Egyptian Journal of Chemistry

http://ejchem.journals.ekb.eg/

Risk Assessment of Groundwater Pollution by Radionuclides Released from A hypothetical Waste Disposal Site Northeast Sinai – Egypt

E.M. Abdou[a*], S.G. Abd El-Samie[a], N.S. Mahmoud[a], S. M. El-Didy[b], M.S.A. Abdel-Mottaleb[c]

[a] Nuclear and Radiological Safety Research Center - Egyptian Atomic Energy Authority, Egypt. [b] Faculty of Engineering, hydraulics department, Cairo University, Egypt. [c] Nano-photochemistry and Solar Chemistry Laboratories, Department of Chemistry, Faculty of Science, Ain Shams University, Abbassia, 11566 Cairo, Egypt.

Abstract

A risk assessment study of a hypothetical near-surface geological repository of low and intermediate radioactive wastes was estimated to determine the potential risks to future generations from the migration of five radionuclides in groundwater. Quantifying risk was done from the output concentration, of the radionuclides released due to degradation and total damage of the engineered and geological barriers of the disposal site. This simulation started after 100 years of institutional period through two scenarios of continuous release of 0.1%, and instantaneous release of the radionuclides to groundwater. The annual effective dose was calculated for Tritium, Cesium-137, Strontium-90, Iodine-129, and Technetium-99 that leached out to groundwater to determine the health risk to each critical individual with the time-dependent dose received to the human body through drinking water. The highest dose results for all radionuclides in both cases have exceeded the maximum dose limit at about 100 - 300 m within 47:100 years. The calculated risk obtained was much higher than the permissible risk limits at 100m in the two released scenarios and continuously decreases till 300m, except ^{3}H has higher human risk values up to 1.5 km. So, the groundwater monitoring program should be continued for 200 y, and groundwater shouldn't be drilled at less than 1500 m from the disposal site.

Keywords: Risk assessment; drinking water; Radioisotopes; Radiological health risk; Transport; maximum dose rate; nuclear waste disposal site.

1. Introduction

Nuclear activities have been widely increasing in recent years from the operation and decommissioning of nuclear research plants, medical, and industrial activities that resulted in a considerable amount of radiological waste that needs to be safely dumped to prevent human exposure to considerable levels of radiation [1], [2]. Entering these levels of artificial radionuclides into the human body by inhaling, ingesting, and or injecting even in small quantities, can result in health risk effects. Storing of various wastes needs safe disposal systems considering the various elements of the disposal system including physical components and control procedures to achieve safety functions over large timescales covering the site area [3].

A waste disposal site of low and intermediate-level radioactive waste is one of our country's most critical radiological installations. Based on international and national regulations and requirements, specific processes should be employed for selecting a suitable waste disposal site to bury nuclear waste, including site investigation, construction, operation, and beyond the closure of the disposal facility (ICRP (International Commission For Radiation Protection), IAEA (International Atomic Energy Agency), NRC (Nuclear Regulatory Commission). Consequently,

*Corresponding author e-mail: emanabdou09@gmail.com.; (Eman Mohamed Abdou).
Received date 2023-01-24; revised date 2023-05-23; accepted date 2023-05-28
DOI: 10.21608/EJCHEM.2023.187774.7500

radioactive waste management is considered an essential activity approved for protecting humans and the environment from the harmful effects of ionizing radiation that should be implemented in all stages. The waste disposal site design concept for safety includes that the disposal facility is designed to isolate radioactive waste from the geosphere and intended to retard the dispersion of radioisotopes into the hydrosphere [4]. Each nuclear storage should have a special construction with suitable containment barriers based on the type of radionuclides, amount of radioactivity, and energy levels to isolate radioactive waste in the geosphere. The structure of the engineered barrier system has composed of a top cover, waste form, waste container, backfill, and bottom cover. The radioactive waste should be immobilized in a solidified matrix and preserved inside stainless steel drums, packed, and stored in well-protected disposal facilities with high levels of protection. The top and bottom covers are composed of reinforced cement, and the geological lithology (geological barrier) should be suitable to host radionuclides to prevent radionuclide leakage outside the facility [5]. The facility should also be placed far from the groundwater table to prevent any possible dissolution and/or chemical reactions with waste barriers to retard the release of radioisotopes to the biosphere through the long disposal time.

The waste disposal site may be near the surface for low and intermediate-level radioactive waste (LLW and ILW) or a deep geological repository for high-level radioactive waste (HLW), depending on the type and energy levels of radionuclides. The disposal site considered in this study is a near-surface disposal facility to dispose of radioactive waste containing mainly short-lived radionuclides (^{3}H, ^{90}Sr, ^{137}Cs) and low concentrations of long-lived radionuclides (^{129}I, and ^{99}Tc) [6],[7]. During the filling and closure of the disposal site, the monitoring program proceeds covering the institutional control period of 100y after closure to record if any radionuclides might be released into groundwater. However, after the institutional control period, the probability of degradation and damage of the disposal barriers should be considered, the radionuclides will be released into the surrounding environment moving through the unsaturated and saturated layers leading to groundwater pollution and reaching the drinking water wells.

So, supposing the degradation of the safety barriers of the radioactive waste repository followed by dissolution-controlled release and dispersion of the contaminants in groundwater were simulated to calculate the source term by MODFLOW-MT3D numerical model [8]. From the model output, the calculated concentration of the radionuclides released in groundwater will be essential for establishing dose and risk assessment to estimate the health hazards to humans, which is the scope of this work. Also, implementing a precise environmental monitoring program covers the periodical changes in contaminant concentrations in groundwater in the worst cases, and decides the effective time needed for ensuring the safe level of radionuclides in groundwater depending on radioactivity's attenuation by decay and dilution to be used safely as drinking water.

Nuclear waste has severe hazards to human health and potential risks to future generations from the long-term disposal of nuclear waste. So, effective doses and radiation risks to the workers, the public, and the environment must be assessed and controlled for safety assessment studies [7], [9]. The biological effects of ionizing radiation in humans depend on the types of isotopes involved and their corresponding energies and type of exposure (inhalation, ingestion, injection). [10]. The hazards of ionizing radiation to the human body can appear in destroying or modifying the biologically essential molecules in human organs, such as proteins, DNA, and RNA, which may lead to cell death or change in a cell's functions [11]. If there is massive damage, or the damage occurs for extended periods, the body may not be able to repair itself properly or may reproduce radiation-induced defects.

Increasing radionuclides activities in drinking water pose several health hazards associated with the risk to human organs as high doses of **^{137}Cs** cause medullary dystrophy, disorders of the reproductive system, bone mineralization, brain injury, and effects on liver and renal functions. The lowest dosage of ^{137}Cs causes wakefulness-sleep cycle

disruptions, damage to the cardiovascular system, immune defects, congenital and fetal deformations, increased thyroid cancer, and neurological disabilities. Strontium **^{90}Sr** can induce anemia and oxygen shortages, and at high concentrations, cause cancer [12]. Exposure to a certain level of tritium **^{3}H** in water could enhance spontaneous mutagenesis, and increase the incidence rate of leukemia among young children [13] Long-term exposure to radioactive iodine **^{129}I** can cause nodules or cancer of the thyroid, however, low doses can reduce the activity of the thyroid gland, lowering its hormone production. Technetium **^{99}Tc** concentrates on the thyroid gland and gastrointestinal tract, where inhalation of ^{99}Tc particles in the lungs can cause cancer [14].

So, the exposure to ionizing radiation must be minimized to achieve the ALARA principle representing minimization of the dose limit to be as low as reasonably achievable by decreasing the exposure time, increasing the distance from the radioactive sources, and improving shields [15].

2. Mode of the work

This study has entailed the investigation of drinking water contamination by radionuclides supposed to be released from a proposed waste disposal site dumped into a geological formation above two aquifers (Alluvium and kurkar) The study area is covered by Quaternary sedimentary deposits of the Holocene and Pleistocene layers. The Pleistocene is formed of two layers; the upper layer consists of alluvial deposits represented by two lithological facies of gravely sand and clayey sand, and the old beach is composed of digenetic sandstone intercalated with gravel and clay. The second lower layer is the kurkar of calcareous sandstone of marine deposits. The two layers are partially separated by a non-continuous clay layer about 5m thick, dissected by faults, forming a hydraulic connection between the kurkar and the alluvial layer. The base of the kurkar formation is separated from the alluvial layer by a thick clay deposit, forming a confining bed [16].

The MODFLOW program was selected in this work [8]. It uses a finite-difference method to solve groundwater flow equation in three-dimension to evaluate the groundwater flow dynamic in porous media based on equation (1)

$$\frac{\partial}{\partial x}\left(K_x \frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_y \frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_z \frac{\partial h}{\partial z}\right) \pm W = S_s \frac{\partial h}{\partial t} \quad \ldots\ldots\ldots (1)$$

Where K_x, K_y, and K_z are the of hydraulic conductivity values (LT^{-1}) along the x, y, z coordinate axes, $\partial h/\partial x$ is the hydraulic gradient, W is a volume flux per unit volume (m^3) (a positive sign for inflow and negative sign for outflow), and S_s is the specific storage and t is time (T). Integration of the MODFLOW model with MT3DMS code (Chunmiao and Wang, 1999; Zheng and Wang, 1999) is used to simulate the potential migration of contaminant concentrations of multispecies parameters in groundwater. The main governing equation of 3D, heterogeneous, anisotropic, transient groundwater flow in porous media of unconfined aquifer is given by Rushton, 2003. The simulation equation includes advection, mechanical dispersion, diffusion, chemical reactions (sorption, decay, order of reaction), and volume flux.

The risk assessment is an effective tool for the decision-making of radioactive waste repositories for selection and management processes [17]. In this work, the output radionuclides activities of the transport model have been taken from the simulated model for ^{3}H, ^{90}Sr, ^{137}Cs, ^{129}I, and ^{99}Tc radionuclides reaching the groundwater as indicated in Table (1). The migration was simulated within different scenarios as a function of time, obtaining their activity concentrations that will reach pumping wells located at different distances from the proposed waste disposal site (100, 300, 600, 1000, and 1500 m). This simulation was performed over 100 years beyond the institutional control period (100y) for the waste disposal facilities covering the restricted area of 100m and extended to 1500m along the groundwater flow direction.

Table (1) Radionuclide concentration released from the waste repository

		Alluvial max. activity Bq/L					Kurkar max. activity Bq/L				
	Isotope/ distance m	^{3}H	^{90}Sr	^{137}Cs	^{129}I	^{99}Tc	^{3}H	^{90}Sr	^{137}Cs	^{129}I	^{99}Tc
Scenario-1	100	$3.58E^{+07}$	$3.10E^{+04}$	$5.44E^{+03}$	$5.44E^{+03}$	$6.33E^{+03}$	$4.65E^{+06}$	$3.58E^{+01}$	$1.18E^{+00}$	$5.88E^{-03}$	$2.53E^{+02}$
	300	$2.76E^{+07}$	$1.84E^{+01}$	$5.39E^{-01}$	$5.39E^{-01}$	$6.29E^{+03}$	$3.22E^{+06}$	$1.01E^{-02}$	$2.67E^{-06}$	$8.34E^{-08}$	$1.90E^{+02}$
	600	$7.95E^{+06}$	$6.25E^{-09}$	$1.65E^{-12}$	$1.65E^{-12}$	$3.17E^{+03}$	$1.00E^{+06}$	$3.42E^{-12}$	$1.76E^{-16}$	$6.10E^{-17}$	$6.33E^{+01}$
	1000	$1.46E^{+06}$	$1.26E^{-21}$	$1.48E^{-27}$	$1.48E^{-27}$	$6.31E^{+02}$	$1.75E^{+05}$	$5.17E^{-25}$		$1.05E^{-30}$	$1.20E^{+01}$
	1500	$1.79E^{+05}$				$6.30E^{+01}$					
Scenario-2	100	$3.58E^{+08}$	$3.32E^{+05}$	$3.04E^{+04}$	$3.04E^{+04}$	$3.17E^{+04}$	$1.29E^{+07}$	$2.50E^{+02}$	$7.17E^{+00}$	$5.35E^{-02}$	$4.43E^{+2}$
	300	$7.16E^{+07}$	$1.79E^{+02}$	$4.80E^{+00}$	$4.80E^{+00}$	$1.01E^{+04}$	$6.09E^{+06}$	$8.49E^{-11}$	$4.30E^{-15}$	$1.70E^{-15}$	$1.90E^{+2}$
	600	$4.65E^{+06}$	$1.46E^{-07}$	$3.85E^{-10}$	$3.85E^{-10}$	$3.17E^{+03}$	$6.80E^{+05}$	$2.04E^{-23}$	$4.80E^{-30}$	$4.51E^{-29}$	$6.33E^{+1}$
	1000	$5.37E^{+05}$	$4.81E^{-20}$	$5.68E^{-25}$	$5.68E^{-25}$	$1.27E^{+03}$	$9.31E^{+04}$				$3.48E^{+1}$
	1500	$1.08E^{+05}$				$3.17E^{+02}$					

3. Results and discussion

Contamination assessment of radionuclides released from a disposal site to groundwater is derived from the calculation of the maximum prediction of the annual effective dose through 100y of simulation of radionuclides migration and the associated risk effect due to the ingestion of drinking water as:

3.1. Annual Effective Dose

The radiation dose due to the radionuclide intake through ingestion of the drinking water pathway was calculated as the product of the concentration of radionuclides in the groundwater, the amount of drinking water intake of 2.2 l/day (803 L/yr) [18], and the ingestion dose coefficients applicable to the general population from the ICRP [19].

When considering stochastic radiation effects, only the total dose represents the quantity of radiation absorbed or delivered per unit of time. Each incremental dose unit increases the probability that the stochastic effect will happen [20] The effective dose resulting from the ingestion of drinking water at the boundary of the site area has to remain <1 mSv/y, even if all drinking water is taken from the highest contaminated location [17]. The annual effective dose has been calculated according to equation (2) [17] as follows:

$$E_D = R_C \times I_{ing} \times D_c \qquad (2)$$

Where E_D is the annual effective dose (mSv/year), R_C is the radionuclide activity concentration in groundwater (Bq/L), I_{ing} is the consumption rate of drinking water (L/y), and D is the dose coefficient representing the conversion factor from the activity of the ingested radionuclides to the internal dose (mSv/Bq), the reference values of effective ingestion dose for radionuclides were taken from the ICRP as: $4.20E^{-11}$, $2.80E^{-08}$, $1.30E^{-08}$, $1.10E^{-07}$, 6.40 E^{-10} Sv/Bq for ^{3}H, ^{90}Sr, ^{137}Cs, ^{129}I, and ^{99}Tc respectively [19].

Based on equation (1) the calculated values of the annual effective dose for the five radionuclides released reaching the receptor (drinking pumping wells) at different distances from the released point are assessed according to the two released scenarios proposed in the model (0.1% and 100%) as:

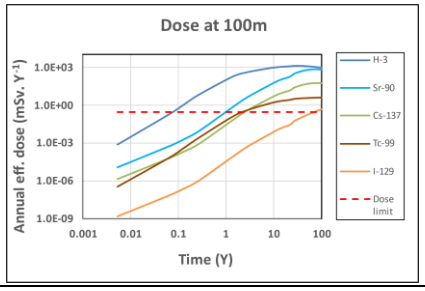
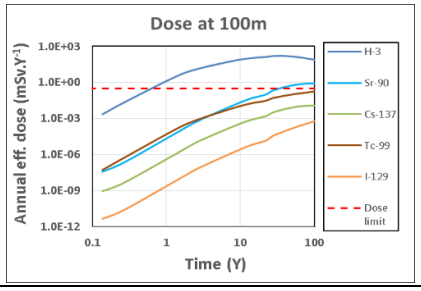
3.2. Scenario 1: Continuous release of 0.1% from the disposal site

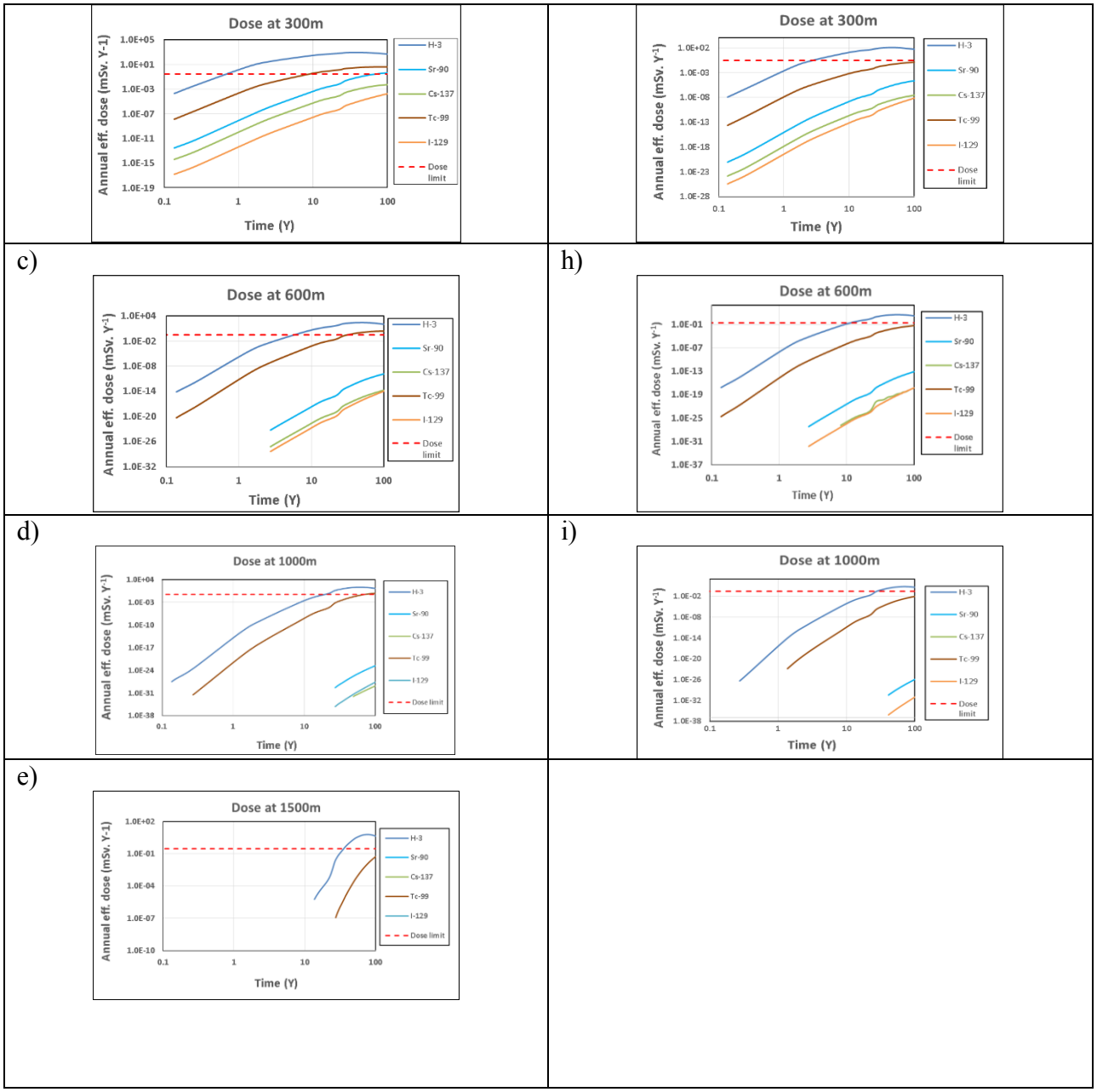
Quantifying the annual effective dose due to the consumption of contaminated groundwater by continuous release of 0.1% of radionuclides concerning time in the two different formations of the Quaternary aquifer (Alluvial and Kurkar) are indicated in Table (2). The maximum values of radionuclide activities at distinct distances have resulted in the following annual effective dose values of the five radionuclides as shown in Figure (1).

Table (2) Maximum annual effective doses ($mSv.y^{-1}$) and travel times (y) at each monitoring wells of continuous release (0.1% leaking) of radionuclides in groundwater.

Isotope		^{3}H		^{90}Sr		^{137}Cs		^{129}I		^{99}Tc	
	Distance m	An.eff. dose	Time (y)	An.eff. dose	Time (y)	An.eff. dose	Time (y)	An.eff. dose	Time (y)	An.eff. dose	Time (y)
Alluvial	100	$1.2E^{+3}$	23.6	$7.0E^{+2}$	66.6	$5.8E^{+1}$	68.2	$4.7E^{-1}$	88.1	$4.2E^{+0}$	65.3
	300	$9.4E^{+2}$	35.7	$4.4E^{-1}$	93.6	$5.6E^{-3}$	100	$2.0E^{-4}$	94.7	$2.3E^{+0}$	69.2
	600	$2.7E^{+2}$	46.5	$1.4E^{-10}$	100	$1.7E^{-14}$	100	$1.0E^{-14}$	100	$2.2E^{+0}$	92.2
	1000	$4.9E^{+1}$	58.8	$2.8E^{-23}$	100	$1.5E^{-29}$	100	$2.3E^{-28}$	100	$6.7E^{-1}$	95.3
	1500	$6.1E^{+0}$	72.8							$5.3E^{-2}$	96.5
Kurkar	100	$1.6E^{+2}$	37.7	$8.1E^{-1}$	85.6	$1.2E^{-2}$	100	$6.0E^{-4}$	92.4	$1.7E^{-1}$	91.2
	300	$1.0E^{+2}$	47.9	$2.2E^{-5}$	100	$2.7E^{-8}$	100	$7.3E^{-9}$	100	$1.3E^{-1}$	94.7
	600	$3.4E^{+1}$	55.7	$7.6E^{-14}$	100	$1.8E^{-18}$	100	$5.3E^{-18}$	100	$5.3E^{-2}$	96.2
	1000	$5.9E^{+0}$	70.2	$1.1E^{-26}$	100		100	$9.2E^{-32}$	100	$8.8E^{-3}$	97.6

The calculated results for radionuclides releases in terms of the estimated maximum annual effective dose against the time of arrival at each distance in alluvial and kurkar aquifers are shown in Table (2). The time pattern of dose variations of each radionuclide during migration in comparison to the permissible dose limit is indicated in Figure (1). In the alluvial layer, within the restricted area at 100m from the disposal site, tritium has the highest effective dose of the other 4 radionuclides, however, all exceed the permissible limit of 0.3 $mSv.y^{-1}$ established by the world health organization (WHO) for drinking water ingestion [2]. Tritium exceeded the permissible dose limit within 0.1 to 100 y from the beginning of release to groundwater affecting the suitability of water for drinking. From 300 to 1000m, the annual effective dose of ^{90}Sr, ^{137}Cs,[12, and] ^{9}I in groundwater continually decreases through the downstream migration of groundwater reaching values lower than the permissible limit and diminishing at 1500m. [2],[21]

Alluvial (sand–gravel) Aquifer	Kurkar (carbonate) Aquifer
a) 	f) 
b)	g)



Figs 1. The annual effective doses of the five radionuclides leaking 0.1% of their concentration against time at distances from 100m to 1.5 km in alluvium and Kurkar aquifers.

As the result of the vertical migration of radionuclides to Kurkar's groundwater, the effective dose is relatively lower than the upper aquifer. At 100m, ^{137}Cs, ^{129}I, and ^{99}Tc are lower than the permissible limit while ^{3}H exceeds the limit after 0.8y. Strontium- 90 dose started to be higher than the dose limit from 50y, and gradually decreases below the dose limit at the other distance as shown in figure (1).

However, ^{137}Cs, ^{129}I, and ^{99}Tc radionuclides from 300:600m are decreased below the dose permissible limit and diminished at 1000m except for ^{3}H which exceeds the dose limit till the end of the simulation time.

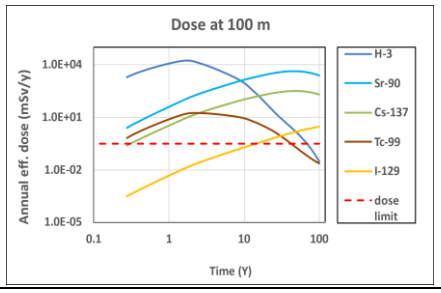
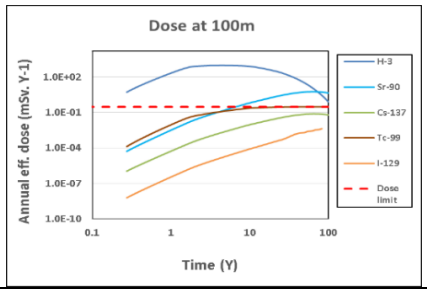
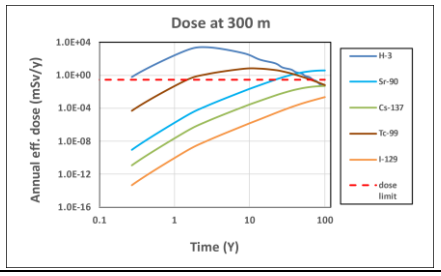
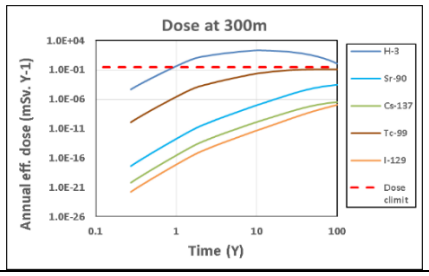
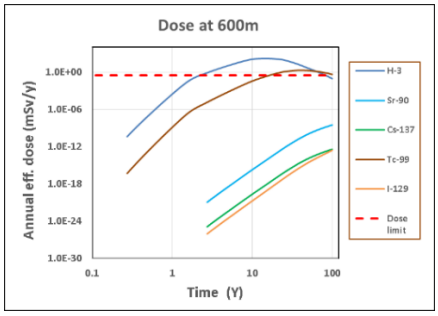
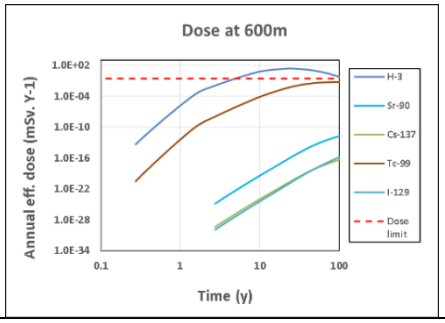
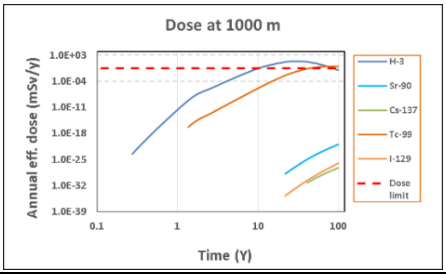
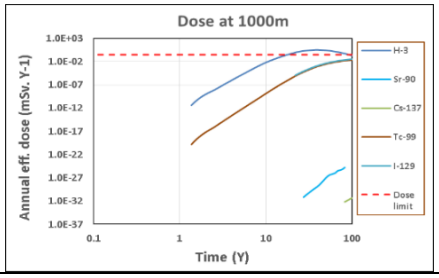
3.3. Scenario 2: Instantaneous release from the disposal unit

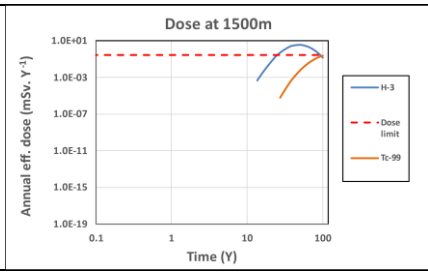
This scenario includes a postulated breakdown of the engineered and the geological barriers resulting in a total release of the bulk concentration of radionuclides from the site to the nearby groundwater. Table (3) shows the maximum annual doses of the radionuclides that will reach the human body by ingestion as drinking water intake against the time of release at distinct distances within the two aquifers.

Table (3) Maximum effective doses ($mSv.y^{-1}$) and travel time (y) at the monitoring points in scenario-2 instantaneous release (breaking down of the whole waste disposal facility)

Isotope		^{3}H		^{90}Sr		^{137}Cs		^{129}I		^{99}Tc	
	Distance M	An.eff. dose	Time (y)	An.eff. dose	Time (y)	An.eff. dose	Time (y)	An.eff. dose	Time (y)	An.eff. dose	Time (y)
Alluvial	100	$1.5E^{+4}$	1.2	$4.2E^{+3}$	46.7	$3.1E^{+2}$	47.3	2.9E+0	47.3	$1.7E^{+1}$	2.93
	300	$3.0E^{+3}$	3.9	$4.0E^{+0}$	94.7	$5.0E^{-2}$	82.8	$2.0E^{-3}$	82.8	$6.0E^{+0}$	11.18
	600	$2.0E^{+2}$	15.5	$3.0E^{-9}$	100	$4.0E^{-13}$	100	$3.0E^{-13}$	100	$2.0E^{+0}$	40.12
	1000	$8.0E^{+0}$	30.2	$1.0E^{-21}$	100	$6.0E^{-28}$	100	$1.0E^{-26}$	100	$9.0E^{-1}$	77.35
	1500	$4.0E^{+0}$	47.0							$2.0E^{-1}$	97.67
Kurkar	100	$9.0E^{+2}$	61.6	$6.0E^{+0}$	63	$8.0E^{-2}$	57.9	$5.0E^{-3}$	97.2	$3.0E^{-1}$	21.33
	300	$2.0E^{+2}$	100	$3.0E^{-4}$	100	$4.0E^{-7}$	100	$1.0E^{-7}$	100	$1.9E^{-1}$	80.64
	600	$2.3E^{+1}$	100	$1.9E^{-12}$	100	$4.4E^{-17}$	100	$1.5E^{-16}$	100	$6.8E^{-2}$	96.51
	1000	$3.2E^{+0}$	61.6			$5.0E^{-32}$	100	$3.4E^{-2}$	100	$2.3E^{-2}$	97.18

From the output results of the instantaneous release of radionuclides, the relation between the time of migration of radionuclides in groundwater versus maximum annual doses in alluvial and kurkar aquifers is presented in Figure (2). In the alluvial aquifer, the maximum dose values of all radionuclides at 100m distances are higher than the recommended dose limit set by the ICRP because of the bulk migration of all radionuclide concentrations to the end of simulation time. Iodine-129 and ^{137}Cs are lower than the recommended dose limit at 300m from the released point; however, ^{90}Sr start to increase after 40 years of release exceeding the dose limit and gradually decreasing below the limit as distance increase.

Alluvial (sand–gravel) Aquifer	**Kurkar (carbonate) Aquifer**
a) 	**f)** 
b) 	**g)** 
c) 	**h)** 
d) 	**i)** 
e)	



Figs 2. The maximum doses of the five radionuclides released all their concentration in groundwater against time at distances from 100m to 1.5 km in Alluvium and Kurkar aquifers.

Tritium (^{3}H) and ^{99}Tc are exceeding the dose limit till 1000m, while at 1500m their annual dose limit relatively reaches the permissible limit after 100 y of migration in groundwater.

The downward migration of the contaminated groundwater by the bulk concentration of radionuclides to the Kurkar aquifer showed a significant decrease in the annual effective dose of all radionuclides more than in the alluvial aquifer. At a 100m distance from the release point, ^{3}H and ^{99}Tc exceed the dose limit, while 90Sr is closely near the permissible dose limit within 100y of migration and gradually decreases to lower values up to the end of the simulation time at the longer distances. Cesium-137 and ^{129}I are significantly lower than the permissible dose limit and gradually decrease by lateral migration to diminish at 1000m. Tritium and ^{99}Tc are relatively decreasing to reach the permissible dose limit at 1000m at the end of simulation time (100y).

3.4. Risk assessment

Quantifying the potential risk to the public that may arise from the release of radionuclides at any time after disposal is considered a guidance process for site selection and the repository design base analysis as a safety management process. This step is an effective tool for the decision-making of the waste repository selection and the management of the repository system. The risk factor for a critical individual from the near-surface disposal site of low-level radioactive waste was calculated based on the calculated annual effective dose and a total risk factor that was set to be $7.3x10^{-5}$ mSv^{-1} for the public [18]. These risk factor includes non-fatal cancer, severe hereditary effects, and fatal cancer. The risk was computed as the product of the annual effective dose received (mSv/y) multiply by the risk factor according to equation (3):

Risk to a critical individual = dose received x risk factor (3)

The risk obtained over time is in Tables 4 and 5 for the two scenarios as follows:

Table (4) Risk assessment for scenario 1

		Risk (y^{-1})				
	Distance m	**H-3**	**Sr-90**	**Cs-137**	**I-129**	**Tc-99**
Alluvial	100	**$8.76E^{-02}$**	**$5.0E^{-02}$**	**$4.23E^{-03}$**	**$3.0E^{-05}$**	**$3.07E^{-04}$**
	300	**$6.79E^{-02}$**	**$3.0E^{-05}$**	**$4.09E^{-07}$**	**$1.0E^{-08}$**	**$1.68E^{-04}$**
	600	**$1.97E^{-02}$**	**$1.0E^{-14}$**	**$1.24E^{-18}$**	**$7.0E^{-19}$**	**$1.61E^{-04}$**
	1000	**$3.58E^{-03}$**	**$2.0E^{-27}$**	**$1.10E^{-33}$**	**$2.0E^{-32}$**	**$4.89E^{-05}$**
	1500	**$4.4E^{-04}$**				**$3.8E^{-06}$**
Kurkar	100	**$1.17E^{-02}$**	**$6.E^{-05}$**	**$8.76E^{-07}$**	**$4.E^{-08}$**	**$1.24E^{-05}$**
	300	**$7.30E^{-03}$**	**$2.E^{-09}$**	**$1.97E^{-12}$**	**$5.E^{-13}$**	**$9.49E^{-06}$**
	600	**$2.48E^{-03}$**	**$6.E^{-18}$**	**$1.31E^{-22}$**	**$4.E^{-22}$**	**$3.87E^{-06}$**
	1000	**$4.31E^{-04}$**	**$8.E^{-31}$**		**$7.E^{-36}$**	**$6.42E^{-07}$**

The assessment of the obtained result from the calculated risk to a critical individual is compared with the observed risk values of ($1E^{-4}$ - $1E^{-3}y^{-1}$) supposed to be generated from industrial and natural

accidents [22]. From Table (4) in the first case of 0.1% release in the alluvial layer, it is noticed that the risk obtained from ^{3}H exceeds the observed risk value reaching 1000 m. Strontium-90 and ^{137}Cs are higher than 99Tc values of the observed risk at 100m. At the same time, ^{99}Tc and ^{129}I are below the observed risk value at all distances. In the Kurkar aquifer, ^{3}H only exceeds the observed risk till 600m and the other radionuclides are below the observed risk as shown in Figure (3)

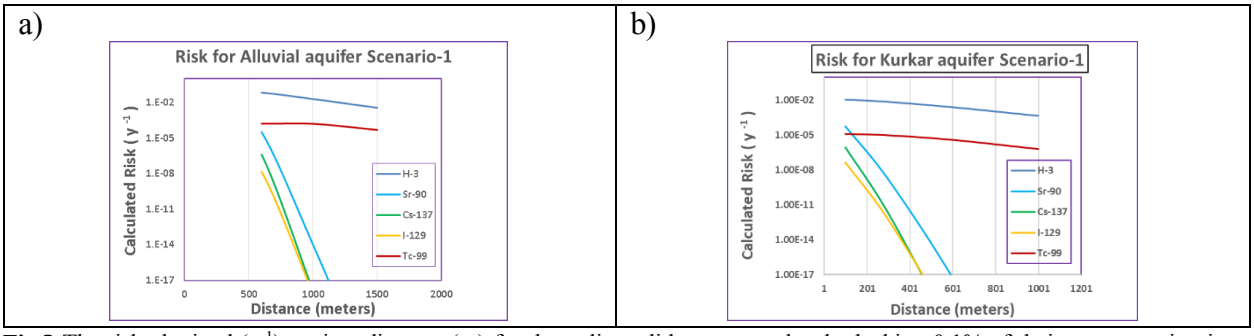


Fig.3 The risk obtained (y^{-1}) against distance (m) for the radionuclides supposed to be leaking 0.1% of their concentration in a. Alluvial and b. Kurkar aquifers.

Table (5) Risk assessment for scenario 2

		Risk (y^{-1})				
	Distance m	**H-3**	**Sr-90**	**Cs-137**	**I-129**	**Tc-99**
Alluvial	**100**	**$1.10E^{+00}$**	**$3.E^{-01}$**	**$2.26E^{-02}$**	**$2.14E^{-04}$**	**$1.24E^{-03}$**
	300	**$2.19E^{-01}$**	**$3.E^{-04}$**	**$3.65E^{-06}$**	**$1.46E^{-07}$**	**$4.38E^{-04}$**
	600	**$1.46E^{-02}$**	**$2.E^{-13}$**	**$2.92E^{-17}$**	**$2.19E^{-17}$**	**$1.46E^{-04}$**
	1000	**$5.84E^{-04}$**	**$7.E^{-26}$**	**$4.38E^{-32}$**	**$7.30E^{-31}$**	**$6.57E^{-05}$**
	1500	**$2.92E^{-04}$**				**$1.46E^{-05}$**
Kurkar	**100**	**$6.57E^{-02}$**	**$4.E^{-04}$**	**$5.84E^{-06}$**	**$3.65E^{-07}$**	**$2.19E^{-05}$**
	300	**$1.46E^{-02}$**	**$2.E^{-08}$**	**$2.92E^{-11}$**	**$7.30E^{-12}$**	**$1.39E^{-05}$**
	600	**$1.68E^{-03}$**	**$1.E^{-16}$**	**$3.21E^{-21}$**	**$1.10E^{-20}$**	**$4.96E^{-06}$**
	1000	**$2.34E^{-04}$**	**$0.E^{+00}$**	**$3.65E^{-36}$**	**$2.48E^{-25}$**	**$1.68E^{-06}$**

In case 2, the calculated total risk values of the instantaneous release of radionuclides are indicated in Table 5 and Fig.(4a,4b) as; in the alluvial aquifer, all radionuclides have exceeded the observed risk values at 100m except ^{129}I. Tritium exceeds the risk limit reaching 600 m, while the others are below the observed risk value by more than 100m. In the kurkar aquifer, H-3 is only higher than the observed risk value reaching 600 m distance away from the waste site.

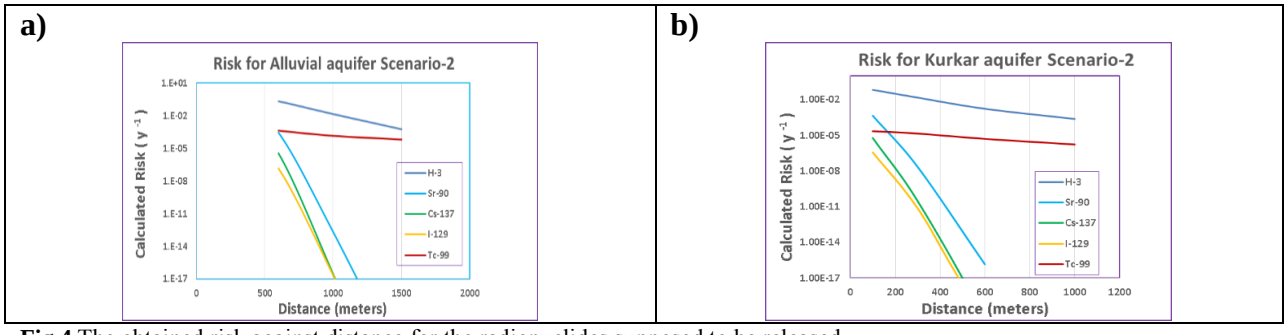


Fig.4 The obtained risk against distance for the radionuclides supposed to be released totally from the disposal site in a. Alluvium and b. Kurkar aquifers.

It can be deduced that tritium is the most significant radioisotope to the total maximum doses and cancer risk. Also, the rest of the radioisotopes can pose a significant risk if consumed through drinking water from the wells along the groundwater flow direction within 300m from the nuclear waste disposal site.

So, the groundwater could be of high-risk effects due to the duration of the hazard associated with the waste to a wide range of human beings and living creatures by consuming contaminated groundwater by radionuclides within 100: 300 m by most radionuclides and up to 1.5 km by ^{3}H for 200 y from the closure time of the waste disposal site.

4. Conclusion and recommendation

A risk analysis has been developed for the safety assessment of a proposed near-surface disposal facility concerning ^{3}H, ^{137}Cs, ^{90}Sr, ^{99}Tc, and ^{129}I radioisotopes. The annual effective dose received for a critical individual and risk due to waste disposal failure was calculated. The quantitative results indicate doses from drinking water consumption as activity is released from the repository to groundwater aquifers. In this study, ^{3}H is the nuclide with the most significant contribution to a dose exceeding the permissible limit of 0.3mSv/year. For the other radionuclides, the received doses at various receptor locations were significantly higher than the maximum dose limit in some cases. The risk is sometimes higher than in industrial accidents and natural catastrophes. So, more precautions should be taken when establishing this waste disposal repository at this site. Moreover, water shouldn't be consumed within 1500 m along the groundwater flow direction for more than 200 years.

The institutional control period of the waste disposal site should be extended to 200y instead of 100 years with continuing monitoring program to evaluate any impacts that the presence of the repository may have on natural processes and the environment. So, the groundwater could be of high-risk effects to a wide range of human beings and living creatures by consuming contaminated groundwater by radionuclides within 1.5 km far from the disposal site for 200 y from the closure time of the waste disposal site.

Statements and Declarations

Competing Interests: This work was done in the Nuclear and Radiological Safety Research Center (NRSRC) in the Egyptian Atomic Energy Authority (EAEA) and was not funded directly or indirectly for publication.

Declarations

Conflict of interest: The authors declare that they have no conflict of interest.

Acknowledgment

We acknowledge the Atomic Energy Authority for enabling us to complete this work in it, which is a part of research work for a Ph.D. thesis in the Faculty of Science – at Ain Shams University.

References

1. Kamunda, C., M. Mathuthu, and M. Madhuku, *Health risk assessment of heavy metals in soils from Witwatersrand Gold Mining Basin, South Africa.* International Journal of Environmental Research and Public Health, 2016. **13**(7): p. 663.
2. Organization, W.H. and WHO., *Guidelines for drinking-water quality*. Vol. 1. 2004: world health organization.
3. Agency, I.A.E., *Safety Assessment of Near Surface Radioactive Waste Disposal Facilities: Model Intercomparison Using Simple Hypothetical Data (Test Case 1)*. 1995: IAEA.
4. Bachu, S. and T. McEwen, *Geological media and factors for the long-term emplacement and isolation of carbon dioxide and radioactive waste*, in *Geological disposal of carbon dioxide and radioactive waste: a comparative assessment*. 2011, Springer. p. 23-79.
5. IAEA, *safety standards for protecting people and environment, disposal of*

radioactive waste. 2011, International atomic energy agency, Vienna..
6. Louvat, D., J. Rowat, and J. Potier, *The management of low activity radioactive waste: IAEA guidance and perspectives.* Disposal of Low Activity Radioactive Waste, 2005: p. 31.
7. Bennett, D., *Near Surface Disposal of Radioactive Waste: Safety Requirements (Safety Standards Series No WS-R-1) and Safety Assessment for Near Surface Disposal of Radioactive Waste: Safety Guide (Safety Standards Series No WS-G-1.1)*. 2002, IOP Publishing.
8. IAEA, *Safety assessment of near surface radioactive waste disposal facilities: Model intercomparison using simple hypothetical data (test case 1)*. 1995, IAEA Vienna, Austria.
9. Lee, Y.-M. and J. Jeong, *Evaluation of nuclide release scenarios for a hypothetical LILW repository.* Progress in Nuclear Energy, 2011. **53**(6): p. 760-774.
10. Organization, W.H., *Guidelines for drinking-water quality: second addendum. Vol. 1, Recommendations*. 2008: World Health Organization.
11. Radiation, U.N.S.C.o.t.E.o.A., *Sources and effects of ionizing radiation, united nations scientific committee on the effects of atomic radiation (UNSCEAR) 2008 report, volume I: Report to the general assembly, with scientific annexes A and B-sources*. 2010: United Nations.
12. Tauchi, H., et al., *Assessment of biological effect of tritiated water by using hypersensitive system.* Fusion Science and Technology, 2011. **60**(3): p. 1173-1178.
13. Wakeford, R., *The risk of leukaemia in young children from exposure to tritium and carbon-14 in the discharges of German nuclear power stations and in the fallout from atmospheric nuclear weapons testing.* Radiation and environmental biophysics, 2014. **53**(2): p. 365-379.
14. Brooks, A.L., D. Hoel, and W.M. Glines, *Radiobiology of Select Radionuclides in Hanford Site Tank Waste.* Health Physics, 2022: p. 10.1097.
15. No, I.S.S., *International basic safety standards for protection against ionizing radiation and for the safety of radiation sources.* 1996.
16. El Samanoudi, M., et al., *Assessment of groundwater resources in northeastern Sinai Peninsula constrained by mathematical modeling techniques.* J. Earth Sci. Eng, 2011. **1**: p. 23-34.
17. Sujitha, S., Datta, S. and Babu, G. *Risk Assessment of Low Level Radioactive Waste in Near Surface Disposal Facilities*, in *Geotechnical Safety and Risk V*. 2015, IOS Press. p. 425-430.
18. Kinahan, A., et al., *Assessment of radiation dose from the consumption of bottled drinking water in Japan.* International Journal of Environmental Research and Public Health, 2020. **17**(14): p. 4992.
19. Eckerman, K., et al., *ICRP publication 119: compendium of dose coefficients based on ICRP publication 60.* Annals of the ICRP, 2012. **41**: p. 1-130.
20. Carlsson, S. and J. Le Heron, *Radiation Protection. Chapter 3.* 2014.
21. Weiss, W., et al., *ICRP Publication 122: radiological protection in geological disposal of long-lived solid radioactive waste.* Annals of the ICRP, 2013. **42**(3): p. 1-57.
22. Nair, R. and T. Krishnamoorthy, *Probabilistic safety assessment model for near surface radioactive waste disposal facilities.* Environmental Modelling & Software, 1999. **14**(5): p. 447-460.