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**NUCLEAR PHYSICS**

# POST-CLOSURE SAFETY CONCEPT PROPOSED FOR THE SALIGNY NEAR SURFACE REPOSITORY*

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*Abstract*. The paper presents the safety concept proposed for Saligny Near Surface Repository, integrating the considerations, factors, arguments and evaluation methods used to demonstrate the safe evolution of the repository during its lifetime. Based on a preliminary disposal concept initiated under the National Agency for Radioactive Waste coordination, the long term safety evaluation of the new proposed repository is presented.

*Key words*: safety concept, safety assessment, evolution scenarios, safety indicators.

## 1. INTRODUCTION

According to the Romanian legal provisions, ANDRAD – Romanian National Agency for Radioactive Waste is in charge to develop and operate a new repository, proposed for disposal of the low and intermediate short-lived active wastes resulted from operation and decommissioning of the four CANDU Units of Cernavoda Nuclear Power Plant (NPP). The new repository will be near surface type, with multiple barriers, and it will be located in Saligny site, within the exclusion zone of Cernavoda NPP. At the beginning of 2008, the partial siting license was obtained, with the recommendations to continue the site investigations and safety evaluation in order to confirm Saligny site as suitable for hosting the proposed repository [1].

The safety evaluation of a disposal facility is a step by step process, developed in the early stages of a repository sitting. Recently, it was recognized that, in order to build the confidence in the overall safety of a repository, it is not

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enough to develop only a safety analysis, but an overall approach regarding the repository safety, in other words a *safety concept*.

In this paper we present and discuss our results concerning two long term evolution scenarios developed for the new near surface repository whose proposed location will be the Saligny site, in the nearest vicinity of Cernavoda NPP.

## 2. THEORETICAL BACKGROUND

### 2.1. PREREQUISITES FOR DEVELOPING OF THE SAFETY CONCEPT

The fundamental safety objective, established for all nuclear and radiological facilities and activities, including radioactive waste management, is to protect peoples and the environment against the harmful effects of ionizing radiation [2], [3]. The fundamental safety objective has to be achieved without unduly limiting the operation of facilities or the conduct of activities that give rise to radiation risks. In order to demonstrate that a disposal facility deals with the fundamental safety objective, it is necessary to develop a safety concept, integrating the considerations, factors, arguments and evaluation methods used to demonstrate the safe evolution of the repository during its lifetime.

As it was presented in the reference [4], as prerequisite to develop the safety concept it is necessary to establish the set of applicable regulations, the safety objective, as well as the design of repository necessary to fulfill the safety objective. For the Saligny Near Surface Repository, we considered the requirements from Romanian regulations [15] as basis to establish the safety objective. Also, the conceptual design of repository is those proposed in reference [5]. Details about the proposed safety concept are summary presented in the section 3 of the present paper.

### 2.2. HYPOTHESES FOR SAFETY EVALUATION

Geologically, the Saligny site is located in the Dobrogean part of the Moessic platform and it is placed at south of Ovidiu-Capidava fault. The geological characteristics of the Saligny site are those presented in the references [4, 8] and [9]. Table 1 presents the top-down compartments considered in the conceptual model of the disposal system. The loess layers, the red clay and the upper part of the pre-quaternary clay layers are considered as unsaturated zone. All of them are laying on a compact Barremian limestone fundament, host of the main aquifer and considered as a saturated zone [6]. The disposal system barriers, considered to work in synergy with the host site, are: waste conditioning matrix, disposal container, disposal cell and the improved foundation ground.

*Table 1*

Parameters of the disposal system compartments considered in the long term safety evaluation

| **Compartment** | **Depth [m]** | **Dry bulk density [kg/m$^3$]** | **Water filled porosity [-]** | **Hydraulic conductivity [m/yr]** |
|---|---|---|---|---|
| Waste form | 4.4 | 2300 | 0.15 | 0.31 |
| Slab foundation | 1 | 2500 | 0.15 | 0.31 |
| Foundation ground | 3 | 1760 | 0.32 | 1.58 |
| Silty loess | 1 | 1540 | 0.12 | 31.5 |
| Clayey loess – a1 | 2 | 1780 | 0.26 | 6.31 |
| Clayey loess upper Ib | 8 | 1570 | 0.14 | 6.31 |
| Clayey loess Iab2 | 2 | 1720 | 0.25 | 6.31 |
| Clayey loess lower Ib | 6 | 1690 | 0.25 | 6.31 |
| Red clay | 8 | 1760 | 0.32 | 1.58 |
| Pre-quaternary clay-1 | 5 | 1760 | 0.31 | 2.84 |
| Sand lenses | 5 | 1560 | 0.34 | 2.84 |
| Pre-quaternary clay-2 | 6 | 1760 | 0.31 | 2.84 |
| Aquifer (Barremian limestone) | 15 | 1800 | 0.30 | 315 |

In order to demonstrate the fulfillment of the fundamental safety objective proposed for Saligny Repository, we developed the normal evolution scenario, as well as an alternative evolution scenario. It is necessary to mention that for a specific repository there are a lot of alternative evolution scenarios, but the present paper notes only an important alternative scenario selected in accordance with the sensitivity analysis performed for Saligny repository.

The Saligny evolution scenarios were developed methodologically, using the ISAM methodology developed by IAEA (2004) and applied previously for the Saligny repository in the references [8-10].

The normal evolution scenario considers the water infiltration through the repository structures and the subsequent transport of radionuclides through the unsaturated geological layers and the saturated zone. Further, after the institutional control period of the repository, we considered a well drilled in the saturated zone. It represents the water source for a farm located on the Saligny site.

The main phenomena related to the radionuclide transport are advection, diffusion, dispersion and decay. The exposure pathways considered for a representative person are: ingestion of contaminated water and food (crops, meat and milk), inhalation of contaminated air (with gases or dust particles), external irradiation from the contaminated soil and internal contamination by accidental ingestion of contaminated soil.

The end points of the scenarios evaluation are the safety indicators defined for the Saligny repository, namely the radiological dose and the radionuclide concentration in the disposal system compartments.

The input data specific for the Saligny repository compartments and are presented in Table 1, while Table 2 illustrates the radionuclide distribution coefficients.

Based on the information from reference [5], the repository will have 60 cells containing about 62,000 cubic meters of conditioned wastes (compactable waste, non-compactable waste, organic liquids, spent resins and spent filter cartridges). The total radioactive inventory considered in the present evaluation takes into account the operation (40 years) and decommissioning of 4 CANDU units of Cernavoda NPP, as well as the information from reference [7].

The radioactive waste will contain the following inventory: $^{3}$H (7.6 E+14Bq), $^{90}$Sr (2.7 E+14Bq), $^{137}$Cs (8.9 E+14Bq), $^{134}$Cs (4.5 E+05Bq), $^{14}$C (3 E+14Bq), $^{94}$Nb (1.5 E+10Bq), $^{129}$I (8.9 E+09Bq), $^{60}$Co (2.9 E+11Bq), $^{99}$Tc (8.9 E+10Bq), $^{59}$Ni (6.4 E+09Bq), and $^{63}$Ni (9.2 E+11Bq).

It is worth mentioning that the values of distribution coefficients for carbonate, cesium, cobalt and strontium in the silty loess, clayey loess, red clay and pre-quaternary clay have been obtained experimentally on the samples collected from Saligny site for different horizons, as is presented in ref. [5].

*Table 2*

Distribution coefficients of the radionuclides – in the geological layers of Saligny site ($m^3$/kg)

| Element | Silty Loess | Clayey Loess | Red Clay | Pre-quaternary Clay | Sand Lenses | Aquifer |
|---|---|---|---|---|---|---|
| H | 0 | 0 | 0 | 0 | 0 | 3 E-05 |
| Cs | 0.774 | 1.131 | 4.131 | 2.366 | 0 | 1 |
| C | 0.003 | 0.005 | 0.008 | 0.005 | 0.005 | 0 |
| Ni | 0.6 | 0.6 | 0.6 | 0.6 | 0.4 | 1 |
| Nb | 1 | 1 | 1 | 1 | 0.55 | 1 |
| Tc | 0.001 | 0.001 | 0.001 | 0.001 | 0.0001 | 0 |
| Co | 0.033 | 0.03 | 0.031 | 0.03 | 0 | 1 |
| I | 0.001 | 0.001 | 0.001 | 0.001 | 0 | 0.001 |
| Sr | 0.006 | 0.011 | 0.012 | 0.012 | 0 | 0 |

The distribution coefficient values for the other elements and other input data are taken from available literature [11-13].

In the normal evolution scenario, the water infiltration rate was considered to be about 0.02 m/yr, which is the infiltration rate determined during the characterization process of the Saligny site [5]. During the institutional control period of the repository, only 10% of the rainwater will enter the repository structures, after this period the water infiltration rate will increase gradually, so that after 500 years the infiltration rate will be the same like in the natural ground.

The alternative scenario considers the infiltration rate in the natural ground to be 10 times higher than the infiltration rate considered in the normal evolution scenario. Also, the waste and engineered barrier degradation is considered to be a continuous process, beginning from the operational period of the repository. In the first 100 years after the repository closure, the infiltration rate will be about 50%, and will increase gradually, so that after 300 years it will be about equal with the infiltration rate in the natural ground.

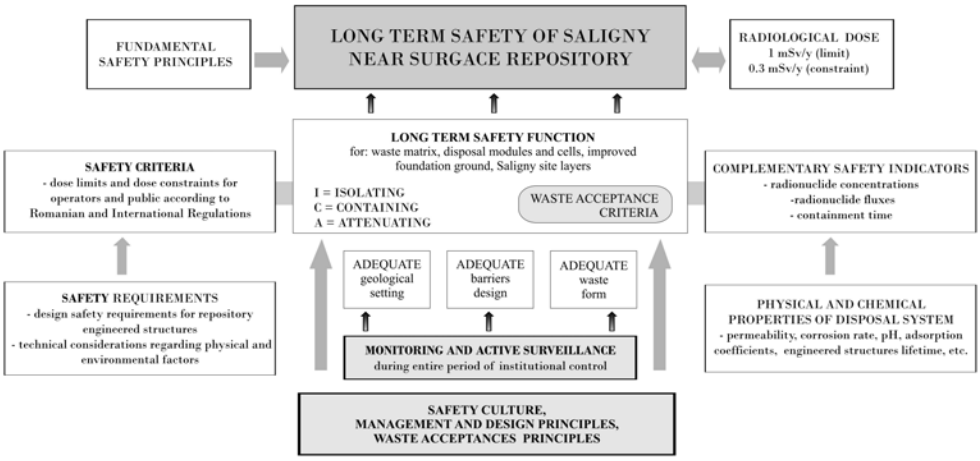


Fig. 1 – Safety concept proposed for Saligny Near Surface Repository.

All calculations were done by using the AMBER 5.0 [14] computer code which considers a global compartmental model and integrates all system compartments, migration processes as well as the exposure mechanisms. For details regarding mathematical equations see ref. [8-9].

## 3. RESULTS AND DISCUSSION

### 3.1. SAFETY CONCEPT

Fig. 1 presents a diagram of safety concept proposed for Saligny Near Surface Repository, which represents the practical way to fulfill the safety principles from [2]. The integrated picture proposes the safety pillars for the Saligny repository safety, namely the basic safety functions and waste acceptance criteria. The safety objective fulfillment is demonstrated by applying a safety assessment methodology to determine the safety indicators. The main safety indicator proposed for Saligny repository is the radiological dose, while the radionuclide concentration in the disposal system compartments and the radionuclide transfer time were selected as secondary safety indicators. The reference value [15] for the long term radiological dose received for public during one year is of 1 mSv/yr, with a constraint of 0.3 mSv/yr. The proposed safety concept is a specific case of those proposed in the reference [4], applied to the Saligny Near Surface Repository proposed for low and intermediate waste resulted from Cernavoda NPP.

### 3.2. SAFETY EVALUATION

For the normal evolution scenario, as is presented in Fig. 2.I, the total annual radiological dose received by a representative person in the post-closure period of the Saligny repository will have a peak value of 9.27 E-5 Sv/yr. The main peak value will occur at 6588 years. A second peak value is very late, at about 1 E+06 years. The main contributors to the first peak value are $^{99}$Tc and $^{129}$I. Other important contributor is $^{14}$C (at about 28 500 years) (see also Fig. 2.I). The contributor to the late peak value of 6.24 E-15 Sv/yr is the long lived radionuclide $^{59}$Ni. The contribution of all other radio-nuclides is negligible. The radionuclide concentration was evaluated as secondary safety indicator, mainly for the period longer than 10 000 years, when the radiological dose is not a relevant safety indicator [16]. The time variation of the concentration in the main aquifer (Barremian limestone) is presented in Fig. 2.III and in Table 3, too.

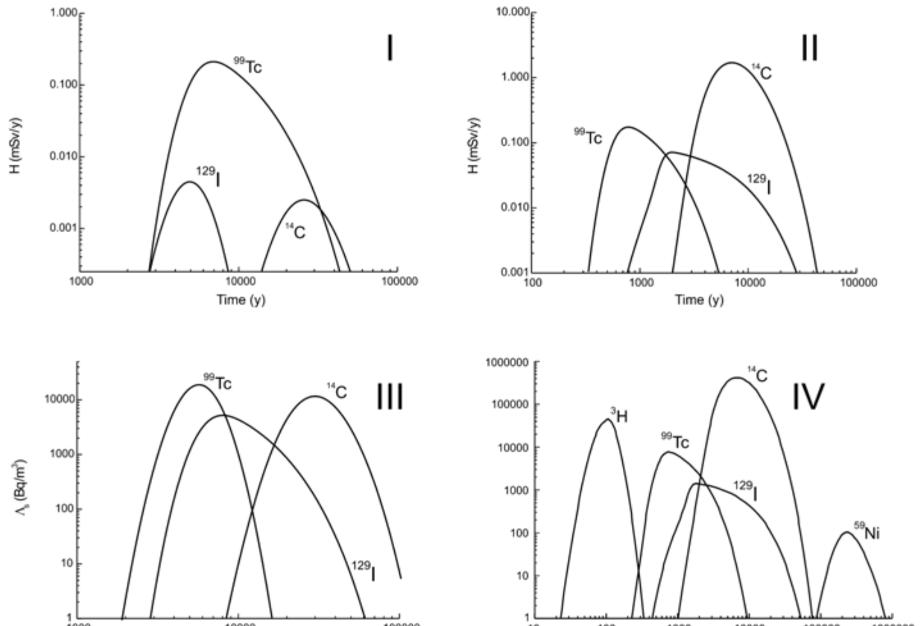


Fig. 2 – Time dependency of the annual effective dose debits (in mSv/y) in the cases of first (I) an second scenario (II) as well as the corresponding specific activity (in Bq/m$^3$) of the main radionuclides in Barremian aquifer (III and respectively IV).

Figures 2.II and 2.IV present the total annual radiological dose as well as the radionuclide concentration in the main aquifer, evaluated for the alternative scenario. The increased infiltration rate has an important effect on the long term behavior of the radionuclides contained in the Saligny repository. As presented in Fig. 2.II, the total radiological dose has an early peak value of 1.7 E-04 Sv/yr, about 2 times lower than the dose constraint. This early peak value will occur at about 730 years, the main contributor being $^{99}$Tc. The second, but very important peak value is about 1.7 E-03 Sv/yr, about one order of magnitude higher than the dose constraint specified in the Romanian regulations [15]. This second peak value will occur at about 6500 years, the main contributor being $^{14}$C. Even if the iodine and strontium will reach early the aquifer, their contribution to the total dose will not be very important. Also, the long lived and not very mobile radio-nuclides like $^{59}$Ni and $^{94}$Nb will reach the aquifer earlier than in the normal evolution scenario, but their contribution to the total dose will be under 1E-09 Sv/yr.

We can emphasize that in the assumptions of the alternative scenario, the radio-nuclides will reach the aquifer earlier than in the normal evolution scenario (see the Fig. 2.IV and Table 3). Also, their concentrations will have greater peak values, with same order of magnitude or higher than the drinking water limits. At the same time it must pointed out that regardless the tritium peak value in the aquifer is about 2.8 E+05 Bq/m3, *i.e.* the same order of magnitude as the drinking water limit established by Romanian Regulations [17], its contribution to the total radiological dose is not important, because the tritium specific dose factor. It is necessary to mention that we considered a farm built on the repository site only at the end of the institutional control period.

For a better illustration, Table 3 presents the peak values of radionuclide concentration in the Barremian aquifer, both for normal and alternative scenarios with respect to drinking water limits as reported in the available legislation.

*Table 3*

Peak values of radionuclide concentration in the Barremian aquifer

| **Radio-nuclide** | **Concentration Peak value for normal evolution scenario [Bq/m$^3$ ]** | **Peak time for normal evolution scenario [years]** | **Concentration Peak value for alternative scenario [Bq/m$^3$ ]** | **Peak time for alternative scenario [years]** | **Drinking water limit [Bq/m$^3$ ]** |
|---|---|---|---|---|---|
| $^{3}$H | 3.1 E-13 | 7.3 E+2 | 2.8 E+5 | 1.1 E+4 | 1.0 E+05 [17] |
| $^{99}$Tc | 1.2 E+4 | 5.7 E+3 | 3.5 E+4 | 7.3 E+2 | 3.3 E+04 [18] |
| $^{129}$I | 3.2 E+3 | 7.6 E+3 | 4.4 E+3 | 2.0 E+3 | 3.7 E-03 [19] |
| $^{14}$C | 7.2 E+3 | 2.9 E+4 | 3.4 E+6 | 6.6 E+3 | 9.3 E+04 [19] |
| $^{59}$Ni | 8.3 E-4 | 1.1 E+6 | 2.4 E+3 | 2.2 E+05 | - |
| $^{94}$Nb | 8.2 E-15 | 4.6 E+5 | 5.9 E-2 | 2.5 E+5 | - |
| $^{90}$Sr | 5.9 E-29 | 1.3 E+3 | 2.39 E-8 | 7.3 E+2 | 3.7 [19] |

## 4. CONCLUSIONS

In the present paper, the safety concept together with the evaluation of two long term evolution scenarios developed for the new near surface repository which will be located on Saligny site were presented. The safety concept describes the Saligny repository safety objective, safety functions and arguments, as well as the parameters to be evaluated and the evaluation methods used to demonstrate the fulfillment of safety objective.

Analyzing the obtained results, one can note that the total annual radiological dose received by a representative person from the critical group of the long term normal evolution scenario of the Saligny repository, is lower than the dose constraint established in the Romanian Regulations. The obtained results emphasize also the role of geological layers to confine and retain the radio-nuclides. One can also observe that the peak values in the Barremian aquifer are lower than the peak values in the upper layers while the time of occurrence show retardation between the upper and the lower geological layers of the site.

In the assumptions of the alternative scenario, the increased infiltration rate has an important effect on the long term behavior of the radio-nuclides contained in the Saligny repository. The peak value of the total radiological dose is at the level of dose limit established in the current Romanian Regulations.

At the same time, our results emphasize the role of geological layers to confine and retain the short lived radio-nuclides, mainly.

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