SUDOKU: Near-surface disposal optimization based on knowledge and understanding

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Outline

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- Consortium
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- Management team
- Technical description of SUDOKU Tasks & Sub-tasks
- Deliverables & Milestones
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  - ✓ other EURAD-2 WPs
  - ✓ previous European projects
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Objective

To deepen the current understanding of the behaviour and performances of **multilayer covers** and **cementitious barriers** in **near-surface disposal facilities**

Duration : 60 months

Start month: **October 2024**

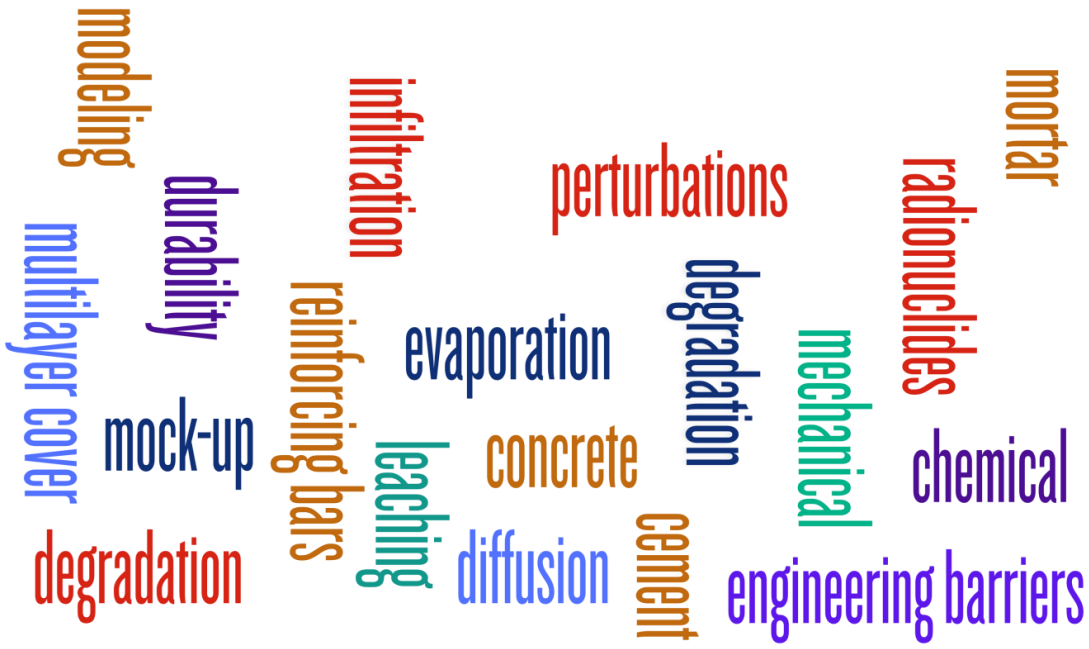
End month: **September 2028**

Total effort

626 pm / **248.8 pm for the first 2 years**

Total cost:

5 M € / **~ 2 M € for the first 2 years**



Approach

The SUDOKU approach combines the investigations on **multilayer covers** with the **durability studies of cementitious barriers** to assess the **transport properties** of mobile radionuclides (such as C-14, Cl-36, I-129, Mo-93, Tc-99) in **damaged cementitious barriers** according to their chemo-mechanical evolution.

The combination of **on-site and laboratory studies** with **state-of-the-art numerical models** will ensure the **necessary reliability of the results** and facilitate the **elaboration of recommendations for optimal EBS design from the safety point of view**.

SUDOKU Consortium

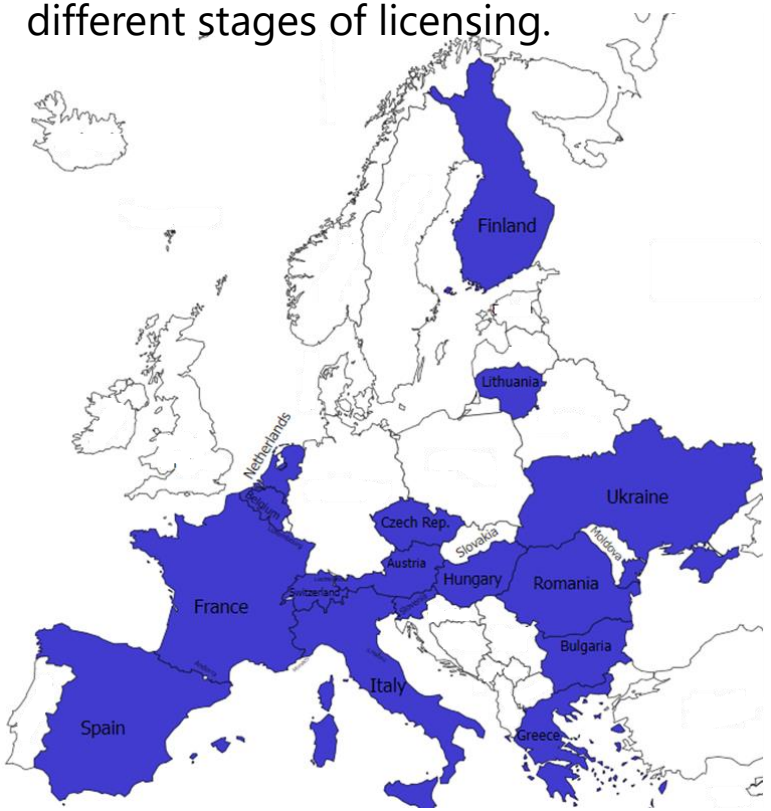
✓ **29 partners:**

- 15 Mandated Actors, 13 AEs and 1 AP
- 19 Res, 7 TSOs, 3 WMO

RE		TSO	WMO
AMPHOS21	PSI	AGES	ANDRA
BRGM	RATEN	CIEMAT	ENRESA
CEA	SCK-CEN	GI-BAS	ONDRAF/NIRAS
CSIC	UAM	IRSN	
CTU	UHelsinki	NRG	
EDF	ÚJV	NTUA	
HUN-REN EK	UNIPR	SSTC NRS	
LEI	UPoitiers		
MINES ParisTech	ZAG		
POLIMI			

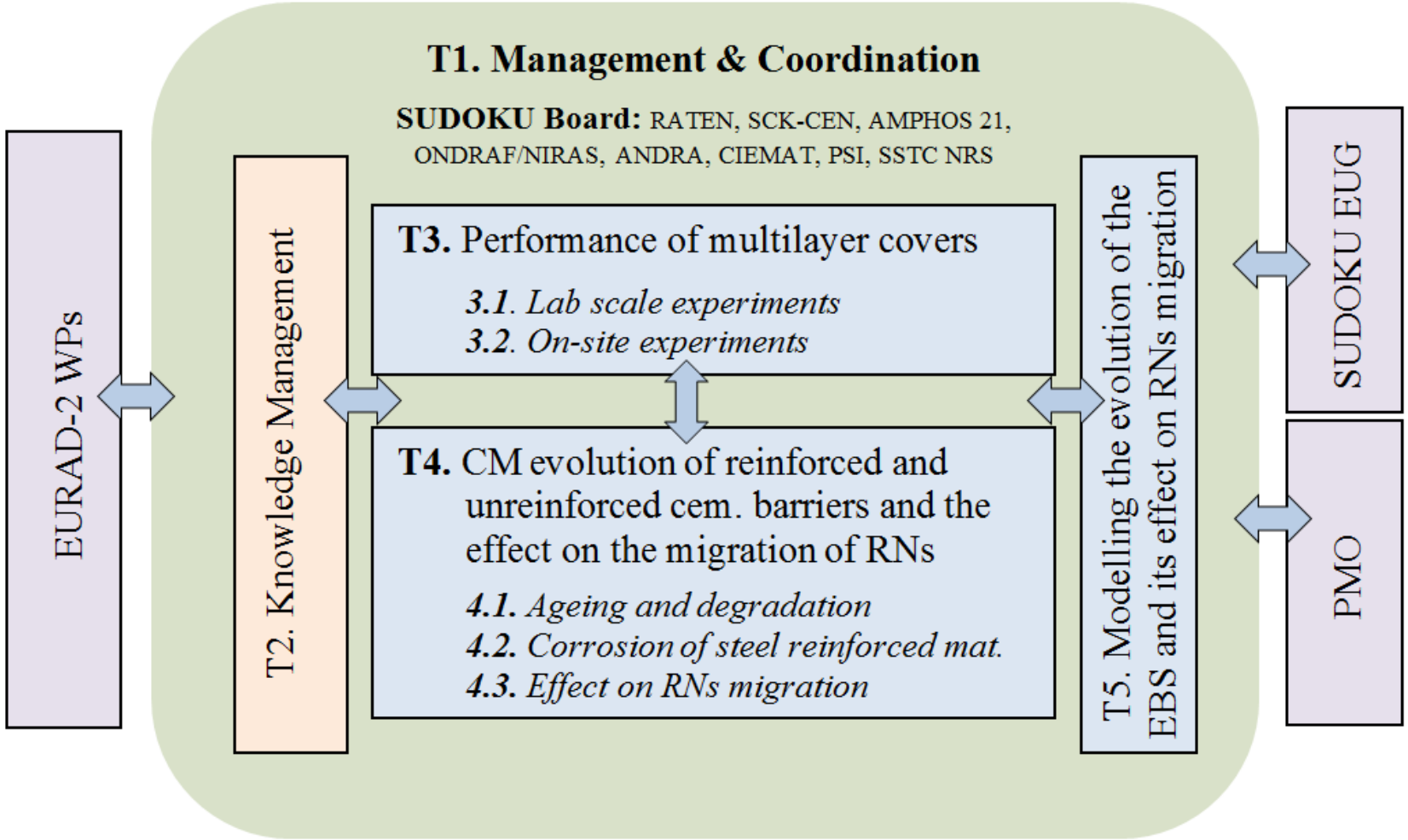
✓ **from 16 European countries**

- with near-surface disposal facilities in operation, under construction, or in different stages of licensing.



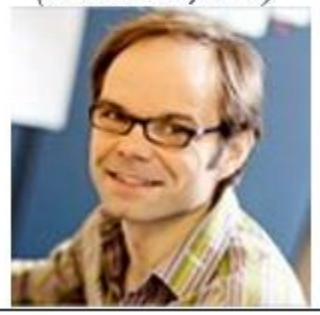
➢ 8 End Users
ANDR (*RO*)
ARAO (*SL*)
DEKOM (*DK*)
NAGRA (*CH*)
NWS (*UK*)
SURAO (*CZ*)
SOGIN (*IT*)
SKB (*SE*)

SUDOKU structure & interactions



SUDOKU management team

T1. Management/ coordination	**T2.** Knowledge Management	**T3.** Performance of multilayer covers	
Crina Bucur *(RATEN, RO)*	Diederik Jacques *(SCK-CEN, BE)*	Meritxell Gran *(Amphos 21, ES)*	Frank Lemy *(ONDRAF, BE)*
			

T4. EBS Degradation & RNs mobility		**T5.** Modelling evolution of EBS and its effect on RNs migration	
Tiziana Missana *(CIEMAT, ES)*	Pierre Henocq *(ANDRA, FR)*	Georg Kosakowsk *(PSI, CH)*	Oleksandr Soloviov *(SSTC NRS, UA)*
			

Technical description of SUDOKU tasks/sub-tasks

TASK 3. Performance of multilayer covers

Objective: to improve the current knowledge of **processes that control infiltration in multilayer covers** for surface disposal facilities and **to evaluate cover effectiveness and its long-term performance**

This will be achieved by performing **in-situ monitoring** on under construction and existing multilayer cover mock-ups, complemented by **laboratory scale experiments** to study separately and under controlled conditions the **behaviour of different barriers or combinations of layers** that form the cover.

- **Expected outputs:** better understanding of the **behaviour** and **evolution of different multilayer cover concepts**

  recommendations regarding **design optimisation, construction and monitoring** of multilayer covers

Task 3 partners: **ENRESA, AMPHOS 21 & CIEMAT**

ONDRAF/NIRAS & SCK-CEN

ANDRA & MINES ParisTech

CTU & UJV

GI-BAS

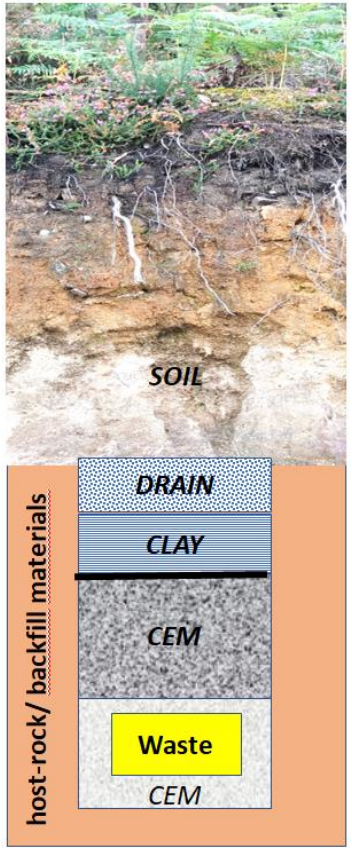
Subtask 3.1: Lab scale experiments

Experiments to study the factors that govern cover effectiveness and their evolution in time under controlled conditions

- to improve the knowledge of **processes that control infiltration in multilayer covers**
- to evaluate the **cover efficiency** and its long-term performance describing **long-term interactions and processes affecting the barrier system effectiveness**

Different types of experiments will be performed, focusing on:

- separately study the **behaviour of different barriers** that form the multilayer cover
- study the **effect of erosion** due to runoff **on covers' long-term integrity**
- **behaviour of a geotextile /simplified asphalt** layer/**clay** based layer/**soil** layer system by analysing the effects of **water interactions, saturation/desaturation, thermal effects** (*heating/freezing*) on **chemical** (*leachate composition*), **physical** (*porosity, permeability*) and **mineralogical properties**
- developing a **conceptual model of a simplified multilayer cover** consisting of natural materials without synthetic geomembranes while maintaining its functional requirements



Subtask 3.2: On-site experiments on multilayer cover mock-ups

- Study of **long-term performance** and **potential degradation processes on existing cover mock-up** in Spain
- In situ monitoring on **new multilayer cover mock-up to be constructed** during SUDOKU implementation (*construction financed by the national WMOs*):
  - ✓ a new **multilayer cover to be constructed at the Spanish surface disposal facility** in 2025
  - ✓ study of the initial state and performance of the **two cover concepts considered in the Belgian surface LLW** disposal program **during the construction of a multilayer cover mock-up** and the year following its construction

TASK 4. Chemo-mechanical evolution of reinforced and unreinforced cementitious barriers and the effect on the migration of mobile radionuclides

Objective: To improve the knowledge on the **chemo-mechanical degradation of cement engineered barrier systems** and to evaluate its **consequences on radionuclide migration** in the conditions of shallow and surface disposal facilities

Achieved by:

- ✓ investigating the **coupling of mechanical constraints and chemical alterations on unreinforced cement**-based materials (mortars and concretes) for characterizing the behaviour of the cementitious matrix including aggregates (T4.1)
- ✓ Investigating **similar systems with steel reinforcement** for characterizing the **effect of corrosion** in terms of **cracking and diffusion of corrosion products** (T4.2)
- ✓ Studying the **migration of mobile radionuclides in degraded samples** from the T4.1 and T4.2 (T 4.3)

Task 4 partners: **4 consortia**: **CIEMAT / CSIC / UAM (C1)**

BRGM / UPoitiers / UHelsinki (C2)

IRSN / CEA / MINES ParisTech (C3)

SCK-CEN / ONDRAF/NIRAS (C4)

7 individual partners: **CTU; HUN-REN EK; POLIMI; PSI; RATEN; UJV; ZAG**

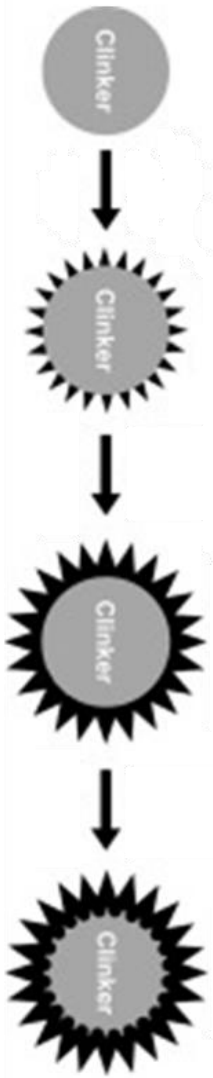
T4.1: Cementitious materials ageing and degradation - CMH evolution

Samples considered: **Concrete and mortars**, drilled on site or casted in laboratory, based on **different CEM types** representative for the current **European L-ILW repositories**

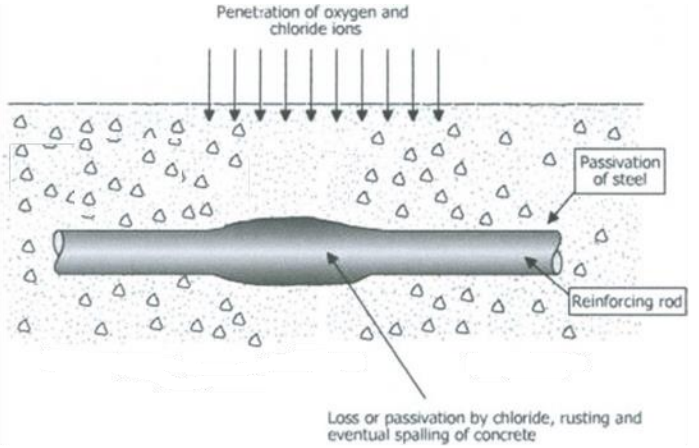
Different degradation processes, including **carbonation and/or leaching** with different types of solutions

Degradation conditions, that will **be agreed among task partners** (MS4), **representative of the disposal sites in terms of water compositions and temperature**

- to understand the **mechanisms involved in the degradation** and to evaluate the **effect of degradation on mechanical and transport properties**
- **Spectroscopic and microscopic techniques** will be used to characterize the chemical and mechanical evolutions of the materials depending on the degradation degree



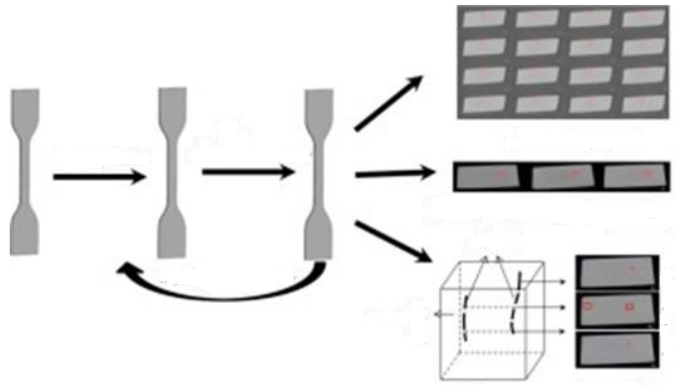
T4.2: Corrosion of steel reinforced materials



Samples considered: Reinforced mortars or concretes

Degradation conditions: similar to those used in T4.1

- to characterize the **damages induced by the corrosion of steel reinforcement bars** as it should occur in the context of shallow and surface disposals
- **characterization of corrosion processes** and the **initiation of cracking** supported by a chemo-mechanical model
- **microscopic techniques** will be used to characterize **the cracking pattern** (micro-tomography, µSEM and µXRD, autoradiography)

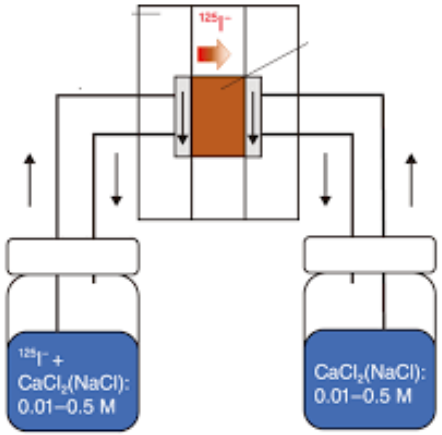


T4.3: Effect of CMH evolution of cementitious materials and steel corrosion products on the migration of mobile RNs

Samples considered: degraded mortar and concrete samples obtained in T4.1 and T4.2

Radionuclides considered: ^{14}C (different speciation) , ^{36}Cl, ^{99}Tc, $^{75}Se(VI)$, $^{125/129}I$, ^{238}Pu

- the effect of cement degradation on transport properties will be specially studied in terms of **diffusion coefficient** but also in terms of retention, to assess the **sorption capacity of damaged cement-based materials**
- the ingress of radionuclides within the cement-based samples will be characterized by solution measurements (**diffusion tests**) but also by solid characterizations such as post-mortem autoradiography



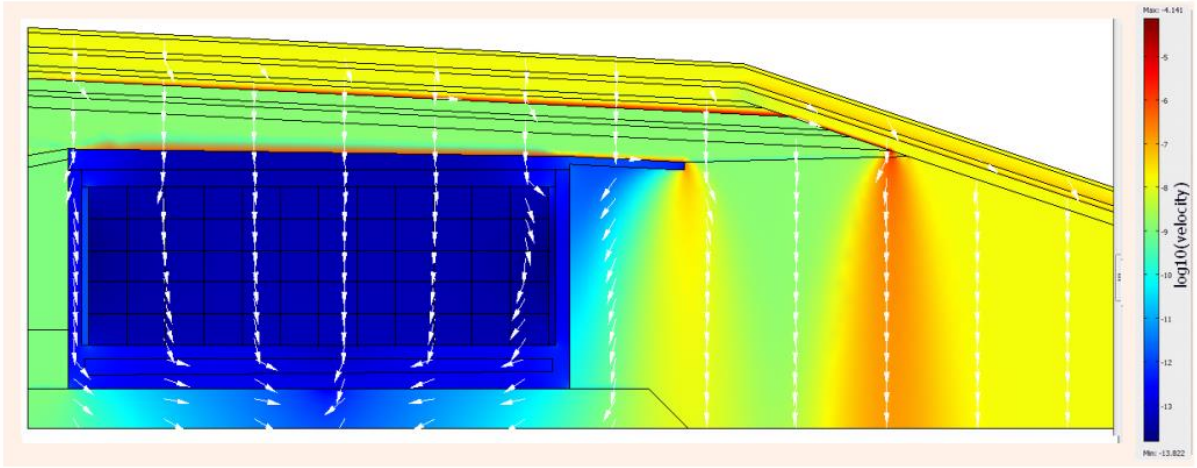
TASK 5. Modelling of the evolution of the EBS and its effect on radionuclide migration on the basis of the experimental results obtained in T3 & T4

Objective: to assess the **effect of the multilayer cover performance** and **cementitious barriers degradation on the radionuclide migration** in the disposal area integrating the experimental results obtained in T3 and T4.

Multiphase and chemical transport will be modelled at **large scale**, but also **modelling of the relevant subsystems** that will be defined at the beginning of this task will be included.

Task 5 partners:

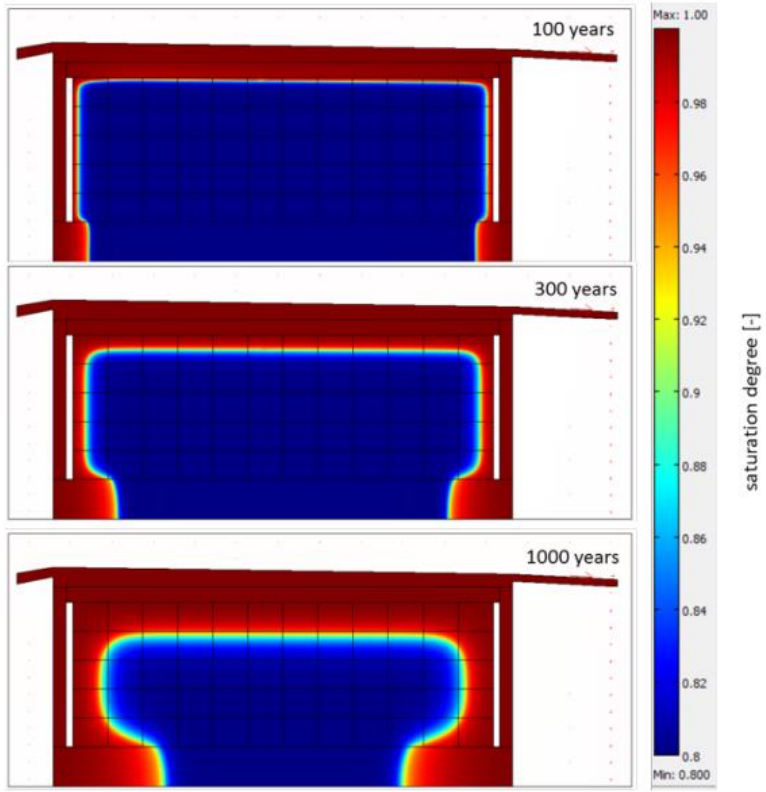
AGES, AMPHOS21, ENRESA, EDF, LEI, NRG, NTUA, PSI, RATEN, UNIPR, SSTC NRS



TASK 5. Modelling of the evolution of the EBS and its effect on radionuclide migration on the basis of the experimental results obtained in T3 & T4

To predict **the long-term integrity evolution of the multilayer cover**, numerical simulations will be used to quantify the processes that are not measurable in the field

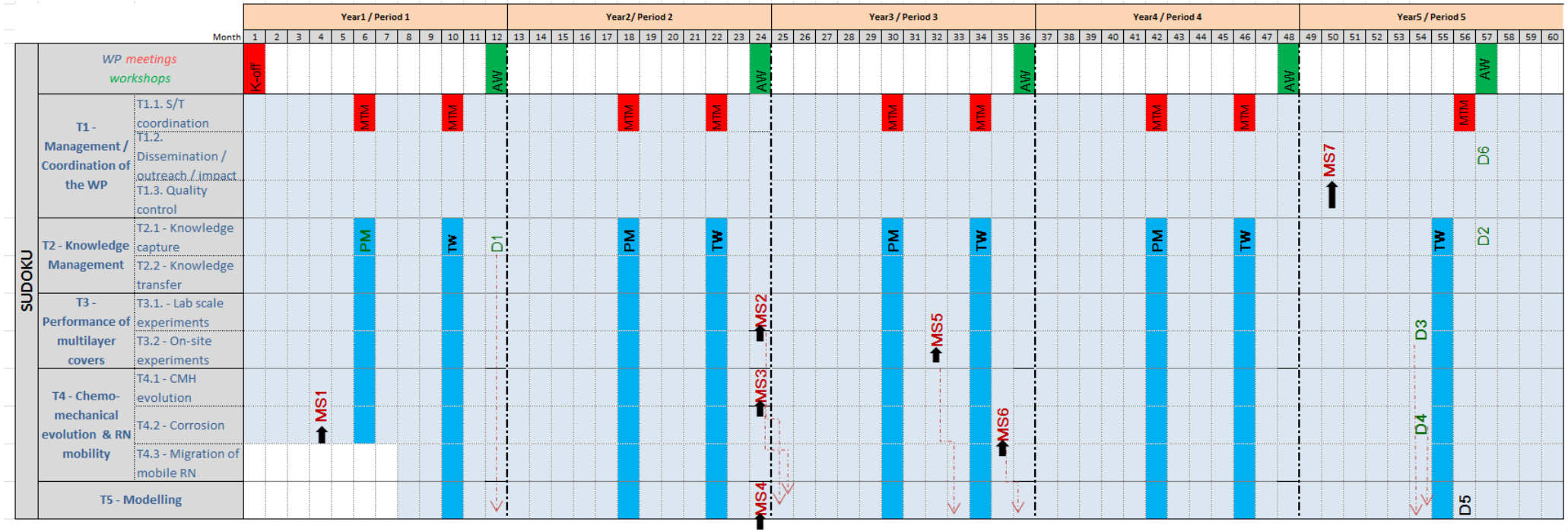
For given **near surface waste disposal configurations**, a **comparison** will be carried out between **the radionuclides (RN) leaching fluxes released from the disposal area, with improved EBS modelling** (i.e. using the outcomes of task 3 and 4) and **a reference case based on conservative constant values** of the transport parameters



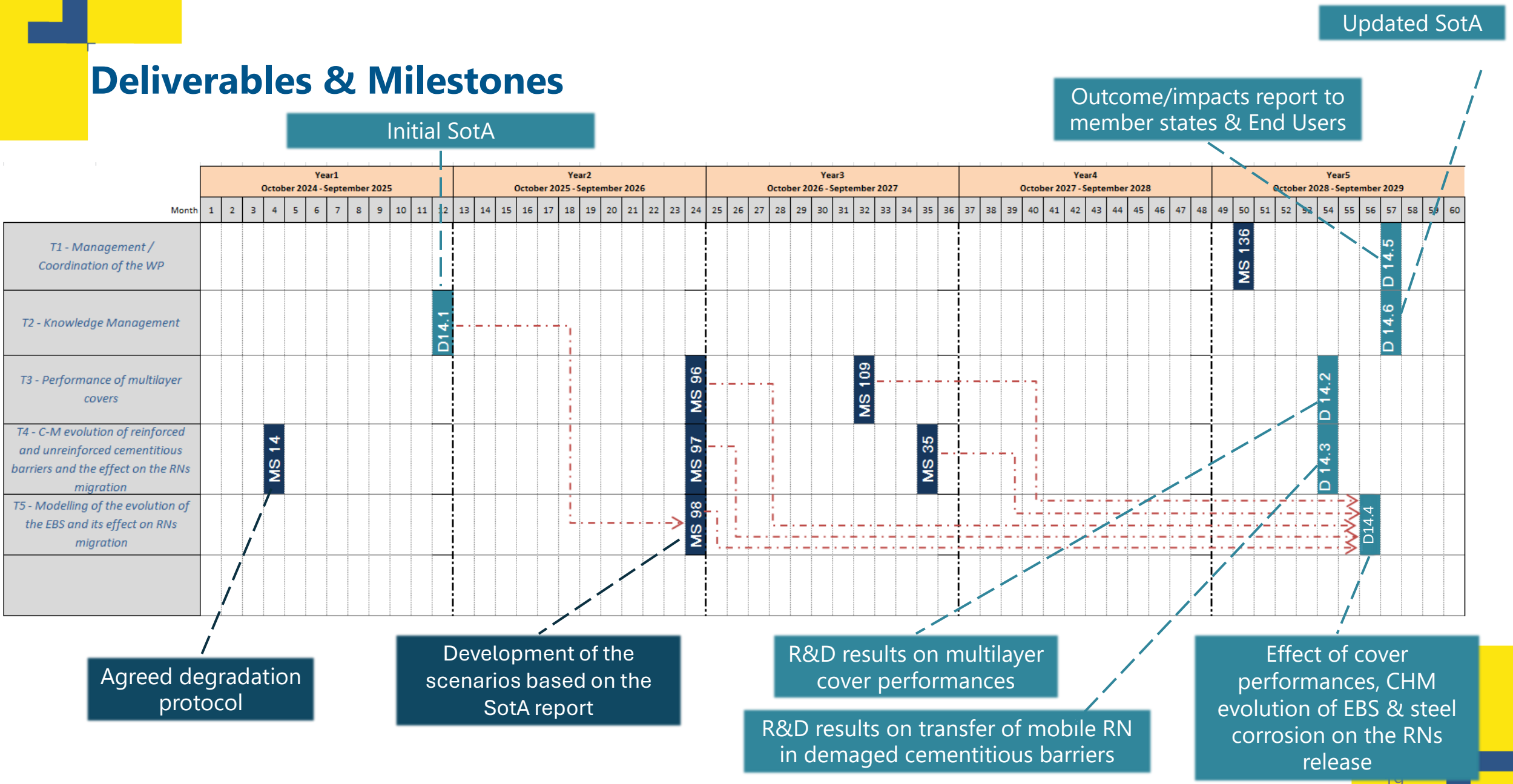
Gantt Chart

SUDOKU Kick-off meeting: **November 7th, 2024 -** *online*

Task kick-off meetings will be organized during November - *online*



Deliverables & Milestones



Links with the other EURAD-2 WPs

WPs	Links
WP5 ICARUS	Input from WP5 regarding methods for **measurement of DTM RNs** in degraded concrete samples
WP7 LOPERA	Inputs / feedbacks to WP7 related to the **disposal facilities specifications** in the development of the boundary conditions (task 3)
WP11 CLIMATE	*Inputs from WP11:* effect and **impact of climate change** on the factors that control different combinations of layers in the multilayer cover structure *Inputs to WP11*: **composition of multilayer cover** used in different surface disposal facilities (in operation or planned to be in operation in near future) *A **joint workshop** on the common topics will be organized*
WP 12 RAMPEC	Organisation of **common workshop on RN mobility in cementitious environment**. Options for **joint training** activities exist
WP13 OPTI	Exchange on the **basic processes in optimization**, mainly on not strictly technical aspects (regulation/management,…)
WP 15 DITOCO2030	Input from WP15 on **how the digital twins can be used in optimisation of near-surface disposal facilities**
WP 16 HERMES	Input from WP 16 regarding **the application of high fidelity numerical models for repository design optimization**
WP 18 DITUSC	Inputs from WP 18: thermodynamic data; identification of the **missing data regarding the systems and conditions studied in SUDOKU**

Links with previous European projects

Name of the project	Type of link
EURAD MAGIC	The **outcomes of MAGIC** related to the cementitious behaviour in unsaturated conditions will be included in the **initial SotA report** for WP14 SUDOKU
EURAD CORI	For the SUDOKU relevant radionuclides, **output of CORI** related to effect of cement degradation on **RNs mobility** will be used in developing the SUDOKU experimental programmes (Task 4)
FEBEX I and II	Participation in the assembly and implementation of a full-scale in situ monitored test at the Grimsel Test Site. Both the in situ test and the mock-up test, the latter still operational after more than 25 years, have provided **background (lessons learned) for the implementation of large-scale instrumented mock-up tests** from which the SUDOKU project will benefit.
NF-PRO	Design and implementation of two large-scale monitored test at the CIEMAT facilities under controlled conditions (GAME mock-ups). The implementation of these two models has provided **knowledge (lessons learned) for the implementation of large-scale instrumented model tests** from which the SUDOKU project will benefit.

Links with national projects

Name of the project	Type of link
Belgian surface disposal programme	SUDOKU will take **advantage of the multilayer cover mock-up** constructed in the framework of the **Belgian surface disposal programme** which will in turn **benefit from the knowledge gained through the SUDOKU**.
Bulgarian near-surface disposal programme	LILW near surface disposal facility at Radiana site near to Kozloduy NPP is under construction in Bulgaria. The **final multilayer layer cover** will be based on the data and experience obtained by a multilayer test cover. The results from the proposed research activities will be **valuable input for the envisaged multilayer test cover at Radiana site**.
Czech surface disposal programme	Experimental data obtained within SUDOKU Task 3.1 on covering layer materials will be applied in **detailed safety analysis and SA of the Czech repositories,** under SURAO project on the periodic SA for the operational radioactive waste repositories
Romanian near-surface disposal programme	A near surface disposal facility is going to be in operation in 2028 in Romania, for short lived-LILW. Romanian programme will take advantage of the **Task 3 outcomes in designing the final multilayer cover** for this disposal facility.
Spanish project on multilayer cover	ENRESA designed and constructed in 2009 **two multilayer covers** at the Spanish surface disposal facility. A complete monitoring system was installed in the two covers to monitor flow and heat fluxes inside the soil. The monitoring system provides comprehensive information to assess the performance of the different barriers within each cover and to compare the performance of the two multilayer designs. The **SUDOKU project will benefit from the existence of these two covers and the data their monitoring system generates**.

Thank You!

We are confident that together we'll solve our SUDOKU challenges!

☺☺☺