Integration of CAST results in the safety assessment for a generic concept of spent fuel disposal in Romania

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Abstract

Romania operates in open fuel cycle two CANDU 600 units. The spent fuel (SF) and the long-lived intermediate level waste (ILW-LL) are foreseen to be disposed off in a geological repository starting with 2055. Since no host rock was yet selected, the in-house safety assessments are aimed to the comparison of different types of rocks from the point of view of their performances as repository host rock. The modelling is based on a generic concept similar to the Canadian one. The previous simulations used as input data assumptions and values from the Canadian studies.
As C-14 plays an important role in the total annual dose, any improvement in C-14 source term can decrease the associated uncertainty. Therefore, as part of the CAST project, RATEN continued to elaborate on the performance assessment of SF disposal in granite, refining and updating the input data related to C-14 inventory and release.
The model considered only the C-14 released from spent fuel and Zy-4 claddings. More realistic values for the C-14 inventory in Zy-4 claddings were used as input based on experimental data obtained by RATEN in the CAST project using Romanian samples from Cernavoda NPP. The new calculations made in CAST included C-14 speciation, considering the experimental values as a reference case, and differentiated for the first time the radiologic impact of CO_2 and CH_4.
Based on the model proposed, the sensitivity analysis followed the influence on the total dose summing the biosphere pathway of: the C-14 instantaneous release fraction from UO_2, the C-14 release rate from Zy-4, the organic/inorganic ratio in the C-14 release from Zy-4 claddings, the diffusivity coefficient in bentonite and granite and the Kd in bentonite and granite.
The sensitivity analysis (addressing only C-14 from spent fuel) pointed out that the most sensitive parameters are the IRF from the UO_2 pellets and the Kd in bentonite.

CURRENT STATUS IN SAFETY ASSESSMENT FOR SPENT FUEL GEOLOGICAL DISPOSAL IN ROMANIA

6 potential host rocks have been identified as suitable for a deep geological repository but no decision has been taken on site selection approach yet.

- generic safety assessment for SF disposal in salt and granite considered the Canadian concept and inventory resulted from ORIGEN simulations.
- C-14 is an important contributor to the total dose for SF disposal in granite.
- no C-14 speciation has been considered.

The modelling is done in the framework of a first development and implementation of an in-house safety assessment model, as preliminary work for the host rock selection.

MODELING ASSUMPTIONS

- **Host Rock:** Granite
- **Inventory:** 1350 double-walls canisters in steel and copper containing 360 spent fuel bundles each;
- **Emplacement:** Vertical holes
- **Buffer/ Backfill**: Compacted bentonite
- **C-14 Activity in SF [Bq/canister]**:
  in UO_2 : 8.94E10 (ORIGEN calculations)
  in Zy-4: 1.69E10 (CAST measurements)

REFERENCE SCENARIO

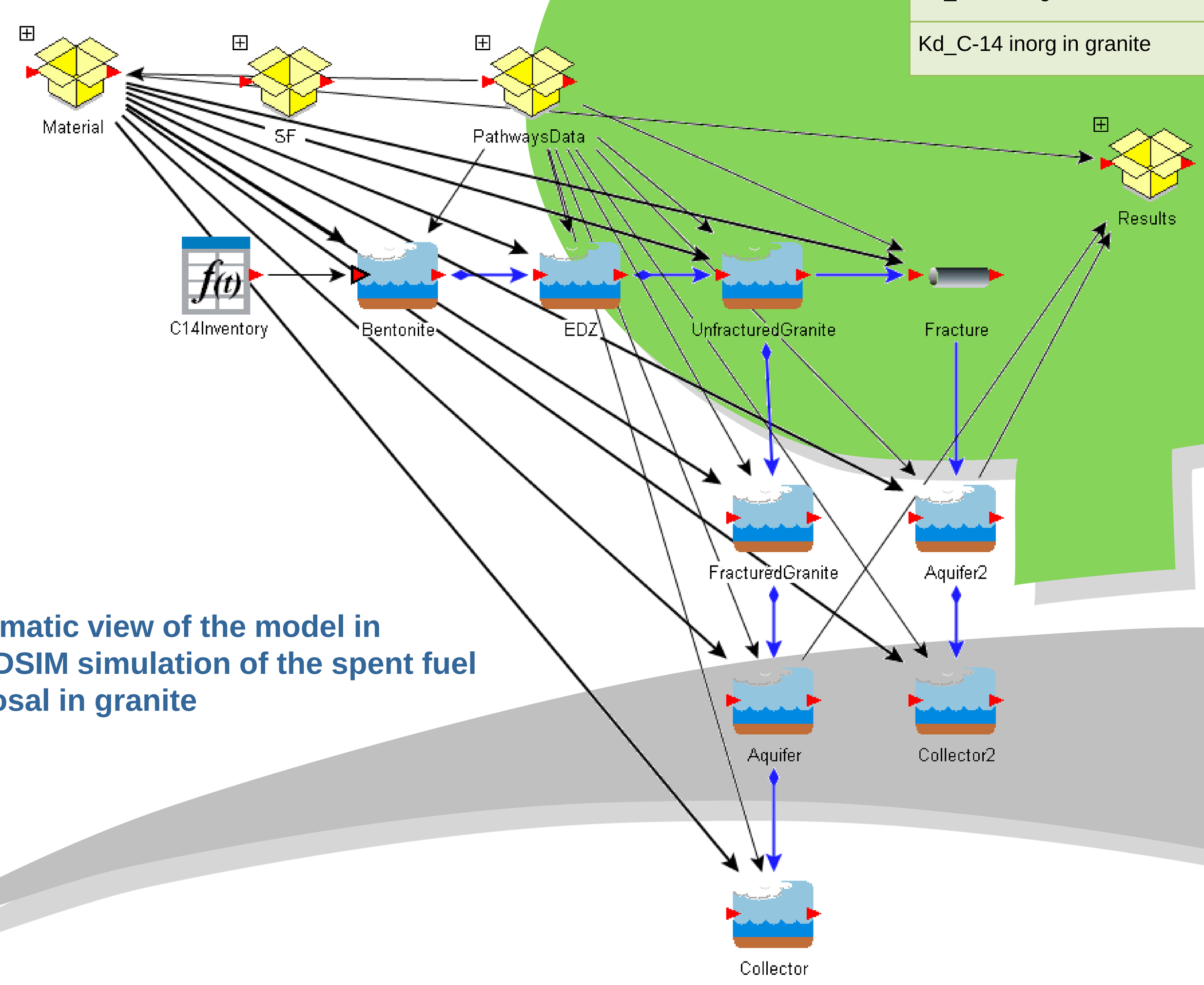
- The barrier effect of canister fails at 1500 years after closure generating an C-14 immediately releases into the volume of dissolution both from the Zy-4 and UO_2
- A small fraction of C-14 is released instantaneously as $^{14}CO_2$ from the fuel pellets, the rest of it being released at a constant rate equal to the UO_2 degradation rate
- In the same time, a small amount of the C-14 from the oxide layer of the fuel cladding releases rapidly; the rapid release is followed by a constant C-14 release equal to the Zy-4 corrosion rate. Both organic and inorganic C-14 compounds are released during the two stages (instantaneous release phase and congruent release phase), in the same proportion.
- The two C-14 species considered ($^{14}CO_2$ and $^{14}CH_4$) are transported in liquid phase by diffusion through the bentonite buffer and granite matrix and by advection through the EDZ and the granite fractures
- Different diffusion coefficients in bentonite and granite for $^{14}CO_2$ and $^{14}CH_4$.
- No Kd for $^{14}CH_4$
- Low Kd for CO_2 in bentonite and granite.
- No microbial effects on the speciation
- Distinction in the dose assessment between $^{14}CO_2$ and $^{14}CH_4$

SENSITIVITY ANALYSIS OBJECTIVES

the influence on the ingestion dose of :

- C-14 instantaneous release fraction from UO_2
- C-14 release rate from Zy-4;
- organic/inorganic ratio in the C-14 release from Zy-4 claddings
- diffusivity coefficient in bentonite and granite;
- Kd in bentonite and granite

IRF[C-14_UO2]	3%
C-14 inorg fraction [UO_2]	100%
Fractional release rate of C-14	9.00E-05 1/yr
IRF[C-14_Zy]	20%
C-14 inorg fraction [Zy]	40%
Corrosion rate of Zy cladding	10 nm/yr
(C-14 inorg, C-14org) Diffusion coefficient in bentonite	(1.92E-9; 1.49E-9) m^2/s
(C-14 inorg, C-14org) Diffusion coefficient in granite	(5.18E-13; 4.023E-13) m^2/s
Kd_C-14inorg in bentonite	1E-5 m^3/kg
Kd_C-14 inorg in granite	1E-4 m^3/kg



Schematic view of the model in GOLDSIM simulation of the spent fuel disposal in granite

IMPACT OF CAST RESULTS ON THE ROMANIAN SAFETY ASSESSMENT

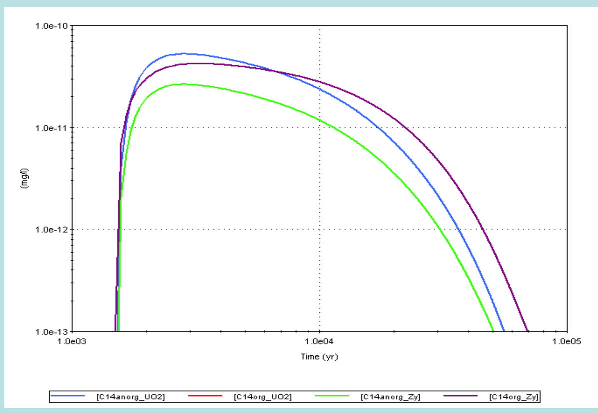
Results achieved by RATEN ICN in CAST project brought the first experimental data on the C-14 content in Zy-4 claddings and SIERs from Cernavoda NPP. The values obtained on Zy-4samples showed a very good correlation with the ORIGEN calculations. These findings increased the confidence in the total inventory of C-14 in the Zy claddings. Using these data, the new safety assessments presented in this study included therefore more realistic values for the C-14 inventory in Zy-4 claddings.

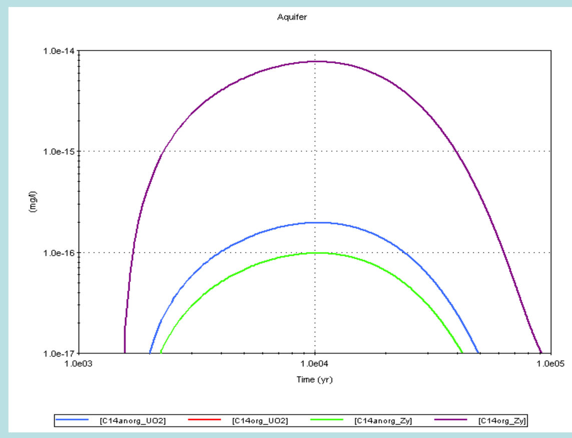
Experimental data on C-14 release from Zy-4, SIER and graphite contributed to a better understanding of the governing processes and provided the first data on the organic/inorganic ratio of C-14 released in liquid phase, in alkaline conditions. Based on data obtained on irradiated Zy-4, the new calculations made in CAST included C-14 speciation, considering the experimental values as a reference case.

Data on SIER, an important component of the deep geological repository, will be further included in the safety assessment, completing the source term of the generic safety case.

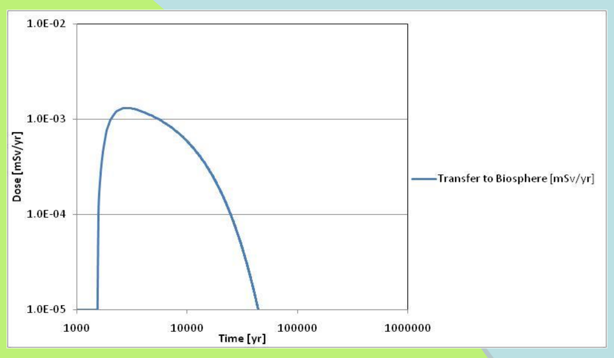
The sensitivity analysis (addressing only C-14 from spent fuel) pointed out that the most sensitive parameters are the IRF from the UO_2 pellets, and the Kd in bentonite.

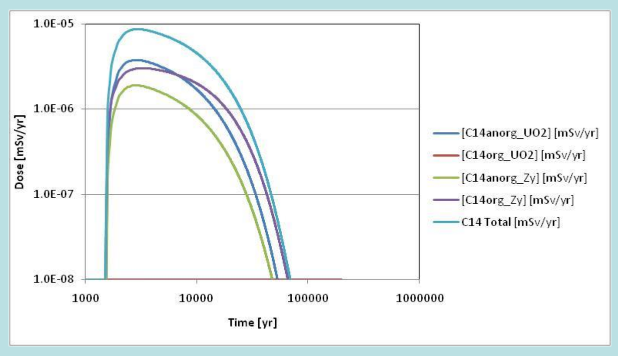
RESULTS



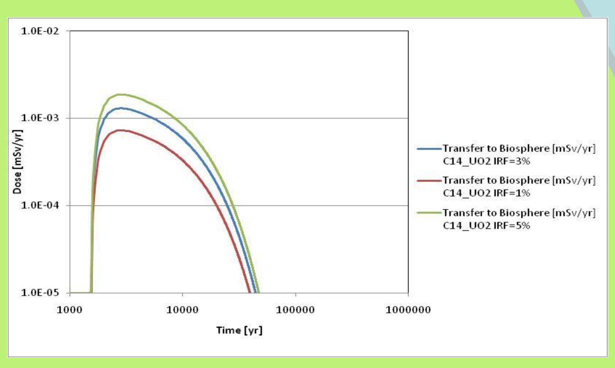


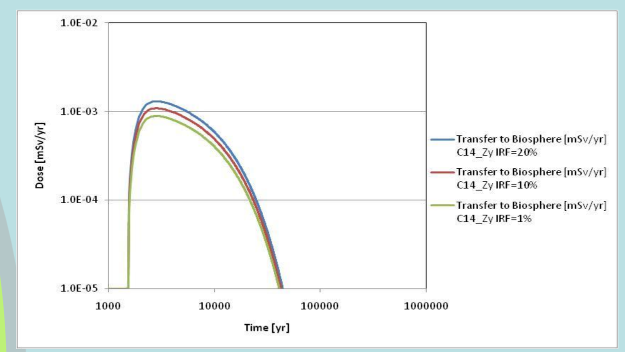
Due to the advective flow through the fractures, the maximum C-14 concentration in the aquifer is reached at 1100 years after canisters failure (left), while the diffusive component through granite which represents the larger part of the C-14 inventory, reaches the maximum release at 9800 years (right)



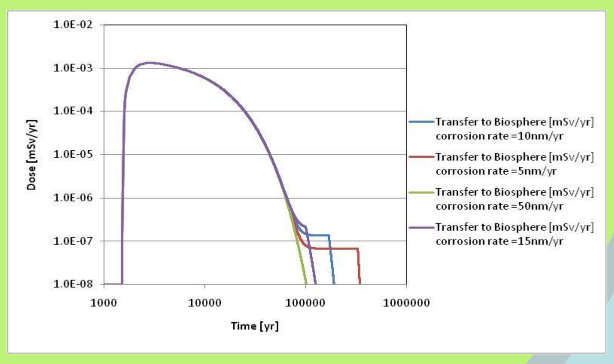


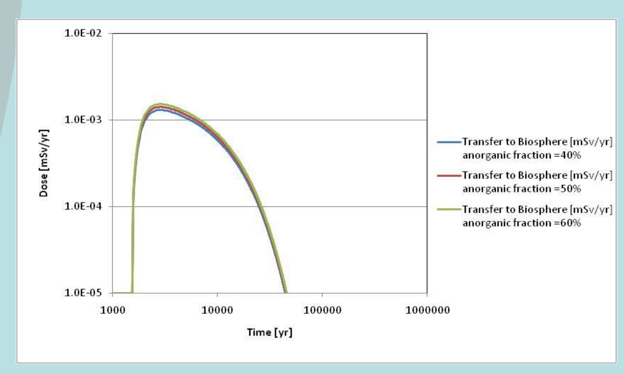
The annual dose from drinking water received by a member of the critical group (right) has much lower impact than the impact of the contaminated food ingestion (left)





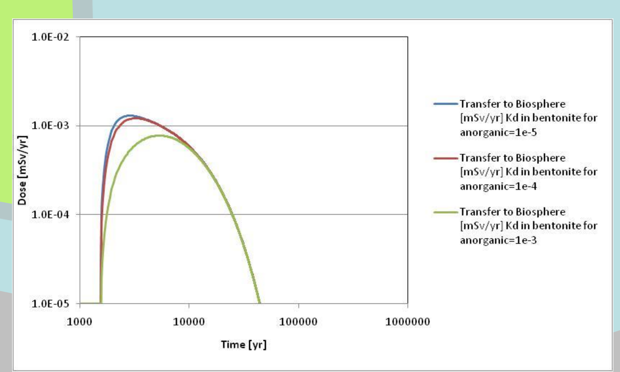
Variation of instantaneous release fraction (IRF) variation from UO_2 (left) and Zy-4 (right) brings changes in the dose, with a higher sensitivity for IRF from UO_2 compared to Zy-4, for which larger levels of variation the IFR produce much lower changes in the dose.

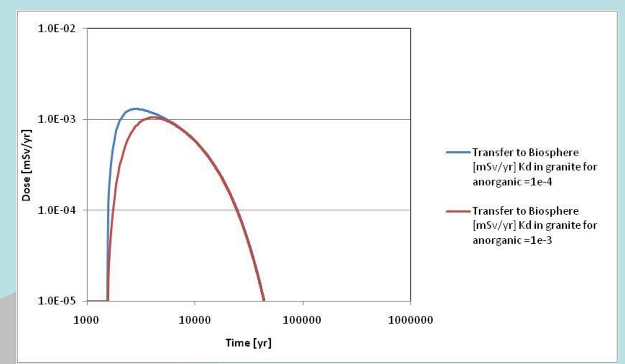




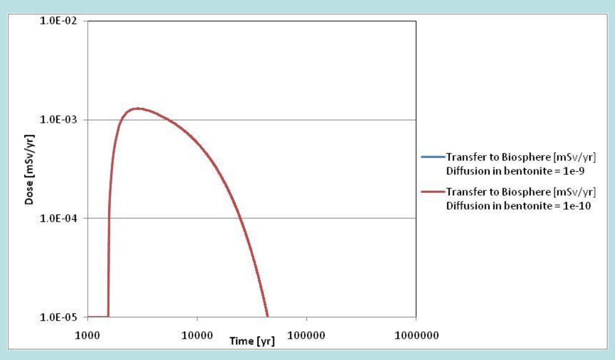
Variations of the congruent release of C-14 from Zy claddings do not show impact on the maximum dose, which is practically given by the IRF. The impact of different corrosion rates considered for the sensitivity analysis can be observed only at times higher than 100000 yr when the dose drops below 10^{-6} mSv/yr

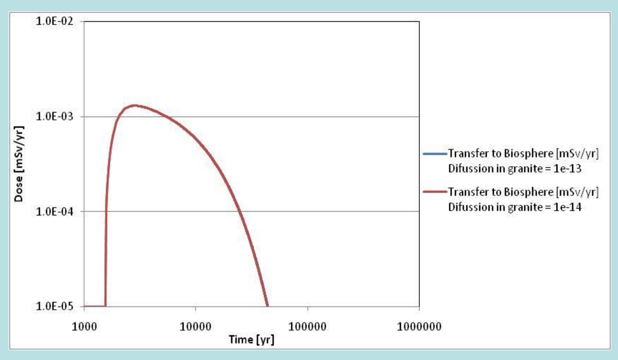
The model does not show significant deviations from the reference case for larger amounts of inorganic C-14 released from the Zy claddings





$^{14}CO_2$ sorption on bentonite (left) and host rock (right) could diminish the total inorganic C-14 released into the biosphere, contributing therefore to a lower dose. Stronger sorption of CO_2 both in bentonite and granite decreases indeed the maximum value of the dose, and shifts it at longer times. For the same variation in Kd (one order of magnitude), sorption in bentonite has a stronger impact on the maximum dose than sorption in granite due to the fact that the major element contributing to the C-14 release in the aquifer is the fracture where no C-14 sorption is assumed. The most significant deviation was observed for a variation with two orders of magnitude of the Kd in bentonite (at Kd=$10^{-3}$$m^3$/kg).





No significant influence has been found for the increase with one order of magnitude of the diffusion coefficients in bentonite and granite compared to the reference case, as long as the fractures remain the most effective transport pathway for radionuclides.

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