Long-term Performance of Engineered Barrier Systems
PEBS

Contract (grant agreement) number: ***FP7 249681***

DELIVERABLE (D-N°: D2.3-2.2)

Report on GAME status, 2nd period

&

DELIVERABLE (D-N°: D2.3-5)

GAME data analysis report before dismantling

Author(s):

CIEMAT: P.L. Martín and J.M. Barcala

Date of issue of this report: 01/07/13

Start date of project: 01/03/10 Duration: 48 Months

Project co-funded by the European Commission under the Seventh Euratom Framework Programme for Nuclear Research &Training Activities (2007-2011)		
Dissemination Level		
PU	Public	PU
RE	Restricted to a group specified by the partners of the [PEBS]	
CO	Confidential, only for partners of the [PEBS] project	

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 GENERAL DESCRIPTION AND OBJECTIVES

The Geochemical Advance Mock-up Experiments (GAMES) have been designed to accomplish the following objectives:

- Research on the potential changes that may occur in the key parameters of the buffer material as a result of thermo-hydro-mechanical (THM) and thermo-hydro-geochemical (THG) processes.
- Monitoring geochemical (G) changes by using specific sensors or by sampling, without interference with the system.
- Evaluation of the performance and long-term behaviour of the G monitoring systems.
- By the improvement of the knowledge of the THG(M) processes in the EBS, the GAMES will enable to improve the calibration and validation of the THG(M) numerical models with “on line” GCh information, not a final picture after dismantling

The GAME tests simulate the components of the engineered barriers system (EBS) in accordance with the ENRESA AGP Granite and Clay reference concepts (ENRESA, 1994 and 1995). The tests are installed in the same test room of the THM Mock-up experiment of RTDC 3, at CIEMAT facilities in Madrid, Spain. The building is air-conditioned, so that the temperature is maintained around 22ºC.

The current infrastructure of the tests consist of five basic units, represented in Figure 1-1: the confining structure that includes the surfaces for hydration and heating, the hydration system, the heating control system (HCS); the clay barrier, and the instrumentation (external and internal) with the data acquisition systems (DAS).

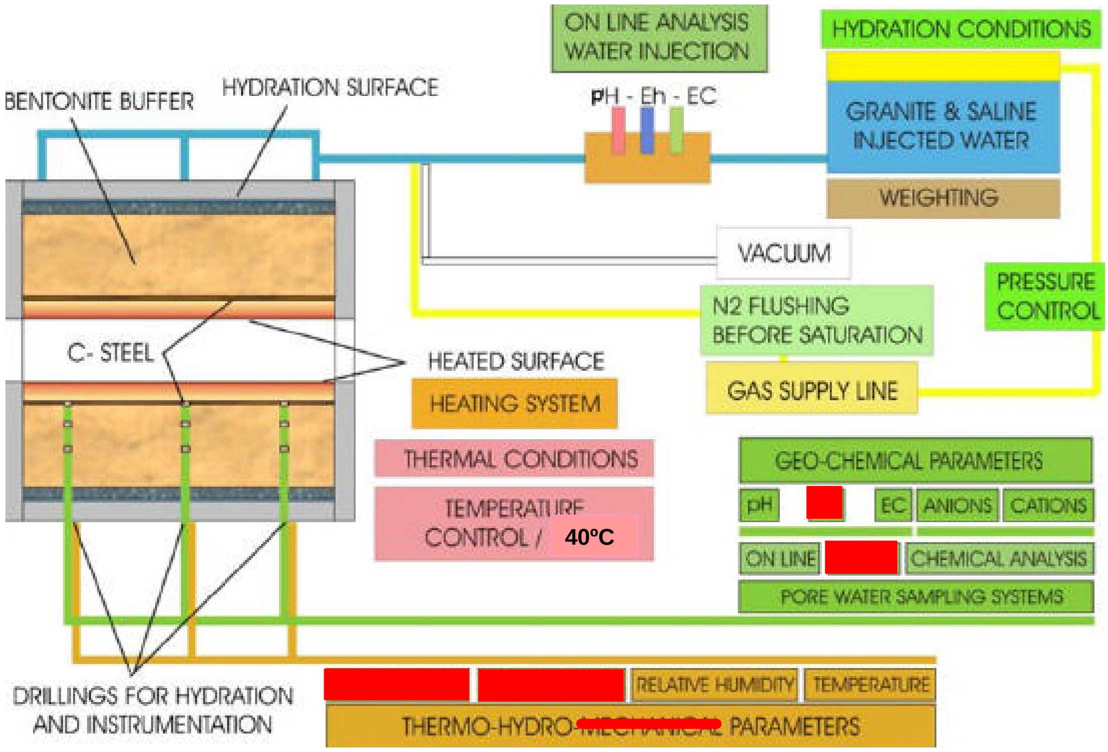

Figure 1-1: General scheme of the GAME test

2 COMPONENTS OF THE TESTS

This section describes the main elements of the experimental setup (Martín & Barcala, 2007 a-b) that have not been changed or modified in a significant way during the operational life of the tests.

However, due to the detected problems in the experimental set-up, several recommendations were indicated at the end of the NF-PRO project (Martín & Barcala, 2007-c; Turrero et al, 2007). Following these recommendations, geochemical sensors and the insertion system in the measuring chambers were eliminated and the others setup modifications adopted (as resumed in D23-2, 2010).

2.1 Confining structure

Two concentric cylindrical bodies, closed with two annular covers, compose the confining structure, completely made of SS316L. The whole set was placed on a mobile metallic bed.

The external cylinder of the confining structure is perforated in 29 points: 5 large-diameter I/Os for insertion of the instrumentation rods, 6 medium-diameter I/Os for the exit of sensor cables, and 18 small-diameter I/Os for water injection (Figure 2-1)

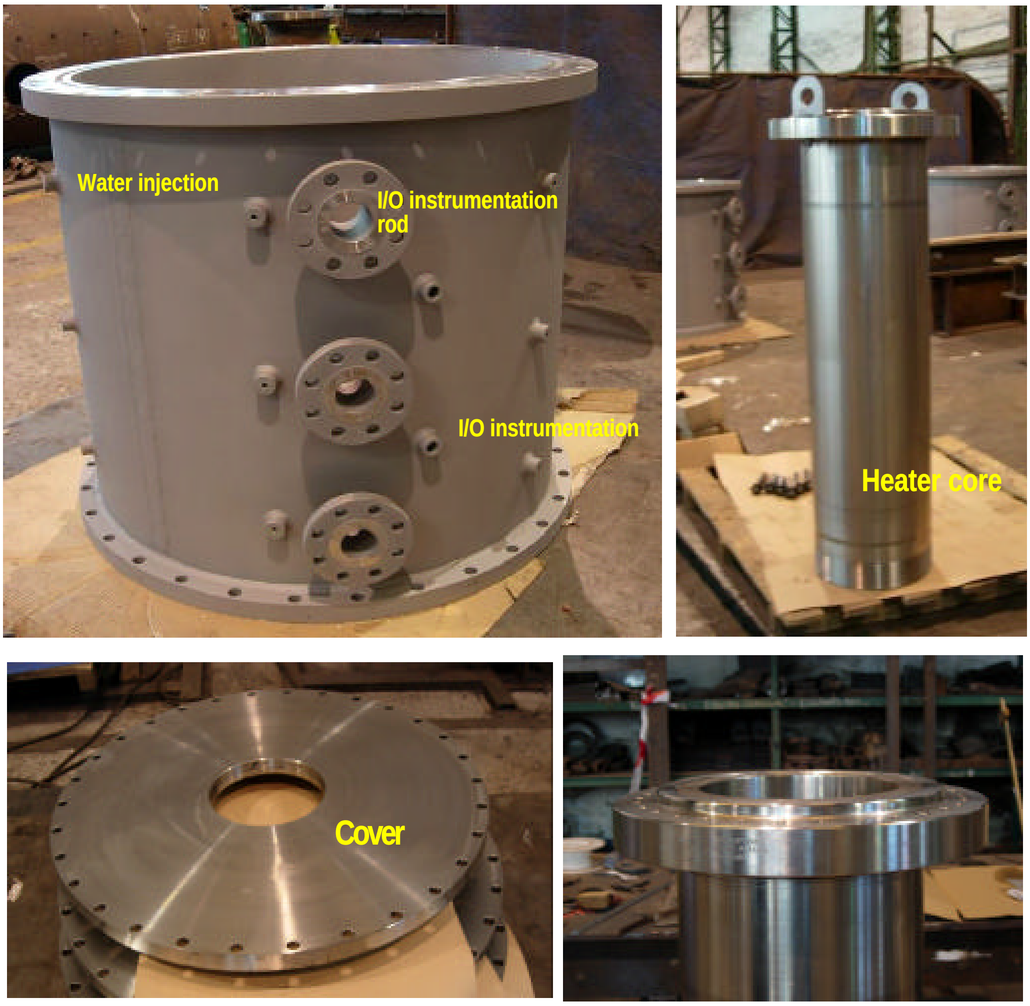

Figure 2-1: Main parts of the structure: external cylinder, heater core,annular cover and heater flange.

The inner cylinder blocks the strains of the annular covers under pressure and provides the heating surface of the experiment. In each end cover there is an exit for the power and temperature sensor cables from the heaters.

The main characteristics of the confining structure are as follows:

Inner diameter	0.94m
Inner length	1.00 m
Wall thickness	0.05 m
Design pressure	5 MPa
Total empty mass (estimated)	5280 kg

2.2 Hydration system

The basic elements of the system are as follows:

Nitrogen line under 2.0 MPa pressure

OLAER AAV300-25 Hydro-pneumatic accumulator vessels, with the following characteristics:

Material	Carbon steel
Height	1.475 m
Diameter	0.63 m
Working pressure	2.5 MPa
Test pressure	3.7 MPa
Internal volume (estimated)	0.3 m^3
Total empty mass (estimated)	202 kg

Weighting system for measurements

Network of pipes to the confining structure

Filters and geotextile for the protection of the water injection points (nozzles).

Geotextile lines the interior surface of the confining structure. The purpose of the geotextile lining is to homogenize the water supply around the periphery of the barrier.

The system consists of a tank with a total capacity of approximately 0.3 m^3 that supplies water through a network of pipes joined to the 18 water injection nozzles in the confining structure. The hydration water is pressurized through N2 gas, at a constant and controlled pressure. Each tank is supported on three metallic legs, where three load cells let us weight the loss of mass, which corresponds to the injected water. (Figure 2-2). Using the values from the weighting system and the nitrogen pressure of the hydration tanks, the injected water mass is determined and registered in the DAS.

The parts of the system in contact with the water are of stainless steel, AISI 316, or elastomer. The internal surface of the confining structure is covered with two layers of geotextile TERRAM 4000 (from Exxon) that compose a homogeneous surface of hydration for the barrier.

Figure 2-2: Hydration system: accumulator vessel and detail of the load cells.

2.3 Heating system

The system consists of a cylindrical heater and corresponding Heater monitoring and Control Systems (HCS). The heater is the central part of the internal cylinder of the structure (1.0 m long and 0.3 m in diameter) and it is in direct contact with the bentonite. It has been divided in eight heating zones that can be controlled independently. Each heating zone is heated with four flexible electrical flat resistors. The total power supply installed is about 2000 W.

To protect the heater core surface from induced corrosion during the experiment time, a SS316L mesh was installed around it. The mesh also enhances the corrosion of the tested carbon steel materials (Figure 2-3).

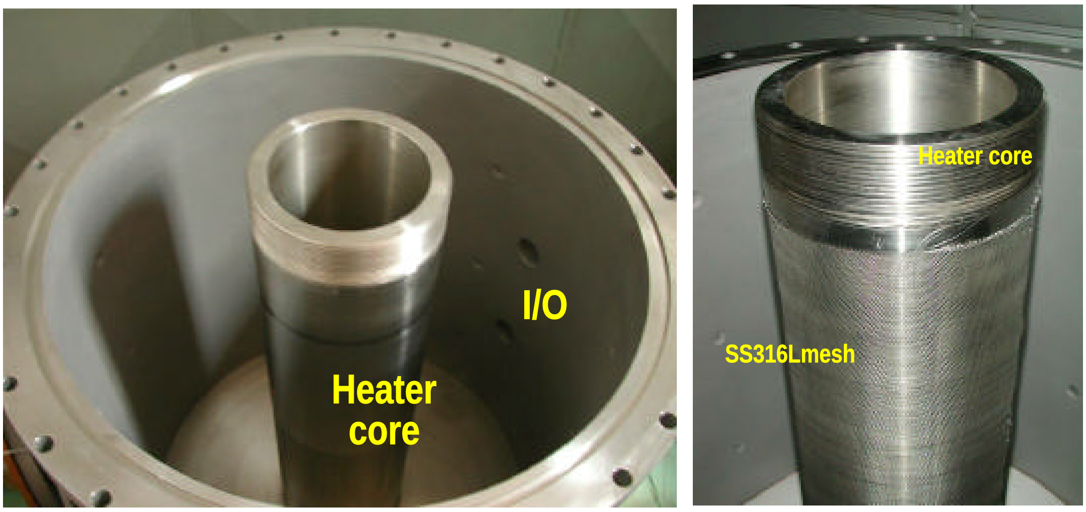

Figure 2-3: Heaters core and SS316L mesh.

The HCS is based on a closed loop control with a WEST MLC9000+ Controller that regulates the power supply by means of solid state relays. The four resistors of each zone are controlled as a set.

2.4 Instrumentation

The main components of the system (hydration system, heating system and clay barrier) were instrumented with the appropriate sensors.

The clay barrier of each test was instrumented by five instrumentation rods that include three levels of SS316L filters to sample water, connected to chambers with RH and temperature transmitters. The measurement chambers contain the new supports for the RH-T transmitters and for the water sampling ports.

The items to coding the sensors are the type of variable and the location in the experiment. A distinction was made between three main groups of sensors: in the clay barrier, in the heaters, and outside the confining structure.

Sensors in the clay barrier

Most of the sensors are in the barrier, grouped in five instrumentation rods—initially 3 in the top of the structure and 2 in the bottom, then rotated 90º.

The sensor coding used in the clay barrier is indicated below. Each installed sensor is identified by an alphanumeric code of the following type: **S# XX_Y_#**

#: 1 for the bentonite experiment; 2 for the bentonite+concrete experiment.

XX Variable—T (temperature) and HR (relative humidity).

Y: Designation of the rod—A, B, C, D and E

#: Numbering of instrumented level as installed in each rod—from 0 to 2, increasing with the radial distance from the hydration surface.

Temperature sensors on the heaters

These sensors are located on the inner surface of the heater, in the central area of its heating zone, and are numbered from 1 to 8. These sensors do not follow the general coding rule; they are identified by the following alphanumeric code: **T WX_#**

X: 1 for the bentonite experiment; 2 for the bentonite+concrete experiment.

T W1: Temperature point on the heater from West controller

#: Numbering of order of installation on the heater, from 1 to 9

Sensors, instruments, and measurements outside the confining structure

These sensors include all those not dealt with above, such as for example those measuring in the hydration system— weight of the tanks. The calculated values (injected volume of water, average control temperature, and supplied power) are included in this group. No coding system is used for these values but description tags.

Position of the sensors

The sensors are located in the structure following the scheme below.

<table>
<tr><td colspan="8">ROD A</td><td colspan="8"></td><td colspan="8">ROD B</td><td colspan="8"></td><td colspan="8">ROD C</td></tr>
<tr><td colspan="8">S# A0
S# A1
S# A2</td><td colspan="8"></td><td colspan="8">S# B0
S# B1
S# B2</td><td colspan="8"></td><td colspan="8">S# C0
S# C1
S# C2</td></tr>
<tr><td colspan="5">T_W2_1</td><td colspan="5">T_W2_2</td><td colspan="5">T_W2_3</td><td colspan="5">T_W2_4</td><td colspan="5">T_W2_5</td><td colspan="5">T_W2_6</td><td colspan="5">T_W2_7</td><td colspan="5">T_W2_8</td></tr>
<tr><td colspan="8"></td><td colspan="8">S# D2
S# D1
S# D0</td><td colspan="8"></td><td colspan="8">S# E2
S# E1
S# E0</td><td colspan="8"></td></tr>
<tr><td colspan="8"></td><td colspan="8">ROD D</td><td colspan="8"></td><td colspan="8">ROD E</td><td colspan="8"></td></tr>
</table>

The positions of the sensors taking as origin the centre of symmetry of the heater are described in Table 2.1.

Table 2.1: Average coordinates of instrumentation levels

Level	X (m)	Y (m)	Distance to heater (m)
A0	-0,30	0,395	0,245
A1	-0,30	0,315	0,165
A2	-0,30	0,225	0,075
B0	0,00	0,405	0,255
B1	0,00	0,295	0,145
B2	0,00	0,205	0,055
C0	0,30	0,425	0,275
C1	0,30	0,335	0,185
C2	0,30	0,245	0,095
D0	-0,15	0,445	0,295
D1	-0,15	0,355	0,205
D2	-0,15	0,265	0,115
E0	0,15	0,465	0,315
E1	0,15	0,375	0,225
E2	0,15	0,285	0,135

2.5 Data acquisition system (DAS)

It includes all the components, as well as the software necessary to autonomously supervise, register and store on a disk the set of data obtained from the test. It provides conversion of the analogue signals from the transducers into numerical data and performs data conversion and analysis, data display and storage on disk over the long time period (years) that data are being acquired.

The central control of the DAS consists of a PC. The DAS PC is connected simultaneously to the Sensirion EK-H3 multiplexer and to the MLC9000+ controller of the HCS to obtain and register information from the heater.

An OPC client managed under LabView DSC (generic commercial client-server SCADA system) gets data from the digital transmitters (relative humidity and temperature, SENSIRION, 2005a-c) read on a serial specific multiplexer, and from the Ethernet 8-loops MLC900+ controller (Danaher Controls, 2004) that manages the heating process.

The data are stored in ACCESS files generated by the SCADA application, with a frequency selected by the user. The program has its own internal database.

The DAS PC functions independently of the HCS, although it is connected to a local network to allow for maintenance and file transfer operations.

At beginning 2013, the memory of the Pc has been substituted due to some hardware errors detected during the last year, which produced some lags in the database without shooting the alarms in the system.

2.6 Barrier materials: clay and concrete

In both experiments, the clay barrier was constructed with highly compacted bentonite blocks. The same bentonite was used throughout the FEBEX project, so its THM-G properties are widely described elsewhere (ENRESA, 2006). This final value of the dry density, around 1.6 g/cm^3, corresponds to the design criterion of the ENRESA's reference concepts: AGP Granito and AGP Arcilla (ENRESA 1994, 1995). The water content of the blocks is the hygroscopic for the raw bentonite, from 13.6% to 14.4%.

Concrete for test S2 is a mixture of sulphate resistant Portland cement (type CEM I-42.5R) and aggregates of quartz sand. The sand/cement ratio is 3:1. The cement/water ratio is 0.6.

2.6.1 Test S1: clay

Figure 2-4 shows the geometry of the barrier in a section: the external diameter is 0.93m and the internal one is 0.31 m. This geometry is made with two blocks of bentonite: type A (internal ring) and B (external ring).

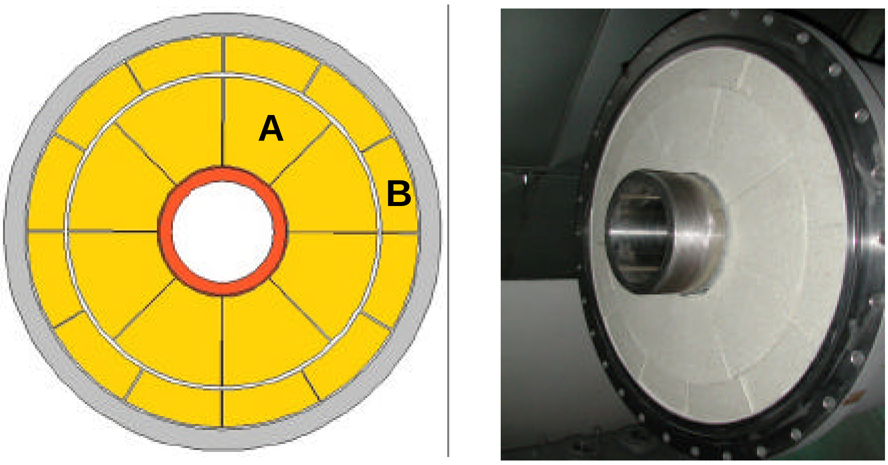

Figure 2-4: Geometry of the clay barrier in test S1: end section

About 1105 kg of bentonite were compacted to manufacture 365 blocks. The average weighted values of the water content and dry density of the installed bentonite were 14.4% and 1.59 g/cm^3, respectively.

Table 2.2 shows the average characteristics and the number of blocks installed in the external and internal ring with the average dry density after expansion of bentonite.

Table 2.2: Average values of the physical properties and number of blocks installed

Type of block	A	B
Weight (kg)	6.080	2.680
Water content (%)	14.4	14.4
Dry density (g/cm^3)	1.56	1.62
Number of installed units	102	156
Total weight (kg)	666	437

This hydration water is Grimsel groundwater (received on 19th December 2005 at CIEMAT) from borehole BO – ADUS, close to the Migration shear zone). The pH value is measured on line.

2.6.2 Test S2: clay and concrete

Figure 2-5 shows the geometry of the barrier in a section: the external diameter of the bentonite is 0.47m and the internal one is 0.31m. This geometry is made with blocks of bentonite, type A, in the inner ring and blocks of concrete, type B.

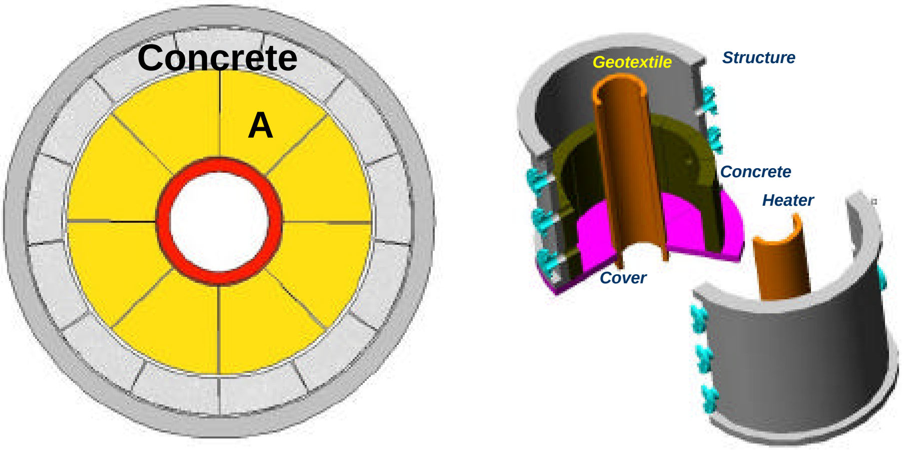

Figure 2-5: Geometry of the clay-concrete barrier in test S2

About 650 kg of bentonite were compacted to manufacture 104 blocks. The average weighted values of the water content and dry density of the installed bentonite barrier were 13.75% and 1.57 g/cm^3, respectively.

Table 2.3shows the average values of the characteristics of blocks.

Table 2.3: Average values of the physical properties and number of blocks installed

Type of block	A
Weight (kg)	6.239
Water content (%)	14.4 / 13.6
Dry density (g/cm^3)	1.60
Number of installed units	104
Total weight (kg)	649

Thirteen concrete blocks (9 cm thickness) that cover completely the geotextile surface compose a half of the length of the concrete ring. Small gaps between blocks permit a faster hydration of the barrier and the expansion of clay through them (Figure 2-5). The total mass of concrete in the experiment is 519 kg.

This hydration water in this test is a synthetic RAF water (water from a reference clay formation) made at CIEMAT laboratories. It has a pH of 7.95 and an electrical conductivity of 12.21 mS/cm (measured on line)

3 OPERATION AND RESULTS

The previous data from NF-PRO phase of the tests were shown in the deliverable D231. The following description contains only figures from PEBS phase from March 10' to June 13'. The figures correspond to the data from the zero reference time (March 1st 10' at 12:00 hours).

3.1 Hydration

The structures were tested to be gastight (by injection of nitrogen at 0.15 MPa) and the piping networks to be watertight (by pressurising the system with nitrogen at 1.0 MPa). Then the injection of water began. A first injection was made to flood the barrier system and prevent the formation of preferential pathways of hydration between blocks by the swelling of the bentonite.

Test S1

From this time up to the beginning of the PEBS project a total amount of 99.6 kg of water was injected in the test. This value is our zero mass reference at 23/02/10 (day -7; Figure 3-1).

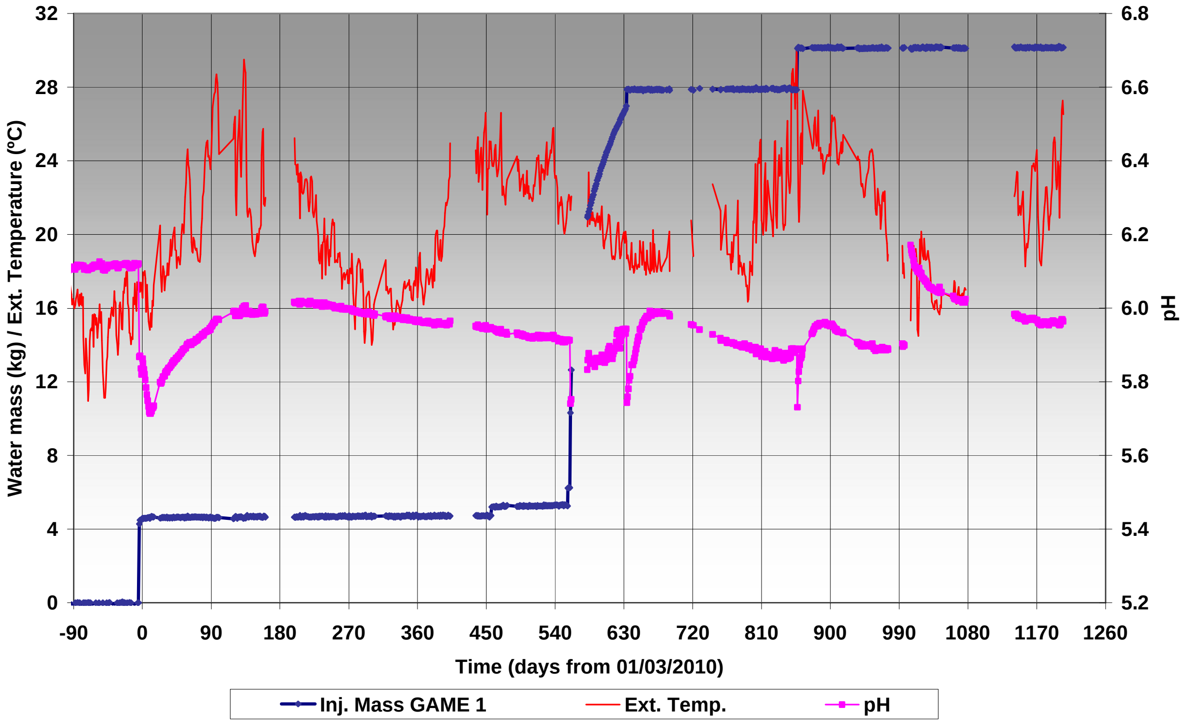

Figure 3-1: Test S1 hydration: injected water, pH and temperature.

At this time, a first injection of water was made before any modification in the system, but new leakages were observed. Hydration was stopped after injecting 4.64 kg.

After the major modifications (turning of the structure and changes in the instrumentation ports), other injections were made from June 11' to October 11' but slight leakages have also been observed (Table 3.1; Figure 3-1, increasing mass up to day 630). From November 11' to July 12', a new sealing system was implemented in the head of the sensors while the hydration was stopped. In July 12', a new injection was performed but slight leakages were detected in the sensors. From this date, corresponding to an increase in the target temperature of the heaters (to 40ºC), the hydration was stopped again but, as before, the injection water in the structure was not purged to sustain a passive water intake of the barrier.

Table 3.1: Series of injections of water: test S1.

DATE	Time (days)	Tank Weight (kg)	Total mass of water (kg)
23/02/2010	-5	**87.0**	
01/03/2010	0	82.4	4.6
01/06/2011	457	81.8	5.2
09/09/2011	557	80.8	6.2
12/09/2011	560	76.7	10.4
13/09/2011	561	74.4	12.6
14/09/2011	562	73.5	13.5
04/10/2011	582	66.1	20.9
07/07/2012	857	56.9	30.1

No major variations were observed during injections in the temperature but the pH values seem to be related with the water movement in the hydration line (first movement produced a sharp decreasing, days 0, 560, 633 and 857, to be re-equilibrated). A sharp increasing (0.2 pH units) is observed at day 1005, without explanation. Values observed are in the range of those in the previous project.

Test S2

As in the S1 test, from the first flooding up to the beginning of this project a total amount of 91.5 kg of water was injected in the test. This value corresponds to our zero mass reference at 23/02/10 (day -7; Figure 3-2).

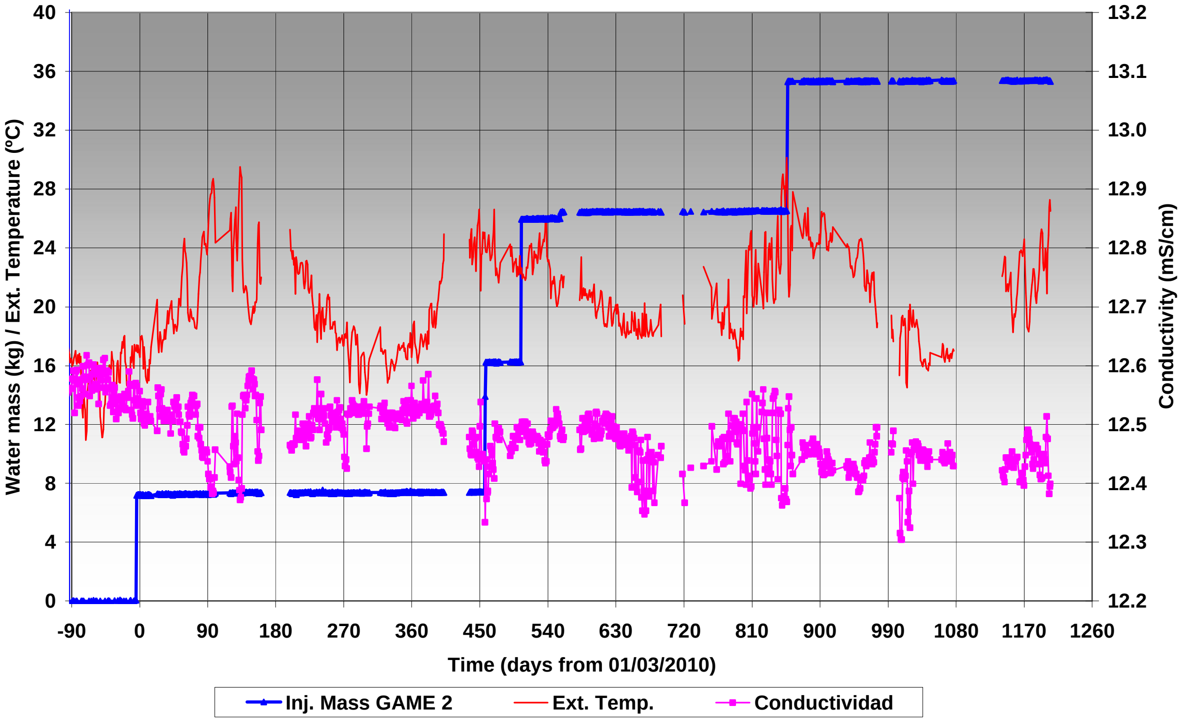

Figure 3-2: Test S2 hydration: injected water, EC and temperature.

At this time, as in test S1,a first injection of water was made, but leakages were observed. Hydration was stopped after injecting 7.3 kg.

After the major modifications, new injections were made from June 11’ to September 11’ but massive leakages were observed (related to the steps, Table 3.2; Figure 3-2). From November 11’ to July 12’, the new sealing system was implemented as in S1 test. In July 12’, the new injection was performed but major leakages were detected in the rods. From this date, corresponding to the increase in the target temperature of the heaters, the hydration was stopped but, as in the S1 test, the injection water in the structure was not purged to sustain a passive water intake of the barrier.

Table 3.2: Series of injections of water: test S2.

DATE	Time (days)	Tank Weight (kg)	Total mass of water (kg)
23/02/2010	-5	**113.6**	
01/03/2010	0	106.3	7.3
01/06/2011	457	99.6	14.0
02/06/2011	458	97.3	16.3
19/07/2011	505	87.6	26.0
09/09/2011	557	87.1	26.5
07/07/2012	857	78.2	35.4

Conductivity values seem to follow a seasonal wave to be confirmed, but not affected during injections. Values observed are in the range of those in the previous phase.

3.2 Heating

The power supply to the heater systems was checked before beginning the operational phase, by heating at low power to prevent the bentonite from changing its moisture content. Previous works that were described in PEBS deliverable D232 showed that the system fixed the target temperatures in both tests.

Heating has been active at low temperature, with target temperatures of 25ºC in all heating zones, from June 09’, before the beginning of the project. These targets were changed to 26ºC, low enough to prevent the thermally-induced movement of water inside the barrier, but high enough to manage the operation of the heaters.

Two types of behaviour have been observed in both experiments. First, some period of apparent anomalous function of the heaters (Figure 3-3 and Figure 3-5) can be attributed to external temperatures so high that induce heater temperatures higher than the target ones, Second, the lose of data transmission has not affected the operation of the heating control (Figure 3-4 and Figure 3-6).

It was expected than higher target temperatures will prevent this anomalous behaviour occurs and has been.

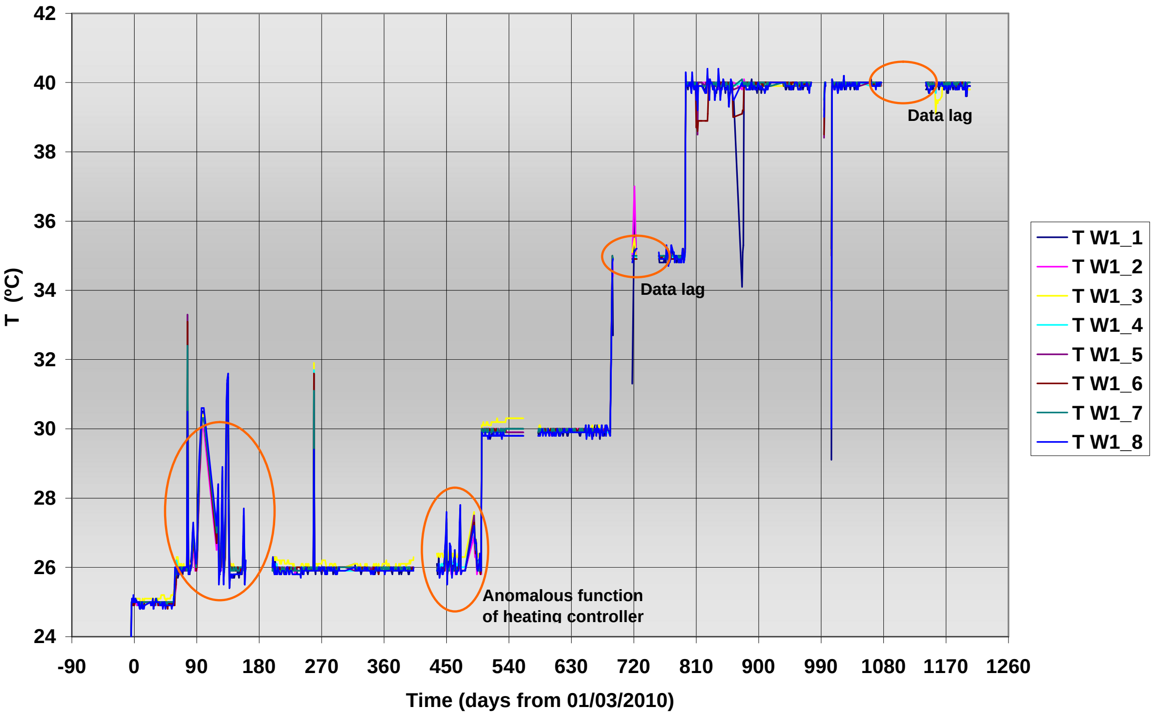

Figure 3-3: Heater temperatures from the controller: test S1

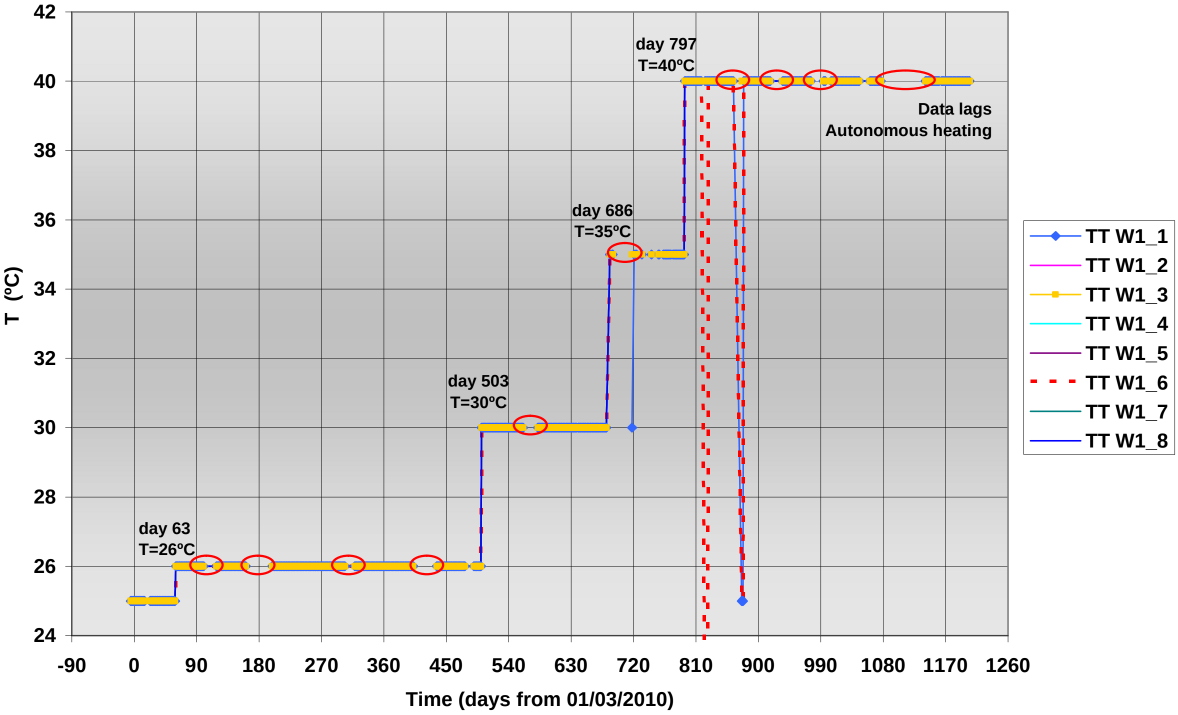

Figure 3-4: Target temperatures from the controller: test S1

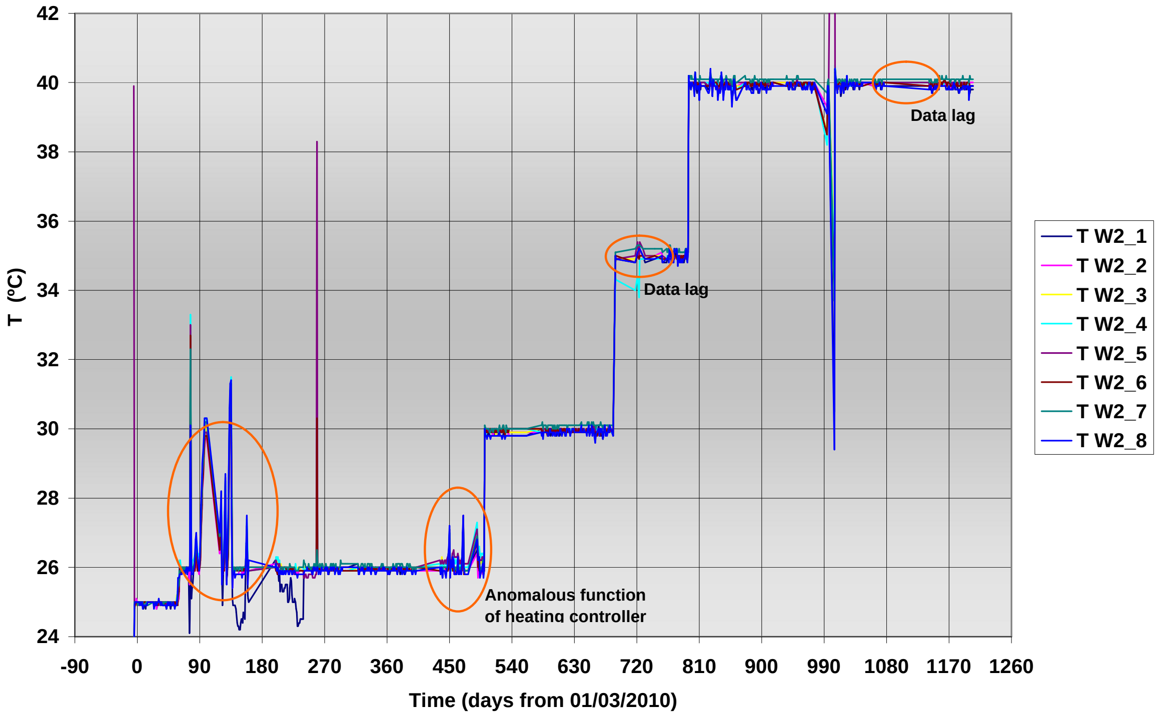

Figure 3-5: Heater temperatures from the controller: test S2

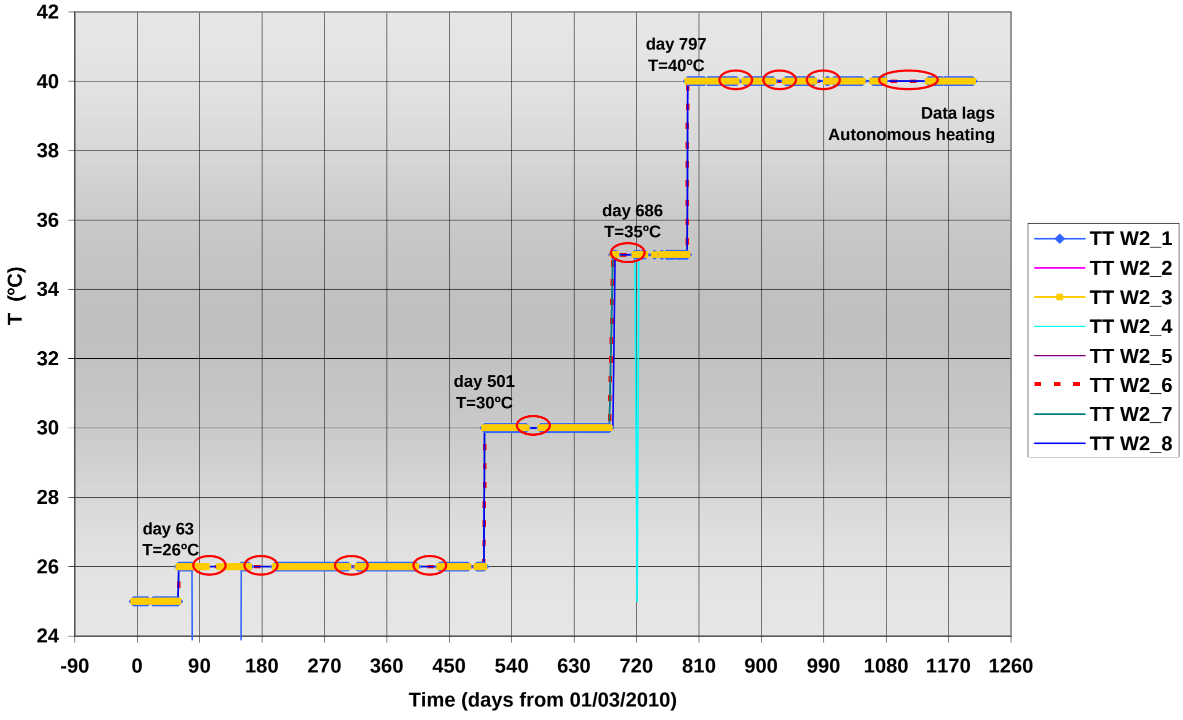

Figure 3-6: Target temperatures from the controller: test S2.

3.3 TH behaviour

The readings from the sensors within the bentonite are presented arranged by instrumentation rods, in a consecutive way from rod A to rod E. The sensors are plotted by measured parameters (temperature and RH). Similar plots have the same ordinate axis to facilitate the comparison.

Temperature and relative humidity are measured with SENSIRION digital transmitters. A problem to be noted is that when temperature transmitter fails, it sends a value of -42ºC. This characteristic produces zero values in RH (calculated from temperature).

Previous works that were described in PEBS deliverable D232 showed the redistribution of internal water. Sensors showed the initial RH increase due to the heating and the subsequent thermally-induced drying (very slight due to the low temperatures) in all rods. The temperature distribution was homogeneous, in spite of the small waves observed. This behaviour of the RH/T sensors was only altered by the injection events. Finally, most of the operative RH sensors measured values higher than 80%.

The damage of the sensors in both tests, lower in test S1, was also shown. Several factors could explain this fact: the different type of water and chemical processes involved, the effect of the alkaline plume generated by the concrete, or some kind of failure in the installation of the rods.

The whole set of sensors was changed at and installed in the new supports. If a sensor resulted damaged during operation, it was replaced if possible. So, in some way, the number of replacement curves of the sensors indicates the reliability of the test.

The figures are grouped by test, S1 and S2. Figures correspond to the RH and temperature values; first by instrumentation rod, from A to E, then by levels (distance to heater): outer (0.245, 0.255, 0.275, 0.295 and 0.315 m), intermediate (0.165, 0.145, 0.185, 0.205 and 0.225 m) and inner (0.075, 0.055, 0.095, 0.115 and 0.135 m)

Test S1

From Figure 3-7 to Figure 3-14, it is clear that the damage of the sensors is smaller in test S1 again. Three sensors were replaced before the water injection around day 450: A1, D2 and E0. Two of them were damaged again after the water injection around day 550.

The RH figures (top pictures in the range above) indicate the relative position of the sensor with respect to the hydration surfaces (placed on the inner surface of the structure and the heater surface). So, the RH values are related to installation factors as position, gaps between blocks, distance to hydration surfaces, preferential pathways on such rods, etc…

After the initial increasing (from average values around 70%), the evolution of the RH measures is related to the major water injection events around day 557 and day 857, but with a smooth slope. Anyway, most of the values are higher than 90%.

If the sensors are grouped by distance to heater surface (three groups: outer, intermediate and inner; Figure 3-12 to Figure 3-14, respectively), it can be observed that the values of the inner positions (level 2, Figure 3-14) are more homogeneous. The external temperature is also shown for comparison.

The temperature figures (bottom pictures in the above range) show a yearly seasonal tendency over the small waves observed (in Figure 3-12 to Figure 3-14). The expected behaviour, as described in the previous phase, is observed in all the rods and level, but is clearer in the longer rods and during the colder phase of the thermal waves. During the hotter phases, the differences between levels decrease.

The 90-degree turn of the structure (done before day 450 to prevent major leakages) does not seem to affect the measured values in this test.

Test S2

From Figure 3-15 to Figure 3-22, it is clear that the damage of the sensor is greater in test S2. Almost all sensors have been replaced, some of them even twice, before they could be considered as flooded by the saline water. In other cases, the sensors were operating during long time in oversaturated conditions.

As in test S1, the RH figures (bottom pictures in the above range) indicate the relative position of the sensor with respect to the hydration surfaces. So, the expected RH values are modified by the previously cited factors and preferential pathways between the concrete blocks and the rods, etc…

After the initial increasing (from average values higher that in test S1, between 75 and 85%), the evolution of the RH measures is related to the major water injection events around day 457 and day 505, but presents a step behaviour. Again, most of the measured values are higher than 90% but coming from initial values higher than those of test S1.

If the sensors are grouped by distance to heater surface (three groups: outer, intermediate and inner; Figure 3-20 to Figure 3-22, respectively), it can be observed that the values of the intermediate levels (Figure 3-21) are more homogeneous. The external temperature is also shown for comparison.

Some sensors were damaged immediately after the injection around day 450 and, at least, nine sensors, the closest to the hydration surfaces, were damaged during the water injection event on day 505. When the sensors were not damaged, the ones placed close to the hydration surfaces (external level 0, Figure 3-20, and internal level 2, Figure 3-2) registered a RH step associated to the injection events. No sensors remain operative from day 810.

The relation of the damage of sensors to the water injection pulses indicates the possibility of some defect in the installation of the rods or related to the interaction between the concrete blocks and the sampling filters. This could be possible the direct flow of water within the sensors.

The temperature figures (even numbers in the above range) show the same yearly seasonal tendency with small waves observed in test S1. This behaviour is observed in all the rods and level, more clearly in the longer rods and during the colder phases of the thermal waves (due to the higher difference between the heater temperature and the room temperature.

As in test S1, the 90-degree turn of the structure (done before day 450 to prevent major leakages) does not seem to affect the measured values in spite of the possibility of water flow among the concrete blocks.

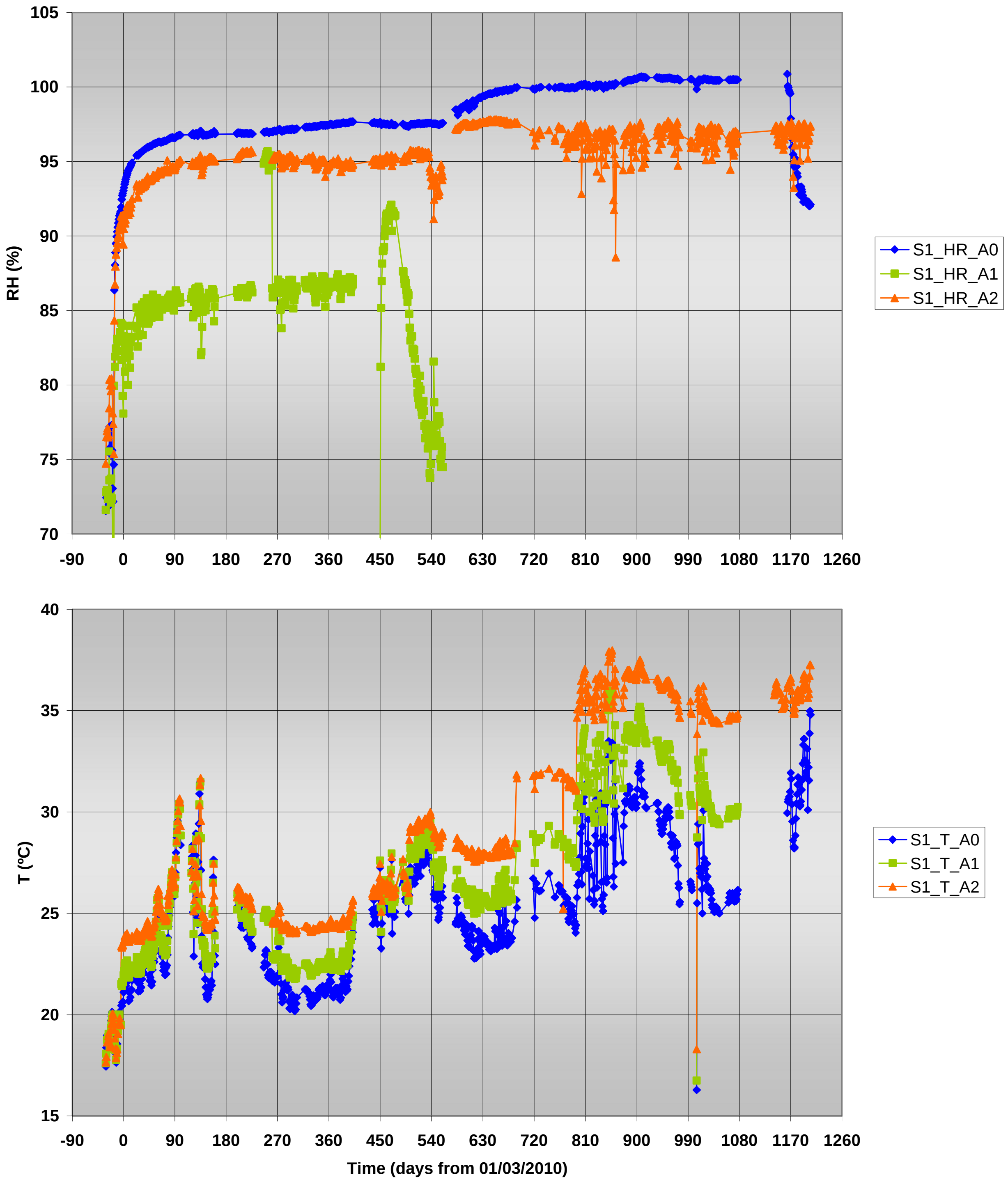

Figure 3-7: Test S1 PEBS phase: RH and T values from rod A: sensors A0, A1, A2 located at coordinates (X= - 0.3; Y= 0.395, 0.315, 0.225, respectively)

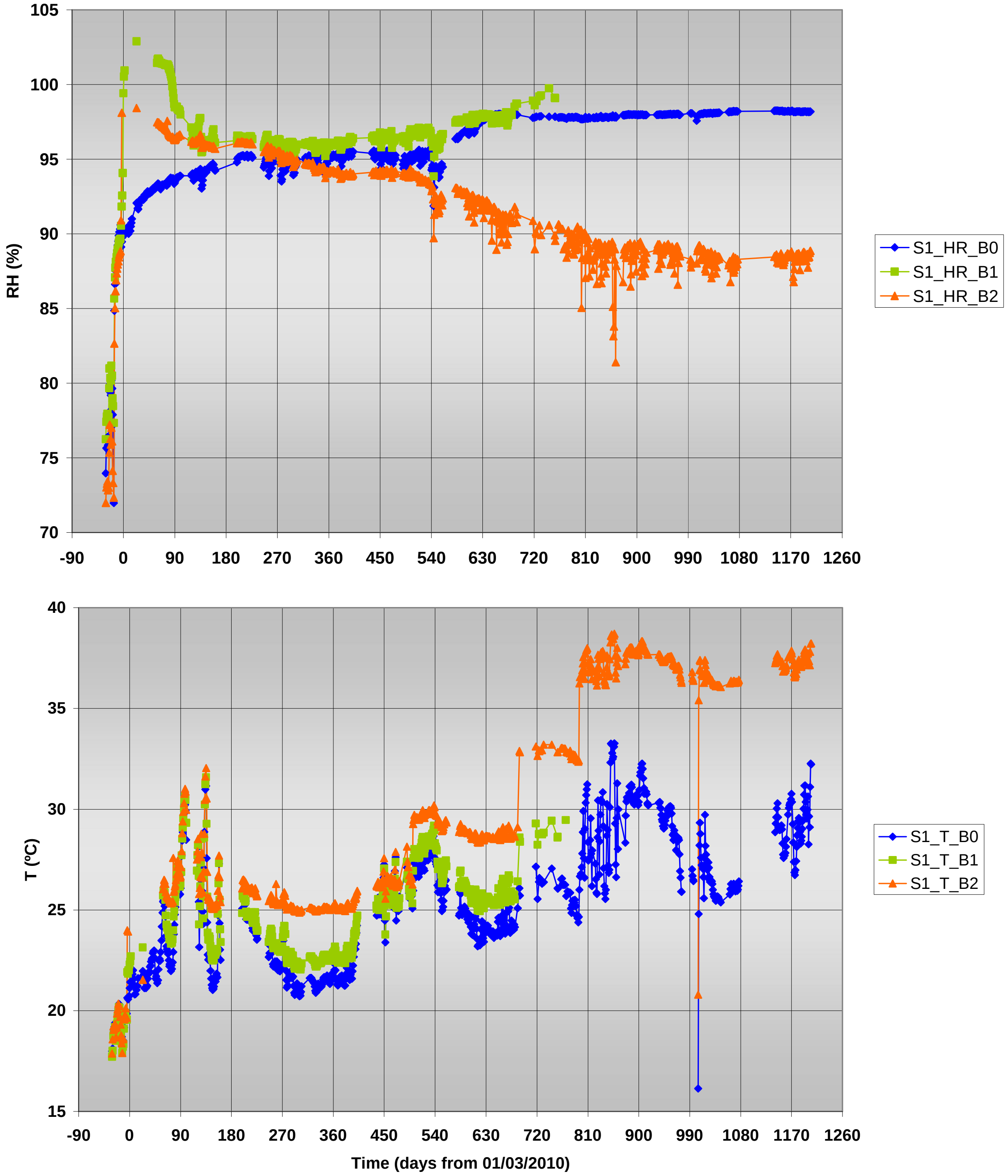

Figure 3-8: Test S1 PEBS phase: RH and T values from rod B: sensors B0, B1, B2 located at coordinates (X= 0.0; Y= 0.405, 0.295, 0.205, respectively)

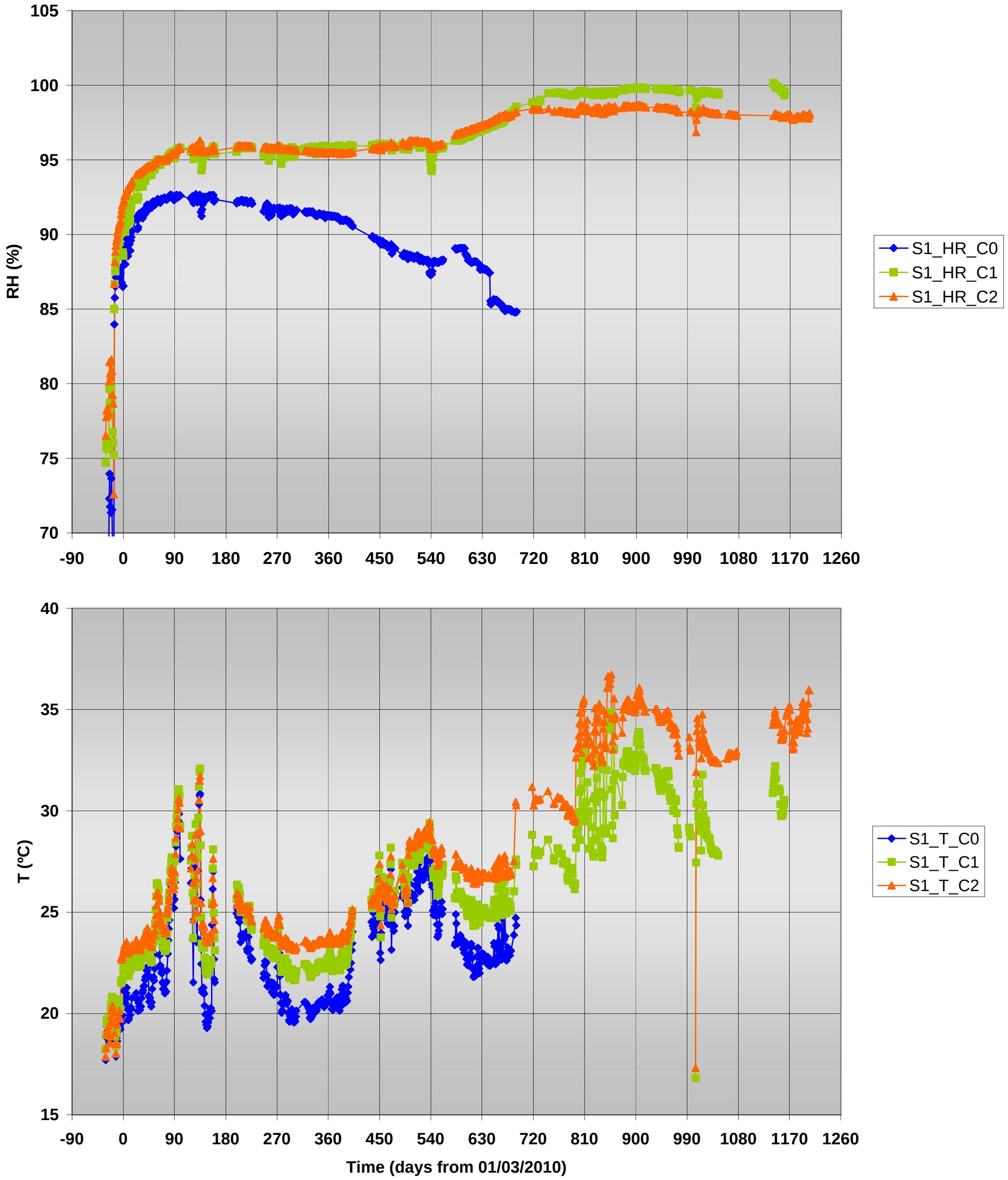

Figure 3-9: Test S1 PEBS phase: RH and T values from rod C: sensors C0, C1, C2 located at coordinates (X= 0.3; Y= 0.425, 0.335, 0.245, respectively)

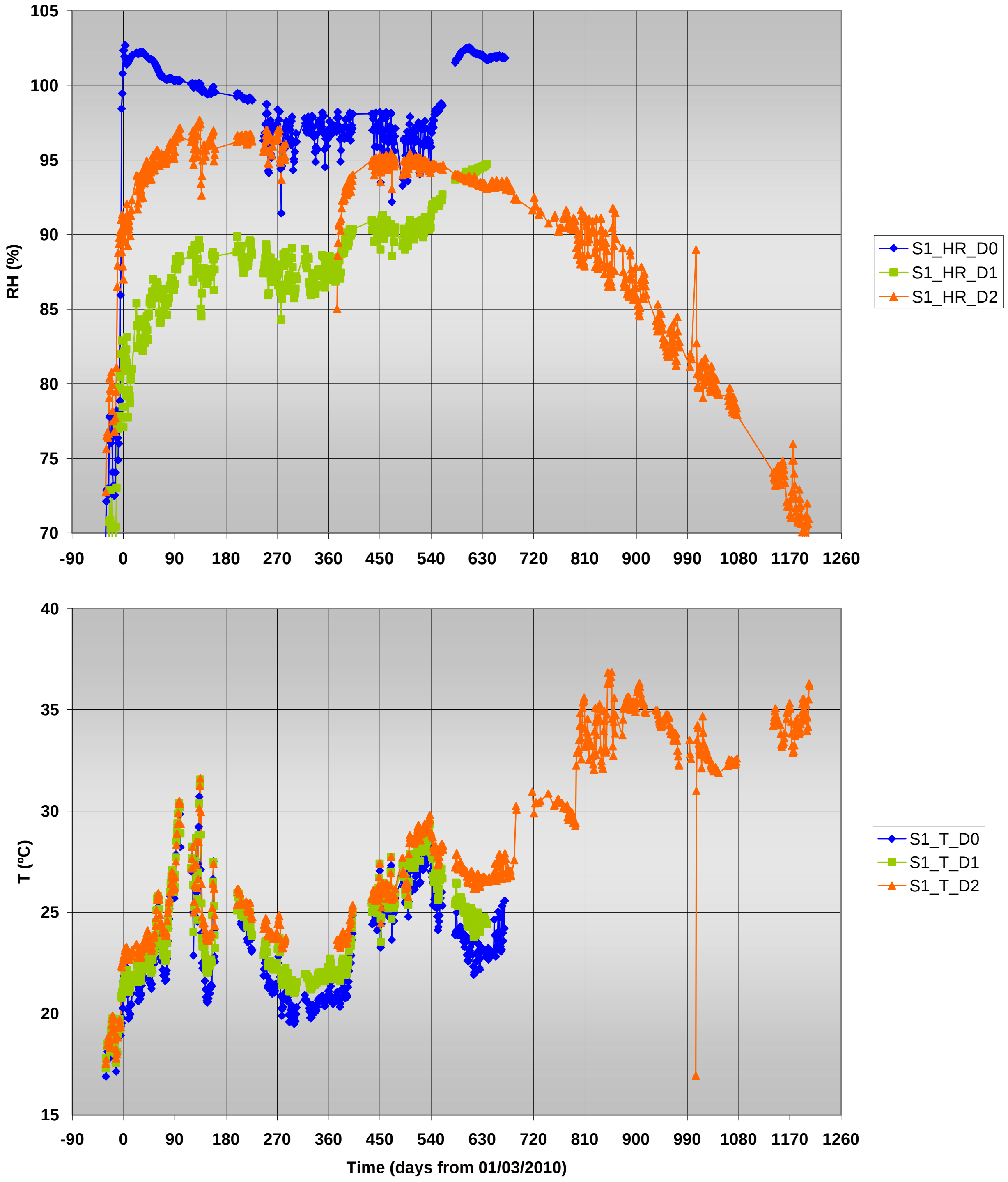

Figure 3-10: Test S1 PEBS phase: RH and T values from rod D: sensors D0, D1, D2 located at coordinates (X= - 0.15; Y= 0.445, 0.355, 0.265, respectively)

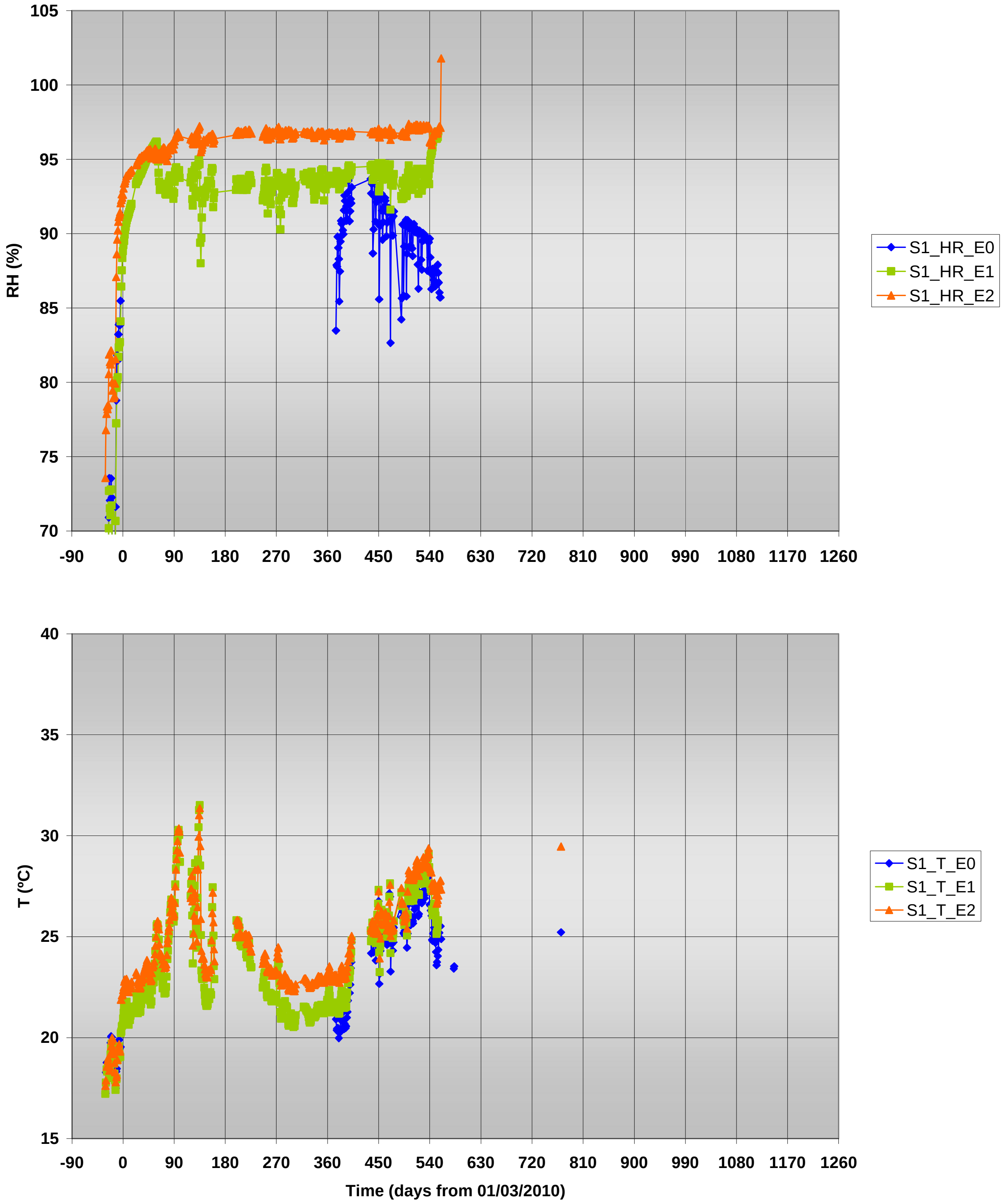

Figure 3-11: Test S1 PEBS phase: RH and T values from rod E: sensors E0, E1, E2 located at coordinates (X= 0.3; Y= 0.465, 0.375, 0.285, respectively)

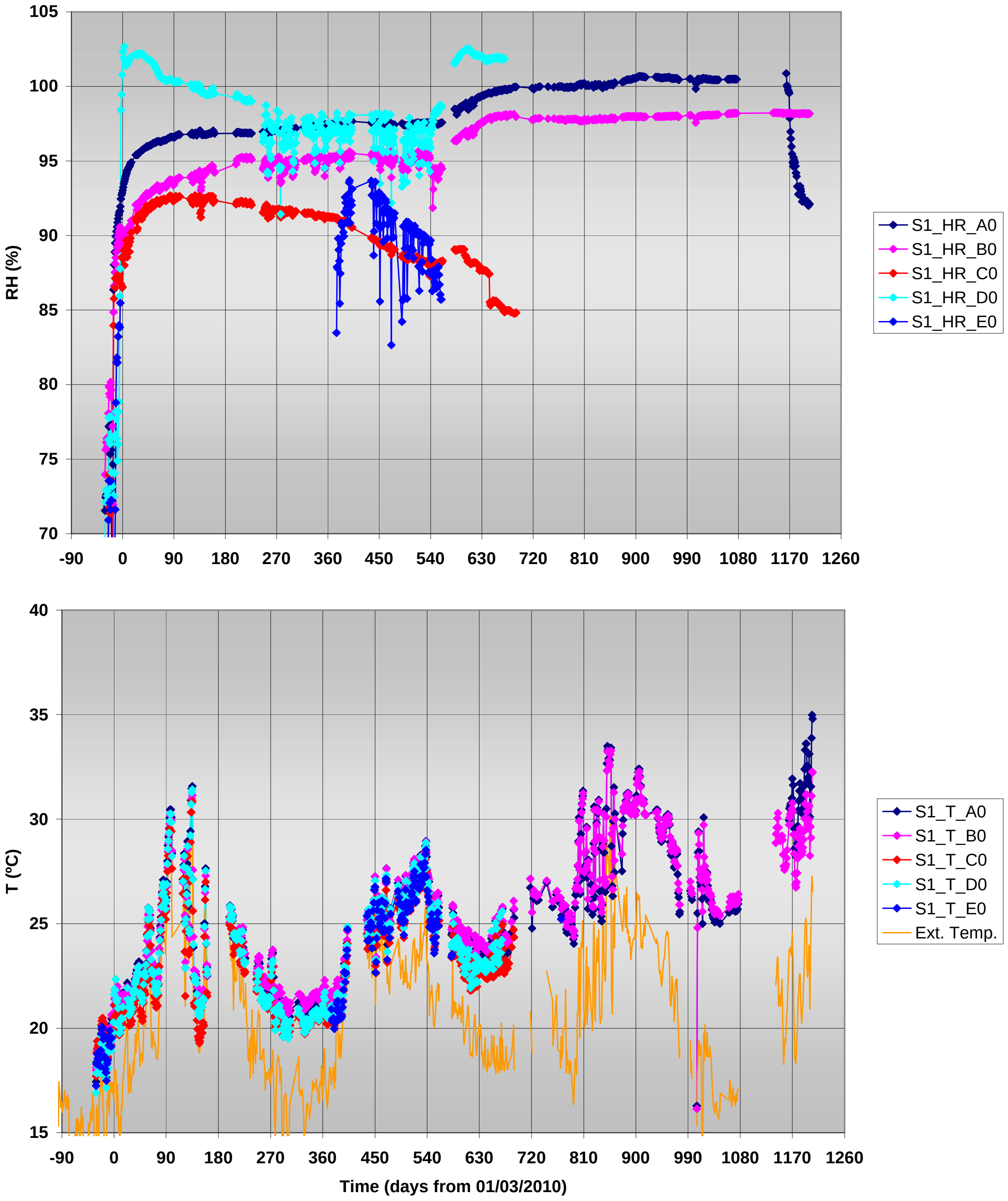

Figure 3-12: Test S1 PEBS phase: RH and T values from outer levels: (X, Y) location: A0(-0.3, 0.245), B0(0.0, 0.255), C0(0.3,0.275), D0(-0.15, 0.295), E0(0.15, 0.315)

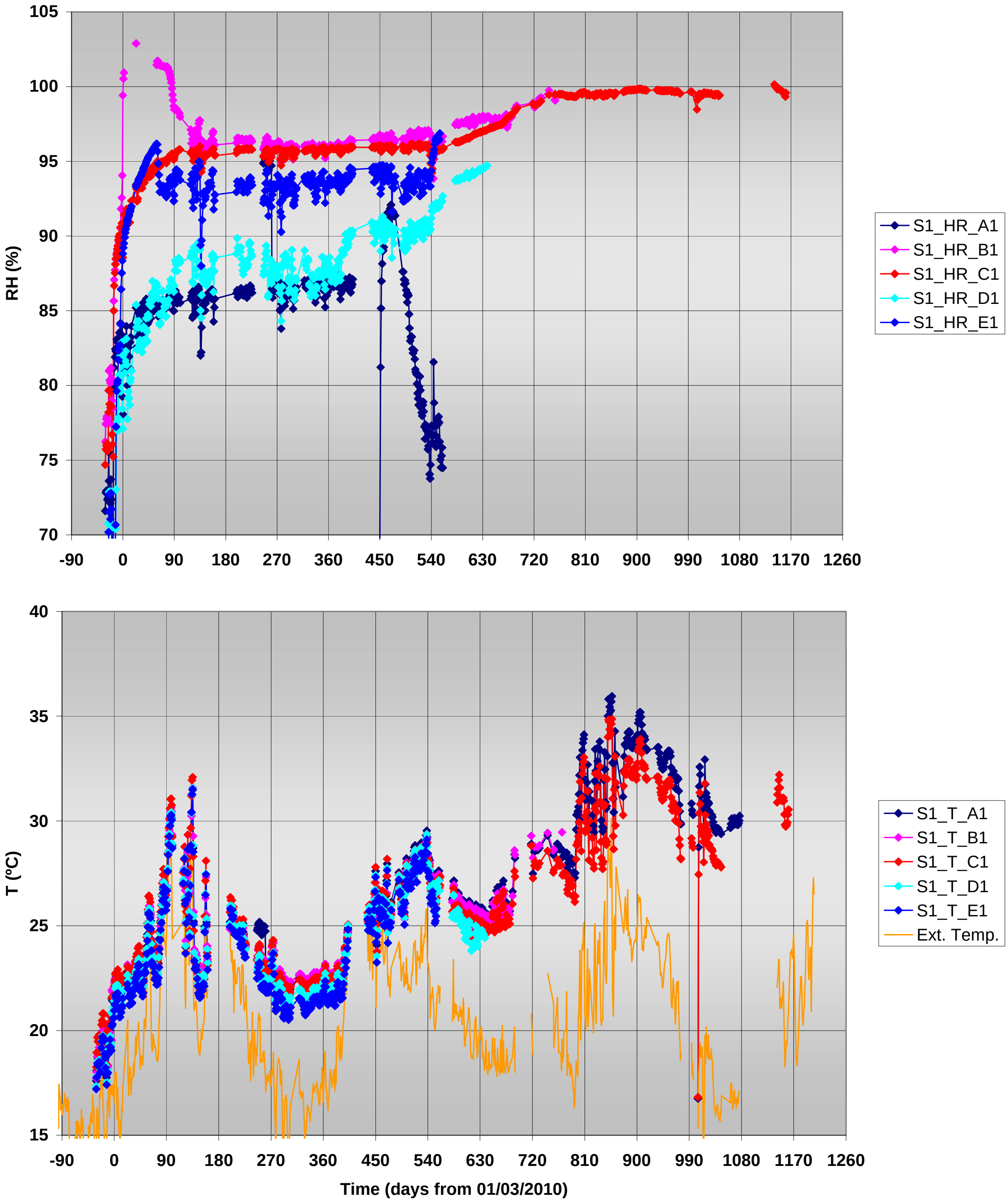

Figure 3-13: Test S1 PEBS phase: RH and T values from intermediate levels: (X, Y) location: A1(-0.3, 0.165), B1(0.0, 0.145), C1(0.3, 0.185), D1(-0.15, 0.205), E0(0.15, 0.225)

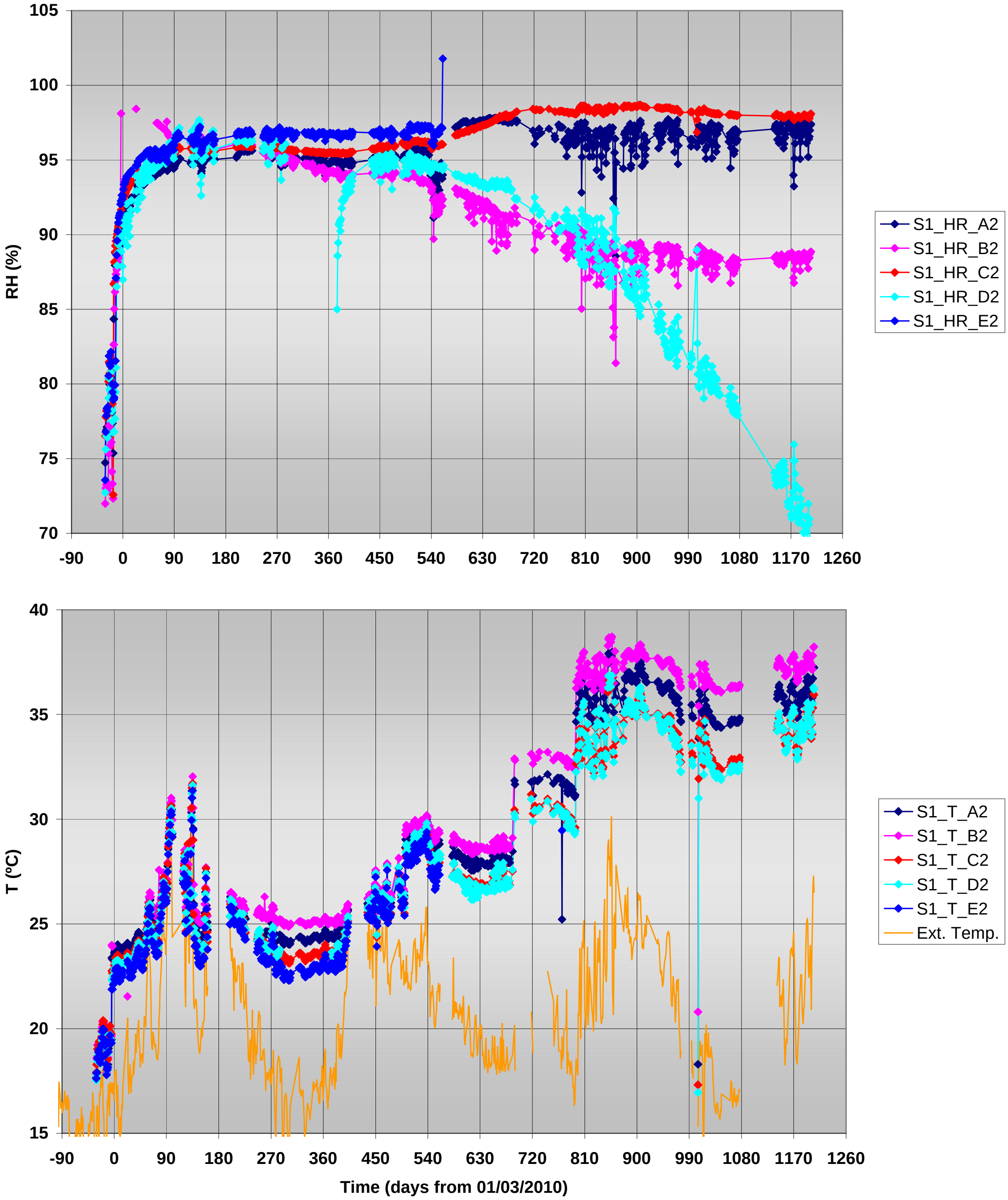

Figure 3-14: Test S1 PEBS phase: RH and T values from inner levels: (X, Y) location: A2(-0.3, 0.075), B2(0.0, 0.055), C2(0.3, 0.095), D2(-0.15, 0.115), E2(0.15, 0.135)

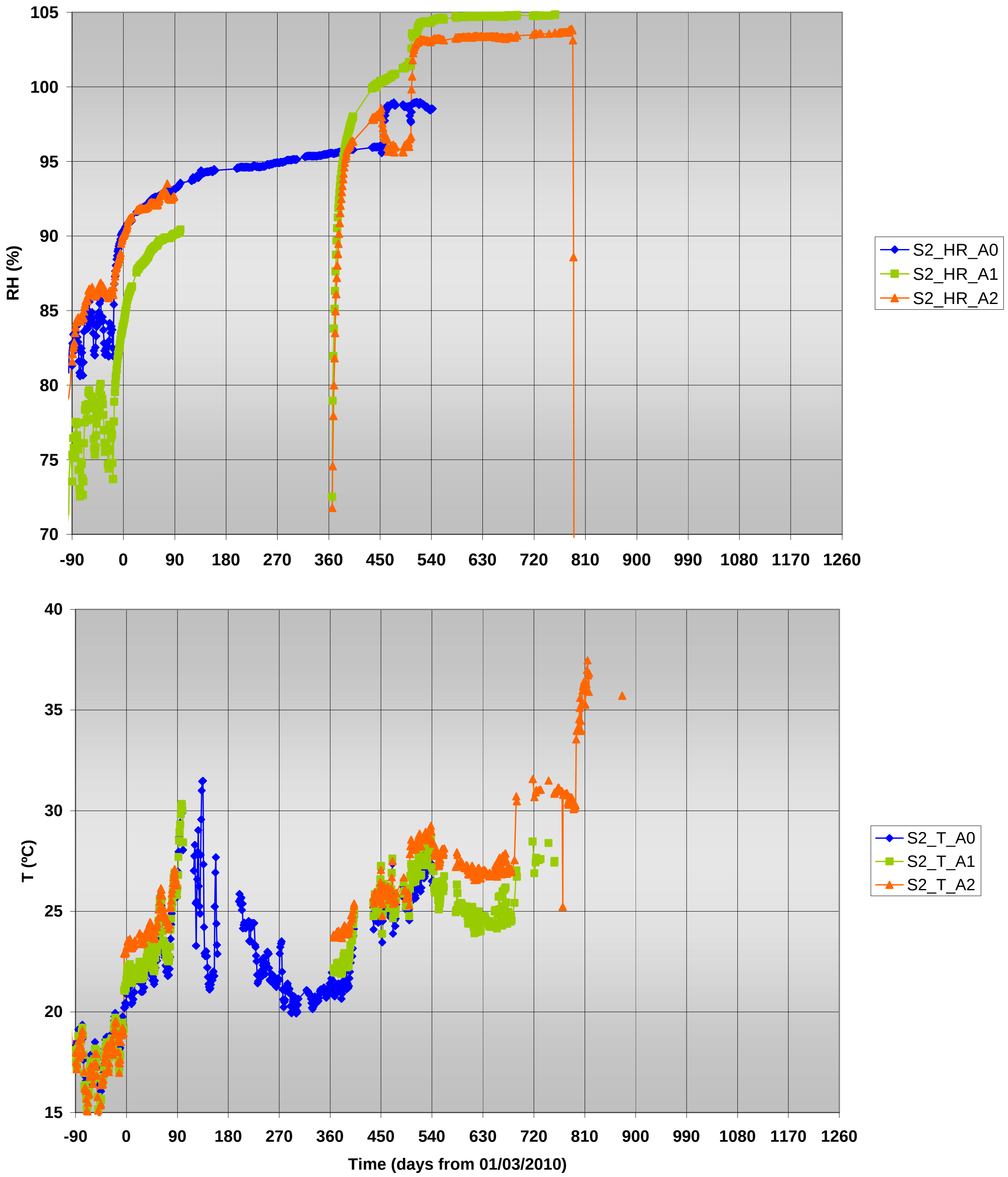

Figure 3-15: Test S2 PEBS phase: RH and T values from rod A: sensors A0, A1, A2 located at coordinates (X= - 0.3; Y= 0.395, 0.315, 0.225, respectively)

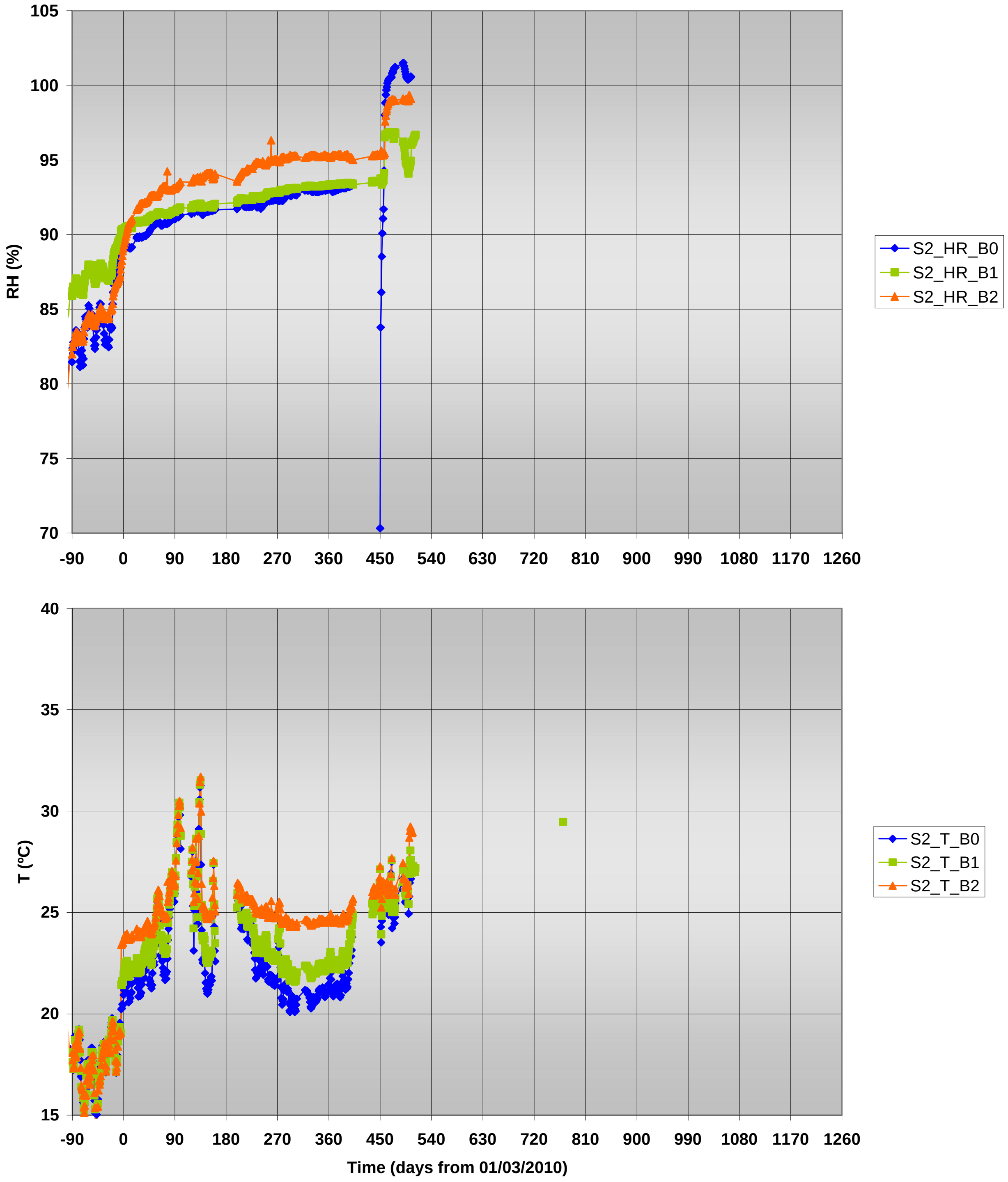

Figure 3-16: Test S2 PEBS phase: RH and T values from rod B: sensors B0, B1, B2 located at coordinates (X= 0.0; Y= 0.405, 0.295, 0.205, respectively)

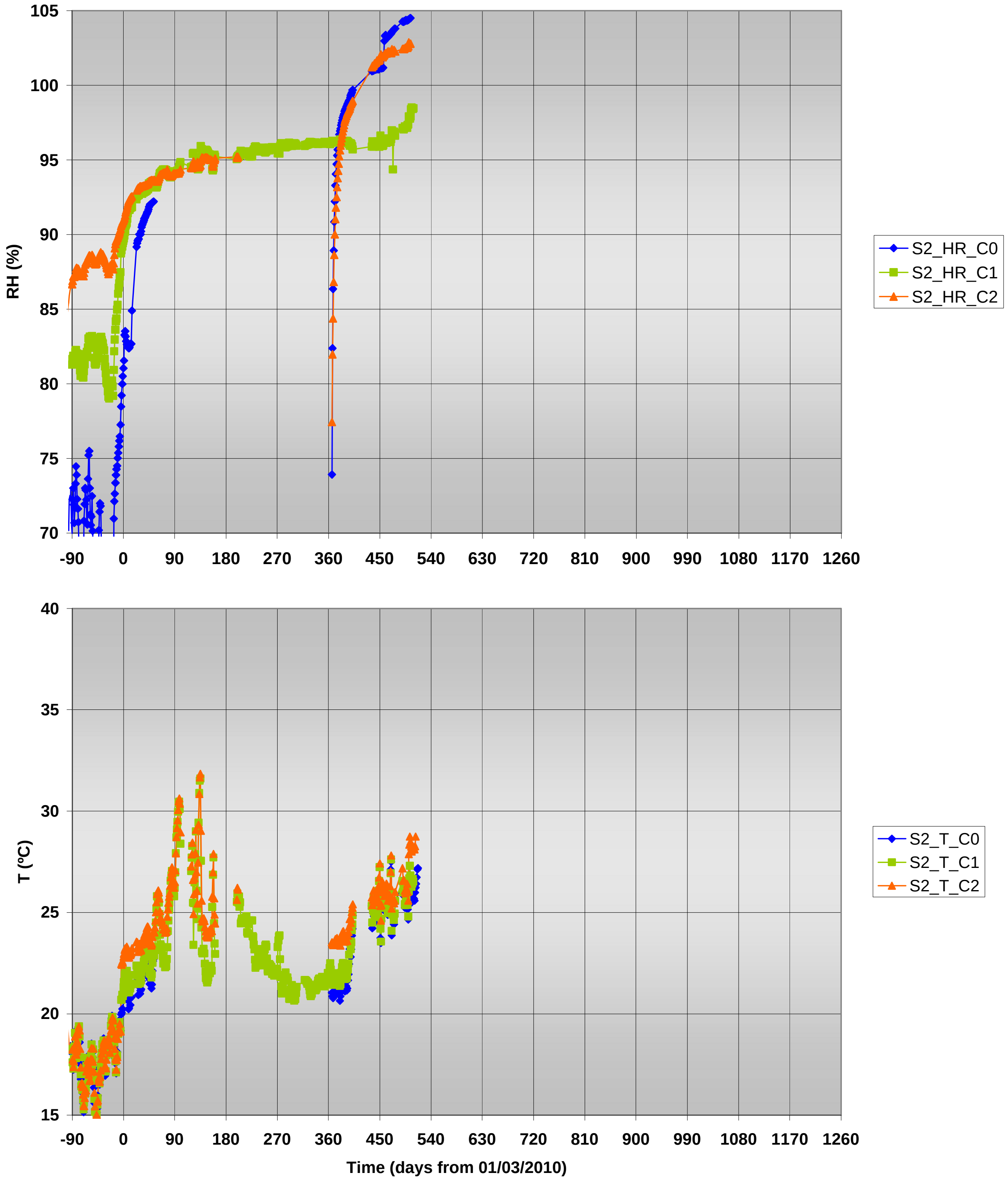

Figure 3-17: Test S2 PEBS phase: RH and T values from rod C: sensors C0, C1, C2 located at coordinates (X= 0.3; Y= 0.425, 0.335, 0.245, respectively)

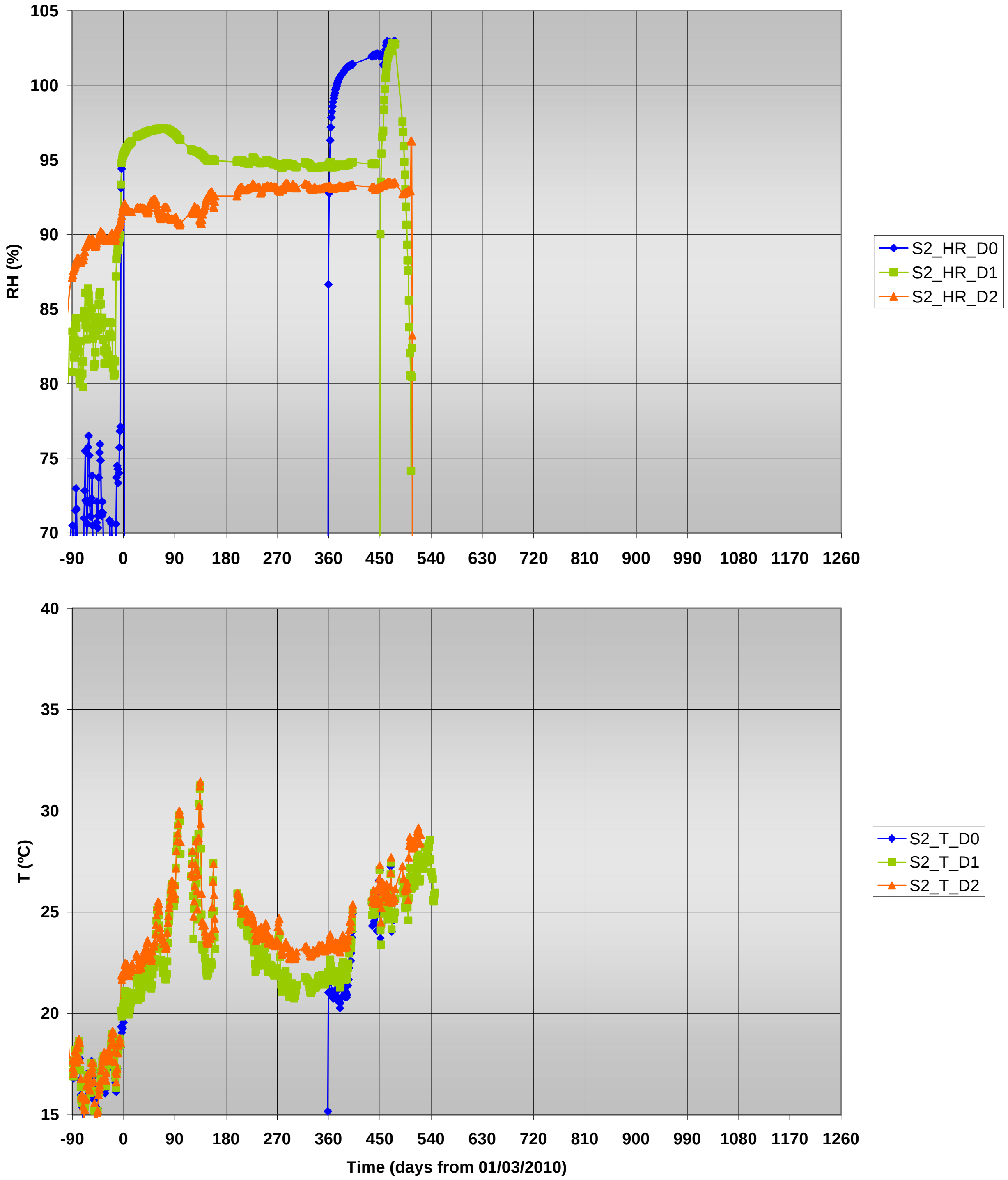

Figure 3-18: Test S2 PEBS phase: RH and T values from rod D: sensors D0, D1, D2 located at coordinates (X= - 0.15; Y= 0.445, 0.355, 0.265, respectively)

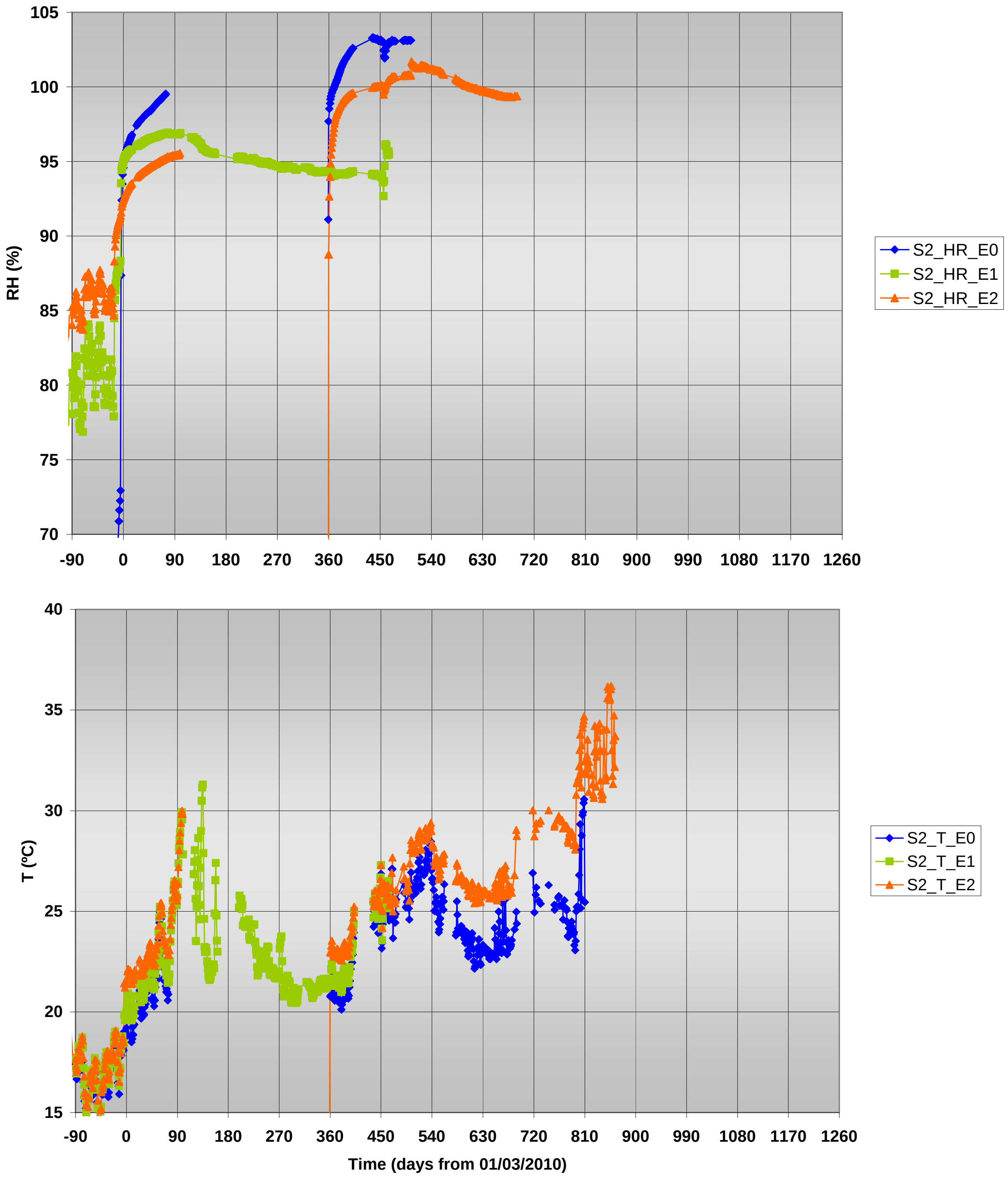

Figure 3-19: Test S2 PEBS phase: RH and T values from rod E: sensors E0, E1, E2 located at coordinates (X= 0.3; Y= 0.465, 0.375, 0.285, respectively)

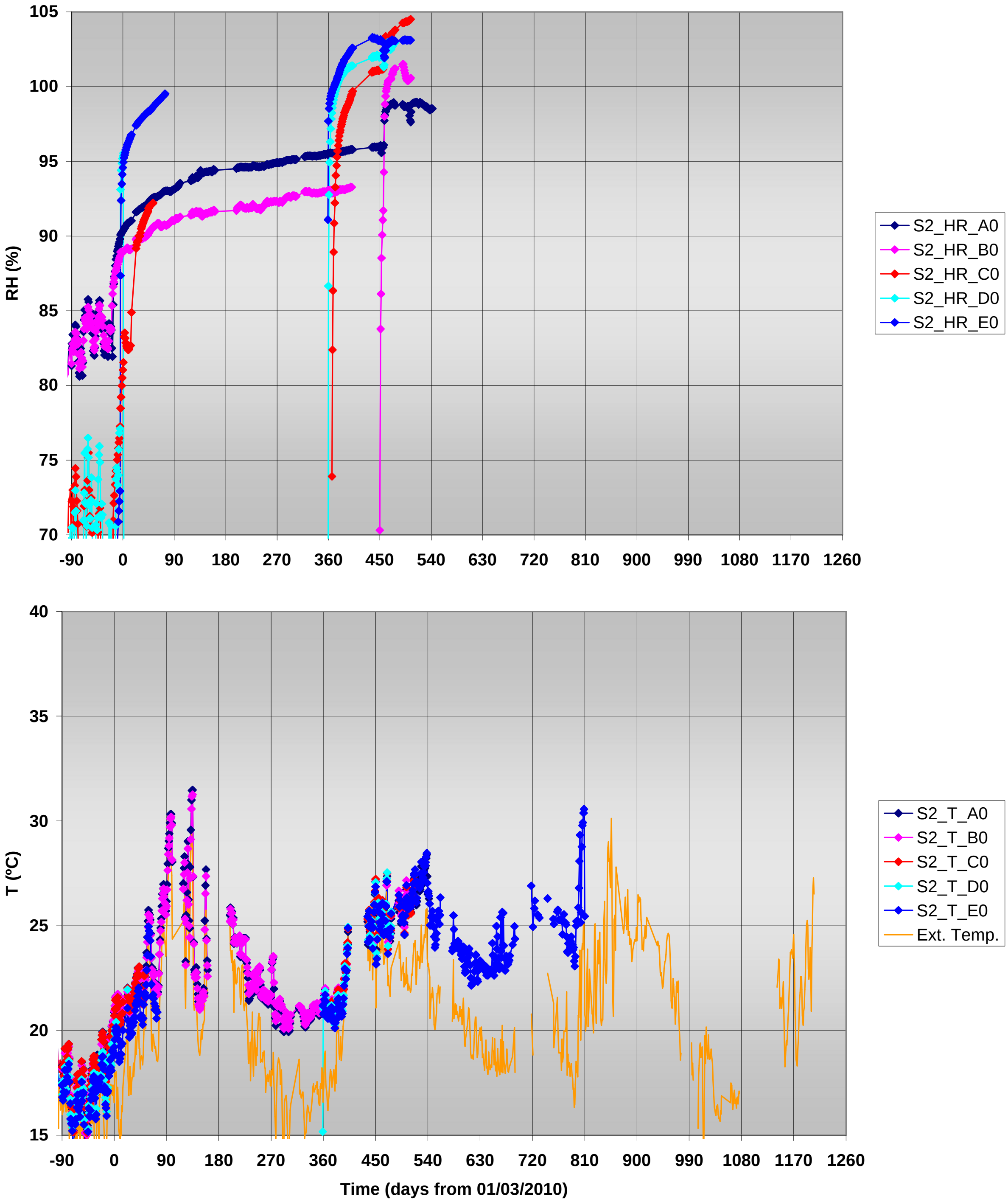

Figure 3-20: Test S2 PEBS phase: RH and T values from outer levels: (X, Y) location: A0(-0.3, 0.245), B0(0.0, 0.255), C0(0.3,0.275), D0(-0.15, 0.295), E0(0.15, 0.315)

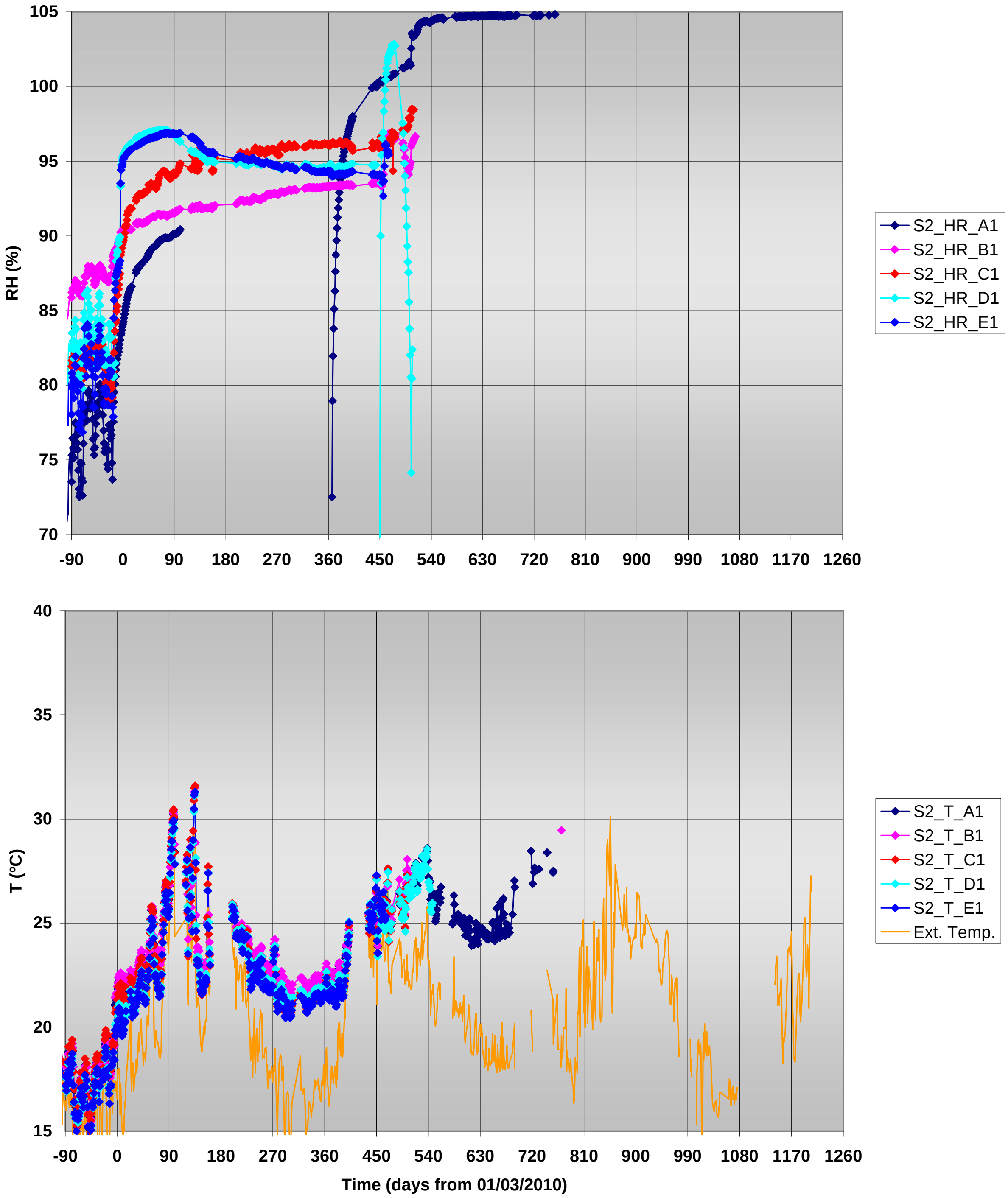

Figure 3-21: Test S2 PEBS phase: RH and T values from intermediate levels: (X, Y) location: A1(-0.3, 0.165), B1(0.0, 0.145), C1(0.3, 0.185), D1(-0.15, 0.205), E0(0.15, 0.225)

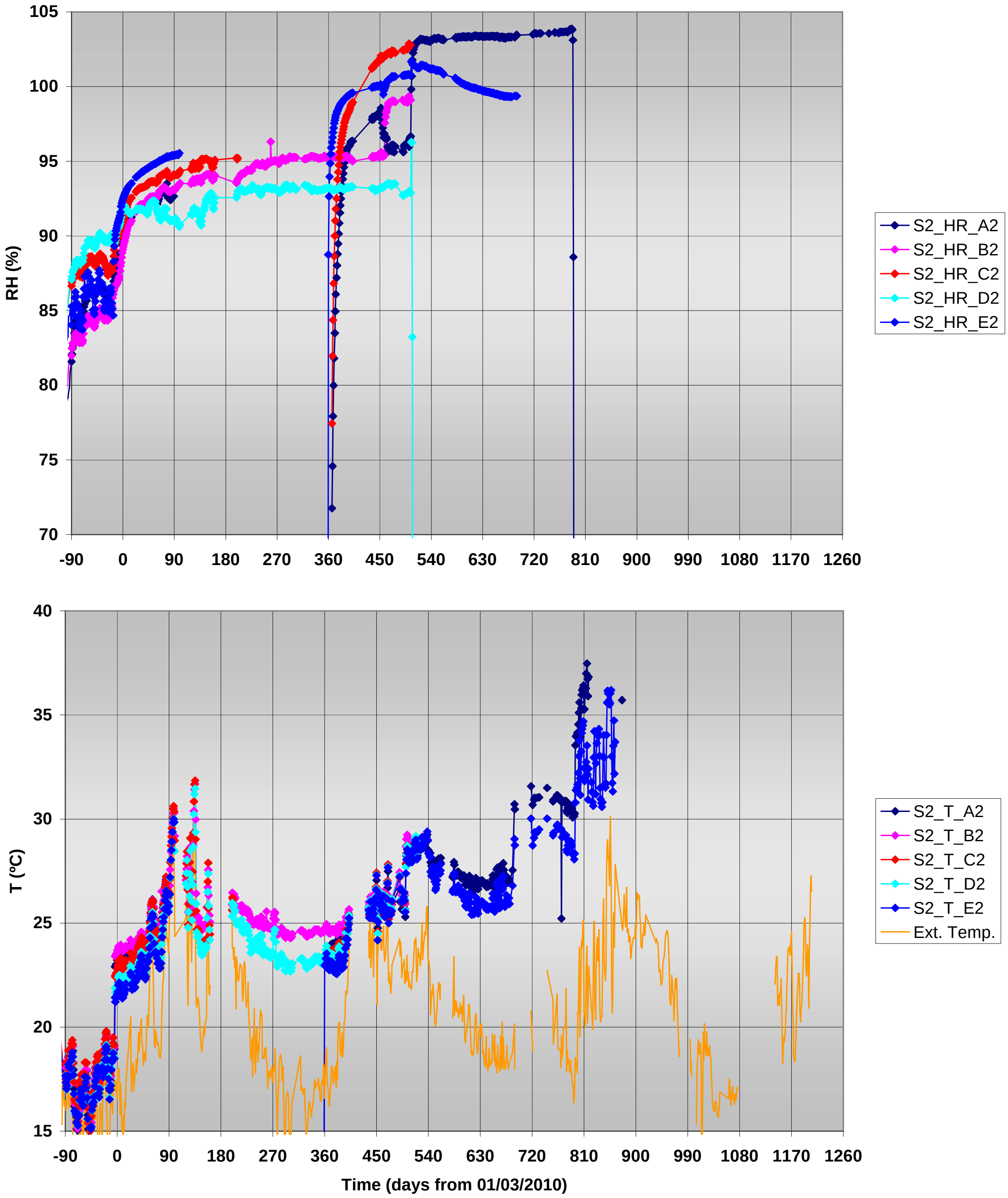

Figure 3-22: Test S2 PEBS phase: RH and T values from inner levels: (X, Y) location: A2(-0.3, 0.075), B2(0.0, 0.055), C2(0.3, 0.095), D2(-0.15, 0.115), E2(0.15, 0.135)

4 CONCLUSIONS

The GAME experiment has demonstrated that installation of an EBS and the thermo-hydraulic (TH) instrumentation in a large-scale experiment, with the hydration and heating infrastructures, is feasible for the granite and clay HLW repository concepts.

However, the present development of the miniaturised sensors for geochemical and TH measurement does not permit to install them in the extreme working conditions of the expansive barrier materials under a thermal load: mainly high swelling pressure (> 5 MPa) and harsh saline environment. This is also applicable to all type of sensors with active electronic components, even after protecting them mechanically.

Consequently, the development and implementation of suitable sampling systems was selected as the best option to solve the observed problems. Modifications in the instrumentation rods were developed and tested, but the results were not as good as expected.

The results indicated that:

1. At the end, all the sensors become damaged by exposition to saline water that is generated within the bentonite (test S1) or is supplied by the hydration system (test S2).
2. Change of the damage transmitters is complicated (due to the compression of the rods) but possible; however, leakages from the instrumentation rods themselves go on.
3. Last recorded data indicate high RH values and the expected temperature distribution within the barrier material; so, corrosion processes are going on inside the tests due to vapour, but pore-water is not available in the sampling ports.
4. The experimental setup is operative: hydration, heating and data-acquisition systems.

At present, the presence of massive leakage possibility is a major issue in the test S2, due to the concrete blocks and their multiple internal gaps and interfaces, both with the structure (body and covers) and with the rods, which make difficult the sealing effects of the inner bentonite.

So, the test are currently running under a heating phase (at 40ºC) with a low-pressure (less than 0.1 MPa) pulse hydration phase. By this way, corrosion processes will be allowed to go on inside the structures for future work.

5 REFERENCES

DANAHER CONTROLS (2004): MLC 9000+: Full User Guide. 59367, Edición 1. Marzo 04. http:/www.danacon.com.

ENRESA (1994): Almacenamiento Geológico Profundo de residuos radioactivos de alta actividad (AGP). Conceptos preliminares de referencia. Publicación Técnica 7/94. Madrid. 60 pp.

ENRESA (1995): Almacenamiento geológico profundo de residuos radiactivos de alta actividad (AGP). Diseños conceptuales genéricos. Publicación Técnica 11/95. Madrid. 105 pp.

ENRESA (2006): FEBEX Full-scale Engineered Barriers Experiment. Updated Final Report: 1994-2004.

Martín P.L. & Barcala J.M. (2007a): Construction and beginning of operation of mini mock-up (WP2.3) Contract Number: FI6W-CT-2003-02389. NF-Pro project DELIVERABLE (D-N°: 2.3.3)

Martín P.L. & Barcala J.M. (2007b): Construction and start of operation of GAME mini mock-up (WP 2.4). Contract Number: FI6W-CT-2003-02389. NF-Pro project DELIVERABLE (D-N°: 2.4.3)

Martín, P.L. & Barcala, J.M. (2007c): Final Activity Report for CIEMAT: WP 2.4. Contract Number: FI6W-CT-2003-02389. NF-Pro project DELIVERABLE (D-N°: 2.4.6).

Martín P.L. & Barcala J.M. (2011): Combined report for: DELIVERABLE (D-N°:D2.3-1) “Feasibility report on GAME mock-ups” and DELIVERABLE (D-N°:D2.3-2) “Report on GAME status”. Contrac: FP7-249681. PEBS project.

SENSIRION (2005a): SHT1x / SHT7x Relative Humidity & Temperature Sensor System. v2.04, May 2005. http:/www.sensirion.com.

SENSIRION (2005b): SHTxx Application Note CRC Rev 1.06, May 2005. http:/www.sensirion.com.

SENSIRION (2005c): SHTxx Application Note Non-Linearity Compensation Rev. 1.32, May 2005. http:/www.sensirion.com.

Turrero M.J., Torres E., Martín P.L. & Barcala J.M. (2007): Final Activity Report for CIEMAT WP 2.3. Contract Number: FI6W-CT-2003-02389. NF-Pro project DELIVERABLE (D-N°: 2.3.6)