An iterative approach to achieving Safety
Application in the dossier Argile 2005

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Why a Safety Case ?

- Integration of arguments and evidences
- Impact evaluation is one of the elements
- Other elements :
  - Multiple safety functions
  - Robustness of the disposal concept to uncertainties
  - Soundness of scientific bases
- Within a repository's iterative development process in view of decision making (Law 1991)
  - Acquisition of Knowledge
  - Design solutions
  - Safety Analysis

=> Feasibility Phase

Basic principles

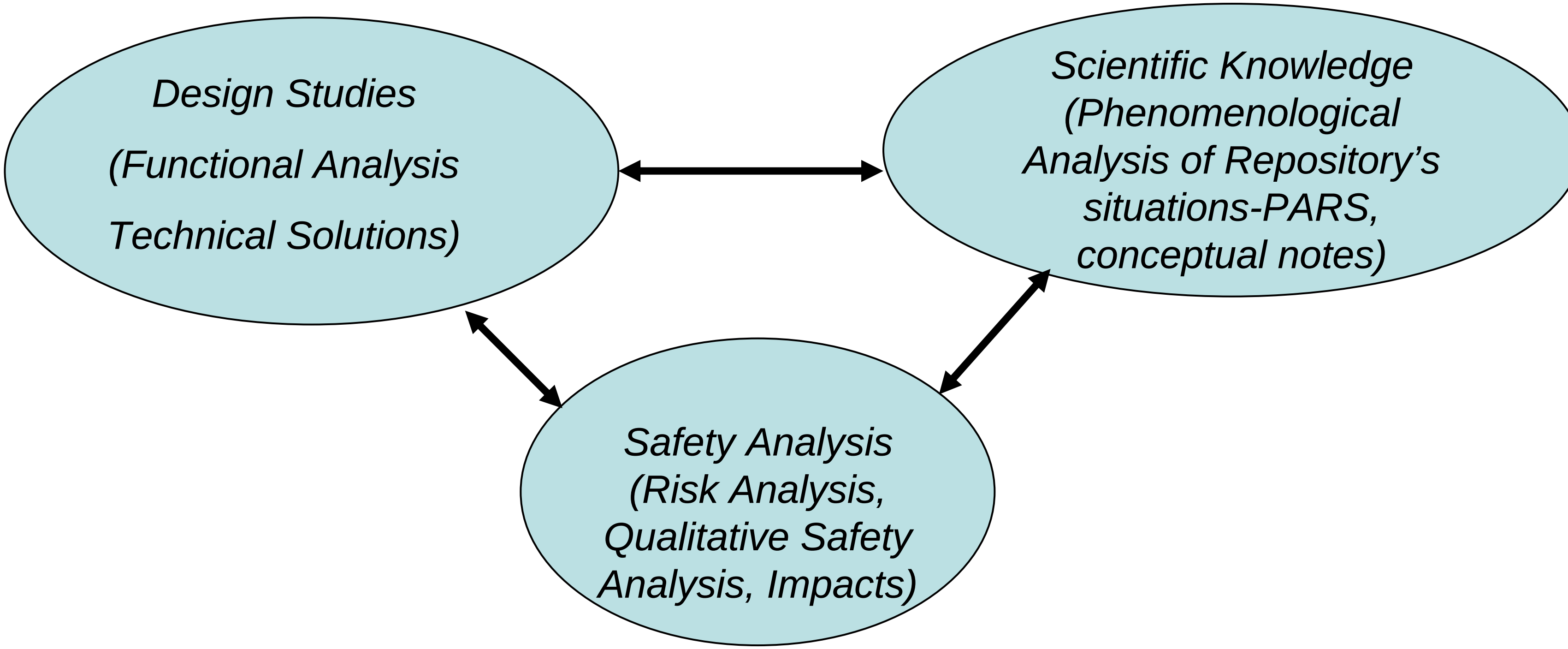
- Post-closure safety guaranteed without any intervention – « Passive Safety »
- Robustness of the disposal concept
  - Robust design solutions against external disturbances and uncertainties
- Demonstrability
  - Safety to be checked as easily as possible
  - Simple demonstration as much as possible

=> Best possible usage of multiple arguments (qualitative reasoning, safety calculations, analogy, experiments, technical demonstrators)

Specificity of Dossier 2005 Argile Safety Case

- Feasibility Stage :
  - Purpose is to focus on several technical solutions
  - Safety utilized in defining solutions and verifying
  - No optimization
- Related to a « real site »
  - Observations and results from experiments on the Meuse/Haute Marne laboratory site
  - Callovo-Oxfordian host formation
  - Repository's location not irrevocable (conventional choice of the URL within the transposition zone)

Safety Case – an Iterative Process



- Two – Fold Specificity Safety Analysis :
  - Operational - a more « conventional approach »
  - Long-term - emphasizes on the scientific knowledge and uncertainties

- Both qualitative and quantitative arguments:
  - Qualitative arguments based on the analysis of uncertainties and risks
  - Quantitative arguments based on the quantification of scenarios

Safety Case - Need for Sound Data

- Understanding waste and materials
- Understanding the geological medium
- Definition of repository architectures
- Development of modelling and simulation tools

→To a safety assessment

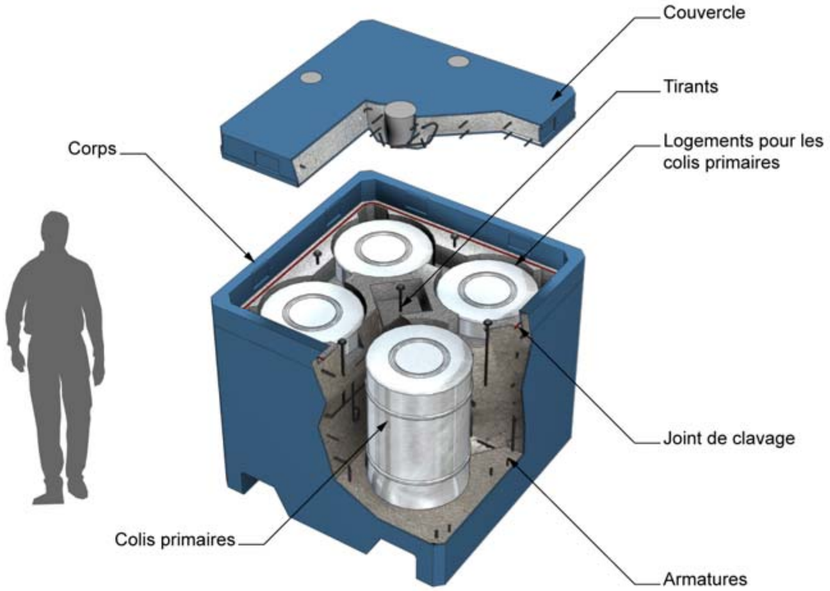
Data for Safety - Waste packages

- Various types of waste to consider
  - Waste already produced
  - Waste to be produced

- Two main categories of waste in the feasibility study
  - High level waste
    - Vitrified waste, also called C type waste - Represents 1% of the total volume of waste **(approx 6 000 m^3)**
    - Spent fuel – considered as waste from a shutdown of reprocessing process
  - Medium level long-lived waste, also called B type waste
    - Resulting from fuel fabrication and reprocessing. Little release of heat
    - Considerable variety, including in their packaging (bitumen, concrete matrix, or compacting) – **approx 80 000 m^3**

- Inventory of RN :
    - 44 short lives-16 intermediate lives-84 long lives

Data for Safety-Waste packages



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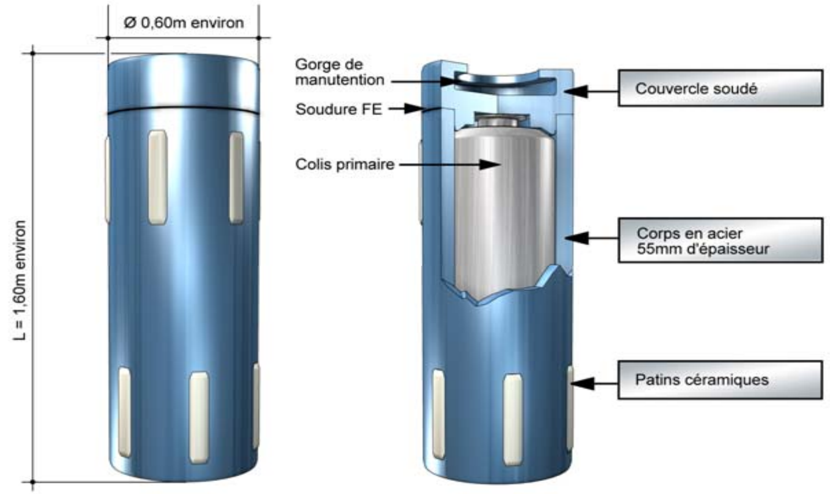
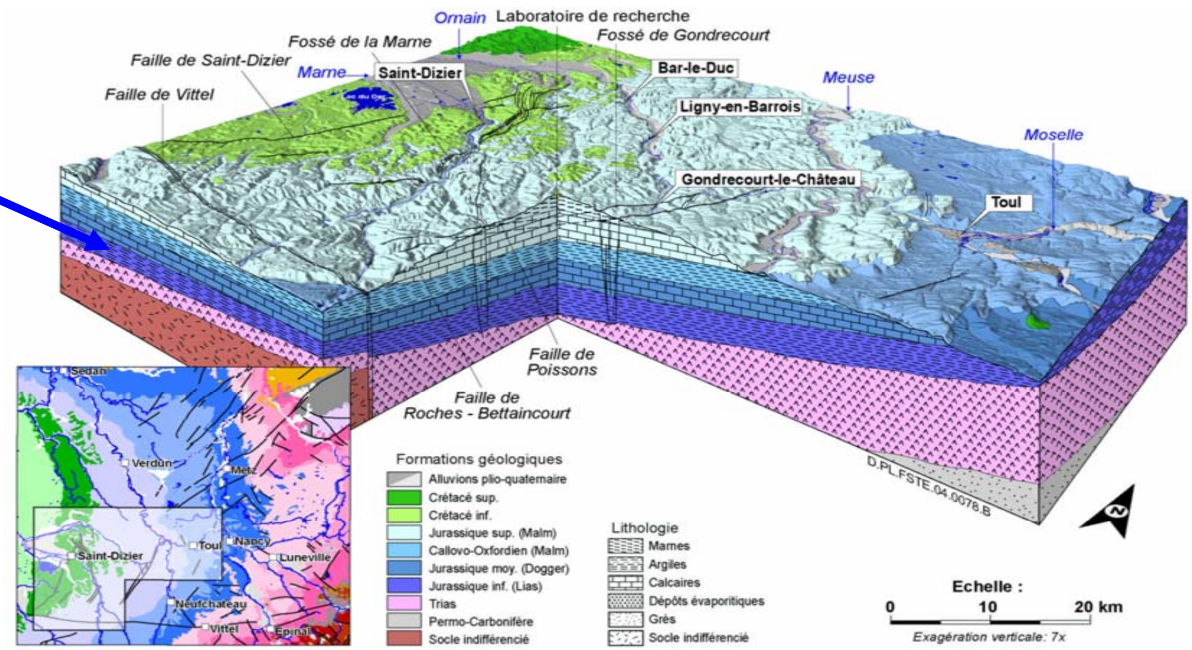
B-waste package

C-waste package



Data for Safety- Geological context

- **Clay Formation**
- **Surface area is approximately 500 km²**



- **Favourable characteristics of Callovo-Oxfordian formation**
  - **homogeneous – low permeability – low water content (7-8 %) – high retention capacity**
  - **Callovo-Oxfordian surrounded by two large limestone formations with low permeability**
  - **Stable site (formed 155 M years ago)**
  - **Absence of natural resources**

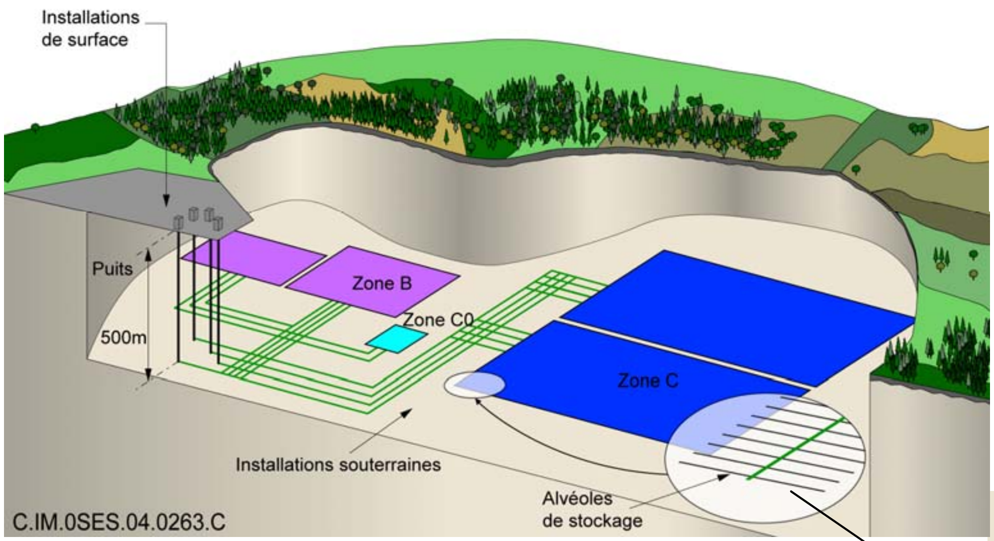
Data for Safety - Architecture

- **Simplicity and robustness** given the current knowledge limits : high degree of conservatism

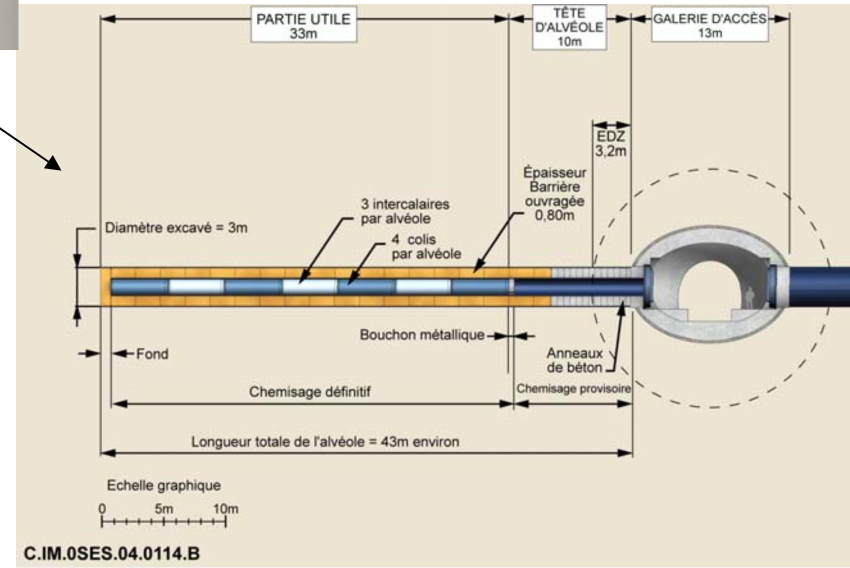
- **Realistic** in industrial terms
  (construction and operating resources and processes based on available technology)

- but at this stage does **not aim for optimisation**
  (it does not therefore freeze the design of any repository)

Data for Safety - Architecture



Example of C-waste cell



Repository and design functions

- Need to identify functions to be fulfilled and matching them to technical solutions
- Functions depending on various objectives and external needs other than safety :
  - Cost, reversibility, Constructability …
- Safety functions depending on timescales :
  - Designer defines functions to be fulfilled by each component for each timescale taking into account the predictable behaviour of components

Timescales and Physical Extent

- Based upon the physical extent and time analysis of the THMCR processes, a segmentation into “situations” of the repository evolution (PARS)

  ⇒ A situation is the phenomenological state of part of the repository or of its environment during a given period of time

- The evolution of the repository is analysed from the very beginning of the construction up to 1 million years (time cut-off)

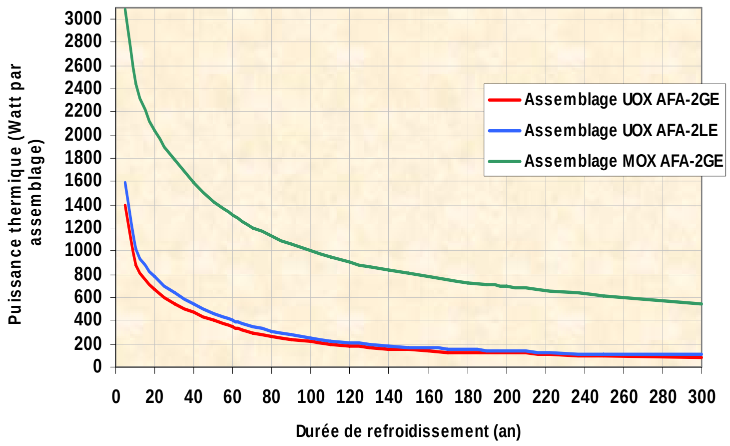
- Spatial fractioning according to the main repository components (Geological medium, Surface environment, Surface facilities, Access shafts, Principal access galleries, 4 disposal zones : ILW (B), HLW(C), and SF)

Timescales associated with the Thermal evolution

- **Processes associated with the characteristics of the waste and their radiological evolution with time (decay)**

- **Vitrified waste and spent fuels release significant quantities of heat.**

- **Type B waste produces a lower power output**.



- **For spent fuel, the waste's heat output is a phenomenon which occurs over a thousand to a few tens of thousands of years.**

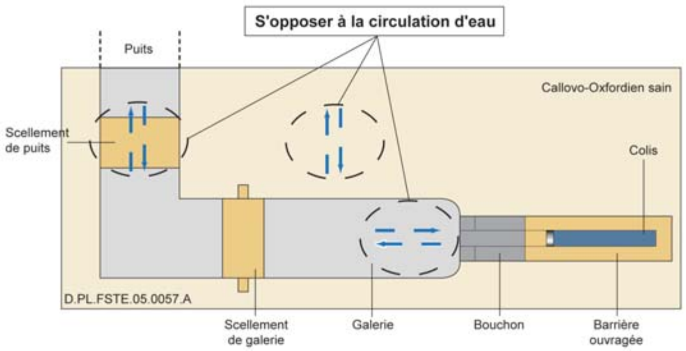
  $\Rightarrow$ **possible impact of the temperature on the host rock and transport phenomena**

  $\Rightarrow$ **design criteria (functional analysis) : T $\leq$ 90°C**

Safety functions over time (post-closure)

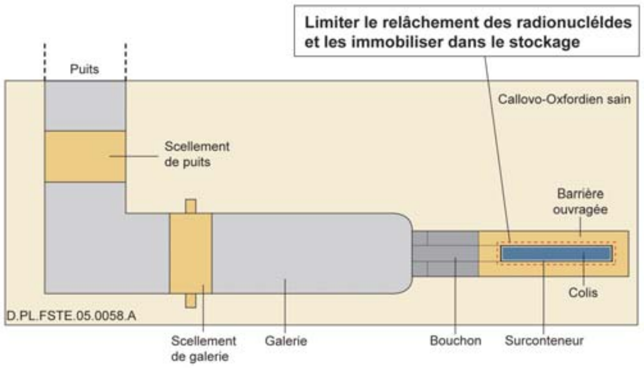
“Opposing the circulation of water”

- Control the water flow
- Reflects the requirement for sealing resaturation



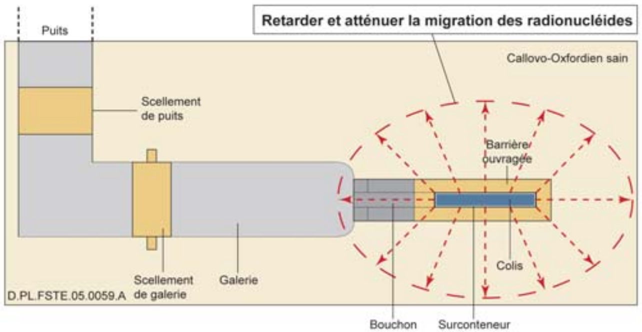
“Limiting the release of radioactive nuclides and immobilising them within the repository”

- Control the thermal flow
- During the initial thermal phase
- Reflects the requirement to protect the waste packages from water and place them under favourable physico-chemical conditions.



“Delaying and reducing the migration of radioactive nuclides”

- Control the radionuclide flow
- Act after radionuclide have been released in the geological medium
- Reflects the transport properties, time for diffusive transport process



Operational Safety

- Risk of external exposure- Irradiation
- Risk of Internal exposure – Ingestion- inhalation
- Risk analysis :
  - Various situations (ex: Fire Hazard,…)
  - Measures to reduce the likelihood– prevention
  - Measures to mitigate – protection
- Risk analysis covers industrial activities of construction, operation and closure

Operational Safety-Examples of Measures

- Risk analysis :

  Measures to reduce the likeliness– prevention

  Measures to mitigate limit the effect – protection

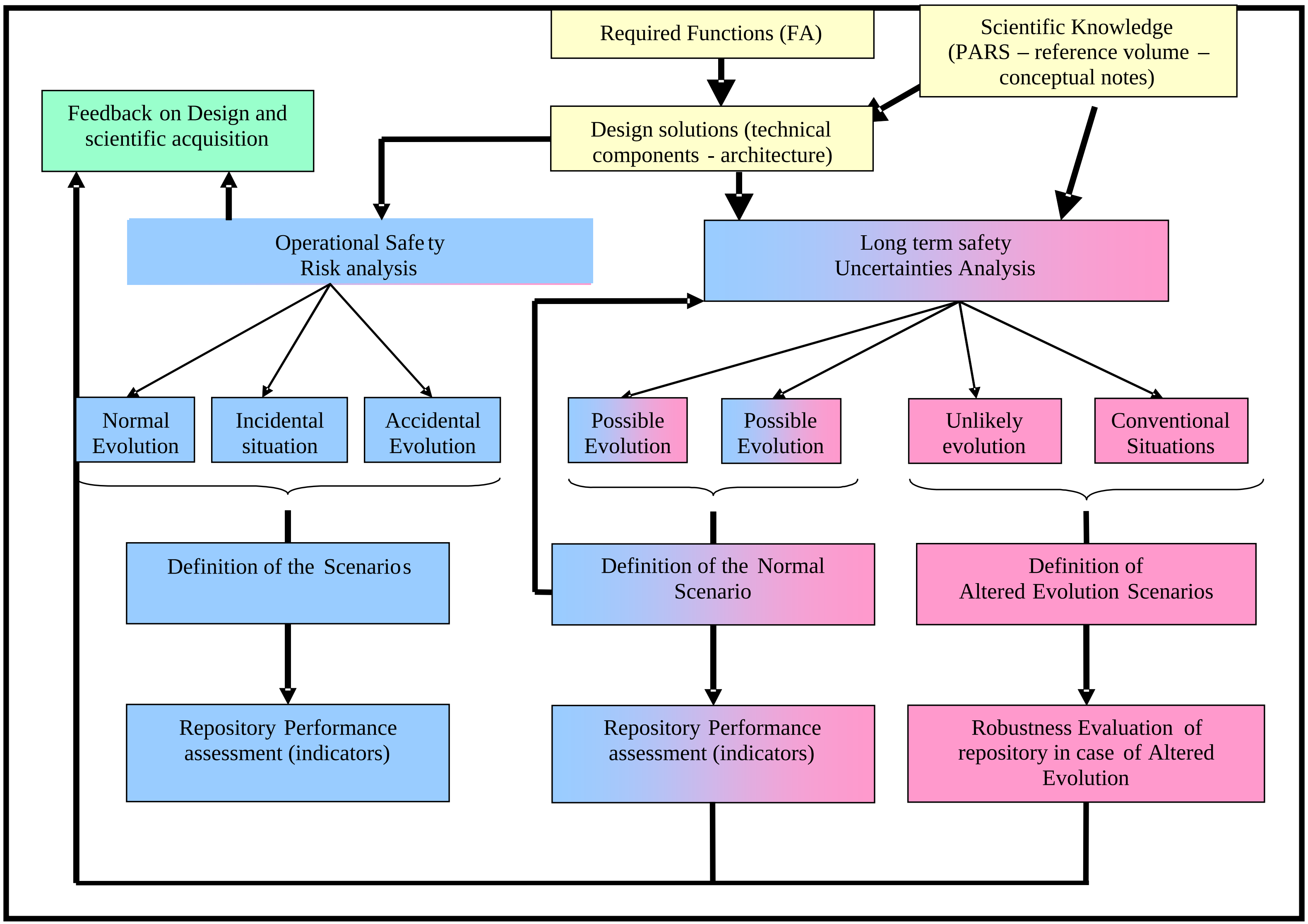
- Explosive Gases(most of B wastes) - Ventilation characteristics of disposal cells

- Fire Hazard - Architecture to permit emergency escape - Training

- Cell Fall – B waste packages' fall in disposal cell– preventive measures and simulations when appears

- Criticality – Architecture arrangements of waste packages - geometry

An Iterative Process



Objectives

- To identify whether uncertainties (of all types) or external events are accounted for :
  - By design
  - or in the definition of scenarios:
    - Likely events : in the normal evolution scenario (including sensitivity studies)
    - Unlikely events : in the altered evolution scenarios (including their sensitivity studies)

- Secondarily, used as a second-level of verification for most important scientific and phenomenological documents.

What uncertainties are taken account of ?

- Uncertainties on the initial data of the project (waste inventory)
- Uncertainties on the characteristics of components:
  - Measurement uncertainties
  - Validity of the use of data taken from the literature
  - Limitations due to changes of scales
  - Limitations on the definition of the features (e.g.: the notion of Kd)…
- Uncertainties on processes:
  - Validity of models used to represent them
  - Validity of the use of these models over very long timeframes…
- « Technological » uncertainties
- External risks

AQS - a way to systematize uncertainty management

1. Look at uncertainties on:
   - each component's characteristics,
   - its evolution,
   - its interactions with other components.

2. That may:
   - affect its ability to perform a safety function,
   - have an influence on another component's ability to perform a safety function,
   - modify the component's environment in a way that could affect the way the component fulfils its functions.

3. Check
   - if this is taken into account by design or by the way the SEN is represented.

The AQS relies on the Functional analysis and on the PARS, it does not duplicate them.

AQS- Example

Safety function :
Immobilise radionuclides

Phenomena :
Dissolution of vitrified matrix

Component :
C wastes

→ **For each model/parameter, the uncertainties are identified from various information sources (APSS, referential notes…)**

For each uncertainty identified :

How does the concept address the uncertainty? Could the disposal concept fail?

→ Ex : uncertainty about the alkaline plume within the C waste cells and pH limitation is a characteristic of the functional analysis. The C waste plug of the cell permit to limit the ph plume by isolation the cell from the concrete plug.

Is the range of uncertainty covered by sensitivity cases in SEN?

→ Vo → Vr is a model with a large experimental feedback, but underlying mechanisms are yet to be completely understood (=> sensitivity calculation in SEN)

→ Surface accessible to water (S) is subject to uncertainties (=> sensitivity calculation in SEN)

Which uncertainty may conduct to an altered evolution?

→ By referring to the AQS on C waste cell plugs, one can identify situations that may lead to the loss of the « controlling the pH within the cell » function. These situations are said to be covered by the « sealing failure scenario » (=> in this scenario, one has to take into account a possible modification of the dissolution rate of the glass matrix).

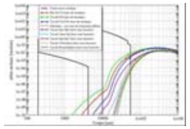
Safety Analysis- the Scenarios-1

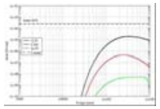
- Normal evolution scenario permits to :
  - evaluate the repository impact upon conservative assumptions
  - check that the performances of the design components are reached to ensure the overall safety ,
  - illustrate the understanding of the behaviour of the disposal , particularly with regards to radionuclides transfer.

- But :
  - No prediction of the impact according to the CIPR 81 because of uncertainties and envisaged timescales,
  - Favour simple representations of processes in order to facilitate the interpretation of results.

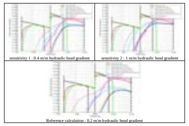
Safety Analysis- the Scenarios-2

- Normal evolution scenario :
  - Permits to check the performance of three safety functions using relevant indicators (e.g. Péclet number, transfer pathways….)





- Altered evolution scenarios
  - Container/over-pack failure
  - Seal failure

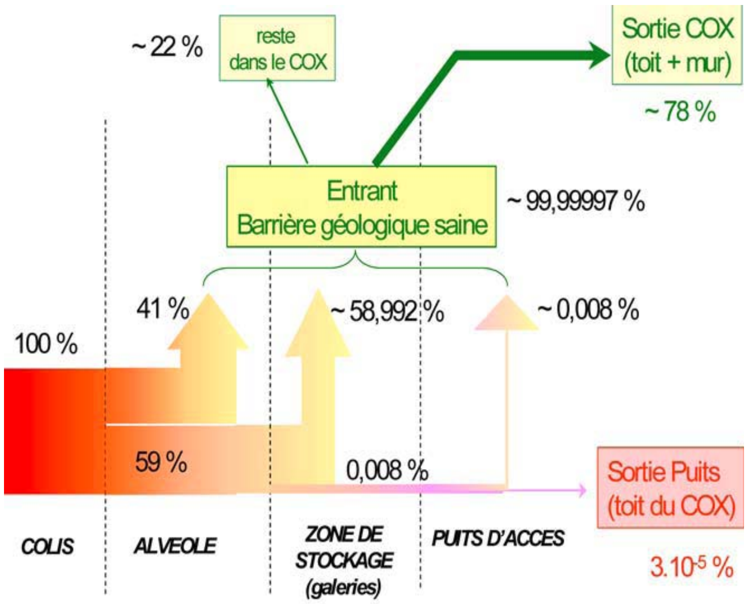


  - Intrusive borehole drilled through the repository
  - Heavily degraded operation (all safety functions are set at a more pessimistic level than normally expected, i.e. COX permeability, etc)

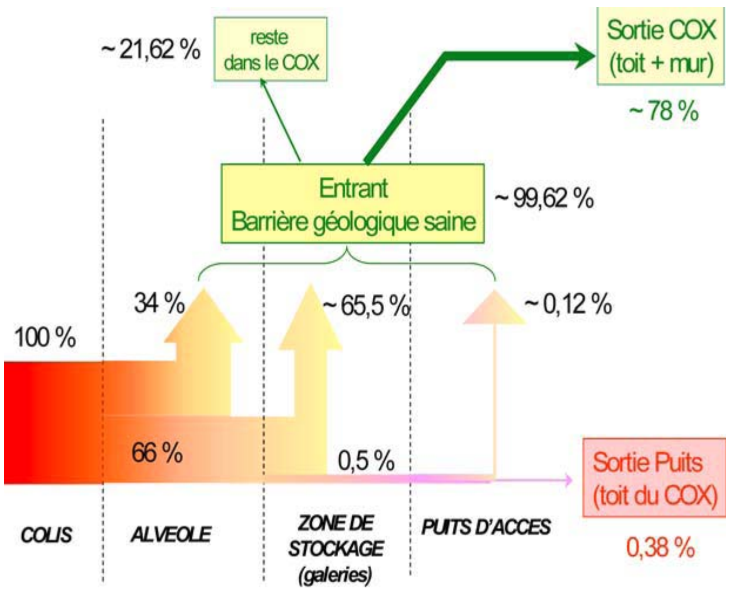
– Both type of scenario include sensitivity cases

Example of quantitative studies : Transfer pathways

- Whatever the situation is, the dominating transfer pathway is the Callovo-Oxfordian host rock (ex of Indicator : molar flow of I129 below)



Normal Evolution Scenario



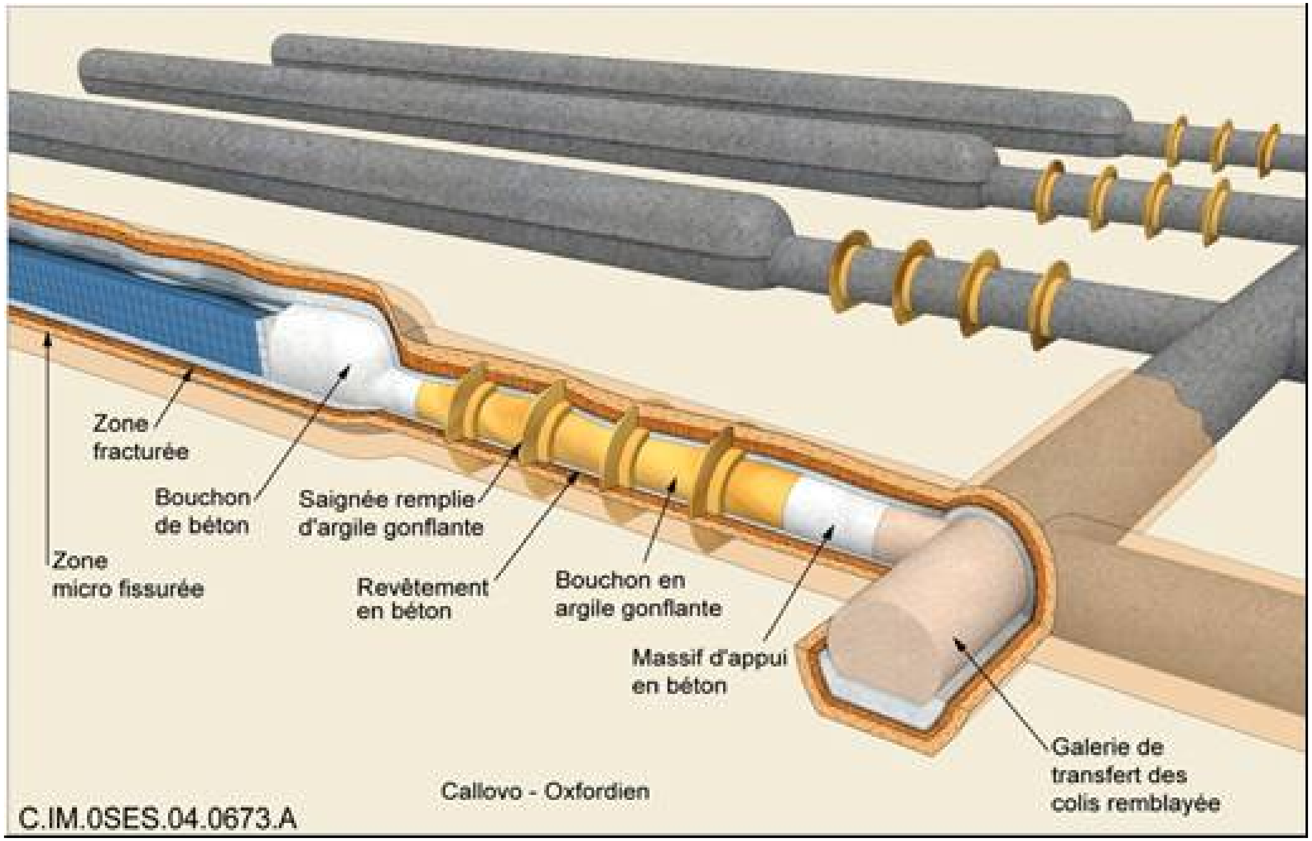
Severely degraded evolution scenario
(lower performance of the three safety functions)

Conclusions

- Reasonable degree of confidence in the feasibility of repository and LT safety. Operational safety demonstration to be completed.
- Repository's safety relies on a multi-functional concept : Robustness.
- Host formation is the essential component of the system and rock’s properties are now well-known because a major characterization program.
- Safety assessments are connected to engineering and research studies (incl. URL) in a stepwise process.
- Qualitative analysis lessons and safety calculations constitute a sound knowledge base which supports future engineering and research programmes : on our way to next steps : siting and licensing.

Any Question ?

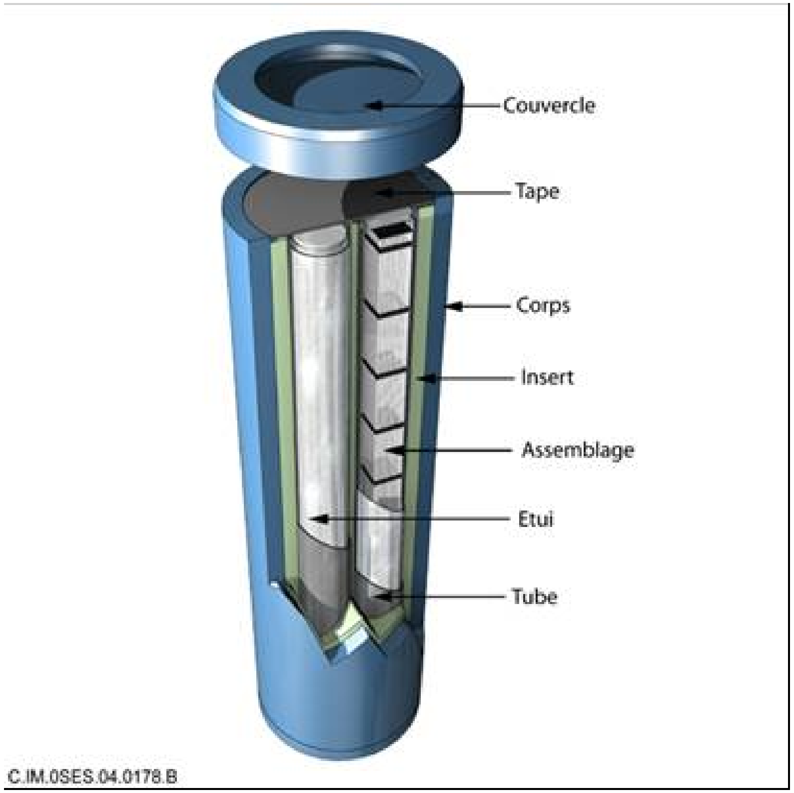
Data for Safety - Architecture



Schematic diagram of a B waste cell with a plug anchored in the micro-fissured zone

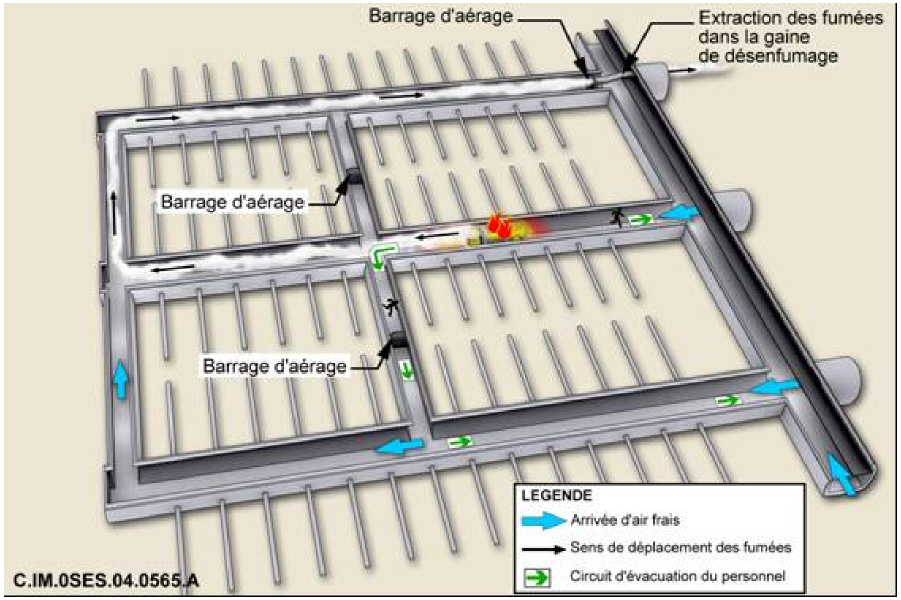
Type C and spent fuel - Waste packages

Schematic diagram of a disposal package for vitrified C reference packages (glass, container and overpack)



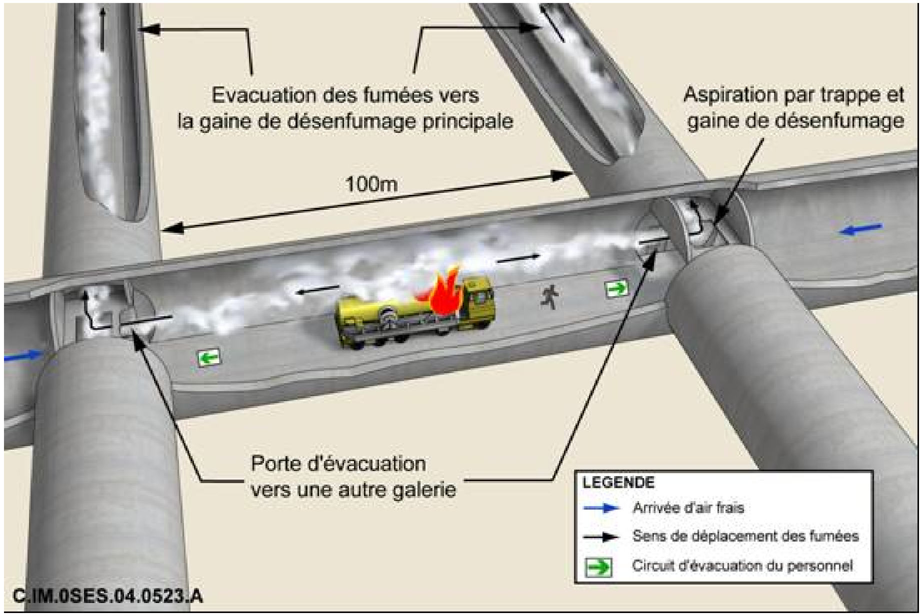
Schematic diagram of a spent fuel container (UOx)

How fires develop

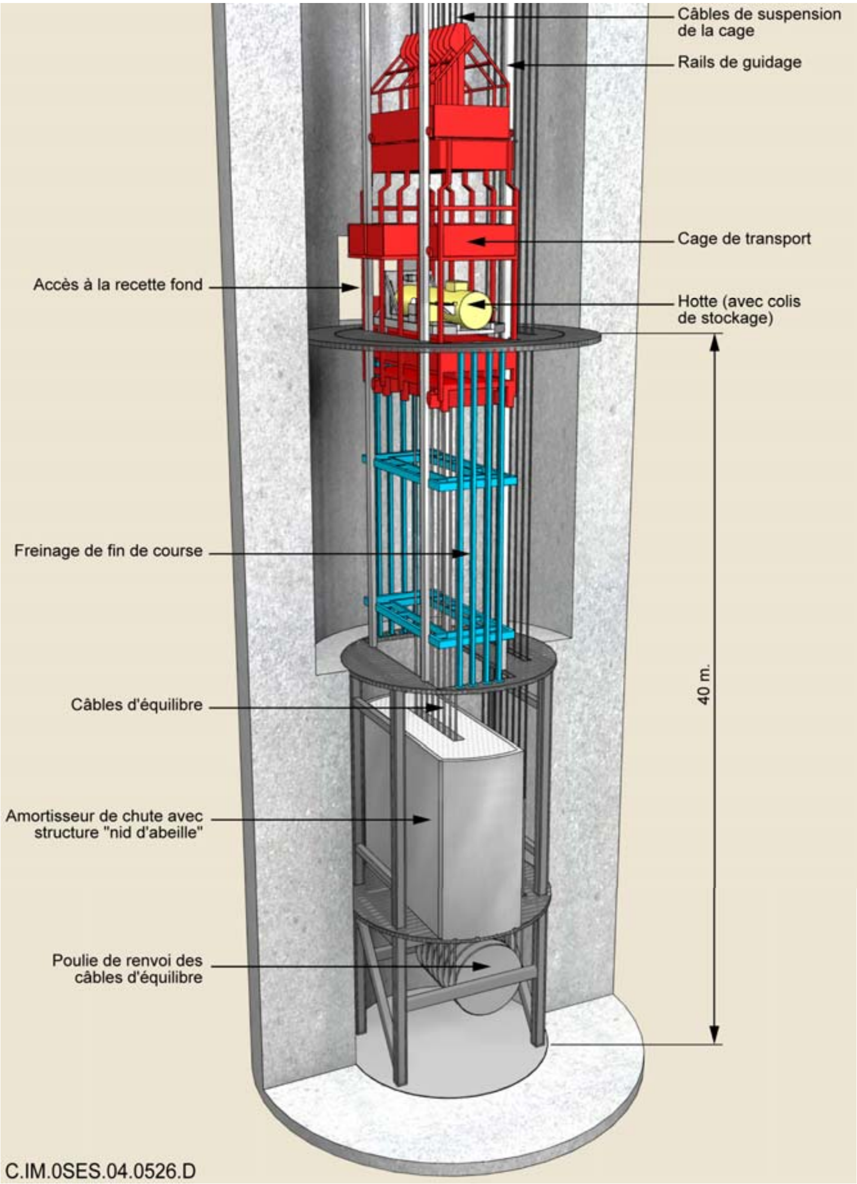


Fires with smoke de-layering *:*
Smoke circulation and evacuation in the case of a fire in an operational type C (or CU) unit

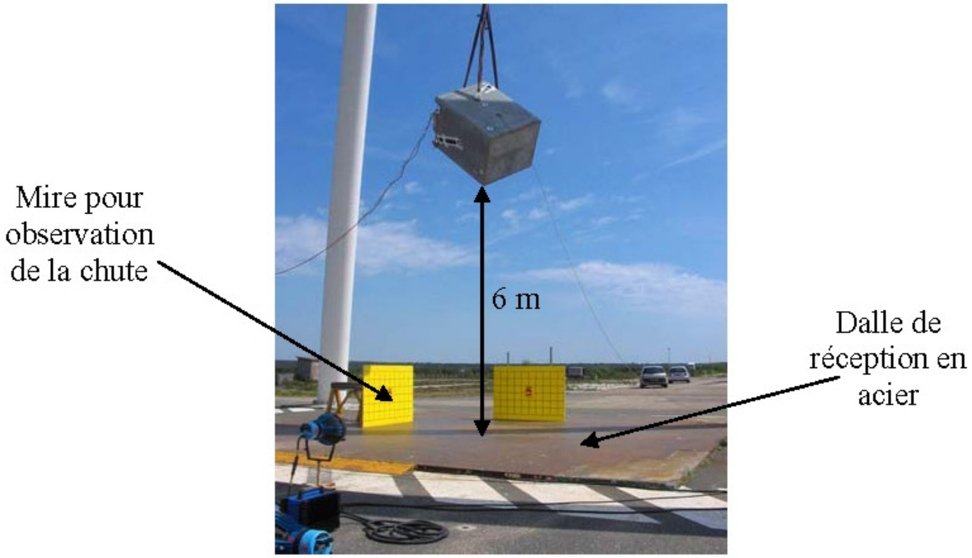
Fires with smoke layering :
Case of a fire in a connecting drift : evacuation either side of the fire

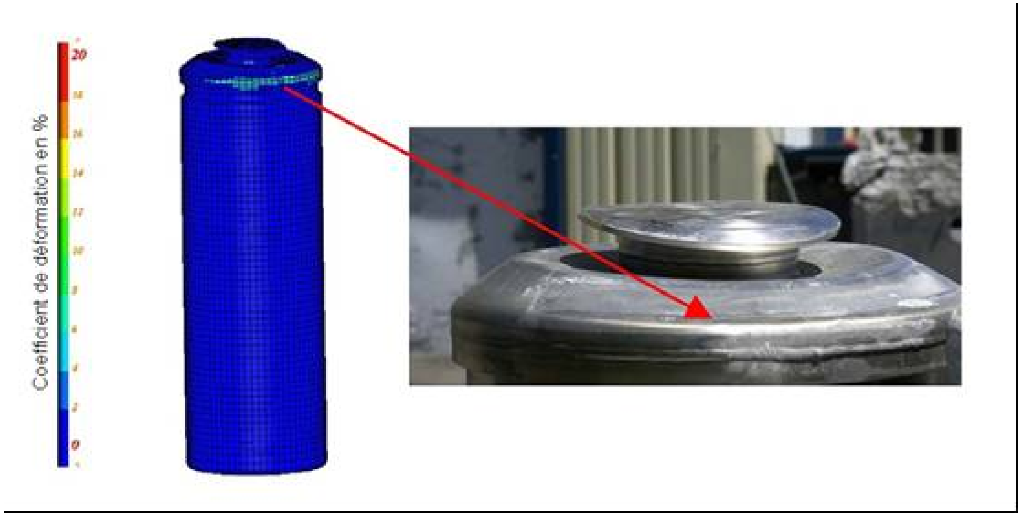


3D representation of the lower section of the shaft equipped with the fall shock absorber system



Drop tests on the demonstrators





SEN - CU1 reference package – Example of History of molar flows

	sortie colis	sortie BO	sortie COX	sortie C3a-C3b
I129	100,0%	100,0%	**40,3%**	39,5%
Nb94	36,0%	atténuation totale	sans objet	sans objet
Ni59	93,4%	57,6%	atténuation totale	sans objet
Cl36	96,7%	96,6%	**16,6%**	15,5%
Se79	84,9%	0,5%	**0,013%**	0,010%

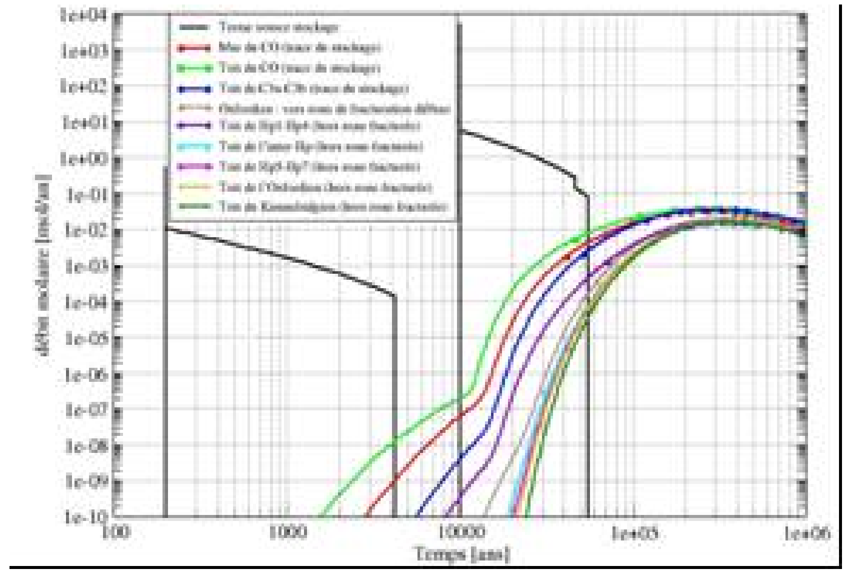
Vers exutoires Ornain et Barrois

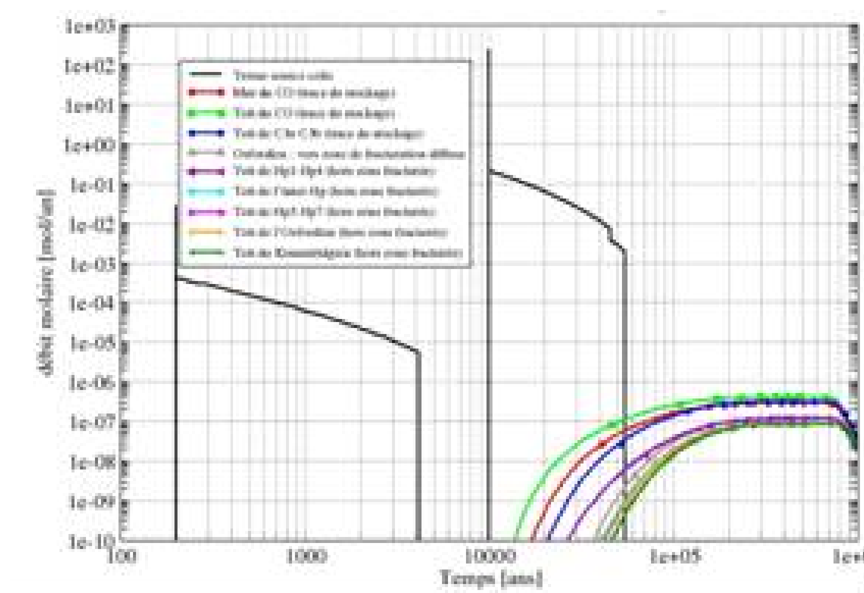
	sortie TOIT OXFORDIEN + ORNAIN
I129	17,0%
Nb94	sans objet
Ni59	sans objet
Cl36	6,2%
Se79	0,003%

Vers exutoire Saulx de l'Oxfordien

	sortie LIMITE ZONE DE FRACTURATION DIFFUSE
I129	21,5%
Nb94	sans objet
Ni59	sans objet
Cl36	7,9%
Se79	0,004%

History of molar flows through different surfaces of the geological medium and quantification of the attenuation of different formations for the million-year model

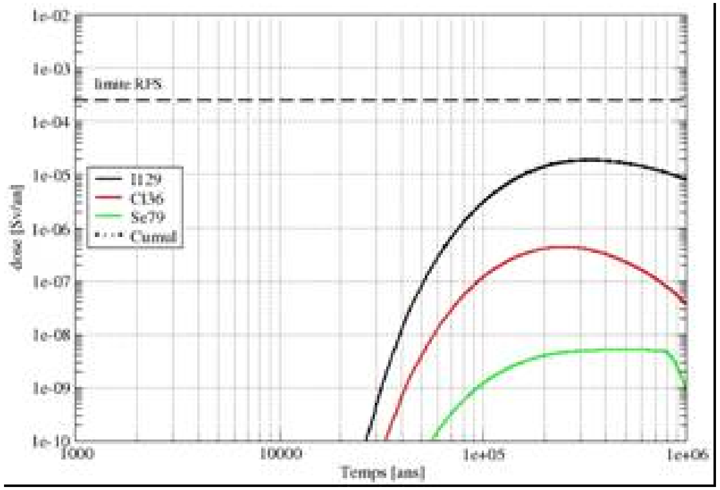




SEN – Total dose

Reference packages	Maximum dose (mSv/year)	Date of maximum [years]	Contributing radionuclides
« Ornain » outlet as a reference			
Total B waste (S1b)	No Ornain outlet		
Total C waste [C1/C2 (S1b) and C3/C4 (S1a)] (No C0 Ornain outlet)	Around 0.000002	660 000	^{129}I ; ^{36}Cl
Total spent fuel (without CU3) (S2)[1]	0.0006	towards 500 000	^{129}I
« Barrois » outlet			
Total B waste	around 0.000013	towards 300 000	^{36}Cl (^{129}I to a lesser degree)
Total C waste	0.0000055	500 000	^{129}I ; ^{36}Cl
Total spent fuel (without CU3)75	around 0.000099	towards 530 000	^{129}I
« Dogger » outlet			
Total B waste	All doses < 10^{-7} mSv/year		Not applicable
Total C waste	All doses < 10^{-7} mSv/year		Not applicable
Total spent fuel	0.000016	1 000 000	^{129}I

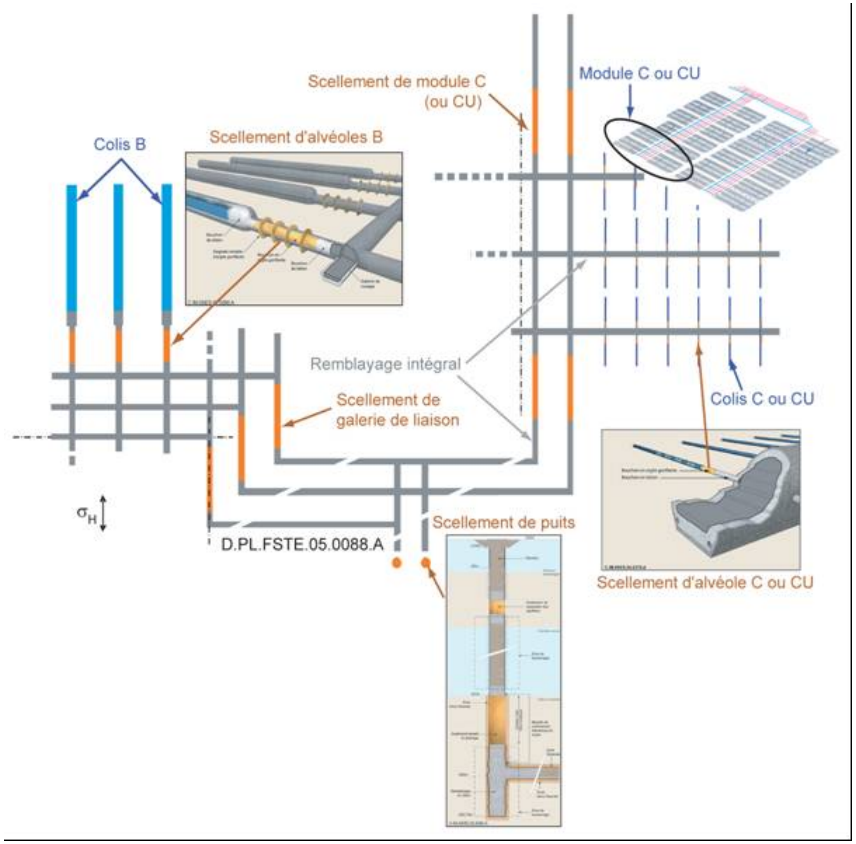
SEN – Total dose – date of maximum dose and main contributors at the other outlets – 1 million-year model – all waste



RN	DoseMax[Sv/an]	t(DoseMax)[an]
Cumul	1.9E-05	3.3E+05
I129	1.8E-05	3.4E+05
Cl36	4.3E-07	2.5E+05
Se79	5.0E-09	4.7E+05

SEN – Reference calculation – million year model - Doses at the Saulx outlet of the Oxfordian – CU1 reference package

«Seal failure» altered evolution scenario – List of calculation cases analysed

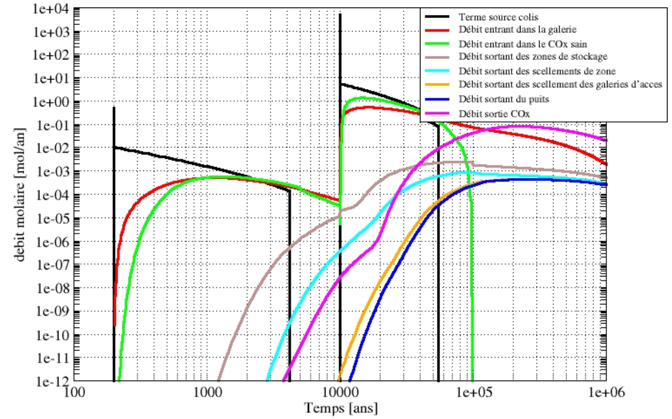


Schematic representation of the various seal structures

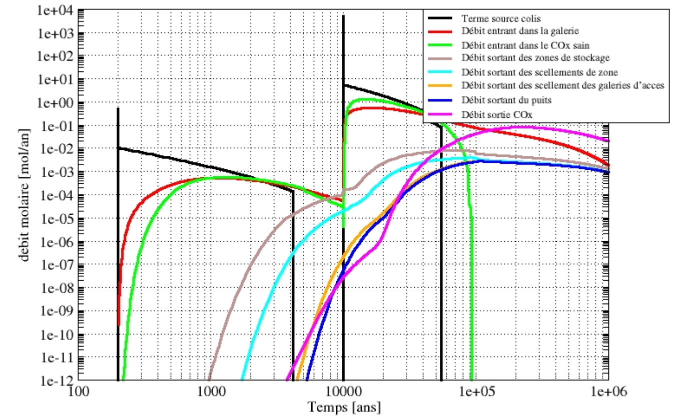
	Cell plugs	Repository module and zone seals	Connecting drift seals	Access structure seals
Normal evolution scenario (reminder)	Isolated failure[1]	Efficient	Efficient	Efficient
Shaft seals defective	Isolated failure	Efficient	Efficient	Defective
Drift seals defective	Isolated failure	Defective	Defective	Efficient
All seals defective	Defective C and B waste disposal cell plugs	Defective	Defective	Defective
Abandonment of repository	Isolated failure	Efficient	Efficient	Not sealed

[1] Reminder : An isolated failure is analysed by considering the defective C waste disposal cell plug. Calculations have shown that this is negligible in the normal evolution scenario.

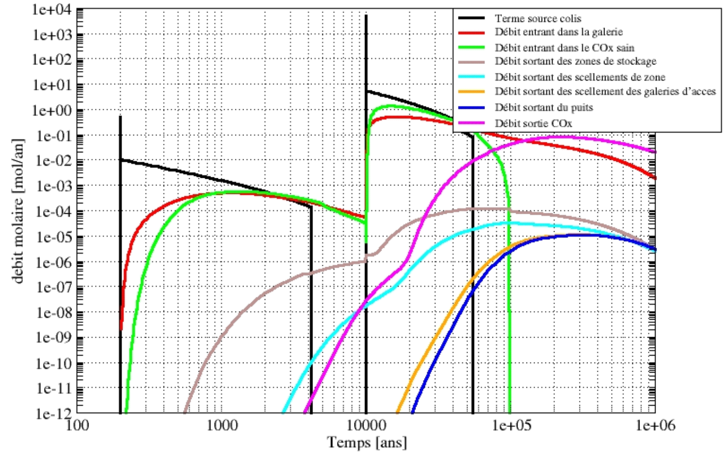
Seal failure altered evolution scenario - hydraulic head gradient sensitivity study



sensitivity 1 : 0.4 m/m hydraulic head gradient



sensitivity 2 : 1 m/m hydraulic head gradient



Reference calculation : 0.2 m/m hydraulic head gradient

Molar flow histories - all seals failed situation - CU1 spent fuel - ^{129}I