OECD/MCCI-2009-TR03

OECD MCCI Project
Small-Scale Water Ingression and Crust Strength Tests (SSWICS)
SSWICS-13 Design Report

Rev. 1 - FINAL

November, 2009

by:

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1. 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 a third Category 2 Test to supplement the two that have already been approved. In particular, the following PRG recommendation was approved at the 5th PRG meeting:

> Regarding the Category 2 small scale tests, PRG recommends that a SSWICS-13 test be performed with the bottom injection system partitioned into 2 parts, one with water only, the other with water and nitrogen. The test design report will be prepared by the OA with input from KAERI.

1.2 Objectives

This report is a design and test plan for the third Category 2 test, which is denoted SSWICS-13. The design includes input from KAERI.

1.3 Summary Design Approach

KAERI envisions SSWICS-13 as a companion test to COMET-U2, which was performed for Forshungszentrum Karlsruhe (FZK) in 1997. It involved water injection through nine nozzles cast into a concrete basemat with the top of the nozzles positioned 15 mm below the surface of the concrete. The melt consisted of 50% UO_2, 18% ZrO_2, and 23 % borosilicate glass with the balance in chromium. The initial melt mass, depth, and temperature were 150 kg, 41 cm, and 2320 K, respectively. The melt was cooled to the solidus temperature within ~15 minutes of the onset of water injection and completely quenched after another ~22 minutes.

SSWICS-13 will differ from COMET-U2 in that it is to be partitioned into two regions by tungsten plates in a fashion similar to that of SSWICS-12, which was partitioned into four regions. In addition, there will be four nozzles rather than nine and the melt depth will be 30 cm rather than 40 cm. The main test parameters for SSWICS-12, -13, and COMET-U2 are provided in Table 1.1 for reference.

For SSWICS-13, each nozzle will be supplied by a dedicated reservoir so that water level changes can be used to determine flow rates. The two nozzles on one side of the partition will include a capillary to supplement water injection with a stream of nitrogen gas. The apparatus is therefore configured to provide, in effect, two independent and simultaneous injection tests: one with a water/nitrogen mixture and a second only with water. The test data will be used to evaluate the effects of gas injection on the corium cooling rate and crust morphology. Ideally, the COMET-U2 melt depth and water injection rate would be replicated in SSWICS-13 to facilitate a comparison with the previous data. Unfortunately, the SSWICS operating envelop is unable to accommodate the COMET-U2 melt depth and condenser heat load. The remainder of this report describes the test apparatus, instrumentation, test procedure, and data reduction.

2. System Description

2.1 General

The SSWICS reaction vessel (RV) has been designed to hold at least 100 kg of melt at an initial temperature of 2500^{o}C. The RV lower plenum consists of a 67 cm long, 46 cm outer diameter carbon steel pipe (Fig. 2.1). The pipe is insulated from the melt by a 6.4 cm thick annulus of cast MgO that is denoted the “liner”. The selected pipe and insulation dimensions result in a melt diameter of 30 cm and a surface area of 707 cm^2. The melt depth for a typical corium charge of 75 kg is about 15 cm. This particular test will use a 136 kg charge to create a 30 cm deep melt. The RV lower flange is insulated with a “basemat” consisting of 38 mm cast MgO covered by 25 mm of concrete The basemat and liner form the crucible that holds the corium.

The RV upper plenum consists of a second section of pipe with a stainless steel protective liner. Three 10 cm pipes welded near the top of the vessel provide 1) a vent line for the initial surge of hot noncondensable gases generated by the thermite reaction, 2) a pressure relief line with a rupture disk (7.7 bar at 100^{o}C), and 3) an instrument flange for the absolute pressure transmitter that measures the reaction vessel pressure. A baffle is mounted below the upper flange prevents water droplets from being

Table 1.1. Selected test parameters for SSWICS-12, -13, and COMET-U2.

Parameter	SSWICS-12	SSWICS-13	COMET-U2
Molten Corium Property	100 % oxidized PWR with 15 wt % siliceous concrete UO_2 55.61, ZrO_2 22.84, SiO_2 11.03, MgO 0.11, Al_2O_3 0.63, CaO 2.18, Cr 7.60%	100 % oxidized PWR with 15 wt % siliceous concrete UO_2 55.61, ZrO_2 22.84, SiO_2 11.03, MgO 0.11, Al_2O_3 0.63, CaO 2.18, Cr 7.60%	100 % oxidized PWR with 23 wt % borosilicate glass UO_2 49.92, ZrO_2 17.95, SiO_2 13.37, MgO 0.73, Al_2O_3 1.11, CaO 4.44, Cr 11.21, B_2O_3 1.27%
Test section diameter	30 cm	30 cm	30 cm
Initial melt mass	136 kg	136 kg	150 kg
Initial melt depth	30 cm	30 cm	40 cm
Initial melt temp.	2100 °C	1930 °C	2050 °C
Corium density	6000 kg/m^3	6000 kg/m^3	5120 kg/m^3
Specific heat	700 J/kg-K	700 J/kg-K	870 J/kg-K (2220-373K)
Basemat nozzles	4ea (same radius = 108mm)	2ea water 2ea water/gas (same radius = 106mm)	3×3 array (80mm pitch)
Nozzle diameter	32 mm	13.2 mm	13.2 mm
Nozzle characteristics	Porous concrete	Single tube for water Double tube for water/gas	
Concrete thickness above nozzles	0 mm	10 mm	15 mm
Partition	4 regions	2 regions	None
Water supply pressure	0.2, 0.15, 0.1, 0.05bar	0.2 bar	0.2 bar
Max. water flow rate	~ 2.4 lpm	~ 1.2 lpm	~ 13 lpm
Max. gas flow rate	N.A.	0.12 lpm (20% of water flow rate)	N.A.
Basemat construction	Inert MgO	25 mm thick siliceous concrete with underlying 38 mm thick inert MgO	Glass 75.8%, Type 1 Cement 15.2%, Water 9.0%
Quenching time	~ 60 min (to 100^{o}C)	-	~ 35 min (<500K)
Average heat flux during quenching transient	TBD	-	~ 1.45 MW/m^2

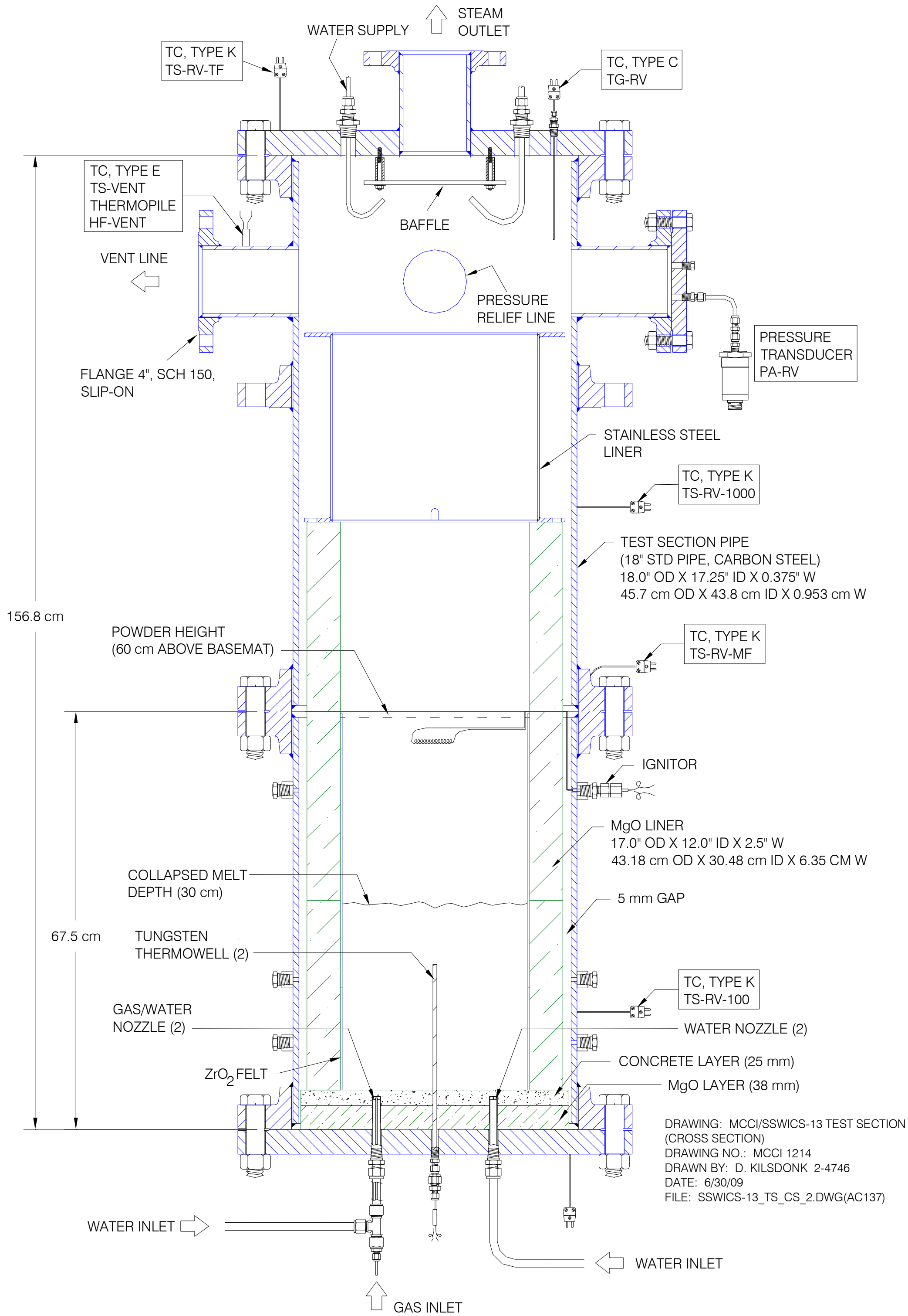

Figure 2.1. Side view of reaction vessel.

carried up towards the condenser, which would adversely affect the heat flux measurement. A fourth 10 cm pipe welded to the top flange provides an outlet to carry steam from the quenching melt to four cooling coils. The water-cooled coils condense the steam, which is collected within a 200 cm high, 20 cm diameter condensate tank (CT). Fig. 2.2 gives an overview of the entire SSWICS melt-quench facility.

Like SSWICS-12, the corium will be divided into sectors using metallic partitioning plates. As part of the planning process for SSWICS-12, it was concluded that tungsten was the best candidate material for this application since it has the highest strength of the refractory metals at high temperature, which minimizes the required thickness and, thereby, the heat sink provided by the partition. A plate thickness of 10 mm was selected for that test, and the same is recommended for this one. The test section will be divided into two by a 60 cm-high wall made up of three 20 cm high plates. The partition is supported by grooves in the liner to discourage shifting under lateral loads. The basemat detail is shown in Fig. 2.3.

2.2 Injection Supply System

Each nozzle is served by a single supply tank so that a differential pressure transmitter can be used to measure the flow rate to individual nozzles. The nozzles are gravity fed so that the driving pressure for injection is set by the elevation difference between the nozzle and the tank water level (Fig. 2.4). A check valve in each line prevents back flow up into the tank. There is also an isolation valve in each line that will be opened after the RV preheat phase of the test has been completed.

The tanks are positioned at identical levels to generate the same water head on each nozzle. A pressure equalization line links the RV gas space to the gas spaces of all four tanks, ensuring that the driving head for the nozzles is set only by the nozzle/tank elevation difference. This is necessary because the RV pressure spikes for a short period following initial water injection. If the reservoirs are not at the absolute pressure of the RV, the initial pressure spike will halt water injection, causing steam production and RV pressure to drop, which in turn permits continued water injection. It is likely that the system would oscillate during the early period of the test. Connecting the gas spaces of the reservoirs with that of the RV should prevent such oscillations.

Figure 2.4 shows the positioning of the tanks, which are set to provide a driving head of 0.2 bar. The net driving head ΔP is defined here as the head remaining after subtracting the hydrostatic head associated with the melt:

$$\Delta P = \rho_l g L - \rho g h \Big|_{corium}$$

where h is the height of the corium, 30 cm for this test, L is the distance from the bottom of the corium pool to the tank water surface, and ρ_l and ρ are the coolant and corium densities, respectively. The head associated with the corium was calculated to be 0.15 bar by assuming a density of 5120 kg/m^3. Assuming a water head of 10 meters/ bar, the tanks are thus positioned 3.6 meters above the bottom of the corium pool.

In the interest of simplicity, no system is used to replenish the tanks during the test to maintain water level and so the driving head falls as water is injected into the melt. The drop in water level can be made small by using large-diameter tanks, but they serve as pressure vessels and so there is a strong incentive to minimize their size. Initial water inventory for each tank will be 15 liters, which was chosen by noting

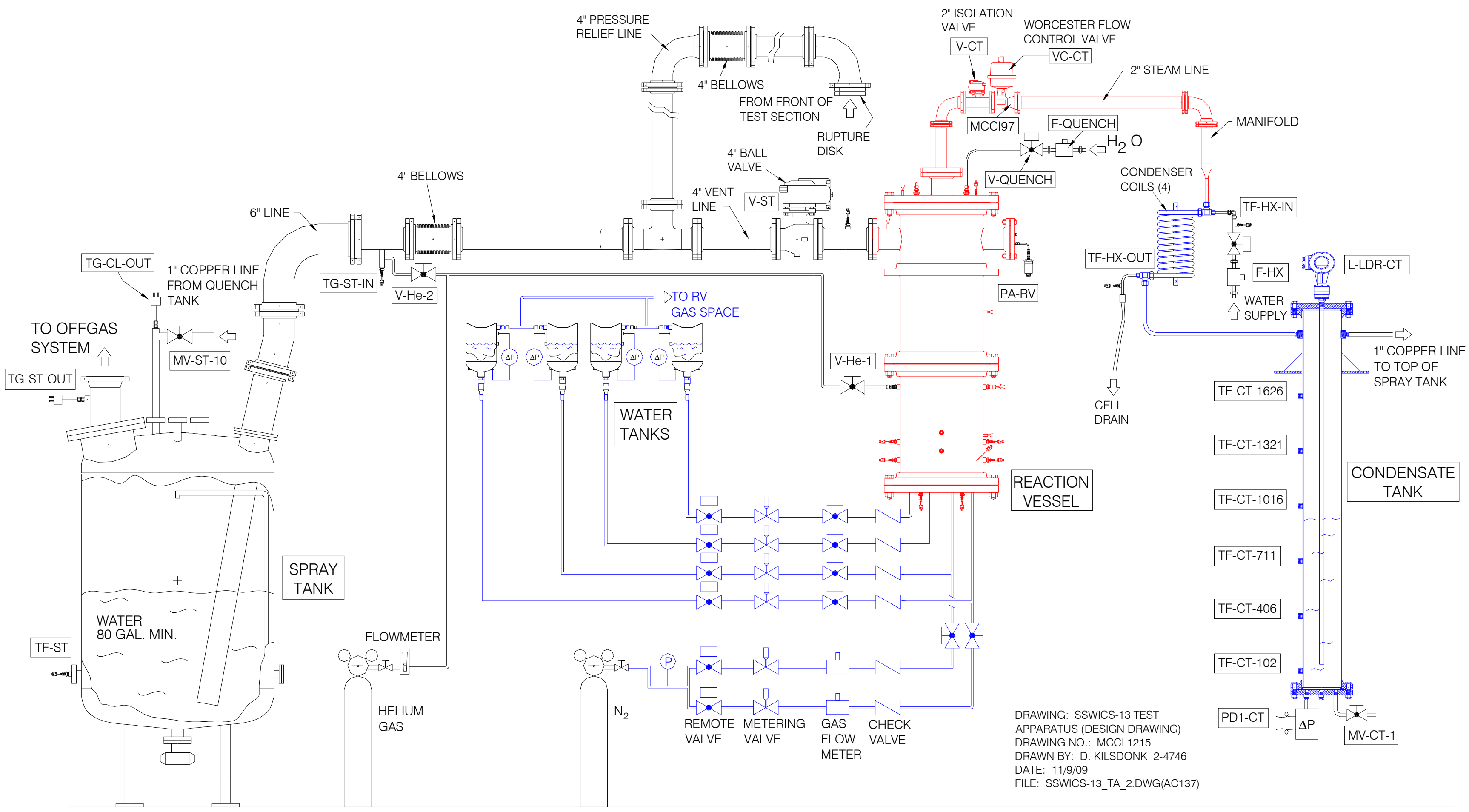

Figure 2.2. SSWICS melt quench facility.

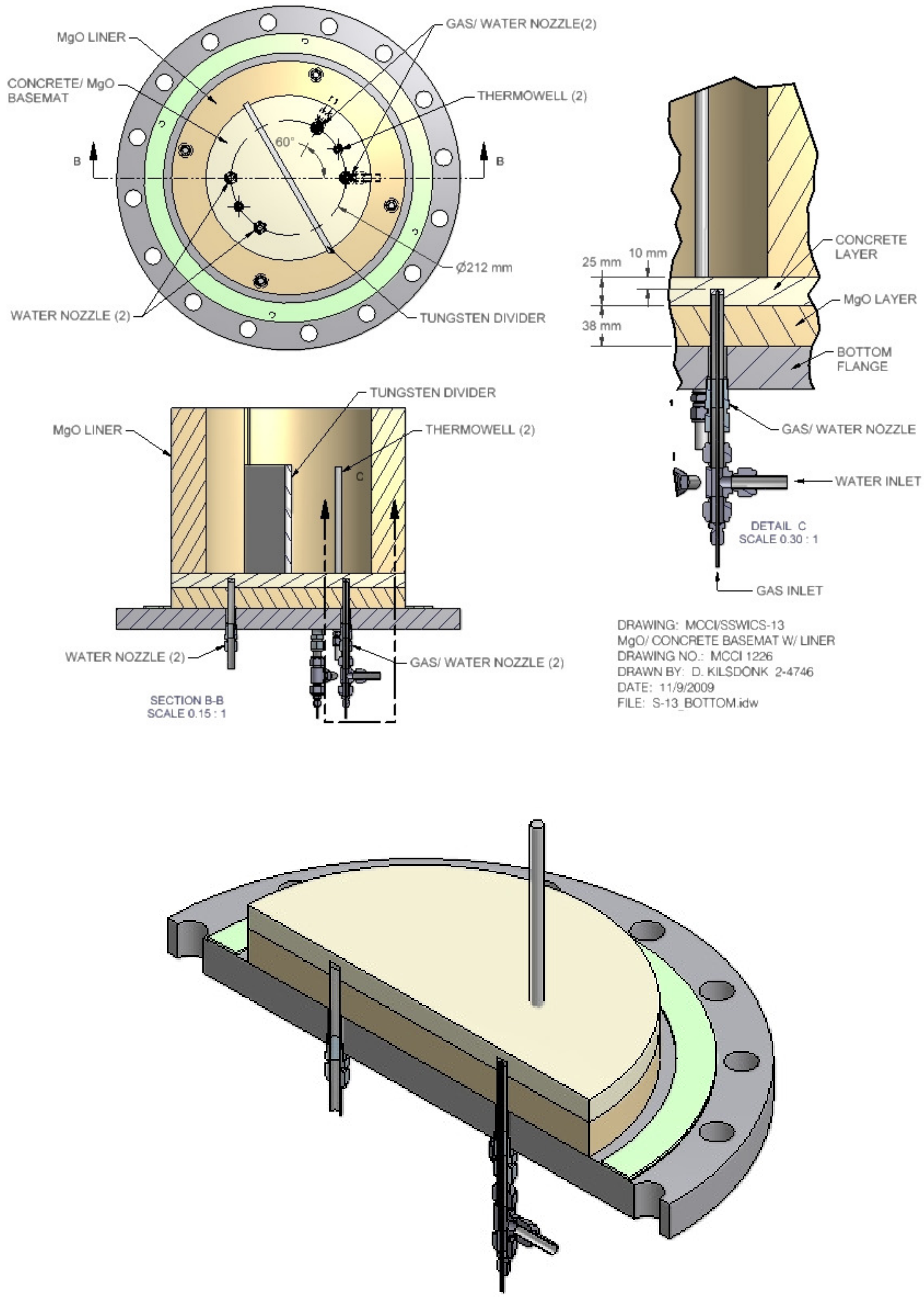

Figure 2.3. Lower plenum and basemat detail.

that approximately 30 liters of water is collected by the condensate tank during a typical 75 kg test. Since this test will involve 136 kg of corium and a higher than normal initial temperature, it is expected that about 60 liters of water will be boiled off while quenching the melt. Unless a test anomaly occurs, all 60 liters from the four tanks will be injected into the RV.

The PRG has recommended supplementary water injection from the top shortly after water flow from below is established. The purpose is to cool the superheated steam that will be generated in the very early stages of the test. During the first minutes of SSWICS-12, a peak upper plenum temperature of 1700^{o}C was measured, which is excessive for the steel vessel. Twenty liters will be injected from above as soon as bottom injection is confirmed. Details are provided in the test procedure description in Section 4.

During the early stage of the experiment, it is likely that water will be completely vaporized as it is injected into the melt. It is therefore necessary to limit the injection flow rate so that the condensing system is not overwhelmed. The condensing system has a capacity of approximately 0.08 kg/s. The flow limit for SSWICS-12 was set at 50% this capacity. The condensing system proved adequate for those conditions, but melt was ejected from the lower plenum and left a coating over most of the inside of the RV. In hopes of avoiding melt ejection in this test, the flow rate limit will be cut in half to 0.005 kg/s per nozzle. At this maximum flow rate of 0.02 kg/s into the melt, complete vaporization would dissipate 45 kW, or 600 kW/m^2.

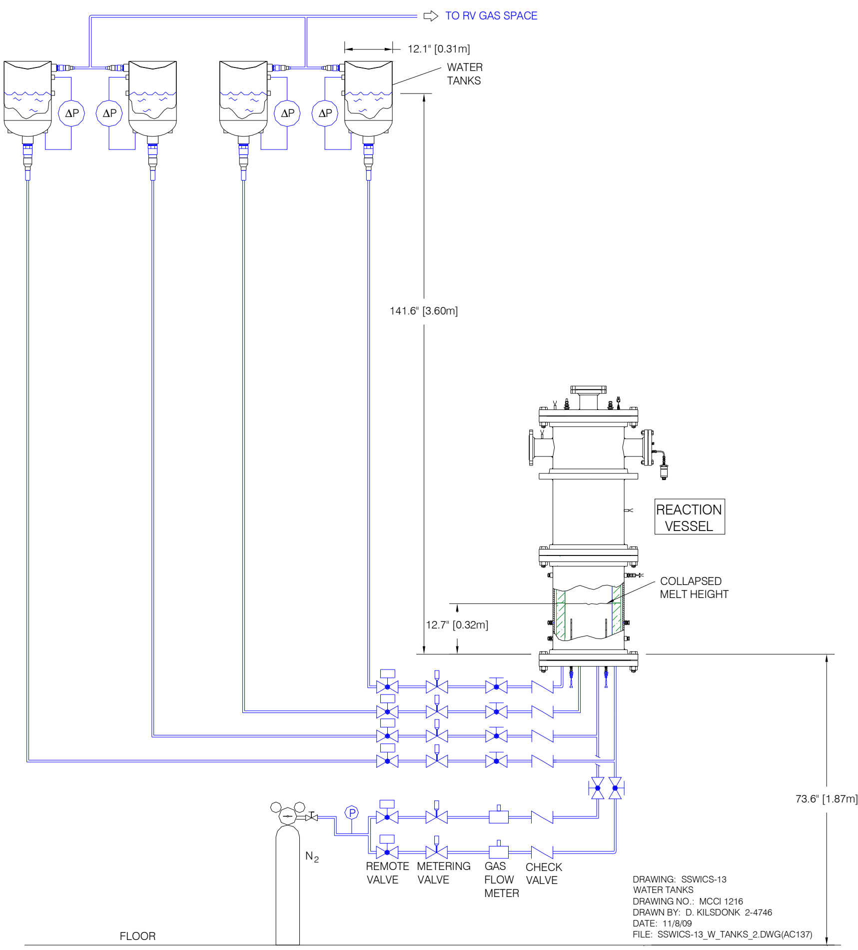

Figure 2.4. Water injection system geometry (drawn to scale).

Nozzle permeability is high enough that a restriction must be put in the injection line to prevent the flow rate from exceeding the specified limit. Each line has a metering valve set to allow 0.005 kg/s at the initial fill level, which would empty the tanks in ½ hour if this maximum rate could be maintained. The injection rate will, however, decline with driving head and so the injection period will be longer. This is noted to emphasize that the water injection phase of the test will be much longer than that of previous SSWICS tests, which generally dispense with water injection in less than five minutes.

2.3 Injection Nozzles

The design of the nozzles is illustrated in Fig. 2.5. Water leaves the nozzle and enters the melt through four 1 mm-diameter holes. The holes are positioned 4.5 mm from the nozzle center. The nozzle itself has a diameter of 12 mm and all components are made of stainless steel. The two nozzles injecting nitrogen have an additional 1-mm hole at the center. The nitrogen and water are expected to mix together as they enter the melt and it is thought that the noncondensable gas will reduce the likelihood of vapor explosions.

KAERI has specified the flow rate of the gas to be 20% the initial volumetric flow rate of the water. It was originally planned to deliver the gas using a flow controller set at a constant flow rate. However, there is concern that the forced gas flow might suppress the natural circulation water flow since the two are combined beneath a heavy corium pool. There is also concern that the combination of forced and natural circulation flow will not generate good gas/water mixing near the nozzle. To address these concerns, we have switched to a pressure regulated flow.

The gas system (Fig. 2.6) is configured with essentially the same approach used for the water. The initial flow rate to each nozzle is defined (0.06 lpm) as is the net driving head at the nozzle exit (0.2 bar to match the initial net driving head set for the water). The orifice size required to achieve the target flow depends upon the pressure loss characteristics of the gas system, which are not yet known. They will be measured once the gas system has been assembled. The line will be pressurized and gas will be run through the valves, flow meter, and a length of 1/8” capillary identical to that used in the nozzles. The metering valve will then be adjusted to provide a flow rate of 0.06 lpm for a nozzle pressure of 0.2 bar.

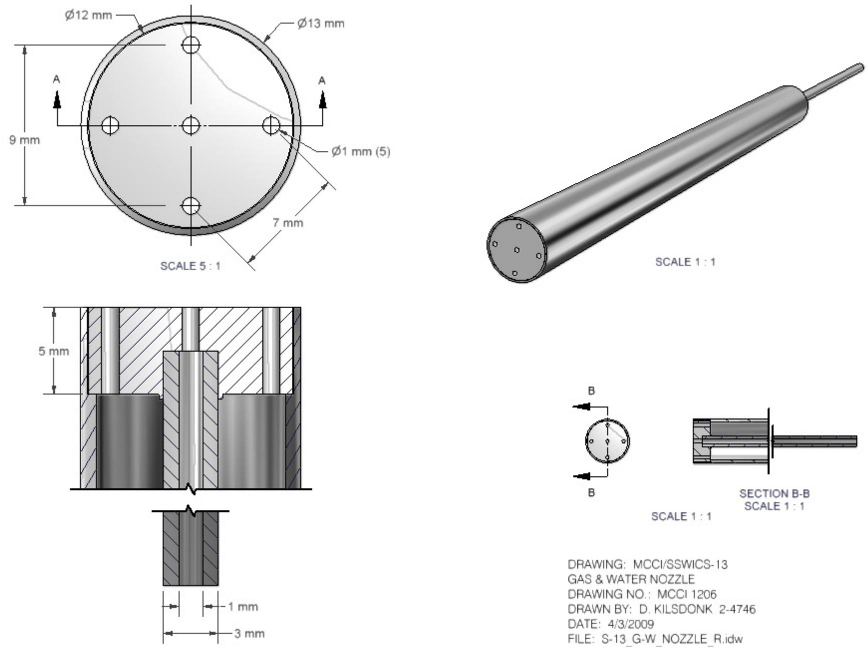

Figure 2.5. Nozzle layout on basemat (top) and nozzle detail (bottom).

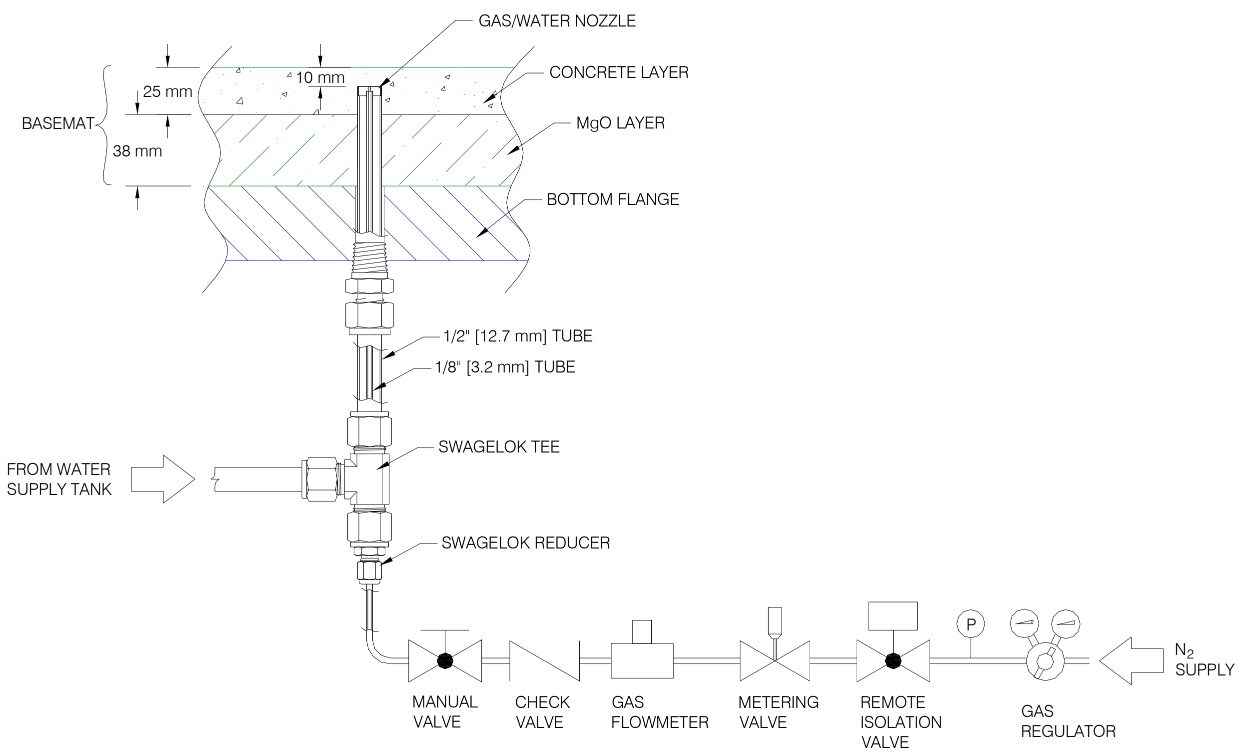

Figure 2.6. Details of nozzle design with gas injection.

3. Data Acquisition and Control Systems

3.1 Instrumentation

This test is intended to determine the efficacy of a particular engineered melt cooling concept. The directive to test a partitioned melt with separate injectors is, in effect, an instruction to combine two quench experiments into one. The instrumentation must therefore provide data sufficient to determine the boundary conditions and cooling behavior of the two partitions. The flow rate and driving pressure of each nozzle will be measured along with melt temperatures. The nitrogen gas flow rates to the two nozzles will also be measured. The condensate collection and measurement system used in past tests to determine the steaming rate will also be used in this test, but it cannot provide the cooling rate of an particular partition. It will instead provide the gross melt cooling rate. Only indirect indications of individual partition cooling rates, obtained through measurements of melt temperature and water flow rate into each quadrant, are available for this test.

Figure 3.1 shows the thermocouple layout in the basemat and the liner. Each partition is allotted one 5-junction C-type thermocouples in tungsten thermowells. The thermocouples are spaced every 51 mm so that the uppermost thermocouple is 195 mm above the basemat surface. The tungsten thermowells are 9.5 mm diameter, which is the same size used in CCI tests but larger than that used in previous SSWICS tests (6 mm). Though thermowell size should be minimized to limit fin cooling effects, the thermowells for this test are too long to fabricate in a diameter less than 9.5 mm.

MgO liner thermocouples used in previous tests to detect water bypass around the melt at the melt/liner interface are omitted as they were in SSWICS-12. These measurements are irrelevant here as water injection is expected to create widespread melt porosity that should indeed allow liquid flow across

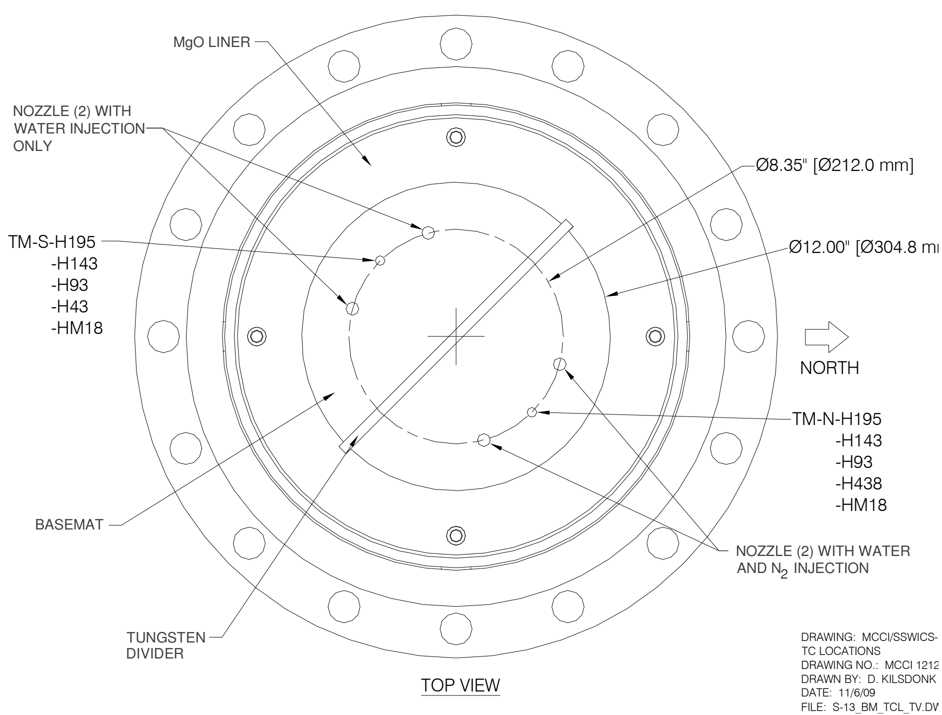

Figure 3.1. Melt thermocouple locations.

the melt/liner interface. Thus there is no notion here that water could go "around" the melt, as it might have during previous water ingression tests, distorting the predominantly one-dimensional character of the quench front.

The nomenclature used to identify thermocouples is as follows: TM (temperature within the corium melt), TF (fluid temperature), TG (gas space temperature), TS (structure temperature), H# (height above the bottom of the melt, in mm, and N, S, E, W representing the cardinal points. The partition is to be situated so that the "wedges" face towards the cardinal points. For example, TM-N-H195 is the melt thermocouple in the north facing wedge, 195 mm above the bottom of the melt. An instrument list is provided in Table 3.1.

3.2 General

All data acquisition and process control tasks are managed by a PC executing LabVIEW 8.2 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 (Fig. 3.2). 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 0.75 s to scan the channel list (16.7 ms * 45 channels). In practice, however, the acquisition of a single scan is at a frequency of approximately 0.5 Hz.

Selected valves are controlled with the PC using a relay card housed within an SCXI chassis (National Instruments); see Table 3.2. 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 Fig. 3.2, 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.

4. Test Parameters

The oxide phase of the corium composition for SSWICS-13 will be the same as that of SSWICS-6 and SSWICS-12 (i.e., 60.3/24.7/15.0 wt % UO_2/ZrO_2/siliceous concrete). However, consistent with SSWICS-12, the thermite reacts at a higher temperature relative to SSWICS-6 to minimize crust formation on the basemat that might impair initial water flow through the nozzles. This thermite reacts at ~ 2100°C, which can be compared to ~ 1950°C for SSWICS-6. Reformulation of the thermite to produce the higher reaction temperature results in a slightly higher Cr metal byproduct content of 7.6 wt % in the melt, which can be compared with to the level of 6.4 wt % for the SSWICS-6 thermite. The corium constituents are listed in Tables 4.1.

The water head is set at 0.2 bar and the gas back pressure to a level that generates 0.06 lpm at the beginning of the test.

The proposed test procedure is summarized as follows:

1) Preheat RV structures to ~100°C.

2) Preheat water for top injection to ~100°C.
3) Set back pressure for gas injection system.
4) Arm thermite ignition system.
5) Ignite thermite to begin test.
6) Note melt peak temperature and the timing of completion of the thermite burn (usually within one minute of the first sign of ignition).
7) Ten (10) seconds after the burn is completed, open isolation valves on basemat water and gas injection lines to nozzles.
8) At the first sign of a drop in reservoir water levels, begin top injection. Continue until 20 liters of water have been injected.
9) No other operator actions are required until the corium is quenched, which is expected to take place in less than two hours.
10) The melt is considered quenched, and the test complete, when readings from all melt thermocouples reach the saturation temperature of 100°C.

A contingency situation would arise in the event that both concrete nozzles failed to open after the thermite burn. This would be evidenced by a lack of thermal loading on the steam condensers that is displayed at the console during the test. In this event, supplemental top flooding will be used to supply the cavity with an additional 60 liters of water.

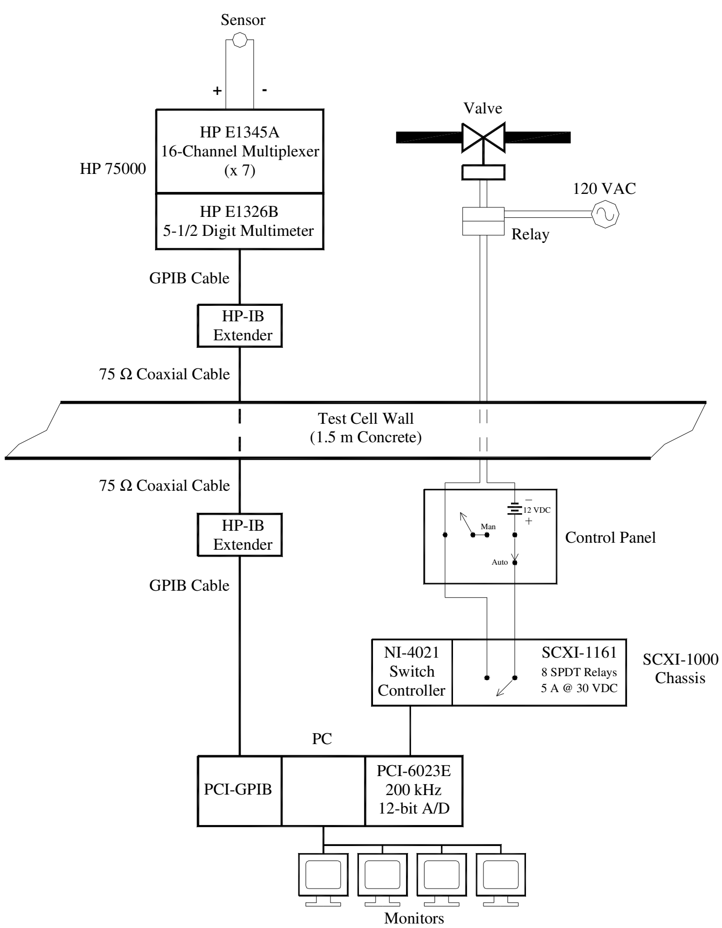

Figure 3.2. Data acquisition and control systems.

#	Channel	Name	Type	Description	Serial #	Output	Range	Accuracy
0	HPS-0	T-CJ-HPS	AD592 IC	Cold junction compensation sensor.	-	1□A/K	0-70°C	±0.5°C
1	HPS-1	TM-N-H168	TC type C	Melt temp. 195 mm above bottom of melt (in tungsten thermowell).	-	0-37 mV	0-2320°C	±4.5°C or 1%
2	HPS-2	TM-N-H117	TC type C	Melt temp. 143 mm above bottom of melt (in tungsten thermowell).	-	0-37 mV	0-2320°C	±4.5°C or 1%
3	HPS-3	TM-N-H67	TC type C	Melt temp. 93 mm above bottom of melt (in tungsten thermowell).	-	0-37 mV	0-2320°C	±4.5°C or 1%
4	HPS-4	TM-N-H16	TC type C	Melt temp. 43 mm above bottom of melt (in tungsten thermowell).	-	0-37 mV	0-2320°C	±4.5°C or 1%
5	HPS-5	TM-N-Hm35	TC type C	Melt temp. 18 mm below bottom of melt (in tungsten thermowell).	-	0-37 mV	0-2320°C	±4.5°C or 1%
6	HPS-6	TM-S-H168	TC type C	Melt temp. 195 mm above bottom of melt (in tungsten thermowell).	-	0-37 mV	0-2320°C	±4.5°C or 1%
7	HPS-7	TM-S-H117	TC type C	Melt temp. 143 mm above bottom of melt (in tungsten thermowell).	-	0-37 mV	0-2320°C	±4.5°C or 1%
8	HPS-8	TM-S-H67	TC type C	Melt temp. 93 mm above bottom of melt (in tungsten thermowell).	-	0-37 mV	0-2320°C	±4.5°C or 1%
9	HPS-9	TM-S-H168	TC type C	Melt temp. 43 mm above bottom of melt (in tungsten thermowell).	-	0-37 mV	0-2320°C	±4.5°C or 1%
10	HPS-10	TM-S-Hm35	TC type C	Melt temp. 18 mm below bottom of melt (in tungsten thermowell).	-	0-37 mV	0-2320°C	±4.5°C or 1%
11	HPS-11	Reserve	-	-	-	-	-	-
12	HPS-12	Reserve	-	-	-	-	-	-
13	HPS-13	Reserve	-	-	-	-	-	-
14	HPS-14	Reserve	-	-	-	-	-	-
15	HPS-15	Reserve	-	-	-	-	-	-
16	HPS-16	Reserve	-	-	-	-	-	-
17	HPS-17	Reserve	-	-	-	-	-	-
18	HPS-18	Reserve	-	-	-	-	-	-
19	HPS-19	Reserve	-	-	-	-	-	-
20	HPS-20	TF-quench	TC type K	Temperature of water injected into RV	-	0-50 mV	0-1250°C	±2.2°C or 0.75%
21	HPS-21	TG-RV	TC type C	Gas temp. in reaction vessel upper plenum.	-	0-37 mV	0-2320°C	±4.5°C or 1%
22	HPS-22	TS-RV-tf	TC type K	Temperature of RV top flange.	-	0-50 mV	0-1250°C	±2.2°C or 0.75%
23	HPS-23	TS-RV-1000	TC type K	Outer wall temp. of RV 1000 mm above bottom of melt.	-	0-50 mV	0-1250°C	±2.2°C or 0.75%
24	HPS-24	TS-RV-mf	TC type K	Temperature of RV middle flange.	-	0-50 mV	0-1250°C	±2.2°C or 0.75%
25	HPS-25	TS-RV-100	TC type K	Outer wall temp. of RV 100 mm above bottom of melt.	-	0-50 mV	0-1250°C	±2.2°C or 0.75%
26	HPS-26	TS-RV-bf	TC type K	Temperature of RV bottom flange.	-	0-50 mV	0-1250°C	±2.2°C or 0.75%
27	HPS-27	Reserve	-	-	-	-	-	-
28	HPS-28	TF-CT-102	TC type K	Fluid temp. in condensate tank at a water level of 102 mm.	-	0-50 mV	0-1250°C	±2.2°C or 0.75%
29	HPS-29	TF-CT-406	TC type K	Fluid temp. in condensate tank at a water level of 406 mm.	-	0-50 mV	0-1250°C	±2.2°C or 0.75%
30	HPS-30	TF-CT-711	TC type K	Fluid temp. in condensate tank at a water level of 711 mm.	-	0-50 mV	0-1250°C	±2.2°C or 0.75%
31	HPS-31	TF-CT-1016	TC type K	Fluid temp. in condensate tank at a water level of 1016 mm.	-	0-50 mV	0-1250°C	±2.2°C or 0.75%
32	HPS-32	TF-CT-1321	TC type K	Fluid temp. in condensate tank at a water level of 1321 mm.	-	0-50 mV	0-1250°C	±2.2°C or 0.75%
33	HPS-33	TF-CT-1626	TC type K	Fluid temp. in condensate tank at a water level of 1626 mm.	-	0-50 mV	0-1250°C	±2.2°C or 0.75%
34	HPS-34	TF-HX-in	TC type K	Fluid temp. at HX coolant inlet.	-	0-50 mV	0-1250°C	±2.2°C or 0.75%
35	HPS-35	TF-HX-out	TC type K	Fluid temp. at HX coolant outlet.	-	0-50 mV	0-1250°C	±2.2°C or 0.75%

Table 3.1. Instrumentation list for water ingression tests (part 1 of 2).

36	HPS-36	PD-sparge	-	□P transmitter for sparge gas back pressure		0-13 V	0-0.35 bar	±0.004 bar
37	HPS-37	I-ign	DC supply	Current supply for thermite ignitor.	-	0-100 mV	0-25 Amps	-
38	HPS-38	F-sparge1	FMA1810	Flow rate of nitrogen into injector for gas sparging	243485-3	0 - 5 V	0-200 ml/m N2	±3 ml/m
39	HPS-39	F-sparge2	FMA1810	Flow rate of nitrogen into injector for gas sparging	243485-2	0 - 5 V	0-200 ml/m N2	±3 ml/m
40	HPS-40	PA-RV	1810AZ	Absolute pressure in reaction vessel.	02351-00P1PM	1-6 V	0-14 bar gage	±0.14 bar
41	HPS-41	PD-CT	1801DZ	□P transmitter to measure condensate inventory.	-	0-13 V	0-0.35 bar	±0.004 bar
42	HPS-42	L-TDR-CT	BM100A	Time domain reflectometer to measure CT level.	A02331879A	4 - 20 mA	0 - 2 m	±3 mm
43	HPS-43	VDC-P-supply	-	Voltage of the power supply for the pressure transmitters.	-	0 - 15 V	-	-
44	HPS-44	PD-R1	-	□P transmitter to measure level in reservoir.	D2	0-13 V	0-0.35 bar	±0.004 bar
45	HPS-45	PD-R2	-	□P transmitter to measure level in reservoir.	D5	0-13 V	0-0.35 bar	±0.004 bar
46	HPS-46	PD-R3	-	□P transmitter to measure level in reservoir.	D3	0-13 V	0-0.35 bar	±0.004 bar
47	HPS-47	PD-R4	-	□P transmitter to measure level in reservoir.	D4	0-13 V	0-0.35 bar	±0.004 bar
60	HPQ-50	T-CJ-HPQ	AD592 IC	Cold junction compensation sensor.	-	1□A/K	0-70°C	±0.5°C
61	HPQ-51	TF-ST	TC type K	Fluid temp. in spray tank.	-	0-50 mV	0-1250°C	±2.2°C or 0.75%
62	HPQ-52	TG-CL-out	TC type K	Gas temperature in condensate tank outlet line to spray tank.	-	0-50 mV	0-1250°C	±2.2°C or 0.75%
63	HPQ-53	TG-ST-in	TC type K	Gas temp. in the spray tank line inlet.	-	0-50 mV	0-1250°C	±2.2°C or 0.75%
64	HPQ-54	TG-ST-out	TC type K	Gas temp. in the spray tank line outlet.	-	0-50 mV	0-1250°C	±2.2°C or 0.75%
65	HPQ-55	F-quench	Paddlewheel	Flow rate of water into reaction vessel (for quenching melt).	3144	0-5 V	0-50 gpm	±0.5 gpm
66	HPQ-56	F-HX	Paddlewheel	Flow rate of cold water to heat exchangers.	3143	0-5 V	0-50 gpm	±0.5 gpm

Table 3.1. (continued).

LabVIEW Channel #	Valve Name	Type	Description	Actuator
1	V-CT	Ball valve	Valve on steam line between reaction vessel and quench tank.	Pneumatic
2	V-quench	Ball valve	Valve on quench water supply line into reaction vessel.	Solenoid
3	V-quench-i	Ball valve	Isolation valve on quench water supply line into reaction vessel.	Solenoid
4	V-quench-b	Ball valve	Valve on back-up quench water supply.	Solenoid
5	V-ST	Ball valve	Valve on vent line between reaction vessel and spray tank.	Pneumatic
Panel	V-HX	Ball valve	Valve on cooling-water line to heat exchangers.	Solenoid
Panel	VC-CT	Ball valve	Control valve on steam line between reaction vessel and quench tank.	Electric
Panel	V-R1	Ball valve	Control valve on water injection line from reservoir R1.	Electric
Panel	V-R2	Ball valve	Control valve on water injection line from reservoir R2.	Electric
Panel	V-R3	Ball valve	Control valve on water injection line from reservoir R3.	Electric
Panel	V-R4	Ball valve	Control valve on water injection line from reservoir R4.	Electric
Panel	V-sparge1	Ball valve	Control valve on sparge line one.	Electric
Panel	V-sparge2	Ball valve	Control valve on sparge line two.	Electric

Table 3.2. Remotely operated valves.

Constituent	Mass (kg)
U_3O_8	78.61
CrO_3	19.90
CaO	2.96
Zr	22.98
Mg	0.10
Si	3.51
SiO_2	7.49
Al	0.45
Total	136.0

Constituent	Wt %	
	Reactant	Product
U_3O_8	57.80	-
UO_2	-	55.61
Zr	16.90	-
ZrO_2	-	22.84
Si	2.58	-
SiO_2	5.51	11.03
Mg	0.07	-
MgO	-	0.11
Al	0.33	-
Al_2O_3	-	0.63
CaO	2.18	2.18
CrO_3	14.63	-
Cr	-	7.60

Tables 4.1. Corium powder charge and reaction product mass fractions.