IAEA CO-ORDINATED RESEARCH PROGRAMME

ON

"THE SAFETY ASSESSMENT OF NEAR-SURFACE RADIOACTIVE
WASTE DISPOSAL FACILITIES (NSARS)"

(1st Research Co-ordination Meeting-RCM)

RELEASE OF RADIONUCLIDES FROM BURIED WASTES AND TRANSPORT TO GEOSPHERE

(Research Agreement Nº 6539/CF)

IPEN-CNEN/SP

BRAZIL

1991

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INTRODUCTION

Until now there is no permanent LLW site to receive the radioactive wastes produced by nuclear and radioactive installations in Brazil. There is a forecast of a total of 8000 m^3 of wastes for the year 2010 plus 3500 m^3 resulting from the Goiânia accident. Some studies are being performed by CNEN (Comissão Nacional de Energia Nuclear) at IPEN (Instituto de Pesquisas Energéticas e Nucleares) to establish criteria for the land disposal of radioactive wastes as well to evaluate its safety.

At present there is a suitable site under consideration for disposal of the contaminated materials resulting from the Goiania's accident, occurred in Sep. 1987, with a cesium radiotherapy source.

Beyond the authorities' requirements for an assessment of the proposed practice to be undertaken, there is a strong pressure from the society for safety. Thus a program that involves the validation of probabilistic or deterministic codes, in the evaluation of the safety of disposal practices, may contribute as other important argument for public acceptance.

As was not available any computer code to evaluate the radiological impact of disposal facilities as a first phase it was taken the PRESTO II (Prediction of Radiation Effects from Shallow Trench Operations) (1) to obtain expertise in such area.

A sensitivity analysis of the computer code PRESTO-II was developed at IPEN (2), based on the surface response replacement and statistic sensitivity estimator, to address the relative importance of the input parameters on the model input.

Concerning our analysis with connection to the exposition path, the ingestion was always the dominant process for the maximum annual dose.

Nowadays there is a preliminary computer code seeking to simulate more realistic equations for different scenarios.

It allows, for instance, to simulate a large number of years, to calculate the amount of water leaving the cap surface as overland flow; to correct the annual inventory of radionuclides for decay series and to estimate the dispersion of radionuclides into the aquifer. The annual output for the activity concentration in the well is given as the sum of contributions from all release years.

DESCRIPTION OF THE SCENARIOS

Earth trench scenario

This study will provide an evaluation of an earth trench idea of a near-surface waste disposal facility.

The wastes have miscellaneous trash materials (paper, plastics, metals, etc.). They are considered randomly emplaced in the trench, backfill with previously excavated earth, compacted, and covered with a thick cap composed with a low hydraulic conductivity material. Generally, the compacted cap contains clay that expands when moist, to retard infiltration of rain water. It is then mounded to favor the runoff.

Rain or groundwater that enters a trench leach the contents of the buried wastes. The leached material is carried to the aquifer by the infiltrated water vertically through the subtrench soil. The contaminated water, after arriving the aquifer, is transported through the ground to a downgradient well where a person can use it. For the vertical displacement from the trench to the aquifer it was not considered any dispersion.

The aquifer is supposed to be water saturated where the radionuclides are transported considering mechanical mixing described by longitudinal and transverse dispersion coefficients applied in analytical groundwater transport models (3).

Engineered vault design

Engineered barriers that retard the release of contaminants from the land disposal facilities and reduces a potential inadvertent intruder was also considered as a scenario. The idea envisaged is a multiple concrete vault used to reduce the probability of radionuclides release to the environment. This developing computer code is in progress connected with laboratory experiments to model more realistically the involved transport phenomena.

Some intruder scenarios speculate the habits of the country and the supposed evolution of the generations.

DESCRIPTION OF THE CODE

The code used for the inter-comparison of the release to geosphere and exposure of a man via well use permitted that the proposed earth trench scenario be evaluated. Our aim is to improve it soon to permit that engineered vault designs can be simulated with the same code structure.

Water infiltration mechanism

The water enters the trench via infiltration through the intact or failed portions of the cap. On the failed portion of the cap, the infiltration is the sum of rainfall plus irrigation. On the intact portion of the cap only a fraction of the water available for infiltration is allowed to enter the trench. This fraction is the ratio of the hydraulic conductivity of the cap to the infiltration water velocity through a soil layer neighbor to the disposal facility.

The volume of water available to enter the trench annually is:

$$W_T = A_T[\ f_c(P+I) + (1 - f_c)W_a]$$

where

W_T = volume of water penetrating the trench (m^3/a)
A_T = area of trench (m^2)
f_c = fraction of the cap that has failed
P = annual precipitation (m/a)
I = annual irrigation (m/a)
W_a = annual infiltration rate for intact portion of cap (m/a)

The annual infiltration rate for the intact portion of the cap is evaluated from the water balance equation:

$$P + I = W_a + E + R$$

where

E = annual total evapotranspiration (m/a)
R = annual runoff (m/a)

Here, a runoff fraction is defined as:

$$f_R = R/P$$

Thus, the value of W_a can be expressed by the expression:

$$W_a = (1-f_R)P+I-E$$

The fraction of rainfall or irrigation water lost as surface runoff depends upon the hydraulic conductivity and slope of the cap.

That fraction is estimated in the model by (3):

$$f_R = s[1-K/(P+I)]$$

where

s = slope of the cap = $\Delta h/\Delta x$
K = permeability of the cap defined as the water volume transmitted per unit surface area per unit of time

Leaching of radionuclides

To calculate the concentration of radionuclides in the leaching water it was considered the distribution coefficient K_D combined with the hypothesis of waste totally wetted by the water infiltration into the trench.

Also, the concentration can be evaluated considering the solubility of radionuclides in the water, or any other formulation supplied by the user.

Several technical papers exist in the literature claiming one or other explanation for the leaching mechanism but until now there is no definitive model that explain fully the leaching behavior for all radionuclides (4). This is specially true for scenarios of disposal facilities where the boundary conditions are different of the controlled leaching experiments.

Vertical transport of radionuclides

After the contaminated material has been leached in the trench it is assumed to be transported vertically to the aquifer.

The model used by Matsuzuru (5) utilizes a complex way of evaluation for that displacement. The present model assumes that there is no dispersion on the vertical movement and that the material travels with a velocity equal to the water infiltration rate divided by the soil porosity.

Thus, it was considered simply that the velocity of radionuclide transport is retarded about water by the vertical retardation factor R_V calculated by:

$$R_V = 1 + \rho_S K_D / \epsilon_V$$

where

ρ_S = density of subtrench soil
K_D = distribution coefficient
ϵ_V = porosity of subtrench soil

Transport of radionuclides in the aquifer

For the transport of radionuclides to a well through an aquifer were considered longitudinal and transverse dispersion coefficients.

The concentration of each radionuclide at some point downgradient of the projected trench bottom into the aquifer was evaluated using a simple analytical model. It considers a horizontal area source of length L and width W centered at coordinates (0,0,0) in an aquifer of constant depth H (6). The length and width are the same of the trench and the length of the facility was supposed perpendicular to the direction of the ground water flow.

The expression used to calculate the annual concentration in the well is:

$$\text{Concentration} = X_2 * Y_2 * Z_2 / (\epsilon * R_H)$$

where:

ϵ = porosity of the aquifer
D_L = longitudinal dispersion coefficient = dispersivity * velocity of water in the aquifer
D_W = transverse dispersion coefficient = dispersivity * velocity of water in the aquifer
R_H = horizontal retardation coefficient
v = velocity of water in the aquifer
X = distance of well in x-axis
Y = distance of well in y-axis

$$X_2=(1/2L)\left[\operatorname{erf}\frac{(X+L/2-vt/R_H)}{\sqrt{4D_Lt/R_H}}-\operatorname{erf}\frac{(X-L/2-vt/R_H)}{\sqrt{4D_Lt/R_H}}\right]\exp(-\lambda t)$$

$$Y_2=(1/2W)\left[\operatorname{erf}\frac{(W/2+Y)}{\sqrt{4D_Wt/R_H}}+\operatorname{erf}\frac{(W/2-Y)}{\sqrt{4D_Wt/R_H}}\right]$$

and

$$Z_2=1/H$$

The annual total well activity concentration for each radionuclide is a sum of contributions from all release years.

Dose evaluation

The dose calculation, in this first phase of the code, is obtained simply by using the dose conversion factors of each radionuclide (7) and the annual ingestion or inhalation rate together with the radionuclides concentrations in the water of the well or in the air. Doses resulting from the ingestion of meat, milk or any other food grown on the surroundings of the site area are also considered in the scenario.

SPECIFICATION FOR TEST CASE 1 FROM IAEA (CASE 1T)

Nuclides and inventory

For the modeling some nuclides have been chosen with features that permits to examine a range of characteristics and limitations of some codes.

The inventory was established arbitrarily for time t = 0 at one TBq for each radionuclide. The radionuclides considered are shown in Table I. Other characteristics of the radionuclides to be considered in the proposed problem are shown in Table II and III.

Table I - NUCLIDES AND DAUGHTERS WITH HALF-LIVES

NUCLIDES	HALF-LIFE
H3	12.35 a
C14	5730 a
Cs137	30.0 a
Th230	77000 a
Ra226	1600 a
Rn222	3.8235 d
Po218	3.05 m
Pb214	26.8 m
Bi214	19.9 m
Po214	1.643 E-4 s
Pb210	22.3 a
Bi210	5.012 d
Po210	138.38 d
Pb206	Stable

Table II - SORPTION COEFFICIENTS

ELEMENT	Sorption coefficient (m_3/kg)
H	0
C	0
Cs	0.3
Th	3
Ra	0.1
Po	0.1
Pb	0.3

Table III - DOSE CONVERSION FACTORS

NUCLIDE (including daughters)	ADULT DOSE PER UNIT INTAKE (Sv/Bq)	
	INHALATION	INGESTION
H3	1.7 E-11	1.7 E-11
C14	5.7 E-10	5.7 E-10
Cs137	8.7 E- 9	1.4 E- 8
Po210	2.2 E- 6	4.4 E- 7
Pb210	3.4 E- 6	1.4 E- 6
Ra226	2.1 E- 6	3.1 E- 7
Th230	8.6 E- 5	1.5 E- 7

Characteristics of the trench (1T)

A general idea of the trench idea used for the simulation is shown in figures 1 and 2. The main dimensions are displayed in figure 2 and other details are presented in Table IV.

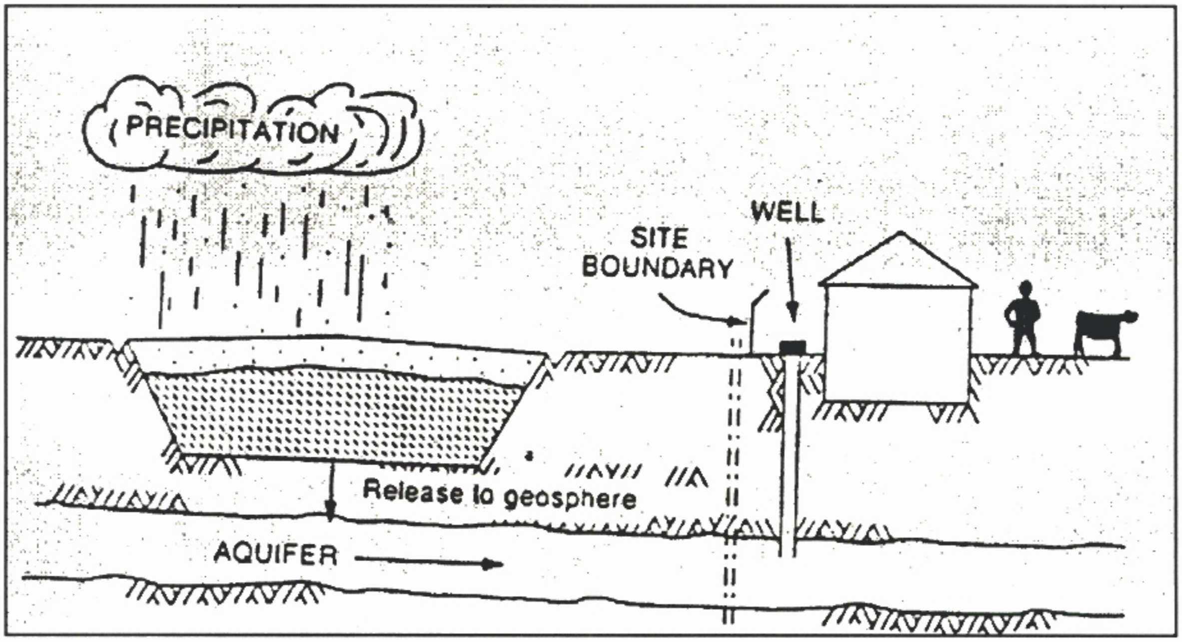

Figure 1 - Scenario of drinking water outside the site boundary

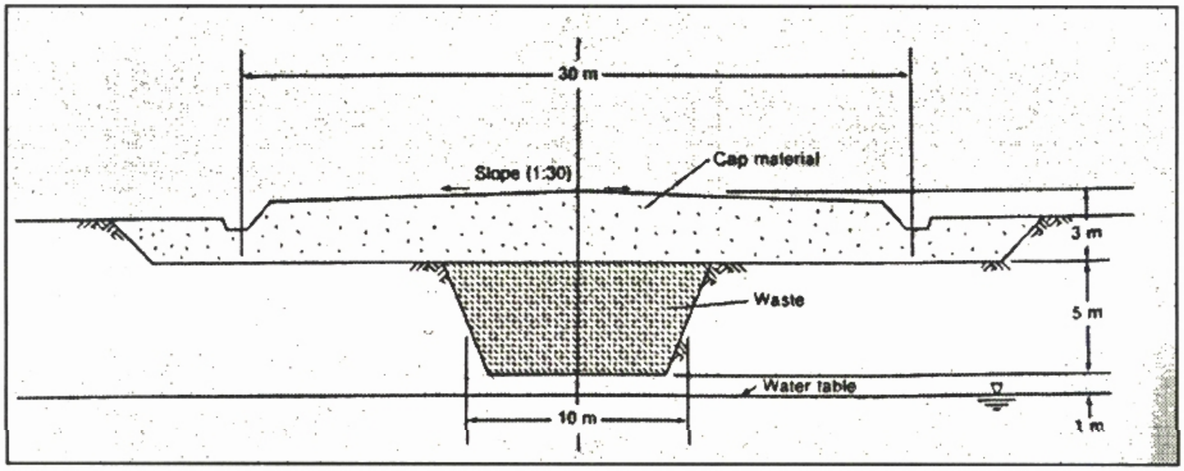

Figure 2 - Earth trench disposal (T)

Waste form

The contamination was assumed be loosely attached to the waste material so that the simple contact with water was sufficient to

Table IV - PARAMETER VALUES FOR THE EARTH TRENCH CONCEPT

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

leach it according to the distribution coefficient K_D. In addition, the concentration of radionuclides in the water passing through the waste was calculated as a function of the K_D of each radionuclide. For this earth trench scenario it was not considered any time delay in the leach mechanism.

RESULTS

In Table V is displayed the results obtained for the maximum geosphere release for each radionuclide from the inventory. The time of maximum for the release was the same for all radionuclides. This occurred, in part, due that it was not considered any selective delay of release for the radionuclides into the leaching mechanism and that ^{230}Th, ^{226}Ra, ^{210}Pb and ^{210}Po were assumed to be in secular equilibrium.

The figure 3 shows the release rate of radionuclides for the subtrench region as function of time.

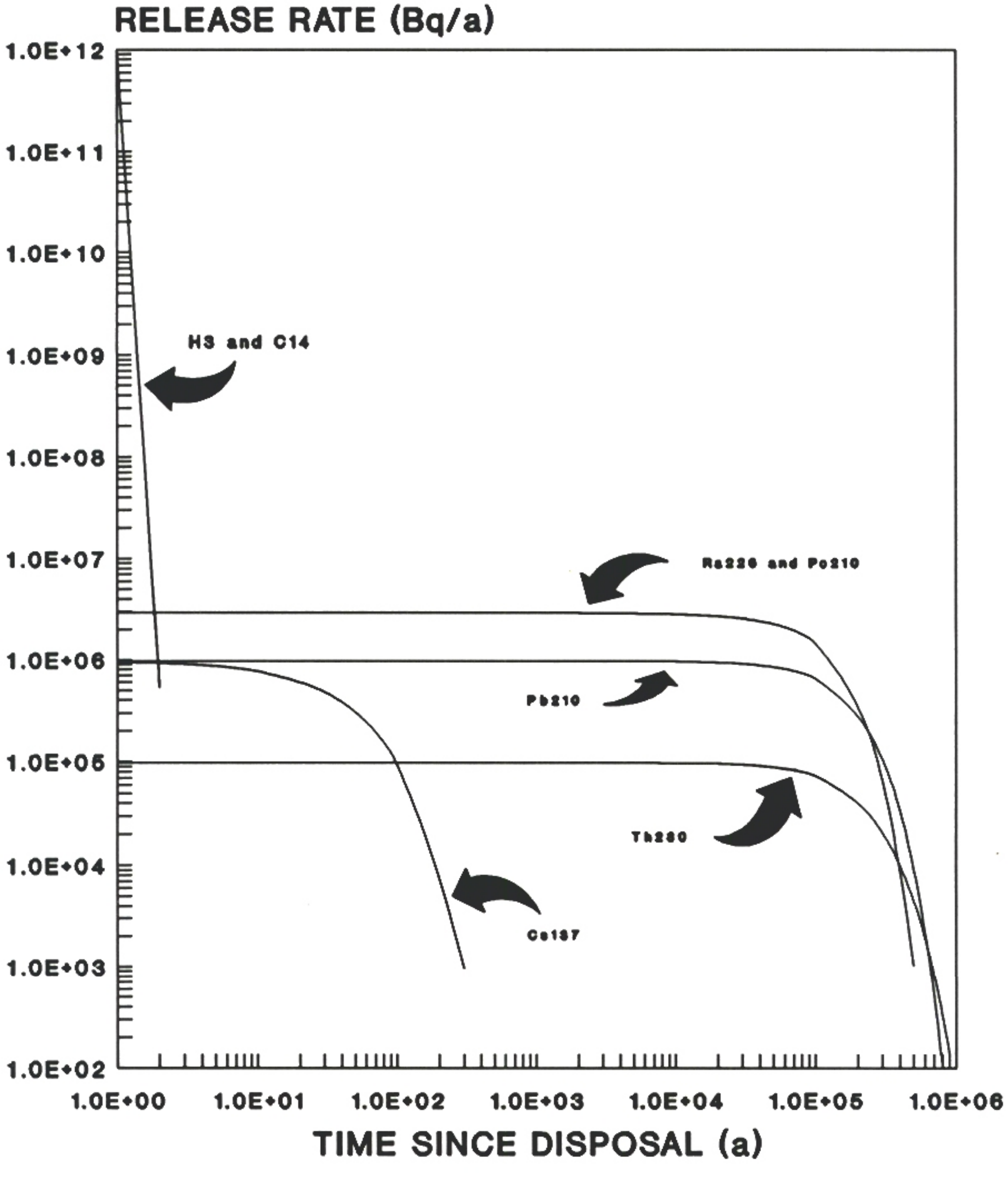

Figure 3 - Activity release rate to geosphere

Table V - MAXIMUM RELEASE RATE TO GEOSPHERE

Nuclide (incl. daughters)	Maximum release rate (Bq/a)	Time of maximum (a)
H-3	9.450E+11	1
C-14	9.994E+11	1
Cs-137	9.516E+05	1
Th-230	9.742E+04	1
Ra-226	2.922E+06	1
Pb-210	9.738E+05	1
Po-210	2.922E+06	1

In Table VI is presented the maximum effective dose equivalent for drinking well water for all radionuclides. Three of them do not contribute for the dose since none of them reaches the aquifer.

Table VI - EFFECTIVE DOSE EQUIVALENT FOR DRINKING WELL WATER

Nuclide (incl. daughters)	Maximum dose (Sv/a)	Time of maximum (a)
H-3	5.280 E-16	453
C-14	2.354 E-03	461
Cs-137	none	none
Th-230	none	none
Ra-226	3.100 E-06	380280
Pb-210	none	none
Po-210	4400 E-06	380280

In Figure 4 is shown the activity concentration distribution in the well, for a source of 37 GBq, as a function of time in the aquifer. Figure 5 shows the annual dose contribution for each

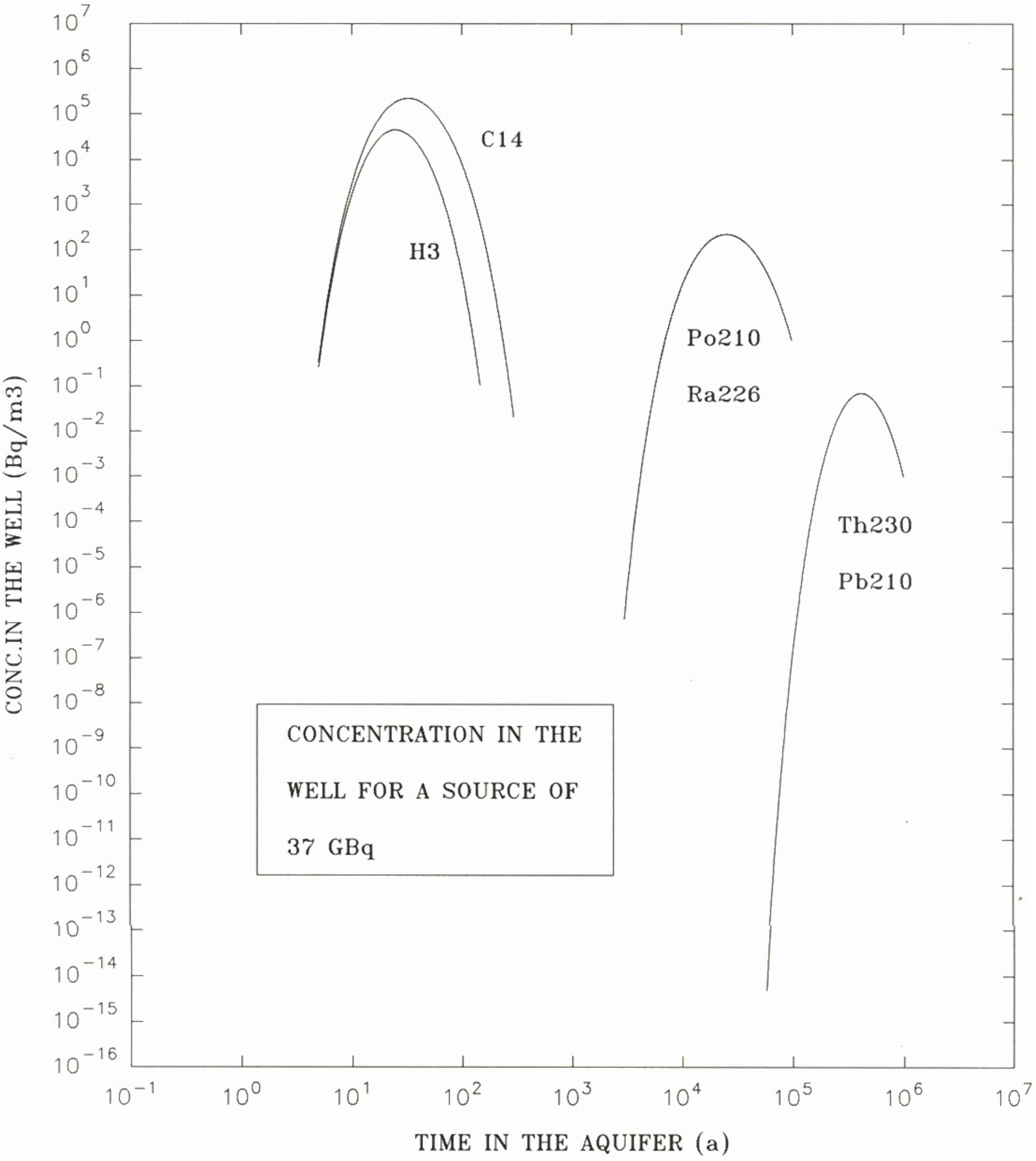

Figure 4 – Activity concentration in the well

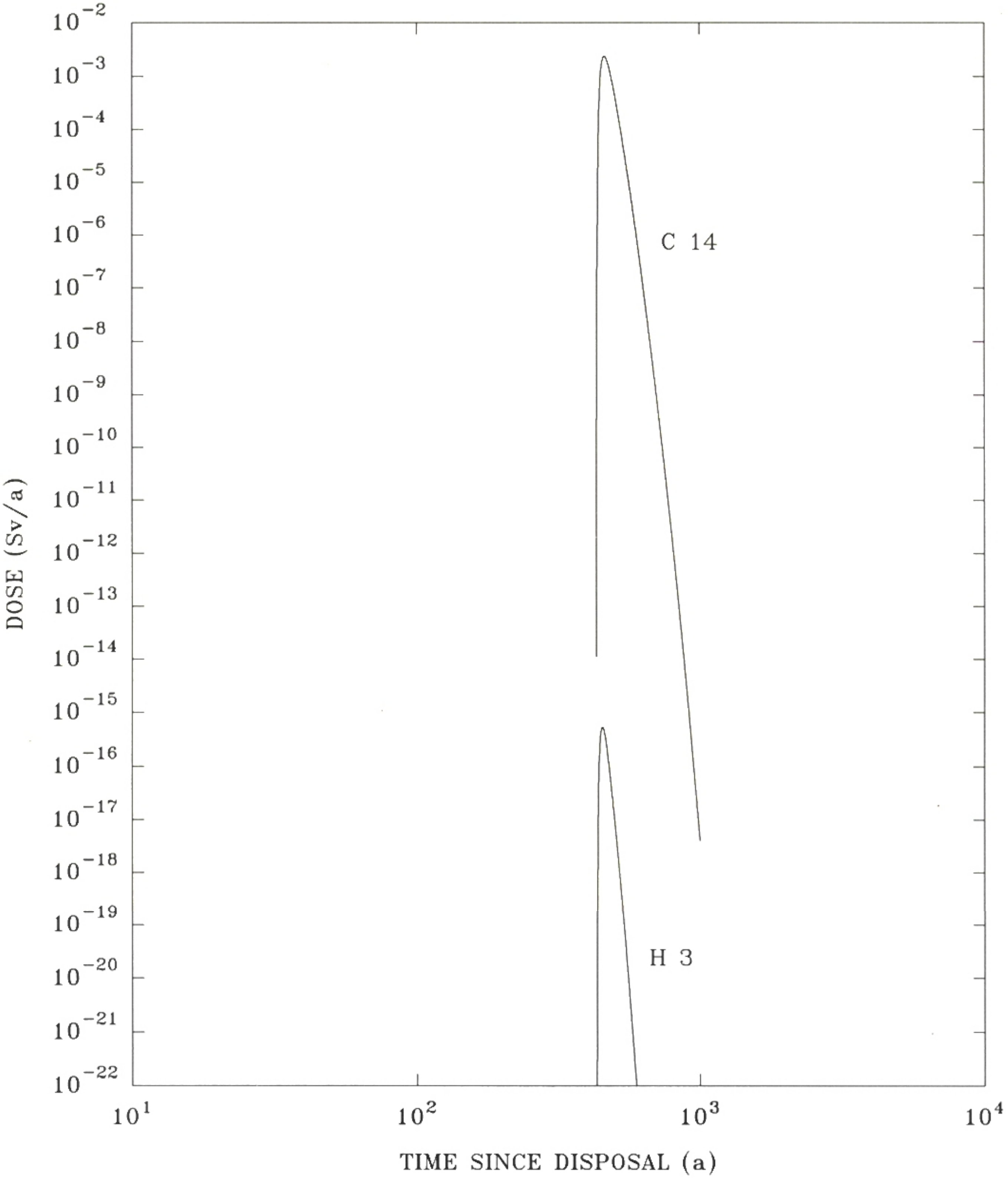

Figure 5 – Dose for drinking well water

radionuclide as function of time since disposal.

CONCLUSIONS

IPEN started the developing of a computer code to evaluate the environmental radiological impact due to the release of radionuclides from a disposal facility for shallow-land burial of Low Level Wastes. The staff involved in such task prepared some scenarios that fit with those proposed by IAEA. The code is still in development so that most of the available results are preliminary.

The use of the code allowed that the release to the geosphere as well the dose to a man making use of the water from a well be evaluated for the IAEA Test Case 1T.

The water infiltration in soil depends of several input parameters, which are not always available. Since a specific model that represents the real world process is time consuming and does not improves so much the result it was decided to simplify it.

For that purpose the infiltration rate into the trench cap was estimated as a fraction of the water infiltrating in the neighbor soil. That fraction was approximated by the ratio between the hydraulic conductivity of the cap to that of the neighbor soil.

For the Test Case 1T it was assumed that there was no cap failure and no erosion occurred during all the simulation time. This decision was adopted to compare the results with the data of other participants yet be improbable such happening during so long time. Obviously such supposition gives rise to an underestimate in the final dose.

Due to the chosen parameters of the scenario there was no overflow. If this occurred our code does not considers the influence of the thickness of the cap as a barrier for this event.

The amount of activity leached from the waste was evaluated considering the available annual infiltrating water volume and the distribution coefficient K_D for each radionuclide. However, the code allows to use the solubility limit of each radionuclide as well other mechanism supplied by the user. In these processes were not considered any time delay.

The vertical transport of the radionuclides was simply determined using the water infiltration rate corrected by the retardation factor. No mechanical or molecular diffusion coefficients were considered in such movement. The contribution of this dispersion mechanism is much less than that occurring in the aquifer.

The radioactive decay of all radionuclides was annually corrected. For the ^{230}Th daughters it was assumed to be in secular equilibrium with the father for simplicity because this would not improve significantly in the accuracy of the result.

For the IAEA Test Case 1T only the ^{3}H, ^{14}C, ^{226}Ra and ^{210}Po contribute for the dose received by a man making use of the well water. The others radionuclides do not even reach the aquifer until 10^6 years since their vertical velocity in the subtrench soil is very low.

COMMENTS

The code did at IPEN is not yet ready to run the proposed vault trench scenario. But some comments should be done on it. The foreseen strategy to solve this problem considers the following aspects:

1) For the runoff factor calculation a composed hydraulic coefficient of the three layers of soil (cover material,

rolled clay and cap fill) was used. The effective hydraulic conductivity was calculated according to the expression (8):

$$K_t=\frac{d}{\sum_{i=1}^{n}\frac{d_i}{K_i}}$$

The obtained value for the effective hydraulic conductivity was: 2.994 E-9 m/s.

2) For the calculation of the water infiltration in the trench it is been considered the same idea of the Case Test 1T. On the intact portion of the cap only a fraction of the water is allowed to enter the trench. This fraction is the ratio of an effective hydraulic conductivity of the materials existing till the vault, where the waste is emplaced, to the hydraulic conductivity of the neighbor soil. The obtained value for this coefficient was 2.857 E-9 m/s.

3) For the concrete vault where the wastes are emplaced it was also calculated an effective hydraulic conductivity with the following assumptions:

a) The ratio of overpack volume to backfill volume is 2:1. Thus the number of drums estimated for the vault is 16666.

b) The height of the drum was supposed to be 0.86 m. This gives a total package height of 4.30 m leaving 0.7 m of backfill distributed between them and, the top and bottom of the vault.

c) As the waste form and backfill have different hydraulic conductivity the effective coefficient for the layers containing the drums was calculated as parallel conductances using the Darcy law. Combining the series and parallel hydraulic conductivities the resulting value for the vault was: 4.67 E-9 m/s.

d) To better evaluate the migration of radionuclides in concrete as well backfill material is desirable to have information about diffusion coefficients for each radionuclide of the repository inventory.

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