



Measurement of Uranium ^{238}U And Radium ^{226}Ra Concentration In Arabian Gulf Seawater At Raas Al-Besha/ Basra, Iraq

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Abstract

The present work investigated the levels of uranium-238 and radium-226 in seawater samples collected from the coastal region of the Arabian Gulf at Raas Al-Besha, Basra, Iraq. The study aimed to evaluate whether the measured concentrations comply with internationally accepted safety standards. Thirty seawater samples were analyzed; measurements were performed using CR-39 [SSNTDs]. The findings revealed significant spatial variability in radionuclide concentrations. Uranium concentrations ranged between 0.00258 ppm and 0.00442 ppm, while radium concentrations varied from 0.00185 Bq·kg⁻¹ to 0.00318 Bq·kg⁻¹. The results were compared with the globally accepted standards and discussed. According to International Commission on Radiological Protection (ICRP) guidelines, the majority of the measured values were within the internationally permissible limits. A significant correlation was observed between uranium and radium concentrations in the studied samples. This work provides the baseline dataset for distribution of radium and uranium in seawater at the investigated sites using CR-39 detector techniques. It also demonstrates the applicability of this technique compared with other methods used for measuring radionuclide concentrations in water. The results may serve as a reference for future radiological assessment in this region.

Keywords: ^{238}U , ^{226}Ra , seawater, Raas Al-Besha, CR -39 detector, Basrah.

Introduction

Radionuclides are unstable isotopes of chemical elements that make up Naturally Occurring Radioactive Materials (NORM). When these radionuclides decay, they release gamma rays, alpha and beta particles, and other forms of ionizing radiation. Despite the fact that there are many radionuclides, many radionuclides are either artificially produced or occur rarely in nature (**Patel et al., 2023**). Uranium isotopes (U-238 and U-235), thorium-232, potassium-40, carbon-14, and their decay products, including thorium-234, radium-226, polonium-210, lead-210, and radon-222, are the most common naturally radionuclides in the environment (**EleAbiama et al., 2012; Krishnamoorthi et al., 2025**).

The ionizing radiation released during radioactive decay may pose serious risks to the environment and human health (**Frischknecht et al., 2000**), especially by increasing the cancer risk. Certain radionuclides, such as uranium, have chemical toxicity in addition to radiological effects (**Hon et al., 2015**). By releasing radionuclides into the environment, anthropogenic activities have the potential to significantly increase human exposure to ionizing radiation. Movement of nuclear components, production of nuclear energy, and recycling of radioactive waste (**Ewing et al., 1995**), industrial production and use of fertilizers and coal, oil, and gas extraction "(IAEA, 2003; **Hilal et al., 2014; Al-Nabhani et al., 2017**)", mining and processing of uranium and thorium ores "(**Arogunjo et al., 2009**)", and disposal of spent nuclear fuel (**Johnson et al., 2005**) are some examples of these activities. Furthermore, without human interference, naturally occurring radionuclides can move from geological formations to the atmosphere, soil, water bodies, and living organisms (**Chen et al., 2005; Al-Kharouf et al., 2008; Kiruba et al., 2025; Rasheed et al., 2025; Lapid et al., 2025; Saleh et al., 2016**).

Ionizing radiation emitted during radioactive decay poses considerable health and environmental hazards, particularly by increasing cancer risk. Radionuclides mostly enter the human body through the consumption of contaminated food and water "(**Fisenne et al., 1987; Shiaishi et al., 1997; Kuwahara et al., 1997**)" and the inhalation of airborne particles (**Misdaq et al., 2001**). Individuals exposed to radioactive sources may suffer biological tissue damage from alpha, beta, and gamma radiation

(Bakr, 2010; Al-nabhani et al., 2017). Surpassing the allowable radiation dose thresholds set by the International Commission on Radiological Protection (ICRP) necessitates the adoption of suitable protective measures and compliance with the Commission's recommendations to mitigate radiological hazards. Uncontrolled exposure to ionizing radiation may increase the risk of cancer.

Different analytical methodologies are employed to measure the concentrations of radioactive elements including uranium radionuclide in different substances such as mass spectrometry "(Desideri et al., 2011; Jia et al., 2012; Tzika et al., 2016)", radiochemical separation techniques "(Chakraborty et al., 2014; Guirguis et al., 2015)", extraction chromatography (Wang et al., 2017), for use with SSNTDs and similar devices "(Amin, 2015; Yousef et al., 2016; Omori et al., 2016)" are analytical methodologies employed to ascertain the amounts of radioactive elements, including uranium, in different substances. The SSNTD technique is based on counting alpha alpha-particle tracks emitted by radioactive elements, which are captured on the detector material to quantify uranium concentration and other radionuclides in the environmental samples.

The present study quantified uranium and radium levels in seawater samples collected from the Arabian Gulf coastline in the Raas Al-Besha region of Basra, Iraq. The CR-39 detectors' track densities produced by alpha particles emitted from the uranium decay series were calculated using the SSNTD methodology. Radionuclide concentrations were subsequently determined utilizing these track densities. The study's findings are expected to provide valuable baseline data for the marine ecology in the examined region.

2-Methodology

2.1 Experimental Procedure

In October 2024, seawater samples were collected from 30 distinct sites in the Raas Al-Besha region as shown in Figure 1.

Every sample was taken at a depth of approximately one meter below the surface. Seawater samples were boiled in a large stainless-steel container until its volume was reduced to one-fifth of the original volume. This step was performed to increase the concentration of radioactive materials in

the sample, thereby enhancing their detectability using CR-39 detector. This is necessary because the original radionuclide concentrations in seawater are typically very low, which results in low track density and, consequently, reduced measurement accuracy.

The cylindrical plastic containers used for the experiment have an internal diameter of 2.1 cm and an inner height of 16.5 cm. As shown in Figure 2, a known mass of the prepared sample was positioned at the bottom of each container up to 8.5 cm, and the container was sealed to serve as an irradiation chamber. A disk-shaped CR-39 solid-state nuclear track detector (SSNTD) measuring 2.1 cm in diameter and 500 μm in thickness was attached to the inside of the container lid and positioned at a distance of 8 cm above the sample surface. To improve measurement accuracy, two identical containers fitted with CR-39 detectors were prepared for each sample.



(a)



(b)

(c)

Figure 1: The study area is located along the Arabian Gulf coast at Raas Al-Besha, Basra, Iraq, where the sampling sites are indicated with three layers (a, b, and c).

In order to achieve a secular equilibrium between radium (^{226}Ra) and radon (^{222}Rn) of approximately 98%, the samples were first kept in sealed containers for 22 days in the absence of CR-39 detector. The secular equilibrium relation for radioactive decay, as described by (Azam et al., 1995), was used estimate the equilibrium time.

$$A_{\text{Rn}} = A_{\text{Ra}} (1 - e^{-\lambda_{\text{Rn}} t}) \quad \dots\dots (1)$$

Where t is the time needed to reach the equilibrium situation, A_{Rn} and A_{Ra} are the activities of radon and radium, respectively, and λ_{Rn} is the radon decay constant, which is equal to 0.181 day^{-1} .

To prevent air exchange between the interior chamber and the surrounding environment, the cylinder cover was carefully opened after radioactive equilibrium was achieved. After immediately installing a second pre-made cover with a CR-39 detector film, the cylinder was sealed once more and exposed to alpha radiation for 60 days. The prolonged exposure duration was essential to collect a sufficient number of alpha-particle tracks from uranium and its decay products. At the end of the irradiation period, the detector films were removed and subject

Chemically etched in a sodium hydroxide (NaOH) solution for 5 hours period using a 6.25 N NaOH solution at 70°C . Following the etching

process, alpha-particle tracks (i.e., N_G^{CR}) were visually counted using an optical microscope. In order to determine the overall alpha-particle track densities captured by the CR-39 detector (ρ), the following equation was used:

$$\rho = \frac{N_G^{CR}}{A_G} \dots\dots\dots (2)$$

Where the total field area under the microscope is represented by A_G .

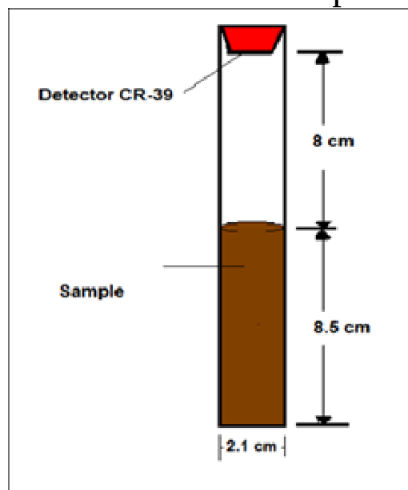


Figure 2: A plastic cylinder that is closed and has a diameter of 2.1 cm contains CR-39 detector films positioned 8 cm above a seawater sample.

2-2: The theoretical section

the following relations (Azam et al., 1995) can be used to calculate radon concentration:

$$\rho = K C_{Rna} T \dots\dots\dots (3)$$

The track density ρ (Track/cm²), diffusion constant (K), radon concentration in the air gap C_{Rna} (Bq/m³) and exposure time T (day) are all variables in this process.

The calibration factor was determined from the Equation (Barillon et al., 1991):

$$K = \frac{1}{4} r(2 \cos \theta_C - r / R_\alpha) \quad \dots (4)$$

Where: r is 1.05 cm, the radius of the cylinder irradiation chamber, R_α is the alpha particle range in air and θ_C is the detector CR-39's critical angle with value equal to 35° .

Thus, by substituting these numbers into Equation (4), gives:

$$K = 0.0312 \text{ Tr.cm}^{-2}.\text{d}^{-1}/\text{Bq}.$$

Radon concentrations in seawater samples was calculated using the following Equation (Al-Bataina et al., 1997):

$$C_{\text{Rns}} = \lambda_{\text{Rn}} C_{\text{Rna}} h T/L \quad \dots (5)$$

Where C_{Rns} is radon concentration in water in Bq/m³, λ_{Rn} The radon decay constant equals 0.1814 d^{-1} , h is the height of air over the water sample in the cylinder, equal to 8 cm, L is the height of the water sample in the cylinder, equal to 8.5 cm, T is the exposure time in days, equal to 60 days.

According to the following formula (Al-Bataina et al., 1997), one can calculate the radon radiation activity:

$$A_{\text{Rns}} = C_{\text{Rns}} V_s \quad \dots (6)$$

$$V_s = \pi r^2 L$$

V_s Is the volume of the sample in m³.

The initial step in finding the uranium concentration in the seawater samples is to determine the number of uranium atoms in the sample N_U .

This was achieved by substituting the radon atom number N_{Rn} into the following equation (Khallil, 1994):

$$\lambda_{\text{Rn}} N_{\text{Rn}} = \lambda_U N_U \quad \dots (7)$$

Where

λ_{Rn} is the radon decay constant equal to $(2.1 \times 10^{-6}) \text{ s}^{-1}$

λ_U Is the ²³⁸U decay constant equal to $(4.9 \times 10^{-18}) \text{ s}^{-1}$

According to (Khallil, 1994), the following equation can be used to determine the gram mass of uranium in the seawater sample W_U :

$$W_U = \frac{N_U A_U}{N_{av}} \quad \dots\dots\dots (8)$$

Where, A_U is the uranium mass number equal to 238 and N_{av} is Avogadro's number equals $6.02 \times 10^{23} \text{ mol}^{-1}$.

The uranium concentration in part per million (ppm) was calculated from Equation 9:

$$C_U (\text{ppm}) = \frac{W_U}{W_s} \times 10^6 \quad \dots\dots\dots (9)$$

Where, W_s is mass of sample in gm.

The following equation is used to calculate the radon surface evaporation rate (E_R) in ($\text{Bq.m}^{-2}.\text{s}^{-1}$) (**Rehman, 2005**).

$$E_R = \frac{C_{Rn} (C_o a + \lambda_{Rn} V_a)}{a(1 - e^{-(\frac{C_o a}{V_a} + \lambda_{Rn})T})} \quad \dots\dots\dots (10)$$

Where: $C_o = \lambda_{RN} L$, C_o The repeat propagation's correction limit (m.s^{-1}), (a) is sample's surface area (m^2), and L is sample thickness (m).

$$V_a = \pi r^2 h$$

V_a is the volume of the air space (m^3).

To calculate the radium concentration in (Bq/ kg^{-1}), we use the following equation (**Rehman, 2005**).

$$C_{Ra} = \frac{E_R}{\rho_s \lambda_{Rn} E L} \quad \dots\dots\dots (11)$$

Where:

$$\rho_s = \frac{W_s}{V_s}$$

ρ_s is sample density (kg.m^{-3}).

E was assumed to be 0.3 according to Rehman (2005)

3. Results and discussion

The values of C_U (ppm) and C_{Ra} ($Bq \cdot kg^{-1}$) were calculated using Equations 9 and 11, respectively. The uncertainty associated with the alpha-particle track density measurements was estimated to be less than 2% for all analyzed samples. Table 1 presents for each sample the sample number, the sample density ρ in ($kg \cdot m^{-3}$), the mass of the sample in gm, the uranium-238 concentration C_U in parts per million (ppm), and the radium-226 activity concentration C_{Ra} in $Bq \cdot kg^{-1}$.

Table 1. Shows the number of water samples from Raas Al-Besha area, Basrah, Iraq, the sample density in ($kg \cdot m^{-3}$), the mass of the sample in gm, the uranium-238 concentration in parts per million (ppm), and the radium-226 activity concentration in $Bq \cdot kg^{-1}$.

Samp. Nu.	Density $\rho(kg \cdot m^{-3})$	mass of sample (g)	^{238}U concentration C_U (ppm)	^{226}Ra concentration C_{Ra} (Bq/Kg)
1	1026.286	30.20	0.00294	0.00212
2	1025.973	30.19	0.00405	0.00291
3	1025.912	30.19	0.00368	0.00265
4	1025.259	30.17	0.00295	0.00212
5	1025.073	30.16	0.00368	0.00265
6	1025.000	30.16	0.00258	0.00185
7	1025.164	30.17	0.00295	0.00212
8	1024.949	30.16	0.00258	0.00185
9	1024.996	30.16	0.00295	0.00212
10	1025.000	30.16	0.00368	0.00265
11	1024.958	30.16	0.00368	0.00265
12	1024.917	30.16	0.00442	0.00318
13	1024.843	30.16	0.00405	0.00291
14	1024.776	30.15	0.00368	0.00265
15	1024.749	30.15	0.00405	0.00291
16	1024.715	30.15	0.00332	0.00238
17	1024.670	30.15	0.00332	0.00238
18	1024.735	30.15	0.00295	0.00212

19	1024.798	30.16	0.00258	0.00185
20	1025.000	30.16	0.00331	0.00238
21	1024.693	30.15	0.00258	0.00185
22	1024.682	30.15	0.00405	0.00291
23	1024.707	30.15	0.00332	0.00238
24	1024.636	30.15	0.00295	0.00212
25	1024.648	30.15	0.00442	0.00318
26	1024.628	30.15	0.00405	0.00291
27	1024.648	30.15	0.00442	0.00318
28	1024.625	30.15	0.00442	0.00318
29	1024.628	30.15	0.00442	0.00318
30	1024.648	30.15	0.00405	0.00291

3-1: Uranium Concentration $^{238}\text{U}(C_U)$

The results indicate that most of the measured concentrations of uranium and radium radionuclides fall within the permissible limits established by the ICRP (ICRP, 1987). In this study, uranium concentrations were specifically determined in seawater samples collected from the Raas Al-Besha area. As presented in Table 1 and illustrated in Figure 3, the uranium concentrations ranged from a minimum of 0.00258 ppm to a maximum of 0.00442 ppm. However, variations in radionuclide levels among different materials reported by the ICRP are influenced by factors such as the depth of seawater, reflecting the natural presence of these elements in the Earth's crust.

Long term exposure to relatively low uranium concentrations may pose potential health risks. Thus, as shown in Table 1 and Figure 3, the detected uranium levels in these waters may still present a potential health risk in accordance with United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) criteria.

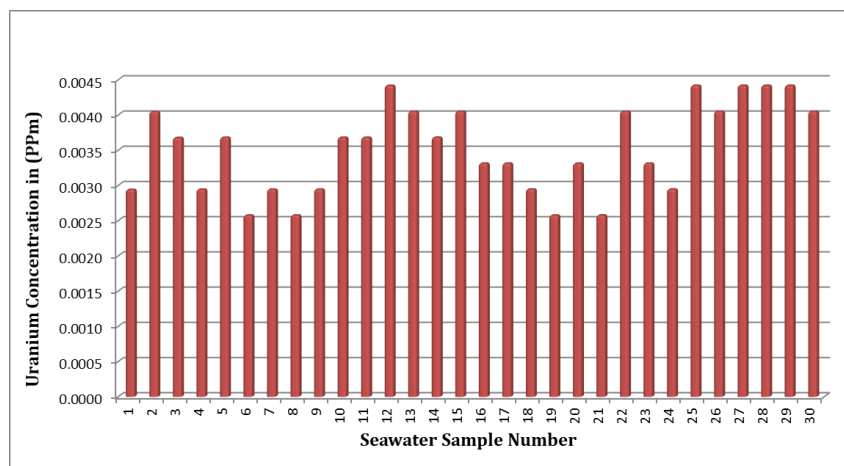


Figure 3. The uranium concentrations in the water samples.

3-2: Radium concentration ^{226}Ra (C_{Ra})

The seawater samples taken from the Raas Al-Besha region were analyzed for radium activity concentration. According to the measurements, the highest reported radium activity concentration was $0.00318 \text{ Bq}\cdot\text{kg}^{-1}$, while the lowest was $0.00185 \text{ Bq}\cdot\text{kg}^{-1}$. The range of radium activity found in the examined water samples is represented by these findings, as presented in Table 1 and illustrated in Figure 4.

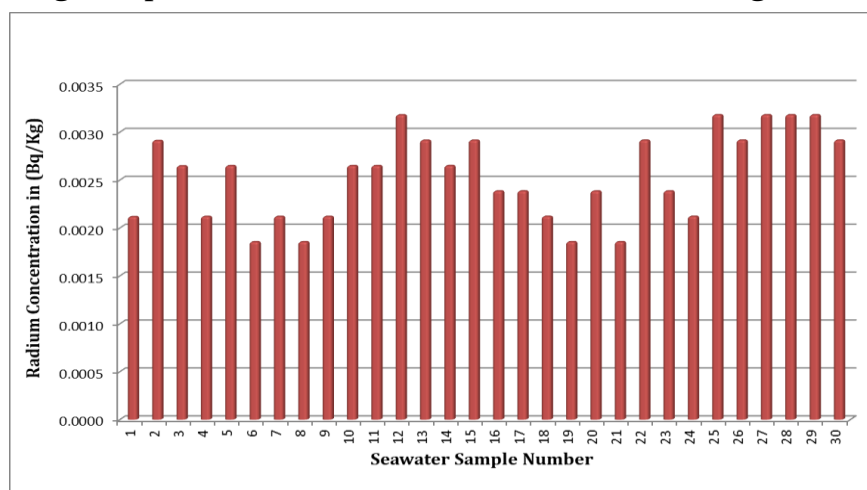


Figure 4. The radium concentration in the seawater samples.

The measured uranium concentrations in seawater samples were plotted alongside the corresponding radium concentrations obtained from the same samples as shown in Figure 5. The findings indicated a positive correlation between uranium and radium concentrations. This correlation can be ascribed to their proven theoretical connection, as delineated in the theoretical part of this study, wherein radium is a decay product in the uranium series. The observed association substantiates the alignment of the experimental data with the fundamental radiological and geochemical laws that dictate the behavior of these radionuclides in marine settings.

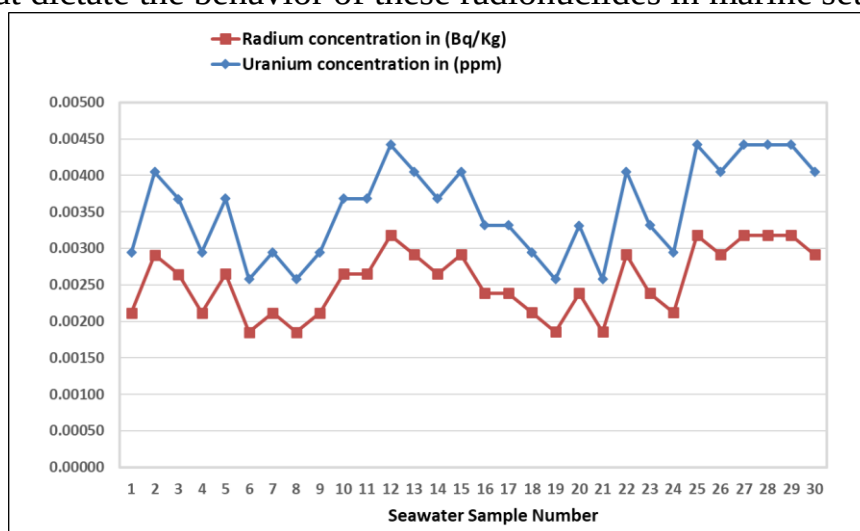


Figure 5. A notable association was identified between uranium and radium values in the analyzed samples.

4. Conclusions

This study assessed the concentrations of uranium (^{238}U) and radium (^{226}Ra) in water samples from the Arabian Gulf Coast in Raas Al-Besha, Basra, Iraq. CR-39 detectors were successfully used for the measurement of the radionuclides' concentration in the investigated area, conducted within sealed cylindrical plastic containers. This study provides baseline radiological data for the area under study, including uranium. Appositive correlation was observed between uranium and radium concentrations, which may reflect the common origin with the uranium series. The physicochemical characteristics of seawater, including salinity, pH, and redox conditions, are essential in governing the mobility and

dispersion of radionuclides, significantly influencing the reported outcomes. Radium typically associates with particulate matter but can be released into saltwater under specific geochemical conditions, whereas uranium is generally more soluble in oxidizing marine environments.

Among the 30 sites examined, sample sites 12, 25, 27, 28, and 29 have comparatively high quantities of uranium and radium radionuclides, as indicated by the tables above. A geochemical relationship between the two radionuclides is shown by the data, which also show that radium concentrations are higher in a number of these locations where uranium levels are also elevated. Their association within the uranium decay series and environmental processes such as desorption, ion exchange, and sediment-water interactions accounts for this relationship. Moreover, contributions from subterranean geological formations abundant in naturally occurring radioactive materials (NORM) and the interaction between seawater and sediment strata may influence the relatively elevated quantities observed in coastal waters. Analysis of prior research completed globally (Kiruba et al. 2025; Abshire et al., 2022; Wang et al. 2021; Haidong et al. 2024; Krachle et al. 2018) reveals that the recorded values in this region are comparatively elevated. Elevated levels of these radionuclides in water may pose health risks to local residents, continuous monitoring is recommended to evaluate any potential radiological effects.

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تقييم اليورانيوم والرادיום في مياه الخليج العربي في منطقة رأس البيشة، البصرة، العراق باستخدام كواشف الأثر النووي ذات الحالة الصلبة

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مستخلص البحث:

يتناول هذا البحث دراسة مستويات اليورانيوم (^{238}U) والرادיום (^{226}Ra) في عينات مياه البحر التي جمعت من المنطقة الساحلية للخليج العربي في منطقة رأس البيشة، البصرة، العراق. الهدف الرئيس لهذه الدراسة هو تقييم ما إذا كانت التراكيز المقاسة تتوافق مع المعايير الدولية المعتمدة للسلامة. تم جمع ثلاثين عينة من مياه البحر من مواقع مختلفة، وأجريت القياسات باستخدام كواشف الأثر النووي بالحالة الصلبة من نوع CR-39. أظهرت النتائج وجود تباين مكاني ملحوظ في تراكيز النويدات المشعة. تراوحت تراكيز اليورانيوم بين 0.00258 جزء في المليون و0.00442 جزء في المليون، بينما تراوحت تراكيز الرادיום بين 0.00185 بيكريل/كغم و0.00318 بيكريل/كغم. تمت مناقشة النتائج ومقارنتها مع القيم المعتمدة دولياً. ووفقاً لإرشادات اللجنة الدولية للوقاية من الإشعاع (ICRP)، كانت غالبية القيم المقاسة مرتفعة. كما لوحظ وجود ارتباط معنوي بين تراكيز اليورانيوم والرادיום في العينات المدروسة. تُعد هذه الدراسة أول قاعدة بيانات مرجعية لتوزيع اليورانيوم والرادיום في مياه البحر في المواقع المدروسة باستخدام تقنية كواشف CR-39. كما تُظهر دقة هذه التقنية مقارنةً بطرق أخرى مستخدمة لقياس تراكيز النويدات المشعة في المياه. ويمكن أن تشكل النتائج مرجعاً مهماً للدراسات المستقبلية في التقييم الإشعاعي.

الكلمات المفتاحية: اليورانيوم، الرادיום، مياه البحر، رأس البيشة، الكاشف النووي الصلب CR-39، البصرة.