THE ASSESMENT OF SELECTION AND APPLICATION OF RELEVANT FEATURES, EVENTS AND PROCESSES FOR BIOSPHERE MODEL OF SLOVAK REPUBLIC

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Abstract

The final step of the management of highly radioactive waste and spent nuclear fuel is the disposal in deep geological repository. Slovakia also considers the implementation of the deep repository on its territory as a preferred option. In order to evaluate the long-term safety of the repository, an initial model of the disposal system, geosphere and biosphere need to be developed. Key activities in development of a repository safety or performance assessment are the comprehensive identification of the relevant factors, often termed "features, events and processes" (FEPs). The use of a well-defined database of FEPs allows detailed simulation of transport process of the contaminants and calculations of the annual effective doses for a representative person from a critical exposure group. This paper describes the principle of selection of relevant FEPs, their application and evaluation of their influence on the reference biosphere model for the conditions of Slovakia.

Keywords: *Deep geological repository, FEPs, Reference biosphere*

Introduction

In the case of the use of nuclear energy, considerable attention must be paid to the safe disposal of radioactive waste and spent nuclear fuel.

At present, in almost all countries with a developed nuclear program, when disposal of radioactive wastes containing long-lived radionuclides and spent nuclear fuel is considered, implementation of the concept of a deep geological repository is necessary. An important step in the creation of a repository model is the development of scenarios and the specification of relevant FEPs for the conditions of the disposal facility.

In order to assess the long-term safety of the deep repository, a comprehensive model of the reference biosphere, geosphere and disposal system should be created to obtain information on radionuclide migration in a given environment, radiation load, etc.

The process of safety assessment

The main aim of the radioactive waste or spent nuclear fuel disposal system is to isolate these types of waste from the population and the environment for the time necessary to ensure that no potential release of radioactive material into the environment causes an unacceptable risk.

The long-term safety of any radioactive waste or spent nuclear fuel disposal system has to be satisfactorily demonstrated before its implementation. The Radioactive Waste Management Commission at Nuclear Energy Agency / Organization for Economic Cooperation and Development (NEA/OECD) has expressed the view, that deep geological disposal with a passive barrier system is a feasible approach that can provide adequate safety and that such disposal system may eventually replace storage systems requiring continuous maintenance and control by the relevant company [1].

Safety analysis can be defined as the behaviour of the entire disposal system, its potential impacts on population and the environment, including the results of comparison with safety standards.

A key conclusion of safety analyses should be to ensure that the disposal system (concept of the repository) can be developed and implemented in such a way that workers and the population are not exposed to radiation above the legal limits. The ultimate goal of data collection, scenario development, and modelling itself is to describe the disposal characteristics and quantify the functionality of the entire system in terms of radiological safety as a function of time.

The process of demonstrating the safety of disposal systems that usually consists of 10 basic steps shows Figure 1. These steps can be defined as elements of the iterative evaluation process [2]:

- step 1 - Context of analysis
- step 2 - Description of the disposal system
- **step 3 - Description of the FEPs**
- **step 4 - Development of scenarios**
- step 5 - Creating a conceptual and mathematical model
- step 6 - Performing of the calculations
- step 7 - Interpretation of the results

• step 8 - Comparison with limits
• step 9 - Modification
• step 10 - Building of trust.

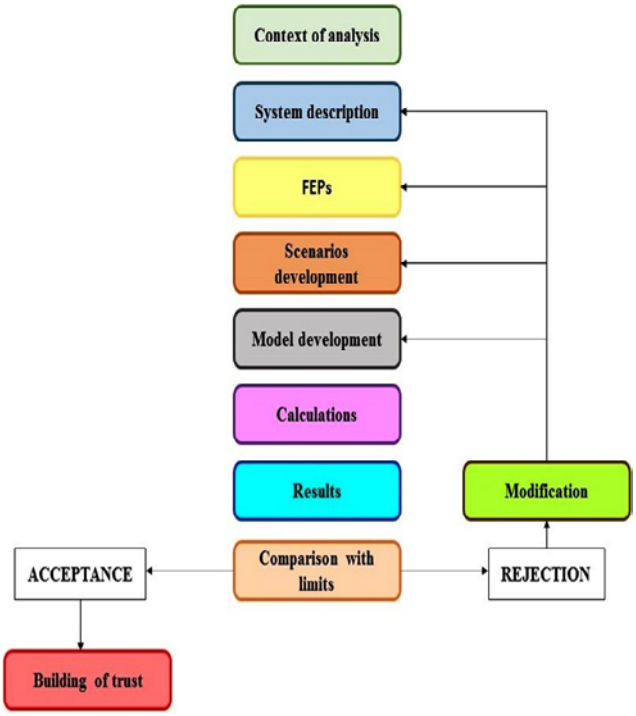


Fig. 1. Basic steps of the safety analysis for the disposal system

Definition and screening of FEPs

Defining scenarios based on a set of features, events, and processes is the main basis for assessing system behaviour. Although at the present level of knowledge some behavioural patterns of a system that can be described as scenarios can be defined without any doubt, a systematic approach for their definition and model descriptions must be based on a wider basis. Each considered scenario is the result of an initiating event, and its course is the result of the FEP file that occurs in the system. These FEPs directly or indirectly affect the leakage and transport of contaminants from the disposal system and consequently the radiation load on the population and the components of the environment.

In order to define the probable or critical course of the scenario, all FEPs should be evaluated and it needs to be determined which ones are relevant for the scenarios. The goal of assessing the system's behaviour is to monitor the FEPs in their full extent and defined events real, probable and affecting. The system behaviour should be described in a relatively simple way that exhausts all critical options and does not neglect essential phenomena [3].

At the beginning of the preparation of the FEP list, the FEP classification is proposed. Currently, there are several international FEP databases that have been developed for national and international purposes.

International programs (IAEA, NEA) are starting to promote multi-level categorization of FEPs based on [4], as shown in Figure 2:

• assessment basis
• external FEPs
• FEPs of the far field
• FEPs of the near field.

The assessment basis defines the scope of the analysis, resulting, for example, from legislative requirements, from requirements to required outputs from analysis and from individual analysis stages.

External FEPs are FEPs that do not come from disposal system and have general and global origin. External factors are not affected by processes in the disposal system, eventually they are affected only minimally. In the development of deep geological repository models they often represent marginal and initial conditions for the model area.

FEPs of the far field are FEPs that affect the development of physical, chemical, biological and anthropogenic conditions in the host structure of deep geological repository. These factors are dominant in estimating the leakage and migration of radionuclides into the biosphere.
FEPs of the near field describe processes that directly affect leakage and migration of radionuclides through engineering barriers implemented in deep geological repository into the geological environment.

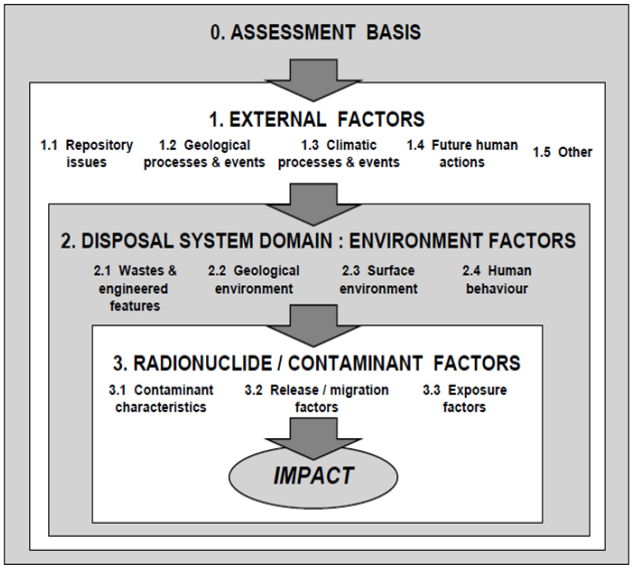


Fig. 2. Basic steps of the safety analysis for the disposal system

Due to the fact that the implementation of the deep repository in Slovakia is not foreseen until year 2065, the detailed selection and evaluation of the relevant FEPs impact have not been carried out yet. For the academic purposes, a basic model of the disposal system, geosphere and biosphere was developed using GoldSim simulation tool to assess the long-term safety of the deep geological repository. The model serves as a demonstration tool for the implementation of FEPs. Some aspects related to, for example, the impact of sea or volcanic activity on deep repository safety being automatically excluded from the list of relevant FEPs. The initial model was created for the conditions of the Slovak Republic.

Creation of the model

The most extensive part represents the model of the reference biosphere. The conceptual model was developed according to the BIOMASS methodology (IAEA, 1996). The role of the BIOMASS document is to provide a methodology in the process of creating practical examples demonstrating ways in which models of the biosphere for long-term safety assessment can be developed and appropriately assessed for the specific purposes.

A relatively simple interface between the geosphere and the biosphere considers the natural flow of contaminated groundwater into the aquifer. This water passes through other transport pathways and then it is discharged into the surface. The ultimate goal is to calculate the effective dose for the individual without considering the evolution of the biosphere system [5].

Disposal system and geosphere

The modelled disposal system is based on a multi-barrier concept, which consists of a combination of engineering and natural barriers providing sufficient protection for the environment and the population over a very long period of time. All elements of the multi-barrier protection system are interacting with each other in such a way to isolate radionuclides from the biosphere.

One of the barriers is the waste itself – very form of spent nuclear fuel. Another important barrier is the disposal container, where spent fuel assemblies (from VVER-440 reactors) are considered to be disposed in. The disposal capacity of one container is 7 fuel assemblies. This container is made of stainless steel (inner part) and carbon steel (outer part), with an outer diameter of 650 mm and a length of 3670 mm. Fuel assemblies are inserted into the inner profiled pipes made of aluminium alloy [6]. Within this assessment, the calculations were performed for the spent fuel with an initial average enrichment of 4.25 % of ^{235}U and a burnup of 60 MWd/kgU. The time of storage before the final disposal was set at 50 years. Disposal container is surrounded by a bentonite buffer with a wall thickness of 300 mm.

Due to normal evolution processes, after 1000 years, the disposal canister fails, water comes into contact with the source term (fuel and structural material), and released radionuclides start to migrate through the bentonite buffer, excavation disturbed zone (EDZ) and crystalline host rock. Within the created model, the theoretical scenario of one disposal container in the repository space was assumed.

After the radionuclides penetrate all the barriers in the near field represented by the spent nuclear fuel matrix itself, the disposal container and the bentonite buffer, they reach the geosphere. In our model, the geosphere is represented by a crystalline host rock environment where radionuclides reach the geospheres through the fractures and faults. The connection between the geosphere and the biosphere is represented by an aquifer, from which the contaminated water flows through the surface flow into the lake.

Biosphere

The primary medium through which radionuclides come into the biosphere is water. Contaminated water from the well or the lake is used as drinking water for the population, water for livestock and also for irrigation of the agricultural land. In the lake fish are being farmed. On such land are cultivated cereals, vegetables, grassland and trees. Radionuclides are transported through the root or leaf system into the plants, hence either directly into the human organism, or into the animal organism from which the animal products enter the human body. Receiving of the radionuclides is also caused by the consumption of contaminated fish meat.

For livestock in our model, we consider bovine animals whose animal products - meat and milk are consumed by residents from the critical exposure group. In the process of creating a reference biosphere, some input elements were selected, representing the constituent elements of the environment within the biosphere model. In the case of crops, cereals, grassland and trees are considered in the model. In the pond fish are kept, which are then also consumed by humans. Figure 3 illustrates the schema of the conceptual model of biosphere and exposure pathways.

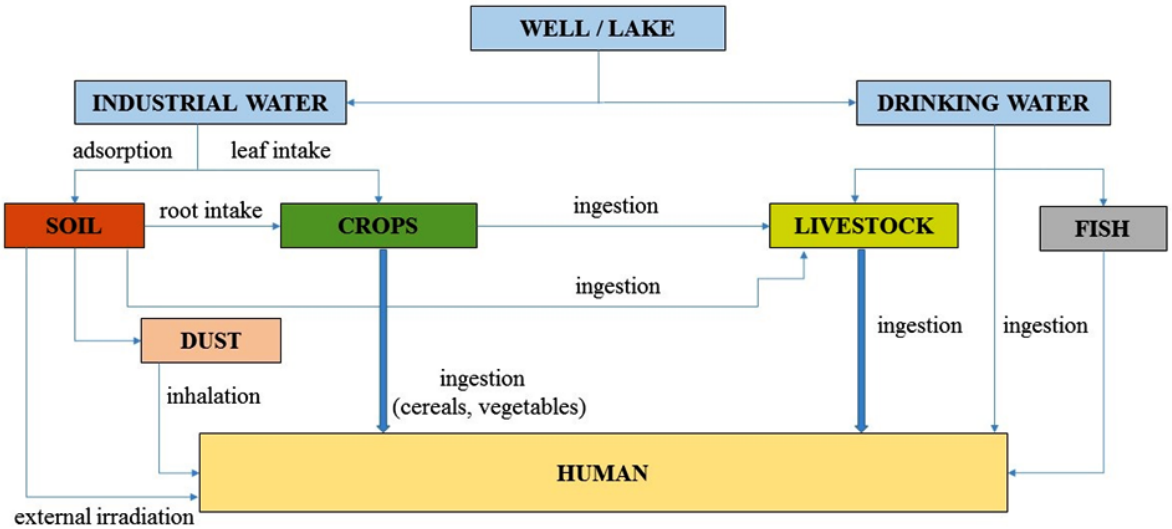


Fig. 3. Schema of the conceptual model developed for the reference biosphere

Conservatively, it is assumed that all consumed environmental components are contaminated with radionuclides, with the primary exposure pathways such as: external exposure, inhalation, and ingestion.

The study considered that the source of external exposure is the contaminated soil. On the surface of the soil, the persons move carrying out, for example, agricultural work. The value of the effective dose from external exposure is therefore dependent on the time spent on the contaminated soil. The exposure pathway of external exposure also includes external irradiation of the person's skin from the dust that is deposited on it. The effective dose caused by inhalation depends, inter alia, on the amount of inhaled dust arising from the contaminated soil and the respiration rate of the exposing object, assuming a constant content of soil particles in the air. The external exposure is caused by inhalation of particles of contaminated dust. The effective dose caused by ingestion depends on the amount of ingested contaminated water and contaminated food.

Safety assessment of the potential deep geological repository

In order to evaluate the long-term safety of the spent nuclear fuel disposal system, the paper aim was to determine the values of the annual effective doses for individuals from the critical exposure group for considered deep geological repository in Slovakia. The representative individual from a critical exposure group is considered to be an adult over the age of 17 years.

The geosphere and the disposal system, which includes disposal containers for spent nuclear fuel and sealing material (bentonite), are modelled conservatively. The scenario is based on the National Program for Spent Nuclear Fuel and Radioactive Waste Management in Slovak Republic [7], which requires the allocation in the repository of 32,658 spent nuclear fuel assemblies produced from the 60-year operation of Slovak nuclear power plants. Since it is assumed that the capacity of one disposal container is 7 fuel assemblies, we assume that approximately 4 665 containers will be disposed in the deep geological repository. The conservative scenario further assumes that each disposal container will fail after 1,000 years due to degradation of the materials used in repository.

It is assumed that the main transport pathway of radionuclide migration is groundwater, which passes through fractures and faults in the geosphere and into the aquifer and then to the well. For each disposal container, the same boundary conditions are assumed (same container distance from host rock fractures, the same transport pathway of released radionuclides etc.).

The chosen scenario for assessing the long-term safety of the deep geological repository considers a normal evolution scenario. It is based on the assumption that the conditions for which the repository was built are unchanged throughout its whole existence and that the properties of engineering barriers correspond to project prerequisites. It is not considered the introspection of the person into the disposal area, the climatic conditions remains unchanged; the use of the environmental components associated with the agricultural and other activities is identical throughout the evaluated period to the current habits. Data on food consumption, water intake and respiration rate are given in Table 1.

Table 1 Food consumption, water intake and breathing rate of an adult, [8]

	ADULTS (> 17 years)
Milk and milk products [l/year]	153
Meat [kg/year]	60
Cereals [kg/year]	157
Vegetables [kg/year]	75
Fish [kg/year]	2,3
Water [l/year]	700
Breathing rate [m^3/s]	2.567×10^{-4}

Radiological limits for the long-term assessment of the safety of a waste disposal facility are recommended by ICRP; the annual dose constraint for the population is set to a value of 0.3 mSv/year [9].

Figure 4 shows the calculated annual effective dose caused by ingestion, inhalation and external exposure, and the total annual effective dose for an adult from the critical exposure group.

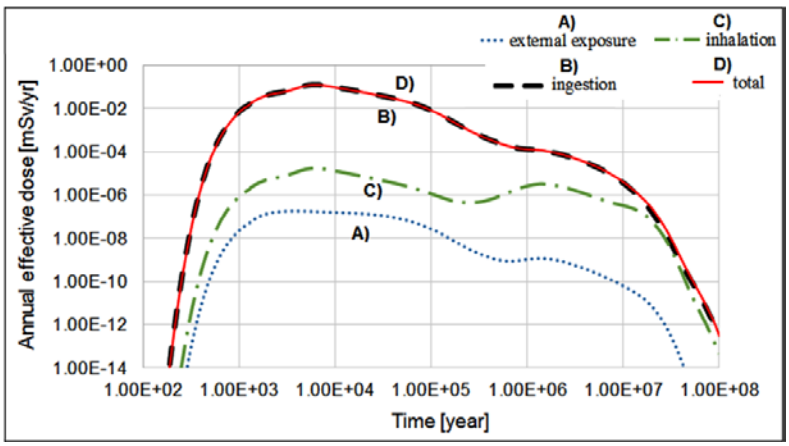


Fig. 4. Annual effective doses for individual from critical exposure pathways

From this figure can be noticed that the dominant process for irradiation is the ingestion, the inhalation and the external exposure having a negligible effect on the total effective dose. The annual effective dose of an individual is mainly caused by the ingestion because the scenario considers that the dominant pathway of intake of radionuclides is consumption of contaminated food and drinking of contaminated water from the well. The rate of intake of radionuclides by an adult in the form of food and drink is incomparably higher compared to radionuclide intake caused only by inhalation of contaminated dust or residence on contaminated soil.

The maximum annual effective dose for an individual of the critical exposure group is 0.1226 mSv/year. When comparing this value with the limit established by regulatory authority for waste disposal facilities, it can be noticed that calculated value is lower than this limit. Based on this finding, we can conclude that the repository we have modelled is satisfactory from the safety requirements point of view.

Conclusions

One of the key activities in assessing the long-term safety of the deep geological repository is development of scenarios of the system and description of the relevant features, events and processes (FEPs) that are specific for each waste disposal repository.

Due to the fact that the implementation of the deep repository in Slovakia is not foreseen until year 2065, the detailed selection and evaluation of the impact of the relevant FEPs has not been carried out yet.

For the academic purposes, a basic model of the disposal system, geosphere and biosphere was developed using the GoldSim simulation tool to assess the long-term safety of the deep geological repository. The model serves as a demonstration tool for the implementation of FEPs.

Based on the model, the long-term safety assessment of a potential deep geological repository was carried out, considering the normal evolution scenario.

The obtained results support the conclusion that the annual effective dose of an individual is mainly caused by the ingestion, because the scenario considers as dominant pathway of intake of radionuclides the consumption of contaminated food and drinking of contaminated water from the well.

The value of the maximum annual effective dose for an individual of the critical exposure group is lower than the limit recommended by regulatory authority (ICRP) for waste disposal facilities. Therefore, we can say it is satisfactory from the safety requirements point of view.

Acknowledgements

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