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Practical Aspects of Deep Radioactive Waste Disposal*

Session 1 - Paper N°04

**Experimental Programme to Demonstrate the Viability of the
Supercontainer Concept for HLW**

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Overview

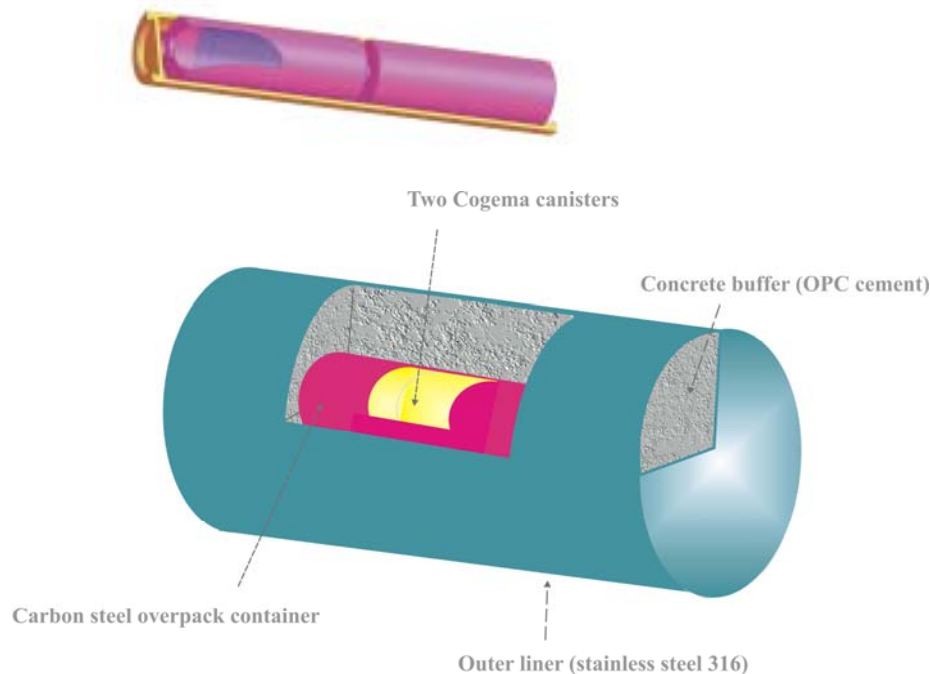
- Introduction
 - Supercontainer concept and fabrication steps
- Supercontainer development programme
 - Experimental programme
- Backfilling the disposal galleries
 - Backfill tests with grout
 - Backfill tests with granular materials
- Conclusions

The Supercontainer Concept

General idea: assembly of all components (EBS) of the supercontainer in surface buildings => better QA, limits underground operation (operational safety)

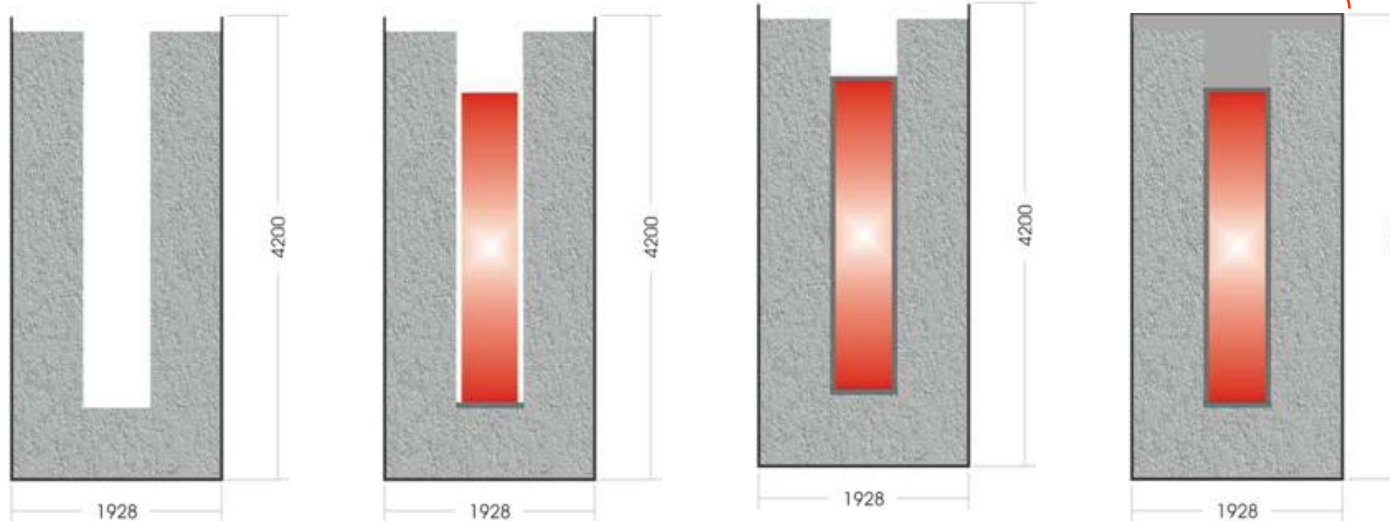
Roles/functions

- ❑ Overpack (30 mm carbon steel) prevent water contacting waste form during thermal phase
- ❑ Buffer and concrete lid:
 - Thanks to its high pH (> 12.5), provides favorable geo-chemical environment to delay overpack degradation
 - Provides permanent shielding for workers (handling of waste packages)
- ❑ Envelope (6 mm stainless steel) delays income of aggressive species. (presence questioned)



Supercontainer construction stages

In hot cell

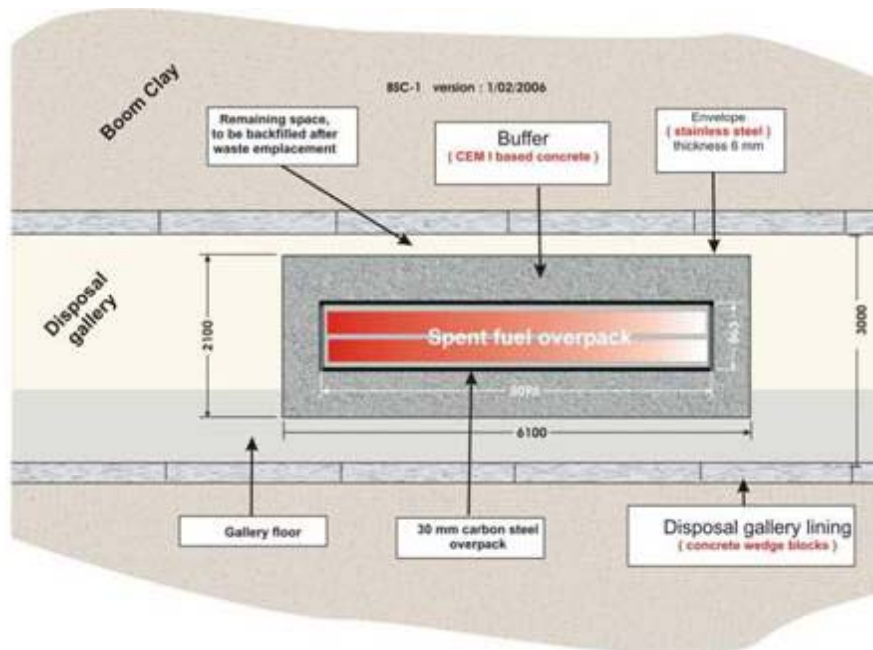
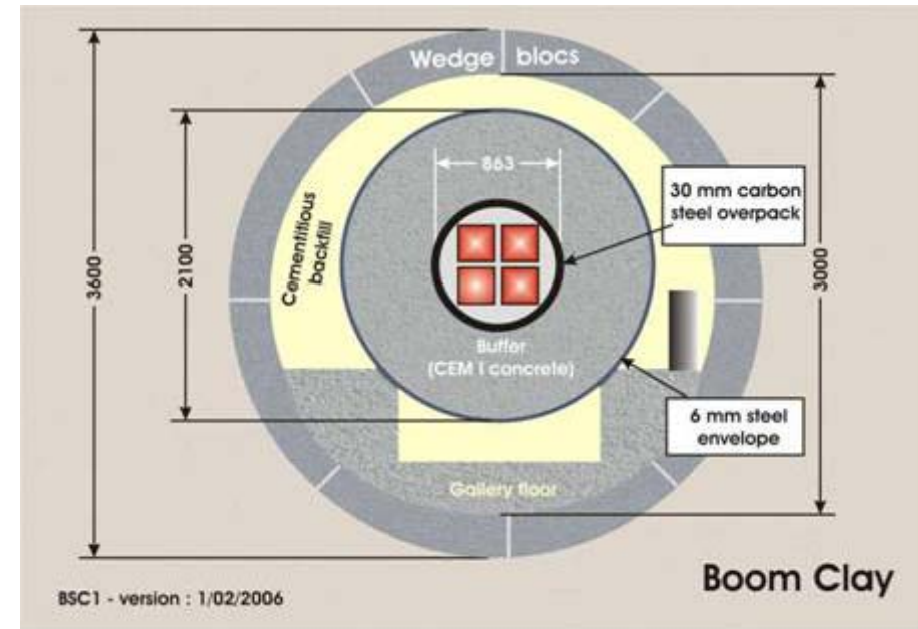
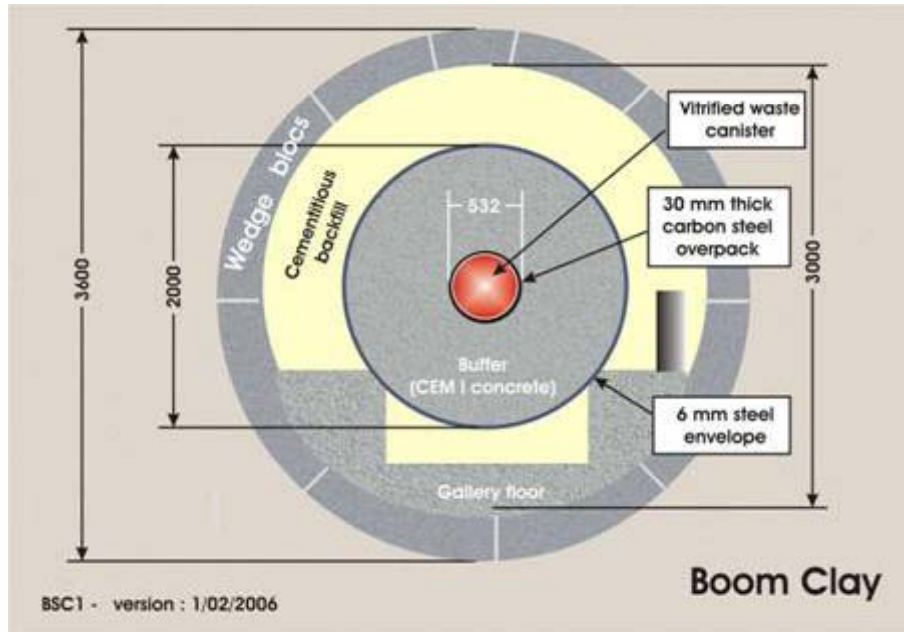


Step 1 :
concrete buffer
fabrication

Step 2 :
Overpack insertion

Step 3 :
Filler emplacement

Step 4 : concrete
lid emplacement
+ closing
envelope (if
present)



	Vitrified waste	UOX	MOX
Canisters or fuel assemblies/ Supercontainer	2	4	1
Outer diameter (m)	2,0 m	2.1 m	1.6 m
Outer length (m)	4.1 m	max. 6.2m	6.1 m
Weight (ton)	30 t	max. 60 t	max. 31 t

Supercontainer development programme

- ❑ **SFC-1 (2013): demonstrate that no fundamental flaws exists regarding supercontainer concept**
- ❑ **Panel expert created (2004)**
 - Propose a first ‘theoretical’ (ideal) composition of concrete
 - Identify critical points to be investigated related to phenomenological behaviour and construction feasibility
- ❑ **Construction feasibility: critical ‘points’**
 - Bring in play of proposed concrete composition
 - Need for reinforcements of the buffer according to construction, handling, storage and in-situ conditions
 - Feasibility to emplace the filler and the concrete lid under specific conditions (temperature, hot cell, scale,...) and according to requirements set on materials
 - (Feasibility to weld the lid of the stainless steel envelope)

E.P specified recommendations for concrete composition

- ❑ CEM I limit consumption of portlandite and favourable for corrosion aspect (fly ashes, silica fumes and blast furnace scoria's concentrations are limited)
 - Limit C_3A phase: limit hydrogarnet formation (porosity) and ettringit formation (SO_4 attack)
 - Limit SO_3 : limit formation of delayed ettringit (and associated expansion)
- ❑ Use of carbonate aggregates (in place of quartz sand) eliminated alkali reaction (formation of sodic silicates which expand)

	Material	SCC [kg/m^3]	RPC [kg/m^3]
Cement	CEM I/42.5N HSR LA (LH)	350.00	350.00
Filler (calcium carbontate)	Calcitec 2001 ME	100.00	50.00
Fine aggregate	Limestone 0/4	840.28	707.86
Coarse aggregate	Limestone 2/6	326.91	413.71
Coarse aggregate	Limestone 6/14	558.55	190.97
Coarse aggregate	Limestone 6/20	0.00	465.17
Plasticizer	Glenium 27/20	14.02	4.41
Water (W/C=0.5)	Tap water	175	175

Construction of large concrete pieces

- ❑ Verification that developed compositions were adequate
- ❑ Dimensions similar to concrete buffer of SC for SF
- ❑ Characterization programme (2 independent labs)
 - Young age: density, workability, absence of segregation and bleeding, air content, ...)
 - THM of hardened (density, porosity, permeability, strength, capillary pressure, creep, E, shrinkage, thermal expansion, ...)
 - Modeling cracks creation → need for reinforcements during construction phase

Tests concluded the 'Very high quality' of the two concrete compositions → RPC selected as reference material (less plasticizer)

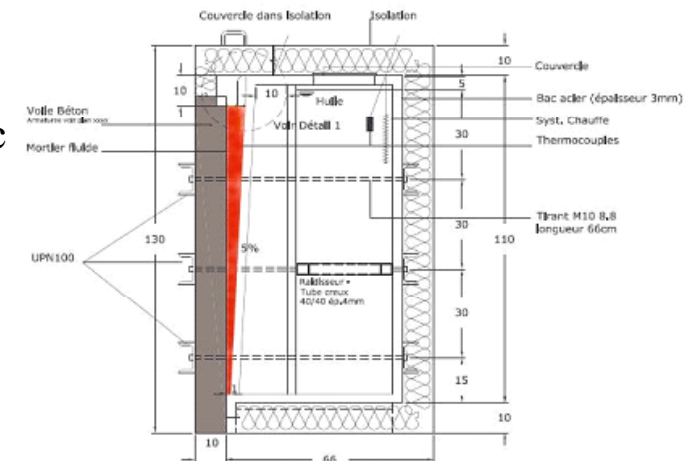
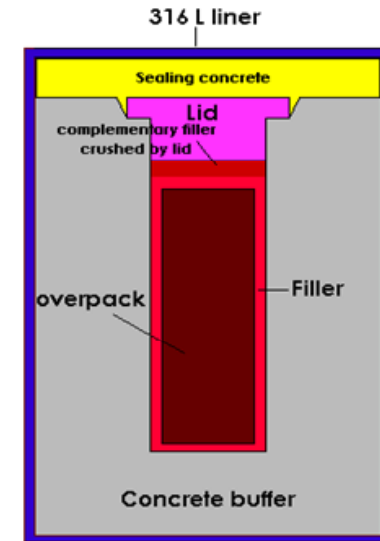


Characterisation: some results...

Parameter	SCC	RPC
Bleeding	None	None
Density (at 28 days)	2420 kg/m ³	2440 kg/m ³
Compressive strength	57 MPa	47 MPa
P-wave velocity	4.69 km/s	4.69 km/s
Tensile strength	4.4 MPa	3.3 MPa
Young's modulus	36 Gpa	32 Gpa
Poisson coefficient	0.39	0.16
Shrinkage (after 6 months)	420 µm/m	380 µm/m
Thermal dilation (10-60°C)	8.0 x 10 ⁻⁶ °C ⁻¹	7.5 x 10 ⁻⁶ °C ⁻¹
Permeability (water)	2.9 cm ³	2.1 cm ³

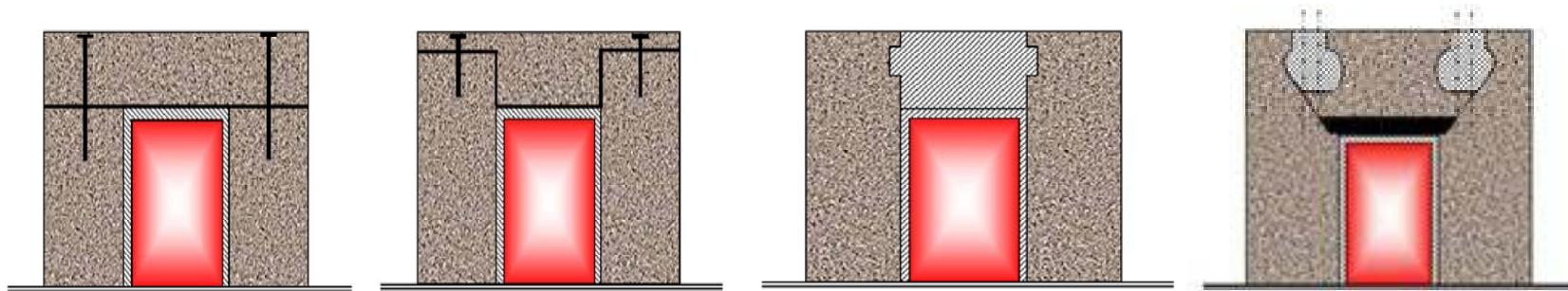
Filler: roles, materials and emplacement tests

- ❑ Most important remaining open question (feasibility)
- ❑ Role: assures favorable containment conditions with regard to the corrosion of the overpack
 - High pH (similar to the buffer - > 12.5)
 - Contact as good as possible with the overpack
 - λ similar to concrete (~ 1.7 W/mK)
- ❑ Reference material : grout
 - Same components as concrete buffer (except size of aggregates limited to some mm) for compatibility reason
- ❑ Tests at small-scale
 - Effect of temperature on hardening process (60 -> 100 °C) and on the quality of hardened grout (shrinkage, λ , compressive strength, void ratio, porosity, quality of contact homogeneity, permeability...),
→ Optimisation of grout composition and annular gap dimension
- ❑ Test at large-scale with selected material from small-scale test
 - + emplacement at representative high



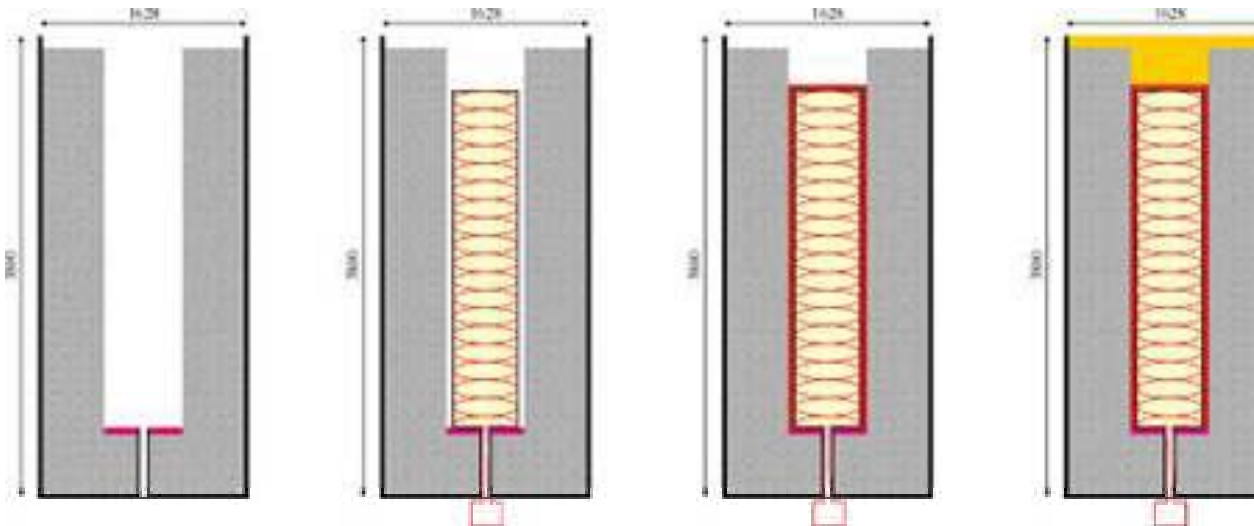
Concrete lid: design and tests

- ❑ 3 options envisaged
 - Concrete lid cast
 - Pre-cast and bolted concrete lid
 - Mixed pre-cast piece (metallic + concrete) + cast joint (preferred option)
 - Small joint → limited shrinkage
 - Pre-cast mixed piece allows joint emplacement in conventional workshop conditions (steel: radiological shielding ; concrete: thermal isolation)
- ❑ Experimental programme
 - Scale 1/1 regarding diameter (emplacement test) + resistance to fall (tilting + chucking)
 - Measurement of shrinkage + permeability of the joint



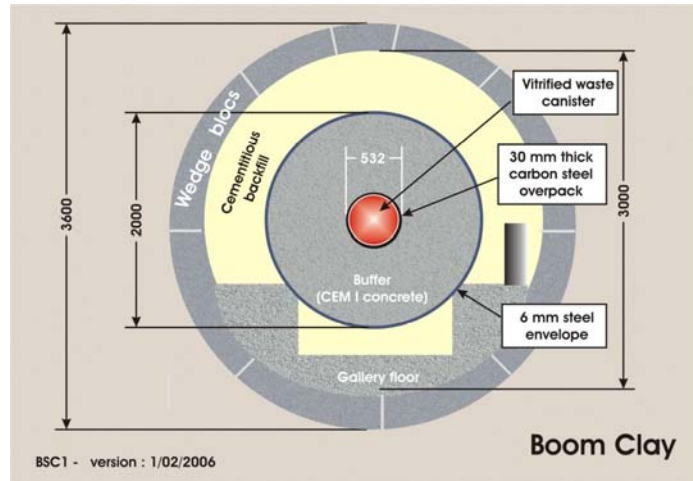
Supercontainer development programme

- ❑ For SFC-1 (2013)
 - ‘Prototype’ to demonstrate the sequence of construction/emplacement simulating ‘hot cell’ conditions)
 - Fall tests and associated modeling → decision about reinforcement need
- ❑ For SFC-2 (2020) : construction of a mock-up to study (longer time) behaviour of components and the interactions between them (programme still to be defined)

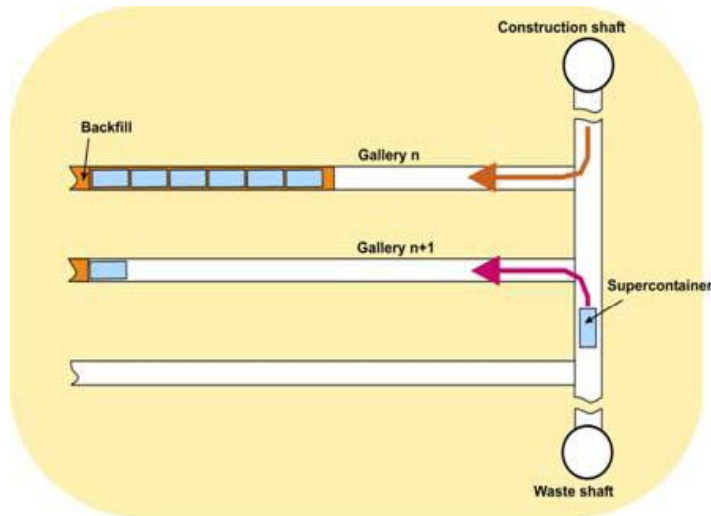


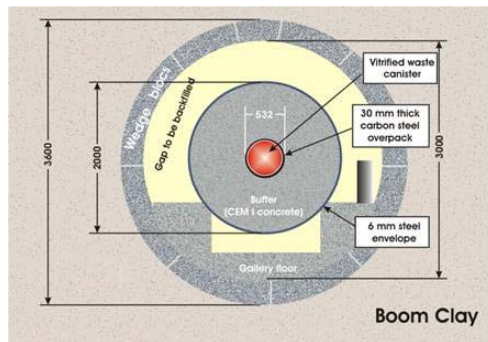
Backfilling of the disposal galleries (ESDRED)

Reference design and scenario for backfilling operations



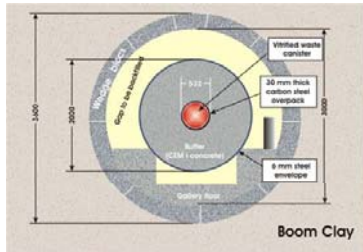
- Supercontainer (SC) **2 m** outside Ø, resting in horizontal disposal gallery, **3 m** inside Ø
 - Floor surface for air cushion trolley, with SC mechanical support incorporated
 - Reference scenario
 - Disposal rate 2 SC/day (without delays)
 - Backfill section: **30 m**, considered minimum length to achieve HLW disposal operations within 10 years (considered duration of operation license)
- Normal backfilling frequency: **weekly**
(30 m \approx 8 SC vitrified waste \approx 4 days)
- Eccentric gap = **15 cm** (SC top to wall) ... 65 cm (floor to wall) → void cross-sectional area \approx 2.6 m²
 - 85 m³ to be filled with the backfill material





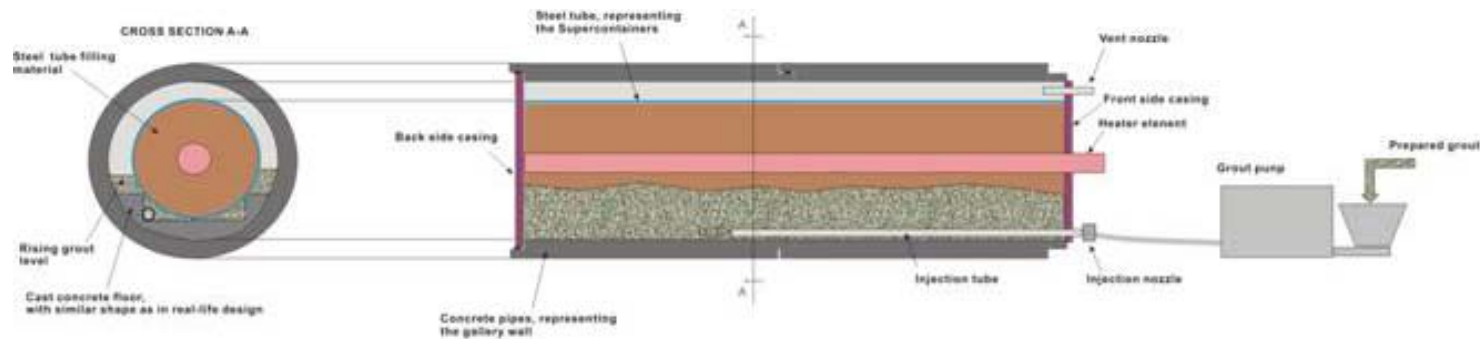
The backfill material has two main roles/functions...

- ❑ Prevents collapse of the gallery lining (and potential damage of the supercontainer)
 - ❑ Prevents/limits creep of Boom Clay (with potential destabilization of the host formation around)
- Main requirement is to obtain a filling ratio as high as possible but constrains on the materials !!!

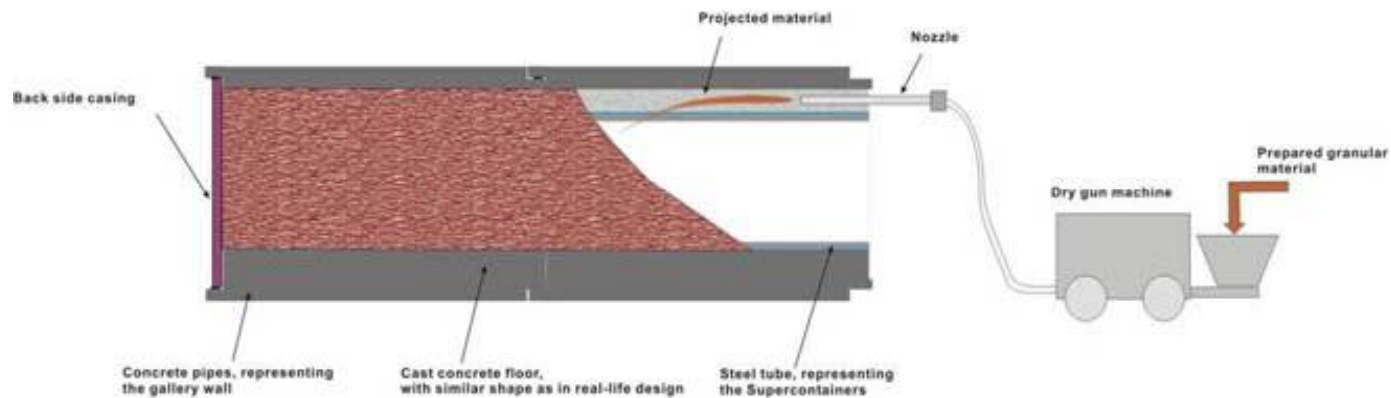


Two backfilling techniques tested in the scope of the ESDRED Project

Backfilling by pumping a grout



Backfilling by projecting a granular material (dry gunite technique)



Backfill tests with a grout - challenges and main objectives

- ❑ **Propose a grout composition taking into account**
 - Operational constrains
 - fluidity/workability for few hours
 - hardening time limited to 4 days
 - mechanical strength limited (between 3 and 10 MPa)- retrievability option open
 - Long-term safety constrains
 - limited quantity of chemical additives – superplasticizers
 - sufficient thermal conductivity (at least 1 W/mK)
- ❑ **To verify the preparation procedure of “industrial” quantity of grout**
- ❑ **To verify the grout emplacement under representative conditions (scale and temperature)**
 - Effect of temperature on fluidity period → Number of injection tubes needed
 - Max filling rate → Design (length) and position of the injection tubes
- ❑ **To verify the modifications of the hardened grout properties**

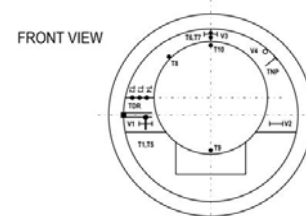
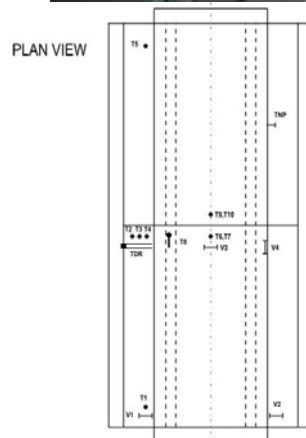
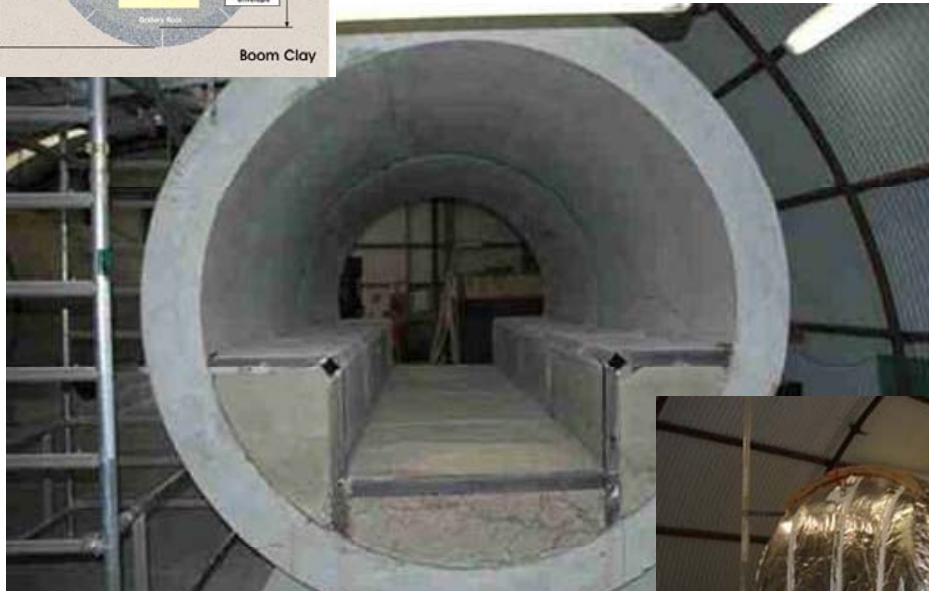
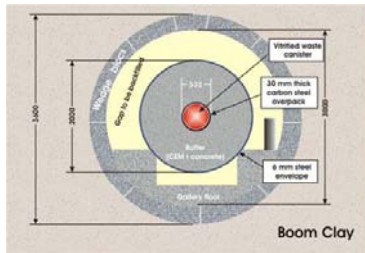
Backfill tests with a grout – content of the testing programme

1. Development of the grout in collaboration with BASF Chemical Construction Belgium (Ham, B)
2. Preparation and emplacement test in a reduced-scale mock-up (preparation for the full-scale test)
3. Large volume preparation test (+ pumping effect)
4. Emplacement test in a full-scale mock-up

Grout material composition

- Composition
 - Binding medium (40 wt.%)
 - $\frac{1}{4}$ CEM I 52.5 N HSR LA
 - $\frac{3}{4}$ Limestone powder (CaCO_3), from Carmeuse
 - Additive (< 0.3 wt.% of the binding medium)
 - Superplasticizer Glenium® (polycarboxylate ether based material)
 - Sand (≤ 60 wt.%)
 - Calibrated river sand 0 - 4 mm, washed and dried

Design of the reduced-scale mock-up



Reduced-scale test (June 2006)

- Flow rate $\sim 3 \text{ m}^3/\text{h}$
- Hardening < 4 days
- Hardened material homogeneous (density measurement and visual observation)

Rheological properties of grout were suitable

- 100 % filling ratio obtained
- Main injection tube sufficient

Design of main injection tube was suitable

- Properties of hardened material
 - o density = 2.2 (homogeneous)
 - o $\lambda = 1.6 \text{ W/mK}$ (fully dried)
 - o Compressive strength = 12 MPa
 - o $K_h \sim 10^{-12} \text{ m/s}$

Not necessary to adapt the grout composition for full-scale test



Construction and design of the full-scale mock-up



Full-scale test: grout preparation and tests before pumping (April 2008)



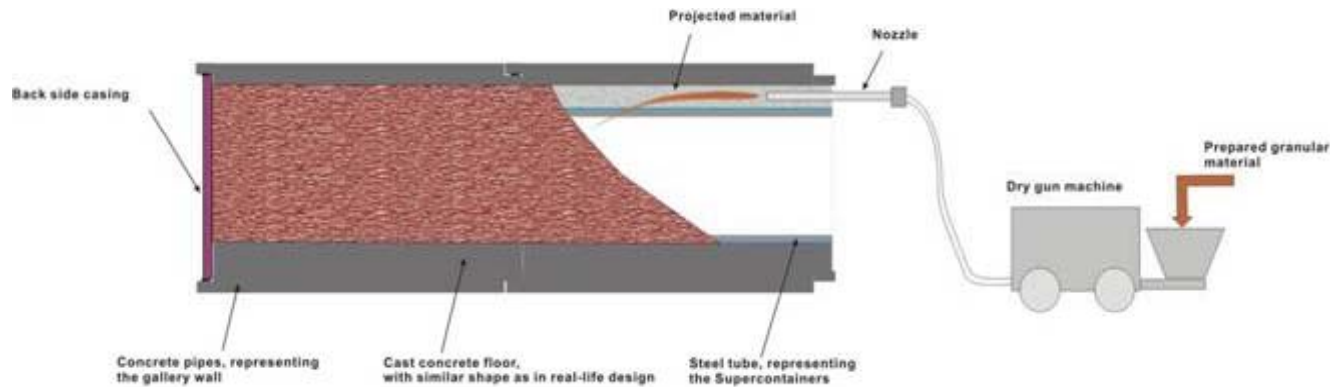
Test in full-scale mock-up (Avril 2008)



Full-scale test: results and first lessons learnt

- ❑ ‘Concrete’ truck can be used as mixer for the developed grout
- ❑ Average backfilling flow rate ~ 12 m³/h (8 h + 1 h pump breakdown)
 - 1 h pump breakdown did not jeopardize the backfilling operations: still possible to pump again in the same injection pipe
- ❑ 100 % filling ratio obtained but (limited) segregation observed on the top
 - Profile imposed during filling is good → suitable length for injection tube
- ❑ Unexpected behaviour
 - Grout material is slowly becoming hard !!!
 - Investigations are on going (chemical analyses)
- ❑ Lessons for actual backfilling operations
 - Not possible to prepare to material in-situ (dust, volume to store dry material, ...) storage → material will be pumped through shaft and galleries (up to 2 km)
 - Most ‘industrial’ material is required (functioning zone larger)

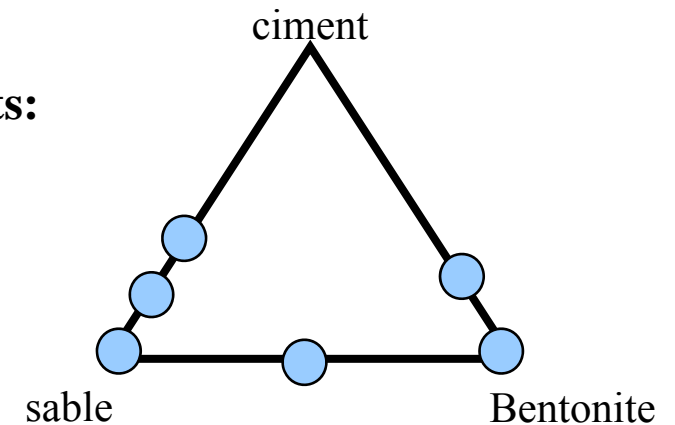
Backfill tests with granular materials

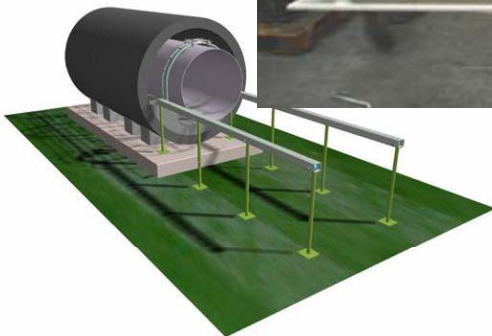
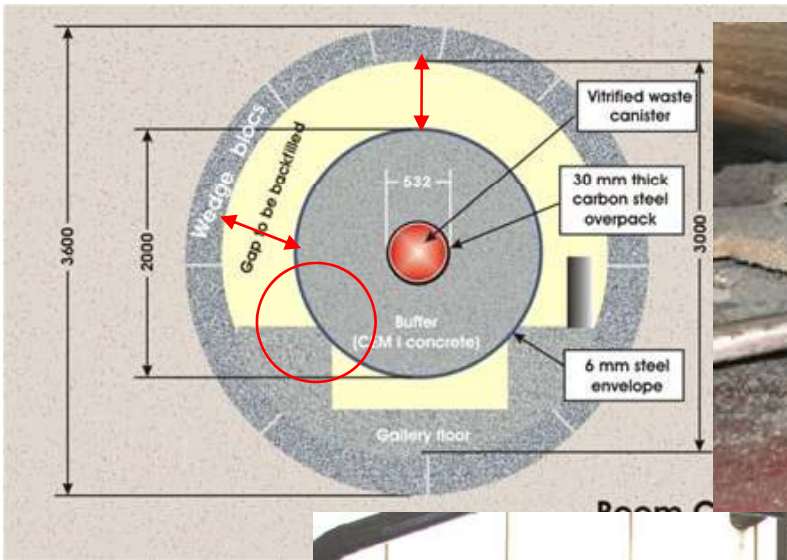


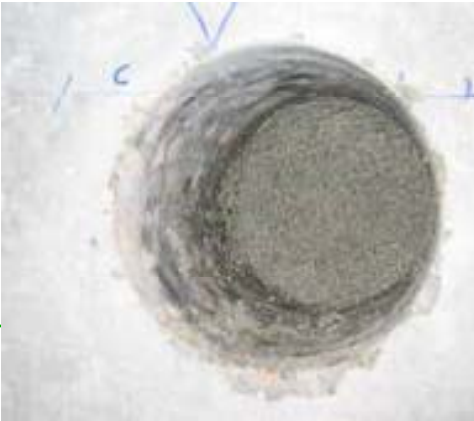
- ‘Dry’ gunite technique: material hydrated at the end of the hose
- Silo clever machine: do not need continuous regulating of water and material flow rate → remote process

Selection of the mixture on the basis of operational aspects:

- Dust production
- Material rebound/adhesion
- Limited water flowing
- ...







Main results and conclusions of the backfill tests with granular materials

- ❑ A filling rate of 1 m/h was obtained for all materials
- ❑ 100 % filling ratio obtained for all materials
- ❑ Dry gunite = technique particularly well adapted for bentonite-based material (adhesion → limited slope → good homogeneity on the whole volume),
- ❑ Optimisation of grain sizes and shapes would limit the rebound effect (sand and sand/cement)
- ❑ For all materials, optimisation of the composition is possible to meet physico-chemical requirements (thermal conductivity)
- ❑ The wagon proved to be well designed and very robust despite the unfavourable environment (water, dusts,)

General conclusions

❑ Supercontainer viability

- Two (main) open questions/critical points to be solved for SFC-1
 - Need to reinforce the buffer (fall)
 - Emplacement and behaviour of the filler material under thermal load
- 2008 - 2011 : experimental programme at small- and large-scales + associated modelling works (fall)

❑ Backfilling of disposal galleries

- Grout: as expected composition of the material is the most critical point → need for further material development
- ...but projection of dry materials constitutes an alternative