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INTERNATIONAL ATOMIC ENERGY AGENCY CO-OPERATED RESEARCH PROGRAMME ON THE SAFETY ASSESSMENT OF NEAR-SURFACE RADIOACTIVE WASTE DISPOSAL FACILITIES (NSARS) RESULTS FOR TEST CASE 1 (Earth Trench Case)

January 1992

Tomoyuki TAKAHASHI, Kazuo KATOH, Hideo KIMURA and Hideo MATSUZURU

日 本 原 子 力 研 究 所
Japan Atomic Energy Research Institute

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International Atomic Energy Agency Co-operated Research Programme on the Safety Assessment of Near-surface Radioactive Waste Disposal Facilities (NSARS) Results for Test Case 1 (Earth Trench Case)

Tomoyuki TAKAHASHI, Kazuo KATOH, Hideo KIMURA and Hideo MATSUZURU

Department of Environmental Safety Research
Tokai Research Establishment
Japan Atomic Energy Research Institute
Tokai-mura, Naka-gun, Ibaraki-ken

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This report outlines the analytical work on the first test case, Test Case 1, specified by the IAEA sponsored co-operative research programme on the safety assessment of near-surface radioactive waste disposal facilities. Descriptions are provided on analytical methods used here, and the concept of an intrusion scenario which is not necessary fully specified in the Test Case 1. The Test Case 1 specifies two different concepts of waste disposal, i.e., disposal in an earth trench and disposal in a engineered concrete vault, and two kinds of scenarios, i.e., groundwater migration and intrusion scenarios. This study concerns with the former disposal concept, and consists of the following analytical steps;

- release of radionuclides from the facility,
- vertical migration of radionuclides in an unsaturated zone,
- horizontal migration of radionuclides in a saturated zone,
- exposure dose to man via a drinking water pathway, and
- exposure dose to an intruder via a construction and residence-farm sub-scenarios.

The results are presented in the standard form specified by the IAEA in the Test Case 1.

Keywords: Safety Assessment, Radioactive Waste, Near-surface Disposal, Groundwater Scenario, Intrusion Scenario, Disposal Facility, Trench, Vault, Migration, Saturated Zone, Unsaturated Zone

国際原子力機関協力研究プログラム
放射性廃棄物浅地層処分施設の安全評価（NSARS）
テストケース1（トレンチケース）の結果

日本原子力研究所東海研究所環境安全研究部
高橋　知之・加藤　和男・木村　英雄・松鶴　秀夫

（1991年12月4日受理）

本報告書は，「放射性廃棄物浅地層処分施設の安全評価」に関するIAEA協力研究プログラムで提案された最初の標準問題，テストケース1，に関する解析結果を取りまとめたものである。なお，ここで使用した解析手法，並びにテストケース1で十分に定義されていない侵入シナリオの概念についても記述した。テストケース1では，2種類の異なる処分方式，即ちトレンチ処分及びコンクリートピット処分が定義され，2種類のシナリオ，即ち地下水シナリオ及び侵入シナリオが定義されている。本研究では，トレンチ処分方式を対象に，以下の解析を行った。

－　施設からの放射性核種の放出，
－　不飽和層における放射性核種の垂直方向移行，
－　飽和層における放射性核種の水平方向移行，
－　飲料水経路による人間への被曝線量，
－　建設及び居住・農耕サブシナリオによる侵入者への被曝線量。

解析結果はテストケース1においてIAEAにより指定された標準形式に基づいて示した。

東海研究所：〒319－11　茨城県那珂郡東海村白方字白根2－4

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1. INTRODUCTION

In order to protect the public from radiation exposure associated with disposal of radioactive wastes, the wastes should be isolated from the human contact as long as radioactivities in the wastes are decayed out to a low level that may cause no significant health hazard. In practice, however, a complete isolation of the wastes might be impossible, and it might be rather natural to assume that radionuclides contained in the wastes may be gradually released into the groundwater environment, which eventually re-enter the biosphere. The safety of the wastes, particularly as regards the requirement for the radiological protection of the public and his environment even in the far future, is therefore essential objectives of all countries engaged in nuclear energy utilization.

Among the wastes, a low-level radioactive waste (LLW), generated mainly at a nuclear power plant in a large amount, is being disposed of near the Earth's surface in many countries. This might be rationalized by that LLW contains mainly short-lived radionuclides and a large portion of them is decayed into innocuous levels during the institutional control period of a few hundred years.

In Japan, LLW will be disposed of in an engineered shallow land disposal facility which based on a multiple barrier concept consisting of a waste form, container, cementitious buffer, reinforced concrete structure, and low-permeable zone [(1)]. The safety of disposal thus depends upon the ability of these engineered barriers to prevent and delay the release of radionuclides in the wastes, and the ability of natural barriers, consisting of the geosphere and the biosphere, to delay the migration of radionuclides. The acceptability of the disposal system proposed was judged in licensing procedures through safety assessment of the whole system.

The IAEA organized a Co-ordinated Research Programme (CRP) on "The Safety Assessment of Near-Surface Radioactive Waste Disposal Facilities (NSARS)", in correspondence with an increasing interest in the safety assessment of radioactive waste disposal. The main aims of the CRP are,

- to improve the confidence which can be attached to the results of safety assessments for near-surface radioactive waste disposal facilities by means of model intercomparison and validation,
- to help in establishing international consensus on the approach to safety assessment,
- and to facilitate exchange of information on safety assessment, its documentation and wider dissemination.

The JAERI is participating in NSARS aiming at the validation of the safety assessment methodology which was developed to evaluate radiological consequences associated with shallow land disposal of LLW containing a radionuclide with decay chain.

This report concerns with numerical works on Test Case 1 (Earth Trench Case), and provides brief descriptions of the methodology used here. The principal items to be analysed are as follows:

- Near-field performance in terms of release to geosphere (Fig. 1) for wastes in earth trench.
- Release from the near-field leading to transport through the aquifer and exposure to man via ingestion of drinking water from a well.
- Intrusion into the earth trench facility as part of construction of house foundations (Fig. 2) and exposures both during the intrusion and subsequently.

Radionuclides to be analysed are H-3, C-14, Cs-137 and Th-230 including daughter nuclides.

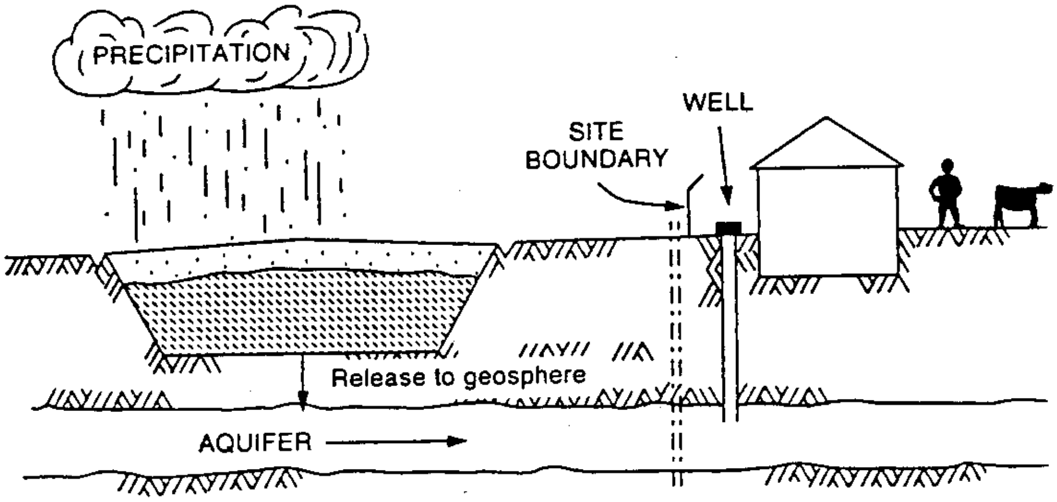

Figure 1. Sketch of the scenario of drinking well water outside the site boundary.

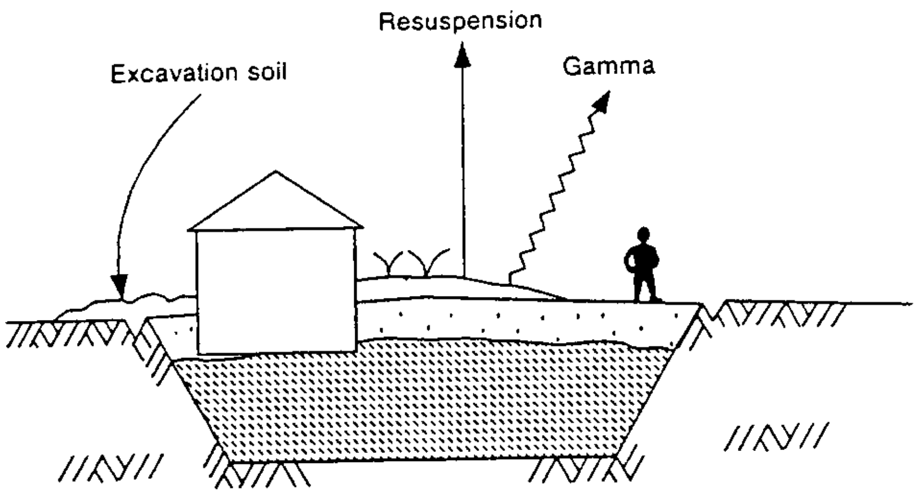

Figure 2. Sketch of the house building intruder scenario.

2. RELEASE OF RADIONUCLIDES TO GEOSPHERE

2.1 Input Specification

Test Case 1 requires the evaluation of the total amount of water infiltrating through the trench, leachate flowrate L (m^3/a), and the amount of the specified radionuclides into the geosphere (the aquifer). The earth trench concept is shown in Fig. 3. The parameter values defined are given in Table 1. The length of the facility is to be assumed perpendicular to the direction of groundwater flow. The site is in a temperate climate with an annual gross precipitation of 1000 mm assumed to be uniform throughout the year and evaporation of 400 mm during the year.

The nuclides and daughter nuclides selected and their half-lives are given in Tables 2 and 3. The inventory is arbitrarily set for time $t = 0$ at 1 TBq of each nuclides in Table 2. The inventories of daughter nuclides are assumed absent at $t = 0$.

The waste disposed of in the earth trench is in the form of miscellaneous trash materials (paper, plastics, metals, etc) with principally surface or absorbed contamination. The waste is assumed to have no significant containment, for example, drum having ruptured during or shortly after emplacement. The parameter values defined are given in Table 4.

Table 1 Parameter Values Defined for the Earth Trench Concept

Parameters	Values
Length of trench (m)	100
Width of trench (m)	10
Depth of trench (m)	5
Width of cap (m)	30
Length of cap (m)	120
Thickness of cap (m)	3
Gradient of cap	1 in 30
Porosity of cap	0.4
Hydraulic conductivity of cap (m/s)	10^{-8}
Distance above water table (m)	1

Table 2 Nuclides Specified and Their Half-Lives

Nuclide	Half-Life
H-3	12.35 a
C-14	5730 a
Cs-137	30.0 a
Th-230	7.7×10^4 a

Table 3 Daughter Nuclides and Their Half-Lives

Nuclide	Half-Life
Ra-226	1600 a
Rn-222	3.8235 d
Po-218	3.05 min
Pb-214	26.8 min
Bi-214	19.9 min
Po-214	1.643×10^{-4} s
Pb-210	22.3 a
Bi-210	5.012 d
Po-210	138.38 d
Pb-206	Stable

Table 4 Density and Porosity of Waste

Parameters	Values
Waste density (kg/m^3)	400
Waste porosity (−)	0.4

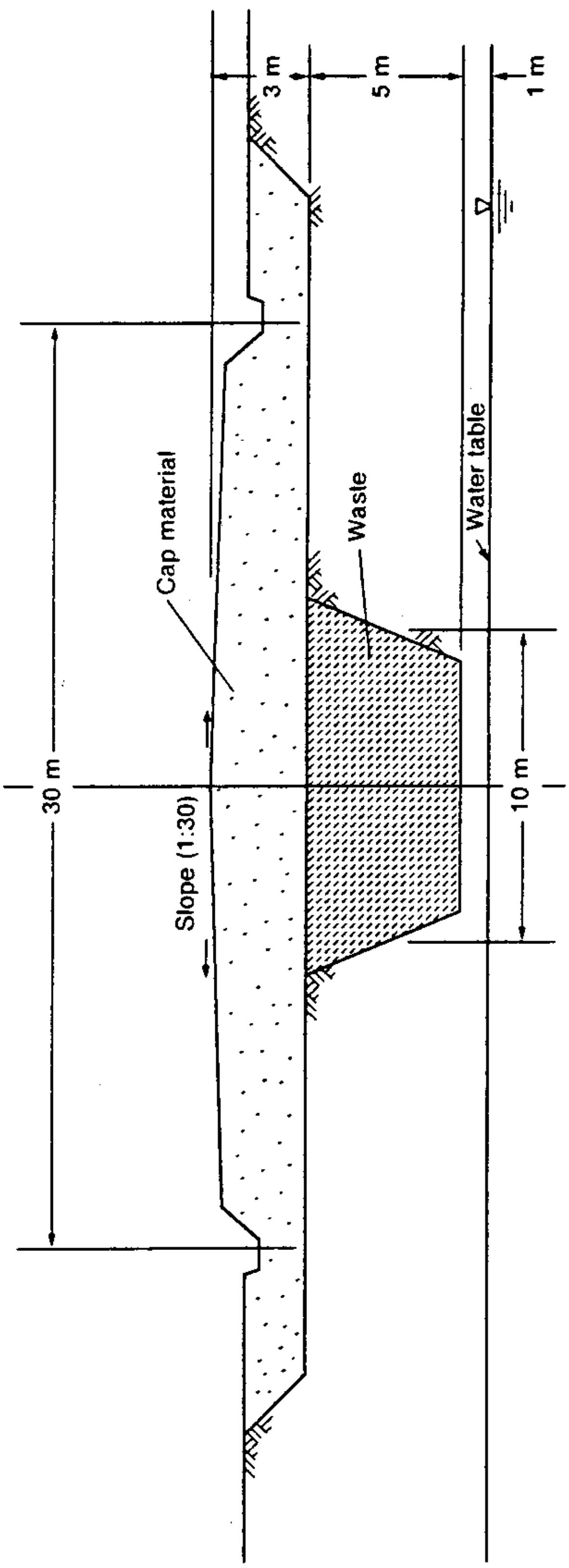

Figure 3. Earth trench disposal (T)

2.2 Infiltration into the Trench

The infiltration rate, v (m/a), of water into a trench was calculated by the following equation;

$$v = (P - E)(1 - R) = 0.186 \text{ m/a} \tag{1}$$

where,

P : precipitation (1 m/a),
E : evaporation (0.4 m/a),
R : run-off factor (0.69, typical value observed in Japan).

The total amount of water infiltrating through the waste having horizontal surface area of 1000 m^2, leachate flowrate L (m^3/a), is 1.86×10^2 m^3/a.

The maximum infiltration flowrate, v_{max}, is given by,

$$v_{max} = K = 0.315 \text{ m/a} \tag{2}$$

where K is hydraulic conductivity (1×10^{-8} m/s). This maximum value is high enough compared with that obtained with Eq.(1), and the infiltration rate of 0.186 m/a was therefore used in analyses.

2.3 Numerical Methodology

The trench is assumed to be composed of a mixture of the waste and surrounding soil. Radionuclides contained in the waste are assumed to be distributed homogeneously on the macroscopic scale, and are released at a given rate, 1 TBq/a, regardless of the nuclides analysed, from the waste into trench water. The transport of the nuclides in the trench is assumed to be governed by an advection, retention and decay. A soil layer existing between the trench and the aquifer is not defined in the specification of Test Case 1. We assumed therefore that the layer has vertical water flow and has the characteristics as given in Table 5.

Table 5 Characteristics of Trench and Soil Layer Domains

Parameters	Values of trench	Values of soil
u (m/a)	1.9×10^{-1}	1.9×10^{-1}
D (m^2/a)	9.3×10^{-2}	1.9×10^{-2}
K_{H-3} (−)	1.0×10^{0}	1.0×10^{0}
K_{C-14} (−)	1.0×10^{0}	1.0×10^{0}
K_{Cs-137} (−)	1.8×10^{2}	9.0×10^{2}
K_{Th-230} (−)	1.8×10^{3}	9.0×10^{3}
K_{Ra-226} (−)	6.1×10^{1}	3.0×10^{2}
K_{Pb-210} (−)	6.1×10^{1}	3.0×10^{2}
K_{Po-210} (−)	1.8×10^{2}	9.0×10^{2}
ε (−)	0.4	0.4
θ (−)	1	1
ρ (kg/m^3)	400	2000

Release of radionuclides from the trench and subsequent migration through the trench and the soil layer are analyzed with a computer code GSRW [(2)] which uses a numerical solution of a mass transport equation involving 1D-advection, 1D-dispersion, retention and 4-member decay chain. The governing equation for the system considered here is given by

$$\frac{\partial}{\partial t}(\varepsilon K_i C_i) = -\frac{\partial}{\partial x}\{uC_i - D_i\frac{\partial C_i}{\partial x}\} + q_i + \varepsilon(-\lambda_i K_i C_i + \lambda_{i-1}K_{i-1}C_{i-1}), \qquad (3)$$

where,

C_i : concentration of a nuclide in pore water (Bq/m^3) ,
u : the Darcy's velocity (m/a) ,
D_i : longitudinal dispersion coefficient (m^2/a) ,
q_i : source intensity (Bq/m^3/a) ,
λ_i : decay constant (a^{-1}) ,
K_i : retardation coefficient (−) ,

$$K_i = 1 + \frac{\rho K d_i}{\varepsilon\theta}$$

ρ : density (kg/m^3) ,
Kd_i : distribution coefficient (m^3/kg) ,
θ : water content (−) ,
ε : porosity (−) ,
x : spatial coordinate (m) ,
t : time (a) ,
i : index for a nuclide ($i-1$: parent nuclide) ,
R : index for a domain.

Let the length of l -th mesh between x_l and x_{l+1} be Δx_l in the domain which is divided into L meshes. Integration of Eq.(3) with respect to the l -th mesh gives,

$$\int_{x_l}^{x_{l+1}} dx \frac{\partial(\varepsilon K_i C_i)}{\partial t}$$

$$= -J_i|_{x_l}^{x_{l+1}} + \int_{x_l}^{x_{l+1}} dx \{q_i + \varepsilon(-\lambda_i K_i C_i + \lambda_{i-1} K_{i-1} C_{i-1})\}, \tag{4}$$

where J_i is a flux of the radionuclide i as defined by,

$$J_i \equiv uC_i - D_i \frac{\partial C_i}{\partial x}. \tag{5}$$

Now we consider the finite difference approximation of Eq.(4), the first term on the right side of the equation can be rewritten as follows:

$$\begin{aligned} -J_i|_{x_l}^{x_{l+1}} &= -J_i(x_{l+1}, t) + J_i(x_l, t) \\ &\simeq -uC_i(l,m) + D_i(l)\frac{C_i^+(l,m) - C_i(l,m)}{\Delta x_l/2} \\ &\quad +uC_i(l-1,m) - D_i(l)\frac{C_i(l,m) - C_i^-(l,m)}{\Delta x_l/2} \\ &= -uC_i(l,m) + uC_i(l-1,m) \\ &\quad + \frac{2D_i(l)D_i(l+1)}{D_i(l)\Delta x_{l+1} + D_i(l+1)\Delta x_l}\{C_i(l+1,m) - C_i(l,m)\} \\ &\quad - \frac{2D_i(l)D_i(l-1)}{D_i(l)\Delta x_{l-1} + D_i(l-1)\Delta x_l}\{C_i(l,m) - C_i(l-1,m)\}, \end{aligned} \tag{6}$$

where,

m	:	index of discretised time,
$C_i^+(l,m)$	:	concentration of a nuclide at the boundary between l-th and $l+1$-th mesh,
$C_i^-(l,m)$	:	concentration of a nuclide at the boundary between l-th and $l-1$-th mesh,
$C_i(l,m)$	:	concentration of a nuclide at the center of l-th mesh (Fig. 1-1).

The relationship between $C_i^+(l,m)$, $C_i^-(l,m)$ and $C_i(l,m)$ is shown in Fig. 4.

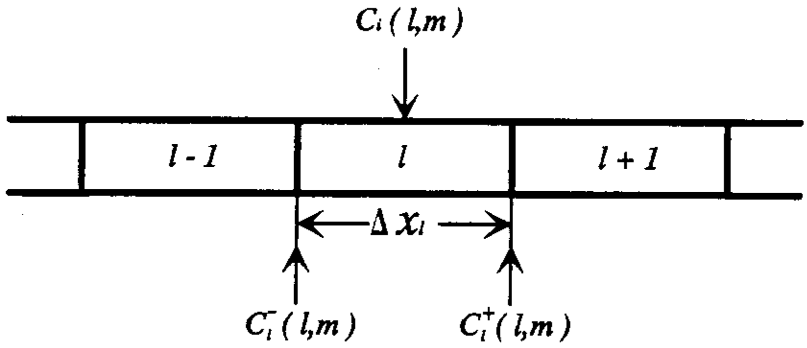

Figure 4 Relationship between $C_i^-(l,m)$, $C_i^+(l,m)$ and $C_i(l,m)$

The second term on the right side of Eq.(4) can be approximated as

$$\int_{x_l}^{x_{l+1}} dx\{q_i + \varepsilon(-\lambda_i K_i C_i + \lambda_{i-1} K_{i-1} C_{i-1})\}$$

$$= \Delta x_l\{q_i(l) - \lambda_i \varepsilon(l) K_i(l) C_i(l,m) + \lambda_{i-1}\varepsilon(l) K_{i-1}(l) C_{i-1}(l,m)\}. \tag{7}$$

And the left side of Eq.(4) is discretised as

$$\Delta x_l \varepsilon(l) K_i(l) \frac{C_i(l,m) - C_i(l,m-1)}{\Delta t}. \tag{8}$$

We thus obtain the following difference equation to be solved;

$$\Delta x_l \varepsilon(l) K_i(l) \frac{C_i(l,m) - C_i(l,m-1)}{\Delta t}$$

$$= -uC_i(l,m) + uC_i(l-1,m)$$

$$+\frac{2D_i(l)D_i(l+1)}{D_i(l)\Delta x_{l+1} + D_i(l+1)\Delta x_l}\{C_i(l+1,m) - C_i(l,m)\}$$

$$-\frac{2D_i(l)D_i(l-1)}{D_i(l)\Delta x_{l-1} + D_i(l-1)\Delta x_l}\{C_i(l,m) - C_i(l-1,m)\}$$

$$+\Delta x_l\{q_i(l) - \lambda_i \varepsilon(l) K_i(l) C_i(l,m) + \lambda_{i-1}\varepsilon(l) K_{i-1}(l) C_{i-1}(l,m)\}. \tag{9}$$

Time integration goes from the parent to daughters, and then the concentration of the parent is known with ease.

Eq.(9) can be rewritten with respect to index l as

$$e_i(l)C_i(l-1,m) + d_i(l)C_i(l,m) + f_i(l)C_i(l+1,m) = v_i(l), \tag{10}$$

where,

$$f_i(l) = \frac{2D_i(l)D_i(l+1)}{D_i(l)\Delta x_{l+1} + D_i(l+1)\Delta x_l}, \tag{11}$$

$$e_i(l) = f_i(l-1) + u, \tag{12}$$

$$d_i(l) = -f_i(l) - f_i(l-1) - u$$
$$-\Delta x_l \varepsilon(l) K_i(l)(\lambda_i + \frac{1}{\Delta t}) \qquad (l \neq 1, L), \tag{13}$$

$$v_i(l) = -\frac{\Delta x_l \varepsilon(l) K_i(l)}{\Delta t} C_i(l, m-1) - \Delta x_l q_i(l)$$
$$-\Delta x_l \varepsilon(l) \lambda_{i-1} K_{i-1}(l) C_{i-1}(l,m) \qquad (l \neq 1), \tag{14}$$

$$e_i(1) = f_i(L) = 0. \tag{15}$$

As the boundary condition, we assume that the top trench surface is no in or out flow boundary, i.e. nuclide flux is zero. In Eq.(4), therefore, we have the relation as

$$uC_i(0,m) + D_i(1)\frac{C_i(1,m) - C_i^-(1,m)}{\Delta x_1/2} = 0, \tag{16}$$

and then we obtain the following relations,

$$d_i(1) = -f_i(1) - u - \Delta x_1 \varepsilon(1) K_i(1)(\lambda_i + \frac{1}{\Delta t}), \tag{17}$$

$$v_i(1) = -\frac{\Delta x_1 \varepsilon(1) K_i(1)}{\Delta t} C_i(1, m-1) - \Delta x_1 q_i(1)$$
$$-\Delta x_1 \varepsilon(1) \lambda_{i-1} K_{i-1}(1) C_{i-1}(1,m). \tag{18}$$

Furthermore, we assume an additional boundary condition that the concentration of a nuclide at the boundary between the soil layer and saturated layer to give the following equation:

$$d_i(L) = -f_i(L-1) - u - \frac{2D_i(L)}{\Delta x_L} - \Delta x_L \varepsilon(L) K_i(L)(\lambda_i + \frac{1}{\Delta t}). \tag{19}$$

As the initial conditions, we assume that $C_i(l,0) = 0$, and all of the nuclide inventory, A_i (Bq), is released into the trench volume, V (m^3), within the first time step. The source intensity is thus given by: For the trench domain,

$$q_i(l) = \begin{cases} \frac{A_i}{V\Delta t} & (0 \le t \le \Delta t) \\ 0 & (t \ge \Delta t), \end{cases} \tag{20}$$

and for the soil layer,

$$q_i(l) = 0. \tag{21}$$

The total nuclide flux released from unsaturated layer to saturated layer is given by the integration the flux over the averaged cross section, S (m^2), of the trench,

$$J_i = \{uC_i(L,m) + D_i(L)\frac{2C_i(L,m)}{\Delta x_L}\}S. \tag{22}$$

It was confirmed that time and space meshes used here, as shown in Table 6, gave a well converged solution.

Table 6 Time and Space Meshes Used

Nuclide	Time mesh (a)	Space mesh (m)
H-3	1.0×10^{-2}	5.0×10^{-4}
C-14	1.0×10^{-2}	5.0×10^{-4}
Cs-137	1.0×10^{0}	5.0×10^{-4}
Th-230 series	1.0×10^{1}	1.0×10^{-3}

2.4 Results

Table 1TR and Fig. 1TR, contained in Appendix, show the results of analyses of radionuclide release rates into the geosphere. The radionuclides analyzed were H-3, C-14, Cs-137, Th-230, Ra-226, Pb-210 and Po-210. Among the daugthers involved in Th-230 series, short-lived nuclides such as Po-218, Pb-214, Bi-214, Po-214, and Bi-210, and a gaseous nuclide, Rn-222, were excluded in the present analyses. This is because that the code used here, GSRW, treats 4-member chain, and short-lived nuclides contribute insignificantly to internal doses which are an end point of the next analytical step.

Table 1TR clearly shows that a radionuclide having a low distribution coefficient gives a higher release rate and a shorter time at when the maximum release rate is obtained, and vice versa. The results obtained with Th-230 further indicate that an extremely long-lived nuclide, even having a higher distribution coefficient, gives a relatively higher release rate while a peak release time being longer. It might be therefore concluded that the release of radionuclides from the trench, analyzed by the model used here, is controlled by the combinational relationship between the distribution coefficient and half life of radionuclides.

3. TRANSPORT OF RADIONUCLIDES IN GEOSPHERE

3.1 Input Specification

The Test Case 1 assumes in "TRANSPORT OF RADIONUCLIDES IN GEOSPHERE" that an individual uses groundwater, as drinking water, taken from a well located at 500 m apart from the center of the trench along with the flow direction of the aquifer. Therefore, the following items are calculated;

- concentration of radionuclides in the aquifer as functions of path length and time,
- time-dependent effective dose equivalent associated from a pathway of drinking of well water.

The geosphere (the aquifer) is characterized as an unconfined sand aquifer with the defined properties given in Table 7. Additional parameters used here are given in Table 8.

Table 7 Characteristics of the Aquifer

Parameters	Values
Density (kg/m^3)	2000
Porosity (−)	0.25
Hydraulic conductivity (m/s)	10^{-5}
Hydraulic gradient	1 in 100
Saturated thickness (m)	10
Path length (m)	500
Longitudinal dispersivity (m)	50
Transverse dispersivity (m)	10
Water extraction rate (l/day)	100
Drinking water rate (l/day)	2.0

Table 8 Additional Parameter Values

Parameters	Values
v (m/a)	1.3×10^1
D (m^2/a)	6.3×10^2
$K_{H-3}(-)$	1.0×10^0
$K_{C-14}(-)$	1.0×10^0
$K_{Cs-137}(-)$	1.8×10^3
$K_{Th-230}(-)$	1.8×10^4
$K_{Ra-226}(-)$	6.0×10^2
$K_{Pb-210}(-)$	6.0×10^2
$K_{Po-210}(-)$	1.8×10^3

3.2 Numerical Methodology

A computer code GSRW, as was used in the analysis of RELEASE OF RADIONUCLIDES TO GEOSPHERE, was used. In this case, Eq.(3) may be simplified as

$$\frac{\partial C_i}{\partial t} = -\frac{v}{K_i}\frac{\partial C_i}{\partial x} + \frac{D'}{K_i}\frac{\partial^2 C_i}{\partial x^2} - \lambda_i C_i + \frac{\lambda_{i-1}K_{i-1}}{K_i}C_{i-1}, \quad (23)$$

where,

$$v = \frac{u}{\varepsilon}, \quad (24)$$

$$D' = \frac{D}{\varepsilon}, \quad (25)$$

The initial and boundary conditions used are;

$$C_i(x,0) = 0, \quad (26)$$

$$C_i(\infty,t) = 0, \quad (27)$$

$$C_i(0,t) = C_i^0. \quad (28)$$

The solutions of Eq.(23) satisfying the above conditions are obtained by the Laplace transformation as follows; for the parent,

$$C_1^S(x,t) = C_1^0 E(0,0,1), \quad (29)$$

for the first daughter,

$$\begin{aligned} C_2^S(x,t) &= C_2^0 E(0,0,2) \\ &+C_1^0\frac{4D'K_1\lambda_1}{v^2(\gamma_{001}-\gamma_{002})}\{E(0,0,2)-E(0,0,1)+E(1,2,1)-E(1,2,2)\}, \end{aligned} \quad (30)$$

for the second daughter,

$$\begin{aligned} C_3^S(x,t) &= C_3^0 E(0,0,3) \\ &+C_2^0\frac{4D'K_2\lambda_2}{v^2(\gamma_{002}-\gamma_{003})}\{E(0,0,3)-E(0,0,2)+E(2,3,2)-E(2,3,3)\} \end{aligned}$$

$$+C_1^0 \frac{4D'K_1\lambda_1}{v^2(\gamma_{001}-\gamma_{002})}[$$

$$\frac{4D'K_2\lambda_2}{v^2(\gamma_{002}-\gamma_{003})}\{E(0,0,3)-E(0,0,2)+E(2,3,2)-E(2,3,3)\}$$

$$-\frac{4D'K_2\lambda_2}{v^2(\gamma_{001}-\gamma_{003})}\{E(0,0,3)-E(0,0,1)+E(1,3,1)-E(1,3,3)\}$$

$$+\frac{4D'K_2\lambda_2}{v^2(\gamma_{121}-\gamma_{123})}\{E(1,2,3)-E(1,2,1)+E(1,3,1)-E(1,3,3)\}$$

$$-\frac{4D'K_2\lambda_2}{v^2(\gamma_{122}-\gamma_{123})}\{E(1,2,3)-E(1,2,2)+E(2,3,2)-E(2,3,3)\}\ ], \qquad (31)$$

and we can obtain the solution for the third daughter as the same manner mentioned before. Where,

$$E(i,j,k) = \frac{1}{2}\exp(\frac{vz}{2D'}-\beta_{ij}t)[\exp(\frac{xv\sqrt{\gamma_{ijk}}}{2D'})\mathrm{erfc}\{\frac{xK_k+vt\sqrt{\gamma_{ijk}}}{2\sqrt{D'K_kt}}\}$$

$$+\exp(-\frac{xv\sqrt{\gamma_{ijk}}}{2D'})\mathrm{erfc}\{\frac{xK_k-vt\sqrt{\gamma_{ijk}}}{2\sqrt{D'K_kt}}\}\ ], \qquad (32)$$

$$\beta_{ij} = \begin{cases} \frac{K_i\lambda_i-K_j\lambda_j}{K_i-K_j} & (i\neq 0, j\neq 0) \\ 0 & (i=j=0), \end{cases}$$

$$\gamma_{ijk} = 1+\frac{4D'K_k(\lambda_k-\beta_{ij})}{v^2}, \qquad (33)$$

Setting a period, during which the concentration at the source injection point is constrained, being T, the solution, C_i^B, is thus given by

$$C_i^B = C_i^S(t) - C_i^S(t-T). \qquad (34)$$

The total flux obtained in section II (RELEASE OF RADIONUCLIDES TO GEOSPHERE) is taken as a set of band release of a certain time interval, and the band release in each year is divided by annual flow rate in saturated layer to give the concentration of a nuclide at the injection point. Under the Dirichlet condition where the concentration at the injection point is fixed, the superimposing of each solution obtained for each time interval gives the concentration of a nuclide at the given point and time.

The effective dose equivalent associated with drinking of well water is calculated by the multiplication of the nuclide concentration in drinking water, annual intake, and dose conversion factor. The conversion factors are tabulated below.

Table 9 Dose Conversion Factors

Nuclide	Dose conversion factor (Sv/Bq)	
	Ingestion	Inhalation
H-3	1.7×10^{-11}	1.7×10^{-11}
C-14	5.7×10^{-10}	5.7×10^{-10}
Cs-137	1.4×10^{-8}	8.7×10^{-9}
Po-210	4.4×10^{-7}	2.2×10^{-6}
Pb-210	1.4×10^{-6}	3.4×10^{-6}
Ra-226	3.1×10^{-7}	2.1×10^{-6}
Th-230	1.5×10^{-7}	8.6×10^{-7}

3.3 Results

Table 1TW and Fig. 1TW, given in Appendix, show the results of the analyses of committed effective dose equivalents resulting from ingestion of drinking water taken from a well. The dose per unit TBq is in the order;

$$\text{C-14} > \text{H-3} > \text{Ra-226} > \text{Th-230} > \text{Pb-210} > \text{Po-210}$$

The dose from Cs-137 is negligible small compared with the other nuclides, reflecting from its shorter half-life and higher distribution coefficient. The nuclides analyzed here are classified into two groups with respect to the time of the peak dose:
Group 1: C-14 and H-3
Group 2: Ra-226, Th-230, Pb-210, Po-210
The nuclides in the group 1 give a relatively high dose at a shorter time, a few tenths years, while those in the group 2 give the peak dose at a longer time, a few 10^5 years. This distinction in the time of maximum might be ascribed to the difference in the distribution coefficient of the nuclides.

4. INTRUSION SCENARIO

4.1 Scenario Description

The Test Case 1 defines the scenario content as follows:

Intrusion into the repository is assumed not to occur before t = 100 a due to institutional controls being in force up till this time. As shown in Fig. 2, the excavation is assumed to penetrate the waste. The remaining features of the scenario and the parameters values are deliberately not specified in order to leave these open to participants and to stimulate discussion of these aspects at the RCM (Research Co-ordination Meeting).

As a part of the intrusion scenario, a construction and residence-farm sub-scenarios are considered here. The construction sub-scenario assumes that at the time immediately after the termination of institutional controls the a worker constructs a house on the disposal facility. To implement this scenario, a construction worker is arbitrarily assumed to dig a 4 meter deep hole for a cellar of the house. This assumption is not based on any construction experience, but is made only to evaluate the function of models involved in a computer code AMORE (3) used here. The mixture of the waste and soil thus excavated is assumed to be used to readjust all of sub-surface of the site. It is natural to assume that the sub-surface to be used for residential purpose will be covered with fresh soil without containing the waste, however this factor is neglected solely for a simplification. It is conservatively assumed that the worker spends 50 h inside the excavation and 500 h on the sub-surface contaminated.

In the residence-farm sub-scenario, a farmer is assumed to dwell in the house constructed as part of the construction sub-scenario, and consumes vegetation grown in soil contaminated during construction activities. The consumption of drinking water taken from a well drilled directly into the trench is not assumed here because of a poor water quality being anticipated. Irrigation by using well water is also excluded here because well water is rarely used in Japan for irrigation purpose except for a paddy field, and even so doing, water from a deep well and surface water bodies such as river lake and pond is used. The volume of waste/soil mixture brought to the surface is arbitrarily assumed to be infinite, and the mixture is assumed to cover all of the surface to be subjected to this analysis. These assumptions are obviously too conservative but are used to simplify the analysis. Transport and exposure pathways considered here for the both sub-scenarios are shown in Fig. 5.

The additional assumptions used here are:

- The trench cover is not eroded and keeps the initial depth.
- Radionuclides are uniformly distributed among the trench materials.
- Radionuclides in the trench are depleted only by radioactive decay.
- The both sub-scenarios initiate at t = 100 years.

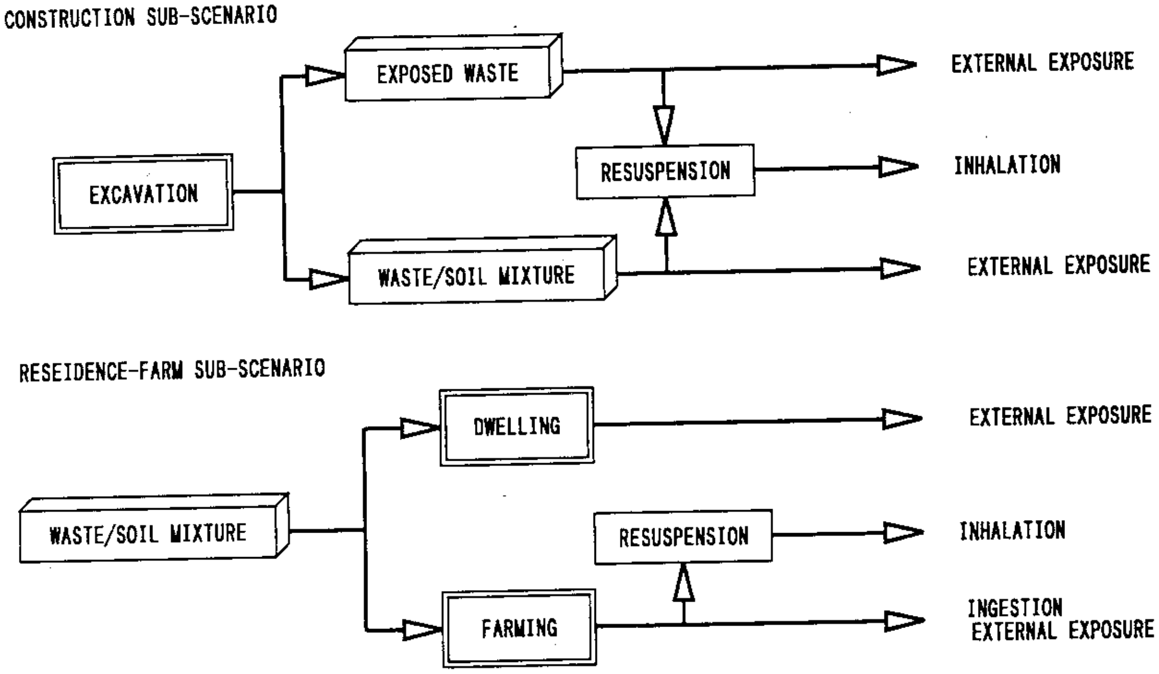

Figure 5   Exposure Pathways of Intrudsion Scenario

4.2 Model Description

(1) External exposure

The expression for effective dose equivalent which may be received by an individual via external exposure from a volume source,i.e. an exposed waste and the contaminated sub-surface, is:

$$R_{EXT,i} = T \cdot C_{e,i}(t) \cdot DF_{EXT,i} \cdot S_i \tag{35}$$

where,

$R_{EXT,i}$	:	effective dose equivalent from external exposure to the radiation from radionuclide i (Sv/a),
T	:	duration of exposure (a),
$C_{e,i}(t)$	:	concentration of radionuclide i in the waste or the mixture of the waste and soil (Bq/m^3),
$DF_{EXT,i}$	:	dose conversion factor for external irradiation from radionuclide i (Sv/a)/(Bq/m^3) which was calculated using QAD-CGGP2 (4) ,
S_i	:	shielding factor for external radiation from radionuclide i (−).

(2) Exposure from inhalation

A committed effective dose equivalent resulting from inhalation of material resuspended from the exposed waste or the contaminated ground is calculated by

$$R_{INH,i} = \frac{T \cdot B \cdot C_d \cdot C_{e,i}(t) \cdot DF_{INH,i}}{\rho} \tag{36}$$

where,

$R_{INH,i}$: committed effective dose equivalent from intake of radionuclide i by inhalation (Sv),

T : duration of exposure (h),

B : breathing rate of the individual(m^3/h),

C_d : concentration of respirable dust in air (g/m^3),

$C_{e,i}(t)$: concentration of radionuclide i in the waste or the mixture of the waste and soil (Bq/m^3),

ρ : density of the waste or the mixture of the waste and soil (m^3/g),

$DF_{INH,i}$: committed effective dose equivalent from inhalation of 1 Bq of radionuclide i (Sv/Bq).

(3) Exposure from ingestion

Among various kinds of foodstuffs to be obtained from agricultural activities, internal exposure from ingestion of vegetation is evaluated here. A committed effective dose equivalent resulting from ingestion of contaminated vegetation is calculated by

$$R_{ING,iv} = U_v \cdot C_{v,i}(t) \cdot D_{ING,i} \tag{37}$$

where,

$R_{ING,iv}$: committed effective dose equivalent from intake of radionuclide i by ingestion of vegetation v (Sv) ,

U_v : annual consumption rate of vegetation v (kg/a),

$C_{v,i}(t)$: concentration of radionuclide i in vegetation v (Bq/kg),

$DF_{ING,i}$: committed effective dose equivalent from ingestion of 1 Bq of radionuclide i (Sv/Bq).

It is assumed that the edible portion of vegetation is contaminated with radionuclides via root uptake from the soil, and then the concentration of radionuclide i in vegetation v is given by

$$C_{v,i}(t) = \frac{D_p \cdot f_r \cdot C_{p,i}(t) \cdot B_{i,v}}{P} \exp(-\lambda_i t_h) \tag{38}$$

where,

D_p : depth of plow layer (0.15 m),

f_r : fraction of the roots in the plow layer (1),

$C_{p,i}(t)$: concentration of radionuclide i in plow layer (Bq/m^3),

$B_{i,v}$: transfer factor for uptake of radionuclide i from the soil in vegetation v (Bq/kg-plant)/(Bq/kg-soil),

λ_i : decay constant of radionuclide i (d^{-1}),

t_h : holdup time between harvest and food consumption (d),

P : soil surface density (224 kg/m^2).

Radionuclides contained in the plow layer are assumed to be transported downward, by infiltrating water, into the layer which does not contribute root uptake mechanism. The concentration of radionuclide i in the plow layer is given by

$$C_{p,i}(t) = C_{e,i}(t) \exp\{-\lambda_{i,t}(t - T_s)\} \tag{39}$$

where,

$C_{e,i}(t)$: concentration of radionuclide i in the mixture of the waste and soil (Bq/m^3),

T_s : time when scenario initiates (100 a),

$\lambda_{i,t}$: removal constant for radionuclide i from the soil by infiltrating water (a^{-1}),

$$\lambda_{i,t} = \frac{v \cdot \varepsilon}{D_p\{\varepsilon + \rho(1-\varepsilon)Kd_i\}}$$

v : infiltration rate as defined by Eq. (1) (0.186 m/a),

ρ : density of the soil (g/cm^3),

ε : porosity of the soil (−),

Kd_i : distribution coefficient of radionuclide i (cm^3/g),

4.3 Input Parameter

Parameters values used here are given in the following tables. Most of the parameter values used here are cited from the IAEA document[5].

Table 10 Parameter Values Used in Construction and Residence-Farm Sub-Scenario

Parameters	Values
Dose conversion factor	
DF_{EXT} { (pSv/s)/(Bq/cm^3) }	
Cs-137	3.39×10^{1}
Th-230	2.82×10^{-2}

Table 11 Parameter Values Used in Construction Sub-Scenario

Parameters	Values
Duration of exposure to exposed waste (h/a)	50
Duration of exposure to waste/soil mixture (h/a)	500
Ratio of waste/soil mixture brought to the surface (−)	1/3
Shielding factor, S_i (−)	
All nuclides	0.5
Dust concentration in air, C_d (g/cm^3)	5×10^{-4}
Breathing rate, B (m^3/s)	3.3×10^{-4}

Table 12 Parameter Values Used in Residence-Farm Sub-Scenario

Parameters	Values
Duration of external and inhalation exposure (h/a)	1,900
Dust concentration in air, C_d (g/cm^3)	6×10^{-5}
Breathing rate, B (m^3/s)	2.7×10^{-4}
Transfer coefficient for soil-plant,	
$B_{i,v}$ { (Bq/kg-plant)/(Bq/kg-soil) }	
H-3	5
C-14	1×10^{-3}
Cs-137	3×10^{-2}
Th-230	1×10^{-3}
Consumption rate of vegetation, U_v (kg/a)	130

4.4 Results

The results of the analyses are shown in Tables 1TI1 (construction sub-scenario) and 1TI2 (residence-farm sub-scenario) of Appendix. Under the assumptions used here, important nuclides and exposure pathways are Th-230 (inhalation exposure) and Cs-137 (external exposure) for construction sub-scenario, and Cs-137 (external exposure), C-14 (ingestion exposure) and Th-230 (ingestion exposure).

5. CONCLUSION

The specifications given by the Test Case 1 are not necessarily fully descriptive, and rather permit the participants of NSARS a great deals of freedom in modelling of the problem proposed. The specifications might be adequate to compare modelling approaches of the participants, but not pertinent for all of the purposes of NSARS proposed by the IAEA. The arbitrariness in comprehension of the problem inevitably result in that the comparison of the results presented by the participants is difficult.

Analyses have been conducted on the Test Case 1 (trench disposal concept) using the computer codes GSRW and AMORE. GSRW was used to evaluate the release and transport of radionuclides in the trench and the soil layer existing between the trench and the aquifer, and transport in the aquifer. AMORE deals with radiological consequences of an intruder resulting from the intrusion scenario, i.e. the construction and residence-farm sub-scenarios. The results which were obtained under the assumptions arbitrarily made here indicate the followings;

- a nuclide having a low distribution coefficient between soil components and water, and a long half-life gives a relatively high consequence,
- a nuclide with a high distribution coefficient and a short half-life offers an insignificant dose,
- a nuclide with a high distribution coefficient and a long half-life yields a relatively high consequence.

To confirm the conclusions mentioned above, an extensive sensitivity analysis might be required, but these analyses have not been addressed here. The numerical values of the doses given in this report have no practical and realistic means, since the assumptions used here were made rather arbitrarily, and do not reflect realistic features of any existing disposal site.

REFERENCES

(1) MATSUZURU,H., WAKABAYASHI,N., SHIMA,S. et al.: Development of Safety Assessment Methodology for Shallow-Land Disposal Low-Level Radioactive Waste, Pro. of the 1989 Joint International Waste Management Conference, Ed. by FEIZOLLAHI,F. et al., the American Society of Mechanical Engineers (1989).

(2) KIMURA,H.: To be published.

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(5) IAEA:Exemption of Radiation Sources and Practices fro regulatory Control, IAEA TECDOC-401, IAEA (1987).

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APPENDIX

RESULTS OF ANALYSIS

COUNTRY : JAPAN
ORGANIZATION : JAERI

RESULTS FOR NSARS TEST CASE 1T: EARTH TRENCH

1TR. RELEASE TO GEOSPHERE

Description of release model :

The infiltration rate, v (m/a), of water into a trench was calculated by the following equation;

$$v = (P - E)(1 - R)$$

where,

P : precipitation (m/a),

E : evaporation (m/a),

R : run-off factor (0.69).

The trench is assumed to be composed of a mixture of waste and surrounding soil. Radionuclides contained in the waste are assumed to be distributed homogeneously on the macroscopic scale, and are released, at a given rate, from the waste into trench water. Release of radionuclides from the trench and subsequent migration through the trench and unsaturated layer are analyzed with a computer code GSRW which uses a numerical solution of a mass transport equation involving 1D-advection, 1D-dispersion, retention and 4-member decay chain. The governing equation for the system considered here is given by;

$$\frac{\partial}{\partial t}(\varepsilon K_i C_i) = -\frac{\partial}{\partial x}\{uC_i - D_i \frac{\partial C_i}{\partial x}\} + q_i + \varepsilon(-\lambda_i K_i C_i + \lambda_{i-1} K_{i-1} C_{i-1}), \qquad (1)$$

where,

C_i : concentration of a nuclide in pore water (Bq/m^3) ,

u : the Darcy's velocity (m/a) ,

D_i : longitudinal dispersion coefficient (m^2/a) ,

q_i : source intensity (Bq/m^3/a) ,

λ_i : decay constant (a^{-1}) ,

K_i : retardation coefficient (−) ,

ε : porosity (−) ,
x : spatial coordinate (m) ,
t : time (a) ,
i : index for a nuclide ($i-1$: parent nuclide) ,
R : index for a domain.

Parameter values (additional to those specified) :

Table 1 shows the values of parameters used here. Since the parameter values related to unsaturated layer are not specified, the porosity of the layer is assumed to be those of the trench domain, the density is those of saturated layer, and the water content is 1.

Table 1 Characteristics of Trench and Soil Layer Domains

Parameters	Values of trench	Values of soil
u (m/a)	1.9×10^{-1}	1.9×10^{-1}
D (m^2/a)	9.3×10^{-2}	1.9×10^{-2}
K_{H-3} (−)	1.0×10^{0}	1.0×10^{0}
K_{C-14} (−)	1.0×10^{0}	1.0×10^{0}
K_{Cs-137} (−)	1.8×10^{2}	9.0×10^{2}
K_{Th-230} (−)	1.8×10^{3}	9.0×10^{3}
K_{Ra-226} (−)	6.1×10^{1}	3.0×10^{2}
K_{Pb-210} (−)	6.1×10^{1}	3.0×10^{2}
K_{Po-210} (−)	1.8×10^{2}	9.0×10^{2}
ε (−)	0.4	0.4
θ (−)	1	1
ρ (kg/m^3)	400	2000

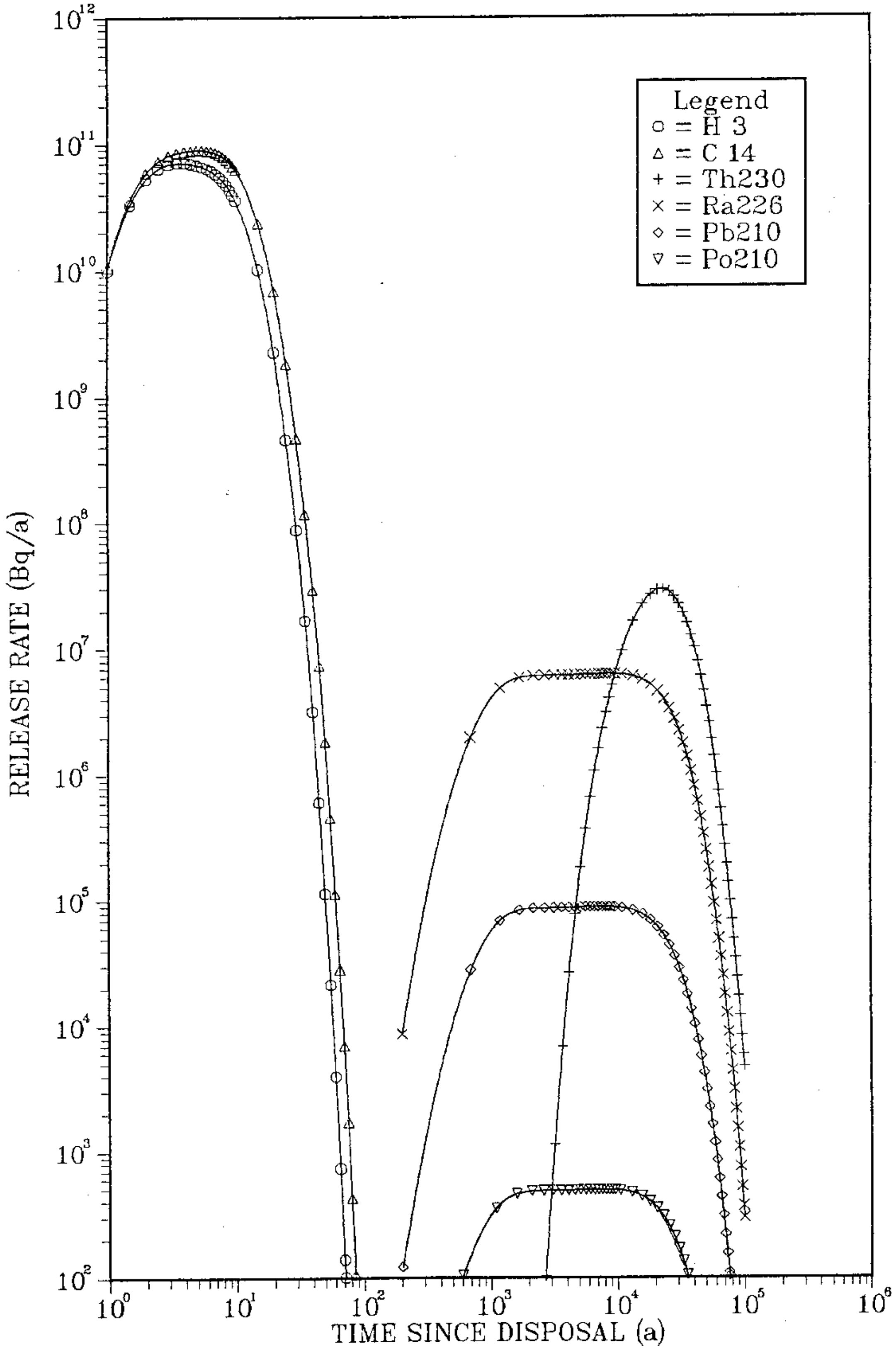
Leachate flowrate (m^3/a) : 1.86×10^2

TABLE 1TR. MAXIMUM RELEASE RATE

Nuclide (incl. daughters)	Maximum release rate (Bq/a)	Time of maximum (a)
H−3	7.1×10^{10}	3.7×10^{0}
C−14	9.0×10^{10}	5.1×10^{0}
Cs−137	1.4×10^{1}	4.4×10^{2}
Th−230	2.9×10^{7}	2.3×10^{4}
Ra−226	6.3×10^{6}	8.6×10^{3}
Pb−210	8.8×10^{4}	7.6×10^{3}
Po−210	5.0×10^{2}	7.6×10^{3}

RESULTS FOR NSARS TEST CASE 1T: EARTH TRENCH

FIGURE 1TR. RELEASE TO GEOSPHERE



COUNTRY : JAPAN
ORGANIZATION : JAERI

RESULTS FOR NSARS TEST CASE 1T: EARTH TRENCH

1TW. EXPOSURE TO MAN VIA WELL USE

Description of transport model :

A computer code GSRW, as was used in the analysis of RELEASE TO GEOSPHERE, was used. In this case, Eq.(1) may be simplified as,

$$\frac{\partial C_i}{\partial t} = -\frac{v}{K_i}\frac{\partial C_i}{\partial x} + \frac{D'}{K_i}\frac{\partial^2 C_i}{\partial x^2} - \lambda_i C_i + \frac{\lambda_{i-1} K_{i-1}}{K_i} C_{i-1}, \quad (2)$$

where,

$$v = \frac{u}{\varepsilon},$$

$$D' = \frac{D}{\varepsilon},$$

The initial and boundary conditions used are;

$$C_i(x,0) = 0,$$

$$C_i(\infty,t) = 0,$$

$$C_i(0,t) = C_i^0.$$

The effective dose equivalent associated with drinking of well water is calculated by the multiplication of the nuclide concentration in drinking water, annual intake, and dose conversion factor.

Parameter values (additional to those specified) :

Table 2 shows the values of parameters used here.

Table 2 Parameter Values

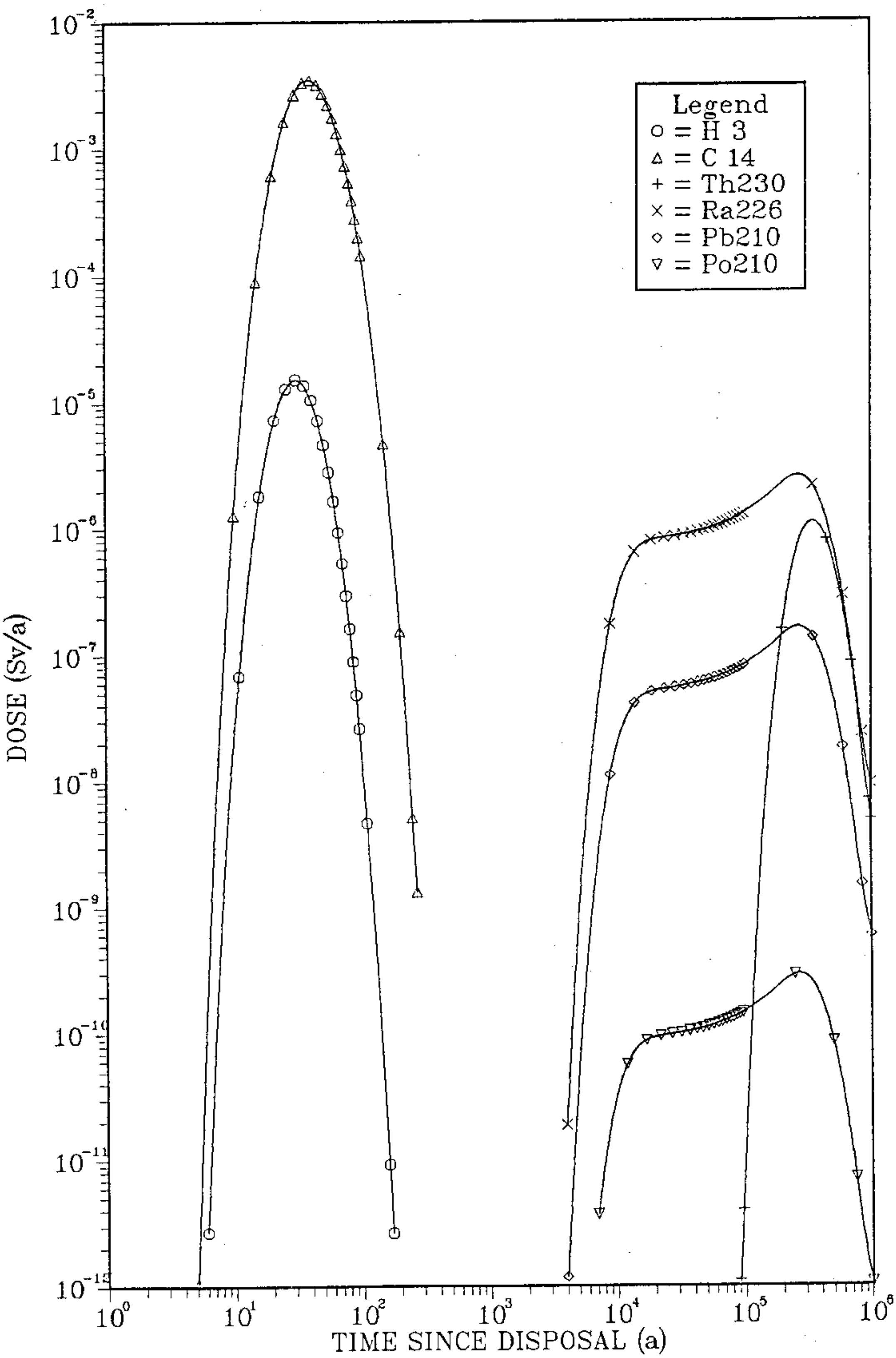
Parameters	Values
v (m/a)	1.3×10^{1}
D (m^2/a)	6.3×10^{2}
$K_{H-3}(-)$	1.0×10^{0}
$K_{C-14}(-)$	1.0×10^{0}
$K_{Cs-137}(-)$	1.8×10^{3}
$K_{Th-230}(-)$	1.8×10^{4}
$K_{Ra-226}(-)$	6.0×10^{2}
$K_{Pb-210}(-)$	6.0×10^{2}
$K_{Po-210}(-)$	1.8×10^{3}

TABLE 1TW. EFFECTIVE DOSE EQUIVALENT FOR DRINKING WELL WATER

Nuclide (incl. daughters)	Maximum dose (Sv/a)	Time of maximum (a)
H-3	1.5×10^{-5}	3.1×10^{1}
C-14	3.5×10^{-3}	3.9×10^{1}
Cs-137	3.9×10^{-65}	3.2×10^{3}
Th-230	1.1×10^{-6}	3.5×10^{5}
Ra-226	2.5×10^{-6}	2.7×10^{5}
Pb-210	1.6×10^{-7}	2.7×10^{5}
Po-210	2.9×10^{-10}	2.7×10^{5}

RESULTS FOR NSARS TEST CASE 1T: EARTH TRENCH

FIGURE 1TW. DOSE FOR DRINKING WELL WATER



COUNTRY : JAPAN
ORGANIZATION : JAERI

RESULTS FOR NSARS TEST CASE 1T: EARTH TRENCH

1TI1. INTRUSION EXPOSURE

Name of the scenario :

Site re-use scenario; Construction sub-scenario

Description of the scenario :

In the final stage of the regulatory control of a disposal site, after the institutional control terminates, the site will be released for unrestrained use. The safety of the site release will be estimated by using a site re-use scenario. In this scenario, it is assumed that the site will be used as a residential area and a farm. The scenario, therefore, involves events associated with the construction of a house, dwelling in the house and farming, and is correspondingly divided into the construction and residence-farm sub-scenarios. In the construction sub-scenario, a worker is assumed to construct a house on the site, and as a part of works he excavate a 4 m deep hole for foundation The potential exposure pathways considered here are:
(1) external direct gamma exposure from exposed wastes and waste/soil mixture,
(2) and internal exposure from inhalation of resuspended materials.

Parameter values :

Ratio of waste/soil mixture brought to the surface : 1/3
Dust concentration in air : 5×10^{-4} g/m^3
Shielding factor for all nuclides : 0.5
Exposure duration for exposed waste : 50 h
Exposure duration for waste/soil mixture : 500 h
Breathing rate : 3.3×10^{-4} m^3/s

TABLE 1TI1. MAXIMUM DOSE FROM INTRUSION EXPOSURE

Nuclide	Individual effective dose equivalent (Sv/a)				
(incl.daughters)	Ingest.	Inhal.	Ext. irr.	Radon exp.	Total
H−3		8.78×10^{12}	———		8.78×10^{12}
C−14		8.02×10^{8}	———		8.02×10^{8}
Cs−137		1.25×10^{7}	4.33×10^{3}		4.33×10^{3}
Th−230		1.23×10^{2}	3.58×10^{5}		1.23×10^{2}

COUNTRY : JAPAN
ORGANIZATION : JAERI

RESULTS FOR NSARS TEST CASE 1T: EARTH TRENCH

1TI2. INTRUSION EXPOSURE

Name of the scenario :

Site re-use scenario; Residence-farm sub-scenario

Description of the scenario :

A farmer is assumed to dwell in a house constructed as a part of a construction sub-scenario, and consume vegetation grown in soil contaminated during construction activities. The potential exposure pathways considered here are:
(1) external direct gamma exposure from exposed waste/soil mixture,
(2) internal exposure from inhalation of resuspended materials,
(3) internal exposure from ingestion of vegetation.

Parameter values :

External and inhalation exposure duration : 1,900 h/a
Dust concentration in air : 6×10^{-5} g/m^3
Breathing rate : 2.7×10^{-4} m^3/s
Consumption rate of crops : 130 kg/a

TABLE 1TI2. MAXIMUM DOSE FROM INTRUSION EXPOSURE

Nuclide	Individual effective dose equivalent (Sv/a)			
(incl.daughters)	Ingest.(crops)	Inhal.	Ext. irr.	Total
H−3	1.43×10^{5}	2.31×10^{13}	———	1.43×10^{5}
C−14	6.42×10^{3}	2.12×10^{9}	———	6.42×10^{3}
Cs−137	1.87×10^{4}	3.30×10^{9}	1.17×10^{2}	1.19×10^{2}
Th−230	3.87×10^{3}	3.42×10^{4}	9.72×10^{5}	4.31×10^{3}