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Factors affecting dispersion of radionuclides in north western coast of Mediterranean Sea, Egypt

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ABSTRACT

This study aims to analyze the principal factors affecting the interaction of ^{137}Cs, ^{60}Co and ^{89}Sr with coastal sediments and their importance for migration of these ions in surface water. The second goal is to assess the acceptability of radiological consequences of proposed routine discharges of nuclear installations for radioactive materials into surface water as well as to confirm the suitability of the site to select and to establish limits for radioactive discharge into water. Uptake of the investigated ions by Mediterranean Sea bottom sediment samples have been studied as a function of liquid to solid ratio (V/m) and contact time using batch technique. The suspended sediment concentration, different discharge rates of radionuclides and the distance between the source point in the sea and the beach were investigated. The obtained results show that K_d of Cs^+, Co^{2+} and $Sr^{2+}$is 20, 32 and 10 l/g, respectively. The lowest effective dose is for ^{89}Sr, while the highest effective dose is for ^{137}Cs, at the same distances. A mathematical model for the migration of the investigated isotopes in surface water was constructed to predict the concentration of these ions for both different distances and time periods.

1. Introduction

Building and operation of proposed nuclear power plant (NPP) in El-Dabaa site in North Western of Egypt may affect the environment in the vicinity of the NPP and other territories adjacent to the plant at its site. This plant will use Mediterranean Sea water for cooling and discharge the low level radioactive wastes into the sea; in relation to authorized limits. So the evaluation of the possible hazards that may occur due to the transfer of some radionuclides into Mediterranean Sea necessitates the study of the behavior of these radionuclides and their interaction with constituents of the Mediterranean Sea environment.

The interaction of cobalt, strontium and cesium ions with coastal sediments strongly affects the migration of these ions in surface water and its knowledge is necessary for mathematical modeling of the migration (Benes, Kuncova, Slovak, & Lamramos, 1988). Selection of liquid to solid ratio (V/m) is very important parameter for determining extent of the interaction. Many authors showed that the distribution coefficient (K_d) depends on (V/m), in many systems (Atsushi, Shinya, Akira, Hirofumi, & Takashi, 2012; Connor & Connolly, 1980). K_d is defined as $K_d = (A_s/A_l)\ (V/m)$, Where A_s and A_l are total

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activities of the ions in the sediment and in aqueous phase, and V and m are the volume of the aqueous phase and mass of the sediment, respectively. The advanced interaction with solid phase in environmental systems should be based on better understanding of the mechanisms and kinetics of this processes involved rather than on the K_d concept (Schweich & Sardin, 1985). The effect of sediment concentration on the uptake of radionuclides is very important for the modeling of radionuclides migration in surface water due to variability of the concentration in surface water. Calculations of dispersion of liquid radionuclides effluents shall be made to show whether the radiological consequences of routine discharges of radioactive materials into surface water are acceptable. The results of the dispersion on surface water will be used to confirm the suitability of the site to select and; to establish limits for radioactive discharge into water; and to assess the radiological consequences of the release.

2. Materials and methods

Three locations along the north western coast of Egypt were selected to collect sediment and water samples for the investigations. These locations are Al Dabaa, Sidy AbdelRahman andEl hamam; they are 60 km along the coast. From each location; five coastal sediment up samples were collected and dried at 80 °C for 24 h and mixed to have one representative sediment sample (using the quartering technique) they are donated with S_1, S_2 and S_3, respectively and five water samples were collected from 50 cm under surface water by "Van Veen grab" sampler (Villeneuve, 2004). 4 L water of each individual samples were gathered into plastic container to have one representative water sample. So there were three representative coastal sediment samples and three representative water samples.

All chemicals utilized in this work were of analytical grade purity and were used without further purification. The main chemicals and reagents are given in Table 1. Stock solutions were prepared using sea water after filtration. Bi-distilled water was used for washing glassware.

It is known that the chemical reaction of radio isotope and stable isotope for any element is the same. So in this work stable isotopes were used for sorption investigations instead of radio isotopes. Sorption of the investigated ions by sediment samples was carried out, using batch technique. The investigated ions measurements were carried out using Atomic Absorption Spectroscopy of type AA-scan-4 from Thermo Jarrell Ash USA, the absorbance for Cs^+, Co^{2+} and Sr^{2+}, at $\lambda_{max} = 852$ nm, 240 nm and 460 nm respectively (San Andres, Marina, & Vera, 1994). The mixtures were shacked at room temperature for equilibrium time using a mechanical shaker of the type "Flask Shaker SF1" made in UK.

Suggested Fortran Program has been built to predict the radionuclide concentrations for different distances along shore and time periods. A model of one-dimensional system with constant characteristics and for the continuous discharge of radionuclides into Mediterranean Sea was used. This was done at velocity equals 0.1 m/s, water depth at the discharge equals 6 m, different discharge rates are 3.7×10^{11}, 8×10^{11} and 15×10^{11} Bq/y, distance between the point source in the sea and the beach are 200 m or 500 m, radioactive decay constants for ^{137}Cs, ^{60}Co and ^{89}Sr were used. The suspended sediment concentration and distribution coefficient (K_d) of the investigated radionuclides were determined and used as input data for the model.

General governing equation for radionuclide transport in surface water bodies is as follows (John & Helen, 2008):

$$\partial C_{w,\,tot}/\partial t = U(\partial C_{w,\,tot}/\partial x) + V(\partial C_{w,\,tot}/\partial y) + W(\partial C_{w,\,tot}/\partial z) \quad (1)$$

where:

$C_{w,\,tot}$ is the radionuclide concentration (Bq m^{-3}); t is the time (s); U, V, W are the flow velocities in the x, y and z directions, respectively (m s^{-1}); x, y, z are the longitudinal, lateral and vertical directions, respectively, (m);

The solution of this equation gives the total radionuclide concentrations in coastal water along the shoreline (Bq s^{-1}).

$$C_{w,tot} = (962U^{0.17}Q_i/Dx^{1.17})\exp[-(7.28\times10^5U^{2.34}y_o^2/x^{2.34}) - (\lambda_i x/U)] \quad (2)$$

where

U is the velocity (m s^{-1}). Q_i is the average discharge rate for radionuclide i (Bq s^{-1}), D is the water depth at the radionuclide discharge effluent outfall (m), x is the longitudinal distance between the discharge point and the receptor (m), y_o is the distance between the release point in the sea and the beach (m), λ_i is the radionuclide decay constant (s^{-1}).

The dissolved radionuclide concentration in surface water ($C_{w,s}$, Bq m^{-3}) can be obtained by

$$C_{w,\,s} = (C_{w,\,tot}/1 + 0.001K_dS_s) \quad (3)$$

where:

S_s is a suspended sediment concentration (g l^{-1}). The 0.001 in the denominator is the unit conversion of K_d from l kg^{-1} to m^3 kg^{-1}.

Table 1 – Chemicals and reagents used in the present work.

Reagents	Reagents	Formula weight	Manufacture
Cobalt chloride	$CoCl_2 \cdot 6H_2O$	237.93	Aldrich
Cesium chloride	CsCl	168.36	Aldrich
Strontium chloride	$SrCl_2 \cdot 6H_2O$	266.62	Merck
Hydrochloric acid	HCl	36.46	Koch
Sodium hydroxide	NaOH	40.00	Light-Laboratories Ltd, UK