

PERFORMANCE ASSESSMENT OF THE NATIONAL RADWASTE REPOSITORY MOCHOVCE

Adela Mrskova (mrskova@vuje.sk), Václav Hanušík (hanusik@vuje.sk),
Ivan Kopcani (kopcani@vuje.sk), Marian Stubna (Stubna@vuje.sk)
VUJE Trnava Inc., Department of Accident Management and Risk Assessment
Okružna 5, 918 64 Trnava, Slovak Republic

ABSTRACT

The Mochovce repository is a shallow land burial construction for disposal of low and medium level radioactive waste resulting from the operation and decommissioning of nuclear facilities in the Slovak Republic, wastes from research institutes, laboratories, hospitals and other institutions involved in activities during which radioactive wastes are produced. The near-surface disposal site at Mochovce is designed as a vault-type concrete structure housing the reinforced concrete containers as the final waste packages.

First safety analysis were performed by SCK•CEN for Nuclear Regulatory Authority in 1993. Calculations were performed with one dimensional codes MODEMO, NUCDSL and LAKE. Following the request of the Slovak Nuclear Regulatory Authority and IAEA WATRP mission in 1994 the number of modifications were adopted to design and construction of the Mochovce repository.

Following an upgrade of the Mochovce repository a new safety report was prepared including performance assessment. A set of new site and radiological data have been prepared and the computer codes originally created by SCK•CEN Belgium were modified and locally adapted. According to progress of experience and knowledge codes DUST-MS for source term release and MODFLOW for ground-water flow have been integrated into performance assessment.

This paper is dealing with the main activities and results of performance assessment of Mochovce LLW/ILW repository. The paper presents the implementation of computer codes and results of comparative calculations performed MODEMO and DUST-MS codes for potential near field interactions.

INTRODUCTION

The near-surface disposal facility at Mochovce is designed for low-level and intermediate-level radioactive waste. It is a vault-type concrete structure housing the reinforced concrete containers as the final waste packages.

The repository was constructed at the end of the eighties but has undergone several upgrades. As a support to the regulatory body position and also for better acceptance of repository concept by public the NRA SR requested on December 1993 the International Atomic Energy Agency (IAEA), Vienna to review the Mochovce Radioactive Waste Disposal Facility within the IAEA's Waste Management and Technical Review Programme (WATRP). The review and recommendations have covered the following topics - the legal framework and waste disposal

strategy; characterisation and inventory of waste; design site characteristics and construction; operation, closure and monitoring of the repository; performance assessment for the operational and post-operational phases; waste acceptance criteria and specific quality assurance issues.

A preliminary pre-operational safety report was developed in 1993 based on original status. The performance analysis were performed by SCK•CEN Belgium. These analysis were based on calculations performed with the codes MODEMO, NUCDSL B and LAKE, developed at SCK•CEN for 6 radionuclides (C-14, Sr-90, Tc-99, I-129, Cs-137, Pu-239) and a limited number of scenarios (Volckaert and Zeevaert, 1993). The SCK•CEN assessment codes were later modified for increased number of the scenario and radionuclides, following the request of the Nuclear Regulatory Authority and IAEA WATRP mission. A set of data for new radionuclides had been prepared. The new assessment for the new version of the safety report for Slovak electricity were prepared during 1998 by VUJE Trnava Inc.

In the framework of the performance assessment iterative process in the Mochovce disposal facility, new computer codes were implemented during recent years. The purpose of the implementation is to offer more complicated models and fully documented data sets, which greatly increase the flexibility of the approaches to handling a variety of processes occurring in the repository, geosphere and biosphere after repository closure. Another aim is to verify the results of the performance assessment, which were done for the safety report.

Waste

The waste which will be disposed at the Mochovce site will mainly be classical low-level WWER-440 operation waste. It will originate from the operational units V-1 and V-2 at Bohunice and 2 units at Mochovce NPP. A lower activity waste from decommissioned A-1 power plant at Bohunice and radioactive waste from medicine, industry and research will be disposed also.

The largest fraction of the waste will be evaporator concentrates, which are bituminised or cemented at Bohunice. All other waste types will be cemented. All waste drums will further be stacked into reinforced concrete containers, which will be backfilled with concrete.

Burial installation

The design of the disposal is shown in Figure 1. It consists of two double rows of reinforced concrete vaults. One double-row consist of 40 vaults from everyone can store 90 containers. The vaults are covered with concrete panels for biological shield protecting of operating staff.

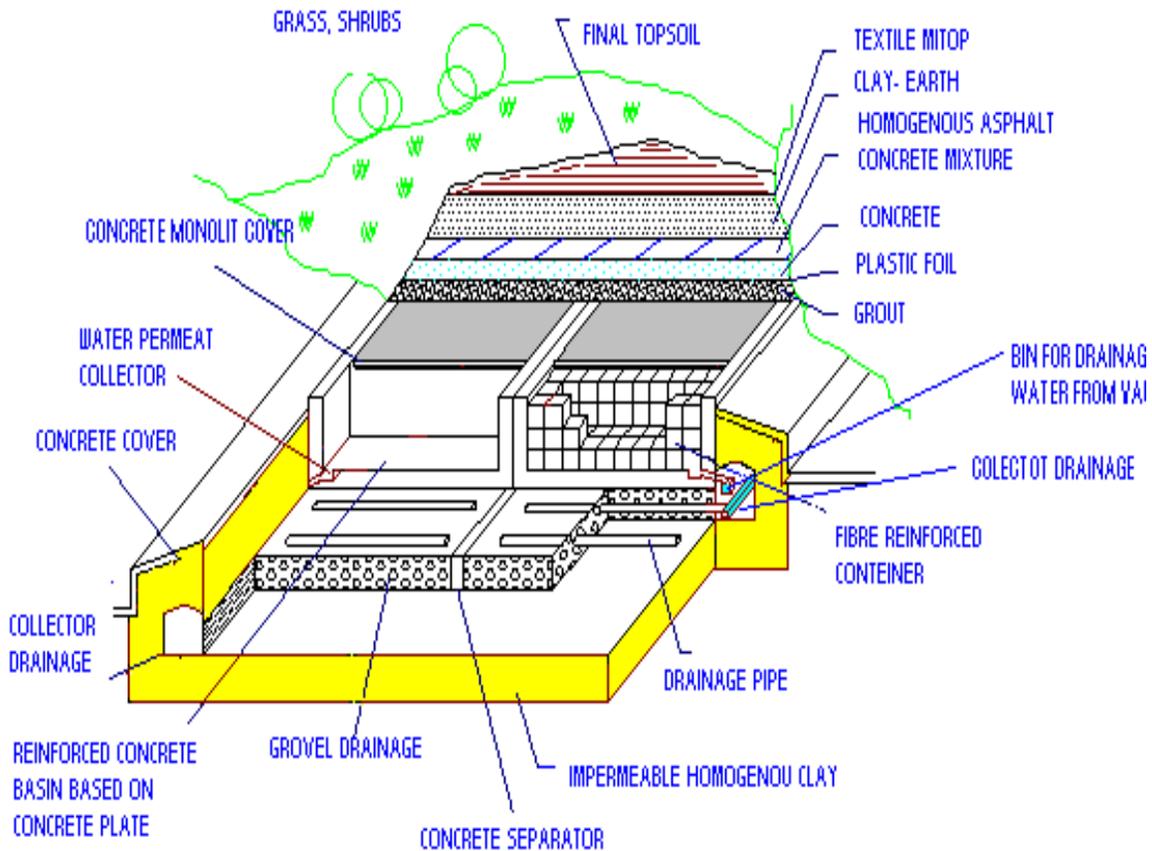


Fig. 1 Cross-section trough a double-row of the storage vaults

As a sealing material preventing both water inleakage and outleakage, compacted clay has been used forming a sort of compact “trough” around each double-row. The wall thickness and the bottom thickness are 3.5 m and 1m, respectively.

Special multilayer isolation, consisting next to others the most important safety assessment barriers clay and drainage layer, with total thickness 4 m will be placed on top of repository in the closure phase.

The facility is located in the upper part of valley, approximately in 1.5 km distance from NPP Mochovce. Total repository area is 11.2 hectares. Hydrogeological conditions of the site are very complex. Permeable and impermeable layers interchange in sediments of Sarmat age. There is often a smooth transition between these layers in the vertical direction as well as the horizontal. The loam thickness was determined between several decimetres and 4-6 m and up to 10 m in the repository southern part. On the valley axis, where repository is situated, a fine and even silt sand layer with considerable area and small thickness changes was found under the Quarternary soils. This layer of permeable sands was identified as the main H aquifer. Another 2-3 aquifers were found in the repository southern part. The groundwater flow velocity is the highest in the aquifer H and rainfall water infiltration controls the groundwater movement here. In the repository

northern part the H aquifer is not saturated permanently. Groundwater is passing from the H aquifer to the surface stream south wards to the repository site.

SCENARIO DEVELOPMENT

Intrusion and ground water path to the biosphere are the main items considered in the radiological impact assessment of the facility area. The normal evolution scenario simulates the simplest and the most probably way of the exposition of the population. The radionuclides breakaway from the containers and barriers of the repository, spreading through water-bearing layer and stream to the reservoir and through biosphere to people. Normal evolution scenario with untight bathtub is modification of normal scenario, which considers the preferential way of the radionuclides escape through the disturbed clay bath barrier. This means the water leave the repository through gravel instead of the clay bath, following the radionuclides spreading in far field. The biosphere model is the same as in the normal evolution scenario.

The additional scenario requested by the IAEA mission concern to the so-called "bathtub" effect. This means that one supposes that water infiltrates the repository faster than that it can leave it. In such a scenario the repository fills with water and finally contaminated water will run over the top of the vaults and infiltrates along the outside bath walls to the water-bearing layer. This scenario considers failure of the top cover, high tightness of the clay barrier around and under the vaults and the failure of the drainage system.

Alternative scenarios assume a well next to the repository walls and inhabitants are exposed directly by drinking the well water. The implementation of this type of scenarios in the codes requires to skip the calculation of transport in the aquifer and foodchain modelling in the biosphere. Additional alternative scenario has the same two modifications as the normal scenario.

According NUREG 1199 philosophy, the intruder scenarios would not be considered if the lifetime of the barriers against intruders is undertaken up to 500 years. However, the intruder scenarios are operative for the concentrations limits for these radionuclides, which are not concentration limited by evolution scenarios.

The human intrusion scenarios, including residence and various construction works, were modelled supposing that the containers will ensure safe mechanical barrier against possible inadvertent intruders during 500 years after closure. The dose to workers involved in the construction works is calculated.

In the residence scenario it is supposed that after the construction of a building, people live in and around the building, the surroundings of which have been contaminated by excavation works needed for the construction. The radiological consequences of the radionuclides present in the waste and not by the total inventory of radionuclides in the disposed waste. Exposure of the inhabitants is due to radioactive material deposited around the house, inhalation of the dust and ingestion of the contaminated products.

The chosen scenarios were scored and divided into three categories by their importance. The radiological limits for inhabitants exposure were set by the State Health Institute. These limits

were taken into account for derivation of the acceptance criteria for the radionuclides contained in the waste (Table I).

Table I. Assigned authorised radiological limits to scenarios

Scenario	Probability	Exposure	Authorised radiological limits
Normal evolution scenario	1	Chronic	0,1 mSv/year
Normal evolution scenario with untight bathtub	< 1	Chronic	0,1 mSv/year
Normal evolution scenario with bathtub effect	< 1	Chronic	0,1 mSv/year
Alternative scenario	<< 1	Chronic	1 mSv/year
Alternative scenario with untight bathtub	<< 1	Chronic	1 mSv/year
Alternative scenario with bathtub effect	<< 1	Chronic	1 mSv/year
Detached house building	<< 1	One-shot	1 mSv
Semidetached house building	<< 1	One-shot	1 mSv
The motorway building	<< 1	One-shot	1 mSv
Residence scenario	<< 1	Chronic	1 mSv/year

PREOPERATIONAL SAFETY ANALYSIS

Models applied for preoperational safety analysis

The computer codes created by SCK/CEN Belgium and locally adapted were used for modelling and safety analysis of the regional near-surface repository in Mochovce.

Near field code NF is adapted version of the original Belgian code MODEMO. A near field model considers radionuclides washout by rainfall water, their partitioning on the waste form, and flow through barriers - high integrity containers, concrete bottom of the vault, and a curative clay layer beneath the repository. Lifetime of the concrete structures and the containers is foreseen 300 years.

One dimensional far field model with constant parameters was used for modelling of the radionuclides dispersion and migration in underground water. The FF - far field code was adapted NUCDIS code.

The model of the radionuclide dispersion in biosphere includes the population exposure through different ways of using the water from the near water reservoir to which the groundwater is discharged. Model is stationary and considers merely equilibrium radionuclides concentrations. In the Biosphere model BS originally named LAKE some modifications were made.

The new code ALT was developed for alternative scenario as a combination of FF and BS codes as it is written previously.

Intruder scenarios are modelled by NARUSITEL code, which is adopted Belgian INSSLB code.

Safety analysis of Mochovce repository consist of two steps: determine the inventory limit of repository by evolution scenarios and the maximal concentration of radionuclides by intruders scenarios.

Inventory limits

Inventory limit is rated by comparison of the consequences due to disposing the unitary inventory with prescribed authorized limits. The limit inventory of each radionuclide is then linearly extrapolated from this comparison and whole model recalculated in order to verify the linearity.

The performance assessment shows, that the alternative scenario with untight bathtub is the most inventory restrictive for majority of the radionuclides Ni-59, Ni-63, Se-79, Sr-90, Cs-135, Cs-137, Pu-238, Am-241. The analysis for the unitary inventory 1MBq/m³ of the waste is presented on the Figure 2.

Limits for the inventory of the three radionuclides C-14, Ca-41, I-129 are dedicated by alternative scenario with bath effect. The majority of the examined radionuclides is practically not limited in the inventory (Mo-93, Zr-93, Nb-94, Tc-99, Pd-107, Sn-126, Sm-151, Pu-239 +U-235 by the alternative scenario with untight bath and every radionuclides except C-14, Ca-41, I-129 by further scenarios). It is either because the solubility limit has been reached or their sorption is so high that 1030 Bq inventory (set as equivalent to practically no limit) decays before it leaves the repository.

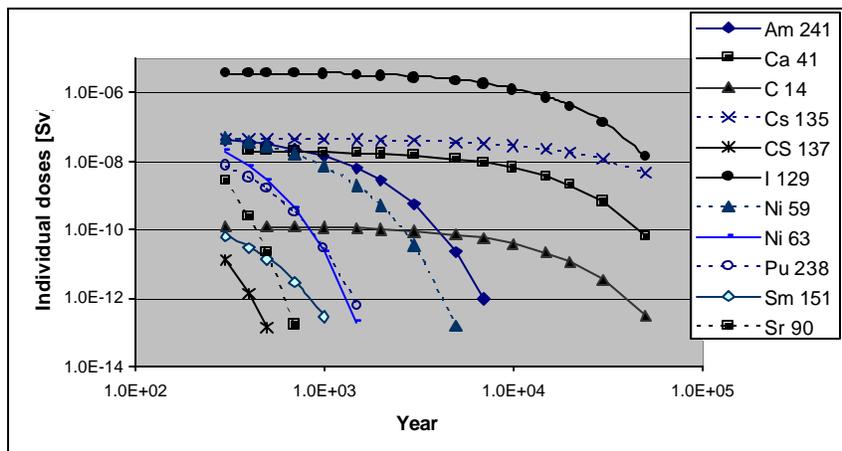


Fig. 2. Time dependency of the individual doses for the alternative scenario and 11 dependent radionuclides, unitary waste inventory 1MBq/m³

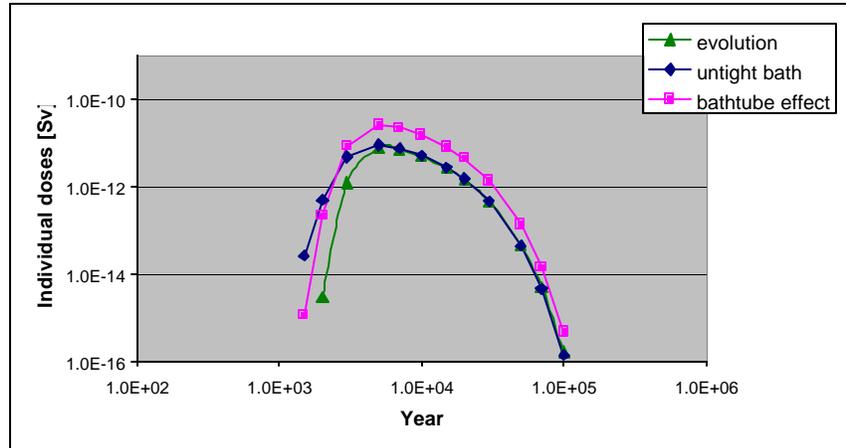


Fig. 3. Time dependency of the individual doses for the normal evolution scenarios C-14 analysis, unitary waste inventory 1MBq/m^3

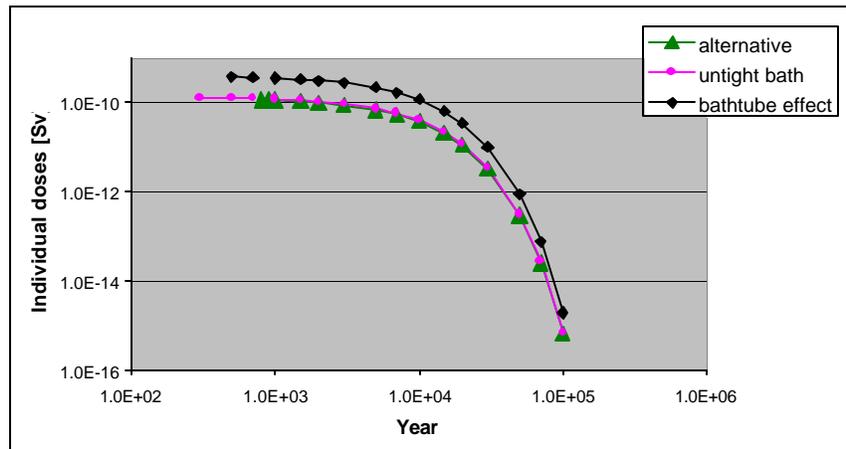


Fig. 4. Time dependency of the individual doses for the alternative scenarios C-14 analysis, unitary waste inventory 1MBq/m^3

Comparing of the results of the analysis of unitary waste packages for 3 variants of normal evolution scenarios and 3 variants of alternative scenarios for C-14 is showed on the Fig. 3 and Fig. 4.

Concentration limits

On the other hand, the radiological consequences of the construction and residence scenarios are determined by the concentration of the radionuclides present in the waste and not by the total inventory of radionuclides in the disposed waste. The intruders scenarios depends on the volume of the excavated radioactive waste, and they impose limits on the radionuclides concentrations in the waste to be disposed of. The volume of the overlap layer of the repository determines the doses from the residence scenario influently to the concentration limits for upper layer of the waste packages. The concentrations of the radionuclides in central and lower layer of the packages are limited by building scenarios. According this each radionuclides have a different

concentration limits for the upper and medium+lower layer of the waste packages (Table II, grey windows).

Table II. Intruder scenarios concentration limits

Radionuclide	Building scenarios		Residence scenario
	1 mSv/year		1 mSv/year
	Upper layer [Bqm ⁻³]	Medium+lower layer [Bqm ⁻³]	Upper layer [Bqm ⁻³]
C-14	1,85E+13	1,90E+13	3,37E+09
Ca-41	2,96E+13	3,04E+13	3,09E+09
Ni-59	2,72E+13	2,79E+13	1,97E+11
Ni-63	4,29E+14	4,40E+14	2,60E+12
Se-79	3,91E+12	4,02E+12	2,03E+10
Sr-90	2,39E+16	2,46E+16	3,67E+12
Mo-93	1,03E+12	1,06E+12	3,34E+10
Zr-93	1,27E+11	1,30E+11	8,32E+11
Nb-94	4,16E+07	4,27E+07	2,76E+07
Tc-99	4,24E+12	4,36E+12	1,78E+09
Pd-107	2,32E+12	2,38E+12	3,98E+11
Sn-126	4,28E+08	4,40E+08	2,84E+08
I-129	6,57E+10	6,75E+10	1,20E+08
Cs-135	1,00E+13	1,03E+13	3,64E+09
Cs-137	1,17E+13	1,20E+13	7,24E+12
Sm-151	3,82E+13	3,92E+13	7,20E+13
Pu-238	4,57E+09	4,70E+09	2,00E+10
Pu-239	8,24E+07	8,46E+07	3,58E+08
Am-241	1,96E+08	2,01E+08	1,06E+09

NEW CODES IMPLEMENTATION

Performance assessment of repository is iterative process. The new situations came out in LLW/ILW disposal, for example need to dispose new radioactive waste streams, hence more flexible tool needless arise from these requirements. Another aim of new code implementation is to verify the results of preoperational performance assessment.

Code selection criteria

The selection process was accomplished with criteria, which follow directly for any code and with criteria describing attributes of computer codes that may not be presently attainable:

- the code preferably has been extensively used or accepted by the user community,
- the selected code should be verified to demonstrate correctness of the source code,

- the selected code should be documented in a technical report which contains description of model theory, assumptions, computation techniques, algorithms and example calculations,
- the code should allow site- and facility- specific applications, i.e. should be capable to simulate the hydrologic, geologic and geochemical environment of the Mochovce site mentioned above, as well as specific design features of the facility over time,
- the degree of complexity of the computer code should be consistent with the quality and quantity of data and objectives of calculation,
- codes should run on personal computers.

The code selection criteria were used to select DUST-MS [3] for near field, MODFLOW and MT3DMS [4] for far field and BS [2] for biosphere analysis.

Source term

Waste form releases and radionuclide transport through engineered barriers to the underlying aquifer are evaluated with the DUST-MS code. The conceptual model considers movement of water and radionuclides through the disposal facility in 1-dimension. The 1-dimensional model represents a transverse section through the disposal facility. The top of the simulation domain is the clay layer and prefabricated concrete. Under prefabricated concrete the three layers of cubical fibre-concrete containers with waste are disposed. The lower part of the domain is concrete floor of the vaults, gravel and clay layer. The vertical dimension of the domain is 10 meters and area of the disposal facility is $7,656 \cdot 10^3 \text{ m}^2$. The finite element approach discretises the domain to be modeled into a 93 small elements for which the flow and transport equations are solved numerically. In order to solve the flow equations, it was necessary to specify boundary conditions and properties of materials present in the simulation domain.

Saturated zone codes

Results of the DUST-MS simulations provide radionuclide flux to the aquifer H. Visual MODFLOW is used as a modelling environment to build and calibrate two-dimensional model of ground water flow beneath disposal site to the nearest stream. The model was built according to previous site investigations and measurements. The first step was to develop a conceptual model that means to identify model boundaries (Figure 5) and fluxes into and out of the system. We have identified that the major and only recharge comes from precipitation lowered by estimation of actual evapotranspiration. The modelled area discharges through drains, that we used for simulating both surface drains along the repository and stream at the south of modelled domain. The 3-rd type of boundary condition (general head boundary) was used for simulation of groundwater runoff in quaternary loams (Figure 5).

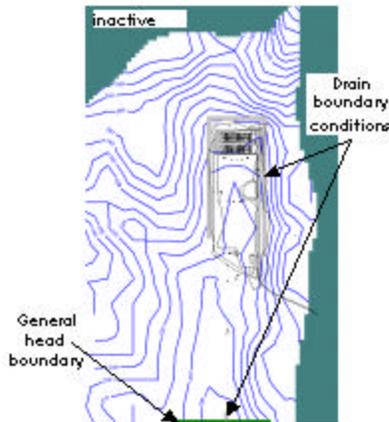


Fig. 5. The repository location with altitude isolines and location of boundary conditions

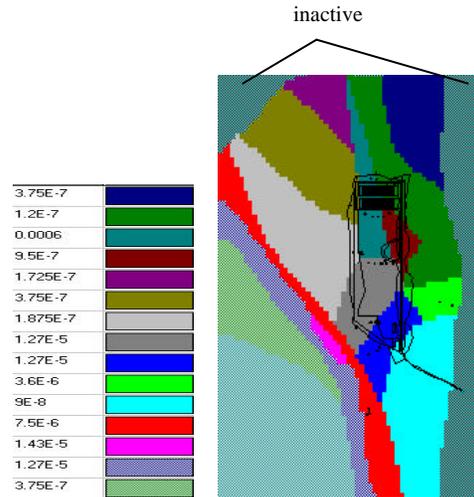


Fig. 6. Final distribution of hydraulic conductivities [m/s]

The second step was to use available pumping test data for realistic estimates of hydraulic parameters. The saturated zone groundwater flow model is assumed to be heterogeneous with respect to hydraulic conductivity and these values have been the subject of model calibration. The final distribution of hydraulic conductivity is shown in Figure 6. Next parameters that we had to input to the model were effective rainfall, effective porosity, drains conductance and longitudinal dispersivity. Most of these parameters were obtained from the previous investigations and were changed slightly in the calibration process particularly because of unsaturated zone influence. The next step was the model calibration. Calibration of the model involved comparison of simulated hydraulic head to measured head data from year 1995 to 1999 (Figure 7). For surface water discharges the measurements from 1991 were used as informative figures. Comparison of modelled and computed hydraulic heads indicates that the model reproduces the head gradients in the respective aquifer fairly, and thus should accurately simulate the flow directions and rates in these units.

After calibration and verification process we changed the model in a way that it simulated uniform groundwater flow through the time by inserting average climatic conditions for whole simulations. Using this approach we were able to simulate long-term processes in “quasi” steady state conditions.

The results of the MODFLOW code simulation are shown in Figure 8. Figure 8 illustrates the distribution of the head equipotential contours with pathlines. The pathlines have direction arrows on them indicating the groundwater flow direction.

The hydrologic model described above is used to generate a transient flow field for Mochovce site. This flow field is utilized in the transport model MT3DMS to predict movement of radionuclides from their area of contact with the water table through the groundwater to the points of interest. Decay and retardation are accounted for in calculating a groundwater concentration.

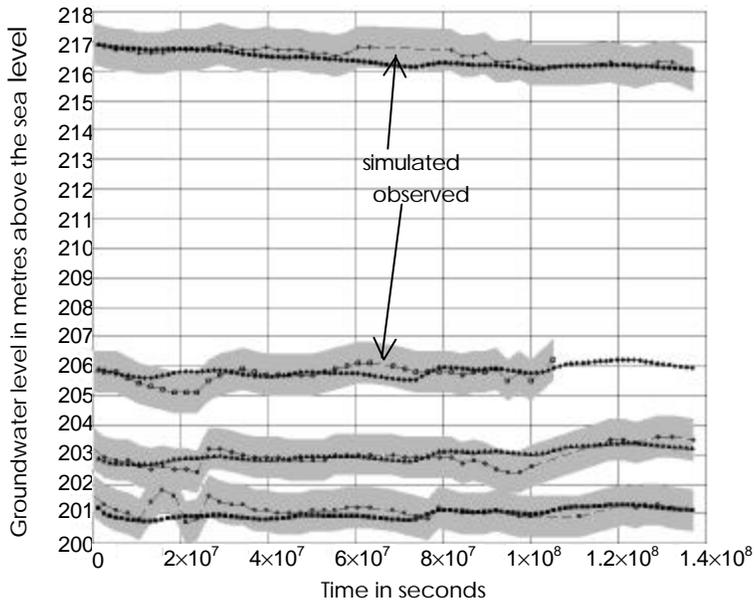


Fig. 7. Comparison of simulated and observed groundwater levels

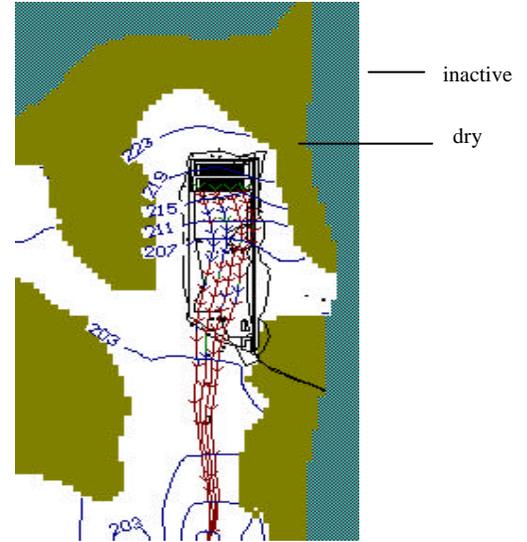


Fig. 8. Groundwater level equipotentials and pathlines

COMPARATIVE CALCULATION

As an example of different model calculations a comparison of radionuclide flux from the repository for both ^{129}I and ^{14}C for the normal evolution scenario is given.

The example considers failure time of all containers and concrete barriers after 300 years. The clay barriers are efficient so rate of water infiltration into disposal facility is low-about $1.25 \cdot 10^{-8}$ cm/s. In the case of DUST-MS code the diffusion release model from waste form is used because cemented waste are supposed. The NF model supposes that the infiltrating water, the concrete and waste form a homogeneous mixture in the burial installation. The model considers that the radionuclides dissolve and that linear adsorption equilibrium is established between the concrete and the dissolved radionuclides. Solubility limits of the radionuclides specific for the disposal conditions are also taken into account.

The results of calculations of the ^{129}I and ^{14}C fluxes which leached from the disposal facility and entered into the aquifer are given in Figure 9 and 10. If maximal activity fluxes below clay bath computed by both models are compared, the correspondence for ^{129}I in range of one place value is existing. Maximum value $1.85 \cdot 10^{-2}$ Bq/cm²/year is reached in 1100th year for DUST-MS code and $8,4 \cdot 10^{-3}$ Bq/cm²/year in 535th year for NF code.

In the case of ^{14}C the differences in activity fluxes are greater. The maximum values are $5.39 \cdot 10^{-6}$ Bq/cm²/year in 10 500th year for DUST-MS code whereas results of NF code gives $2.92 \cdot 10^{-5}$ Bq/cm²/year in 700th year.

For the same parameters we used equal values in both models. The differences in the results are explained by different approaches to release mechanism modelling. NF model assumes that

equilibrium between the infiltrating water and the disposal installation is immediately established. The leaching process of radionuclides will continue until the inventory of the radionuclides is exhausted by radioactive decay or leaching. In estimating the release of radioactivity from the waste form in DUST-MS diffusion process is used.

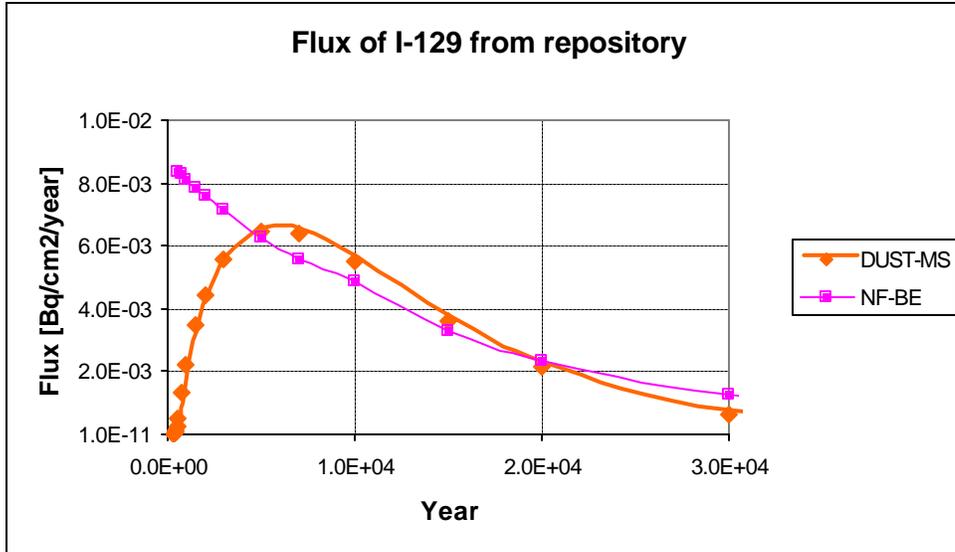


Fig. 9. DUST-MS and NF estimated I-129 release to the aquifer

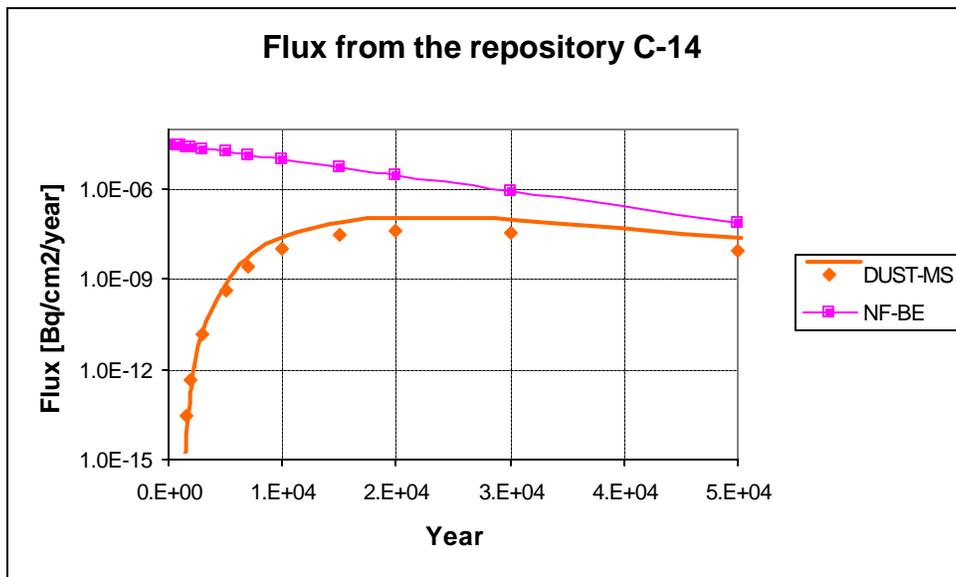


Fig. 10. DUST-MS and NF estimated C-14 release to the aquifer

CONCLUSIONS

Regional repository in Mochovce is intended to receive each low and intermediate level radioactive waste produced in Slovakia. The safety analysis were made for unusual number of radionuclides therefore the dataset of the input parameters preparing was really serious work. The

main results of the analysis are the limits for capacity of the inventory of repository site and concentration limits for each of 19 radionuclides.

As it is showed in analysis, results of the alternative scenario with untight bathtub is the most restrictive for inventory of majority of radionuclides disposed in repository. Merely the inventory of C-14, Ca-41, I-129 is restricted by alternative scenario with bathtub effect. The concentration limits are rated by the most severe limit from intruders scenarios separately for upper and medium+lower layer.

By multiplied conservativity of the safety analysis ensured by models and input parameters the results document sufficient safety of the repository for disposing of the low and intermediate level radioactive waste.

The performance assessment methodology described upper have interconnected three computer codes into computer system DUST-MS-MODFLOW-BS sequentially to perform source term, ground water flow, transport through biosphere and dose assessment. The tests show that this system can be useful tool to evaluate normal and alternative scenarios for LLW/ILW repository in Mochovce.

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