Thermal Analysis of a Special Grout Mixture for In-Situ Decommissioning - 11389

N. Lima (DOE Fellow)*, C. Acevedo (DOE Fellow)*, D. Aranda (DOE Fellow)*, J. Rivera (DOE Fellow)*, E. Polo*, J. Varona*, L. Lagos*, M. Serrato**
*Applied Research Center, Florida International University, Miami, FL 33174
**Savannah River National Laboratory, Aiken, SC 29808

ABSTRACT

The 105-R Reactor at Savannah River Site (SRS) has been obsolete since 1964. The Department of Energy has set a goal to reduce its footprint at SRS; therefore identifying the 105-R Reactor for decommissioning was made in collaboration with stakeholders. The in-situ decommissioning (ISD) approach was used as the end state for the safe and cost effective disposition of a structurally sound, robust nuclear facility. This decommissioning approach involves filling all below grade areas with flowable, self leveling cementitious materials (grout) to entomb this massive nuclear building. Fill material generates heat (heat of hydration) during the curing process, which may influence material compatibility/stability with the existing structure. Temperature differences can affect the curing properties of the grout as well as cause the material to expand and contract as it heats and cools, which may in turn cause thermal cracking. An experimental setup was performed at the Applied Research Center (ARC) at Florida International University (FIU) in order to monitor the temperature along the radial and axial direction of the grout mixture with respect to time. The experiment focused on determining the presence of localized hot spots and determining the extent of thermal uniformity. The experiment also verified that the compressive strength of the grout was not under the minimum site requirement of 345 kPa (50 psi). Obtaining temperature changes as the grout cured had the additional benefit of providing understanding of the material behavior along the radial direction, which provides an indication of material quality; this is an area which has not been studied thoroughly and, therefore, is of interest to SRNL.

INTRODUCTION

The Savannah River Site (SRS) is implementing in situ decommissioning (ISD) at two reactor facilities by filling all subsurface areas within a reactor facility with zero-bleed-flowable-fill-gravel No.8-Diutan Gum (ZB-FF-8-D) grout and placing a water resistant concrete slab over the filled area [1]. This grout was designed by the Savannah River National Laboratory (SRNL) for uncongested dry areas in the reactor building. The 105-R Reactor Disassembly Basin was filled with the aforementioned material. Once the grout is poured, heat is anticipated due to the hydration of the prozzolanic cements in the mix. It is imperative to be able to quantify the levels of heat produced as they may lead to consequences that can occur due to a temperature gradient across the structure. These temperature differences can cause the material to expand and contract, which may in turn cause thermal cracking. An experimental setup was performed at the Applied Research Center (ARC) at Florida International University (FIU) which focused on determining the presence of localized hot spots and determining the extent of thermal uniformity. Localized hot spots occur due to the late reaction of fly ash with lime. Fly ash reacts with calcium hydroxide (lime) as it becomes readily available, producing a cementitious-like material called calcium silicate hydrate (CSH). CSH is similar to the paste created by mixing cement with water; it is the strongest component of the binder in the mix. Confirmation of the compressive strength of the grout to not fall below the minimum site requirement of 345 kPa (50 psi) was also incorporated in to the experiment [2]. Obtaining temperature changes as the grout cured will have the additional benefit of providing understanding of the behavior of the grout along the radial direction, an area which has not been studied thoroughly and, therefore, is of interest to SRS. A thermocouple tree mock-up test was developed to acquire the temperature data of this grout as it cured. Compressive tests were also done to obtain the compressive strength of the grout.

MATERIALS AND TEST STRATEGY METHODOLOGY

SRNL completed a limited thermal study during the 105-R Disassembly Basin D&E Canal filling operation, but the thermocouple configuration only focused on the vertical distribution. The bi-dimensional distribution of heat during the grout curing process was in-question to provide a general indication of cured material quality. The FIU thermal analysis of specialty grout was pursed to supplement the SRNL data set for the ISD application. The experiment consisted of two reinforced concrete pipes (RCP), each measuring 2.4 meters (8 feet) in length with a 0.91 meter (3 foot) inside diameter. A thermocouple tree was placed in the center of each pipe to measure the axial and radial temperatures. The tree skeleton was made of Plexiglass, with T-type thermocouples attached to it. In order to keep consistency with SRNL, the same thermocouples were used. The thermocouples were placed at 4 different vertical levels and radial distances in order to record the axial and radial temperatures, respectively. Before testing, the thermocouples were calibrated using ambient temperature water. The temperature profile along the vertical direction was achieved by placing each array at an equidistance based on the lifts, i.e., 1.5 meters (5 feet) every 24 hours. In this case, the lifts were first a 1.5 meter (5 foot) lift and secondly 0.91 meter (3 foot) lift. For the 1.5 meter (5 foot) lift, the thermocouple distances were 0.46 meters (1.5 feet) and 1.06 meters (3.5 feet) from the base. The remaining 0.91 meter (3 foot) lift had thermocouples at 1.8 meters (6 feet) and 2.1 meters (7 feet) from the base. The radial distances were as follows: the first radial position was located at 7.62 centimeters (3 inches) from the Plexiglass rod located at the center of the inner diameter of the RCP, the second radial position was located at 17.78 centimeters (7 inches), the third radial position was located at 27.94 centimeters (11 inches), and the last radial position was located at 38.1 centimeters (15 inches). A total of 16 thermocouples per RCP were used, each connected to a USB-2416 and USB-TC data acquisition system [1]. Temperatures were recorded every minute for six months. The purpose for the six month data set was to ensure an adequate cementitious material curing cycle.

The RCPs were filled with the SRNL developed ZB-FF-8-D grout. Table I displays the ZB-FF-8-D grout mix design.

Table I. ZB-FF-8-D Grout for Uncongested Dry Areas Mix Materials

Material	**Amount**	**Total (for 2.09 cu yd per RCP)**
Portland Cement Type I/II	89 kg/m^3 (150 lbs/yd^3)	187 kg/m^3 (315 lbs/yd^3)
Fly Ash Type F	297 kg/m^3 (500 lbs/yd^3)	623 kg/m^3 (1050 lbs/yd^3)
Sand (Silica) C-33	1098 kg/m^3 (1850 lbs/yd^3)	2305 kg/m^3 (3885 lbs/yd^3)
Gravel (Granite) No. 8	475 kg/m^3 (800 lbs/yd^3)	997 kg/m^3 (1680 lbs/yd^3)
ADVA CAST 575	2.93 kg/m^3 (79 fl. oz/ yd^3)	6.15 kg/m^3 (165.90 fl. oz/ yd^3)
V-MAR 3	7.60 kg/m^3 (205 fl. oz/ yd^3)	15.60 kg/m^3 (430.50 fl. oz/ yd^3)
Water	247 kg/m^3 (50 gal/ yd^3)	519 kg/m^3 (105 gal/ yd^3)

The quality of the grout was verified using different American Society of Testing and Materials (ASTM) standards. Cylinders were made for each lift and were tested for fresh as well as cured properties. There were six cylinders created for each lift; three were for seven-day compressive strength testing and the remaining three for 28-day compressive strength testing. The following ASTM tests were conducted for the purpose of grout quality assurance [4-7]:

- *Standard Test Method for Temperature of Freshly Mixed Hydraulic-Cement Concrete*
- *Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete*
- *Standard Test Method for Slump Flow of Self-Consolidating Concrete*
- *Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens*
- *Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method*

For support, a unistrut system was placed around the pipes to prevent any movement. In addition, Crack-Stix Permanent Crack Filler was applied to the bottom of the RCPs to prevent grout from leaching out. Figure 1 shows the final setup.

Fig. 1. Experimental setup.

RESULTS & ANALYSIS

The results of the fresh and cured property testing are displayed in Table II.

Table II: Results for Fresh/Cured Grout Property Testing

Test	Day 1	Day 2
Temperature	305.67 K (90.8ºF)	304.67 K (89.0ºF)
Spread	0.48 meters (19 inches)	0.53-0.58 meters (21-23 inches)
Air Content	0.5%	0.3%
Solid Unit Weight	2295 kg/m^3 (143.30 lb/ft^3)	2270 kg/m^3 (141.70 lb/ft^3)
7-Day Compressive Strength	2523 kPa (366 psi)	2365 kPa (343 psi)
28-Day Compressive Strength	5708 kPa (828 psi)	5440 kPa (789 psi)

The grout's 28-day compressive strength values of 5708 kPa (828 psi) and 5440 kPa (789 psi) surpass the material compressive strength requirement of 345 kPa (50 psi) as set by SRS. These values provide evidence that the grout is curing correctly. Similarly, the spread values of 48.3-58.4 centimeters (19-23 inches) are close to or within the range of the 60.9$\pm$10 centimeters (24$\pm$4 inches) as attained by SRS.

After the first pour, the temperatures for both RCPs were collected and plotted to identify the maximum peak reached for the first 24 hours. Figure 2 shows the temperatures for RCP 1 and RCP 2, respectively. These temperatures correspond to the first five feet of the RCP. On the second and final pour, the temperatures for both RCPs were close to the ones from Day 1. Temperature peaks were successfully identified throughout the experiment. Figure 2 also shows some of the peaks identified while the temperature was reaching equilibrium.

In the radial direction, the data did not show significant temperature fluctuations (Figure 3). The data, however, showed that the highest temperature is not necessarily always at the core. For instance, some data points showed higher temperatures in the core with cooler temperatures on the outer segments, while other days the temperature was cooler in the core and warmer at the outer rim.

As seen in Figure 4, the equilibrium, values are usually in the range of 294.15 K to 297.15 K (69.8ºF–75.2ºF). The peaks that occurred are within two to three degrees Fahrenheit higher than the equilibrium range. The identified peaks were found to occur on a weekly basis. Despite the fact that peaks are expected to occur due to the reaction of fly ash with lime, the pattern of the highest peaks observed was consistently taking place early morning on Mondays. It is believed that such behavior may be directly related to the facility management practice of shutting off the air conditioning Friday evening to Monday morning. Gaps shown in Figure 4 can be attributed to malfunctioning of the data acquisition system during their respected time frames.

In comparison with the SRNL values, the variation ranged from 289.15 K to 294.15 K (60.8ºF-69.8ºF) with peaks up to 295.65 K (72.5ºF) [2]. Both thermal studies compliment each other and highlight the heat of hydration consistency during the curing process.

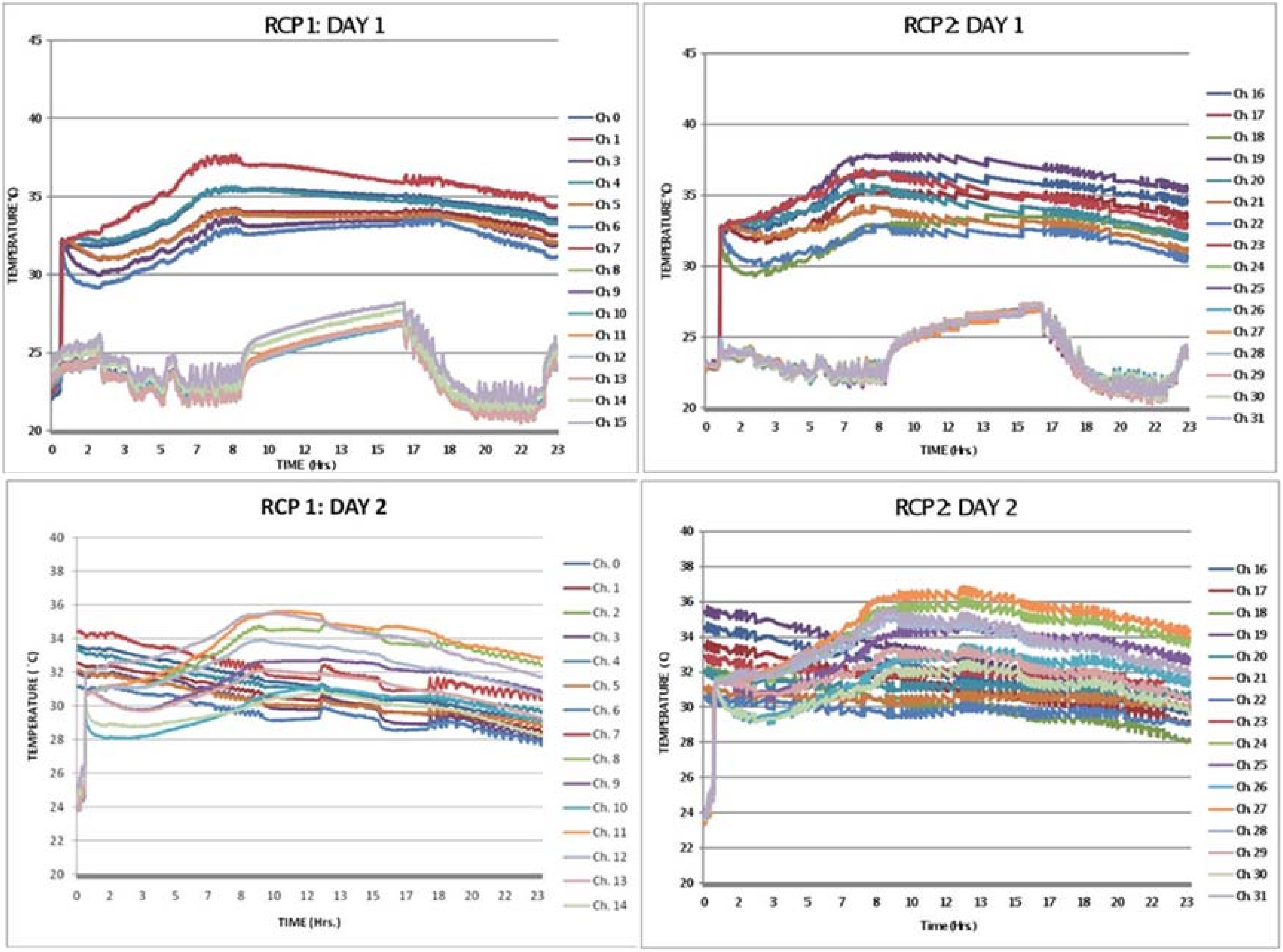


Figure 2: RCPs Day 1 & 2 Temperature Profiles

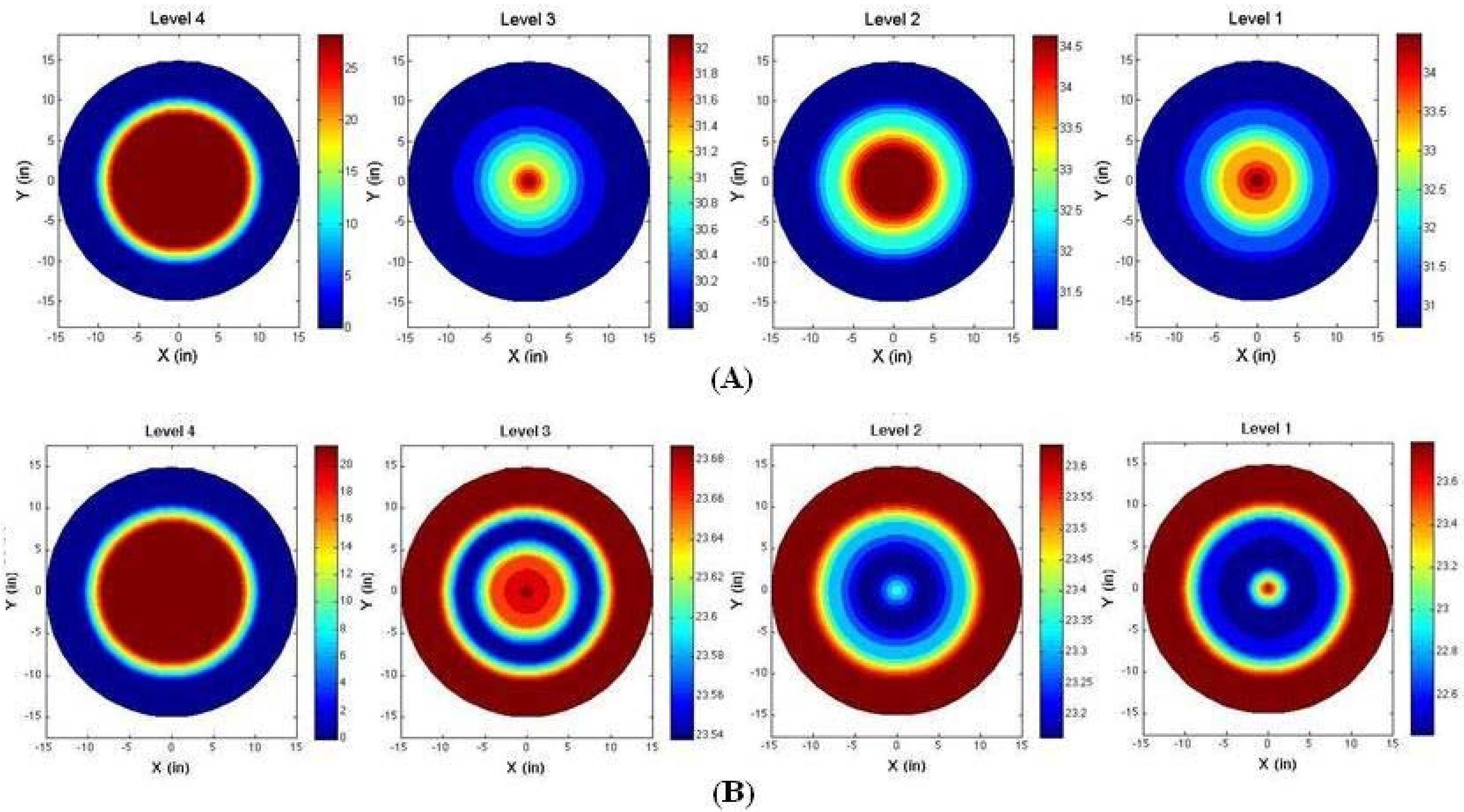
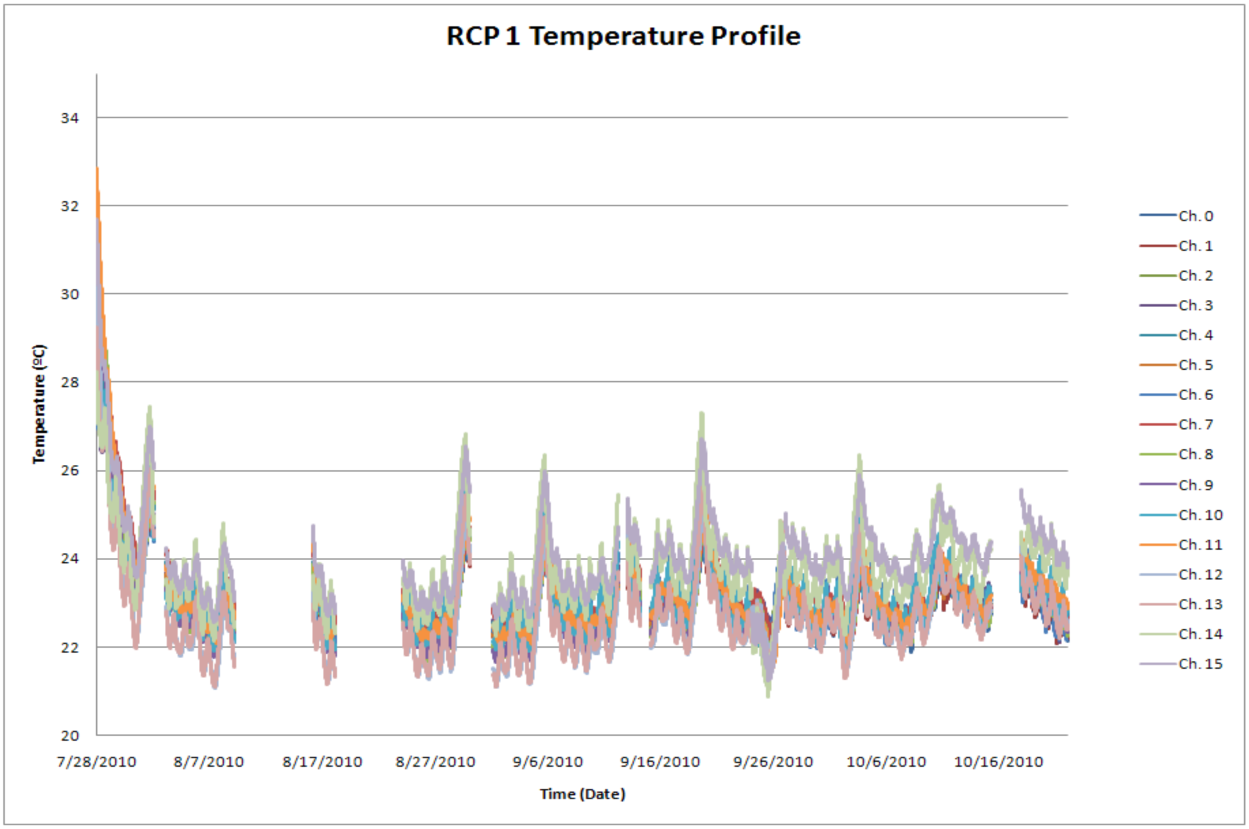


Figure 3: Radial Temperature Profiles for RCP 1; (A) Day 2; (B) Day 7



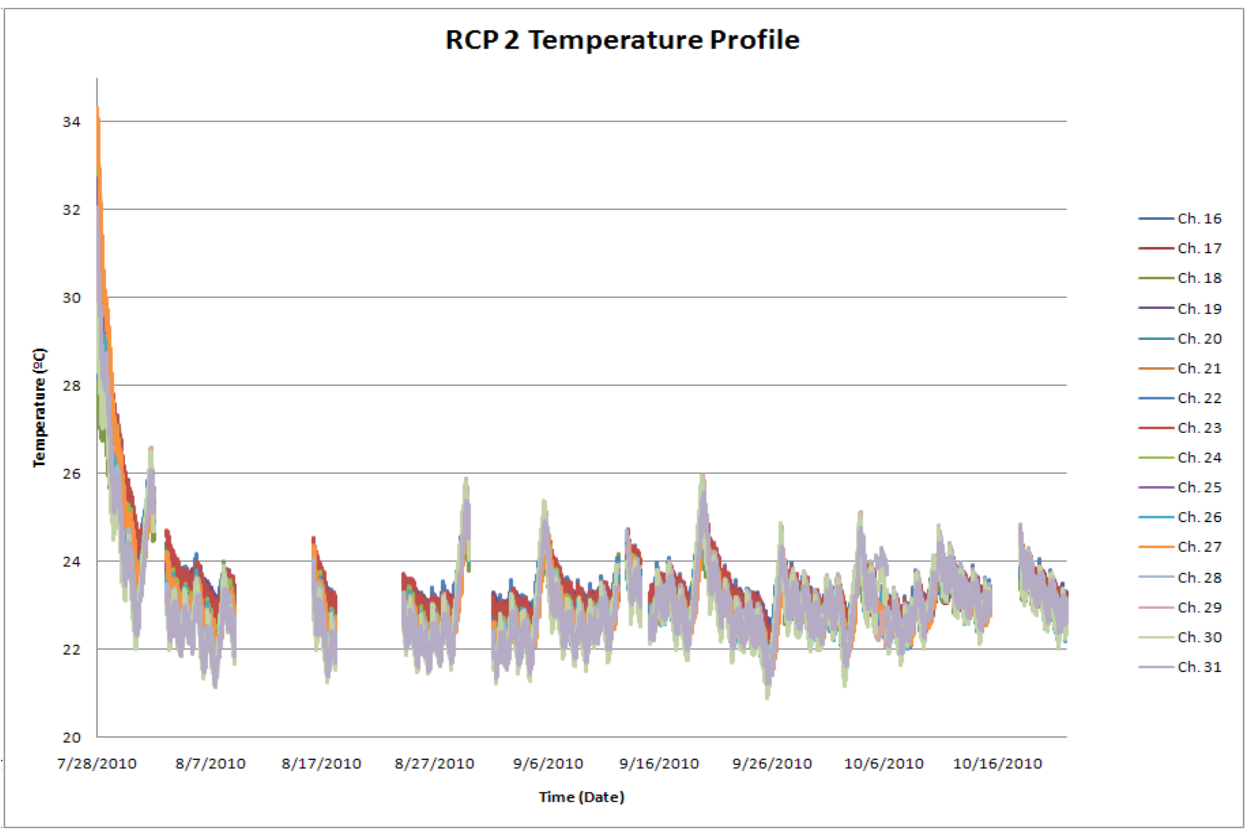


Figure 4: RCP 1 & 2 Temperature Profiles

CONCLUSION

The experiment was successfully conducted and met the proposed objectives. The results proved that the temperature generated by the grout does not affect its properties significantly, and that the grout is curing properly. The grout temperatures during the curing are a general indication of grout quality and material consistency.

Similarly, major temperature peaks were identified and were lower than the maximum temperature reached during the first 24 hours. Temperature peaks found at SRNL were lower than the peaks at FIU ARC. This may be due to the different ambient temperatures in both scenarios. The pouring at SRS took place between February and March when the ambient temperature was approximately 266-272 K (20-30ºF), while at FIU ARC the ambient temperature was around 303-311 K (85-100ºF) [2]. Ambient temperature fluctuations influence initial heat of hydration progression. Both thermal studies (SRNL & FIU) compliment each other and highlight the heat of hydration consistency during the curing process. These data sets provide a general indication of grout quality and material consistency.

Reactor facility decommissioning using an ISD approach of entombing the subsurface areas using zero bleed –flowable-self leveling grout is a viable fill material. Fill material consistency is needed to ensure the sustained durability and performance for the safe and cost effective disposition of robust nuclear facilities.

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