U.P.B. Sci. Bull., Series C, Vol. 69, No. 1, 2007 ISSN 1454-234x

PERFORMANCE EVALUATION FOR A FINAL HYPOTHETICAL REPOSITORY SYSTEM FOR LOW AND MEDIUM RADIOACTIVE WASTE LOCATED IN GRANITE ROCK

A. O. PAVELESCU[1], N. DĂNILĂ[2], G. ŞINDILARU[3]

În lucrare sunt prezentate politicile naţionale de management al deşeurilor radioactive. Se introduc conceptele de depozitare a acestor. Se tratează problema calcului debitelor dozelor. Ultimul capitol este destinat analizei unui sistem ipotetic de depozitare pentru deşeuri slab şi mediu active amplasat în rocă de granit. Analiza este realizată printr-un program original elaborat de primul autor în MATHCAD în două cazuri: determinist şi probabilist şi două scenarii: normal şi anormal. Prezentarea este însoţită de figuri şi grafice comentate în decursul capitolelor. Funcţia obiectiv a sistemului este reprezentată de către debitul dozei totale medii receptata de către om la suprafaţa pământului (in biosferă) . Cazul determinist, pe baza căruia se poate realiza apoi proiectul depozitului este un caz limită al abordării probabiliste.

Radioactive waste management national policies are mentioned in the paper. The waste disposal concepts are presented. The paper deals with the dose rate flow calculation problem. The last chapter is related to the analysis of a hypothetical disposal system for low and medium radioactive wastes repository, located in granite rock. The analysis is made by an original computer program created by the first author in MATHCAD, in two cases, probabilistic and deterministic approach and two scenarios, normal and abnormal. The presentation contains explained figures and graphics. The objective system function is represented by the effective annual total dose equivalent rate flow, collected by human on the surface (in biosphere). The deterministic case is a limit case of the probabilistic approach. The repository design may be based on this case.

Keywords: radioactive, waste, dose, disposal, repository, background, deterministic, probabilistic, evaluation, scenario.

[1] Eng.; Dept. of Electrical Centrals and Industrial Power Engineering, University "Politehnica" of Bucharest, Romania
[2] Prof.; Dept. of Electrical Centrals and Industrial Power Engineering, University "Politehnica" of Bucharest, Romania
[3] Reader; Dept. of Electrical Centrals and Industrial Power Engineering,, University "Politehnica" of Bucharest, Romania

1. Introduction

The management of radioactive wastes and the security of the repository systems represent matters of great actuality. By adopting nuclear energy as an energy source, on one hand a pronounced reduction of CO_2 emissions is achieved, on the other hand the problem of radioactive wastes appears.

This issue created an important point on nuclear industry agenda, which needs to offer and explain the solutions available for the administration of the resulted radioactive wastes.

The main problem regarding radioactive wastes appears to be of political nature, being generated by the lack of public support. This communication issue has to be improved for certain, and the analysis of correct and honest information is recommended, in order to obtain a large acceptation from the public.

In Romania, the matters related to the management of radioactive wastes have recorded quite a remarkable progress, especially in the field of low and medium radioactive wastes.

In what the final disposal, is concerned, for the CANDU spent fuel radioactive waste from Cernavodă Nuclear Power Plant, there is not a clear option yet, regarding a specific geological host medium. For the moment the only decision refers to the disposal strategy for the spent fuel in an interim storage in the proximity of the plant, (an already completed objective) and later disposal without reprocessing in deep geological formations.

The paper presents a post-closure evaluation of performance, for a hypothetical low and medium radioactive waste storage, located in granite deep geological formation. Forewords, the methodology, informational base, modeling, obtained results and the performance evaluation and conclusions have been presented and discussed. [1] [2]

2. The granite formations as an option for final disposal of radioactive waste

The granite formations as an option for final disposal of radioactive waste present the following benefits: [3]

- They reside in stable deep geological formations of large scale.
- The average permeability of rock is very low, unless the strata are quite fractured.
- The underground water flows are very low, and thus the way to the biosphere or to more permeable rocks is very long.
- The hydraulic gradients are very small.

- A certain degree of fissuring or fracturing is expected, but at high disposal depths. These fractures will be almost closed by the lithostatic pressure, or filled with high absorbing minerals.
- Adequate granite formations, very stable for long periods of time, appear in many European Union countries and in Romania as well.

3. Performance evaluations and the incertitude analysis.

The radiological performance evaluation aims to certify the deference, in reasonable limits, of the performance objectives for a radioactive waste repository. The performance evaluation begins from the first phase of repository construction, continues in the operational period and becomes essential in the final post-closure phase. [4]

The performance evaluation methodology:

- STEP 1: Identifying all the adequate requirements and performance objectives which need to be followed.
- STEP 2: Collecting physical data.
- STEP 3: Conceptual model developed for possible ways of human exposure.
- STEP 4: Mathematical description of processes and paths, identified in the previous conceptual model.
- STEP 5: Calculated result evaluation in order to identify the amount of supplementary data and comparison between results and performance objectives.

For the calculation methodology, two complementary approaches can be applied:

1) Deterministic calculations – for describing a calculus conducted with unique parameters values (also known as “realistic” values), resulting in unique values for each output parameter.

2) Probabilistic calculations – for assigning margins of value (probabilistic distribution) to one or more input parameters. After that, a series of calculations is performed, for instance by random selections of input parameters, in a variation interval, (Monte Carlo analysis for instance) in order to obtain an output parameter distribution, and an average value for it as well.

The final result of a performance evaluation consists of the potential dose which has to be compared with the specific performance objective.

The uncertainties can be grouped into three categories:

- Uncertainties in engineering barriers evolution, geological barriers evolution and environment evolution, related to the characteristics, events and processes which need to be considered. (Scenario uncertainties);
- Uncertainties in establishing the adequate model/models for the relevant features, events an processes (model uncertainties or conceptual model uncertainties);

- Uncertainties in parameter values used in modeling (parameter uncertainties). [4]

4. Repository system design

By repository system, one can understand the combination of engineering and geological barriers, designated and selected to ensure the safe, long term disposal of radioactive waste.

For ensure waste insulation on a sufficiently long period of time, the proposed insulation system relays on a multibarrier concept, which reefers to a combination of natural (geological) and engineering barriers. [5]

The engineering (or technical) barriers ensure an initial confination of wastes. The geological barriers provide a stable medium for the engineering barriers, assuring their longevity. On the same time they contribute to the slowing down of the radionuclides which might eventually, escape through the engineering barriers.

The technical barriers consist of the waste form, waste container, and gallery backfilling and closure**.**

The natural barriers comprise to the geological strata and adjacent geological formations (sedimentary geological formations which covers the main geological formation).

The waste form term reefers to the waste considered together with matrix material (the material in which the waste is immobilized). This waste pack contains two separate components, considered as waste form. These components are: the spent fuel and the Zircaloy sheath.

4.1 The calculation of dose flows in case of possible evolution and transfer scenarios

The normal scenario corresponds to the extrapolation in the future of the passed and present geological tendencies (or biases) analyzed through geological anticipation studies. In these studies, interactions between wastes, structural materials and the host rock are taken into consideration. The relevancy of these primary scenarios depends on a high number of parameters and particularly on the host formation type. In some cases, the release of activity into biosphere is anticipated, but in other cases, though, the present conditions extrapolation leads to the absence of release.

The altered (abnormal) scenario deals with the situations in which the repository evolution is disturbed by events of probabilistic nature. These events modify the normal evolution conditions. Examples: unusual climate changes, sudden water intrusion, human intrusion, etc.

These scenarios are evaluated on the basis of appearance certainty (appearance probability equal to 1). There are also uncertainties in parameters utilized in consequences calculation, due to complexity and space and time variability of the geological medium, and an evaluation of these uncertainties is absolutely necessary. For this reason, margins of values are selected for these parameters in sensibility calculations.

5. Waste disposal system analysis for low and medium radioactive wastes located in granite rock

A model for underground disposal of nuclear spent fuel was taken into consideration. [6]

- The system consists of 3 subsystems:[1], [6]
  - The disposal vault (in a granite formation);
  - The geosphere;
  - The biosphere;
- Three submodels are associated with these subsystems. For these submodels, representative analytical equations are written, dealing with the main phenomena that occur.
- In essence, this consists in a radionuclide transport process towards the surface, which takes place in a very long period of time.
- The solution for each submodel represents an input parameter for the next submodel.
- This type of approach takes into consideration 7 radionuclides and a total of 22 parameters of which 14 specific nuclear parameters. These parameters have probabilistically distributed estimated values within the frame of some probabilistic or deterministic models.
- The procedure allows evaluating effective annual doses or average values of those doses, dependently on the deterministic or probabilistic case for which the calculation is performed utilizing the original MATHCAD program included in reference [1].

5.1 Deterministic case

5.1.1 Normal evolution of the disposal system

The radionuclides are released, as the waste form is dissolving. The most important 7 radionuclides considered are successively: Cs-135, I-129, Pd-107, Se-79, Sm-159, Sn-126 and Zr-95 ($i = 1..7$). [1]

The annual dose equivalent H(t) is given by the sum of all radionuclides doses considered: [1]

$$Htotal(T, j) = \sum_{i=0}^{6} H(\lambda_i, I_i, \tau B_i, \tau L_i, \tau H_i, A_i, D_i, T_j) \text{ [Sv/yr] (1)}$$

Hfond = 1.8 x 10^{-3} [Sv/yr]

Htotal (T , j) =

0
$9.455977\cdot 10^{-4}$
$1.042602\cdot 10^{-3}$
$9.773542\cdot 10^{-5}$
0

Where:

i = the number of radionuclides (i = 7)
j = the temporal references
λ = the disintegration (decay) constant [yr^{-1}]
I = the initial inventory of each radionuclide [mol/kg]
τ B = the buffer transit time for each radionuclide. [yr]
τ G = the geosphere transit time for each radionuclide. [yr]
τL,τH = the roots of equation with the undetermined variable, τ G [yr]
A = the specific molar activity [Bq/mol]
D = the ingestion dose concentration factor [Sv/Bq]
T = the time interval for which the calculation is performed.

One can observe very clearly that effective equivalent annual total dose flow rate values for the reference values on various time moments, representative for performance evaluation are inferior to the natural background dose value, Hfond = 1.8 x 10^{-3} [Sv/yr]. - Fig. 1 [1]

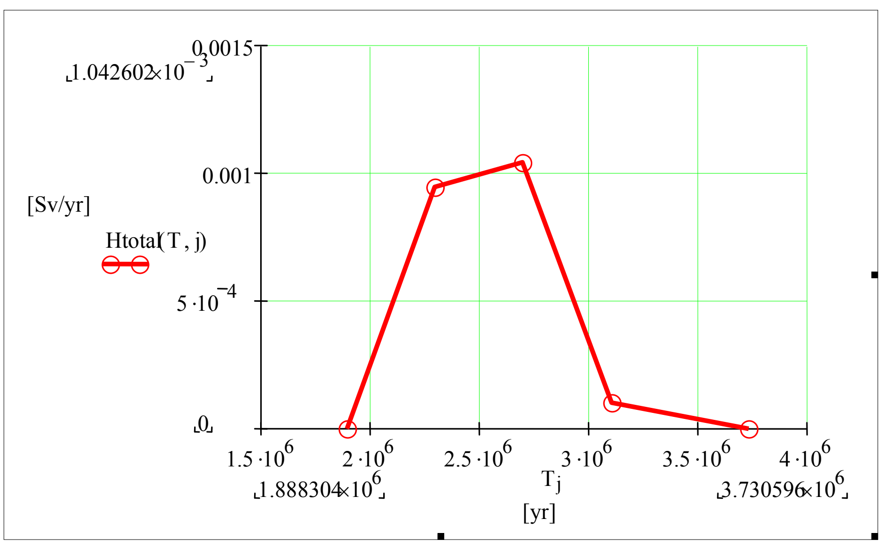

Fig. 1 The time variation of effective equivalent annual total dose flow rate values for reference values XG = 250 m, Q = 2 x 10^8 kg, VG = 0.5 m/yr [1]

Where: XG = reference depth [m]
Q = total waste mass [kg]
VG = water speed in geosphere [m/yr]

5.1.2 Local sensibility analysis

The reference system is characterized by the following values of independent variables:

XG = 250 m; Q = 2 x 10^8; VG = 0.5 m/yr.

The local sensibility analysis consists of the modification of one of the upper variables within a range of +/- 10% of its value, following the system backfeed reaction to this variation.

In Fig. 2, the total dose (Htotal) time variation, is represented for a depth XG = 225 m.

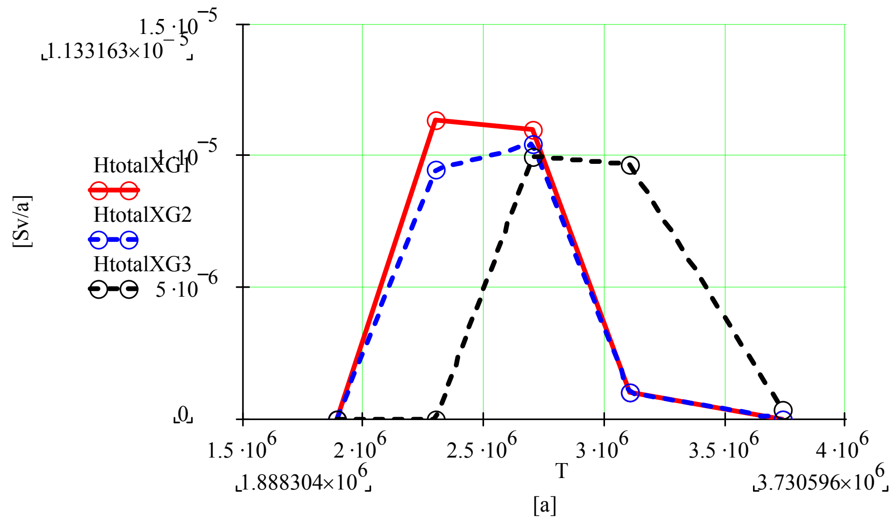

Fig. 2 The time variation of effective equivalent annual total dose flow rate values for the following depths, XG_1 = 220 m, XG_2 = 250 m, XG3 = 275 m, a total reference waste form mass Q = 2 x 10^8 kg and a reference speed VG = 0.5 m/yr [1]

After the local sensitivity analysis, one can observe that the variables can be classified dependently on the influence induced in dose flow rate as follows: XG, Q, and VG. Thus, the depth, XG can be considered the most important variable.

5.1.3 Abnormal (altered) evolution of the disposal system

In this case, it is postulated that throughout later human intrusion in the repository by drilling a deep well, the water quantity remained in the granite rock is reduce by evaporation and the annual extraction rates will diminish. This way, obviously takes place a radioactivity concentration in biosphere, a situation reflected in greater surface doses. Consequently, in this scenario three extraction rates values have been considered, as follows: $w_1 = 5 \times 10^5$ m^3/yr, $w_2 = 5 \times 10^4$ m^3/yr, $w_3 = 5 \times 10^3$ m^3/yr - Fig. 3.

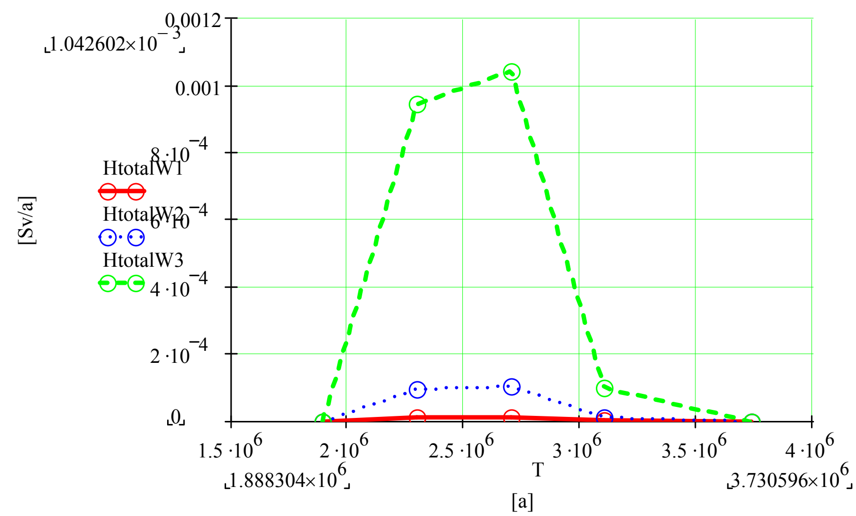

Fig. 3 The time variation of effective equivalent annual total dose flow rate values for the following water extraction rates: $w_1 = 5 \times 10^5$ m^3/yr, $w_2 = 5 \times 10^4$ m^3/yr, $w_3 = 5 \times 10^3$ m^3/yr [1]

In this scenario, as the water extraction rate, w decreases, under the value $w_3 = 5 \times 10^3$, the dose flow rate received at a given moment exceeds the natural background dose, Hfond = 1.8×10^{-3} Sv/yr

Radionuclides transit time towards the surface remains unchanged**.**

5.2 Probabilistic case

In this situation, certain independent variables are not well known. For this reason, one can admit that their values reside in some intervals, being governed by various probabilistic distributions.

There are 4 types of probabilistic distributions involved: uniform, log-uniform, normal and log-normal. One can assume that, 7 of 10 independent variables are governed by the previous 4 probabilistic distributions [1]. Therefore, the r parameter is randomly chosen within [0,1] interval, using a uniform distribution, where r = rnd(1). This way, the independent variables are evaluated as combinations between interval definition values balanced with the r measure. [1]

The probabilistic approach consists of an iterative calculation of Monte-Carlo type in order to evaluate the total average dose, Htotalmed, and the standard deviation, STD, of the total dose from the average total dose.

In the following example, m+1 = 25 iterations have been performed, characterized by different r values, randomly chosen. Every time, Htotal has been obtained for each of the 5 time moments involved in the deterministic case.

The obtained doses are:

$$Htotalmediu = \begin{pmatrix} 0 \\ 2.282226 \times 10^{-6} \\ 2.462763 \times 10^{-6} \\ 1.688266 \times 10^{-6} \\ 3.140076 \times 10^{-7} \end{pmatrix}$$

The time variation of effective equivalent annual total dose flow rate values, in five time moments, which are representative for the performance evaluation, is shown in Fig. 4,

Also, in the probabilistic problem approach, it can be seen that the effective equivalent annual total dose flow rate values are inferior to natural background dose value, Hfond.

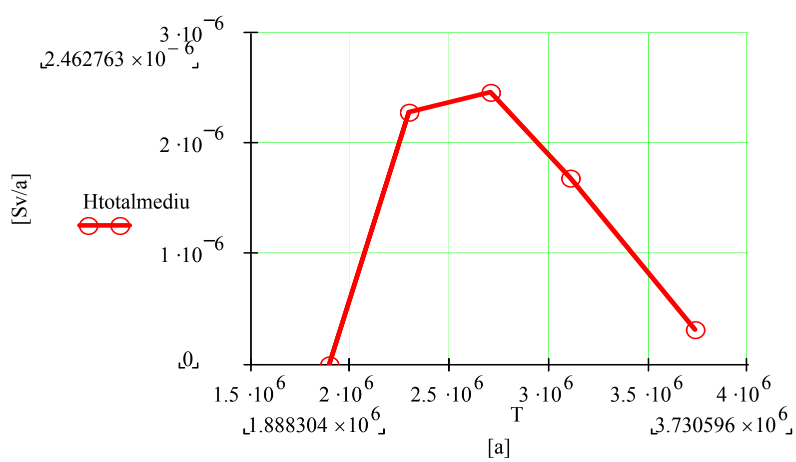

Fig. 4 The time variation of average total dose flow rate [1]

Some of the radionuclides never reach the surface (enter the biosphere) because they have decayed entirely on the way. For this reason we take into consideration only nonzero doses (non-zero doses fraction), as shown in Fig. 5.

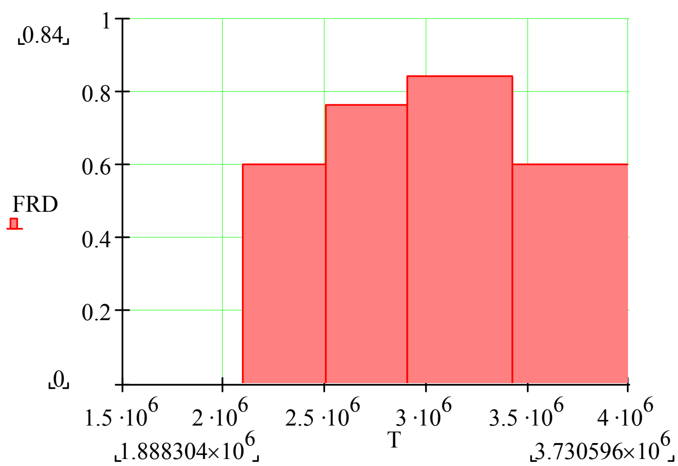

Fig. 5 Time variation of non-zero doses fraction [1]

Within a probabilistic approach, total average doses values have been represented in Fig. 6. The dose was obtained in 25 iterations marked by squares. The average is represented by an intermittent central line. The standard deviation, marked by superior and inferior intermittent lines, is also shown. The standard deviation is relevant due to the fact that statistical nature measures were considered in the calculation.

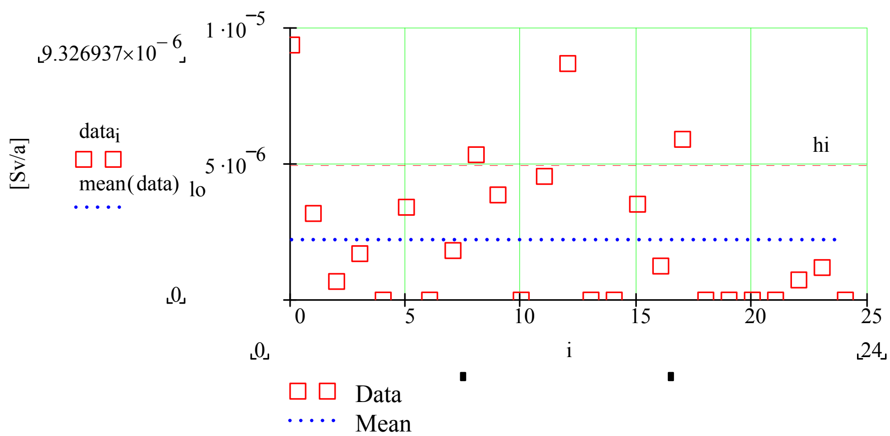

Fig. 6 Average dose and standard deviation graphic [1]

6. Conclusions

1) Thoroughly speaking, the primary evaluation of an insufficiently characterized disposal system, from the independent variables point of view (input parameters), is made under a probabilistic approach.

2) In this (probabilistic) situation, independent undetermined variables are presumed to have distributed values in certain intervals governed by distribution laws with a nonzero r parameter, situated in [0,1 interval. These are combinations for inferior and superior values of variation intervals.

3) In the present paper 10 independent variables and 4 distribution laws, uniform, log-uniform, normal şi log-normal, have been considered.

4) The objective system functions are obtained by repeatedly evaluation for various independent variable values, randomly determined. In this case, these functions represent the average dose values, the standard deviation, non-zero dose fraction, the maximal doses, and the maximal dose average.

5) The probabilistically evaluated system image is improved as the measurement technique are being developed and more undetermined independent variables become determinate by utilizing in situ measurements.

6) In the end of this process, all the independent variables will become determinate and later evaluation of the system will be deterministically made with the r parameter equal to 0, thus the inferior variation interval limits are given by the independent undetermined (probabilistic) values.

7) The deterministic case, in this situation is a limit case for the probabilistic approach.

8) The total surface dose on various time moments is the system objective function.

9) The hypothetical disposal system considered in the paper is a deep one, located in granite rock. There are taken into account only 7 radioactive elements (low and medium radioactive waste). The performance evaluation is made in case of a normal or abnormal evolution scenarios.

10) The considered time scale is represented by millions of years, typically for this type of analysis.

11) Then radiological consequences are found in an interval of [0, 3.730596×10^6] years.

12) The collected radiological doses are inferior to natural background dose.

13) The local sensibility tests have shown that, the first three input parameters, in order of importance, are: the repository depth XG, the waste mass Q, and water speed in geosphere, VG.

14) In the case of disposal system abnormal evolution (human intrusion), as the water extraction rate diminishes, under 5×10^3 m^3/yr, the dose flow rate,

received at a given time moment, exceeds the natural background dose, Hfond = 1.8×10^{-3} Sv/a.

The radionuclides transit time towards surface remains unchanged.

REFERENCES

[1]. *A. O. Pavelescu,* „Evaluarea performanțelor unui sistem de depozitare finală a deşeurilor radioactive” - Proiect de diplomă, Universitatea „Politehnica” Bucureşti, Facultatea de Energetică, 2003.

[2]. *G. Şindilaru*, ”Dozimetrie şi Protecția contra Radiațiilor”, Editura Bren 2002

[3]. *N. Cadelli, G. Cottone, S. Orlowski, G. Bertozzi, F. Girardi, A. Saltelli*, Performance Assessment of Geological Isolation Systems for Radioactive Waste (PAGIS), Summary EUR Report 11775 EN

[4]. *R.. Storck, J. Aschenbach, R. P. Hirsekorn, A. Nies, N. Stelt*, Performance assessment of Geological Isolation Systems for Radioactive Waste (PAGIS): Disposal in Salt Formation, EUR Report 11778 EN, GSF – Bericht 23/88

[5]. *L. H. Johnson, D. M. LeNeveau, F. King, D .W. Shoesmith*: “The Disposal of Canada’s Nuclear Fuel Waste: A Study of Postclosure Safety of In-Room Emplacement of Used CANDU Fuel in Copper Containers in Permeable Plutonic Rock”, volume 2, AECL-11494-2, COG95-552-2, 1996

[6]. *G. Lawson, G. M. Smith* “BIOS: A model to predict Radionuclide Transfer and Doses to Man Following Releases from geological Repositories for Radioactive Waste”, EUR-9755/ NRPB-R 169 (1985).