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Evaluation of Suitability of Cooling Water System of Nuclear Power Plant in Egypt Using ERICA and RESRAD Biota Models

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ABSTRACT

Egypt is planning for the construction of electricity generating nuclear facilities to accommodate population growth and increased industrial and domestic demand for electric energy. This study aims to predicate radiological exposure levels of marine biota such as crustaceans, bivalve mollusks and zooplankton using ERICA and RESRAD models. Due to assuming exposure of these organisms to the emitted radionuclides from the discharge of cooling water system of the suggested Egyptian Nuclear Power Plant (ENPP) on the northern coast of the Mediterranean Sea in Egypt. To achieve this study, eighteen water samples were collected from the three selected sites (Alam El-Aroum, Mina El-Hashish and El Alamein) in the coastal region of the north Mediterranean in Egypt where their activity concentrations were measured using high performance gamma spectrometer. The calculated absorbed dose rates of the selected biota by using both ERICA and RESRAD tools were below the ERICA 10μGy/h screening value. The results of both two models showed that the biota concentration guide BCG and the risk quotient QR of the selected biota have complied with the recommended limits indicating that the minimum radioactive effect of once through cooling system on the selected biota. On the other hand, the results showed that the least radiological impact of the once through cooling system using the ERICA model was at a distance of 1 Km starting from the cooling discharge point to the shore and up to 2 km to the receptor inside the Mediterranean Sea.

INTRODUCTION

El-Dabaa Nuclear Power Plant, which will be the first Egyptian nuclear power plant (ENPP),was selected to be built in Matrouh Governorate on the Mediterranean coast. It may be preferable to use the once- through cooling system for the Egyptian Nuclear power plant because it relies on a large amount of water transported through their pipes and discharged into the Mediterranean Seawater. The occurrence of radioactive substances in the cooling water that returned from NPPs in the aquatic environment can be detected by various indicator organisms which became affected by the activity of radionuclides that accumulated from water and sediments therefore could be used to detect the small traces of radionuclides which found in the marine environment.

The Fukushima Dai-ichi nuclear accident that occurred on 11 March 2011 was a highly significant event for marine radioecology, since about 80% of the radioactive fallout occurred over the Pacific Ocean [1, 2], especially in coastal waters near the Fukushima Dai-ichi nuclear power plant. Releases of radioactive contaminants, especially the long-lived radioactive Cs-137(30 years), into the Pacific Ocean following the Fukushima- Daiichi nuclear accident have raised public concern about the safety of consuming seafood. To address this, many fish samples were harvested from the Canadian west coast to be analyzed for Cesium-137[3].

Therefore, environmental radiation protection and radiological risk assessment, have received a significant attention especially from facilities emitting radionuclides. The evaluation of the biological impact of ionizing radiation on non-human organisms is becoming a necessary approach to protect and mitigate the effects of future radioactive releases on the marine environment. The assessment tools ERICA [4].and RESRAD-

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BIOTAcode [5] use the databases consisting of different radionuclides concentrations and were grouped according to general ecosystems, land, marine and freshwater. Both models were used in the present study to calculate radiological dose rates of non-human biota which resulting from their exposure to the released radionuclides from the once-through cooling system discharge of the selected ENPP.

MATERIAL AND METHODS

The field study was done to select three cooling sites (Alam ElRoum, Minaa Alhasheesh and El Alamein) as they were located on the northern coast of the Mediterranean Sea in Egypt where ENPP may be constructed in this area. Their coordinates are 31˚20'16.7"N and 27˚20'50.1" E of Alam El Roum, 31˚ 22' 6.7" N and 27˚ 20' 30.1" of Minaa Alhasheesh and 30˚ 49' 48"N and 28˚ 57' 18" E of Alamein as shown in Figure (1). The three selected sites will be studied as water sources of cooling system for ENPP, with selecting the suggested once-through cooling system as cooling system will be used in NPP. For this study, eighteen water samples were collected at a depth of 5 meters during September 2018.

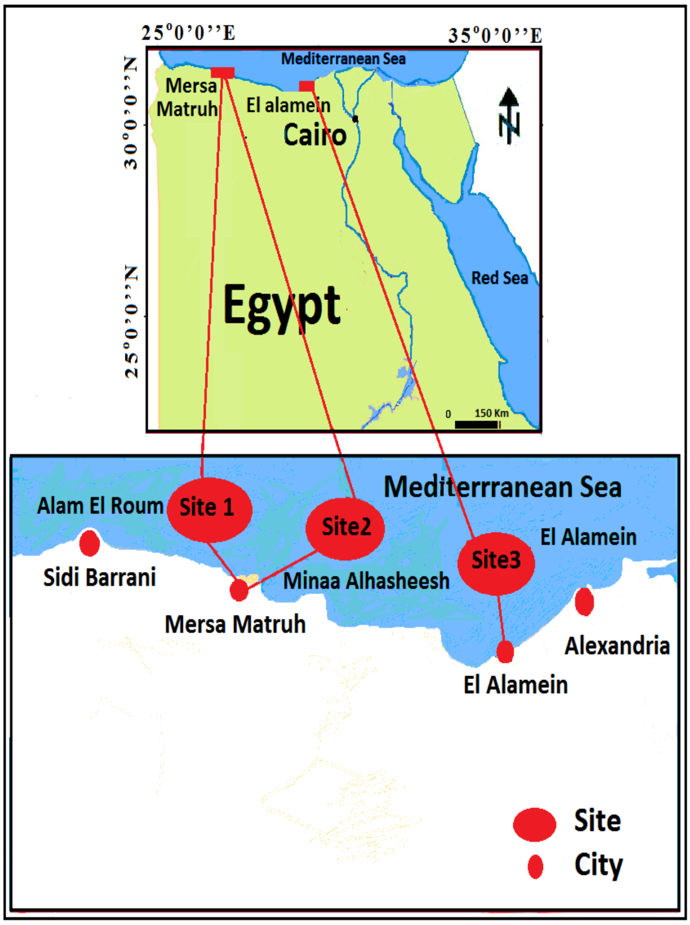

Fig. (1): Three sites of sampling in the study area

Radioactivity Measurements

A gamma-ray spectrometer based on high-purity germanium (HPGe) detector of 40% relative efficiency, 1.92 keV resolution for 1332 keV gamma-ray line of 60Co was used. The detector was coupled with multi-channel analyzer (16 k channels) and GENIE 2000 software. Point sources of ^{137}Cs (661.6 keV) and 60Co (1172 and 1332.3 keV) were used for the spectrometer energy calibration. The minimum acquisition time was 22 h to reduce the statistical as well as area calculation errors. The IAEA reference materials RGU-1 were used for the spectrometer efficiency. Calibration was done in the same geometry as that of the sample measurement. [6] For ^{226}Ra (^{238}U series), gamma-ray energy transitions (intensity %) were 295.2 keV (18.5%) and 351.9 keV (35.8%) of the 214Pb; 609.3 keV (43.6%), 1120.3 keV (14.8%), and 1764.5 keV (15.4%) of the214Bi.

The measured activity concentration of radionuclides ^{238}U, ^{226}Ra and ^{137}Cs of the water samples which were collected from the selected sites (Alam ElRoum,MinaaAlhasheeshand El Alamein) are shown in Table (1).

Table (1): The average radioactivity concentrations (Bq/l) measured in the selected sites

Radionuclides		Measured activity concentration of radionuclides in water Bq/l		
		U-238	Ra-226	Cs-137
Site (1)	Alam El Roum	0.033	0.091	0.061
		0.054	0.096	0.062
		0.049	0.097	0.063
		0.059	0.095	0.068
		0.051	0.091	0.065
		0.049	0.09	0.063
Mean		**0.049**	**0.093**	**0.063**
Site (2)	MinaaAlhasheesh	0.064	0.046	0.079
		0.063	0.045	0.07
		0.066	0.049	0.078
		0.077	0.041	0.073
		0.056	0.053	0.076
		0.061	0.056	0.077
Mean		**0.064**	**0.033**	**0.075**
Site (3)	Alamein	0.89	0.93	0.81
		0.78	0.91	0.87
		0.88	0.9	0.89
		0.75	0.91	0.91
		0.71	0.91	0.84
		0.84	0.95	0.82
Mean		**0.81**	**0.92**	**0.85**

Risk analysis and absorbed dose rates

The Environmental Risk Assessment (ERA) is a systematic process to identify, quantify and characterize the risk posed by radioactive pollutants to the Mediterranean marine environment on selected biological receptors as Crustacean, Mollusc-bivalves, and Zooplankton organisms which are considered as the suitable biological samples for the Mediterranean Sea aquatic organisms [7,8].ERICA and RESRAD-BIOTA models were used in the study for evaluating radiation doses to the selected biota.

Table (1) used the selected radionuclide concentrations as input data in both ERICA and RESRAD-Biota models. The main parameters used in ERICA Tool and RESRAD-BIOTA are the concentration ratios (CRs) that describe radionuclides' transfer within the compartments of the ecosystem, and the dose conversion coefficients (DCCs) or dose conversion factors (DCFs), that describe the exposure of organisms to radionuclides [9,10].

ERICA consists of three Tiers, the Tier 1 in ERICA tool used for aquatic assessments that the water activity concentrations which were used as input data. The risk quotient (RQ) of reference biota was calculated by the quotient of estimated exposure and dose rate.The Environmental Media Concentration Limit EMCL is defined as the activity concentration in the aquatic media that would result in a dose rate to the most exposed reference organism equal to that of the selected screening dose rate probability distribution functions associated with the concentration ratio CR and distribution coefficient $K_d$databases.K_d is used to describe the relative activity concentrations of sediment and water [11,12].

Tier 1 The first stage in the Environmental Media Concentration Limit (EMCL) derivation involves the calculation of intermediate EMCL values for selecting reference organisms for a selected radionuclide and media as in equation (1):

$$\text{EMCL} = \frac{\text{SDR}}{\text{F}} \quad \ldots\ldots \ \mathbf{(1)}$$

Where F, is the maximum dose rate that an organism will receive for a unit activity concentration of a given radionuclide in an environmental medium (mGy h^{-1} per Bq l^{-1}). The F values are calculated using CR values and distribution coefficients Kd, the screening dose rate SDR (mGy h^{-1}) is selected at Tiers 1 and 2 applicable to incremental exposures, of 10 mGy h^{-1}.

The risk quotient (RQ) method determined the ecological risk by calculating the quotient of estimated exposure and dose rate which is assumed to be environmentally safe. A total risk quotient (RQ) is also estimated and definedby equation (2):

$$\text{RQ} = \sum_{n}^{i} \frac{\text{Mn}}{\text{EMCLn}} \ \ldots\ldots. \ \mathbf{(2)}$$

Where total (RQ); M_n, measured or predicted maximal activity concentration for radionuclide ''n'' in the medium in Bq l^{-1} for water, Bq kg^{-1} (dry weight) for sediment and. $EMCL_n$, for radionuclide (n) [9].

If *RQ* is < 1, then the probability of exceeding the benchmark is acceptably low (<5%) and this serves as the justification for terminating the risk calculations at this stage.

In a situation where *RQ* is > 1, there is a > 5% probability that the benchmark has been exceeded and further assessment is recommended (Tier 2).

Tier 2 The evaluation is performed directly against the screening dose rate, with the dose rate and RQs generated for each reference organism selected for assessment as in equation (3)

$$\text{RQ} = \frac{\text{Whole Body Absorbed Dose Rate}}{\text{Screening Level Dose Rate}} \ldots\ldots. \ \mathbf{(3)}$$

$RQ\ cons \geq 1/RQ$ exp< 1, there is a substantial probability that the screening dose rate has been exceeded and in this case, the environmental risk is arguably negligible and the assessment is terminated at this stage. The screening dose rate has been exceeded and assessment should continue to Tier 3.

Tier 3 is a probabilistic risk assessment in which uncertainties within the results may be determined using sensitivity analysis.

The ERICA model was used in conjunction with the SRS-19 model of the International Atomic Energy Agency [13] to determine the minimum distance of lowest radiological impact on the selected organisms between the release discharge point and the recipient organisms.

The RESRAD-BIOTA model consists of two main ecosystems, terrestrial and aquatic media. Biota dose is a function of the contaminant concentration in the aquatic environment and is the sum of internal and external contributions. The BCG in RESRAD-Biota is designed to be the maximum radioactivity concentration limit to guarantee the safety of biota.The BCGs were estimated and assuming the exposure for aquatic organisms and sediment in external exposure. Maximum media activity concentrations are compared to biota concentration guidelines (BCG). Determination of BCG is calculated by the following equation (4):

BCG (By/Kg) = Dose Limit /Internal + External Dose ... **(4)**

For the aquatic ecosystem, the external exposure can be calculated by using the external dose conversion Factor (DCF) and media concentration. For internal exposure, the intake of radionuclide (inhalation of dust particles and ingestion contaminated water, soil, sediment, and foodstuffs) is taken into account and can be calculated by the use of Internal Dose conversion factor DCF and Bioaccumulation factor BIV to estimate activity concentration in organism tissue [14 ,15].

RESULTS

Risk analysis and absorbed dose rates

In this study, two scenarios for ERICA and RESRAD- biota models simulations were used to determine the total dose rate of the selected organisms.

Scenario (1): ERICA model simulation

Tier 1 in the simulation of the ERICA model for water assessments, in which the water activity concentrations in Table 1 were used as the input data for the model. The assessment was used to calculate the RQ of radionuclide activity concentrations in selected organisms.

The risk quotient RQ represents the output of the screening tier and is the ratio of the input media concentration to the EMCL of the selected organisms [9,16] using equilibrium concentration ratios CR and distribution coefficients K_d as shown in Figures (2 and 3).There was an increase in the concentration ratio of Cs-137 up taken in zooplankton than in crustacean and Mollusca-Bivalve as in Figure (2), this was related to the increase of K_d in artificial Cs-137 than both normal originating Ra-226 and U-238 $K_d$values.

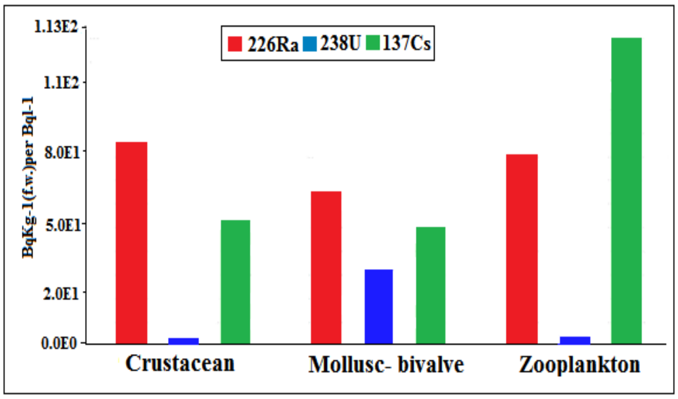

Fig. (2): CR values using in ERICA model

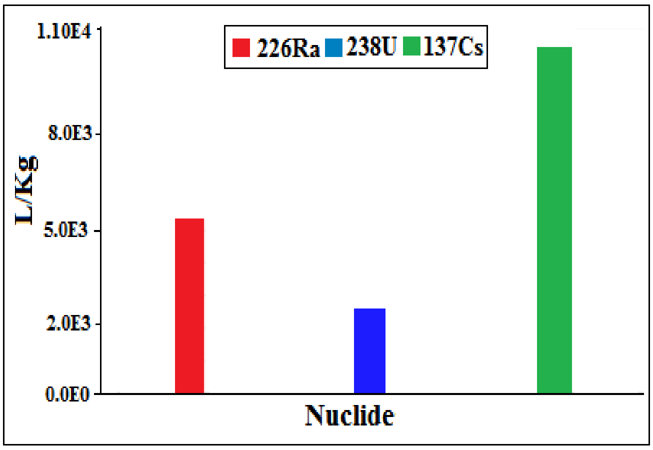

Fig. (3): K_d values using in ERICA model

Table (2) shows the total risk quotient RQ results for each of the radionuclides ^{238}U, ^{226}Ra and $^{137}Cs$for the selected organisms. The results showed that the highest RQ of Crustacean, Mollusc-bivalve and zooplankton organisms was estimated for Alamein organisms and the lowest RQ value for Alum Al-Roum organisms. This was related to the increase of the mean average activity concentrations values Bq/l of selected measured radionuclides in Alamein water compared to the activity concentrations of the selected radionuclides in Alam Al Roum water. Figure (4) shows that the highest Ra-226 concentration value was within Crustacean compared to Molluscs and zooplankton animals while Cs-137 had the highest concentration within zooplankton than other selected organisms. The highest activity of U-238 concentration was within bivalve-mollusks compared to the other selected marine animals. This is due to the fact that the choice of intake of radionuclides differs from one marine organism to another.

Table (2): Total Risk Quotient RQ for the selected organisms

Aquatic biota	Alam Al Roum	MinaaAlhasheesh	Alamein
Crustacean	6.84×10^{-2}	1.1×10^{-1}	1.1
Mollusc-bivalve	5.3×10^{-2}	8.2×10^{-2}	8.5×10^{-1}
Zooplankton	6.1×10^{-2}	9.96×10^{-2}	1.01

At Tier 2 radiation exposure to non-human organisms is calculated on the basis of the rate of external, internal, and total absorbed dose which is defined as the energy deposited per unit mass in living tissue during the exposure period. The calculated activity concentrations in the selected organisms were used to estimate the total absorbed dose as shown in Figure (4).

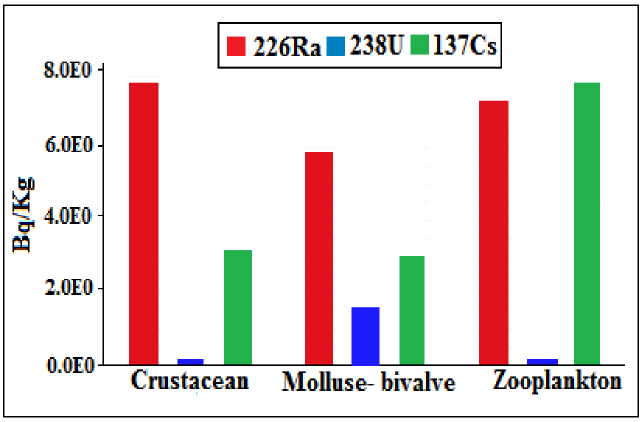

Fig. (4): The calculated activity concentration in the selected organisms

The results of total dose rate µGy/h of ^{238}U, ^{226}Ra and ^{137}Cs for a Crustacean, mollusc-bivalve, Zooplankton calculated by ERICA model were (0.01, 1.1, ND) in Crustacean animals and (0.03, 0.08, ND) in Mollusca-bivalve while (0.011, 1.0, ND) in zooplankton respectively as shown in Table (3).

Table (3): Total dose rate of the selected organisms

Radionuclides	Total dose rate µGy/h		
	Crustacean	Mollusca-bivalve	Zooplankton
^{238}U	0.01	0.03	0.011
^{226}Ra	1.1	0.08	1.0
^{137}Cs	ND	ND	ND

ND: Non Detection Limit

Scenario (2): RESRAD- biota model simulation

The assessment of the initial screening level (Level 1) in the RESRAD simulation was occurred by using the inputs data as the activity concentrations in Mediterranean water of the three sites and K_d values which are shown in Table (4). The highest K_d value obtained was for Cs-137 while the lowest K_d values used were for both Ra-226 and U-238 radionuclides respectively.

Table (4): The $K_d$valuesusing in RESRAD model

Radionuclides	Calculated Kd (l/Kg)		
	Minaa Alhashesh	Alam Alroom	Alamin
Ra-226	70	70	70
U-238	50	50	50
Cs-137	500	500	500

From the initial screening level the BCG guidelines of the selected organisms in Minaa Al-hasheesh, AlamAl-Roum, and Alamein sites were calculated and were below the recommended limits of biota concentration Guideline as shown in Table (5).

Table (5): The results of BCG (Bq/Kg)ofthe selected organisms

Radionuclide	BCG of Alamin	BCG of Mina Hshesh	BCG of AlamAlroom	Recommended limited of BCG
Ra-226	3.7x10^{2}	1.5x10^{2}	1.7 x10^{2}	4.1x10^{2}
U-238	8.0 x10^{3}	7.2x10^{3}	7.6 x10^{3}	8x 10^{3}
Cs-137	3.8x10^{4}	1.6x10^{3}	3.5x10^{4}	4x10^{4}

The average total dose rate of ^{238}U, ^{226}Ra and ^{137}Cs in the Crustacean, Mollusca-Bivalve, Zooplankton organisms were estimated, as shown in Figure (5) and their values were 0.5, 0.04 and 0.0041 µGy/h respectively. In RESRAD-BIOTA model the Aquatic animal (Crab) was used as a source of Crustacean marine type.

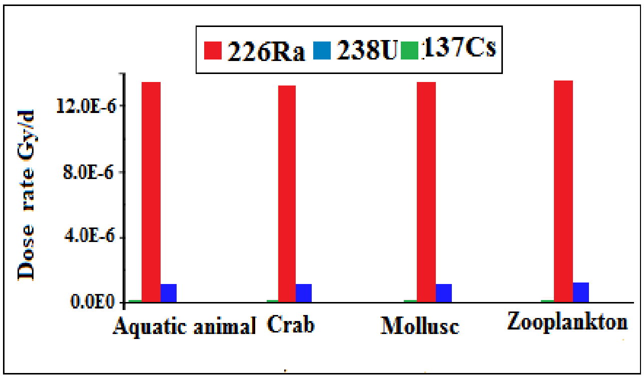

Fig. (5): Total dose rate of the selected organisms

DISCUSSION

The output RQs and BCG which were calculated by ERICA and RESRAD-biota models respectively were within the recommended limits except for the risk quotient of Alamien site which was slightly higher than the RQ of the other biological organisms. It may be attributed to the increasing of the radioactivity concentration of radionuclides in Alamien water than the other sites. While the biota concentration BCG results were complied with the recommended limits of BCG guideline, as a result there will be a minimal risk to the selected biota at these sites.

The results of the two models showed that the average total dose rates calculated by ERICA of ^{238}U, ^{226}Ra and ^{137}Cs for the three organisms;Crustacean, Mollusca Bivalve, and zooplanktonwere (0.97, 0.016, ND)µGy/h, While the other average total dose rates calculated by RESRAD were (0.5, 0.04 and 0.0041)µGy/h respectively. As a result, the calculated dose rates conducted by the two models were far below the reference levels(10µGy/h) proposed of non- human organisms[4]. The calculation showed that the lowest dose rates received by the selected biological organisms were at a distance 1Km from the discharge point of the cooling system to the beach and reached 2km to the receptor point inside the sea.

The activity concentration of non-human organisms refers to the whole-body activity of the organism calculated from the activity measured in the tissues, according to the methodology adopted by Sotiropoulou M (2017) [15]. In ERICA Tool, the dose calculation is based on the concept of dose conversion coefficients (DCCs) while in RESRAD- biota, it is based on the dose conversion factors (DCFs). The DCCs and DCFs are numerical multipliers that relate the dose that the organism receives to the activity concentration to which the organism is exposed. The internal dose rate is calculated by the internal DCC and the activity concentration of radionuclides incorporated in the organisms.

Internal dose conversion DCF and bioaccumulation BIV values of the selected organisms as shown in Figures (6&7) were used to calculate internal exposure of the selected organisms. It is noticed the value of ^{226} Ra was higher than that of both ^{238}U and ^{137}Cs of the selected organisms. It may be related to the abundance of Ra^{2+}in different forms as $RaSO_4$, $RaCl_2$ and $RaCO_3$ in Mediterranean seawater which given that water contains high concentrations of sulphates, chlorine and carbonate. This leads to increased mobility of Ra^{2+} in seawater and its interaction by adsorption through ion exchange with body surfaces of biota. [14,17].On the other hand, DCF values of the internal dose were higher than the DCF values of the external dose for the selected organisms.

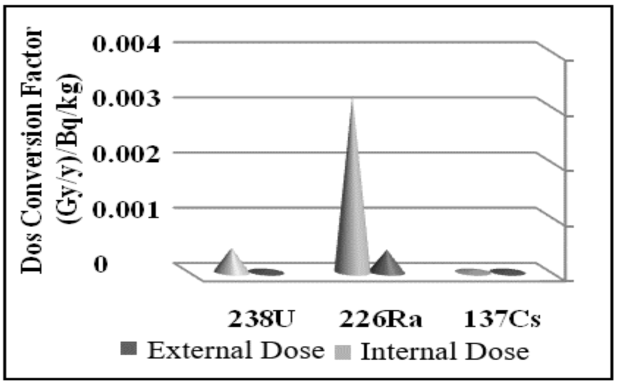

Fig. (6): Dose conversion factor for selected sites

The tissue concentrations of ^{238}U, ^{226}Ra and ^{137}Cs in the selected organisms were calculated through the water activity concentration and bioaccumulation factor (BIV) as shown in figure (7). The mean value of BIV factor of ^{238}U, ^{226}Ra and ^{137}Cs were (0.5, 0.4 and 3.4) respectively for terrestrial animals and (295, 800 and 5400) respectively for the selected organisms. This showed that the BIV bioaccumulation value of ^{137}Cs in the selected organisms was higher than both ^{226}Ra and ^{238}U values.

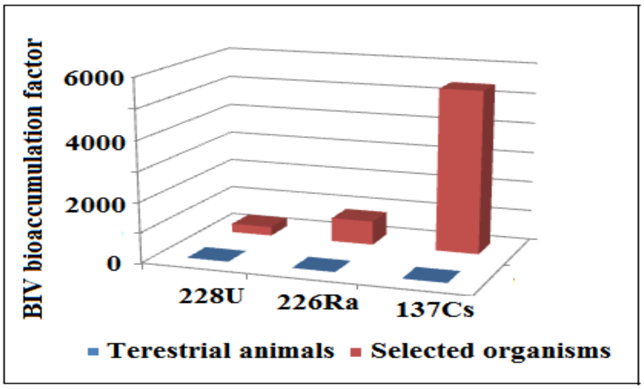

Fig. (7): BIV factor of selected organisms and terestrial animals

Figure (8) shows that the calculated tissue concentrations of ^{238}U, ^{226}Ra and ^{137}Cs in the Crustacean, Mollusca-Bivalve , Zooplanktonorganisms were 0.08, 0.18 and 1.3 Bq/Kg respectively.

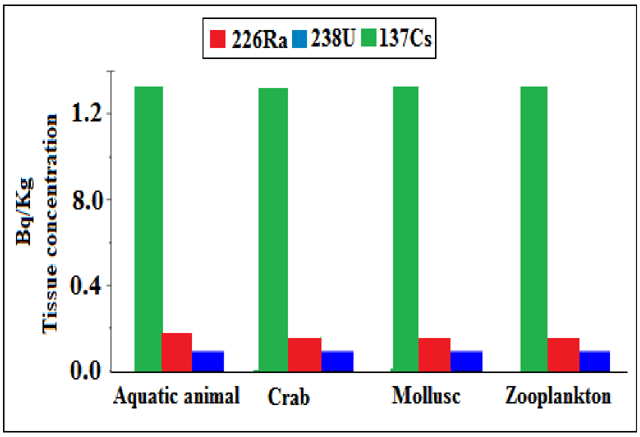

Fig. (8):The calculated tissue concentration Bq/Kg in the selected organisms

Increasing accumulation of artificial ^{137}Cs activity concentration in aquatic organisms occurred through different mechanisms as the direct uptake from water (bio-concentration), uptake of suspended particles (ingestion) and the consumption of contaminated food bio-magnification [18]

CONCLUSION

The output of the two models showed that all RQ values of the selected organisms which were calculated by ERICA were less than 1, which makes them within the accepted limits. On the other hand the BCG valueswhich were calculated by RESRAD-BIOTA also complied with recommended limits of biological concentration BCG guidelines.

The average dose rate results calculated by the two models in case of different ^{238}U, ^{226}Ra and ^{137}Cs radionuclides for Crustacean, Mollusca-Bivalves and zooplankton were ranging from 0.97 to 0.5, 0.04 to 0.016 and ND (µGy/h) respectively, as these results were below reference levels 10µGy/h of non- human organisms.

The results of ERICA model showed that the determined lowest radiological impact distance of the once through cooling system was at a distance 1Km far from the discharge point of the cooling system to the beach and may be reached to 2km from the receptor point inside the sea.

The results obtained from RESRAD model showed that the values of DCF showed differences for both the external and internal dose of the selected organisms. As the DCF values of the internal dose were higher than the DCF values of the external dose of the selected organisms. On the other hand, theDCF value of ^{226} Ra was higher than both ^{238}U and ^{137}Cs of the selected organisms. And the BIV bioaccumulation value of ^{137}Csof the selected organisms was higher than both ^{226}Ra and ^{238}U.

The results obtained from ERICA and RESRAD - biota models showed that there is a minimal radioactive impact of the once-through cooling system on the marine biota if it is used for the different NPP sites along the Mediterranean waters. The results of the two models ERICA and RESRAD-BIOTA may be helpful in selecting the type of cooling system used for the coastal nuclear power plant.

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