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OECD MCCI Project

Category 4 Integral Test to Validate Severe Accident Codes:

Core-Concrete Interaction Test Six (CCI-6) Test Plan

Rev. 6 - Final

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by:

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1.0 INTRODUCTION

1.1 Background

Ex-vessel debris coolability is an important light water reactor (LWR) safety issue. For existing plants, resolution of this issue will confirm the technical basis for severe accident management guidelines (SAMGs). For new reactors, understanding this issue will help confirm the effectiveness of the design and implementation of new accident mitigation features and severe accident management design alternatives (SAMDAs). The first OECD-MCCI program conducted reactor material experiments focused on achieving the following technical objectives: i) provide confirmatory evidence and data for various cooling mechanisms through separate effect tests for severe accident model development, and ii) provide long-term 2-D core-concrete interaction data for code assessment and improvement.

Debris cooling mechanisms investigated as part of the first MCCI program included: i) water ingression through cracks/fissures in the core debris, ii) melt eruption caused by gas sparging, and iii) large-scale crust mechanical failure leading to renewed bulk cooling. The results of this testing and associated analysis provided an envelope (principally determined by melt depth) for debris coolability. However, this envelope does not encompass the full range of potential melt depths for all plant accident sequences. Cooling augmentation by additional means may be needed at the late stage to assure coolability for new reactor designs as well as for various accident sequences for existing reactors. In addition, the results of the CCI tests showed that lateral/axial power split is a function of concrete type. However, the first program produced limited data sets for code assessment. In light of significant differences in ablation behavior for different concrete types, additional data will be useful in reducing uncertainties and gaining confidence in code predictions.

Based on these findings, a broad workscope was defined for the follow-on MCCI program. The workscope can be divided into the following four categories:

1. Combined effect tests to investigate the interplay of different cooling mechanisms, and to provide data for model development and code assessment purposes.

2. Tests to investigate new design features to enhance coolability, applicable particularly to new reactor designs.

3. Tests to generate two-dimensional core-concrete interaction data.

4. Integral tests to validate severe accident codes.

In addition to the experimental work, an analysis task was defined to develop and validate coolability models to form the basis for extrapolating the experiment findings to plant conditions.

As one of the steps required to satisfy these objectives, the Management Board (MB) has approved the conduct of the first Category 4 Test. In particular, the following PRG recommendation was approved at the 5th PRG meeting which contains specifications for this test:

The PRG recommends that the OA design a 70 cm x 70 cm test, with two concrete side walls, using CEA siliceous concrete, 6 wt% concrete composition, early top flooding initiated when ablation is established and melt temperature has stabilized. The melt depth shall be 30 cm. The test will be designed for two specific phases. The first phase will provide for 30 cm for radial ablation and 25 cm for vertical ablation. In the event that the melt is not cooled down by top flooding during the first phase, a second and separate test phase will begin involving bottom flooding. This second phase will be initiated when axial ablation depth reaches 25 cm. The design should be mindful of the curing time of the concrete. The instrumentation should be refined to provide data on the water injection characteristics and melt temperature near the lateral walls.

1.2 Objectives

In response to this recommendation, the objective of this document is to provide a summary test plan for this sixth Core-Concrete Interaction (CCI-6) experiment for PRG review. Test specifications that were developed as part of the design work are provided in Table 1-1.

1.3 Summary Design Approach

The experiment approach is to incorporate an array of water nozzles into the core-concrete interaction test apparatus. The test section has been enlarged to incorporate a 70 cm x 70 cm basemat. The initial melt depth has been increased to 28 cm,[1] which corresponds to a thermite charge mass of 900 kg. The melt depth is noted to be slightly less than the 30 cm level requested by the PRG. The thermite charge has been redesigned to include a reduced amount of concrete decomposition products (i.e., 6 wt %) relative to the previously performed CCI tests. The concrete sidewalls allow for 24 cm of lateral erosion, and the sidewall design has been modified to include refractory MgO with a UO_2 pellet liner to stop the ablation after the 24 cm ablation depth is reached. The basemat and sidewalls also include an array of 45 concrete nozzles that are arranged on a 14 cm lateral pitch and are located at a uniform depth of 27.5 cm below the initial concrete basemat surface elevation. The nozzles are originally sealed at the top, and are fed with water from a common water supply tank that provides a static water head of nominally 10 kPa measured at the upper surface of the nozzles.

The planned operating sequence is to ignite the thermite and then provide 210 kW Direct Electrical Heating (DEH) to simulate decay heat. The concrete will then heat up and begin erosion. At this point, the cavity will be flooded from the top. If the melt is not cooled, then the core-concrete interaction will continue until the 27.5 cm axial ablation depth is reached. At this point, the nozzles will open by erosion and thus initiate cooling by bottom water injection. The test will continue to operate until the melt is quenched, or the maximum axial ablation depth of 32.5 cm is reached. The experiment will then be terminated. The balance of this report provides design and operational details for the CCI-6 experiment.

[1]The 28 cm melt depth is less than the 30 cm requested by the PRG. However, to achieve this depth the metal reaction byproduct in the melt would exceed that which, when oxidized, would produce sufficient H_2 to exceed 80 % of the lower flammability limit (LFL) in the test cell volume. This is one of the current safety limitations for the tests. Thus, the 28 cm melt depth (viz. 900 kg melt mass) is adopted to conform to the safety limitation and thereby minimize scheduling risks related to safety plan approvals.

Table 1-1. Specifications for CCI-6.

Parameter	Specification
Corium	100 % oxidized PWR with 6 wt % siliceous concrete (CEA type)
Test section cross-sectional area	7 cm x 70 cm
Initial melt mass (depth)	900 kg (28 cm)[a]
Test section sidewall construction	24 cm thick concrete followed by MgO protected with a 2.5 cm thick layer of crushed UO_2 pellets and powder.
Test section basemat construction	48.1 cm thick concrete with an array of water injection nozzles embedded at a depth of 27.5 cm from the concrete top surface. Nozzles are uniformly pitched at a lateral spacing of 14.0 cm.
Sidewall maximum ablation depth	24.0 cm
Basemat maximum ablation depth	32.5 cm
System operating pressure	Atmospheric
Melt formation technique	Chemical reaction (~30 second reaction time)
Initial melt temperature	~2300 ºC
Melt heating technique	Direct Electrical (Joule) Heating
Melt heating method under dry cavity conditions	Constant power at 210 kW[b]
Melt heating method after cavity flooding	Constant voltage (preserves melt specific power density established prior to cavity flooding)
Criteria for top cavity flooding	Any combination of two different thermocouples located 2.5 cm within the concrete indicate arrival of the ablation front
Top flooding water inlet conditions	Inlet water temperature: 15 ºC Inlet water flowrate: ~ 2 liters/sec Sustained[c] water depth over melt: 25 ± 5 cm
Criterion for bottom water injection	Passive opening of nozzles once the axial ablation depth reaches 27.5 cm
Bottom injection water inlet conditions	Inlet water temperature: ~ 15 ºC Inlet water flowrate: 3.8 g/sec per nozzle, or 170 g/sec maximum if all 45 basemat nozzles are opened[d] Inlet water pressure at nozzle opening: 10±5 kPad
Test termination criteria	1) melt is quenched, or 2) maximum axial ablation depth of 32.5 cm is reached.

[a]Based on a calculated melt density of 6640 kg/m^3.

[b]Based on 150 kW/m^2 design heat flux to top, bottom, and two sidewall concrete surfaces (1.37 m^2 area), plus an additional 5 kW to compensate for a long-term heat losses of 10 kW/m^2 to MgO sidewalls (0.5 m^2 area).

[c]The water depth over the melt will be maintained in the indicated range until the nozzles open. Additional water will not be added from the top unless the test section plenum temperature climbs above saturation, indicating that the cavity has completely dried out.

[d]The 7.5 g/sec water injection flowrate limit corresponds to a local debris cooling rate of 500 kW/m^2 g/sec over the 14 cm x 14 cm surface area covered by one nozzle, assuming injection of room temperature water. The 170 g/sec injection flowrate limit would be reached if all 45 nozzles opened.

2.0 FACILITY DESCRIPTION

The overall facility design and test operating procedures for CCI-6 contain many elements that are similar to those used in the previous five tests [1-3]. However, at the 5th PRG meeting, the MB requested that several changes be made so that the test can serve as an integral experiment for validation of severe accident codes. In particular, the design has been modified to include a 70 cm x 70 cm siliceous concrete basemat and two concrete side walls. Also, in contrast to the previous CCI tests, this test will focus on coolability and therefore the cavity will be flooded from the top as soon as ablation is established and the melt temperature has stabilized. The target initial melt depth has also been modestly increased from the 25 cm level used previously to 28 cm. Finally, the test is has been designed for operation in two distinct phases. The first phase consists of a conventional 2-D core concrete interaction experiment that provides for 24 cm of lateral ablation and 27.5 cm of axial ablation.

In the event that the melt is not cooled down by top flooding during this first cavity ablation phase, a second and separate test phase will begin which involves bottom flooding. This phase will be initiated when axial ablation depth reaches 27.5 cm. The instrumentation has been refined to provide data on the water injection characteristics, as well as the melt temperature near the concrete walls.

Additional details regarding the facility modifications are provided in the balance of this section, along with a general description of the overall test plan for CCI-6. Specifications for the experiment were provided previously in Table 1-1.

2.1 Test Apparatus

The CCI test facility consists of a test apparatus, a power supply for Direct Electrical Heating (DEH) of the corium, a water supply system, two steam condensation (quench) tanks, a ventilation system to complete filtration and exhaust the off-gases, and a data acquisition system. A schematic illustration of the overall setup for CCI-6 is provided in Figure 2-1. The apparatus consists of three rectilinear sidewall sections and a lid. The overall structure is 3.4 m tall. The two upper sidewall sections have a square internal cross sectional area of 50 cm x 50 cm.

The test section for containment of the core melt is located at the bottom of the apparatus. A top view of this component is shown in Figure 2-2, while a cross-sectional view of the non-electrode sidewalls is provided in Figures 2-3. The test section has been enlarged to incorporate a 70 cm x 70 cm basemat. The concrete sidewalls allow for 24 cm of lateral erosion, and the sidewall design has been modified to include refractory MgO with a UO_2 pellet liner. This is the same inert sidewall design that has been successfully used behind the tungsten electrodes in all previous CCI tests. Thus, the sidewall design is intended to allow for continued test operations after the maximum lateral ablation depth of 24 cm is reached. In this manner, the core melt can be stabilized and allowed to proceed downwards to expose the water injection nozzles in the event that the melt is not successfully cooled by top flooding in the early part of the experiment, and/or rapid sidewall erosion is experienced early in the test.

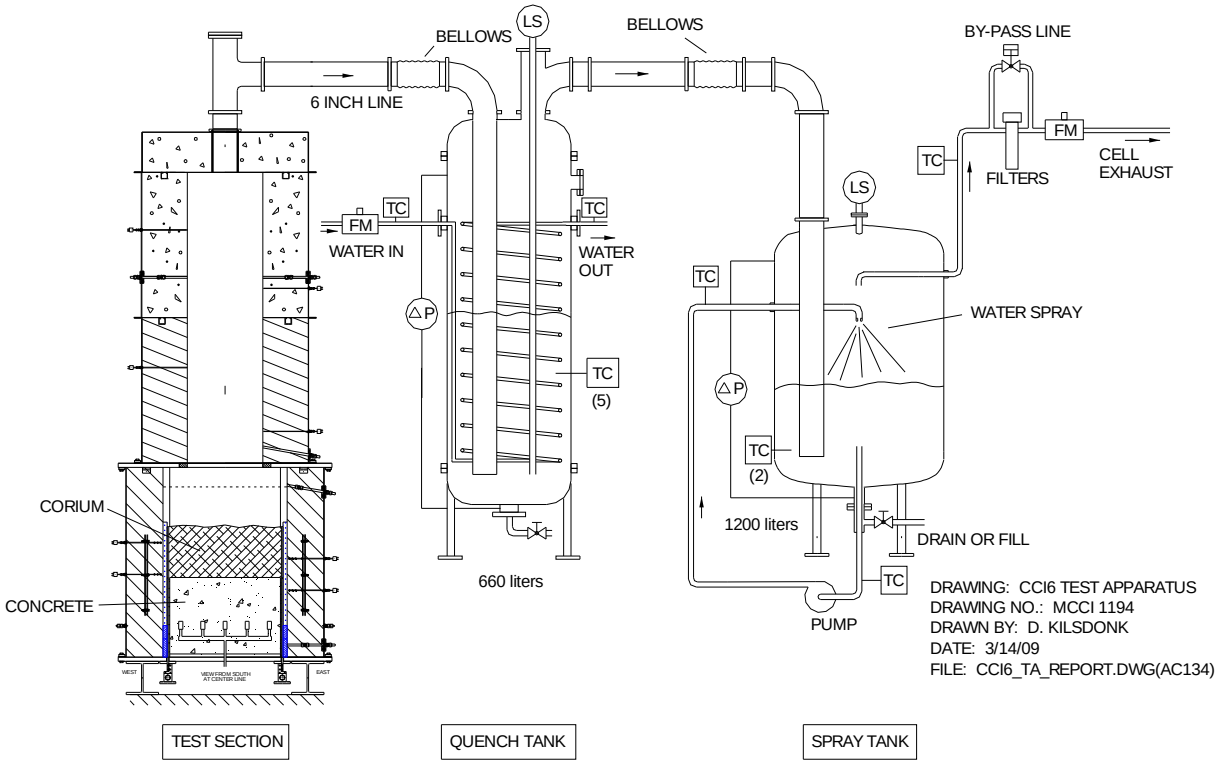

Figure 2-1. Schematic of CCI-6 Test Facility.

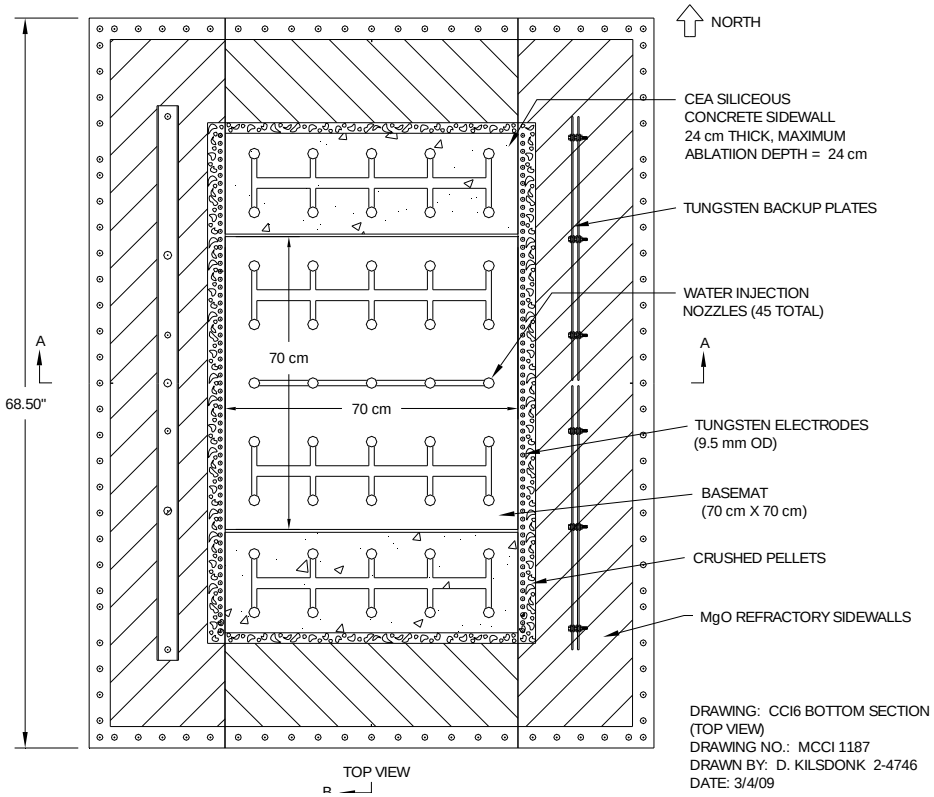

Figure 2-2. Top View of Lower Test Section.

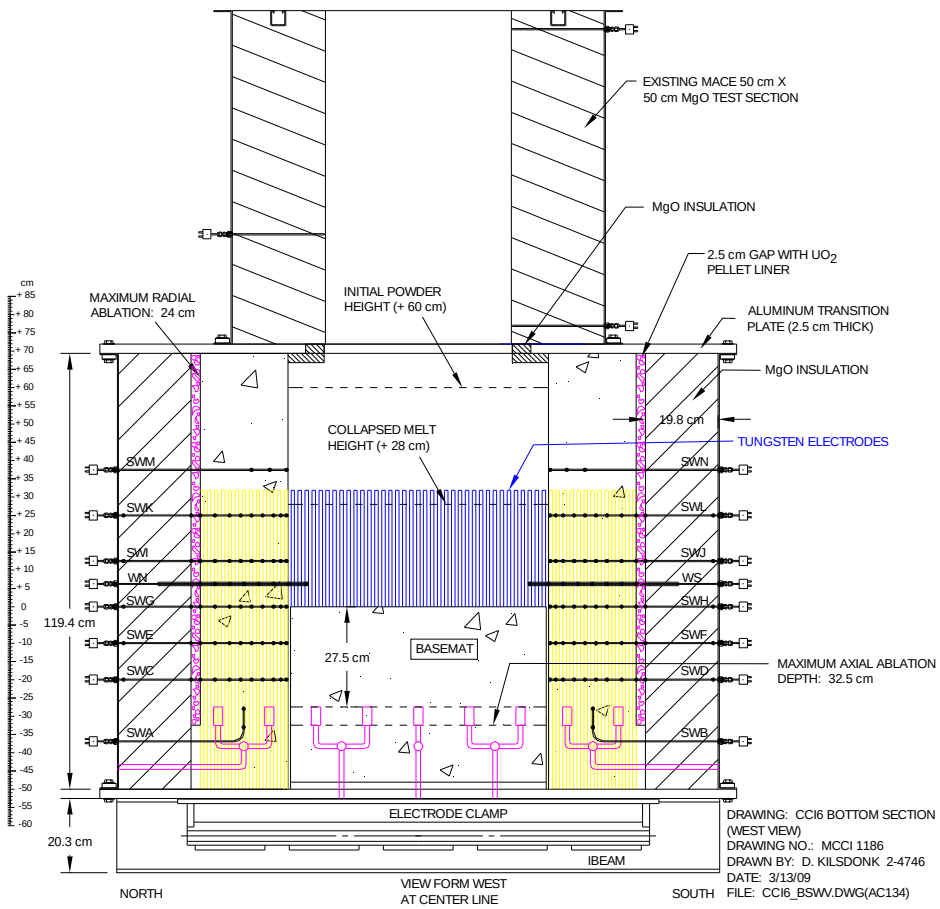

Figure 2-3. Side View of Lower Test Section Showing Concrete Sidewall Sections.

As shown in Figures 2-2 and 2-3, the basemat and sidewall designs have also been modified to include an array of 45 concrete nozzles that are arranged on a 14 cm lateral pitch. Twenty five of the nozzles are configured in the basemat, while ten nozzles are configured in each of the two concrete sidewalls. The nozzle design details are shown in Figure 2-4, while the nozzle configuration on top of the basemat bottom support plate is shown in Figure 2-5. The nozzles are all located at a uniform depth of 27.5 cm below the initial concrete basemat surface elevation. The nozzles are sealed at the top, and all are fed with water from a common header tank that provides a static net pressure of nominally 10 kPa measured at the upper surface elevation of the nozzles. Once the corium melt reaches the 27.5 cm axial ablation depth, the tops of the nozzles will be eroded through, thereby allowing water to be passively injected from below to begin the second phase of the experiment. At this point, the melt may be stabilized, or depending upon the extent of cooling, axial ablation may continue. If ablation continues, then the experiment will be terminated once the 32.5 cm axial erosion depth is reached. The porous concrete used in the nozzles is identical to that used in SSWICS-12 [4]. However, as shown in Figure 2-4, the nozzle design is more robust compared to SSWICS-12 to ensure that these components can survive the concrete pouring process intact. Design robustness is not an issue in terms of whether or not the nozzles will open once the melt front arrives since the melt is continuously heated. Each nozzle is electrically isolated from the test section so that an electrical shorting path cannot develop once the melt contacts two or more nozzles.

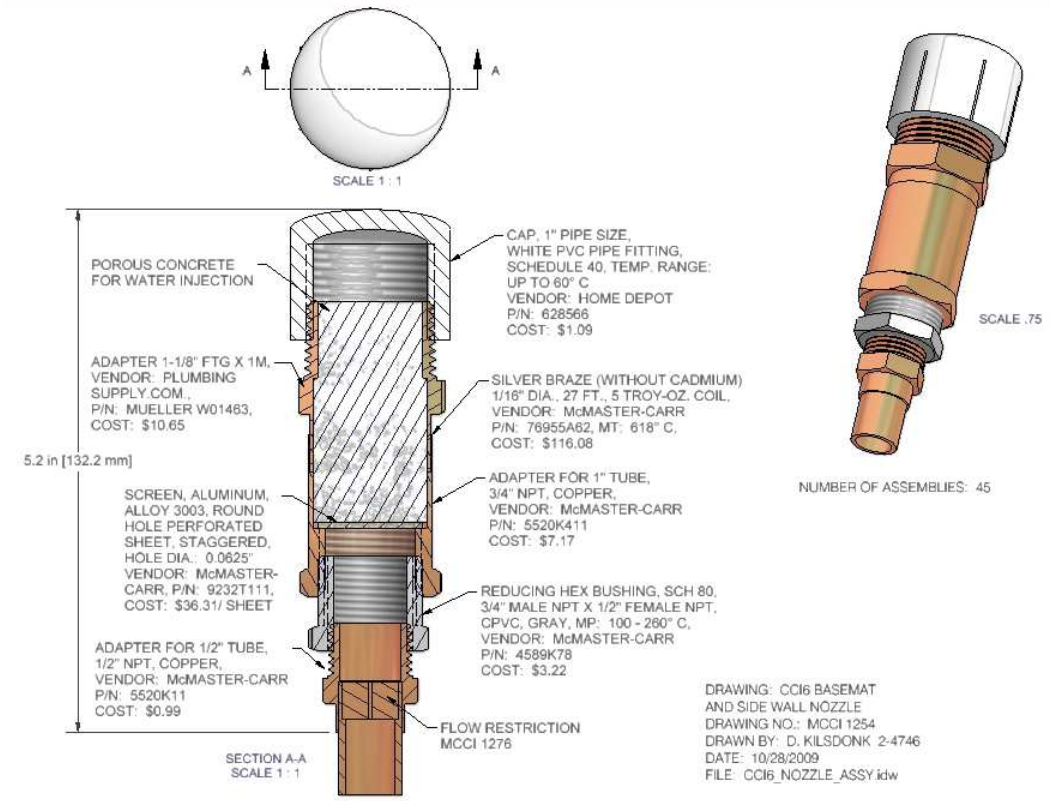

Figure 2-4. Details of the Basemat Nozzle Design.

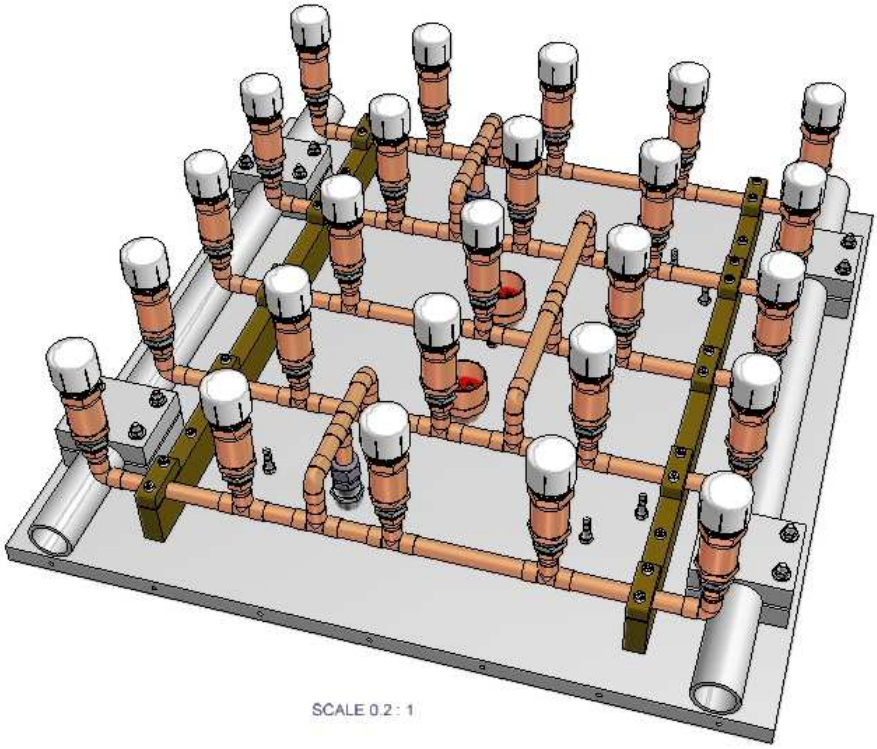

Figure 2-5. Nozzle Configuration on the Test Section Basemat Bottom Support Plate.

As shown in Figures 2-2 and 2-3, the sidewalls of the lower test section are contained within a flanged steel form that is used to secure the section to the balance of the existing test section components with an aluminum transition plate. The flanges allow the lower sidewalls to be disassembled to reveal the solidified corium following the test. As previously noted, a layer of crushed UO_2 pellets is used to protect the interior surface of the MgO sidewalls against thermo-chemical attack by the corium. For the electrode sidewalls, molybdenum and tungsten plates are embedded in the MgO to stop erosion in case the UO_2 protection layer fails. Multi-junction Type K and Type C thermocouple assemblies are cast within the sidewalls so that the time-dependent heat loss from the melt can be calculated from the local temperature gradient and the thermal conductivity of the MgO.

The melt is produced through an exothermic chemical reaction yielding the target mass over a timescale of ~ 30 seconds. After the chemical reaction, DEH simulating decay heat is applied through two banks of tungsten electrodes. As shown in Figure 2-2, the electrodes line the interior surfaces of the two opposing MgO sidewalls. The electrodes are 9.5 cm in diameter and aligned in a row with a pitch of 1.9 cm. They are attached by copper clamps and water-cooled buss bars to a 560 kW AC power supply. The electrodes span a total width of 120 cm on each sidewall of the lower section. At the start of the experiment, the electrical current is drawn through the center, 70 cm-wide section of electrodes that are in direct contact with the melt. As the test progresses and the concrete sidewall is eroded, additional electrodes are exposed to the corium. Current is drawn through these newly exposed heating elements, thereby maintaining a uniform internal heat pattern in the melt over the course of the experiment. With the overall electrode span of 120 cm, the entire 24 cm of lateral sidewall erosion can be accommodated on both sides of the test section while ensuring that the entire melt cross-sectional area is in contact with the electrodes.

A few minutes after the melt is formed, ablation of the concrete basemat and sidewalls will commence. As shown in Figure 2-1 a large (15 cm diameter) gas line is used to vent the helium cover gas and the various gas species arising from the core-concrete interaction (i.e., CO, CO_2, H_2O, and H_2) into two adjacent quench tanks that are partially filled with water (see Figure 2-6). In the early initial phase of the experiment when the cavity is dry, the tanks serve to cool the off-gases and filter aerosols generated from the core-concrete interaction. After the cavity is flooded, the tanks serve to condense the steam and, based on the measured condensation rate, provide data on the corium cooling rate. In either case, the helium covergas and non-condensables (CO, CO_2, and H_2) pass through the tanks and are vented through an off gas system that includes a demister and filters. The gases are eventually exhausted through the containment ventilation system and a series of high efficiency filters before finally being released from the building stack.

Soon after concrete erosion begins, the cavity will be flooded using an instrumented water supply system. During this stage of the test, the water enters the test section through two weirs located in the opposing (non-electrode) sidewalls of the top test section. The water supply system is shown in Figure 2-7. The water supply tank is pressurized and water is injected using gas pressure as the driving force to push water through the interconnected piping to the test section weirs. Makeup water is periodically added to maintain the water level in the test section

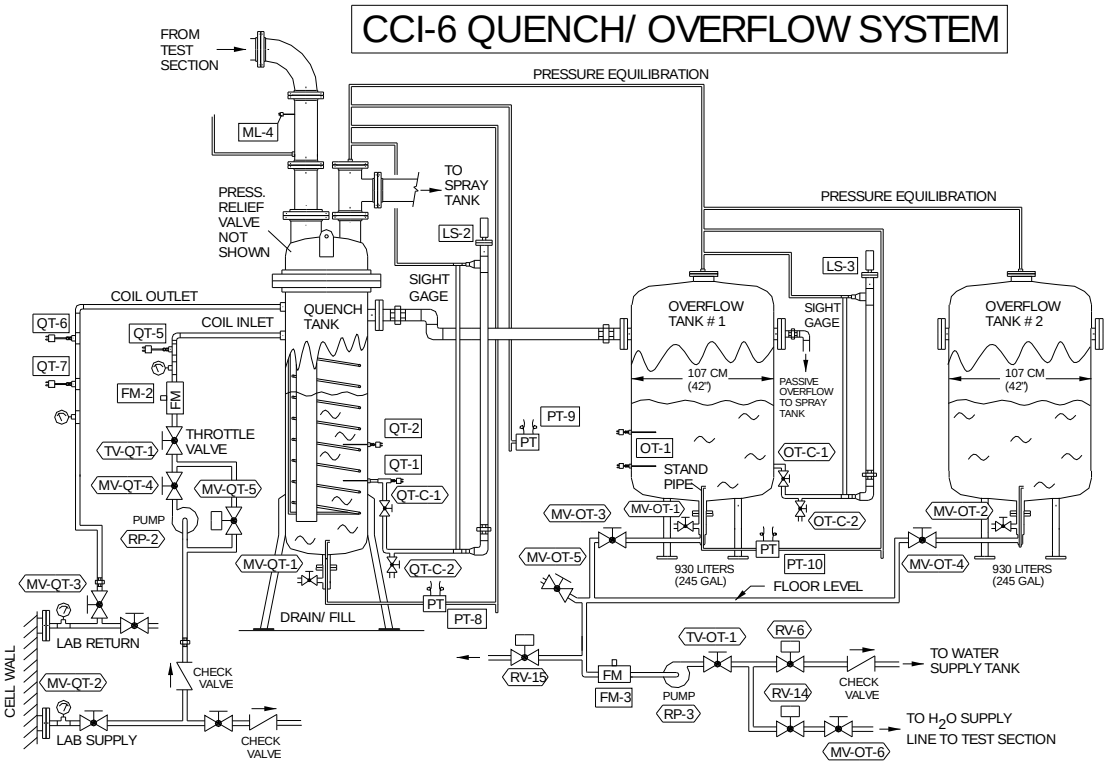

Figure 2-6. CCI-6 Quench System.

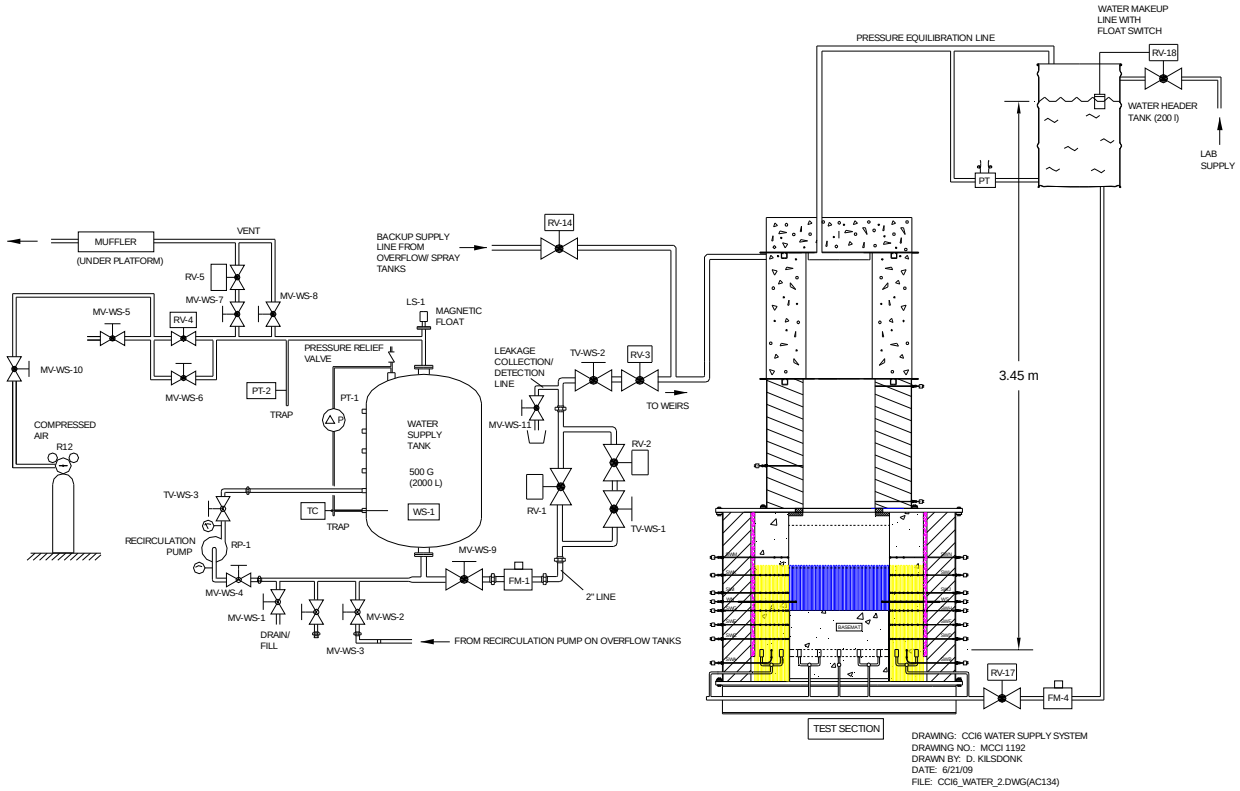

Figure 2-7. Test Section Water Supply System.

at nominally 25 ± 5 cm. This is an increased scale test, and so the system will be set up to recycle water from the quench system overflow tanks to the water supply tank, with a backup provision to inject water directly into the test section. These alternative flow paths are shown in Figures 2-6 and 2-7.

After a specified time with water present in the cavity, the option is provided to break the crust formed at the melt-water interface with an insertable crust lance to obtain data on the crust breach cooling mechanism. An illustration of the lance installed in the test section is shown in Figure 2-8. The lance is made from 2.54 cm diameter, 304 stainless steel rod with a pointed tip. The lance contains an electrical isolation hub so that there is no need to terminate power input to the melt during the crust loading procedure. As shown in Figure 2-8, the driving force for the lance is simply a 450 kg dead weight that is remotely lowered with the crane during the test.

As concrete erosion proceeds, the point will eventually be reached at which the porous concrete nozzles in the basemat will be opened by ablation. When the axial ablation depth reaches a predefined level, the isolation valve that separates the nozzle header tank from the nozzles will be opened (i.e., valve RV-17 in Figure 2-7) in preparation for water injection from below. The total head includes that required to offset the melt hydrostatic head, which is estimated as ~ 23.6 kPa[2]. Thus, the header tank is configured in the test cell to provide a static water height of 3.42 m to the nozzles. The plenum of the header tank is attached by a 1.3 cm ID pressure equilibration line to the test section plenum to ensure that the proper head is maintained as the test section plenum pressure fluctuates. As the quench process progresses, makeup water to the header tank will be provided automatically by a water supply line that includes a float switch so that the net head is maintained in the range of 10±0.1 kPad. The water supply line to the nozzles includes a flowmeter to quantify the total water injection flowrate. The injection flowrate would achieve a peak value of 170 g/sec (10 lpm) if all 45 nozzles completely opened during the test. After bottom water injection is initiated, additional water will only be added from the top if the test section plenum temperature starts to rise above saturation, indicating that the top coolant layer has been evaporated. This step is taken to prevent damage to the upper internals from highly superheated steam that is produced by bottom flooding in the early stages of the transient before the bulk melt temperature has declined significantly.

2.2 Instrumentation and Data Acquisition

The CCI-6 facility is instrumented to monitor and guide experiment operation and to log data for evaluation of the lateral and axial erosion rates. Principal parameters that are monitored during the course of the test include the power supply voltage, current, and gross input power to the melt; melt temperature and temperatures within the concrete basemat and sidewalls; crust lance position and applied load; supply water flow rate to the test section weirs as well as to the

[2]The total melt hydrostatic head at the time of nozzle opening is estimated to be 23.6 kPa, which includes the 18.3 kPa head due to the initial 28 cm collapsed melt depth (melt density taken equal to 6640 kg/m^3), plus an additional 5.6 kPa of head due to the erosion of 27.5 cm of concrete (concrete density taken equal to 2270 kg/m^3, and 13.74 wt% of the concrete mass is assumed to be lost due to liberation of the decomposition gases CO_2 and H_2O from the concrete. See Table 2-5 for concrete composition).

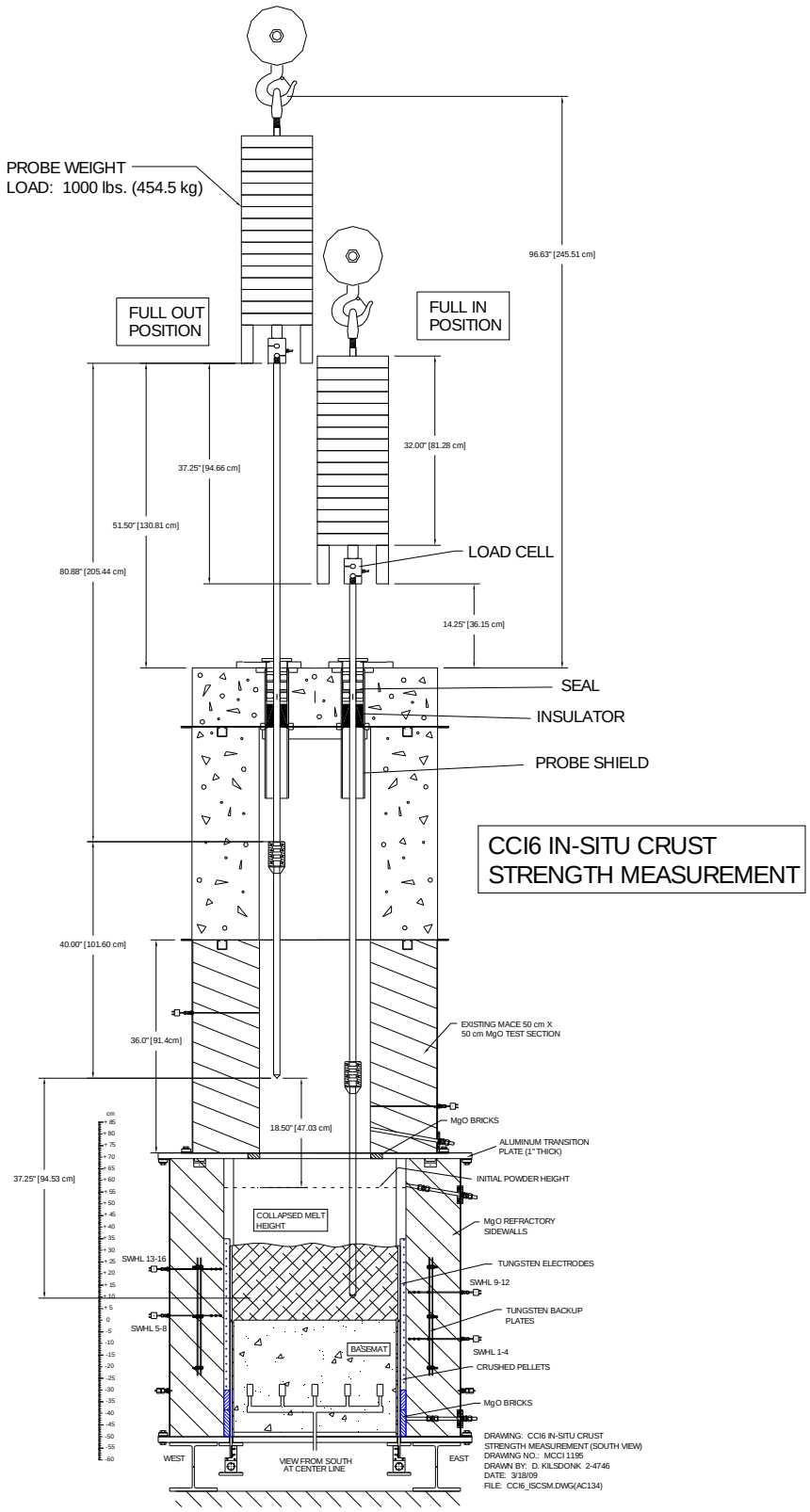

Figure 2-8. Illustration of CCI-6 Crust Lance Assembly Mounted in Test Section.

concrete nozzles; water volume and temperature within the test apparatus, and water volume and temperature within the quench system tanks. Other key data recorded by the DAS includes temperatures within test section structural sidewalls, off gas temperature and flow rate, and pressures at various locations within the system.

Detailed plan and elevation views of the basemat thermocouple layout are provided in Figures 2-9 and 2-10, respectively, while the concrete sidewall instrumentation locations were shown previously in Figure 2-3. Both the basemat and sidewalls are instrumented with multi-junction Type K thermocouple assemblies to determine the 2-D ablation profile as a function of time. In addition, Type C thermocouple assemblies in tungsten thermowells protrude upwards from the basemat and laterally inwards from the concrete sidewall in several locations. The purpose of these instruments is to provide data on the axial and lateral melt temperature distribution as a function of time. Note that the thermocouple junction locations have been positioned to provide melt temperature and ablation front location data over the range of possible

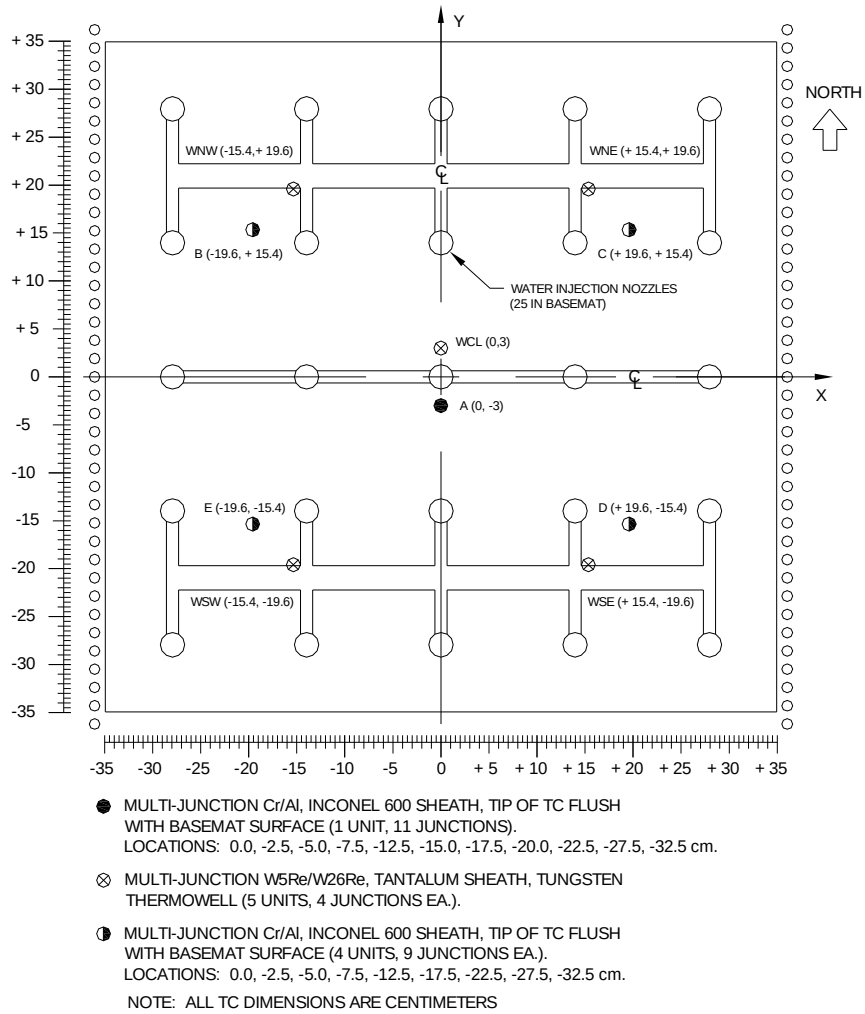

Figure 2-9. Plan View of Basemat Instrumentation Layout (dimensions are in cm).

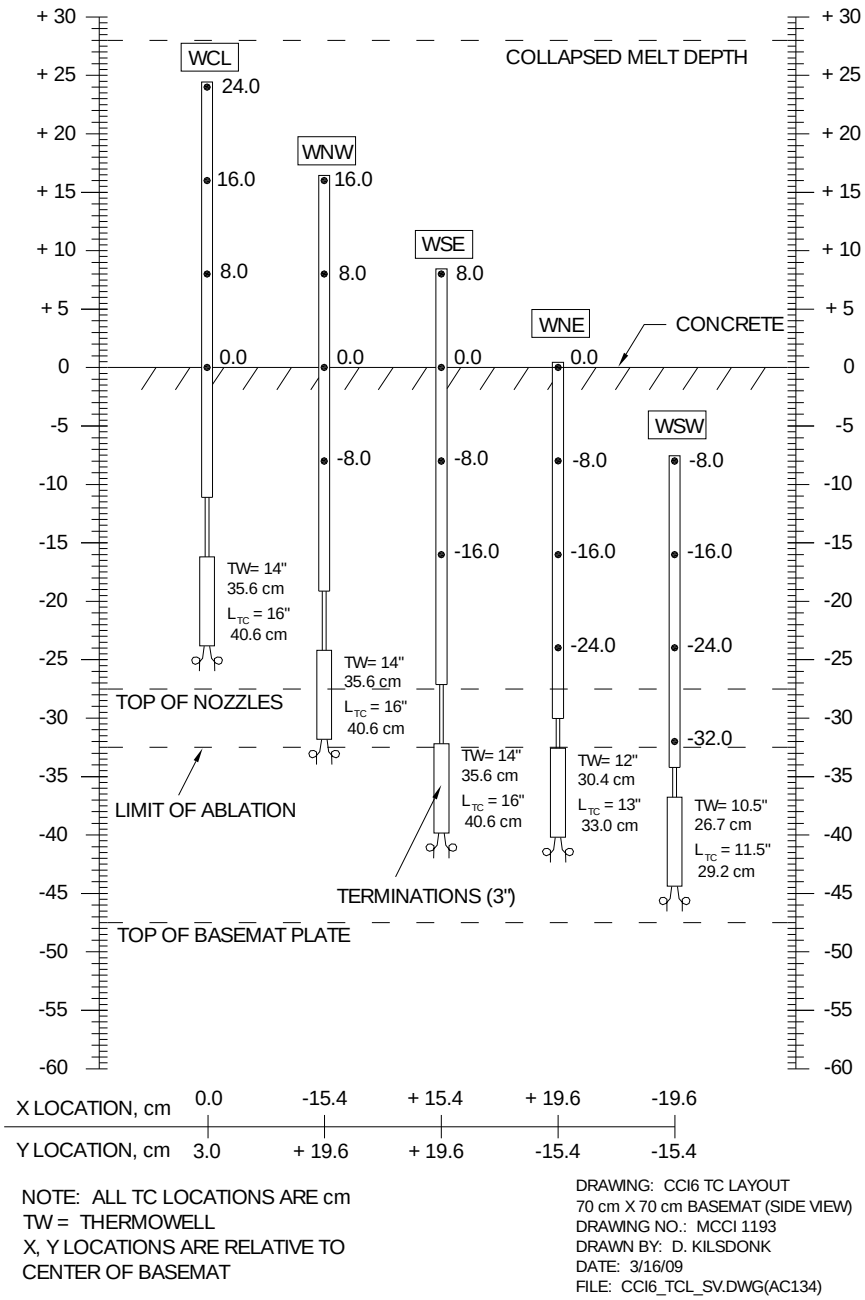

Figure 2-10. Elevation View of Basemat Type C Thermocouple Locations.

concrete ablation depths. A further instrumentation requirement[3] is to provide a sufficient thermocouple planar density to detect concrete ablation to a depth of 2.5 cm into the concrete basemat and/or sidewalls, since the cavity is to be flooded when any combination of two thermocouples at this depth indicate arrival of the ablation front (see Table 1-1). The positions of the various thermocouples that have been installed to achieve this detection capability are shown in Table 2-1.

[3] See Action 6.3 from the Minutes of the 6th OECD/MCCI-2 PRG meeting held at Argonne 20-21 April, 2009.

Table 2-1. Type K Thermocouple Locations Used to Determine the Timing of Water Addition to the Test Section.

Instrument Name	Test Section Concrete Component	Planar Position	Depth Below Concrete Surface
A-2	Basemat	Centerline	2.5 cm
B-2	Basemat	Northwest quadrant	2.5 cm
C-2	Basemat	Northeast quadrant	2.5 cm
D-2	Basemat	Southeast quadrant	2.5 cm
E-2	Basemat	Southwest quadrant	2.5 cm
SWG-2	North wall	Lateral centerline, 0.0 cm above basemat	2.5 cm
SWI-2	North wall	Lateral centerline, +12.5 cm above basemat	2.5 cm
SWK-2	North wall	Lateral centerline, +25.0 cm above basemat	2.5 cm
SWH-2	South wall	Lateral centerline, 0.0 cm above basemat	2.5 cm
SWJ-2	South wall	Lateral centerline, +12.5 cm above basemat	2.5 cm
SWL-2	South wall	Lateral centerline, +25.0 cm above basemat	2.5 cm

Other significant test instrumentation includes a stationary (lid mounted) video camera for observing physical characteristics of the core-concrete interaction. In addition, a pyrometer will be used in order to measure the debris upper surface temperature prior to water addition into the test section.

All data acquisition and process control tasks are managed by a PC executing LabVIEW 8.2 under Windows XP. Sensor output terminals are connected inside the test cell to model HP E1345A 16-channel multiplexers, which are integrated into a mainframe chassis in groups of eight. An illustration of the DAS setup is provided in Figure 2-11. The multiplexers direct signals to an HP E1326B 5 ½ digit multimeter incorporated into each chassis. Three independent 128 channel systems are used for a total capacity of 384 channels.

Signal noise is reduced by the digitizer through 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.

Integration of the signal over the period of a power line cycle limits the speed with which the multiplexer can scan the channel list. The minimum time for the digitizer to scan the channel list is ~1.7 s (16.7 ms • 100 channels/chassis for this test). Though the three systems operate independently, implying the ability to update all 300 channels in roughly two seconds, the actual time required for the update is about 5.5 s.

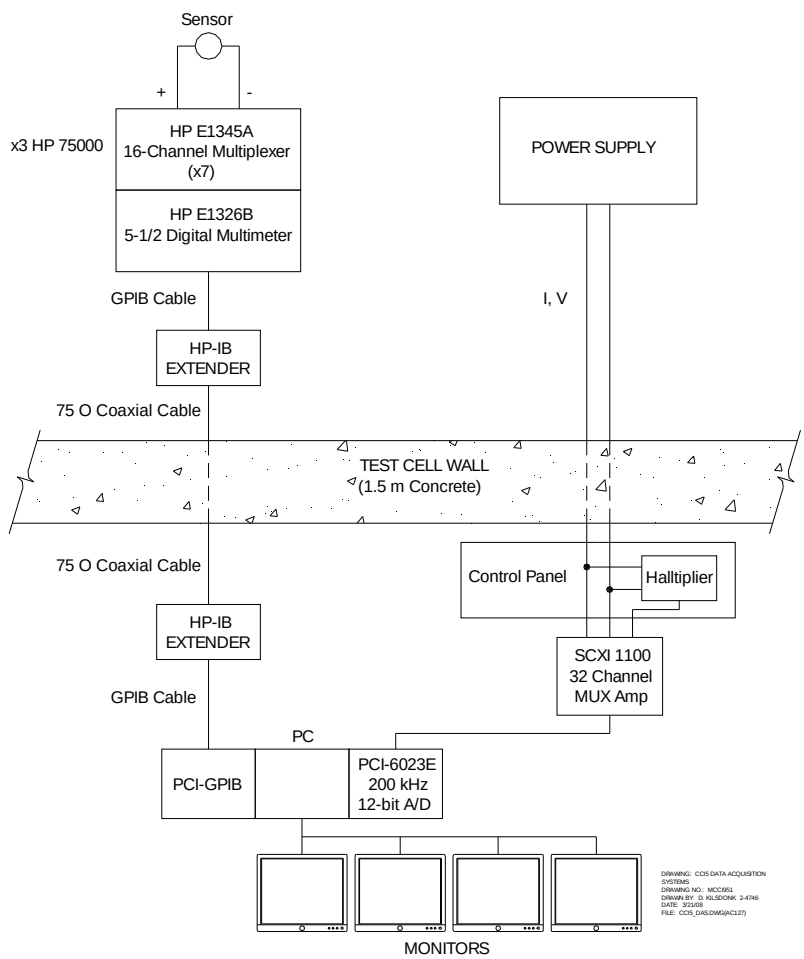

Figure 2-11. CCI Data Acquisition and Control Systems.

2.3 Corium Composition

As shown in Table 1-1, the corium oxide phase composition for CCI-6 is specified to contain 6 wt % calcined siliceous concrete as an initial constituent. As part of the developmental work for this test, a specific thermite was developed to produce this particular melt composition. The thermite reaction is of the form:

$$1.22U_3O_8 + 3.3Zr + 0.649Si + 0.531SiO_2 + 0.017Mg + 0.25CaO + 0.084Al + 1.866CrO_3 \rightarrow$$

$$3.66UO_2 + 3.3ZrO_2 + 1.18SiO_2 + 0.017MgO + 0.25CaO + 0.042Al_2O_3 + 1.866Cr;$$

$$Q = -269.08 \text{ kJ/mole } (1.756 \text{ MJ/kg});$$

$$T_{adiabatic} = 2692 \text{ °C}; T_{actual} \sim 2310 \text{ °C}$$

The composition of the melt produced from this reaction is summarized in Table 2-2, while the detailed pre- and post-reaction compositions are provided in Table 2-3. Note that the pre- and post-reaction compositions shown in these tables do not include the additional mass of crushed UO_2 pellets and powder that are used to line the test section MgO sidewalls. Experience

has shown that this material does not participate in the initial exothermic chemical reaction, and remains essentially intact as a protective layer during the ensuing core-concrete interaction. The actual mass of UO_2 that dissolves into the melt over the course of the experiment is determined as part of the posttest examination activities and documented in the test data report. Note that this is a new thermite composition and so a reaction test will be required to verify reaction temperature and melt fluidity upon reaction.

Table 2-2. Post-Reaction Bulk Composition for CCI-6 Thermite.

Constituent	Wt%
UO_2	62.51
ZrO_2	25.67
Calcined Concrete	5.68[a]
Cr	6.14

[a]Calcined siliceous concrete, consisting of 79.0/0.9/15.6/4.5 wt% SiO_2/MgO/CaO/Al_2O_3

Table 2-3. Detailed Pre- and Post-Reaction Compositions for CCI-6 Thermite.

Constituent	Reactant		Product	
	Wt %	Mass, kg	Wt %	Mass, kg
U_3O_8	64.99	584.91	-	-
UO_2	-	-	62.50	562.50
Zr	18.99	170.91	-	-
ZrO_2	-	-	25.67	231.03
Si	1.15	10.35	-	-
SiO_2	2.02	18.18	4.49	40.41
Mg	0.01	0.09	-	-
MgO	-	-	0.04	0.36
Al	0.14	1.26	-	-
Al_2O_3	-	-	0.27	2.43
CaO	0.89	8.01	0.89	8.01
CrO_3	11.81	106.29	-	-
Cr	-	-	6.14	55.26
Total	100.00	900.00	100.00	900.00

The thermite powders are packed into the test section in a large, 1.7 mil aluminized Saran bag that is pre-installed over the basemat to prevent water absorption by CrO_3 and concrete oxides (principally CaO and SiO_2), since these constituents are hygroscopic. As an additional measure to prevent moisture infiltration into the thermite from the concrete, the basemat and sidewalls are completely covered with continuous sheets of Saran film before thermite loading.

2.4 Concrete Composition

As shown in Table 1-1, the composition of the CCI-6 concrete basemat and sidewalls is specified to be of the siliceous type. The engineering composition for this particular concrete is shown in Table 2-4. The sand and aggregate for the mix are supplied by CEA as an in-kind contribution to the program. The estimated chemical composition for this concrete is provided in Table 2-5. This composition is based on analysis of a specimen taken from the CCI-3 concrete

archive sample [1]. The actual composition of the concrete for Test CCI-6 will be determined through chemical analysis of a specimen that will be collected during fabrication of the sidewall and basemat components.

To prevent downward migration and possible escape of concrete decomposition gases during the course of the experiment, the electrode penetrations through the bottom support plate are sealed using O-rings. As described in the next section, the test section is leak checked at 83 kPa differential pressure as part of pretest operations to verify a low leak rate. On this basis, essentially all concrete decomposition gases migrated upwards through the melt pool during the experiment, as opposed to partial loss through the bottom support plate of the apparatus. Reinforcing rod is eliminated so that it does not mask or delay the attainment of a fully oxidized melt.

The density of the siliceous concrete will be ~ 2270 kg/m^3, which was the calculated value for the CCI-3 concrete based on the measured mass and volume of the CCI-3 concrete archive sample. The actual density of the CCI-6 concrete will be determined once the concrete components are poured.

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 four sidewalls are then set in place on the support plate. The lower section flange bolts and clamping bars are then installed and tightened. Following this step, the basemat instruments are connected to terminal boxes that are prewired to the data acquisition system.

Table 2-4. Engineering Composition of CCI-6 Siliceous Concrete.

Constituent	wt %	Size Distribution
Aggregate	47.4	5-8 mm: 16.6 wt % 8-11 mm: 20.4 wt% 11-16 mm: 10.4 wt%
Sand	30.6	0-2 mm: 12.2 wt % 2-4 mm: 18.4 wt %
Type 1 Cement	15.3	N/A
Tap Water	6.7	N/A

Table 2-5. Chemical Composition of Siliceous Concrete (CCI-3 basis [1]).

Constituent	Wt %
SiO_2	60.99
CaO	17.09
Al_2O_3	3.61
Fe_2O_3	1.52
MgO	0.87
MnO	0.04
SrO	0.04
TiO_2	0.16
SO_3	0.44
Na_2O	0.67
K_2O	0.83
CO_2	9.98
H_2O	3.76[a]

[a]Free water content is 2.33 wt % while bound water content is 1.43 wt %.

Once the lower section is assembled, 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, the thermite is repackaged into this bag to reduce the amount of bagging material present in the thermite charge. Once the large bag is filled with thermite, the sparklers used to initiate the chemical reaction are placed in the top of the powders, and the bag is folded and sealed.

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 instruments, including the sidewall and basemat thermocouples used to monitor melt temperature and ablation front progression, are 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 using the sparklers located at the top of the powder charge. Once the reaction is complete (~ 30 seconds), the power supply is ramped at a rate of ~ 3000 Amps/minute up to the initial target power level. As shown in Table 1-1, target power for the initial phase of the test is 210 kW prior to cavity flooding.

For this test, the operating procedure calls for early cavity flooding after ablation has been established. The specific criterion for initiation of flooding is that any combination of two thermocouples located 2.5 cm within the concrete indicate arrival of the ablation front (see Table 1-1). The specific instruments that will be used during the test to make this determination are shown in Table 2-1. At this point, the cavity will be flooded. Following completion of bulk cooling, the power supply operating mode will be switched from constant power at the initial

level of 210 kW, to constant voltage. Thus, if significant debris quenching occurs, power supply operation in this mode will maintain *the specific power density in the remaining melt constant at the level established prior to cavity flooding* (recall that the direct electrical heating method does not significantly heat solidified debris).

The test will be operated in this manner until the axial ablation depth reaches 22.5 cm. During this phase, water depth over the melt will be kept in the range of 25±5 cm. If the lateral ablation reaches 24 cm, then the backup UO_2 pellet liner and MgO sidewall will terminate sidewall ablation and allow axial ablation to progress further. The crust lance will be used to break the crust at the melt water interface during this phase to provide data on *in-situ* crust strength, as well as information on the nature and extent of cooling after the crust is breached.

If the melt is quenched and stabilized during the early flooding stage, then the test will be terminated. However, if the 22.5 cm ablation depth is reached, the water injection system will be reconfigured to inject water from below under a static water head of ~ 10 kPa as the nozzles gradually open. When the axial ablation depth reaches the 22.5 cm depth, the isolation valve that separates the nozzle header supply tank from the nozzles will be opened (i.e., valve RV-17 in Figure 2-7) in preparation for water injection from below as the nozzles are opened by ablation. As water is injected, makeup to the header tank will be provided by a supply line with a float switch that maintains the head in the range of 10±0.1 kPad. Additional water will only be added from the top at this stage if the test section plenum temperature starts to rise above saturation, indicating that the top coolant layer has been evaporated. Past this point, the melt will either quench, or axial ablation will proceed to 32.5 cm. In either case, the experiment will be terminated by turning off the power supply that provides DEH to the melt.

3.3 Posttest Operations

Following the experiment, the apparatus will be 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, a vertical core sample will be drilled through the extent of the corium if possible. The core will be removed, photographed, a few 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 these measurements are collected, the MgO and concrete sidewalls of the lower test section will be removed, thereby fully revealing the solidified corium over the remaining basemat. Once the corium is revealed, a detailed map of the cavity erosion profile will be developed. Additional samples will be collected at this point in order to further characterize the debris through chemical analysis. When these measurements are completed, the basemat and concrete sidewall will be placed in storage containers in preparation for final disposal.

4.0 REFERENCES

1. M. T. Farmer, S. Lomperski, D. J. Kilsdonk, and R. W. Aeschlimann, "OECD MCCI Project 2-D Core Concrete Interaction (CCI) Tests: Final Report," OECD/MCCI-2005-TR05, January 2, 2006.

2. M. T. Farmer, R. W. Aeschlimann, D. J. Kilsdonk, and, S. Lomperski, "2-D Core Concrete Interaction (CCI) Tests:CCI-4 Final Report," Rev.0, OECD/MCCI-2007-TR06, November, 2007.

3. M. T. Farmer, D. J. Kilsdonk, S. Lomperski, and R. W. Aeschlimann, "CCI-5 Quick Look Data Report," OECD/MCCI-2008-TR07, November, 2008.

4. S. Lomperski, M. T. Farmer, D. Kilsdonk, R. Aeschlimann, "Small-Scale Water Ingression and Crust Strength Tests (SSWICS) SSWICS-12 Design," OECD/MCCI-2008-TR06, October, 2008