COMPUTER MODELS FOR SAFETY ASSESSMENT ON LAND DISPOSAL OF LOW LEVEL WASTES

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ABSTRACT

In Japan, a storage and land disposal of the low level wastes (LLW) has been expected to start at the Shimokita site, Aomori prefecture, in a few years.

The objectives of this paper are to develop the computer models for the safety assessment of the land disposal of the LLW and to provide the reliable results needed for the safety assessment at the Shimokita site.

In this paper, we calculated preliminaryly not only the geoenvironmental diffusion of radionuclides discharged from the site under predetermined conditions but also the internal radiation dose to individual, by using the computer codes developed by CRIEPI.

From the results of this trial estimation, we obtained 0.003 mrem/yr as radiation dose derived from the activities of the storage and land disposal, and clarified that the computer codes were available for the preliminary safety assessment.

INTRODUCTION

In Japan, the concentrical storage of the low level wastes (LLW) generated from nuclear power plants has been expected to start in a few years at the Shimokita site, Aomori prefecture. The storage of the LLW could be transformed into the land disposal if its positive safety is confirmed. However, it shall be needed that the safety for the storage or disposal of the LLW is gravely confirmed before getting those operating licence.

In view of the aforementioned situation, CRIEPI has researched and developed the safety assessment methods for the storage or land disposal of the LLW.

In this paper, we describe the outline of a whole safety assessment method including the mathematical models to analyze the ground-water flow and the radionuclide migration in saturated-unsaturated zones developed by CRIEPI. Furthermore, we calculated preliminaryly not only the geoenvironmental diffusion of radionuclides discharged from the site under preditermined conditions, but also the internal radiation dose to individual, by using the computer codes developed by CRIEPI.

COMPOSITION OF SAFETY ASSESSMENT CODE

Table I shows a composition of the available computer models developed by CRIEPI for the safety assessment on the storage and land disposal of the LLW.

We describe respectively the outline of these mathematical models as follows.

TABLE I

Composition of Safety Assessment Code

Computer Model	CRIEPI Code
Contaminant Source Model	CDRF
Ground-Water Flow Model	FEGM
Radionucride Migration Model	FERM
Food Chain/Radiation Dose Model	FORADO

CONTAMINANT SOURCE MODEL (CDRF)

CDRF is a computer model to estimate the discharge of radionuclides from a disposal facility for the safety assessment on the land disposal of the LLW (1).

In this model, the leaching rate of radionuclides from a solidified package is simulated by the diffusion source model in a semi-infinite medium. The following equation (1) and the initial/boundary conditions (2) are commonly used to express these phenomina (2).

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2} - \lambda C \tag{1}$$

$$\begin{cases} t = 0,\ 0<x<\infty\ ;\ C=Co \\ t > 0,\ x = 0\ ;\ C=o \\ t > 0,\ x = \infty\ ;\ C=Co\cdot\exp(-\lambda t) \end{cases} \tag{2}$$

where

- C concentration of contaminant materials
- D diffusion coefficient
- λ radionuclide decay
- t time
- x internal distance from boundary

Co initial concentration of C

The solution of (1) for these conditions is

$$C = Co \cdot \exp(-\lambda t) \cdot \mathrm{erf}\left(\frac{x}{2\sqrt{Dt}}\right) \qquad (3)$$

The total amount of leaching substances M from the whole surface of a package is given by

$$M = S \int_0^t D \left(\frac{\partial C}{\partial x}\right)_{x=0} dt \qquad (4)$$

where

Mo initial total amount of substances in package
S whole surface area
V volume of pakcage

From (3) and (4), we have (3).

$$\frac{M}{Mo} = \frac{S}{V} \sqrt{\frac{D}{\lambda}}\, \mathrm{erf}\,(\sqrt{\lambda t}) \qquad (5)$$

in which

$$Mo = CoV \qquad (6)$$

In this model, the total amount of discharge of radionuclides from the land disposal facility is calculated, considering the scientific basic conditions (radioactive species contained in packages, radionuclide-leachability from packages, number and corrosion of packages stored at repositories, the discharge rate of radioactivity from rapositories, etc).

GROUND-WATER FLOW MODEL (FEGM)

FEGM is a computer model to analyze the groundwater flow in saturated-unsaturated zones, and is based on FEMWATER developed by ORNL (3).. However, FEGM has been improved from FEMWATER and developed as a new code by CRIEPI (4).

The governing equation is given by

$$F \frac{\partial h}{\partial t} = \nabla[\bar{\bar{K}}\nabla(h + Z)] + Q \qquad (7)$$

$$\text{in which} \begin{cases} F = \theta \rho_f \beta' + \dfrac{d\theta}{dh} + \dfrac{\theta}{n}\alpha' \\ H = h + Z \end{cases} \qquad (8)$$

where

F generalized specific storage
h pressure head
$\bar{\bar{K}}$ hydraulic conductivity tensor (unsaturated)
Z potential head
Q recharge inflow rate
θ moisture content
ρ_f fluid density
β' modified compressibility of water
$d\theta/dh$ specific water content capacity
α' modified compressibility of medium
H total head

The major functions with FEGM are summarized as Table II. In this table, the several points which has been improved from FEMWATER are shown with a underline.

TABLE II

Major Functions with FEGM

Physical Law
Continuity of fluid Continuity of solid Motion of fluid (Darcy's low) Consolidation of medium Compressibility of water Mixing of salt water
Analytical Dimension
Two dimension (horizontal, vertical) Quasi three dimension Three dimension
Computation Method
Finite element method Linear isoparametric element (triangle, square, hexahedron) ∿Automatic mesh generation Approximation of time derivative Lumping of mass matrix
Boundary Condition
Dirichiet Neumann (Cauchy) Variable Seepage face (quasi three dimension)

RADIONUCLIDE MIGRATION MODEL (FERM)

FERM is a computer model to analyze the radionuclide migration in saturated-unsaturated zones, and has also been improved from FEMWASTE developed by ORNL (Refs. 3 and 5).

The governing equation is given by

$$(\theta+\rho_b K_d)\frac{\partial C}{\partial t} + C\frac{\partial \theta}{\partial t} + \alpha'(\theta+\rho_b K_d)C\frac{\partial h}{\partial t} + \nabla(VC)$$
$$-\nabla(\theta D \nabla C) + \lambda(\theta+\rho_b K_d)C$$
$$+(K_w\theta + K_s\rho_b K_d)C - M = 0 \qquad (9)$$

where

θ moisture content
ρb bulk density of medium
K_d distribution coefficient
C solute concentration
D dispersion coefficient
K_w, K_s decomposition rate constant
V Darcy's velocity
M mass source

The major functions with FERM are summarized as Table III. In this table, a few points which has been improved from FEMWASTE are shown with a under-line.

TABLE III

Major Functions with FERM

Transport Law
Advection Dispersion (Fick's law) Radionuclide decay Adsorption (linear isotherm, non-linear isotherm, reaction rate) Decomposition rate
Analytical Dimension
Two dimension (horizontal, vertical) Three dimension
Computation Method
Finite element method Linear isoparametric element (triangle, square, hexahedron) Approximation of time derivative Lumping of mass matrix
Boundary Condition
Dirichlet Neumann Cauchy

FOOD CHAIN/RADIATION DOSE MODEL (FORADO)

FORADO is a computer model to estimate the radiation dose for the safety assessment on the land disposal of the LLW (7). This model, in which the migration path-way of radionuclides was predetermined as shown in Fig. 1 considering its generality and the own condition in Japan, has been developed by CRIEPI based on the NRC model. (8)

In this model, the concentration of radionuclides in environments (unsaturated-saturated groundwater and sea water) can be estimated using the analytical solutions for a advective-diffusion equation and it in foods can be determined by the method of using the concentration factors. Furthermore, the internal radiation dose to individual is estimated by the method of using the ingestion dose factors.

On the other hand, FORADO has been developed so that we could also estimate the external radiation dose.

PRELIMINARY SAFETY ASSESSMENT FOR LAND DISPOSAL OF LLW

We calculated preliminaryly not only the geoenvironmental diffusion of radionuclides discharged from a generic site under predetermined conditions, but also the internal radiation dose to individual, by using the aforementioned computer codes CDRF, FEGM/FERM and FORADO.

Scenario of Storage and Disposal of LLW

It was supposed that the annual production of the solidified packages is 50,000 drums through 20 years (1981-2000) and that the start of carrying those in concrete pits and of those disposal are respectively in 1991 and 2001. (Refer to Fig. 2)

The leaching of radionuclides from packages was supposed to start after 15 years as a result of the drum corrosion that increase linealy to full surface after 30 years and is generated by diffusion. (Refer to Fig. 3)

Discharge of Radionuclides from Land Disposal Facility

The scientific basic conditions, that are the

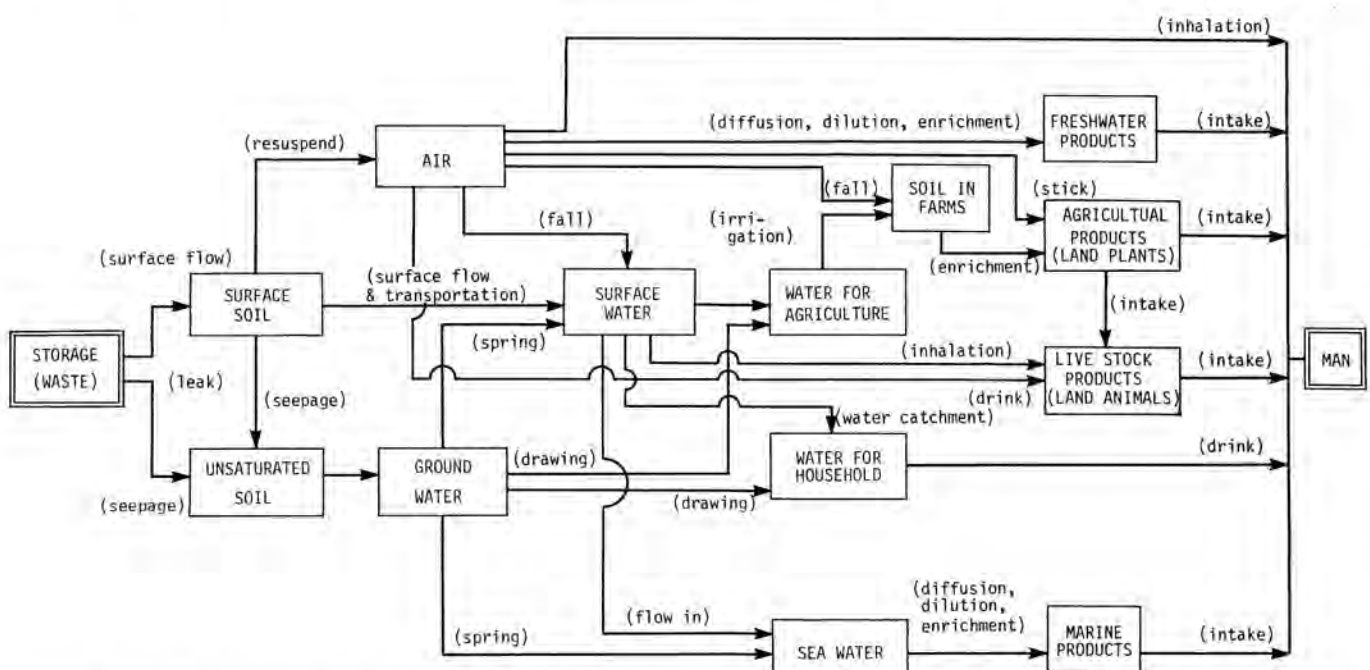

Fig. 1 The Predetermined Migration Path-Way of Radionuclides in the Environments of the Assessment Model

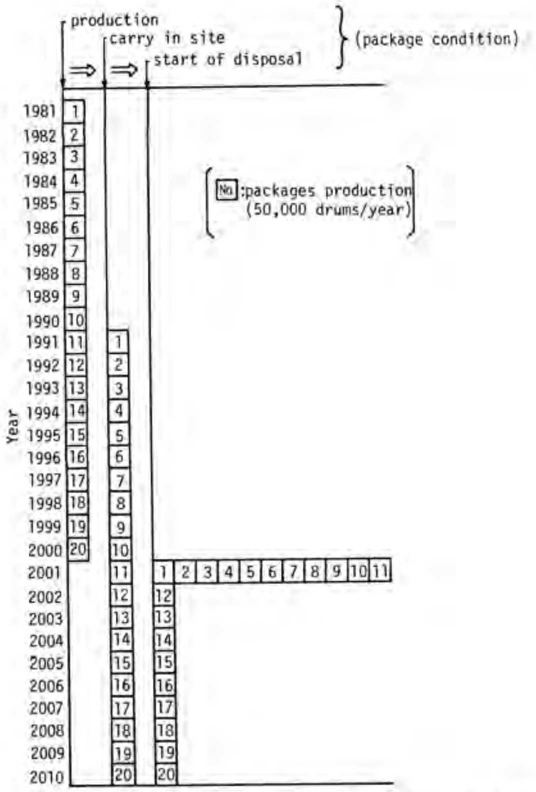

Fig. 2 Scenario for Storage and Disposal of LLW

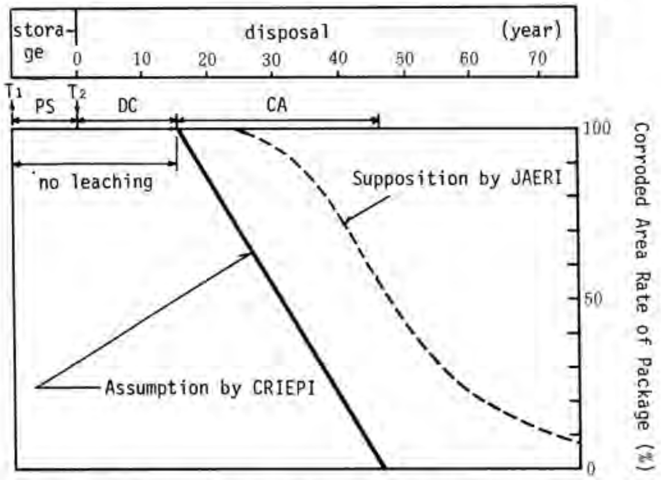

Fig. 3 Assumption of Corroded Area of Packages with Time

radioactive species contained in packages, radionuclide-leachability from package and so on, were predetermined.

Furthermore, it was also supposed that the radionuclides leached from packages are directly discharged from the disposal facility.

Under the predetermined and above-mentioned conditions, the calculated results of the annual discharge of radionuclides from the land disposal facility is shown in Fig. 4. (1) From these results, it is shown that the each maximum annual discharge of radionuclides (Cs-137, Co-60, Sr-90) is from 0.1 to 0.0001 Ci/Yr and is in order of Cs-137, Co-60 and Sr-90.

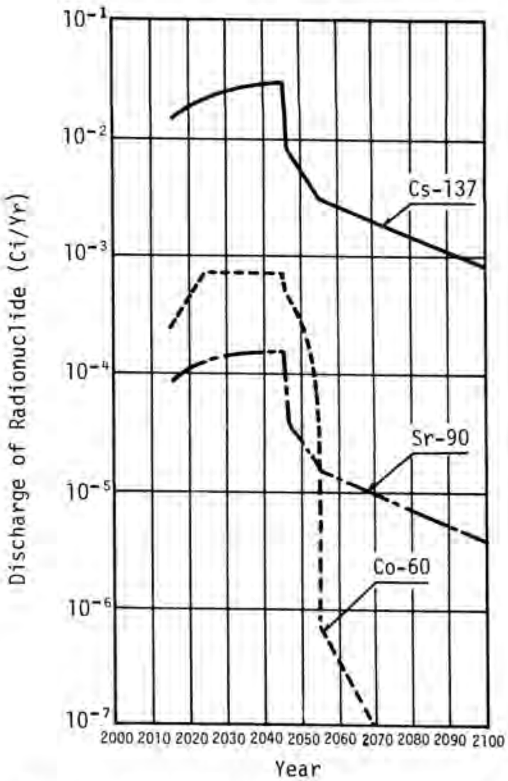

Fig. 4 Predicted Annual Radioactivities Discharged from Facility

Determination of Generic Site Conditions

The Generic site conditions were determined as shown in Fig. 5, refering to the results investigated for the geological and meteorological conditions with general coast regions in Japan. Table IV shows the major parameters needed for the calculation of the ground-water flow and the radionuclide migration on this site.

Simulation of Radionuclide Migration

We simulated the ground-water flow and the radionuclide migration based on the above conditions using FEGM and FERM. (5)

First, the critical horizontal direction of the saturated ground-water flow was roughly determined using the computer code FEGQ3D which is a quasi 3-dimensional submodel in FEGM.

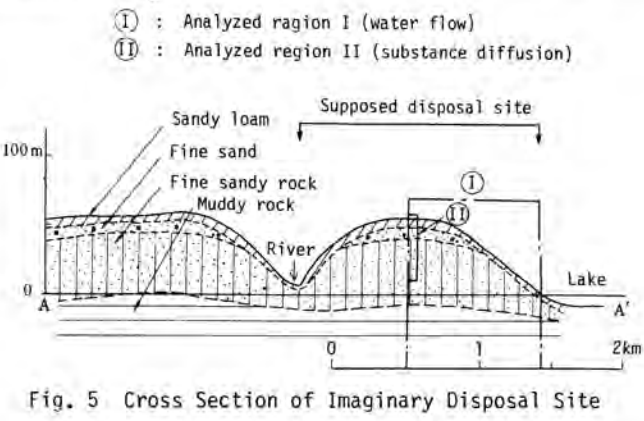

Fig. 5 Cross Section of Imaginary Disposal Site

TABLE IV

Major Input Condition for Simulation

(C.G.S. Unit)

Soil Layer / Item	Sandy Loam	Fine Sand	Fine Sandy Rock	Muddy Rock
Porosity	0.60	0.40	0.20	0.10
Permeability	$2x10^{-3}$	$8x10^{-2}$	$8x10^{-3}$	$1x10^{-5}$
Soil Density	2.6	2.5	2.5	2.6
Distribution coefficient ^{60}Co	100	10	10	100
Distribution coefficient ^{90}Sr	50	5	5	50
Longitudinal dispersivity	50	100	100	5
Lateral dispersivity	5	10	10	0.5
Tortuosity	3.5			
Radionuclide decay ^{60}Co	$4.2x10^{-9}$ 1/s			
Radionuclide decay ^{90}Sr	$7.6x10^{-10}$ 1/s			
Molecular diffusion coefficient	10^{-6} cm^2/sec			
Effective rainfall	900 mm/year			
Discharge rate of radionuclides (per floor area of a pit = 7.5m x 32m)	1 mCi/year/pit			

Next, the vertical 2-dimensional flow of saturated and unsaturated ground-water on the critical section A-A in Fig. 5 was analyzed by FEGM.

Based on the calculated ground-water flow and geological conditions, the migration of radionuclides (Cs-137, Co-60, Sr-90) was analyzed by FERM.

Fig. 6 shows an example of the simulated results for Sr-90, in which the discharge rate of each radionuclide from the bottom floor of a concrete pit was set annualy 1 m Ci per one pit and constant relating to Fig. 4. For the diffusion extent of Sr-90, it is shown that there is a remarkable difference between two cases that are saturated or not in the neighbourhood of the pit bottom.

From these results under the aforementioned conditions, it has been shown that Sr-90 might be rather critical than the other radionuclides and the unsaturated zone should be have the superior ability as a barrier to the radionuclides.

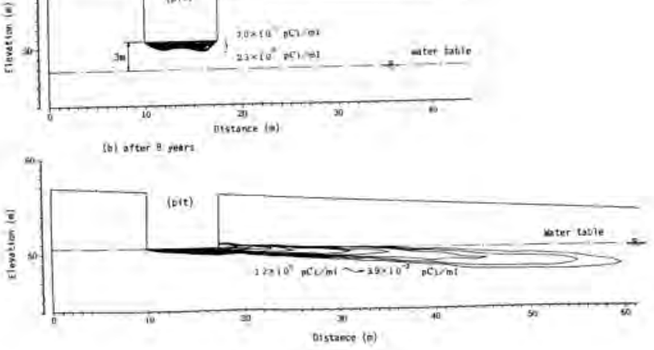

Fig. 6. Simulated Results of Diffusion (Sr-90).

Internal Radiation Dose to Individual

Under the site conditions and calculated results as aforementioned, the generic site conditions and the major input parameters needed for the estimation of radiation dose were respectively predetermined as shown in Fig. 7 and Table V.

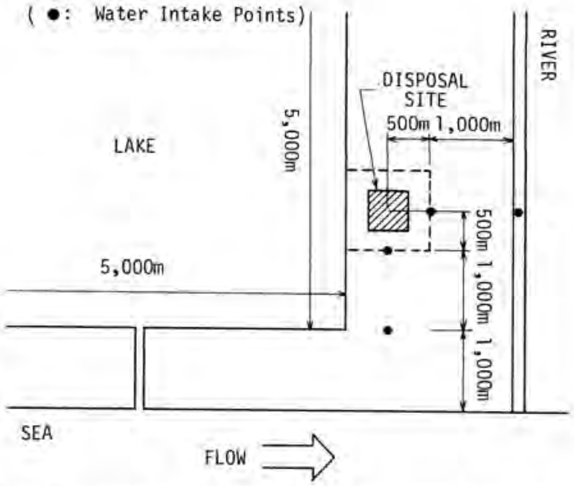

Fig. 7 Schematic Model of the Disposal Site for Preliminary Assessment

TABLE V

Available Parameters for Site Condition in the Assessment of Radiation Dose

		Unsaturated Zone	Saturated Zone
Area of disposal facility		500 x 500 = 250,000 (m^2)	
Effective rainfall		900 (mm/yr)	
Porosity		0.4	0.4
Degree of saturation		0.7	-
Flow velocity	sea	-	0.173 (m/day)
Flow velocity	lake	-	0.258 (m/day)
Flow velocity	river	-	0.345 (m/day)
Soil density		2.5 (g/cm^3)	2.5 (g/cm^3)
Distribution coefficient	^{60}Co	100 (ml/g)	10 (ml/g)
Distribution coefficient	^{90}Sr	50 (ml/g)	5 (ml/g)
Distribution coefficient	^{137}Cs	1,000 (ml/g)	100 (ml/g)
Thickness of the zone		3 (m)	1 (m)
Standard diffusion coefficient		10 (cm)	10 (cm)
Sea	Distance from the center of the disposal facility	2,500 (m)	
Sea	Flow velocity (10 km offshore)	8.6×10^4 (m/day)	
Sea	Diffusion coefficient (offshore direction)	10^5 (cm^2/sec)	
Sea	Diffusion coefficient (flow direction)	5.0×10^5 (cm^2/sec)	
Sea	Diffusion coefficient (depth direction)	10^2 (cm^2/sec)	
Lake	Distance from the center of the disposal facility	500 (m)	
Lake	Area	5,000 x 5,000 = 2.5×10^7 (m^2)	
Lake	Depth	1.0 (m)	
River	Distance from the center of the disposal facility	1,500 (m)	
River	Width	5.0 (m)	
River	Flow velocity	3.0 (m/sec)	
River	Depth	5.0 (m)	

The trial estimation was performed on the generic site by using the computer code FORADO, so that 0.003 mrem/yr was obtained as the internal radiation dose to individual. (Refer to Fig. 8.)

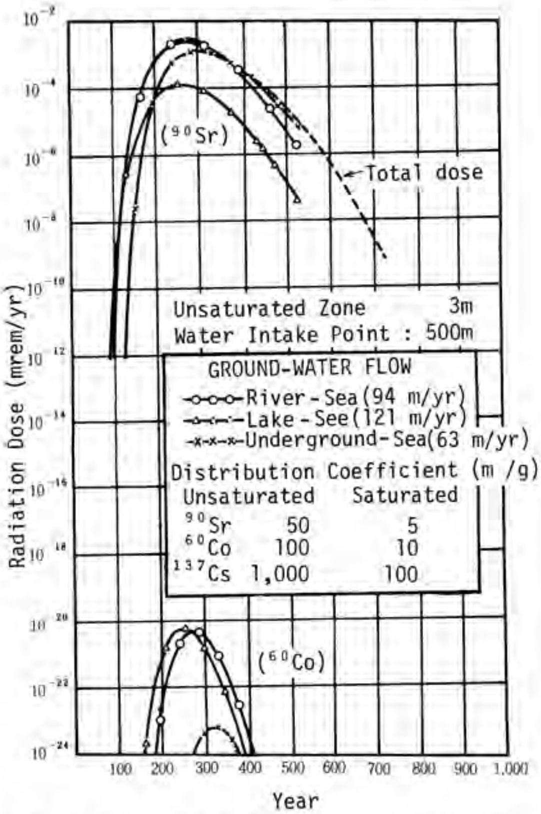

Fig. 8 Variation of Radiation Dose Increasing the Passage Time after Land Disposal

This result corresponds to a quarter million times as low as the permissible radiation dose recommended by ICRP. (7,9).

CONCLUSIONS

The computer code which is composed of the contaminant source model, ground-water flow model, radionuclide migration model and food chain/radiation dose model has been confirmed for the safety assessment on the land disposal of the LLW.

A preliminary safety assessment on the generic site under predetermined conditions has been performed by using the computer code developed by CRIEPI. In this trial estimation, it was shown that the unsaturated zone should be have the superior ability as a barrier to the radioactivities and the internal radiation dose should be a quarter million times as low as the permissible threshold value recommended by ICRP.

It has been clarified that these computer code should be enough to provide the reliable result in the safety assessment aimed at the Shimokita site.

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