of Basrah, natural radioactive materials are accumulated in various equipment like wellheads, pumps, and separation vessels, often manifested as scales, sludge, and other forms of waste. Without proper preventive measures, these accumulations pose significant risks to workers, the public, and the environment. This study aims to assess the lifelong cancer risks associated with production processes and the handling of resultant waste, be it scale sediments, sludge, or soil. Sample collection across different regions was based on the evaluation of production and storage facilities. Using a high-purity germanium detector (HPGe), activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K were measured. These concentrations were then used with standard equations to determine indoor effective dose rates. The regional-weighted (the lifetime risk of cancer is a measure of the cumulative risk of cancer over a specific age range and has a clear, intuitive appear) average of the lifetime excessive cancer risk was varied between (0.40 to 0.11 $\times 10^{-3}$) for $ELCR_{outdoor}$, (3.13 to 0.86 $\times 10^{-3}$) for $ELCR_{indoor}$ and (0.97 to 3 $\times 10^{-3}$) for $ELCR_{total}$, significantly surpassing the global average value of (0.29×10^{-3}). This disparity underscores the heightened risk posed by these activities, emphasizing the urgent need for enhanced safety measures and regulatory oversight to safeguard human health and the environment.

Keywords: Soil Contamination, Cancer risk, Annual effective dose, high-purity germanium, Activity
Concentrations.

تحديد المخاطر المفرطة للإصابة بالسرطان مدى الحياة للعاملين المعرضين للمواد المشعة الطبيعية في المعدات المختلفة في قطاع النفط والغاز

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الخلاصة

تتراكم المواد المشعة الطبيعية في معدات مختلفة ترافق عملية انتاج وصناعة النفط والغاز في ابار النفط في البصرة، مثل الآبار والمضخات وأوعية الفصل. قد يتخذ التراكم شكل قشور وحمأة وبعض النفايات المشعة الأخرى. ما لم يتم استخدام التدابير الوقائية المناسبة، فإن هذه التراكمات تشكل خطراً على العمال والأشخاص

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العاديين والبيئة. يهدف هذا العمل إلى تحديد مخاطر الإصابة بالسرطان مدى الحياة المرتبطة بعمليات الإنتاج أو التعامل مع النفايات المشعة المتولدة، سواء كانت رواسب قشرية أو حمأة أو تربة. تم تحديد عدد العينات التي تم جمعها في كل منطقة من خلال الوصول إلى محطات الإنتاج والتخزين في مناطق مختلفة. تم قياس تركيزات النشاط من Ra226− وTh232− وK40− باستخدام كاشف الجرمانيوم عالي النقاء (HPGe). تم تحديد هذه التراكيز مجتمعة مع المعدلات القياسية لتقييم معدلات الجرعة الفعالة في الأماكن المغلقة في هذا البحث. وجد ان تفاوت المتوسط المرجح الإقليمي لخطر الإصابة بالسرطان مدى الحياة بين (×10− 381.027 إلى 0.11048) لل ELCRoutdoor و (×10−3683.175 إلى 0.863) لل ELCRindoor و 764.203 3−10×0.9741 to لل ELCRtotal وتعد هذه القيمة أعلى من متوسط القيمة العالمية (0.29 × (10−3 . ويؤكد هذا التفاوت في قيم المتوسط الاقليمي لخطر الاصابة بالسرطان مدى الحياة المخاطر المتزايدة التي تشكلها هذه الأنشطة، مما يؤكد الحاجة الملحة لتعزيز تدابير السلامة والرقابة التنظيمية لحماية صحة الإنسان والبيئة.

1.Introduction

During oil and gas extraction processes, radioactive materials may accumulate in various equipment involved in the process, so it is essential to ensure the health and safety of both workers and the environment. Workers in the fields of oil and gas production must be aware of the rules and methods of dealing with natural radioactive materials associated with the production processes, emphasising on radiation protection requirements, which have become an urgent necessity [1].

As it is known, underground reservoirs contain water, oil, and gas in different proportions, in addition to radioactive materials of natural origin, such as calcium, barium, strontium, and other radioactive materials. Pumping water results in chemical incompatibility, which leads to the formation of sediments squamous, clay and sludge. When burning carbon-based materials, such as coal or petroleum, Naturally Occurring Radioactive Materials (NORM) waste dust is created because it contains trace amounts of uranium, thorium and other radioactive isotopes that are naturally present in these materials and will remain in the waste even after combustion. When concentrations of a radioactive substance exceed a certain threshold that can be classified as NORM or TENORM (Technologically Enhanced Naturally Occurring Radioactive Material), special treatment is required [2].

At some stages during the extraction and production processes, exposure to radionuclides of natural origin (NORM) can occur, where exposure levels are more significant than the radioactive background. This exposure is the concern for radiation protection teams. Exposure to wastes containing radionuclides, with concern of their entry into operators (workers) bodies, will lead to potential health damage [3].

The total radiation dose to which humans are exposed is due to gamma radiation, called natural (ambient) radiation, which is estimated to be about 80%. The effective annual dose rate of gamma radiation per person is 2.4 mSv/year [4].

Metals and raw materials containing radioactive substances (radionuclides) of natural origin and low radioactive concentration are usually referred to as U-238 / Th-232 decay series and K-40. Exposure to ionizing radiation leads to potential health effects, such as harming and destroying the living cells of an organism's body, and the initiation of cancer [5]. Moreover, inhaling radionuclides, such as uranium, radium, and thorium, has many health effects. Thorium exposure can cause lung, pancreatic, liver, bone, kidney, leukemia, and skin cancers [6]. Exposure to radioactive decay chains uranium, thorium and potassium in addition

to radioactive radon chains and through the interaction of their energy with the cell that has been exposed to it causes changes in the DNA of the cell, and therefore, radon-associated cancers can develop [7]. Interest in the long-term effects of ionizing radiation is Excessive Lifetime Cancer Risk (ELCR), which is the probability of developing or dying from cancer during one's lifespan [8]. To estimate the possibility of cancer at a certain age or death, models were prepared by studying the environmental sites. UNSCEAR has indicated that reducing exposure to sustained low doses over the long term (months or years) to avoid or reduce the effectiveness of cell damage recommends a lifetime risk estimate of 5% (Sv^{-1} for fatal cancer) and using a maximum reduction factor of 2 [9,10].

This work aims to determine the Excessive Lifetime Cancer Risk (ELCR) related to handling the generated waste, whether scale sediments, sludge or soil associated the production processes in the oil and gas stations from

2. **Experimental Work**

2.1**Collecting samples**

The samples were collected from different oil and gas production stations of Basrah (scales collected from production pipes or valves, soil from under the pipes, sludge from collection ponds) where they are known:

- Scale deposits: The radioactive isotopes associated with water, oil and gas extracted from the depths of the earth's layers are deposited at the surface during various treatment processes such as separation and through transmission lines resulting from deposits of sulfate or radium carbonate with sulfate and carbonate of barium, strontium or calcium when the existing water is mixed. In oil reservoirs, salt water is injected into them, and it precipitates to form what is called squamous sediment.
- Sludge is the sediment resulting from cleaning of the separation basins in oil production facilities. It is the deposition of solid materials from the produced water due to changes in temperature and pressure.

Eighteen samples were collected from different locations in oil and gas plants. The samples were crushed and dried in an oven at 110°C for 24 h to get rid of moisture. Each sample was placed in a 1000 ml Marinelli container, closed tightly and stored for 40 days to attain secular equilibrium between ^{226}Ra and its short-lived daughters [11].

2.2 Radioactivity measurements

Activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K were measured with a high-purity germanium detector (type P) (ORTEC), which requires a high operating voltage (4000 V). This type of detector is cooled to (-196 ° C) when powered by liquid nitrogen. The detector is surrounded by a thick wall of lead (10 cm) to reduce the radiation background and coated from the inside with a thin layer of cadmium and copper to reduce the X-rays produced from the interaction of gamma rays with lead [12].

2.3 Radiation indices measurements

The human body is continually exposed to radioactive radiation from ^{226} Ra, ^{232}Th, and ^{40} K particles found in the earth's crust.

The values of the radioactivity concentrations of ^{226}Ra, ^{232}Th and ^{40}K present in the eighteen studied samples, and their radioactivity indices: external (D_{out}) and internal (D_{in}) dose rates of gamma rays, annual outdoor effective dose rate ($AEDA_{outdoor}$) and annual indoor effective dose rate ($AEDA_{indoor}$), ($ELCR_{outdoor}$) and ($ELCR_{indoor}$) excessive lifetime cancer risk were evaluated according to the equations presented in the literature.

According to the activity concentrations of radionuclides, measured with the high-purity Ge detector, the amount of outdoor absorbed dose rate was calculated according to the following equation [12]:

$$D_{out}\left(\frac{nGy}{h}\right) = 0.436\,A_{Ra} + 0.599\,A_{Th} + 0.0417\,A_K \quad (1)$$

where: D_{out} is the outdoor absorbed dose rate (n Gy / h), 0.436, 0.599, 0.0417 are the conversion factors of ^{226}Ra, ^{232}Th, and ^{40}K, respectively (nGy/h per Bq/kg), A is the activity concentration of a nuclide (Bq/kg).

The indoor absorbed dose rate of gamma rays was calculated using the relationship [13]:

$$D_{in}\left(\frac{nGy}{h}\right) = 0.92\,A_{Ra} + 1.1\,A_{Th} + 0.081\,A_K \quad (2)$$

where: D_{in} is the indoor absorbed dose rate (nGy / h), 0.92, 1.1, 0.081 are the conversion factors of ^{226}Ra, ^{232}Th, ^{40}K, respectively (nGy/h per Bq/kg).

The total absorbed dose rate can be calculated from the relationship:

$$D_{total} = D_{out} + D_{in} \quad (3)$$

The annual outdoor effective dose rate was computed taking into account the outdoor occupancy factor (OF) (OF = 20%) and the conversion coefficient from absorbed dose in air to effective dose [14]. According to UNSCEAR (1993) report, this conversion factor is equal to 0.7$\left(\frac{Sv}{Gy}\right)$. The annual outdoor effective dose rate ($AEDA_{outdoor}$) was estimated as [14]:

$$AEDA_{outdoor}\left(\frac{nSv}{y}\right) = D_{out}\left(\frac{nGy}{h}\right) \times 8760\,(h/y) \times 0.2 \times 0.7\left(\frac{Sv}{Gy}\right) \quad (4)$$

$$AEDA_{outdoor}\left(\frac{mSv}{y}\right) = D_{out} \times 0.001226 \quad (5)$$

The annual indoor effective dose rate ($AEDA_{indoor}$) was calculated by the following equation [14]:

$$AEDA_{indoor}\left(\frac{nSv}{y}\right) = D_{in}\left(\frac{nGy}{h}\right) \times 8760\,(h/y) \times 0.8 \times 0.7\left(\frac{Sv}{Gy}\right) \quad (6)$$

$$AEDA_{indoor}\left(\frac{mSv}{y}\right) = D_{in} \times 0.004905 \quad (7)$$

where 0.8 is the outdoor occupancy factor (OF = 80% of 8760 h/year or 0.8 of 8760)

From the above relationships, the total annual effective dose rate is:

$$AEDA_{total} = AEDA_{outdoor} + AEDA_{indoor} \quad (8)$$

Excessive Lifetime Cancer Risk (ELCR) gives the lifetime probability of developing cancer as a result of a given exposure level

The outdoor ($ELCR_{outdoor}$), indoor ($ELCR_{indoor}$) and total ($ELCR_{total}$) excessive lifetime cancer risk (ELCR) values were calculated according to the following equations [14]:

$$ELCR_{outdoor} = AEDA_{outdoor} \times DL \times RF \quad (9)$$

$$ELCR_{indoor} = AEDA_{indoor} \times DL \times RF \quad (10)$$

$$ELCR_{total} = ELSR_{out} + ELSR_{in} \quad (11)$$

where: DL is the average duration of a lifespan (70 years), and RF is the risk factor (Sv^{-1}), i.e. fatal cancer risk per Sievert. For stochastic effects, ICRP 60 gives an RF value of 0.05 Sv^{-1} for the public.

3. Results and discussion

This study is a radiological study aimed at estimating the values of the activity concentration of the three radionuclides in the samples and their resulting annual effective dose and excessive lifetime cancer risk. For a global comparison, the total activity concentration for ^{226}Ra, ^{232}Th and ^{40}K showed, that the samples studied have high values compared to those of the global levels [15]. The values of the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K for the different samples, listed in Table 1, varied from (13.77 to 73.37), (7.04 to 87.4) and (89.19 to 654.72) Bq/kg, respectively. The highest value for ^{226}Ra was for sample

(3), while the highest for ^{232}Th and ^{40}K were for sample (2 and 7), respectively. On the other hand, the highest value of the outdoor and indoor absorbed dose rate was (93.35 and 182.43 nGy/h) for sample 7, as shown in Table 2.

Table 1: Values of activity concentration for Ra-226, Th-232 and K-40 radionuclides in the samples

Sample Number	Activity concentration (Bq/kg)			Remarks
	Ra-226	Th-232	K-40	Sample types
S-1	53.32	58.7	554	Sludge
S-2	63.36	87.4	89.19	scale
S-3	73.37	64.72	322.36	scale
S-4	55.61	19.11	384	Soil
S-5	32.52	40.35	420	Soil
S-6	46.77	34.15	481.27	scale
S-7	67.96	60.8	654.72	scale
S-8	30.37	30.26	306	scale
S-9	48.24	35.37	351.59	scale
S-10	45.57	39.31	433	scale
S-11	53.4	7.04	182.25	Soil
S-12	67.41	11.89	298.88	Soil
S-13	44.56	7.95	182.33	Soil
S-14	68.9	86.6	154.85	Soil
S-15	57.4	14.5	359.19	Soil
S-16	13.77	11.09	313.99	Soil
S-17	60.6	12.81	319.18	Soil
S-18	32.83	42.34	275.75	Sludge

Table 2: Absorbed dose rate values for Ra-226, Th-232 and K-40 radionuclides in all samples

Sample Number	Absorbed dose rate (nGy/h)		
	D_{out}	D_{in}	D_{tot}
S-1	81.51	158.49	240.00
S-2	83.69	161.65	245.35
S-3	84.19	164.80	249.00
S-4	51.70	103.28	154.99
S-5	55.86	108.32	164.18
S-6	60.91	119.57	180.49
S-7	93.35	182.43	275.78
S-8	44.12	86.01	130.13
S-9	56.88	111.76	168.64
S-10	61.47	120.23	181.70
S-11	35.09	71.63	106.73
S-12	48.97	99.30	148.28
S-13	31.79	64.50	96.30
S-14	88.37	171.19	259.56
S-15	48.69	97.85	146.54
S-16	25.74	50.30	76.04
S-17	47.40	95.69	143.10
S-18	51.17	99.11	150.28

In Table 3 it is noted that the annual effective dose rate values for most of the samples under study are relatively lower compared to the average annual effective dose rates in the world, which will pose a radiological threat to the population of the areas near the study site. The ELCR factor was evaluated during the current study on the basis of the external $AEDA_{outdoor}$ and $AEDA_{indoor}$ dose. One can show the higher value of $AEDA_{outdoor}$ and $AEDA_{indoor}$ were varied between (0.03 to 0.11 mSv/y) and (0.24 to 0.89 mSv/y) in samples (7 and 16), in addition, the excessive lifetime cancer risk value of outdoor and indoor varied between (0.11 to 0.40 $\times 10^{-3}$) and (0.86 to 3.13 $\times 10^{-3}$) in samples (7 and16) respectively, taking into account the risks of long-term exposure increasing the likelihood of developing cancer**.**

Table 3: Radiation hazards indices, and excessive lifetime cancer risk in the equipment samples of oil and gas sector of Basrah

Sample Number	$AEDA_{(outdoor)}$	$AEDA_{(indoor)}$	$ELCR_{(outdoor)}$	$ELCR_{(indoor)}$	$ELCR_{(total)}$
	mSvly	mSv/y	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$
S-1	0.09	0.77	0.34	2.72	3.07
S-2	0. 10	0.79	0.35	2.77	3.13
S-3	0.10	0.80	0.36	2.82	3.19
S-4	0.06	0.50	0.22	1.77	1.99
S-5	0.06	0.53	0.23	1.85	2.09
S-6	0.07	0.58	0.26	2.05	2.31
S-7	0.11	0.89	0.40	3.13	3.53
S-8	0.05	0.42	0.18	1.47	1.66
S-9	0.06	0.54	0.24	1.91	2.16
S-10	0.07	0.58	0.26	2.06	2.32
S-11	0.04	0.35	0.15	1.22	1.38
S-12	0.06	0.48	0.21	1.70	1.91
S-13	0.03	0.31	0.13	1.10	1.24
S-14	0.10	0.83	0.37	2.93	3.31
S-15	0.05	0.48	0.20	1.68	1.88
S-16	0.03	0.24	0.11	0.86	0.97
S-17	0.05	0.46	0.20	1.64	1.80
S-18	0.06	0.48	0.21	1.70	1.92
Reference			0.29 (world's av) [14-16]		1.45 (world's av) [19]

Figure1 shows the maximum value of ELCR was in the sample 7 and lower value was in sample 11 and most of ELCR values are higher than allowed value [18] .

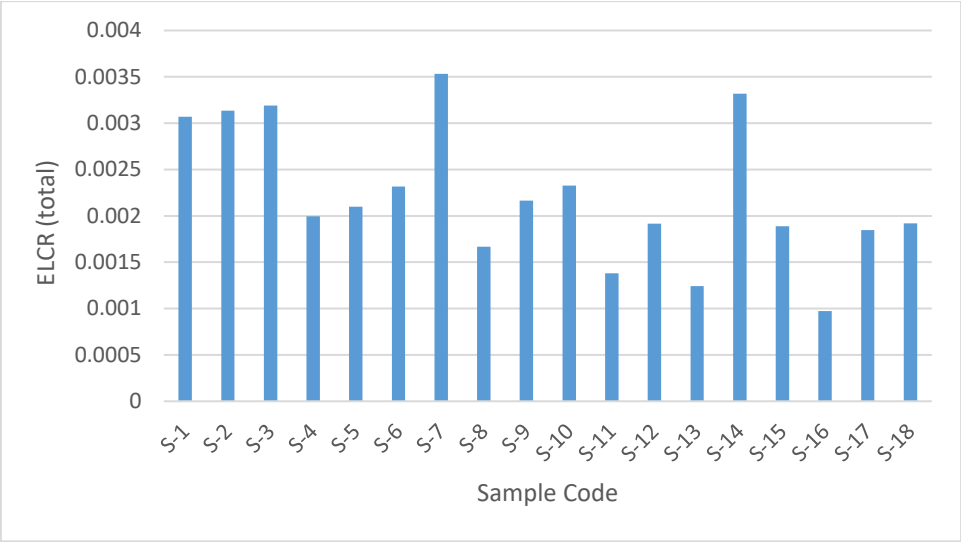

Figure 1: The relationship between sample code and ELCR (total)

4.Conclusions

This study assessed the excessive lifetime cancer risk (ELCR) for individuals working in the oil and gas sector, where natural radioactive materials accumulate in the used equipment, such as wellheads, pumps, and separation vessels, often appearing as scales, sludge, and other waste forms. These accumulations were found to pose significant risks to both public health and the environment. The estimated excessive lifetime cancer risk values varied widely from (0.11 to 0.40 $\times 10^{-3}$) for outdoor exposure, from (0.86 to 3.13 $\times 10^{-3}$) for indoor exposure, and (0.97 to 3.53$\times 10^{-3}$) for total exposure, notably exceeding the global average value of 0.29$\times 10^{-3}$[14-16]. This notable difference highlights the heightened risk associated with these activities, emphasizing the urgent need for improved safety measures and regulatory oversight to protect human health and the environment.

Long-term exposure to radiation increases the likelihood of developing certain types of cancer at some point in life. Therefore, it is advisable that residential areas be situated at a safe distance to mitigate these risks. Implementation of guidelines set forth by local and international regulatory bodies regarding radiation protection requirements is strongly recommended to address these concerns effectively [19].

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