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OECD MCCI Project
Long-Term 2-D Molten Core Concrete Interaction Test
Design Report

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by:

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1.0 INTRODUCTION

1.1 Background and Objectives

The Melt Attack and Coolability Experiments (MACE) program at Argonne National Laboratory addressed the issue of the ability of water to cool and thermally stabilize a molten core-concrete interaction when the reactants are flooded from above. These tests provided data regarding the nature of corium interactions with concrete, the heat transfer rates from the melt to the overlying water pool, and the role of noncondensable gases in the mixing processes that contribute to melt quenching. As a follow-on program to MACE, The Melt Coolability and Concrete Interaction Experiments (MCCI) project is conducting reactor material experiments and associated analysis to achieve the following two technical objectives:

1. resolve the ex-vessel debris coolability issue through a program that focuses on providing both confirmatory evidence and test data for the coolability mechanisms identified in MACE integral effects tests, and

2. address remaining uncertainties related to long-term two-dimensional molten core-concrete interactions under both wet and dry cavity conditions.

Achievement of these two objectives will demonstrate the efficacy of severe accident management guidelines for existing plants, and provide the technical basis for better containment designs for future plants.

In terms of the first program objective, the Small-Scale Water Ingression and Crust Strength (SSWICS) test series has been initiated[1,2,3] to provide fundamental information on the ability of water to ingress into cracks and fissures that form in the debris during quench, thereby augmenting the otherwise conduction-limited heat transfer process. A test plan for Melt Eruption Separate Effects Tests (MESET) has also been developed[4] to provide information on the extent of crust growth and melt eruptions as a function of gas sparging rate under well-controlled experiment conditions.

In terms of the second program objective, the project Management Board (MB) has approved startup activities required to carry out experiments to address remaining uncertainties related to long-term two-dimensional molten core-concrete interaction. In particular, for both wet and dry cavity conditions, there is uncertainty insofar as evaluating the lateral vs. axial power split during a core-concrete interaction due to a lack of experiment data. As a result, there are differences in the 2-D cavity erosion predicted by codes such as MELCOR, WECHSL, and COSACO. The first step towards generating this data is to produce a test plan for review by the Project Review Group (PRG). The purpose of this document is to provide this plan.

1.2 Summary of Input Received from PRG

Technical guidance was requested from member organizations at the last PRG meeting to optimize the utility of the data obtained from these tests. A preliminary design description was developed by the project[5] and distributed by the Operating Agent to provide a basis for this input. In this document, it was proposed to carry out a test similar in scale to the MACE Scoping Test[6], which utilized a 30 cm x 30 cm concrete test section and ~ 100 kg initial melt mass. The basis for this test scale was that it would fit conveniently within the existing MACE test facility. However, the test would be carried out without water addition, which is consistent with the current test objectives.

Input was received from two organizations. The first was a combined response from the French institutions IRSN, CEA, and EDF[7]. The second was an in-kind contribution provided by the project Operating Agent, USNRC, in which a parametric series of calculations were carried out for the proposed experiment design using the CORCON module within MELCOR[8].

In the French analysis, both simplified scaling analysis and code calculations were carried out with the MCCI module MEDICIS within the ASTEC code V1. The results of this study indicated that although a test conducted in a 30 cm x 30 cm test section would provide plausible experiment results, a test within a 60 cm x 60 cm test section using ~ 400 kg corium melt mass would better match reactor scale conditions. In all cases computed with the ASTEC code, the radial and axial ablation depths were virtually identical, indicating a radial/axial power split (i.e., ratio) of ~ 1.

In the NRC MELCOR analysis, calculations focused on the 30 cm x 30 cm test design. A number of parameters were systematically varied to investigate the effect on the overall cavity erosion behavior, including heat transfer in radial and axial directions, total input power simulating decay heat, initial core melt mass, and initial core melt temperature. The parametric studies were carried out around a base case consisting of a 120 kg core melt mass in a 30 cm x 30 cm test section (viz. ~ 20 cm collapsed melt depth), 2250 K initial temperature, and standard heat transfer coefficients. The principal finding from this study was that the radial/axial power split was ~ 3 irrespective of most parametric variations. A calculation was also carried out for the 60 cm x 60 cm test section design using a 20 cm melt depth. The radial/axial power split was found to be ~ 3 for this case also. Note that the power splits predicted by the MELCOR and MEDICIS codes differ by a factor of three, highlighting the need for experimental data.

The results from these two sets of calculations[7,8] were factored into the test designs described in the next section.

2.0 FACILITY DESCRIPTION

The overall design resembles in large part the MACE Scoping Test[6], since this experiment was successful in demonstrating the approach for performing a 2-D core concrete experiment using Direct Electrical Heating (DEH). However, this experiment had several shortcomings that are addressed in the current design. These shortcomings included: i) inadequate basemat and sidewall instrumentation to resolve the power split (since it was a scoping test), and ii) poorly defined test initial conditions. The latter shortcoming resulted from the use of DEH for generating the initial melt volume *in situ*, which initiated radial sidewall ablation at least 60 minutes before axial ablation began.

In the design presented below, the first shortcoming is addressed by increasing the amount of instrumentation and performing posttest examinations to accurately determine the ablation profile. The second shortcoming is addressed by generating the melt with an exothermic chemical reaction to ensure well-defined initial conditions.

As described in Section 1.2, the preliminary test plan[5] assumed a 30 cm x 30 cm lower test section design, but the French analysis[7] indicated that a 60 cm x 60 cm design would produce test results that were more easily extrapolated to plant conditions. Thus, test section designs for both cases are presented below for consideration. The overall facility design is essentially the same in either case. On this basis, the overall design is described first, followed by presentation of the designs for the two different test section sizes.

2.1 Test Apparatus

The proposed 2-D core-concrete interaction test utilizes equipment and technology developed as part of the MACE program, which included long term experiments with sustained internal heating. The system consists of a test apparatus, a power supply for Direct Electrical Heating (DEH) of the corium, two off-gas cleanup tanks, a ventilation system to complete filtration and exhaust the off-gases, and a data acquisition system. A schematic illustration of the facility is provided in Figure 2-1. The apparatus for containment of the core material consists of a test section that is ~ 3 m tall with a square internal cross-section. The concrete crucible is located at the bottom of the test section. Figure 2-1 illustrates the 30 cm x 30 cm lower section installed in the facility; however, the overall facility design is the same for either lower test section size. As described in greater detail later in this section, the basemat and sidewalls of the lower section are instrumented with multi-junction Type K thermocouple (TC) arrays to measure the ablation front location. The basemat is also instrumented with axially mounted multi-junction Type C (tungsten/rhenium) TC's in long-body tungsten thermowells to measure MCCI temperatures.

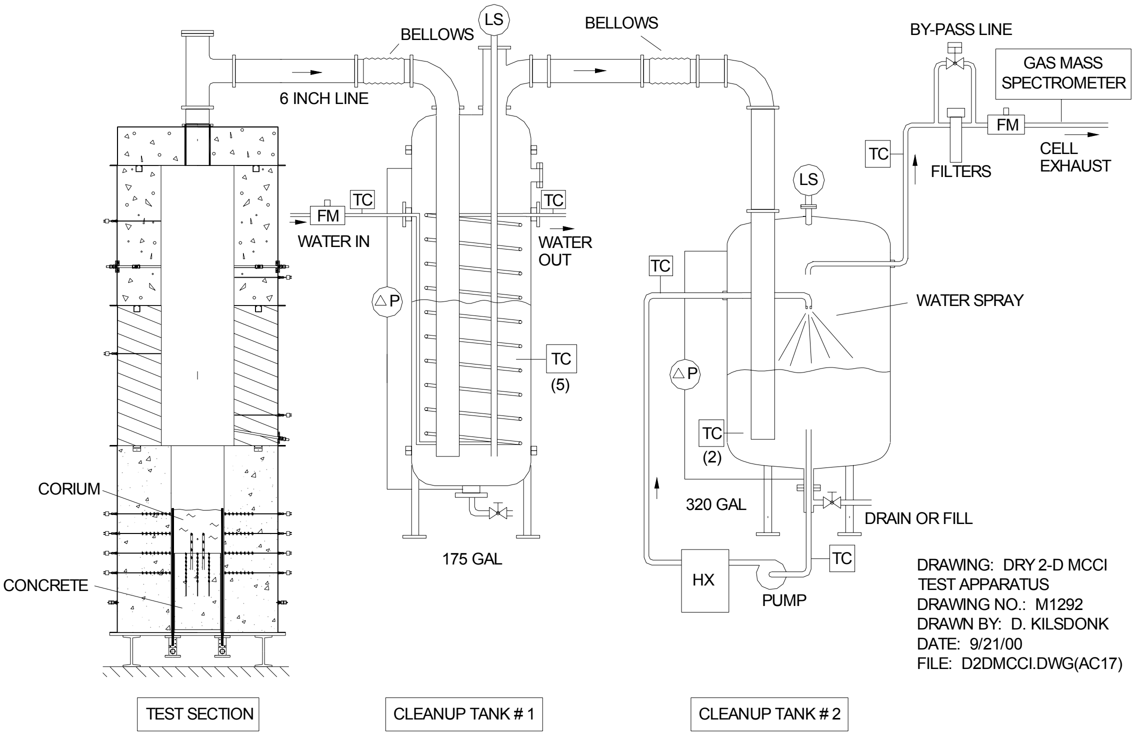


Figure 2-1. Apparatus for Long-Term 2-D Core-Concrete Interaction Tests.

Melt generation is achieved through an exothermic chemical reaction yielding the target initial melt mass over a timescale of ~ 1 minute. A wide range of initial melt depths can be generated, ranging from 10 to 25 cm in either test section design. There is also considerable flexibility in the initial concrete content of the melt, which can range from 8-20 wt %. Since DEH is used to simulate decay heat, the amount of metal in the initial melt mass is limited. Results of the ACE/MCCI tests indicate that this limit is nominally 10 wt %.

After the exothermic chemical reaction, DEH is supplied to the melt to simulate decay heat through two banks of tungsten electrodes mounted on opposing sides of the test section. The power supply for these tests has a capacity of 560 kW. The supply can be operated in either voltage or current control modes. The system is capable of delivering up to 1000 W/kg fuel equivalent power density. Results from the ACE/MCCI tests series indicate that melt mixing by sparging concrete decomposition gases is sufficient to ensure a relatively uniform melt temperature during the tests. Thus, the input power essentially appears uniform within the molten core debris. Furthermore, the results of the Scoping Test[6] indicate that the sidewall ablation behavior is essentially the same on both the electrode and non-electrode sidewalls of the test section, which further supports the apparent uniformity of the input power distribution.

As shown in Figure 2-1, a large (15 cm diameter) gas line is used to vent the helium cover gas and noncondensables from the MCCI to two adjacent tanks that are partially filled with water. In the MACE experiments, these tanks served to condense the steam and, based on the measured condensation rate, provided data on the corium cooling rate. However, in these dry core-concrete interaction experiments, the tanks serve only to cool the off-gases and filter aerosols generated from the MCCI. After passing through these two tanks, the cover gas and concrete decomposition gases (CO, CO_2, and H_2) are vented through an off gas system that includes a demister, filters, and a gas flow meter. A gas mass spectrometer provides information on the off gas composition versus time. The gases are exhausted through the containment ventilation system and a series of high efficiency filters before finally being released from the building stack.

It is important to note that these tests are conducted in the same facility where the debris coolability experiments are performed. Thus, the capability exists to add water atop the core debris at some pre-selected point in the experiment sequence.

2.2 Instrumentation

Instrumentation is selected to provide all measurements necessary to determine the time-dependent 2-D concrete ablation profile and the melt temperature distribution. The basemat and sidewalls of the test section are instrumented with multi-junction Type K thermocouple assemblies to determine 2-D ablation profile as a function of time. In addition, Type C thermocouple assemblies in tungsten thermowells protrude upwards from the concrete basemat in several locations. The purpose of these instruments is to provide data on the axial melt temperature distribution as a function of time. Additional information regarding the thermocouple locations is provided in the next two sections. The upper surface temperature of the corium will be monitored with a two-color optical pyrometer.

A uniform flow rate of helium is fed into the test section to suppress burning of combustible concrete decomposition gases (H_2 and CO) and to cool the test section internals.

As shown in Figure 2-1, the gas mixture is transported through a series of clean-up tanks before venting through the off-gas system. The off gas flow rate is measured with a flow meter. A gas sample is continuously drawn from the off-gas stream for analysis by an on-line gas mass spectrometer. This device provides the time-dependent flow rate of noncondensables from the core-concrete interaction (H_2, CO, CO_2) as the test progresses. One key design characteristic of this facility is that the lower test section is sealed to a leak pressure of nominally 70 kPa differential. Thus, all concrete decomposition gases are vented through the instrumented gas cleanup system. On this basis, the flow rate of decomposition gases from the test can be used to evaluate the integrated concrete ablation rate versus time.

Other significant test instrumentation includes a stationary (lid mounted) video camera for observing physical characteristics of the core-concrete interaction.

2.3 30 cm x 30 cm Lower Section Design and Test Specifications

Side and top views of the 30 cm x 30 cm test section design are shown in Figures 2-2 and 2-3, respectively, while plan and elevation views of the basemat thermocouple layout are provided in Figures 2-4 and 2-5. This particular test section size is noted to be identical to the MACE Scoping Test[6]. Specifications and parameter ranges for the 30 cm x 30 cm facility are summarized in Table 2-1. This test section has been designed to mate directly with the existing components from the MACE 50 cm x 50 cm test apparatus. Given the test section outer dimensions and basemat size, the corresponding concrete sidewall thickness is 38 cm. With this layout, the maximum axial and radial ablation depths are specified as 35 and 25 cm, respectively. The lower section can be fabricated from either siliceous or limestone-common sand concretes; the detailed concrete compositions are provided later in this section. Note from Figure 2-3 that the lower section is constructed from four individual sidewall components that are clamped together to form the completed assembly. This design is intended to provide enhanced posttest examination of the solidified corium by allowing all four sidewalls to be removed, thereby fully revealing the cavity erosion profile.

2.4 60 cm x 60 cm Lower Section Design and Test Specifications

Side and top views of the lower 60 cm x 60 cm test section are shown in Figures 2-6 and 2-7, respectively, while plan and elevation views of the basemat thermocouple layout are provided in Figures 2-8 and 2-9. Specifications and parameter ranges for the 60 cm x 60 cm facility are summarized in Table 2-2. To be consistent with the 30 cm x 30 cm design, the maximum radial and axial ablation limits (i.e., 25 cm and 35 cm, respectively) are maintained for this test section size. The sidewall thickness is also maintained at 38 cm to provide adequate margin against sidewall melt through. Given this choice of dimensions, a transition piece is required in order to mate this test section with the existing components from the MACE 50 cm x 50 cm test apparatus; see Figure 2-6. As with the previous 30 cm test section design, the 60 cm section is cast in modular form so that the sidewalls can be removed following the test to fully reveal the cavity erosion profile. The specifications for this facility are very similar to the 30 cm facility, with two exceptions: i) maximum initial melt depth (mass) is reduced to 25 cm (590 kg), and ii) maximum achievable input power density is reduced to 400 W/kg fuel.

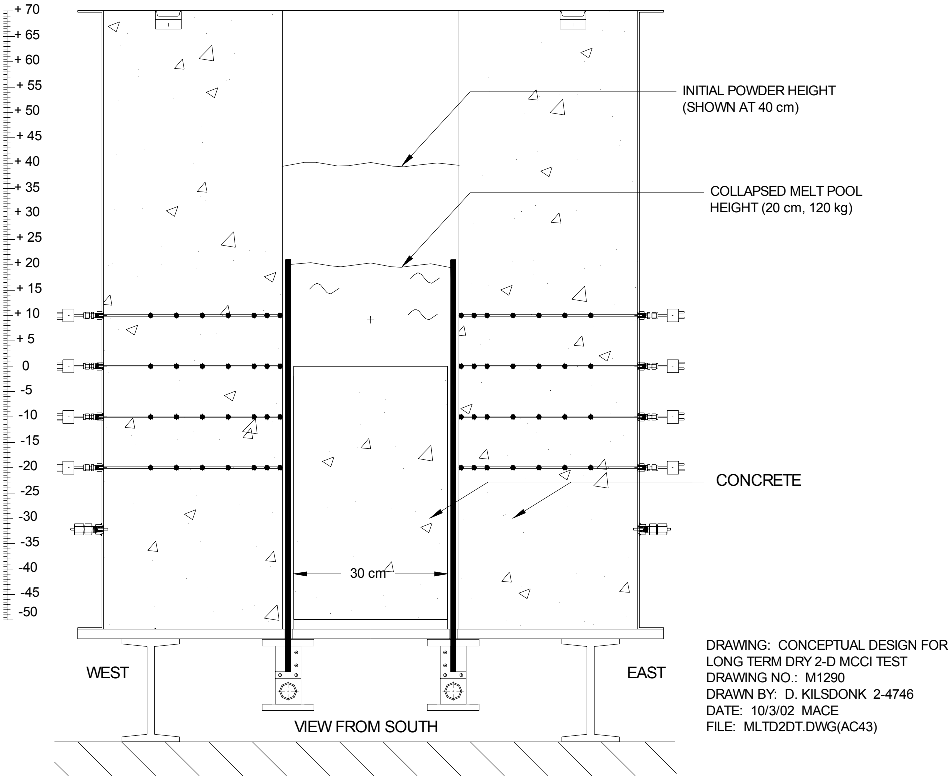


Figure 2-2. Side View of the 30 cm x 30 cm Test Section Design.

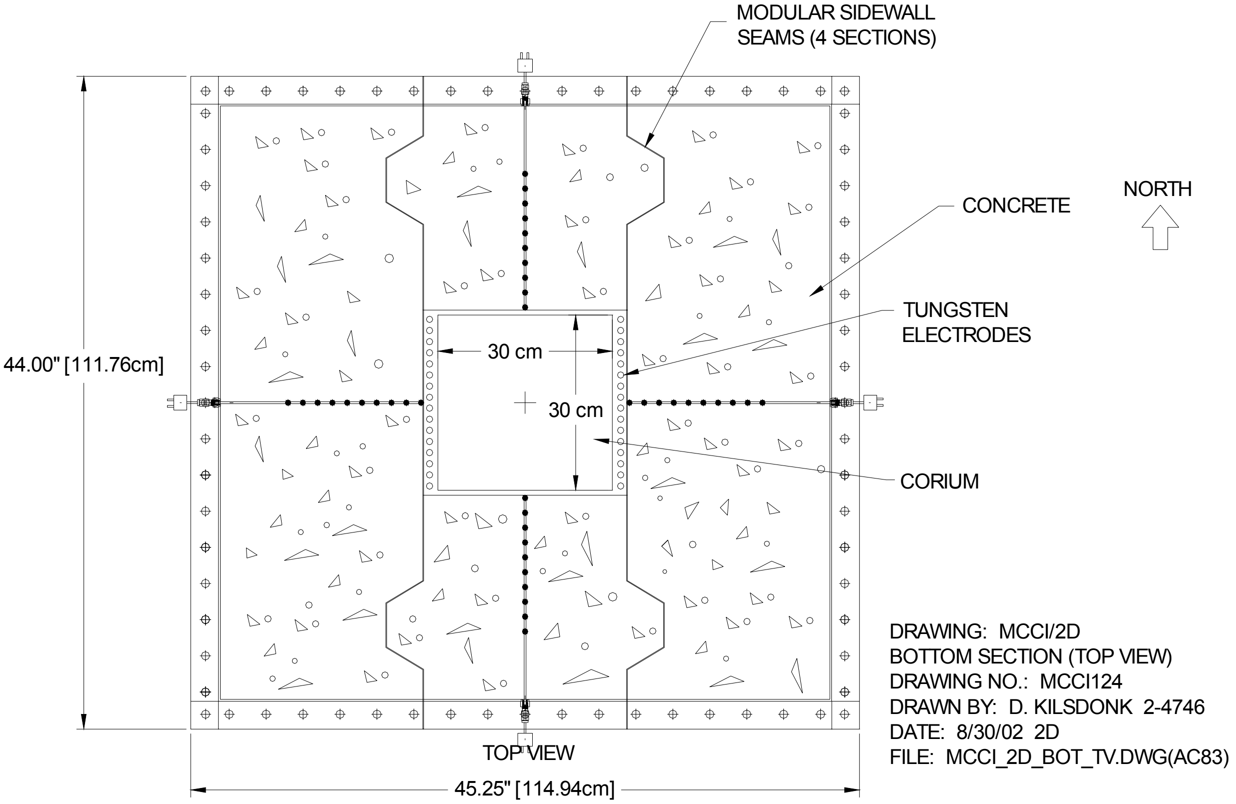
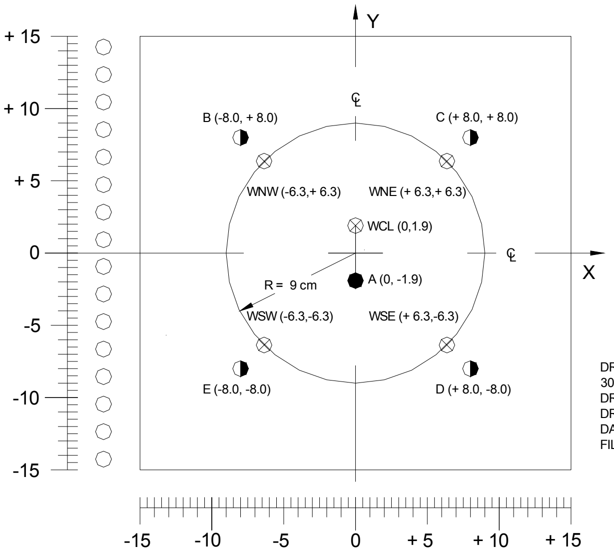


Figure 2-3. Top View of the 30 cm x 30 cm Test Section; Modular Casting Shown.



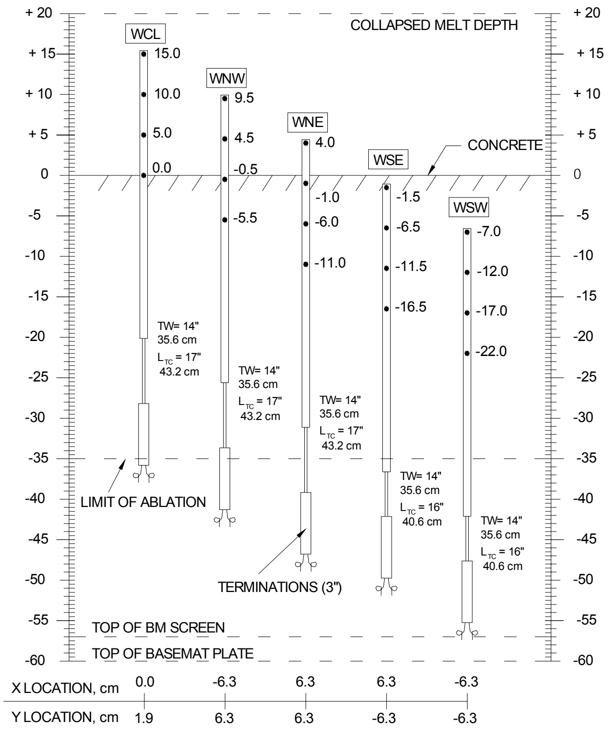
DRAWING: MCCI/CCI TC LAYOUT
30 cm X 30 cm BASEMAT (TOP VIEW)
DRAWING NO.: MCCI163
DRAWN BY: D. KILSDONK 2-4746
DATE: 10/3/02 CCI
FILE: CCI_TCL_30_TV.DWG(AC85)

● MULTI-JUNCTION Cr/Al, INCONEL 600 SHEATH, TIP OF TC FLUSH WITH BASEMAT SURFACE (1 UNIT, 10 JUNCTIONS).
LOCATIONS: 0.0, -2.5, -5.1, -7.6, -11.4, -15.2, -19.1, -24.1, -29.2, -34.3 cm.

⊗ MULTI-JUNCTION W5Re/W26Re, TANTALUM SHEATH, TUNGSTEN THERMOWELL (5 UNITS, 4 JUNCTIONS EA.).

◑ MULTI-JUNCTION Cr/Al, INCONEL 600 SHEATH, TIP OF TC FLUSH WITH BASEMAT SURFACE (4 UNITS, 8 JUNCTIONS EA.).
LOCATIONS: 0.0, -2.5, -5.1, -7.6, -11.4, -15.2, -24.1, -34.3 cm.

Figure 2-4. Plan View of 30 cm x 30 cm Basemat TC Locations (all dimensions are cm).



NOTE: ALL TC LOCATIONS ARE cm
TW = THERMOWELL
X, Y LOCATIONS ARE RELATIVE TO CENTER OF BASEMAT

DRAWING: MCCI/CCI TC LAYOUT
30 cm X 30 cm BASEMAT (SIDE VIEW)
DRAWING NO.: MCCI164
DRAWN BY: D. KILSDONK
DATE: 10/3/02
FILE: CCI_TCL_30_SV.DWG(AC85)

Figure 2-5. Elevation View of 30 cm x 30 cm Basemat Type C Thermocouple Locations.

Table 2-1. Specifications for the 30 cm x 30 cm Core Concrete Interaction Facility.

Parameter	Specification
Test Section Internal Dimension	30 cm x 30 cm
Freeboard Above Melt	> 2 meters
Test Section Internal Geometry	Square
Basemat and Sidewall Material	Concrete
Concrete Type	Siliceous or Limestone/Common Sand
System Operating Pressure	Atmospheric
Maximum Permissible Radial Ablation	25 cm
Maximum Permissible Axial Ablation	35 cm
Melt Formation Technique (Timescale)	Chemical Reaction (1 minute)
Initial Melt Temperature	2400 K (adjustable)
Initial Melt Depth (Range)	10 → 35 cm
Corresponding Initial Melt Mass[a]	60 → 200 kg
Initial Corium Concrete Content (Range)	6→ 20 wt %
Melt Heating Technique	Direct Electrical (Joule) Heating
Equivalent Input Power Density (Range)	0 → 1000 W/kg fuel
Input Power Distribution	Approximately Homogeneous
Input Power Control	Continuous

[a] Based on an assumed melt density of 6500 kg/m^3

Table 2-2. Specifications for the 60 cm x 60 cm Core Concrete Interaction Facility.

Parameter	Specification
Test Section Internal Dimension	60 cm x 60 cm
Freeboard Above Melt	> 2 meters
Test Section Internal Geometry	Square
Basemat and Sidewall Material	Concrete
Concrete Type	Siliceous or Limestone/Common Sand
System Operating Pressure	Atmospheric
Maximum Permissible Radial Ablation	25 cm
Maximum Permissible Axial Ablation	35 cm
Melt Formation Technique (Timescale)	Chemical Reaction (1 minute)
Initial Melt Temperature	2400 K (adjustable)
Initial Melt Depth (Range)	10 → 25 cm
Corresponding Initial Melt Mass[a]	240 → 590 kg
Initial Corium Concrete Content (Range)	6→ 20 wt %
Melt Heating Technique	Direct Electrical (Joule) Heating
Equivalent Input Power Density (Range)	0 → 400 W/kg fuel
Input Power Distribution	Approximately Homogeneous
Input Power Control	Continuous

[a] Based on an assumed melt density of 6500 kg/m^3

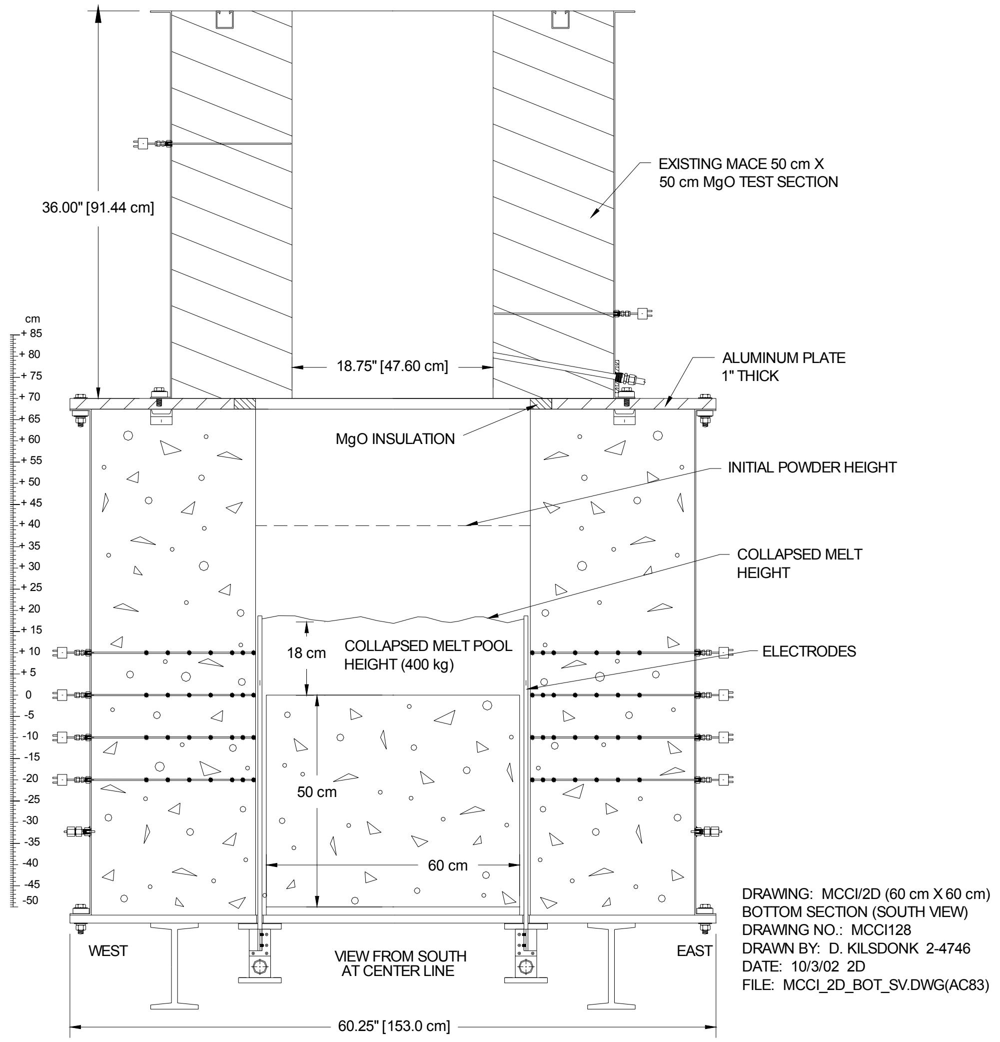


Figure 2-6. Side View of 60 cm x 60 cm Lower Test Section Design, Including the Transition Piece to the 50 cm x 50 cm Middle Test Section.

2.5 Data Acquisition and Control Systems

All data acquisition and process control tasks are managed by a PC executing LabVIEW 6.i under Windows XP. Sensor output terminals are connected to model HP E1345A 16-channel multiplexers and the signals are digitized by an HP E1326B 5 ½ digit multimeter located within the test cell; see Figure 2-10. Signal noise is reduced by integration over a single power line cycle (16.7 ms). The digitized sensor readings are routed from the test cell to the PC in the control room via two HP-IB extenders. The extenders allow the ASCII data from the HP to be sent through the cell wall over a BNC cable. The extender within the control room then communicates with a GPIB card within the PC. This configuration also permits remote control of the multimeter through LabVIEW. The power line cycle integration results in a minimum (theoretical) time of ~ 3.3 s to scan the channel list (16.7 ms • 200 channels). In practice, however, the acquisition of a single scan is at a frequency of approximately 0.2 Hz.

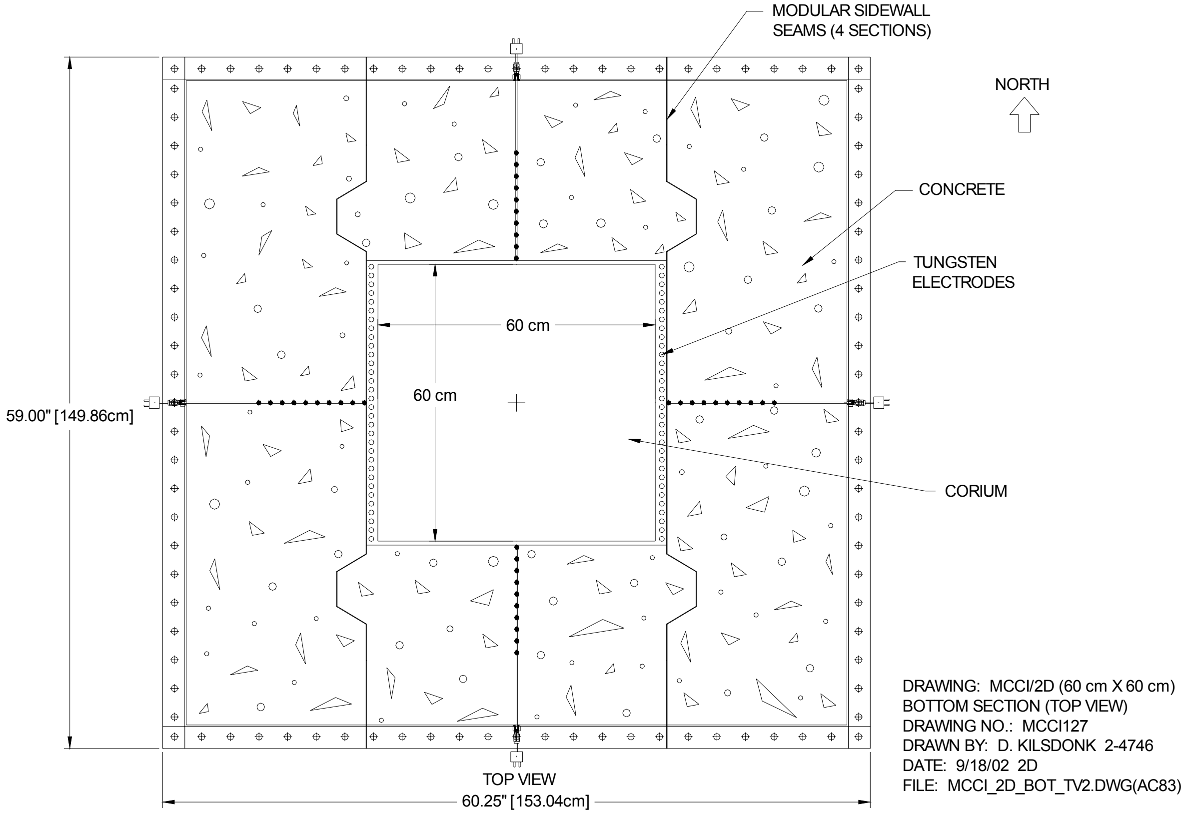
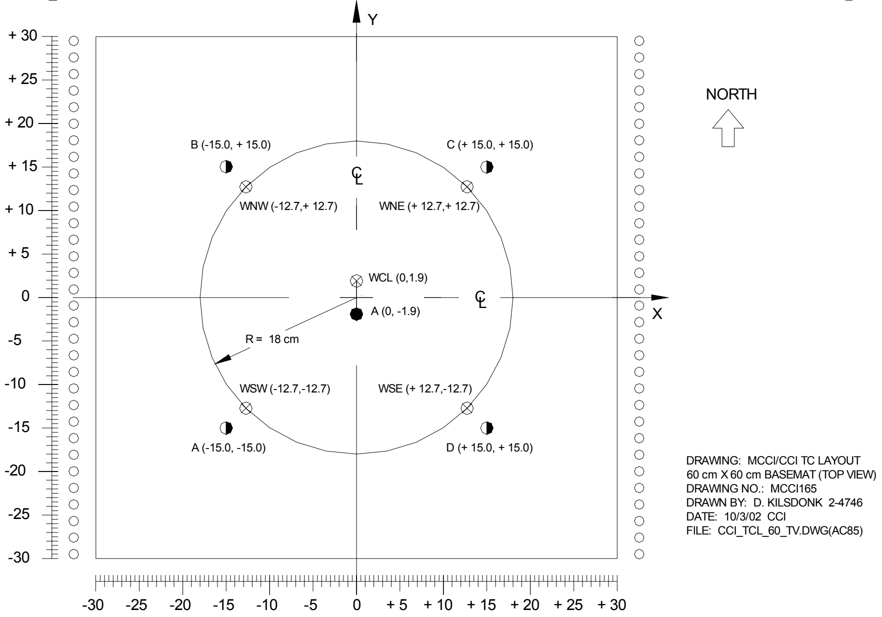


Figure 2-7. Top View of the 60 cm x 60 cm Test Section; Modular Casting Shown.



● MULTI-JUNCTION Cr/Al, INCONEL 600 SHEATH, TIP OF TC FLUSH WITH BASEMAT SURFACE (1 UNIT, 10 JUNCTIONS).
LOCATIONS: 0.0, -2.5, -5.1, -7.6, -11.4, -15.2, -19.1, -24.1, -29.2, -34.3 cm.

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LOCATIONS: 0.0, -2.5, -5.1, -7.6, -11.4, -15.2, -24.1, -34.3 cm.

Figure 2-8. Plan View of 60 cm x 60 cm Basemat TC Locations (all dimensions are cm).

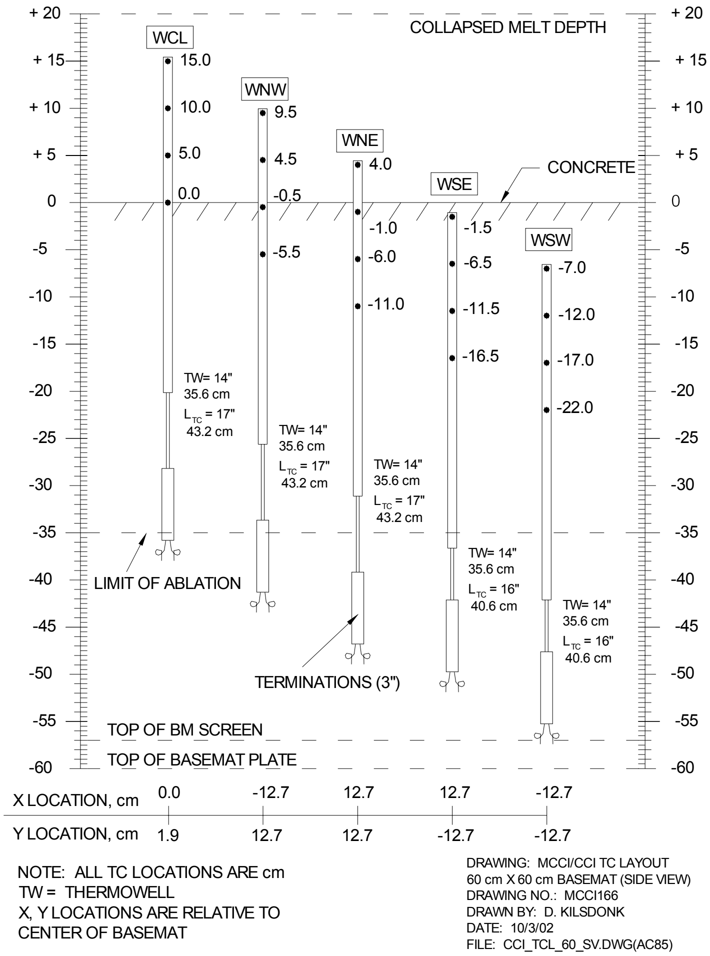

Figure 2-9. Elevation View of 60 cm x 60 cm Basemat Type C Thermocouple Locations.

Valves are controlled with the PC using a relay card housed within an SCXI chassis (National Instruments). These electromechanical relays are capable of switching up to 8 A at 125 VAC or 5 A at 30 VDC. They are operated via a switch controller in the SCXI chassis, which communicates with the PC through a general-purpose data acquisition card. As shown in Figure 2.6, the relays in the control room operate devices within the test cell indirectly, through a second relay. This is intended to provide an additional level of electrical isolation between the NI switching hardware and high voltage sources within the cell. As an added safety measure, all wiring is routed through a control panel that can be switched from automatic (PC) control to manual control in the event of computer failure. The system is currently configured to operate eight relays, but expansion to 24 is possible.

2.6 Corium Compositions

Although a wide variety of corium compositions can be considered in these tests, it is envisioned that at least two experiments will be performed within limestone/common sand and siliceous concrete test sections. As part of the preparations for the SSWICS tests, thermites were developed to produce corium compositions that contain ~8 wt % concrete decomposition products at an initial bulk melt temperature of ~ 2200 C. These thermites

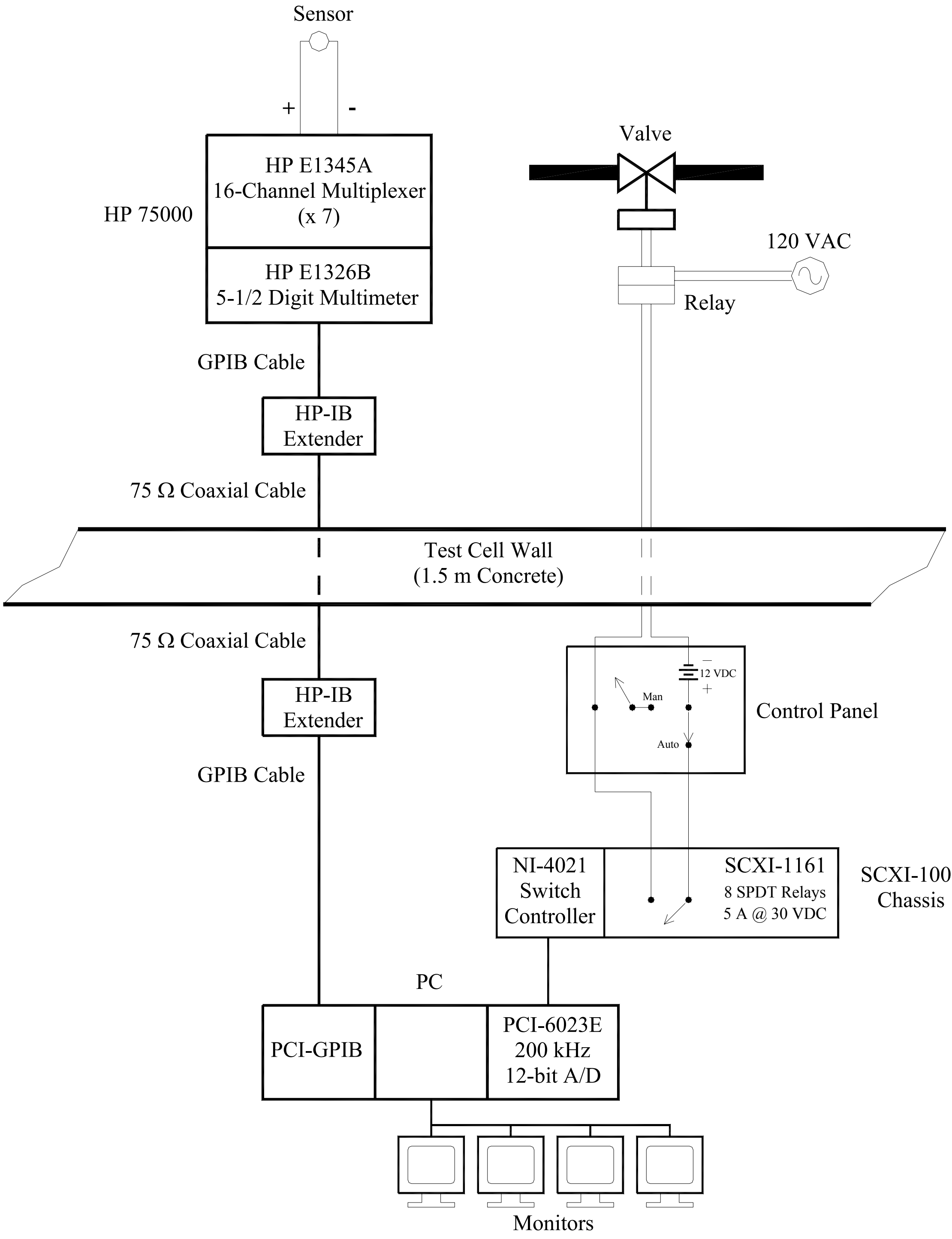

Figure 2-10. Data Acquisition and Control Systems.

were reformulated to achieve a hotter initial temperature in comparison to the MACE thermites, which typically reacted at 1970 C. Secondly, the core/cladding ratio in the reaction byproducts was increased to be more representative of a PWR core melt composition.

The thermite reaction that was developed to produce a fully oxidized (with respect to cladding content) core melt containing 8 wt % limestone/common sand concrete decomposition products is of the form:

$$1.22U_3O_8 + 3.3Zr + 0.6Si + 0.32SiO_2 + 0.46Mg + 0.91\ CaO + 0.13Al + 2.01CrO_3 \rightarrow$$

$$3.66UO_2 + 3.3ZrO_2 + 0.92SiO_2 + 0.46MgO + 0.91CaO + 0.065Al_2O_3 + 2.01Cr;$$

$$Q = -262.2\ \text{kJ/mole}\ (1.816\ \text{MJ/kg});$$

$$T_{adiabatic} = 2568\ \text{C}$$

$$T_{actual} \sim 2250\ \text{C}$$

The composition of the melt produced from this reaction is summarized in Table 2-3, while the detailed pre- and post-reaction compositions are provided in Table 2-4.

The thermite reaction that was developed to produce a fully oxidized core melt containing 8 wt % siliceous concrete decomposition products is of the form:

$$1.22U_3O_8 + 3.3Zr + 0.58Si + 1.14SiO_2 + 0.026Mg + 0.36\ CaO + 0.12Al + 1.842CrO_3 \rightarrow$$

$$3.66UO_2 + 3.3ZrO_2 + 1.72SiO_2 + 0.026MgO + 0.91CaO + 0.36Al_2O_3 + 1.842Cr;$$

$$Q = -252.2\ \text{kJ/mole}\ (1.71\ \text{MJ/kg});$$

$$T_{adiabatic} = 2572\ \text{C}$$

$$T_{actual} \sim 2250\ \text{C}$$

The composition of the melt produced from this reaction is summarized in Table 2-3, while the detailed pre- and post-reaction compositions are provided in Table 2-5. Given the fact that both of these thermites have been developed and tested in experiments at a scale equivalent to 75 kg core melt mass, it is recommended to consider these for use in the core-concrete interaction experiments.

Table 2-3. Post-Reaction Compositions for Thermites Which Produce Fully Oxidized Core Melts Containing 8 wt % Concrete at 2250 C.

Constituent	Wt % Constituent for Test:	
	Limestone/Common Sand Concrete Thermite	Siliceous Concrete Thermite
UO_2	60.62	60.97
ZrO_2	24.90	25.04
Calcined Concrete	8.07[a]	8.08[b]
Cr	6.41	5.91

[a] Calcined limestone/common sand concrete, consisting of 42.0/14.1/38.8/5.1 wt% $SiO_2/MgO/CaO/Al_2O_3$

[b] Calcined siliceous concrete, consisting of 79.0/0.9/15.4/4.7 wt% $SiO_2/MgO/CaO/Al_2O_3$

Table 2-4. Pre- and Post-Reaction Compositions for Thermite Containing 8 wt % Limestone/Common Sand Concrete Decomposition Products.

Constituent	Wt %	
	Reactant	Product
U_3O_8	63.01	-
UO_2	-	60.62
Zr	18.42	-
ZrO_2	-	24.90
Si	1.03	-
SiO_2	1.18	3.39
Mg	0.69	-
MgO	-	1.14
Al	0.22	-
Al_2O_3	-	0.41
CaO	3.13	3.13
CrO_3	12.32	-
Cr	-	6.41

Table 2-5. Pre- and Post-Reaction Compositions for Thermite Containing 8 wt % Siliceous Concrete Decomposition Products.

Constituent	Wt %	
	Reactant	Product
U_3O_8	63.38	-
UO_2	-	60.97
Zr	18.53	-
ZrO_2	-	25.04
Si	1.00	-
SiO_2	4.23	6.38
Mg	0.04	-
MgO	-	0.07
Al	0.20	-
Al_2O_3	-	0.38
CaO	1.25	1.25
CrO_3	11.37	-
Cr	-	5.91

2.7 Concrete Compositions

The test sections can be fabricated from either siliceous or limestone/common sand concretes; nominal compositions for these two materials are provided in Table 2-6. These concretes are identical to those used in the ACE/MCCI and MACE experiment programs.

Table 2-6. Chemical Composition of Siliceous and Limestone/Common Sand Concretes.

Constituent	Weight % Constituent for Concrete Type:	
	Siliceous	Limestone/Common Sand
SiO_2	63.9	28.8
MgO	0.6	9.7
CaO	12.6	26.5
Al_2O_3	3.7	4.0
K_2O	1.3	0.6
Fe_2O_3	0.9	1.0
TiO_2	0.7	0.8
Na_2O	0.6	1.1
H_2O	5.4	6.1
CO_2	10.3	21.4
Total	100.0	100.0

3.0 TEST PROCEDURES

3.1 Pretest Preparations

Assembly of the apparatus begins through the installation of tungsten electrodes into machined copper electrode clamps. The electrode clamps are then attached to the bottom of the 1.9 cm thick aluminum support plate, which serves as the foundation for the entire apparatus. With the electrode clamps installed, the support plate is moved into position on the test stand. The instrumented basemat and lower section concrete sidewall components (four total) are then set in place on the support plate. The lower section flange bolts and clamping bars are then installed and tightened. Before any additional assembly work is performed, the lower section is leak checked to identify any large leakage paths in critical areas located on the bottom of the test section (i.e., instrumentation bundle feed throughs and electrode penetrations), which would be difficult to repair once the test section was fully assembled. Following this step, the basemat instruments are connected to terminal boxes that are prewired to the data acquisition system.

Once the lower section is assembled and leak checked, preparations for loading of the corium charge are initiated. A single large 1.7 mil aluminized Saran bag is preinstalled over the basemat. During loading, most of the thermite is repackaged into this single bag in order to reduce the amount of bagging material present in the thermite charge. Once the large Saran bag is filled with thermite, the top is folded and sealed. Tungsten starter coils (4 total) for initiating the thermite reaction are then connected near the tops of the electrodes and laid on top of the large Saran bag. Finally, several individual bags of thermite are laid on top of the coils, thereby completing the loading procedure.

Once loading is completed, the remainder of the test apparatus is assembled. This includes installation of the two upper sections and the enclosure lid. Peripheral instrumentation, including the lower section sidewall Type K TC's used to monitor the radial ablation progression, is then installed and connected to terminal boxes. The main gas line from the test section to the quench tank is installed, as well as the pressure relief line from the test section to the auxiliary tank. After assembly is completed, system checkout is performed to ensure that the facility is in proper working order. This includes a proof test of the test section at 83 kPad, which is 20 % in excess of the pressure relief system activation pressure of 69 kPad.

3.2 Test Operations

Prior to initiating the thermite reaction, a helium gas flow rate is established through the lid of the test section. The thermite is ignited by applying 60 Amps to each of the four tungsten starter coils located at the top of the charge. Once the burn is complete (~ 1 minute), the power supply is ramped at a rate of ~ 3000 Amps/minute up to the initial target power level which is part of the test specifications. After this point, input power is maintained at the initial level until onset of basemat ablation is detected by the Type K thermocouples located in the basemat. Experience in the MACE program has shown that a crust initially forms on the basemat after the thermite reaction (and presumably on the concrete sidewalls also). Thus, a preheat stage of 10-20 minutes duration is required before the basemat interface is heated sufficiently to initiate ablation. During this period, it is recommended to maintain constant input power.

At the point basemat ablation is initiated, the time is marked. After this time, the power supply voltage is continuously adjusted to match a specified power input profile. The test continues in this manner until the axial ablation limit of 35 cm is reached, or the radial limit of 25 cm is reached in any one of the four sidewalls. At this point, the test is terminated.

It is of interest to evaluate the duration of the core-concrete interaction for this experiment under a few different modeling assumptions. For the 30 cm test section design, if an initial melt depth of 20 cm is utilized and an input power of ~ 250 W/kg fuel is assumed, then the initial gross input power will correspond to 17 kW. Assuming that 100 % of the input power is dissipated through radial ablation, then the average heat flux to the sidewalls is evaluated as ~70 kW/m^2 (i.e., 17 kW distributed over 0.24 m^2 of sidewall surface area initially in contact with the melt). Assuming a LCS concrete density of 2450 kg/m^3 and a decomposition enthalpy of 2.6 MJ/kg, then the radial ablation rate for this case is evaluated as 4 cm/hour. On this basis, the test would be terminated after ~ 6.25 hours of core-interaction after reaching the maximum radial ablation depth of 25 cm.

Conversely, assuming 100 % of the input power is dissipated through axial ablation, then the heat flux to the basemat is evaluated as 190 kW/m^2 given the basemat surface area of 0.09 m^2. The axial ablation rate for this case is thus evaluated as 10 cm/hour given the assumed thermophysical properties. On this basis, the test would be terminated after 3.5 hours of core-concrete interaction after reaching the maximum axial ablation depth of 35 cm.

Finally, assuming that the input power is uniformly distributed over all surfaces of the melt (top, bottom, and sides) then the average surface heat flux amounts to 40 kW/m^2. In this case, the average concrete ablation rate is evaluated as 2.2 cm/hour, and the test would be terminated after 11.4 hours after reaching the maximum sidewall ablation depth of 25 cm. Similar results would be predicted for the 60 cm x 60 cm test section if the same power density is assumed.

3.3 Posttest Operations

Following the experiment, the apparatus is carefully disassembled to document the posttest debris configuration. The test section main gas line, lid, and the top and middle sidewall sections are removed to reveal the lower test section, which contains the solidified core debris. The upper surface of the debris is then photographed, and specimens are collected for subsequent chemical analysis. At this point, two vertical core samples will be drilled through the extent of the corium. The cores will be removed, photographed, and samples will be collected at several different axial elevations for characterization by Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP/AES). This analysis will provide raw data on the axial composition variation within the material.

After the samples are collected, a probe will be inserted into at least one core hole to collect more detailed information on the axial distribution of UO_2 within the solidified debris. This probe utilizes Thermal Luminescent Dosimetry (TLD) chips to provide a direct measurement of the radiation dose level as a function of axial location within the solidified corium. This data, when correlated with the chemical analysis results, provides a detailed measurement of the axial UO_2 distribution.

After these measurements are collected, the four concrete sidewalls of the lower section will be removed, thereby fully revealing the solidified corium over the remaining basemat. Since the corium is revealed, a detailed map of the cavity erosion profile can be developed. Additional chemical samples will be collected at this point in order to further characterize the debris through chemical analysis. When these measurements are completed, the corium ingot will be placed in a storage container and archived as part of the test records. The four concrete sidewalls will be disposed of as radioactive waste.

4.0 REFERENCES

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