FEBEX AND FEBEX-DP PROJECTS AT THE GRIMSEL TEST SITE:

ONSITE BENTONITE ANALYSIS

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BEACON Workshop “Mechanical properties of bentonite barriers”
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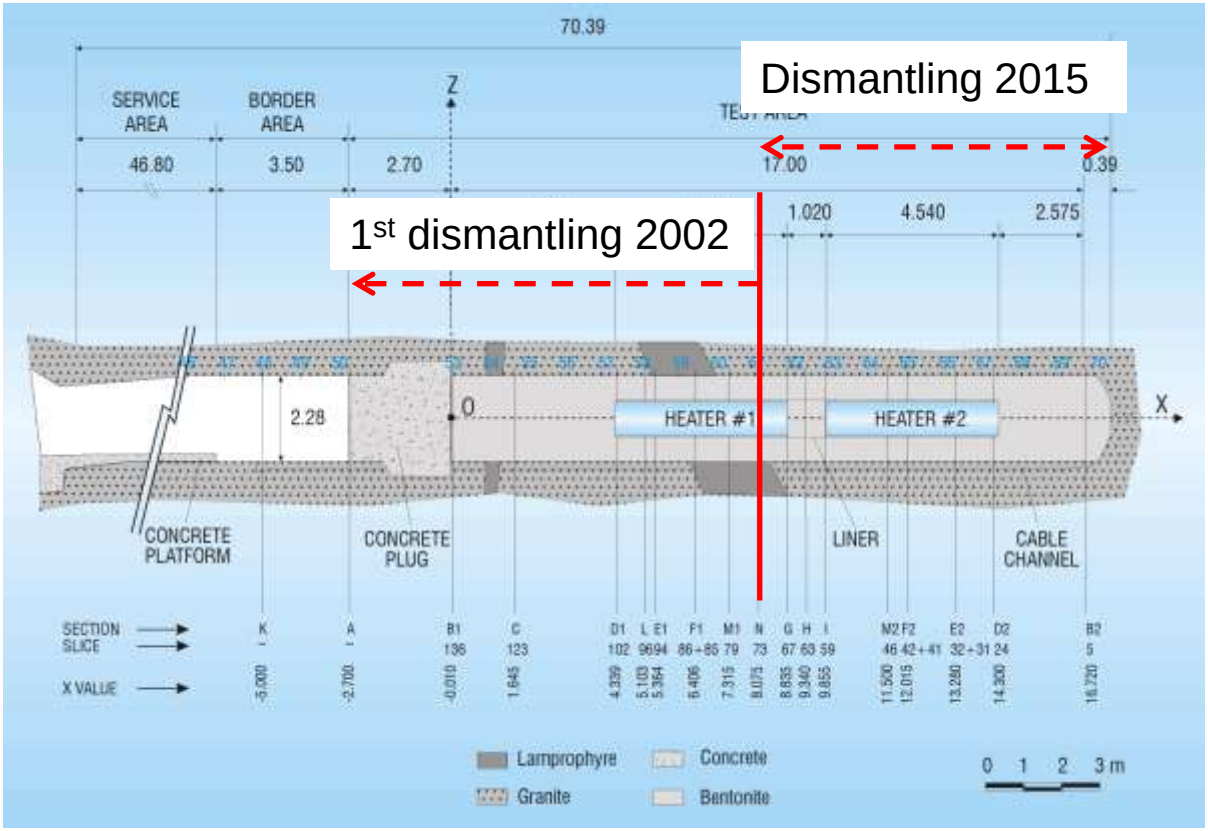
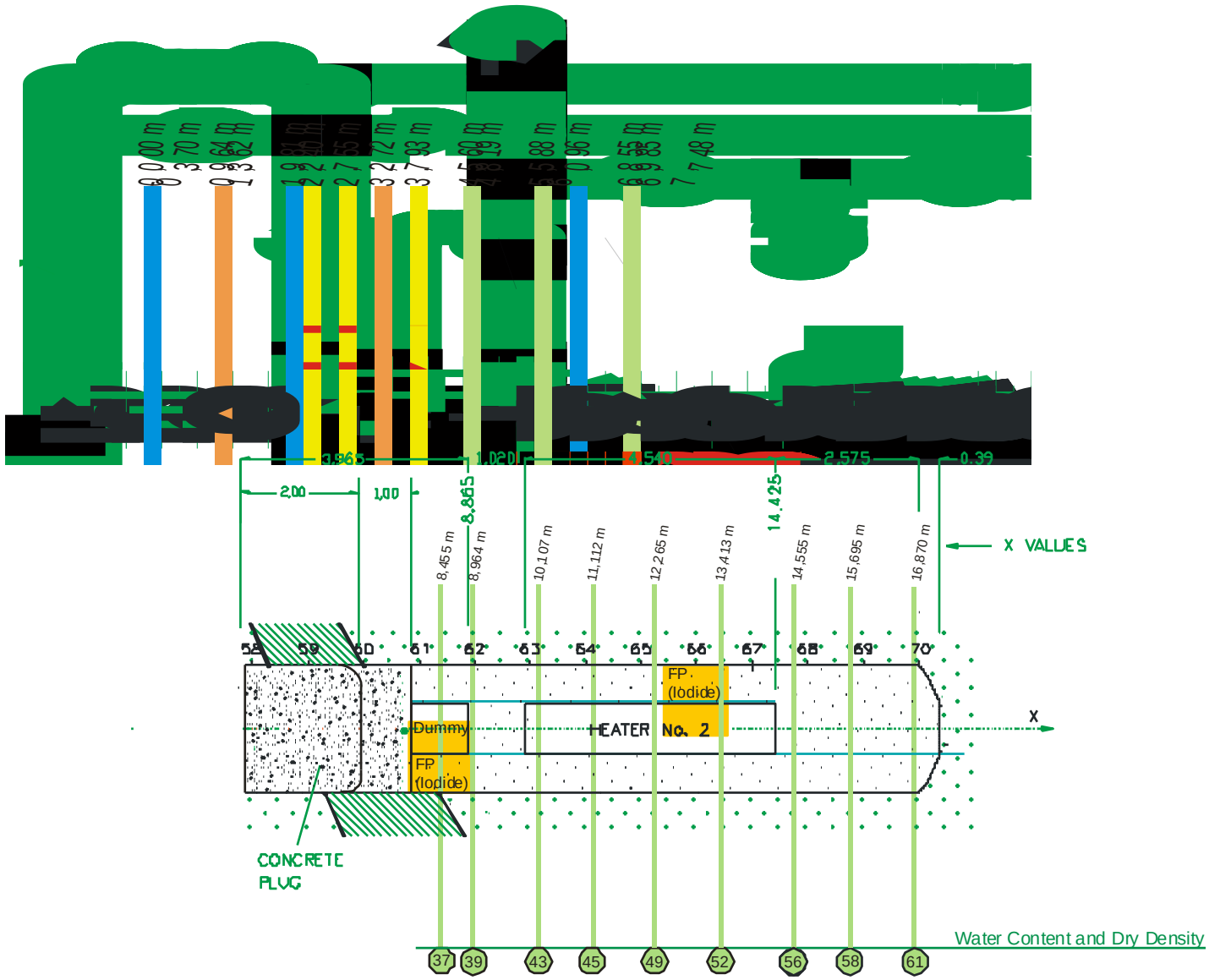
IN SITU TESTS DISMANTLING DATABASES

FEBEX

- Full-scale in situ test at GTS
- Bentonite blocks barrier, natural hydration, two heaters
- In operation since 1997
- Partial dismantling in 2002
- Final complete dismantling in 2015

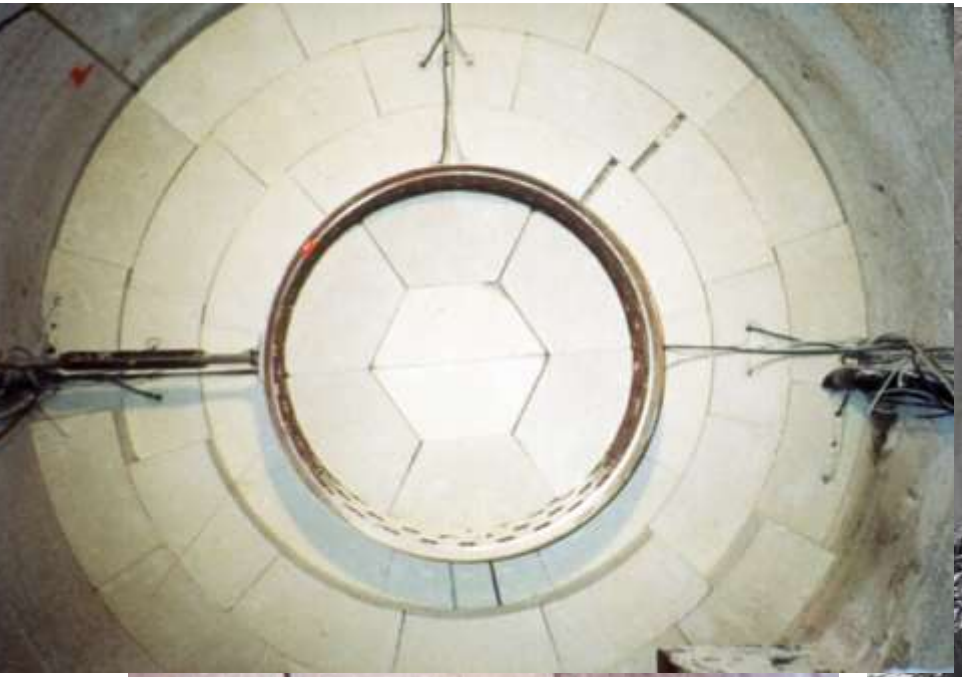


ONSITE DETERMINATION OF WATER CONTENT AND DRY DENSITY



GAP SEALING

1997

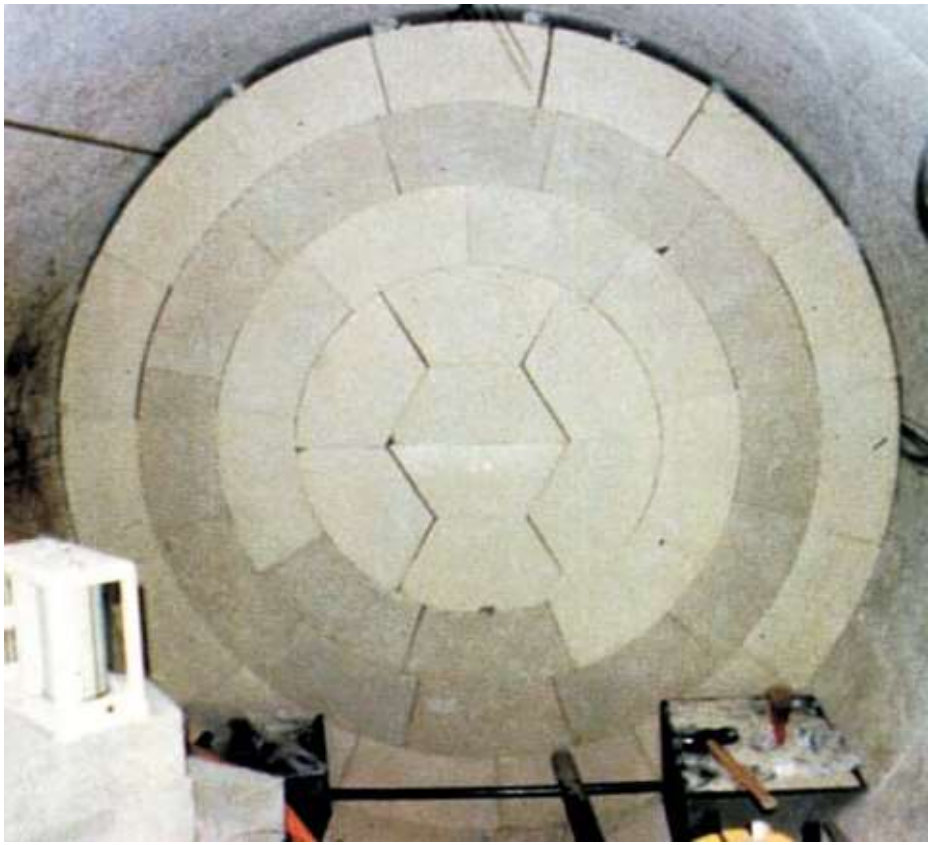


2002

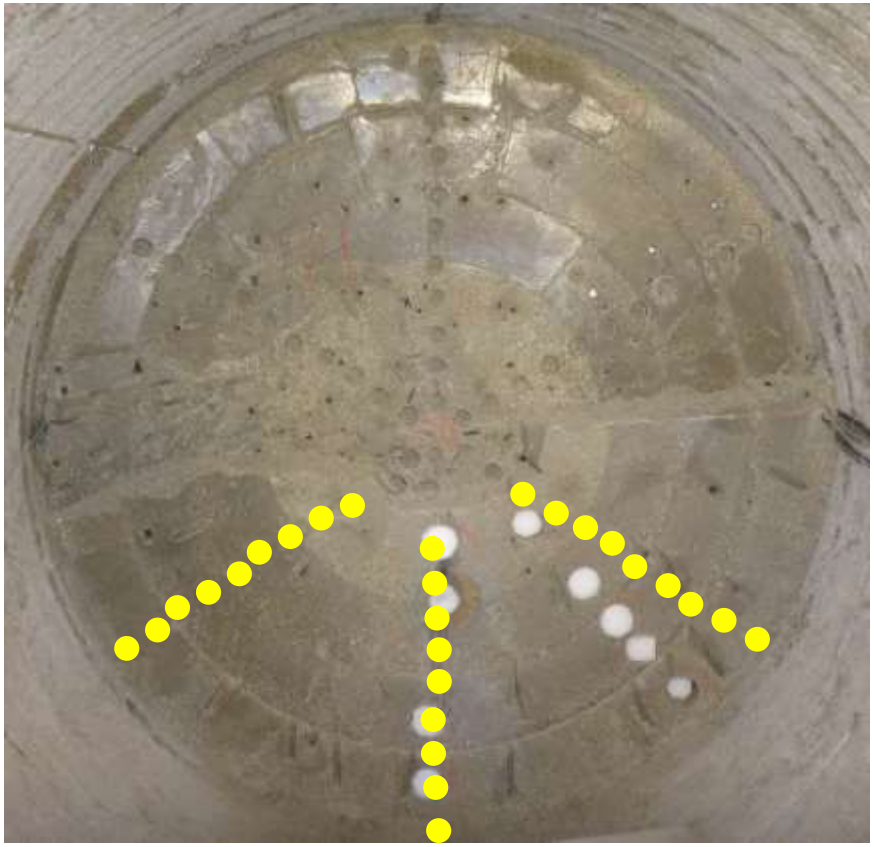
GAP SEALING

The gaps between blocks had dissapeared, as it was already observed in 2002

1997



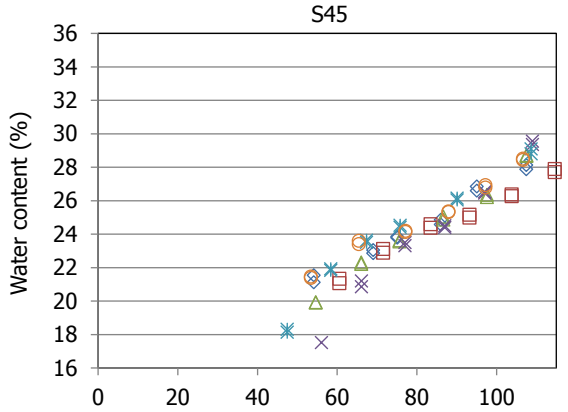
2015

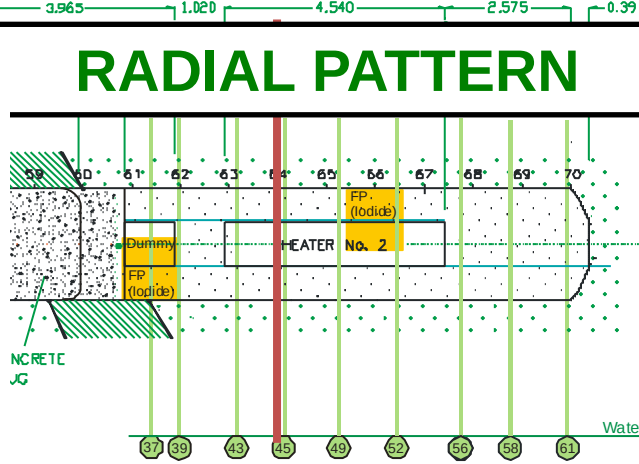


GAP SEALING

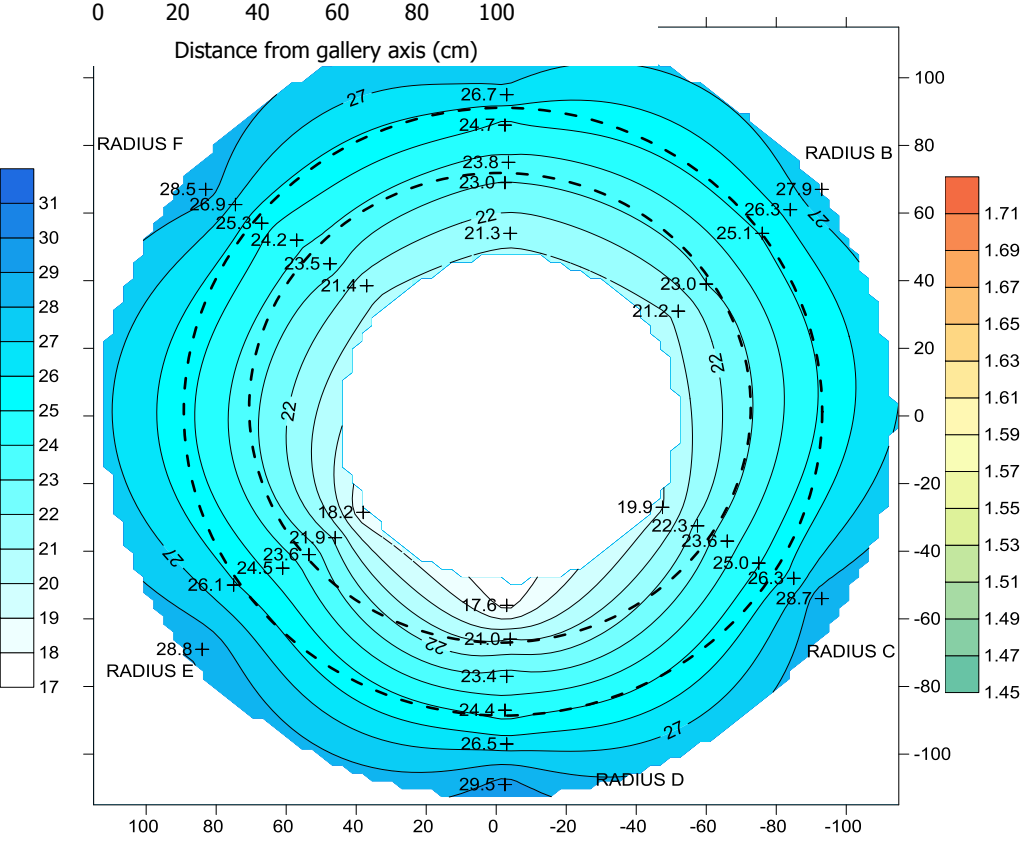
- The gaps between blocks were sealed
- The contact between slices was tight and was not a preferential pathway
- Tight granite/bentonite contact
- This was already observed during first dismantling

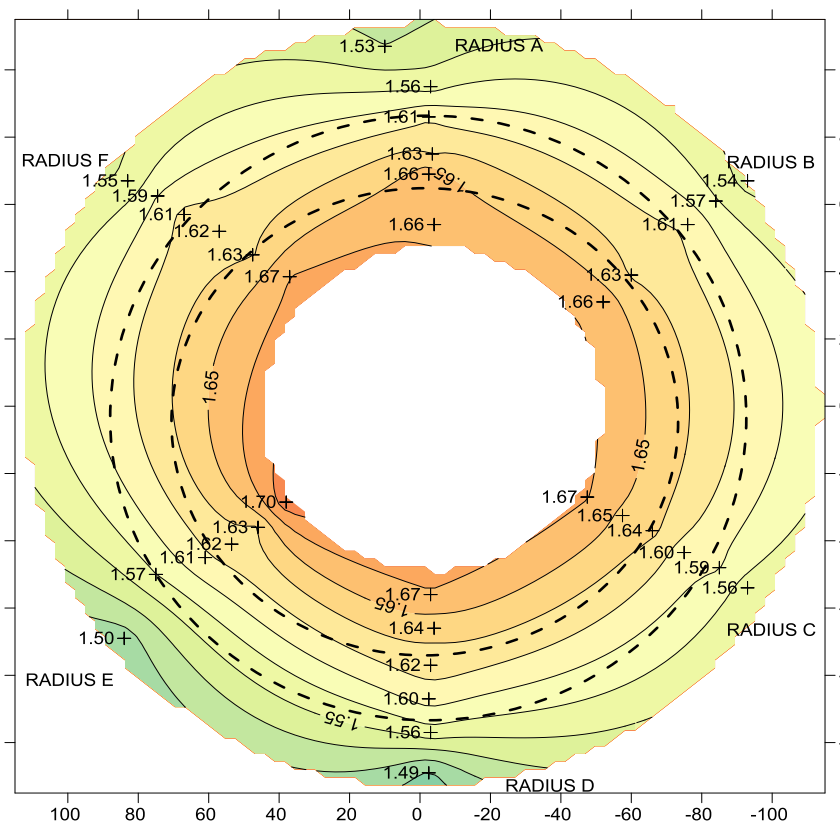
RADIAL PATTERN



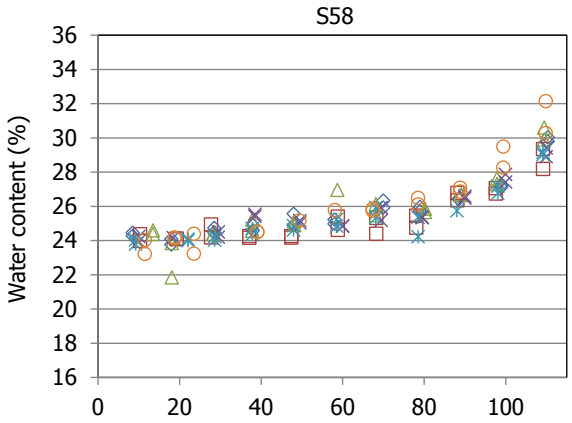


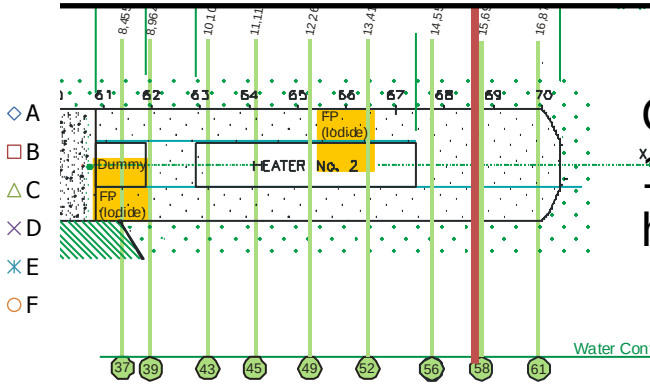
HOT SECTION (S45)
18 years hydration under thermal gradient (92-35°C)
59 days cooling



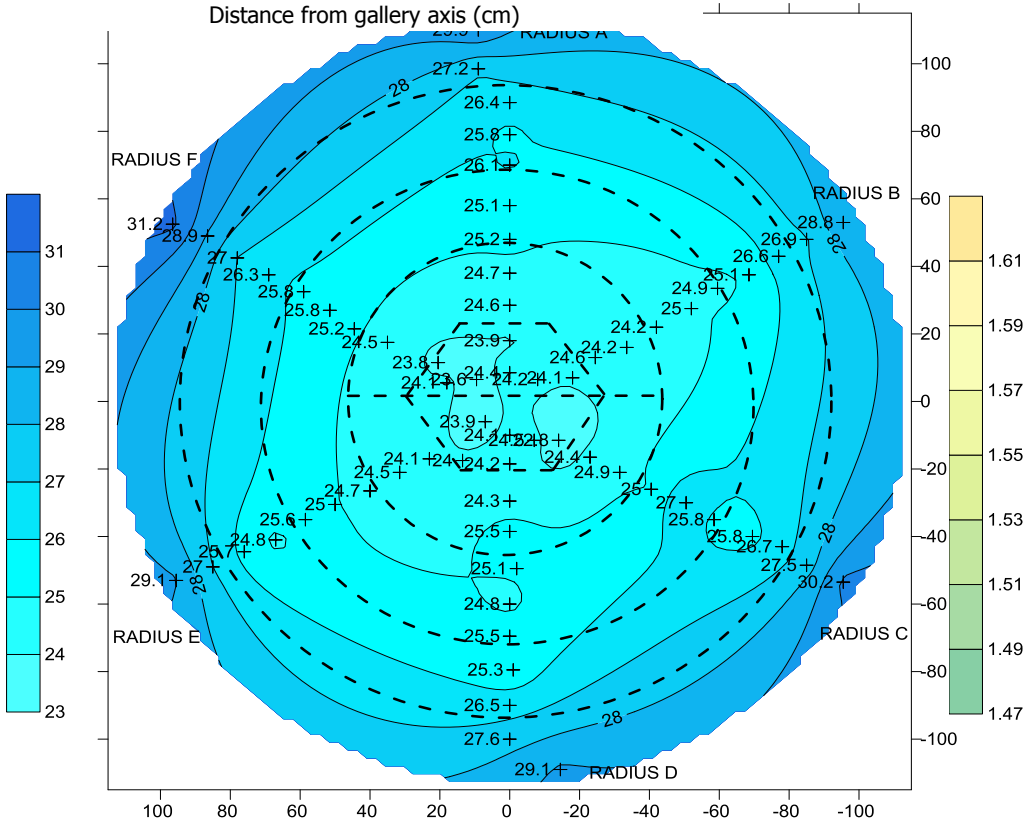


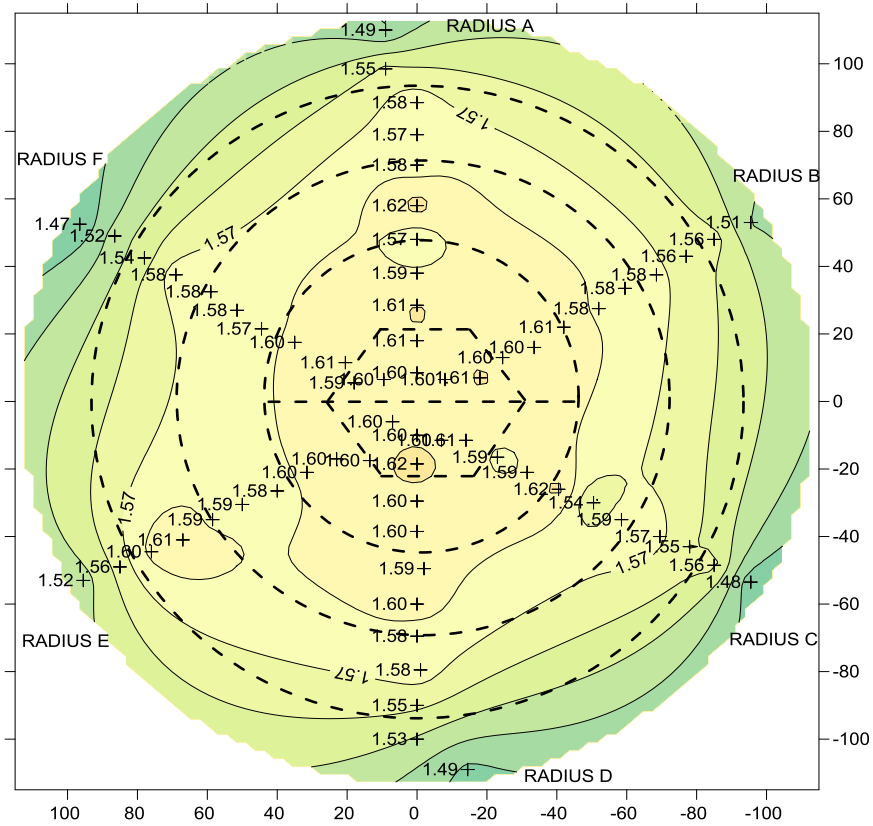
RADIAL PATTERN



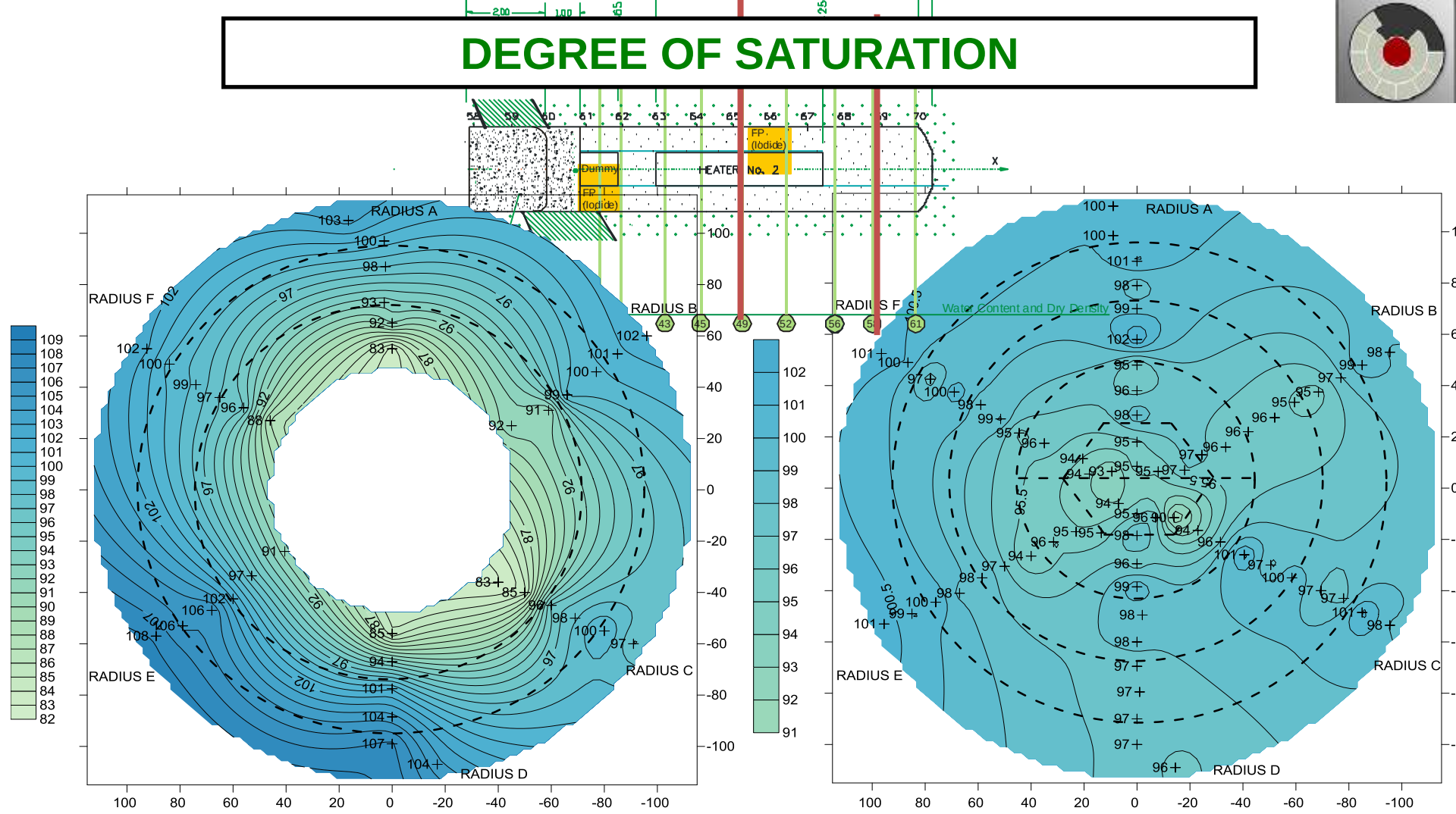


COLD SECTION (S58)
18 years “warm” hydration (>23°C)





DEGREE OF SATURATION

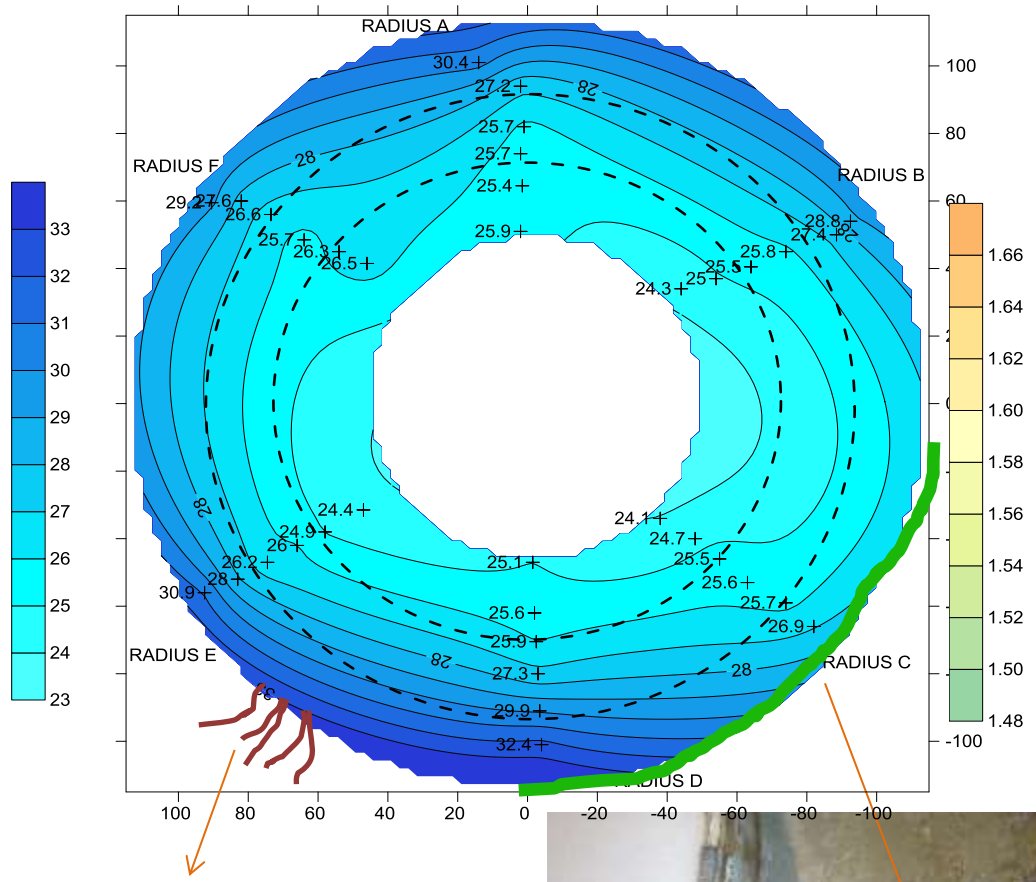


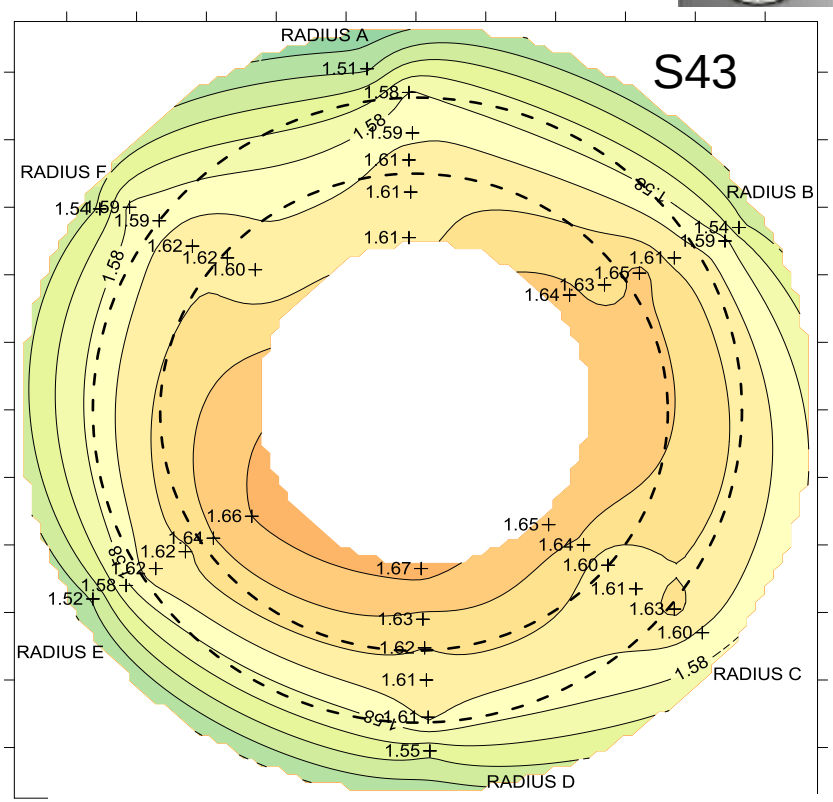
HOT SECTION (S49)

COLD SECTION (S58)

- Following radial pattern around the heater (always >80%)
- Homogeneous and about 100% in cold sections
- >100% in many samples

AXIAL SYMMETRY



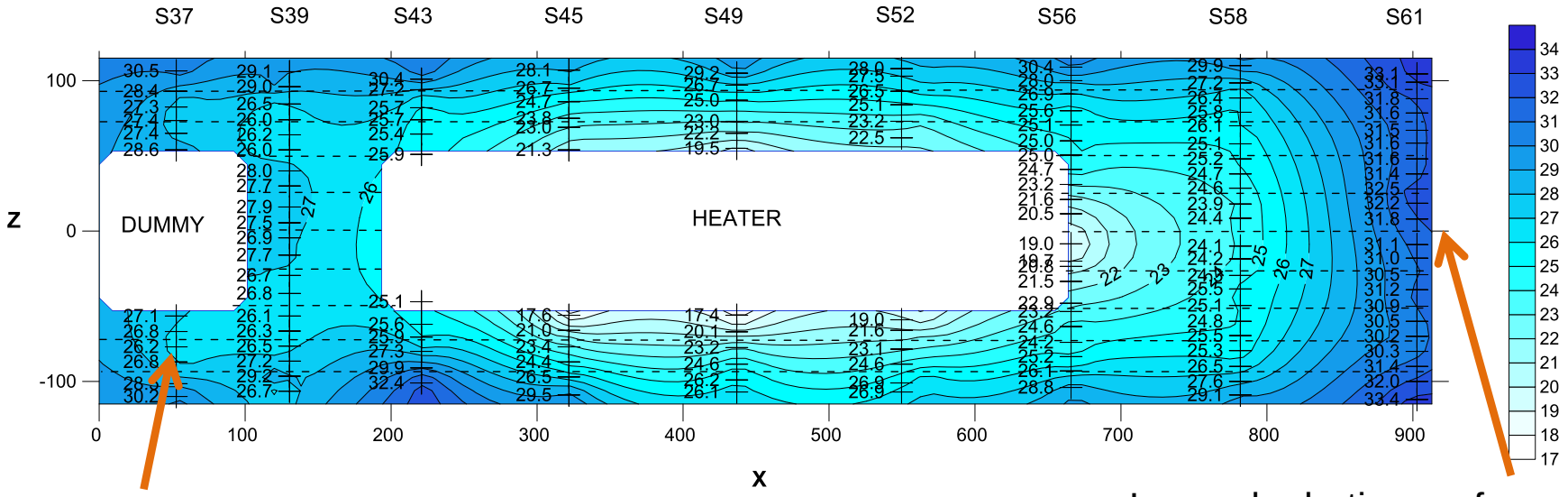


Filled fractures in granite

Lower density in upper part: bentonite intrusion through liner holes

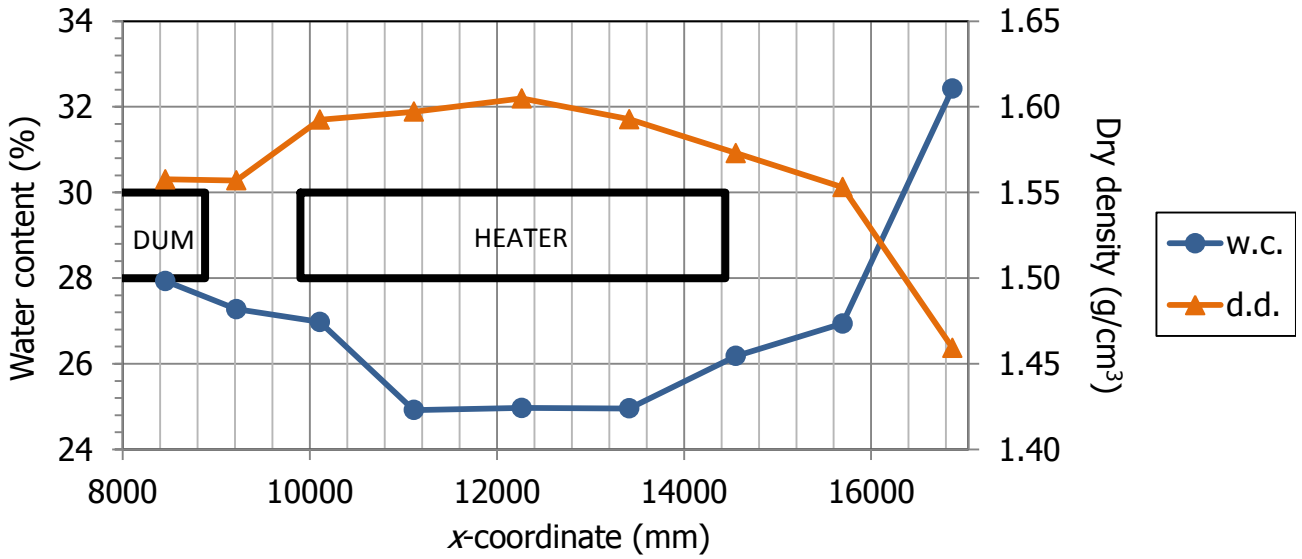
Plastic sheet left behind at the bottom left quarter

LONGITUDINAL DISTRIBUTION: WATER CONTENT

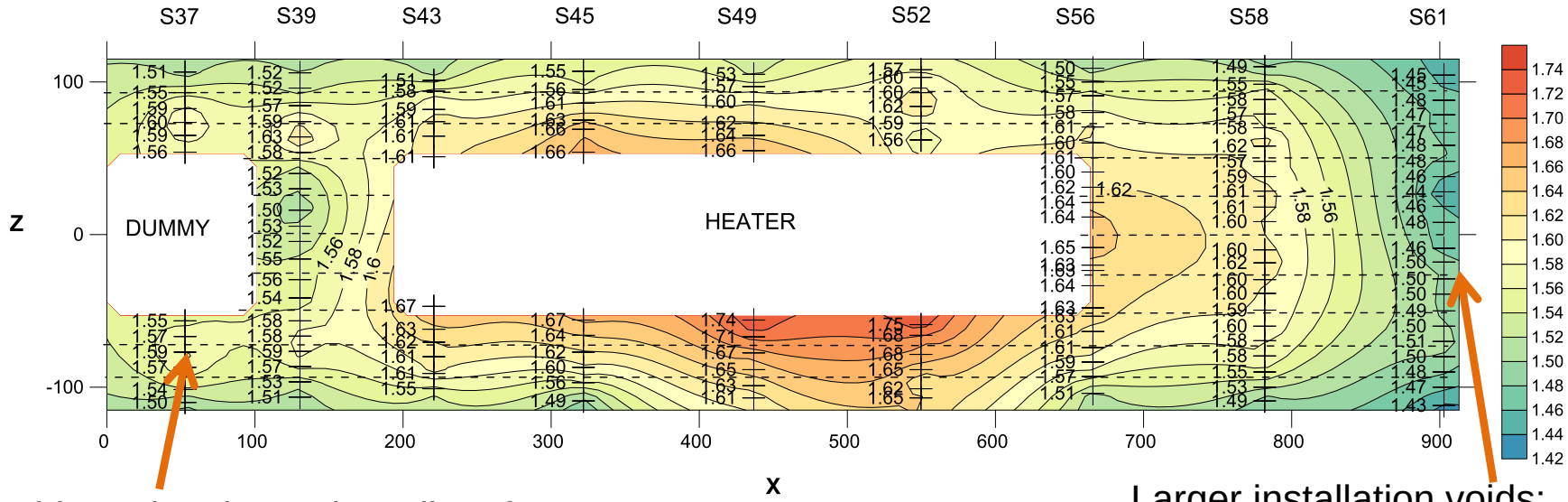


Subjected to thermal gradient for 5 years
Water from concrete?

Larger hydration surface

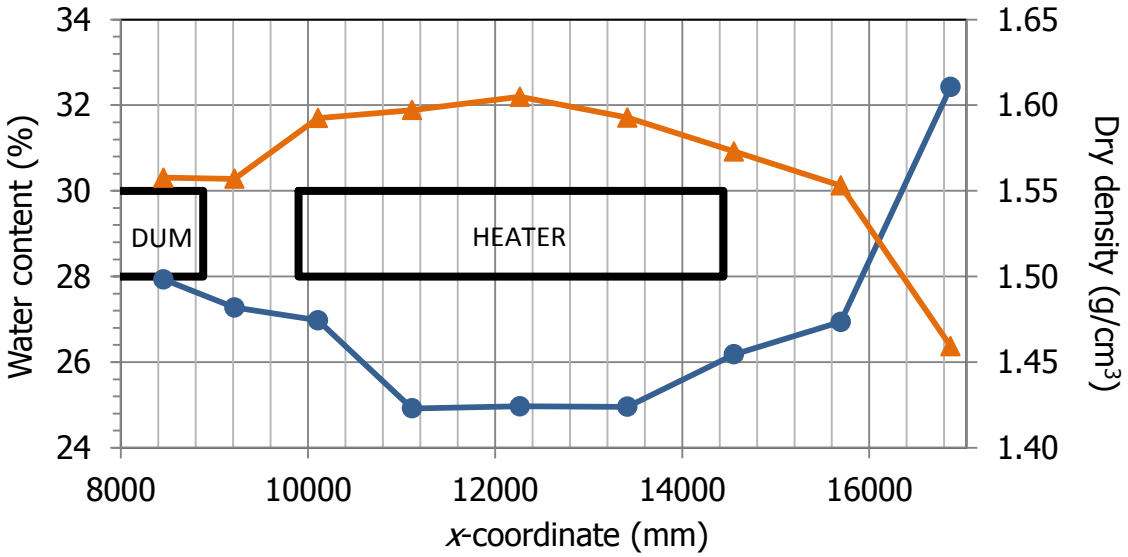


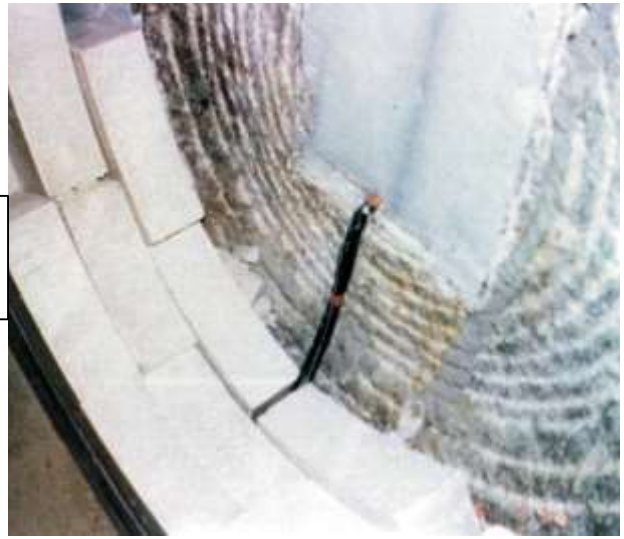
LONGITUDINAL DISTRIBUTION: DRY DENSITY



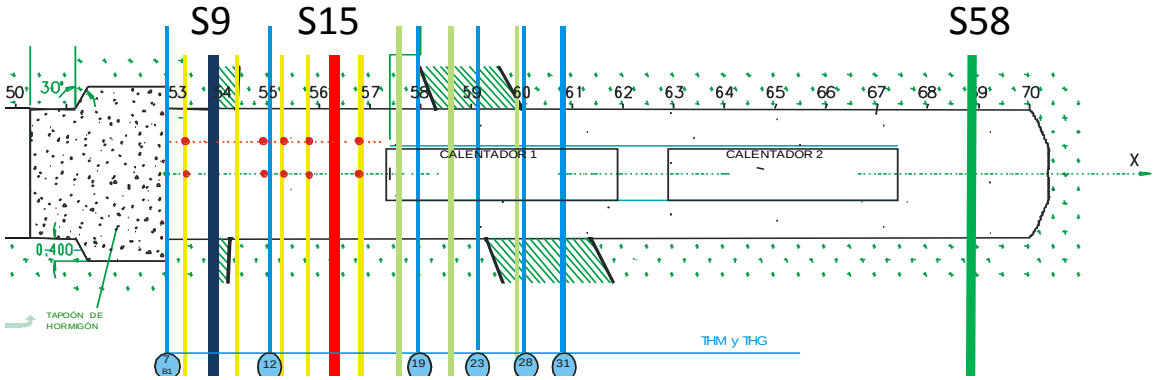
Subjected to thermal gradient for 5 years

Larger installation voids:
37% *vs*. 6%

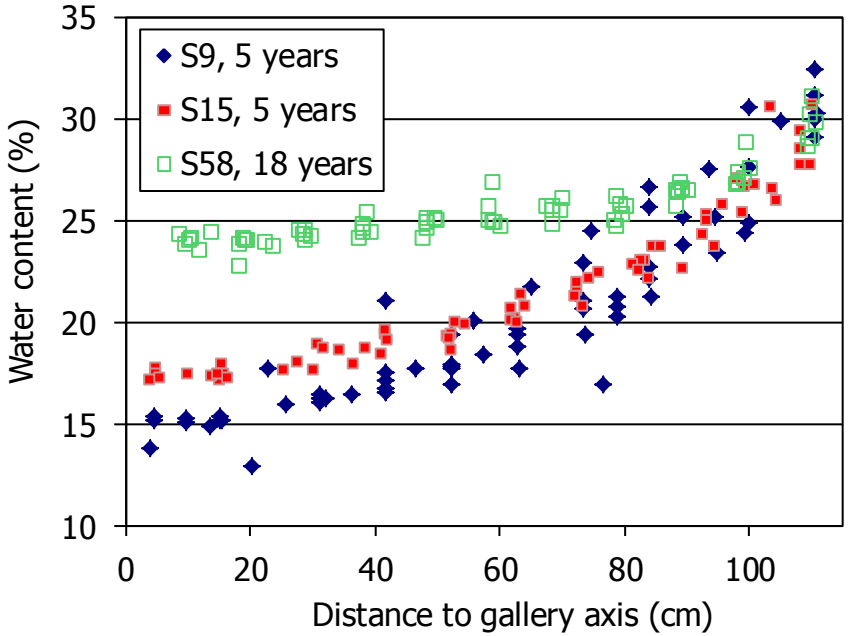




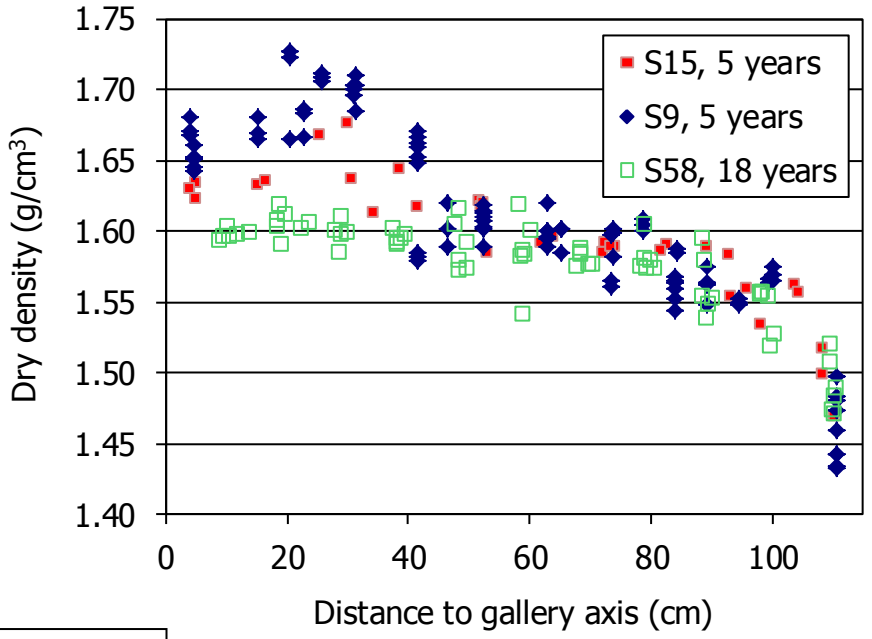
COMPARISON PARTIAL DISMANTLING



COLD SECTIONS



COLD SECTIONS



***w*, %**

S9: 22.9%
S15: 22.8%
S58: 27.1%

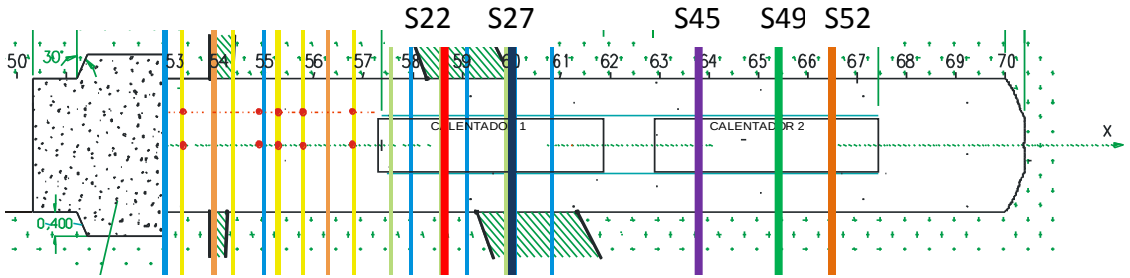
S_r, %

S9: 85%
S15: 86%
S58: 98%

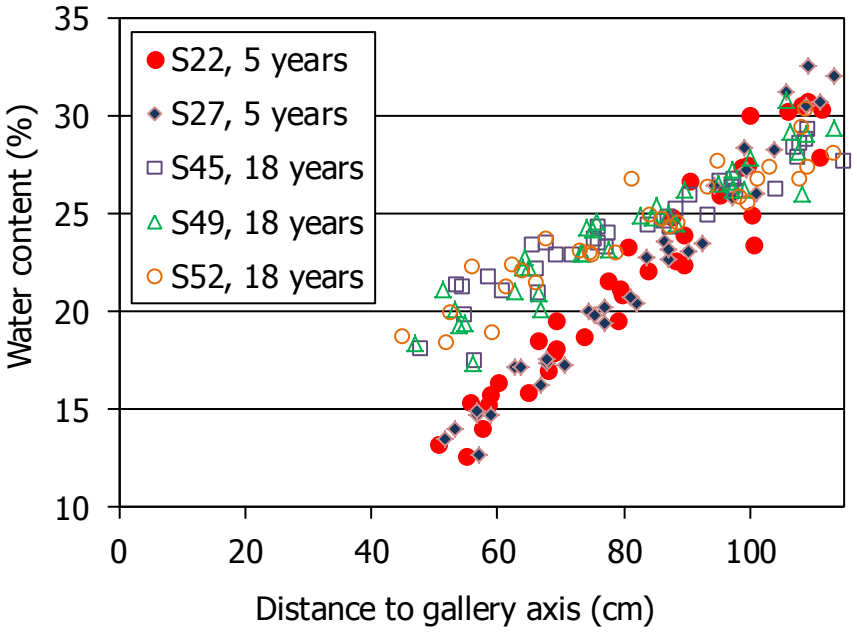
ρ_d, g/cm³

S9: 1.58 g/cm³
S15: 1.58 g/cm³
S58: 1.55 g/cm³

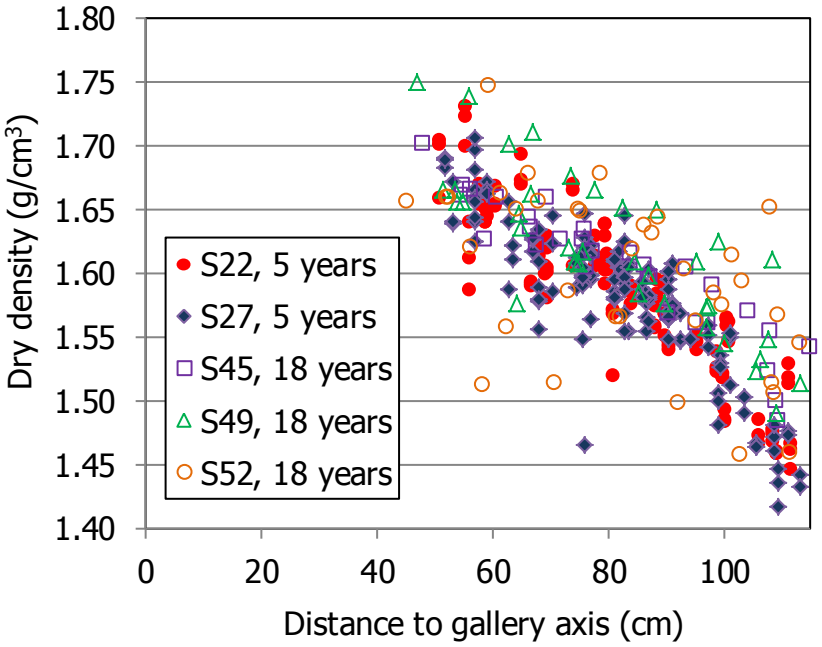
COMPARISON PARTIAL DISMANTLING



HOT SECTIONS



HOT SECTIONS



w, %

S22: 22.6%	S45: 25.7%
S27: 22.6%	S49: 25.9%
	S52: 25.6%

S_r, %

S22: 85%	S45: 98%
S27: 84%	S49: 99%
	S52: 98%

ρ_d, g/cm³

S22: 1.57 g/cm³	S45: 1.59 g/cm³
S27: 1.56 g/cm³	S49: 1.59 g/cm³
	S52: 1.59 g/cm³

SUMMARY OF OBSERVATIONS

✓Sealing capacity develops quickly **if water availability is enough**

✓The thermal gradient delays homogenisation, because it **hinders**(?) saturation

✓The dry density changes take place not only radially but also **longitudinally** along the barrier (effect of the back of the gallery)

✓The state in the external part of the barrier barely changed with respect to the first dismantling: **irreversibility** of initial deformation

✓Low density favours homogenisation (**initial strains** are not too large)

✓Homogeneous water content is not imperative for homogeneous S_r: implications on dry density homogenization

CHANGES DURING DISMANTLING

The state of the barrier just described does not exactly represent the state during operation:

- when the sections were dismantled they had been cooling for periods of time between 24 and 98 days: water redistribution in the internal part of the barrier around the heater ⟹ the gradients were steeper
- dry density decreased because of sampling and trimming (sample preparation). The effect is more significant the higher the water content ⟹ the overall dry density was higher during operation
- expansion of the front of the barrier after plug demolition ⟹ the dry density and degree of saturation of the front sections was higher during operation

UNCERTAINTIES AND FUTURE WORK

- ✓ Role of thermal gradient on homogenisation
- ✓ Scale effect: homogenisation under thermal gradient was observed in small cells. Is the geometry (radial *vs*. axial) also a discriminating factor?
- ✓ Changes in water content and density in the barrier condition the THM properties of bentonite (thermal conductivity, permeability, swelling capacity, water retention capacity)
- ✓ Data base generated in FEBEX and FEBEX-DP very valuable for modellers
- ✓ Detailed study of gas and water permeability in FEBEX-DP samples
- ✓ Detailed study of microstructure (MIP and XRD) in FEBEX-DP samples

The FEBEX project was financed by ENRESA and the EC Contracts FI4W-CT95-006 and FIKWCT-2000-00016

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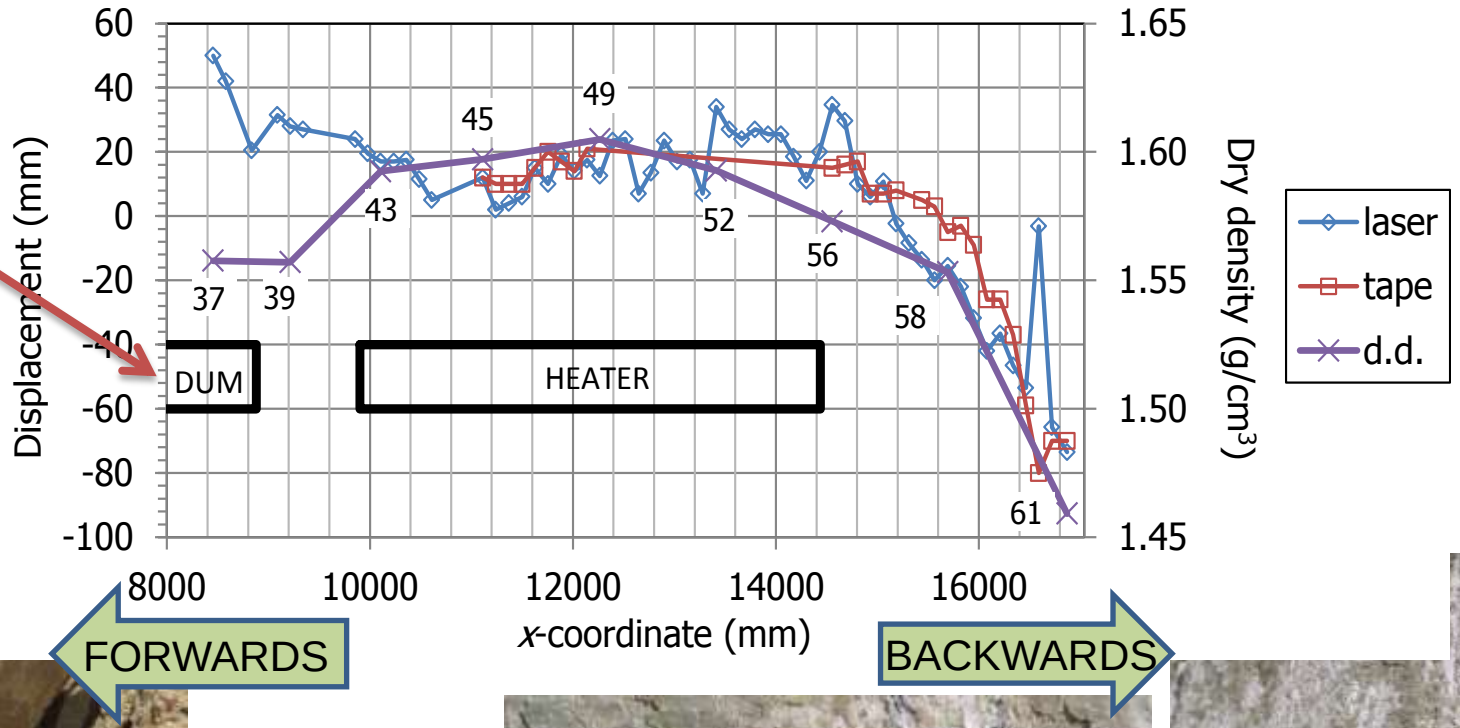
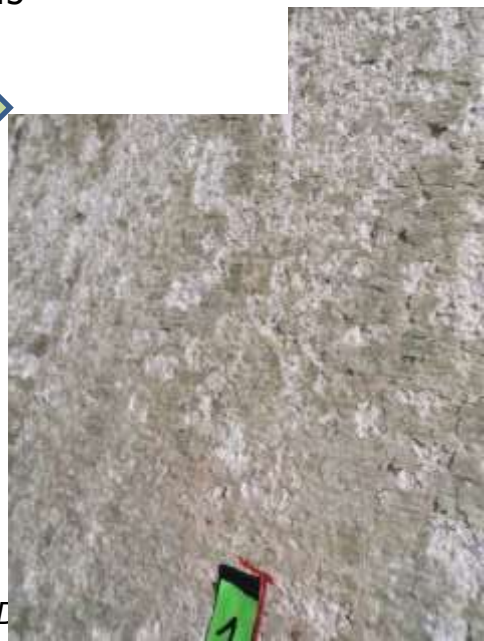
The BEACON project receives funding from the Euratom research and training programme 2014-2018 under grant agreement No 745942

LONGITUDINAL DISPLACEMENT

Measurement of the *x*-coordinate during dismantling: comparison with initial values

Load cell:
6 MPa



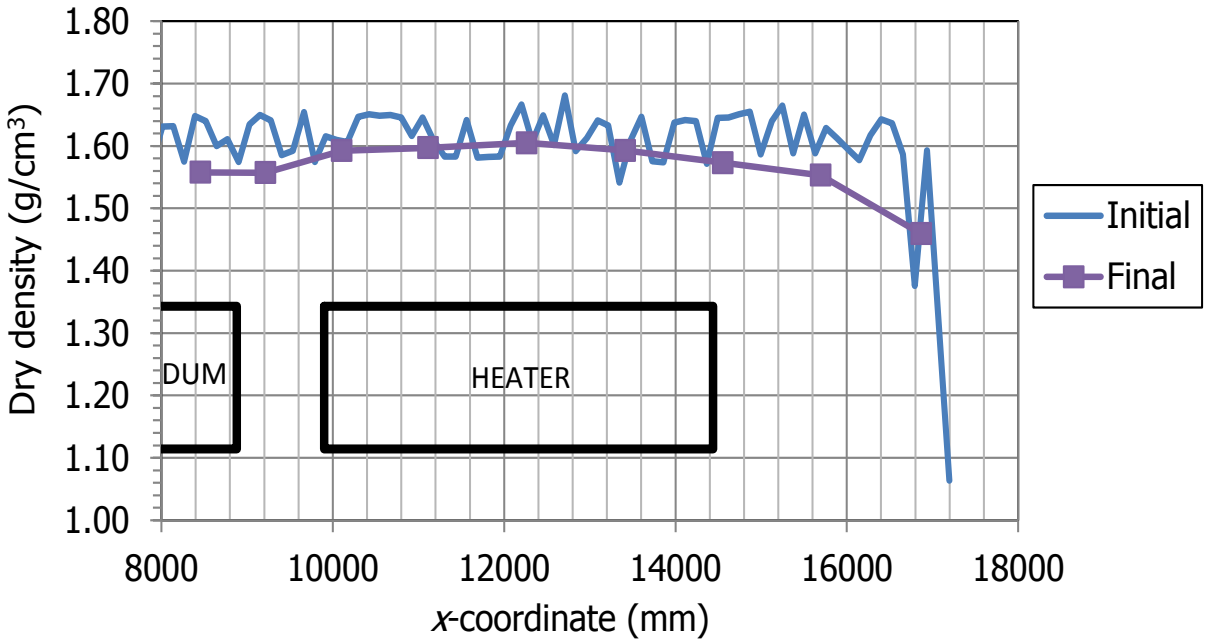


AVERAGE BARRIER VALUES

w (%)	ρ_d (g/cm^3)	S_r (%)
25.5	1.59	97

Installation dry density was 1.61 g/cm^3: this should have not changed during operation (same mass and volume)

This decrease must be a consequence of sampling (expansion, trimming)

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