Radioactive Waste Storage Facility at the Armenian NPP - 12462

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ABSTRACT

We present a detailed contaminant transfer dynamics model for radionuclide in geosphere and biosphere medium. The model describes the transport of radionuclides using full equation for the processes of advection, diffusion, decay and sorption.

The overall objective is to establish, from a post-closure radiological safety point of view, whether it is practical to convert an existing radioactive waste storage facility at Armenian NPP, to a waste disposal facility.

The calculation includes:

- Data sources for: the operational waste-source term; options for refurbishment and completion of the waste storage facility as a waste disposal facility; the site and its environs;
- Development of an assessment context for the safety assessment , and identification of waste treatment options;
- A description of the conceptual and mathematical models, and results calculated for the base case scenario relating to the release of contaminants via the groundwater pathway and also precipitation especially important for this site.

INTRODUCTION

The purpose of this calculation is to use the radionuclide transport model (AMBER) that has been developed to investigate important issues of long term safety regarding the Armenian NPP repository system.

The key issues that have been identified can be summarized as follows:

- It is important that all relevant time dependent processes are represented in system modeling.
- Because of the complexity of the system, it is not always possible to define what choices of modeling assumptions and parameters values can be regarding as conservative.

- Peak impacts are likely to be sensitive to the assumptions made about groundwater flow rates through the vaults.
  The development of the radionuclide transport compartment model for ANPP repository system is a good base in developing models for the repository for long and short lived low and intermediate level waste.
- The general modeling approach that is used can be modeled is represented by a number of compartments.
- The transport of contaminants between compartments is modeled with information on the transport of bulk materials within the system being provided as import information.
- Potential radiological impacts are estimated from calculated radionuclide concentration environmental materials.

The AMBER facilities for undertaking this type of modeling are:

- The ability to represent time dependent processes. The evolution of compartment characteristics and the variation with time of contaminant transfer rates can be modeled. This is very important for ANPP repository system as many of the system change significantly with time.
- The ability to structure the system as a number of sub-systems. This greatly helps to clarify the modeling of the repository system, which can naturally be split up into a number of separate parts.
- The ability to undertake model calculations with all radionuclides of interest at the same time in an acceptable run time.
- The capability to represent some nonlinear processes. This has been used to investigate whether solubility limitations are important for ANPP repository system.

The four sub-systems considered are:

- The repository sub-system which includes models for each of the vaults (1,2,3, . ..), together with associated near-filed rock.
- The Geosphere sub-system which represents the far-filed rock.
- The Terrestrial Biosphere.

This work helped to identify some of the key processes that need to be modeled in Performance Assessment calculations.

CONCEPTUAL MODEL FOR THE LIQUID RELEASE

The starting point for the tracking of water and contaminant transport is the cover, which is directly exposed to the infiltrating water. Due to the water flow through the engineered structure of vault disposal system, the waste is leached out of the waste matrix and contaminates the transport medium water. The time framework of this processes, depending on the degradation of cover, is defined by the Design Scenario. The drums are assumed to remain intact for 100 years and then fail, whilst the concrete is assumed

to physically degraded gradually over a 500 years period and chemically degrade over a 1000 year period from site closure. The cover is assumed to be maintained during the 100 year active institutional control period but then starts to degrade so that it no longer limits the rate of water infiltration by 500 years.
The contaminated water flows downward from the waste matrix and rest of the vault to the far field (the unsaturated layer and aquifer). The aquifer is assumed as the only source of biosphere contamination.
Groundwater is abstracted from the well that is located at the site boundary (4000m from repository). It is assumed that the well is sunk once institutional control of the site has been lost (i.e. 300 years after closure) and abstracts water indefinitely.
Consistent with present day site information, it is assumed that the abstracted water is used to supply a farm. The farm raises sheep, cows and hens. It is assumed that irrigation of pasture results in contamination of the soil. Loss terms from the surface soil are erosion and percolation.
The exposure pathways for humans are:

- Consumption of water;
- Consumption of animal produce (cow milk and meat, sheep meat, eggs);
- Inadvertent consumption of soil contaminated due to irrigation;
- Inhalation of dust contaminated due to irrigation of pasture;
- External irradiation from soil contaminated due to irrigation;
- External irradiation from bathing water.

MATHEMATICAL MODEL FOR THE LIQUID RELEASE

For calculations have been used the AMBER compartment model software application[QuantiSci and quintessa, 2004] to represent the entire disposal system (repository, unsaturated zone and biosphere) and calculated doses via all exposure pathways. According this model the release of radionuclides from the repository and their migration through the unsaturated and saturated zones to a well using analytical solution of the advection dispersion equation.
The processes of advection, dispersion, diffusion, decay and sorption are considered in one dimension and are represented thus:

$$\frac{\partial(\theta C)}{\partial t} = \frac{\partial}{\partial x}\left(\theta D \frac{\partial C}{\partial x}\right) - \frac{\partial}{\partial x}(V C) - \lambda \theta R C + S \qquad (\text{Eq. } 1)$$

where $V = V' + \frac{|D|}{\theta}$ and $R = 1 + \frac{\rho K_d}{\theta}$,

- concentration of the radionuclide in the aqueous phase (Bq m^{-3});
- diffusion – dispersion coefficient for radionuclide ($m^2 y^{-1}$);
-Darcy velocity ($m y^{-1}$);
- moisture content (-);
– retardation coefficient for radionuclide (-);
- radioactive decay constant for radionuclide (y),

- external volumetric source which includes the release from the waste form (Bq $m^{-3}y^{-1}$);
, - effective diffusion coefficient for radionuclide (m^2y^{-1});
- transverse dispersion coefficient (m);
- distribution coefficient for radionuclide (m^3 kg^{-1});
- dry bulk density of the medium through which the radionuclide transported (kg m^{-3}).

ESTIMATION OF DOSE

The annual individual effective dose to a human from the consumption of drinking water (Sv y^{-1}) is given by:

$$= \qquad \text{(Eq. 2)}$$

where - radionuclide concentration in the well from which the water is taken;
- individual ingestion rate of freshwater (m^3 y^{-1});
- dose coefficient for ingestion (Sv Bq^{-1}).

AMBER MODEL

AMBER uses a compartment model approach to represent the migration and fate of contaminants in the environment. A disposal system is represented by breaking it down into compartments, each of which represents a medium which is distinct a compartment, instantaneous mixing occurs so that there is a uniform concentration over the whole compartment. Each compartment is chosen to represent a region of the environment. Radionuclides in one compartment are transferred to another by various processes.
The transfer is described by transfer coefficients that represent the fraction of the activity in a particular compartment transferred from that compartment to another one in unite time. Radionuclides can also be lost from the system by radioactive decay. The mathematical representation of the inter compartmental transfer processes takes the form of a matrix of transfer coefficients that allow the compartmental amounts to be represented as a set of first order linear differential equations. For the - th compartment, the rate at which the compartment inventory changes with time is given by:

$$\text{—} = \sum \quad + \quad + \quad ( ) \; - \; \sum \quad + \qquad \text{(Eq. 3)}$$

where and indicate compartments, and are the amounts (Bq) of radionuclides in a compartment (is the precursor of in a decay chain), ( ) is a time dependent external source of radionuclide (Bq y^{-1}), transfer and loss rates are represented by and is the decay constant for radionuclide and and are transfer

coefficients representing the gain and loss of radionuclide from compartment and . The solution of the matrix of equations given above provides the time dependent inventory of each compartment. Assumption for compartment sizes then result in estimates of concentrations in the corresponding media.

LEACHING OF RADIONUCLIDES FROM THE REPOSITORY

The model developed to represent the repository is shown in Fig.1. A single compartment "Waste facility" is used to represent the entire repository. A similar approach was used to represent the disposal facilities in [1] and was found to be satisfactory [5].

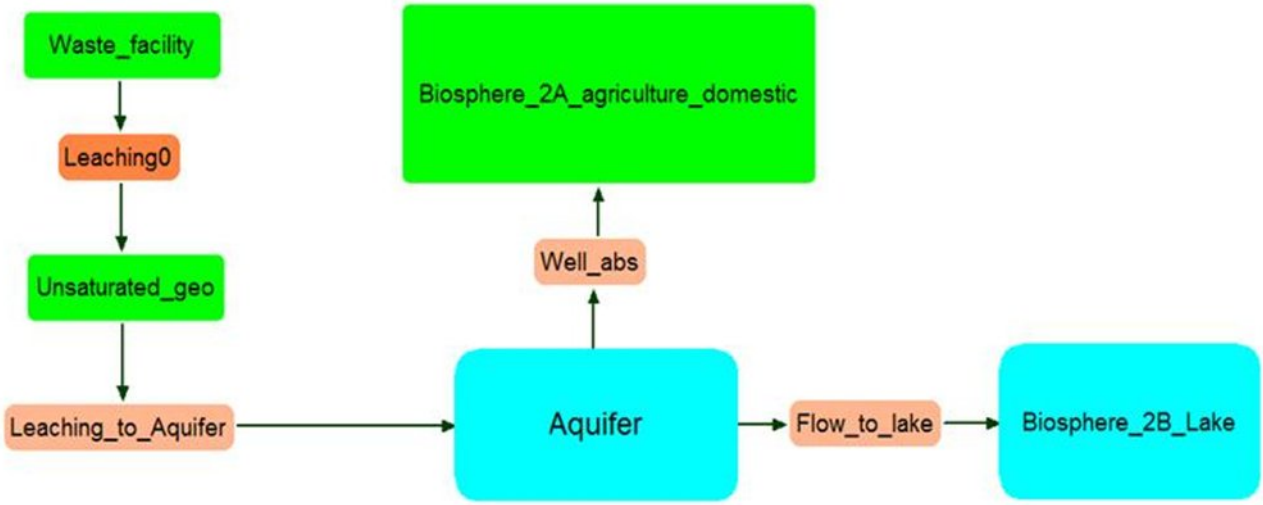

Fig. 1. Representation of the base-case scenario within Amber model

The leaching rate from the waste in the repository depends on the flow rate through the waste and the physical and chemical properties of the waste. It is assumed that the transfer is vertically downwards. It is assumed that leaching occurs once the drums containing the waste fail (i.e. after 100 years).
For a given radionuclide in the facility, the net vertical advective transfer (leaching) rate (y^{-1}) is:

$$= \frac{}{} = \frac{}{\theta} \qquad (\text{Eq. } 4)$$

where is the advective velocity of water, is the Darcy velocity of water through the medium (equivalent to the infiltration rate), θ is the water filled porosity of the medium , is the depth of the medium through which the radionuclide is transported and is the retardation coefficient given by:

$$= 1 + \frac{(\quad \theta)}{\theta} \qquad \text{(Eq. 5)}$$

where is the grain density of the medium, θ is the total porosity of the medium, is the sorption coefficient of the medium. and are time dependent. (All data have been taken from [7]).

For the purpose of the AMBER model, it is assumed that there is a linear failure in the performance of the cap between 100 and 500 years after closure. At closure, multiple layer cover is placed over the vaults. It is assumed that for the first 100 years the cover only allows 10% of the water infiltration through into the vaults, but thereafter it degrades so that by 500 years the cover does not limit water infiltration through into the vault. During the active institutional controls period (e.g. to maintain the cover, monitor environmental performance, restrict access, etc) after closure (100 years) will be time dependent due to cement ageing. Simple approaches have been adopted to account for cement ageing in performance assessments (e.g. [2],[3],[4]). It is also assumed chemical degradation of the repository is linear, starting at closure and lasting until 1000 years after closure (total degraded). Chemical degradation is represented by varying the values.

RESULT PRESENTATION

In presenting the results, it is considered helpful to consider:

- The flux of radionuclides from the repository to the unsaturated zone;
- The flux of radionuclides from the unsaturated zone to the saturated zone;
- The concentration of the radionuclides in the groundwater;
- The annual individual dose resulting from the use of well water.

FLUX OF RADIONUCLIDES FROM THE REPOSITORY TO THE UNSATURATED ZONE

Fig. 2. show the flux of radionuclides from the repository to the unsaturated zone. The figure show that the radionuclides fall into three broad categories. First there are those that have a peak flux during a hundred years, begin at the disruption of the drums (about 100 years, when the metallic drums are not as a barrier for radionuclide release). The radionuclides have low distribution coefficient and relatively short half lives (H-3, Cm-244, Sr-90, Cs-137) and so their peak fluxes are rapidly reached. The second category is those that have peak flux after the few hundred years (about 400 years). These have relatively higher distribution coefficients and longer half lives (I-129, C-14, U-234, Tc-99, Pu-238, Pu-240, Pu-241, Ni-63) and therefore their peak fluxes are reached less rapidly.

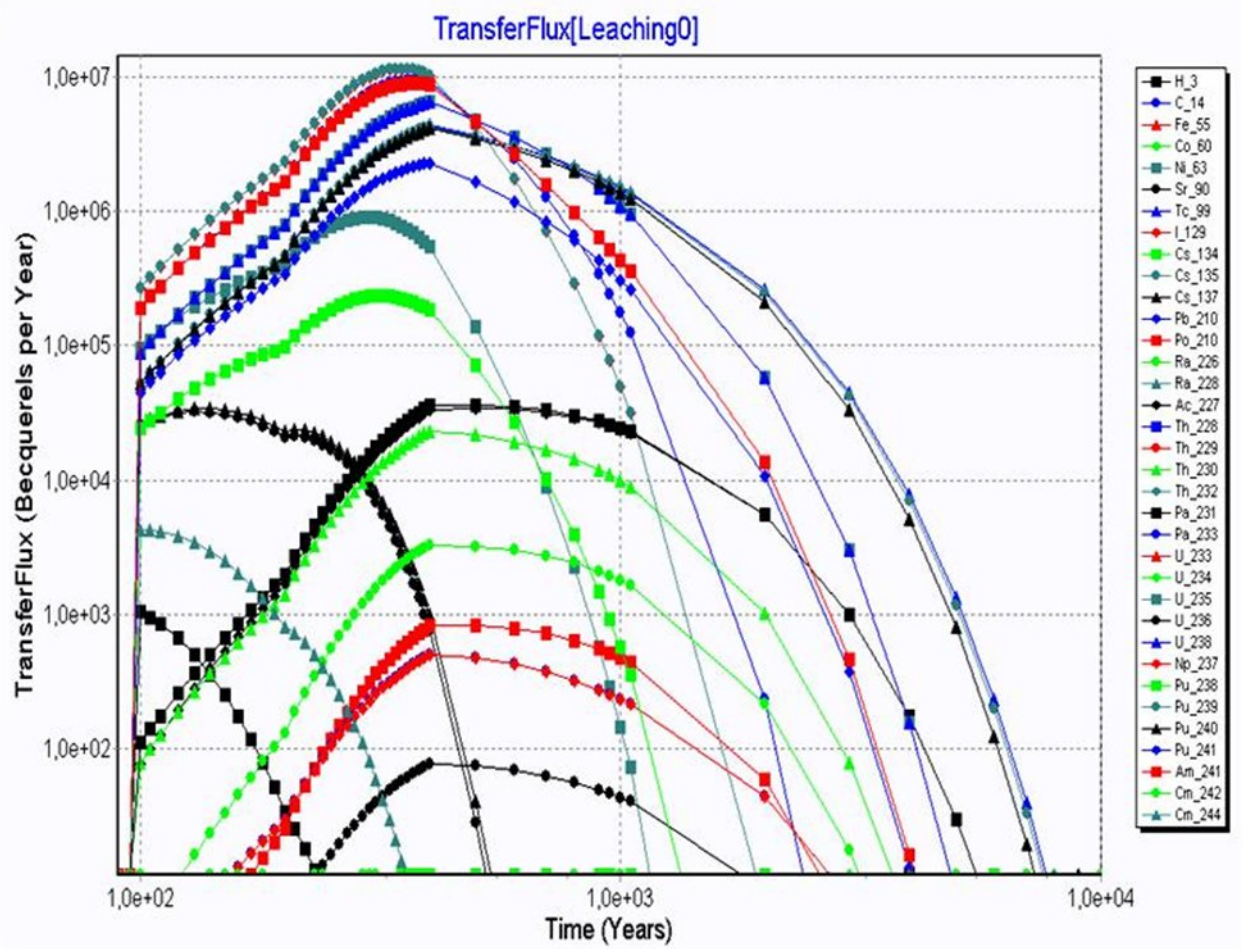

Fig. 2.Radionuclide flux from the repository to the unsaturated zone.

The third category is those that have a some plateau during 600 years (Ac-227, Th-230, Pa-231, Pa-233, Ra-226, Pb-210, U-236). These radionuclides by their distribution coefficient and half life parameters are in keeping with radionuclides of second category, but their flux peak magnitude close to first category radionuclides.

FLUX OF RADIONUCLIDES FROM THE UNSATURATED ZONE TO THE SATURATED ZONE

Fig. 3. show the flux of radionuclides from the unsaturated zone to the saturated zone. It can be seen that the unsaturated zone delays and attenuates the flux of radionuclides due to sorption onto the unconsolidated material and the slow infiltration rate water (0.3 m y^{-1}). Only three radionuclides (I-129, Tc-99 and C-14) have peak flux in excess of 1000 Bq y^{-1} (compared with the 14 radionuclides from the repository to the unsaturated zone that have peak flux in excess of 1000 Bq y^{-1}). There are long lived radionuclides and mobile radionulides, Most mobile radionuclide (I-129), peak flux is reached until

500 years, and other radionuclides are less mobile and the peak flux of which are reached until around 10000 years.

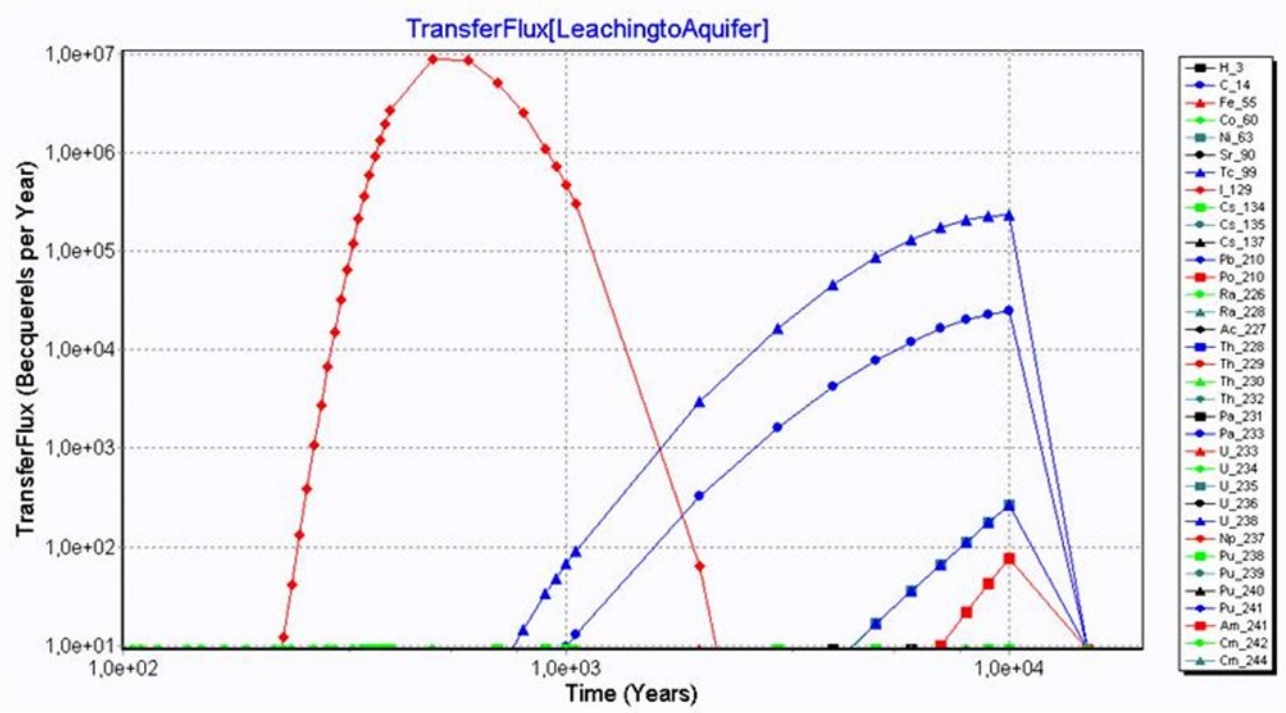

Fig. 3. Radionuclide flux from the unsaturated zone to the saturated zone.

CONCENTRATION OF RADIONUCLIDES IN THE WELL WATER

Fig. 4. show the concentration of radionuclides in the well water. From of this can be seen that the geosphere does not significantly retard the key radionuclides (I-129, C-14, Tc-99, U-234 and Po-210). The timing and relative magnitude of the peak flux to the saturated zone and the peak concentrations in the well water are broadly the same. This is because of the relatively rapid assumed transit time of water along the fractures and the low distribution coefficients for these radionuclides in the geosphere.

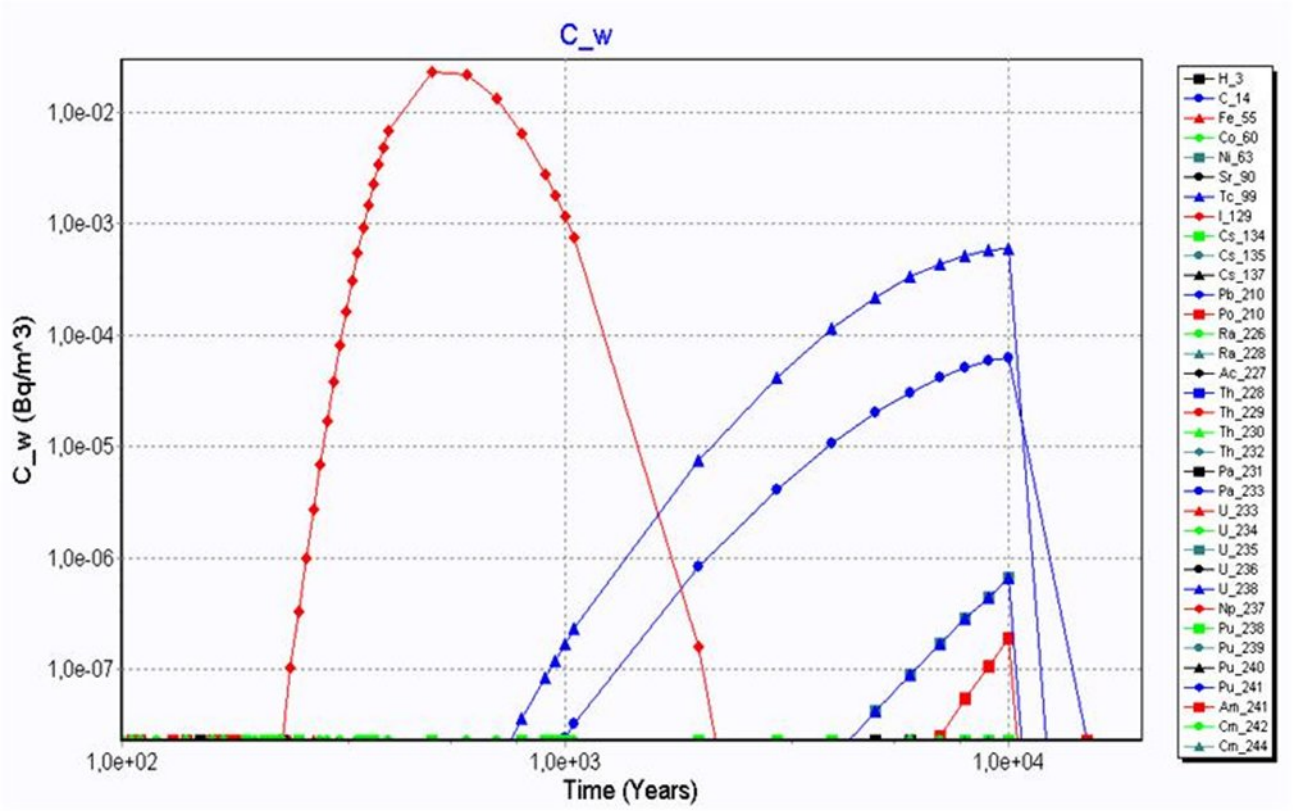

Fig. 4. Concentration of key radionuclides in the well water.

ANNUAL INDIVIDUAL DOSE FROM USE OF WELL WATER

Fig. 5. show the annual individual dose from use of well water and total dose from all pathway. The calculated doses as for the drinking water pathway so for all pathway. Since drinking water doses scale directly with the well water concentrations, the same time history can be seen for concentrations and doses. The dose from the ingestion of I-129 (the dominant radionuclide in terms of dose) via the drinking water pathway is about four order of magnitude higher than that from Tc-99.

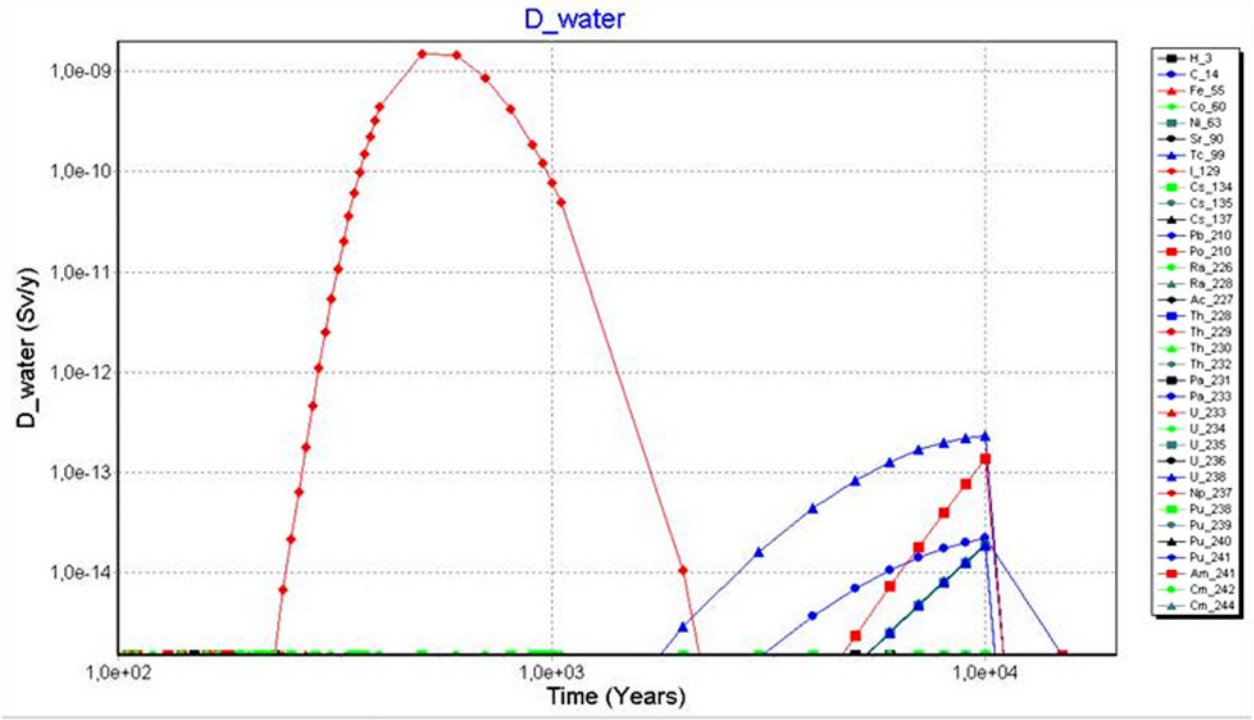

Fig.5. Individual doses from key radionuclides doses for key radionuclides from use of well water and all pathway.

Table. Timing and magnitude of peak of dose from use of well water and all pathways.

Key Radionuclides	Time (y)	Peak individual Dose from Drinking water (Sv y^{-1})	Peak individual Dose from All Pathway (Sv y^{-1})
I-129[a]	500	1.5E-9	6.9E-8
Tc-99	10000	2.3E-13	2.9E-9
C-14	10000	1.4E-13	3.4E-11
U234	10000	2.2E-14	8.9E13
Po-210	10000	1.9E-14	1.8E-13
Total	500	1.5E-9	6.9E-8

[a]The peak dose from all pathways for I-129 is reached at 700 years.

Results from calculations show that, for all radionuclides with the exception of C-14, Th-230, and Ra-226, the dose from the ingestion of drinking water for a radionuclide is within a factor of 49 of the total dose for that radionuclide, indicating that the ingestion of drinking water is a key exposure pathway. Indeed, the dose from the drinking water pathway accounts for 2.2% of the total peak dose summed over all radionuclides.

There is very good agreement between the participants in terms of the timing and magnitude of the drinking water dose for the key radionuclides(C-14, Tc-99, I-129, U-234, and U-238). This reflects the good agreement in well water concentrations.

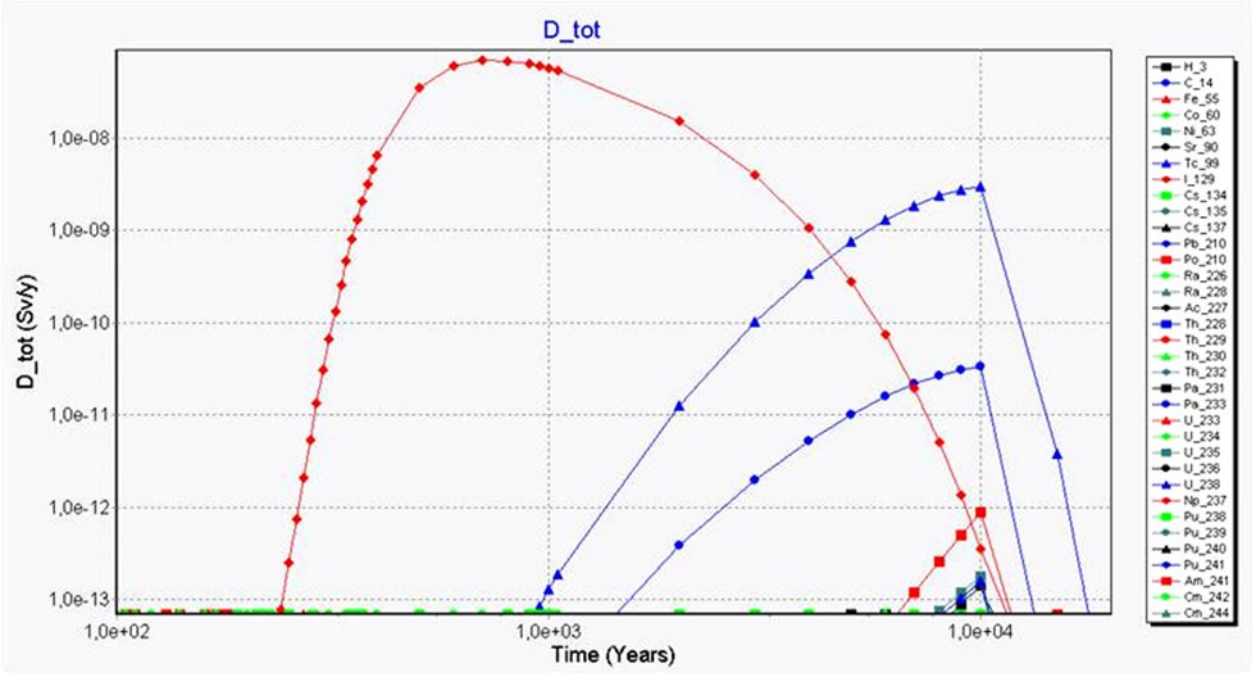

Fig.6. Individual doses from key radionuclides from all pathway.

CANCLUSIONS

The results of the calculations showed that the peak individual dose is < 7E-8 Sv/y arising principally from I-129 after 700 years post closure. Other significant radionuclides, in terms of their contribution to the total dose are I-129, Tc-99 and in little C-14 (U- 234 and Po-210 are not relevant). The study does not explore all issues that might be expected to be presented in a safety case for a near surface disposal facility it mainly focuses on post- closure dose impacts. Most emphasis has been placed on the development of scenarios and conceptual models rather than the presentation and analyses of results and confidence building (only deterministic results are presented).

The calculations suggest that, from a perspective the conversion of the waste-storage facility is feasible such that all the predicted doses are well below internationally recognized targets, as well as provisional Armenian regulatory objectives. This conclusion applies to the disposal of the ANPP present and future arising of L/ILW operating wastes.

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