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DEVELOPMENT OF A SCC COMPOSITION FOR DISPOSAL OF HEAT-EMITTING, RADIOACTIVE WASTE IN BELGIUM

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Abstract

ONDRAF/NIRAS is the national radioactive waste agency in Belgium responsible for the long term management of radioactive waste and enriched fissile materials. For the final disposal of long-lived, heat-emitting vitrified waste and spent fuel (category C waste) in the deep Boom Clay layer, ONDRAF/NIRAS has developed in collaboration with Tractebel and SCK•CEN a design, called *Supercontainer*, bases on the use of an integrated waste package composed of a carbon steel overpack surrounded by an Ordinary Portland Cement buffer. For the choice of this cementitious buffer, different compositions are being considered. One of the possible solutions is the use of self compacting concrete because it will ease considerably the precast process and complies with all other requirements regarding compressive strength, long term durability, chemical interactions,... .

In this paper, the process of choosing a reference composition for the SCC concrete will be explained. The above mentioned requirements differ, at least for some points, significantly from those frequently used in classical constructions. Consequently, an appropriate choice for aggregates, cement and superplasticizer result from these requirements. An intensive laboratory characterization program and large scale tests will be performed in order to obtain concrete parameters used in a 3D thermal and crack modelling program. Finally, the future characterization, demonstration and modelling program, necessary to increase the confidence in the feasibility of the Supercontainer design, will be presented.

1. INTRODUCTION

ONDRAF/NIRAS, the Belgian Agency for Radioactive Waste and Enriched Fissile Materials, is responsible for the design of a repository for High Level Waste (HLW). The Boom Clay can be seen as a potential host formation for disposal of HLW. During the past 25 years several preliminary repository designs were proposed. Today, the Supercontainer was chosen to be the most promising one on the matter of enclosing the vitrified HLW and the spent fuel assemblies [1].

First, the basic conceptual design for the disposal of HLW is explained and demonstrated. The supercontainer aims at maximizing the period of watertight confinement of the waste form within metallic overpack.

Second, the proposed concrete composition is explained. An OPC (CEM I) concrete has been chosen for the buffer in order to provide a highly alkaline chemical environment, which will last for thousands of years. Two compositions are being considered: a traditional concrete and a self compacting concrete.

Third, the paper will discuss the large scale tests performed at SOCEA, Belgium. A column, 6 metres high is cast in order to obtain information on homogeneity, workability, heat development inside the massive column, the fresh concrete characteristics and to perform laboratory test on cores taken from the column. These parameters will be used in an 3D modelling program.

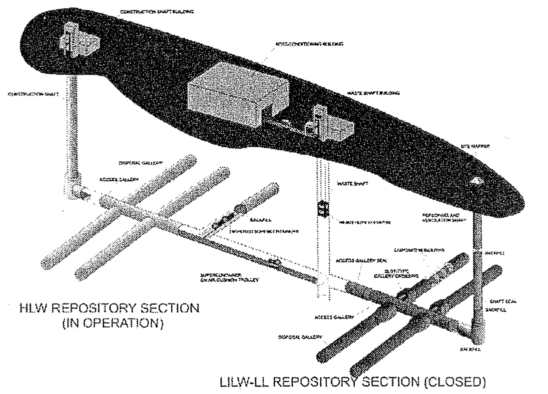
2. THE SUPERCONTAINER CONCEPT

Various types of radioactive waste were and are produced in Belgium. This waste originates from different producers: nuclear power plants, medical applications, industry, research centre, … Based on their activity and the half-live of the included radionuclides, the conditioned waste are subdivided into 3 different categories: A, B and C (Table 1).

Table 1: Different types of radioactive waste

	Low Level	**Intermediate Level**	**High Level (heat emmitting)**
Short-lived (SL) : Half-life (< 30 years)	**A**	**A**	**C**
Long-Lived (LL) : Half-life (> 30 years)	**B**	**B**	**C**

The Supercontainer is intended for the disposal of (vitrified) high level heat-emmitting waste (Table 1, category C) and for direct disposal of spent fuel assemblies. In this concept (Figure 2), the vitrified waste canisters or spent fuel assemblies are enclosed in a carbon steel overpack of about 30 mm thick. This overpack has to prevent contact of the waste with the water coming from the host formation during the thermal phase i.e. the first 500 years for vitrified waste and 2000 years for the spent fuels assemblies. For corrosion protection purposes, the overpack is enveloped by a high pH concrete buffer (high alkaline concrete) [2,3]. This buffer, with a thickness of about 70 cm, also performs as a well-defined radiological protection buffer for the workers, simplifying underground waste transportation operations. This buffer is surrounded by a stainless steel [4] cylindrical enveloppe (also called liner). Once closed, the Supercontainer (length: of about 6 metres) will be transported to the repository (see Figure 1) using an air cushion system. Figure 2 shows a complete cross section of a disposal gallery after supercontainer emplacement. The space between the supercontainer and the gallery lining is backfilled with grout.



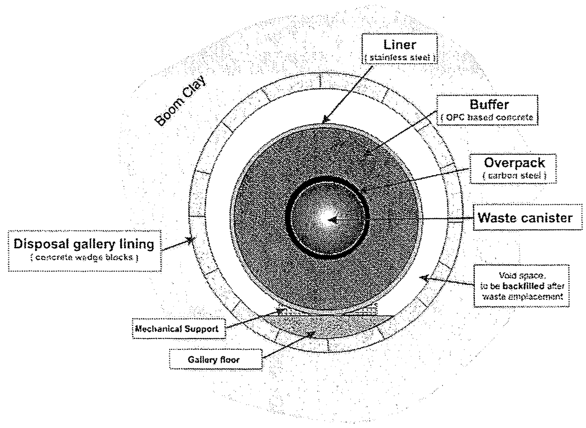


Figure 2: Cross-section in a disposal gallery for vitrified HLW

Current design requirements [5] impose a maximum temperature of 100°C at the surface interface between overpack and concrete buffer. Because Boom Clay is the main barrier against radionuclide migration, the (materials of the) supercontainer may not affect, as much as possible, its retention capacity.

3. CONCRETE BUFFER COMPOSITION

Two types of concrete are considered for the buffer around the overpack: a self compacting concrete (SCC) and a conventional concrete called 'rheoplastic concrete (RPC)'. There are certain restrictions to the different components of the buffer. It is recommended that CEM I, Portland Cement (no fly ashes, no blast furnace slag), is used with additional restriction that the **cement** has a low SO_3 content (< 2%) and that the compound content of C_3A does not exceed 5%. This is to prevent ettringite formation. The cement must have high sulphate resistance to better resist to sulphur species present in Boom Clay fluids. Cement with limited hydration heat production to avoid or limit cracking is also preferable.

It is also recommended that both fine and coarse **aggregates** should be limestone (calcium, carbonate, calcite) containing not more than 2% each of magnesium, silicon and aluminium (as oxides).

No other organic **additives** are acceptable except, as low quantity as possible, superplasticizer. The superplasticizer is preferably based on polycarboxylate.

Other minimal **qualities** are listed below:

- Good workability - preferably pompable;
- Tensile strength 2 MPa (caracteristic value): this requirement is based on the current modelling results where a slight cracked annular zone at the outer border of the buffer may be present at spots with σ_t> 2 MPa;
- Compressive strength sufficient to resist to mechanical normal and accidental loads : a C30/37 or better concrete is a good starting point;
- Micro-cracks are allowed (and cannot be avoided) but radial, through-going cracks that might jeopardize the radiological shielding capacity should be avoided;
- Good quality, homogeneous and dense concrete (no quantitative values imposed).

Finally, two compositions, one self compacting and one traditional concrete are being considered (Table 2a, Table 2b).

Table 2a: Composition of the self compacting concrete SCC

Component	[kg/m³]
Cement CEM I/42,5N HSR LA LH	350
Limestone filler	100
Limestone 0/4	840
Limestone 2/6	327
Limestone 6/14	559
Superplasticizer glenium 27/20	14.02
Water	175

Table 2b: Composition of the traditional concrete RPC

Component	[kg/m³]
Cement CEM I/42,5N HSR LA LH	350
Limestone filler	50
Limestone 0/4	708
Limestone 2/6	414
Limestone 6/14	191
Limestone 6/20	465
Superplasticizer glenium 27/20	4.41
Water	175

4. LARGE SCALE TESTS AT SOCEA

4.1 Discussion

Large scale tests are performed to obtain valuable information and parameters and to determine the characteristics necessary for the 3D modelling program HEAT. HEAT is an outstanding computer software product for the analysis of hardening concrete. It enables advanced thermal and mechanical computations particularly focused on the building practice.

At SOCEA, two 6 metres high columns (side 0,6 m) are cast. The concrete is pumped into the formwork. Fresh concrete tests are performed on both the self compacting and the traditional concrete mixes to evaluate the workability and homogeneity of each concrete composition. The temperature inside the column is also measured using 39 thermocouples placed in 3 different levels inside the column (thus 13 thermocouples on each level). Even the temperature just outside the column is measured using 3 thermocouples. When the concrete is hardened, cores are taken from the column for tests in Magnel Laboratory for Concrete Research and BBRI (Belgian Building Research Institute). These cores originate from a high, intermediate and low level of the column. Tests are necessary to acquire basic parameters in order to perform 3D static and dynamic calculation, at young age and at 28 days.

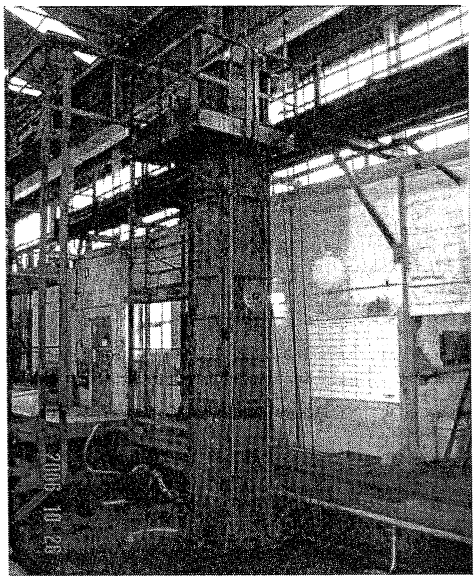


Figure 3a: Formwork of the column

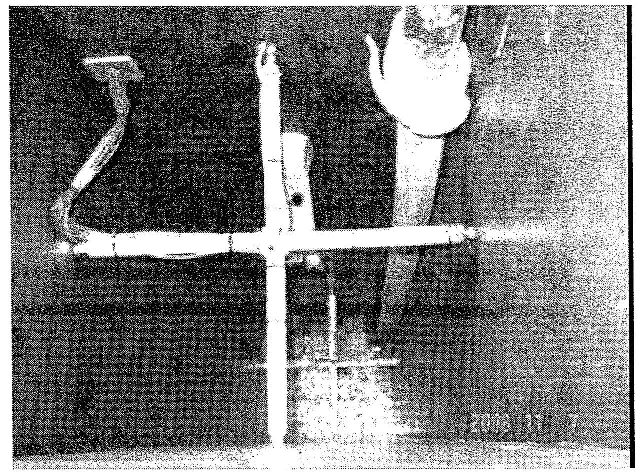


Figure 3b: Thermocouples placed on different levels in the column. The self compacting concrete is pumped into the formwork with the hose

4.2 Tests in situ

Fresh concrete tests are performed on the self compacting concrete mixture according to 'the European Guidelines for Self Compacting Concrete': slump flow, L-box, V-funnel and the sieve stability test. According to NBN EN 12350, slump and flow are measured for the traditional concrete. The results are listed in Table 3a and Table 3b.

Table 3a: Properties fresh SCC

Properties	Values
Slumpflow	710-750 mm
V-funnel	5.5 s
Passing Ability (L-box)	0.77-0.84
Sieve stability	3-5 %
Volumetric mass	2405-2425 kg/m³
Air percentage	1.6 %

Table 3b: Properties fresh RPC

Properties	[kg/m³]
Slump	245 mm
Flow	745 mm
Volumetric mass	2425-2470 kg/m³
Air percentage	0.9 %

The SCC has a good flow rate, filling ability and segregation resistance. The passing ability could be better as it fluctuates round the lower acceptable limit of 0.80. As for the fresh properties of RPC, they can be subdivided into the highest, most liquid category.

The temperature inside the column is measured using 39 thermocouples. When we compare the temperature development inside the column on the different levels (high, intermediate, low), we see not much of a difference. Figure 4 gives the temperature development inside the SCC column (high level), as well as the air temperature.

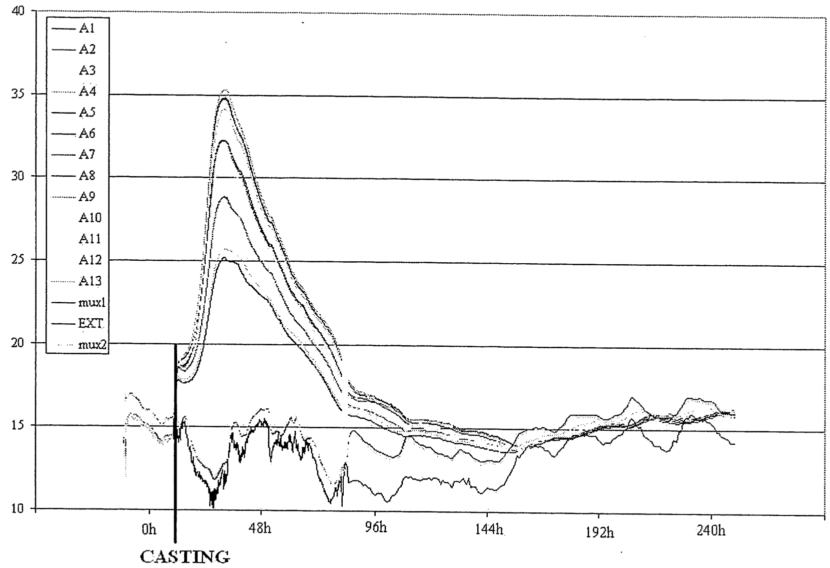


Figure 4: Temperature development inside the SCC column (highest level)

Approximately 20h after casting, the highest temperature is reached: 35.3°C in the centre, and 25.2°C near the formwork. This means a temperature gradient of 10°C. After the peak is passed, the temperature drops, and the differences between the side and the centre becomes smaller. About 96h after casting, the progress of the temperature inside the column follows the outside temperature. The temperature differences inside the column become negligible. Comparing the RPC column with the SCC column, we notice that the peak occurs approximately 17h after casting, and the temperature reaches a maximum of 37.3°C (centre) and 27.9°C (side). The development of temperature is similar to SCC.

4.3 Tests in Magnel Laboratory for Concrete Research

When the temperature measurements are finished, 2 types of cores are taken from the high, intermediate and low level of the concrete columns to investigate the gas and water transport in SCC and RPC. Type A cores are cylindrical, with a diameter of 113 mm and height 100 mm and are meant to experimentally determine the absorption of water by immersing (NBN B15-215) and by capillarity (NBN B15-217). Type B cores are also cylindrical, but have a diameter of 150 mm and height of 50 mm. These cores are tested to obtain the gas permeability of the concrete by different saturation degrees according to the RILEM method TC116-PCD.

Table 4: Absorption by immersing (%)

		$\overline{X}$	s
SCC	Hi	5,18	0,49
	Mi	5,14	0,12
	Lo	4,88	0,27
RPC	Hi	4,99	0,14
	Mi	5,40	0,27
	Lo	5,27	0,15

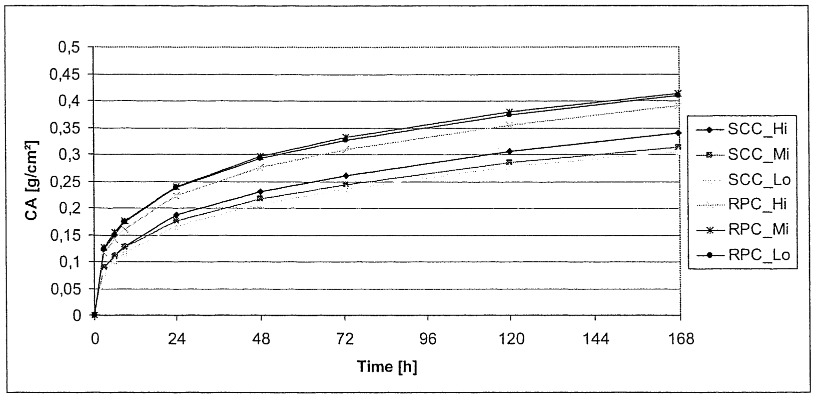


Figure 5: Absorption by capillarity (g/cm²)

Table 5: Gas permeability (10^{-16} m²)
(S = saturation degree)

		S_1 [%]	P_1 [bar]	k_a [10^{-16}m²]	S_2 [%]	P_1 [bar]	k_a [10^{-16}m²]	S_3 [%]	P_1 [bar]	k_a [10^{-16}m²]
SCC	Hi	67	2	0,064	26	2	0,487	0	2	-
			3	0,045		3	0,352		3	-
			4	0,075		4	0,897		4	-
	Mi	72	2	0,034	33	2	0,319	0	2	0,871
			3	0,030		3	0,193		3	0,548
			4	0,036		4	0,163		4	0,483
	Lo	67	2	0,049	31	2	0,261	0	2	0,642
			3	0,034		3	0,163		3	0,382
			4	0,068		4	0,128		4	0,345
RPC	Hi	54	2	0,334	20	2	1,308	0	2	2,343
			3	0,216		3	0,804		3	1,380
			4	0,181		4	0,677		4	1,120
	Mi	61	2	0,127	23	2	0,805	0	2	1,580
			3	0,079		3	0,487		3	1,010
			4	0,080		4	0,422		4	0,747
	Lo	59	2	0,222	22	2	1,073	0	2	2,123
			3	0,143		3	0,677		3	1,226
			4	0,114		4	0,560		4	0,988

After analysing the gas and water transport of SCC and RPC (Figure 5, Table 4 and Table 5), it can be concluded that the self compacting composition is the most impervious one.

5. CONCLUSIONS

- After proposing several designs, the Supercontainer was chosen to be the most promising one on the matter of enclosing the vitrified HLW and the spent fuel assemblies. It contains an overpack which is surrounded by a concrete buffer. This buffer is the main subject of this research and has multiple functions/constraints: 1) Create favourable environment (high pH) to delay overpack degradation (corrosion);

2) Provide permanent radiological shielding for workers; 3) Provide efficient heat dissipation; 4) Provide sufficient mechanical strength; 5) Not affect the retention capacity of Boom Clay.

- Two different concrete compositions are suggested, testes and compared. The first one is a self compacting concrete, the second a traditional one. Tests are necessary to evaluate the workability and homogeneity of each concrete composition and to obtain the basic parameters in order to perform a 3D static and dynamic calculation, at young age and at 28 days.
- A 6 metres high column is cast. This large scale test has been realized to receive valuable information on temperature development, fresh concrete properties and to investigate the gas and water transport inside the concrete.
- The temperature reaches its maximum after approximately 20 hours for SCC with a value of 35°C in the center and 10°C less at the side of the column.
- After testing the cores, it can be concluded that self compacting composition is the most impervious one.

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