Postclosure Safety Assessment of the Proposed Low and Intermediate Level Waste Repository in Slovenia – 14444

Matthew Kozak *, Rodolfo Avila **, Sandi Viršek ***
* INTERA, Incorporated
** Facilia AB
*** Agencija za radioaktivne odpadke

ABSTRACT
An initial safety assessment has been completed for a proposed low and intermediate level waste repository at Vrbina, Slovenia. The repository is intended to accept the national inventory for wastes appropriate for near surface disposal in Slovenia. The repository design is a near-surface silo located below the water table. A summary is provided of the disposal site, design features of the repository, and the safety assessment conducted to evaluate the postclosure performance of the repository system. The results of the safety assessment show that the repository meets relevant standards for protection of human health and the environment with margin. The safety assessment has been submitted for regulatory review and approval.

INTRODUCTION
Agencija za radioaktivne odpadke (ARAO) and its technical support contractors have carried out a safety assessment for the proposed low and intermediate level waste repository at the Krško site in Slovenia. The purpose of the safety assessment is to develop reasonable assurance that the facility will remain within constraints for long times into the future, as established in regulation.

The proposed repository is located on a gravelly lowland area approximately 300 meters (m) east of the Krško Nuclear Power Plant (NPP) in the municipality of Krško in the central part of eastern Slovenia (Fig. 1). The site lies southeast of the village Vrbina, at a distance of 2.5 kilometers (km). The site is on the plain along the Sava River, which is used for agriculture today. The site is just north of the river Sava; at its closest point, the site is about 700 m away from the river. Further north are the Libna hills, which constitute a significant area of recharge to the aquifer in the river valley.

The construction of the LILW repository is planned in a Miocene aquiclude characterized by hydraulic conductivity in the range 10^{-9} to 10^{-7} m s^{-1} located below a 10 m thick highly permeable Quaternary aquifer characterized by hydraulic conductivity in the range 7×10^{-4} to 5.4×10^{-2} m s^{-1}.

Fig 1. Approximate location of the proposed repository site.

The repository is designed as a reinforced concrete cylindrical structure, 55.0 m high and 27.3 m in diameter. The dimensions of the silo provide space for 10 overpack layers, each layer comprising 70 overpacks, in which the radioactive waste is grouted. The size of an overpack is 3.25 m × 2.55 m × 2.55 m. The containers are positioned directly one upon another, while the lateral 0.1 m interspaces between them are filled with sand. Sand also overlies the containers in a 0.76 cm thick layer. On top of the silo, a 5 m thick clay cover layer will be emplaced, located on the contact between the Quaternary aquifer and the Miocene aquiclude. A schematic diagram of the structure of the silo is presented in Fig. 2.

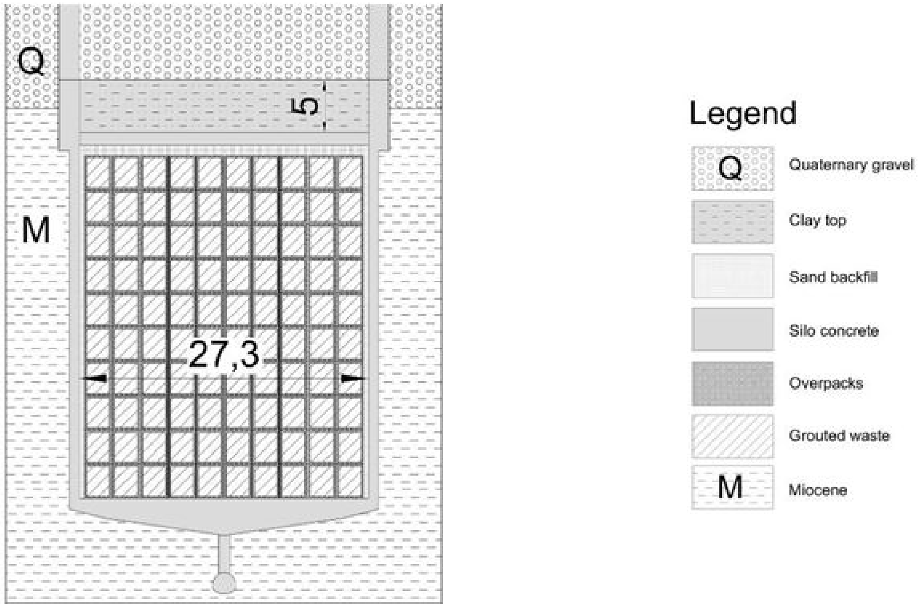

Fig 2. Design basis for the repository silo.

DESCRIPTION OF THE SAFETY ASSESSMENT

The safety assessment was undertaken using the methodology on the International Atomic Energy Agency (IAEA) [1], which has become an internationally accepted standard for conducting safety assessments. The methodology, as diagrammed in Fig. 3, may appear to be a series of unrelated steps in a process. However, a key element of the methodology, which ties all of the elements together, is its comprehensive and formalized approach to the identification and evaluation of uncertainties as they relate to regulatory decisions. At each stage of the process, the methodology is intended to focus attention on key issues that need to be addressed to develop confidence that the final decision is well supported, documented, and coherent.

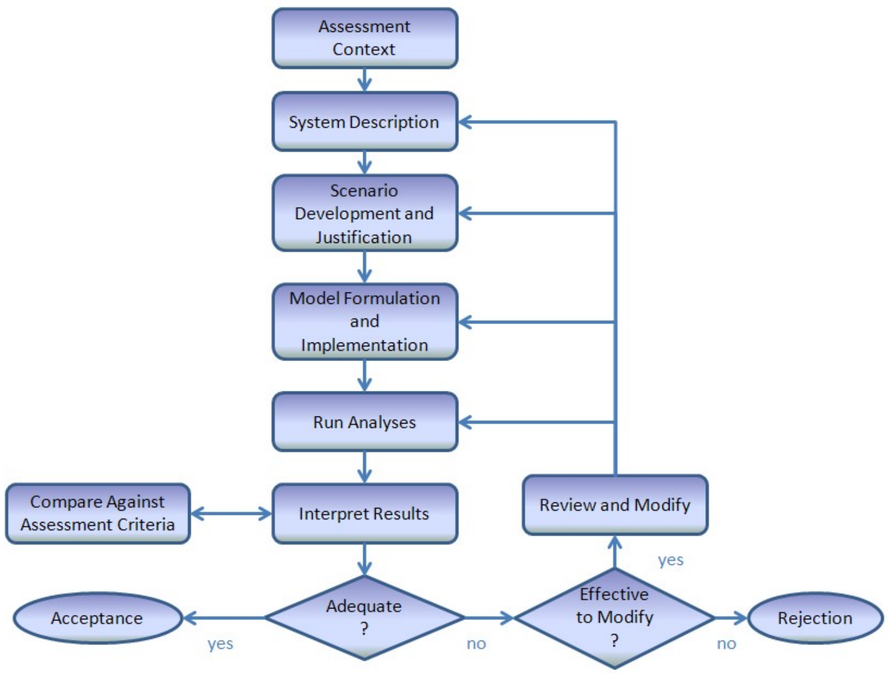

Fig 3. The IAEA Safety Assessment Methodology (adapted from [1]).

Experience has shown that developing confidence in the results of the safety assessment is best accomplished by a thorough evaluation of uncertainties and sensitivities, presented in a clear and unambiguous way. Uncertainties that need to be taken into account include

- uncertainties in the future conditions at the site, accounted for through the use of alternative scenarios,
- uncertainties in model representations of phenomena of importance to the performance of the disposal system, and
- uncertainties in parameter values used in those models.

The safety assessment was developed to address each of these types of uncertainty.

SCENARIO DEVELOPMENT AND JUSTIFICATION

A formal scenario development and justification procedure was followed to provide a foundation for the selection of scenarios for evaluation uncertainties in future conditions. The formal procedure was based on a combination of a screening process for Features Events and Processes (FEPs), combined with identification of safety functions, which focused attention on the features of the system that are key contributors to safety. The scenario process resulted in the identification of five main scenarios for which analyses were conducted.

Nominal scenario

The term “nominal” scenario has been adopted to describe the future evolution of the disposal facility in the absence of unusual or unexpected events and processes. The nominal scenario can be described as follows. At the time of closure, it is assumed that the interior of the silo is water saturated and the behavior of engineered barriers and waste forms are evaluated on that basis. In the nominal scenario the barriers to release of radionuclides are considered to gradually degrade, losing their ability to contain the waste. Releases occur to the surrounding groundwater. A single family dwelling is assumed to be built nearby the site (at 100 m) and a water well in the Quaternary sediments is used to supply the family water needs. This is the primary potential exposure route to humans. In addition, the potential for discharge to the river is evaluated. Several variants of the nominal scenario were considered:

- an alternative conceptual model for barrier degradation in which the barriers failed sequentially;
- a biosphere where there was no well – all water was taken from the river;
- a biosphere is which well water was used for irrigating crop land; and
- a biosphere where the well was used for watering cattle.

Early failure of engineering

This scenario is intended to represent a large number of potential initiating FEPs that may affect the ability of the repository to isolate wastes and contain radionuclides. These FEPs include a major seismic event outside the design basis, manufacturing or construction flaws, and improper operation. These will be evaluated in a generic way, without attempting to specify the manner in which the failure occurs. Necessarily, this generic approach means that the failure will be treated in a more conservative manner than if a detailed process model were applied for how a FEP would affect the facility. For instance, even a major seismic event might result in the formation of only minor and localized cracks if evaluated in a detailed way with process models for mechanical stress. However, such an analysis would rely on many assumptions, and it is more straightforward to treat such effects in a conservative and more easily defensible manner.

The engineered features are assumed to fail during the period 200 – 300 years after closure, with sensitivity analyses to examine the effects of later failures. The consequences of disruptive events or major earlier failure are discounted, however, on the grounds that damage incurred would be remediated or the waste would be retrieved.

The early failure scenario was evaluated in the same way as the nominal scenario, except that components of the engineering will be assumed to undergo a very rapid degradation in properties starting from the end of institutional control. All physical properties of the engineered barriers were assumed to transition to their “failed” condition in one year, at the end of institutional control. This is considered to be a very conservative assumption, taken to bound the likely effects of a variety of events and processes that might affect the degradation rate of the disposal facility. Early degradation of individual features of the repository (silo wall, backfill, overpack, and waste form) was also evaluated.

River meander and surface erosion

Natural or man-made forces in the future have the potential to redirect the Sava River over the repository. The result would be erosion of part of the Quaternary layer of the aquifer and a change in the aquifer flow velocities and direction. It is not considered geologically credible for there to be sufficient erosion to reach the burial depth of the repository during the 10,000 year performance period. The primary effect of the river flowing outside its current path would be changes in the magnitude and direction of the water flow in the vicinity (and through) the repository.

Inadvertent human intrusion

It is considered very unlikely for a human intrusion event to occur, owing to the depth of disposal and, especially its location below the aquifer, which significantly decreases the motivation for intrusion. Consequently the likelihood of occurrence is very low. The main credible intrusion scenario for a repository at the planned depth is a drilling intrusion, and doses have been evaluated for both the driller and for a post-drilling resident after the 300 year institutional control period.

Changes in hydrological conditions

A number of FEPs have the potential to change the regional hydrological setting for the assessment. These FEPs include natural or anthropogenic climate changes, construction of dams or other projects on the Sava River, and other indirect human actions on the aquifer. The effect of all of these changes would be changes in the magnitude and direction of the flow velocities in the near field and aquifer.

PROCESS MODEL FOR GROUNDWATER FLOW

Two detailed models for groundwater flow were implemented. The first was a regional FEFLOW [2] numerical groundwater flow model used to provide Darcy velocity data for further modelling. The results of these analyses were used in two ways in the safety assessment. First, they provide input to the near-field flow modelling analyses, described below. The far field model provides the basic understanding of the directions of flow, gradients, and local hydrological parameters adjacent to the repository, all of which are needed to establish credible boundary conditions for the near field modelling. Second, FEFLOW model was used to provide parameters needed to evaluate transport of radionuclides in the geological formations surrounding the repository, principally in the Quaternary aquifer. For this purpose, flow velocities evaluated using the FEFLOW model were used directly as the best estimate inputs to the safety assessment model, with appropriate uncertainties.

The second groundwater flow model implemented was conducted with HYDRUS-2D/3D [3] for the purpose of estimating the groundwater Darcy velocity in different compartments in the repository silo as the concrete undergoes degradation. The safety assessment was implemented in the computer software Ecolego [4], a state of the art code for building and implementing compartment models for safety assessments. Results from the HYDRUS flow model were abstracted and used as inputs to the Ecolego safety assessment model, so as to support and justify assessment level representation of various stages of degradation of the engineered barriers which make up the near field of the repository.[1] Therefore, the outputs determined from simulations with HYDRUS-2D/3D represent one of the key input parameters in the safety assessment.

ABSTRACTION OF THE NEAR-FIELD FLOW MODEL

Process models, like the FEFLOW and HYDRUS models described in the previous section, provide detailed information on the behavior of the system under fixed boundary conditions, and provide a wealth of information on the behavior of specific features of the system. A drawback to the use of such In addition, process models are typically numerically intensive, and as a result it is difficult to fully explore system uncertainties using Monte Carlo analysis, a process that requires

[1] Any effect of the disturbed zone around the repository on the performance of the facility is expected to be bounded by the analyses in the safety assessment, since lateral flow and associated dispersion of the contamination is conservatively neglected.

many computer runs to generate estimates of the uncertainties in model results. The solution to this problem is to develop an alternative model using a process of model abstraction.

The relationship between the process modeling and system modeling is shown in Fig. 4. Understanding of the behavior of specific elements of the system is provided by considering detailed process models. Specific outputs from those process models are abstracted and used as inputs to the system-level model. This structure, and the complementary use of process and system-level modeling, has become a common feature of safety assessments worldwide. Process models are used to gain specific understanding of specific detailed processes in the system using deterministic analyses and limited sets of sensitivity analyses. The information generated using those approaches is abstracted and used in the full uncertainty analyses in the system-level modeling. The main difference between the two modeling approaches lies typically in the resolution of the representation of the modeled system, particularly in the representation of spatial resolution. By coarsening the resolution in the system level model, it is possible to gain significant numerical benefits, which in turn allows the safety assessment to explore the range of uncertainties more broadly.

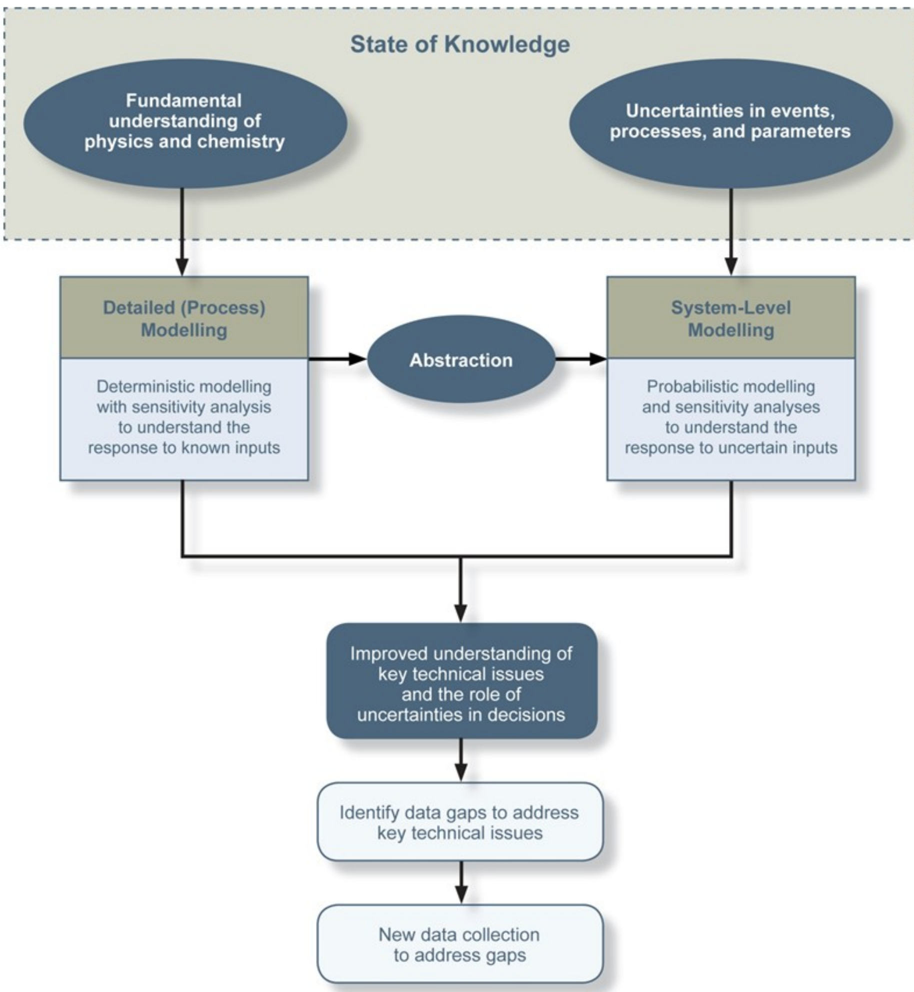

Fig. 4. The combined use of detailed process models and systems-level models in conjunction.

SYSTEM MODEL

The system model puts all parts of the system together in a single model for comparison with regulatory criteria. The general parts of the model are the near field, far field, and biosphere. A depiction of the overall model for the Nominal Scenario is shown in Fig. 5.

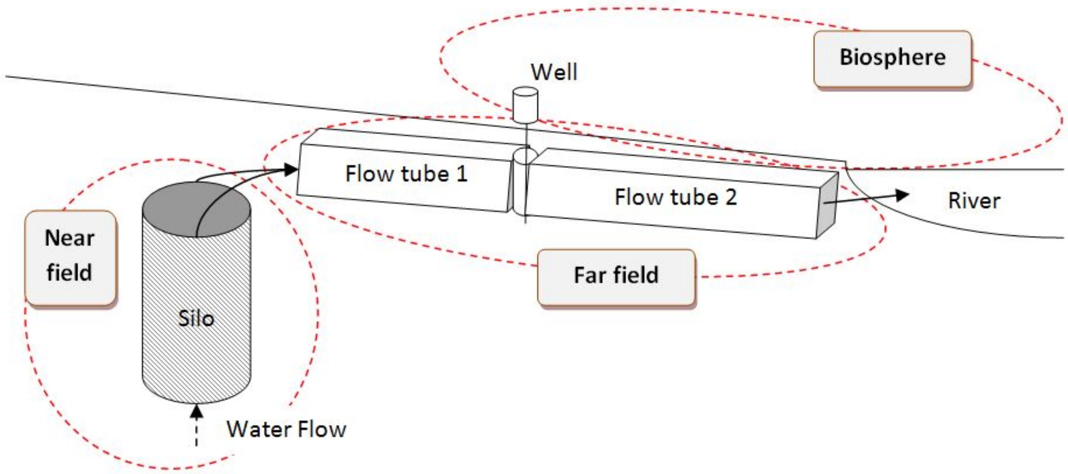

Fig. 5. The overall system model implemented for the Nominal Scenario.

The near field includes the repository and the surrounding excavation-disturbed zone. However, the flow system has been simplified and treated conservatively as a vertical flow through the silo. The actual system is likely to produce flow that, depending on the state of the Sava river, is either upwards or downwards and this will be combined with a sub-horizontal flow component into the adjacent excavation disturbed zone or the low permeability Miocene sediments. By neglecting these alternative flow paths, the model assumes the shortest possible route for contaminant transfer to the Quaternary aquifer and thus overlooks a number of mechanisms for dilution, dispersion and sorption that would tend to lower the radiological consequences.

The near field conceptual model (Fig. 6) envisages radionuclides being contained by the following engineered barriers:

- the wastes themselves; this is especially important for decommissioning wastes where activation leads to the incorporation of radionuclides within the metal itself; consequently, the rate of release of radionuclides is controlled by corrosion of the metal. The corrosion, in turn, is limited by anaerobic conditions and contact with cementitious materials, which tend to passivate their surfaces.
- the encapsulation grout used to immobilize most (though not all) wastes within the disposal containers. These provide low hydraulic permeability and stable favorable chemical conditions for the waste.
- the walls of the disposal overpacks, which provide low permeability and tend to isolate the encapsulation grout from their surroundings.

- the concrete walls and base of the silo. The silo walls are subject to less advantageous conditions compared to the other features of the repository. These conditions include higher mechanical stresses than experienced by the waste forms and overpacks, and exposure to moderately aggressive groundwater chemistry. The combination of these conditions will tend to make the silo walls the first part of the repository to degrade, followed by the features (overpacks, waste form) it contains.

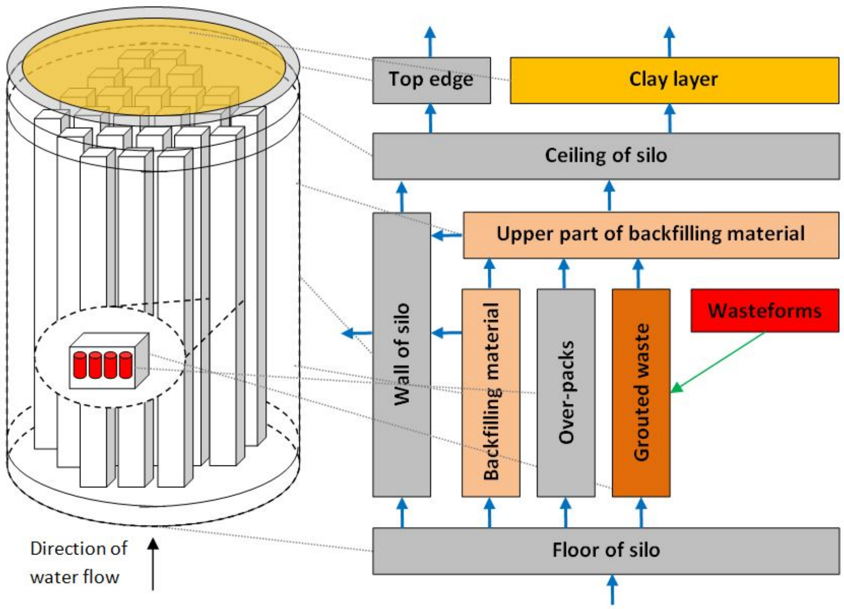

Fig 6. Representation of the near-field model implemented in Ecolego for the Nominal Scenario.

The far field sub-model is implemented in Ecolego using two transport blocks, which internally discretize compartments and their interactions into layers. The first transport block models the migration of radionuclides in the ground water from the silo to the hypothetical well (to compute the concentration in Quaternary pore water at the well location) and the second transport block models the radionuclide migration from the position of the well to the discharge area in the river.

The biosphere sub-model assumes that radionuclides can enter the biosphere by two pathways (Fig. 7): via abstraction of water from a well located at a given distance from the repository and via discharges of radionuclides to the river. Upward movement of the contaminant plume directly to the surface could potentially happen at the site, which would lead to a more direct exposure pathway. However, there is no current evidence that this happens at the site, and it has not been included in the conceptual model. The various exposure pathways shown in Fig. 7 are considered depending on the assessed exposure point.

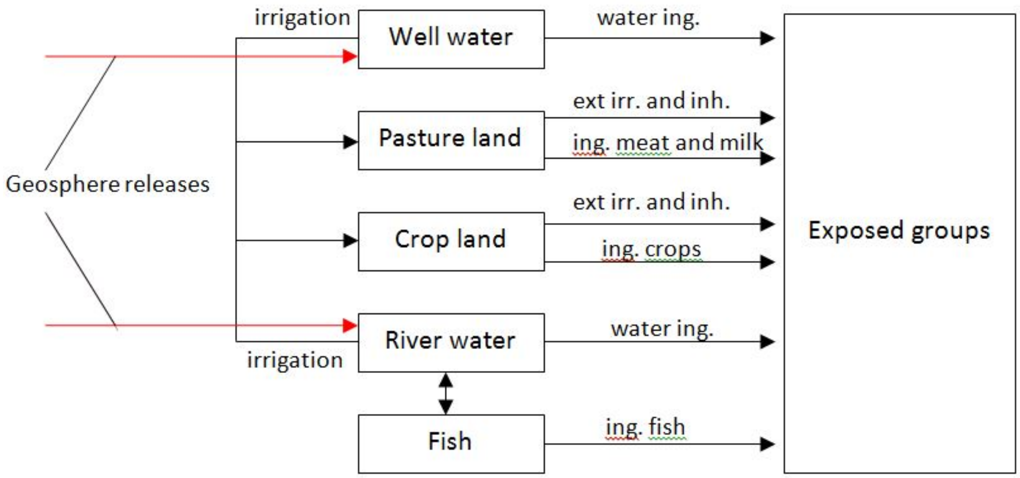

Fig. 7. Biosphere model implemented in Ecolego for the Nominal Scenario.

DISCUSSION OF RESULTS

A key analysis for the post-closure safety assessment is the nominal scenario, the results of which are presented in Fig. 8. Within the 10,000 year time frame for the analysis established in the assessment context, the dose constraint of 300 μSv/y is met with substantial margin. At very long time periods, on the order of 400,000 years, the analysis shows doses approaching the dose constraint. These doses are the result of the ingrowth of Ra-226 and its progeny from uranium in the inventory. Within the assessment context of the safety assessment, it is noted that doses at such long time periods must be regarded as qualitative and not to be rigorously compared to the dose constraint. Nevertheless, the calculations suggest that, even at extremely long time periods, the doses do not grow to very high values and the system remains passively safe.

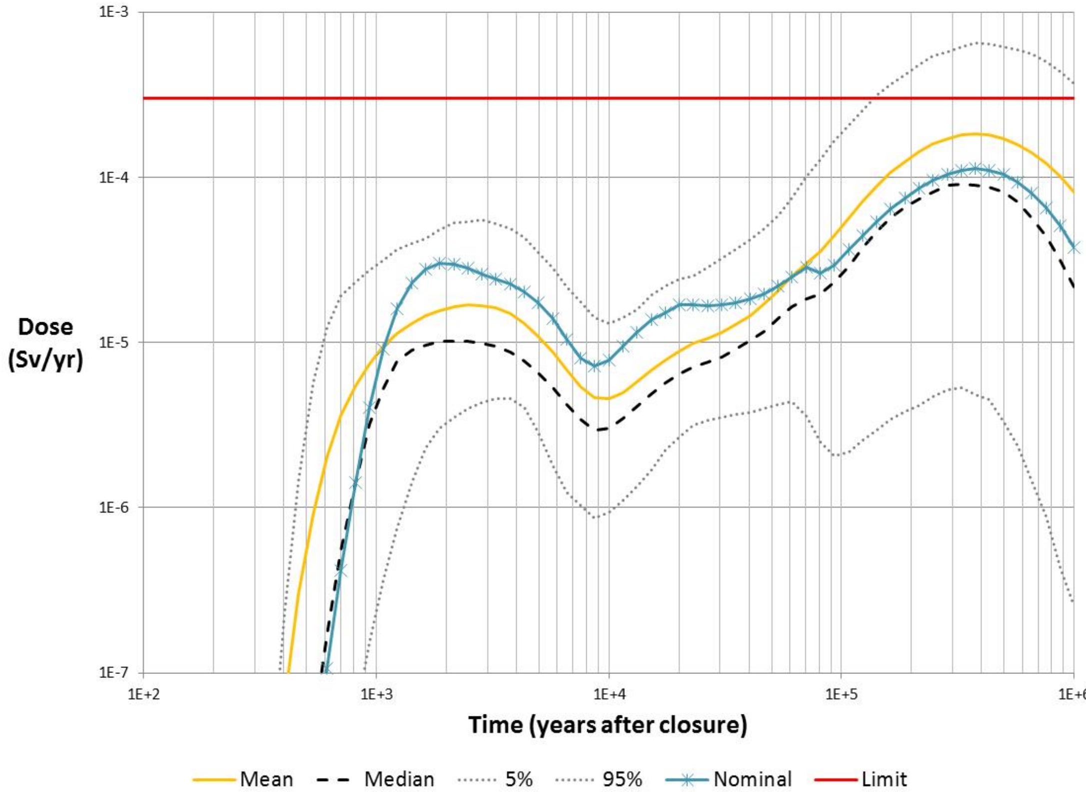

Fig. 8. Doses calculated to a Representative Individual from the Nominal Scenario including a well receptor, using a probabilistic calculation showing the effect of parameter uncertainty. Note that "Limit" indicates the regulatory constraint of 0.3 mSv/y.

CONCLUSIONS

The post-closure safety assessment has shown that the proposed facility meets the regulatory safety criteria for post-closure safety with good margin for all the analyses conducted. This conclusion is contingent on a number of basic assumptions that form the foundation of these safety assessment analyses. While a number of these assumptions require additional study, it is concluded that there is high confidence that the proposed Vrbina repository can meet regulatory constraints with sufficient margin.

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