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Characterization of Hydraulic and Ignition Phenomena of Pressurized Water Reactor Fuel Assemblies: Phase I Test Plan

E.R. Lindgren and S.G. Durbin

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

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E.R. Lindgren and S.G. Durbin
Advanced Nuclear Fuel Cycle Technologies

Sandia National Laboratories
P.O. Box 5800
Albuquerque, New Mexico 87185-MS0537

Abstract

This report summarizes the strategy and preparations for the first phase in the pressurized water reactor (PWR) ignition experimental program. During this phase, a single full length, prototypic 17×17 PWR fuel assembly will simulate a severe loss-of-coolant-accident in the spent fuel pool whereby the fuel is completely uncovered and heats up until ignition of the cladding occurs. Electrically resistive heaters with zircaloy cladding will substitute for the spent nuclear fuel. The assembly will be placed in a single pool cell with the outer wall well insulated. This boundary condition will imitate the situation of an assembly surrounded by assemblies of similar offload age.

Several, initial modeling and design results are detailed in this report and represent the current knowledge base. However, these results are subject to change with new information.

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ABBREVIATIONS/DEFINITIONS

BWR	boiling water reactor
CFD	computational fluid dynamics
CYBL	cylindrical boiling
DAQ	data acquisition
D_H	hydraulic diameter
GC	gas chromatograph
ID	inside diameter
LDA	laser Doppler anemometer
MB	Management Board
MELCOR	severe accident analysis code
NEA	Nuclear Energy Agency
NRC	Nuclear Regulatory Commission
OD	outside diameter
OECD	Organization for Economic Co-operation and Development
PCT	peak cladding temperature
PRG	Program Review Group
PWR	pressurized water reactor
SFP	spent fuel pool or Sandia Fuel Project
slpm	standard liters per minute (standard defined at 0ºC and 1 atm)
SNL	Sandia National Laboratories
TC	thermocouple

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1 INTRODUCTION

1.1 Objective

The objective of the proposed project is to perform a highly detailed thermal-hydraulic characterization of full-length, commercial 17×17 pressurized water reactor (PWR) fuel assembly mock-ups to provide data for the direct validation of MELCOR or other appropriate severe accident codes. MELCOR model predictions based on extrapolations from the results of a previously conducted boiling water reactor (BWR) study indicate that PWR assemblies will ignite and radially propagate in a spent fuel pool complete-loss-of-coolant accident.[1] The proposed PWR characterization will be similar to that successfully conducted for the BWR study and will lead to two full-scale PWR fire tests where the zirconium alloy cladding is heated in air to ignition. The PWR experimental design and data analysis will be closely coupled with MELCOR modeling as was done in the previous BWR study.

1.2 Testing Outline

As previously stated, the study will be conducted in two phases. Phase I will focus on axial heating and burn propagation. A single full-length test assembly will be constructed with zirconium alloy clad heater rods. The thermal mass of the compacted MgO powder used to make the electric heater is an excellent match to spent fuel as demonstrated in the previous BWR study. The assembly will be characterized in two different sized storage cells and conclude with an ignition test. The baseline, testing parameters for Phase I are summarized below.

- Two pool cells – 221.8 and 224.5 mm inner dimension for pre-ignition and ignition testing, respectively
- Pre-ignition test powers – 0.5 to 5 kW
- Ignition test power – 10 kW electrical input (Radial heat losses estimated with 152.4 mm of high temperature insulation)

The ignition test will determine the location in the assembly where ignition first occurs and the nature of the burn along the axis of the assembly. The insulated boundary conditions will experimentally represent a “hot neighbor” situation, which is an important bounding scenario. The remainder of this report outlines the details of the Phase I test efforts. Note: The designs and modeling results contained in this report are preliminary and are subject to refinement.

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2 PHASE I TESTING

The testing in Phase I will focus on axial heating and burn propagation. The test assembly will prototypically represent a commercial 17×17 PWR fuel bundle. The various components comprising a typical 17×17 PWR assembly are illustrated in Figure 2.1. The main structural component of the assembly is the core skeleton, which consists of eleven spacers permanently attached to twenty-five guide tubes. The 264 fuel rods pass through the spacers and are held captive in the assembly by the top and bottom nozzles.

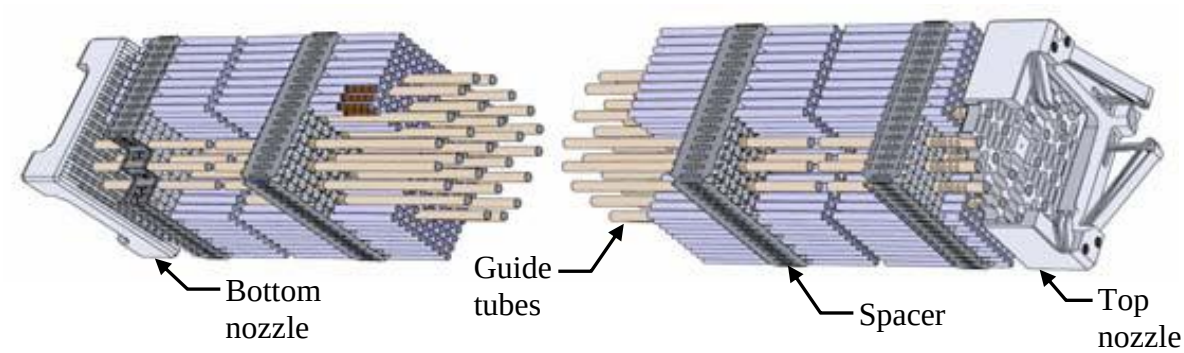

Figure 2.1 Various components in a typical 17×17 PWR fuel assembly.

The single full-length, heated PWR assembly will be fabricated using prototypic, commercial 17×17 PWR components and 9.53 mm (0.375 in.) heater rods made from 11.18 mm (0.44 in.) zirconium alloy tubing supplied by an industrial vendor. The heater rods will be manufactured by a commercial vendor using the same fuel rod simulator design that was highly successful in the BWR study.[1] The spent fuel rod simulators for Phase I will have a linear power profile and a maximum output of 15.8 W/m (4.8 W/ft), which is 50% greater than expected to produce ignition. An important attribute of the heater design is that the specific thermal capacitance of the compacted magnesium oxide (MgO) powder used to electrically insulate the central heating element from the cladding is virtually the same as spent fuel over the entire temperature range of interest (as shown in Figure 2.2). These spent fuel simulators will therefore heat at the same rate and store the same amount of thermal energy as prototypic spent fuel rods.

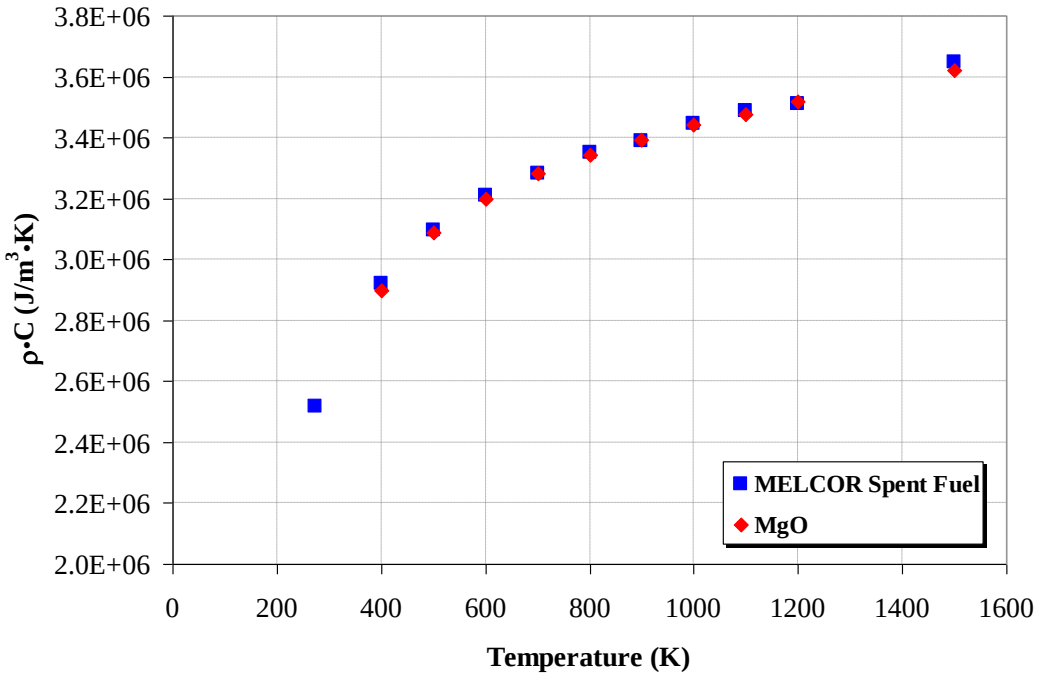

Figure 2.2 Thermal mass comparison of spent fuel and MgO fuel rod simulators.

2.1 Preliminary MELCOR Ignition Test Predictions

A preliminary model was constructed from an existing MELCOR, whole pool input deck. This model was originally created to simulate accident conditions in a PWR 15×15 spent fuel pool.[2] The preliminary Phase I model includes a single assembly surrounded by 152.4 mm (6 in.) of high temperature insulation. Experimental, radial heat losses are expected to be approximately 20% of total power based on previous experience with the BWR testing. The model also accommodates pre-oxidation of the fuel cladding and the magnesium oxide (MgO) surrogate in the heaters.

The input deck was modified to reflect the hydraulics of a 17×17 PWR inside a pool cell with an inner dimension of 224.5 mm (Hydraulic diameter, D_H = 11.75 mm) as shown in Figure 2.3. This pool cell size is common to spent fuel racks within the US commercial fleet. Pool cell sizes are discussed in more detail in Section 2.2.3.

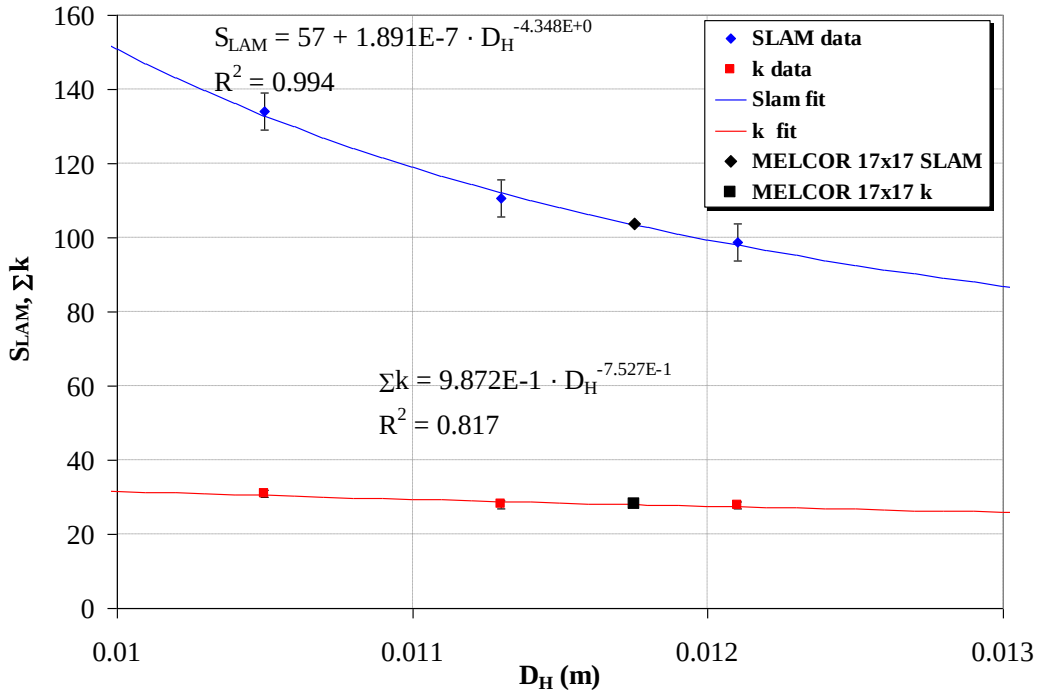

Figure 2.3 Estimation of hydraulic parameters for a 17×17 PWR fuel assembly in a 224.5 mm pool cell.

To summarize, the initial MELCOR model was built from an existing 15×15 whole pool model in order to quickly generate results for this test plan. This model makes the following assumptions.

- Fuel mass and cladding surface area taken from 15×15 assembly in reference PWR SFP MELCOR study[2]
- Hydraulic resistance reflects 17×17 assembly as estimated from SNL Experimental PWR SFP Hydraulic Characterization for SFP storage cell dimensions
- Uniform power distribution and MgO fuel properties
- Initial oxide layer of 50 μm on fuel elements
- Radial heat losses through 152.4 mm (6 in.) of high temperature insulation

Figure 2.4 shows the peak cladding temperature (PCT) for different simulated decay heats. The assembly is predicted to ignite in approximately 5 to 15 hours for decay heats of 15 and 9 kW, respectively. The transient thermal response of a 10 kW assembly is shown in Figure 2.5 at each axial node location. The temperature increases axially within the assembly as expected. An assembly with 10 kW decay heat is currently considered the baseline case for the Phase I ignition test.

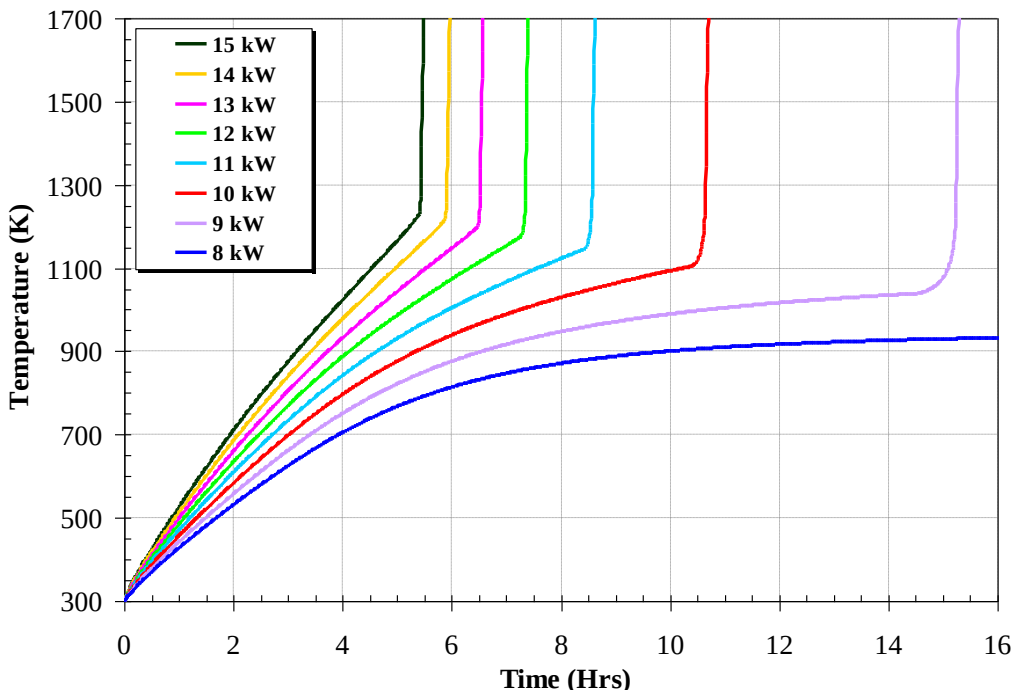

Figure 2.4 **Comparison of the peak cladding temperature as a time for different fuel decay heats.**

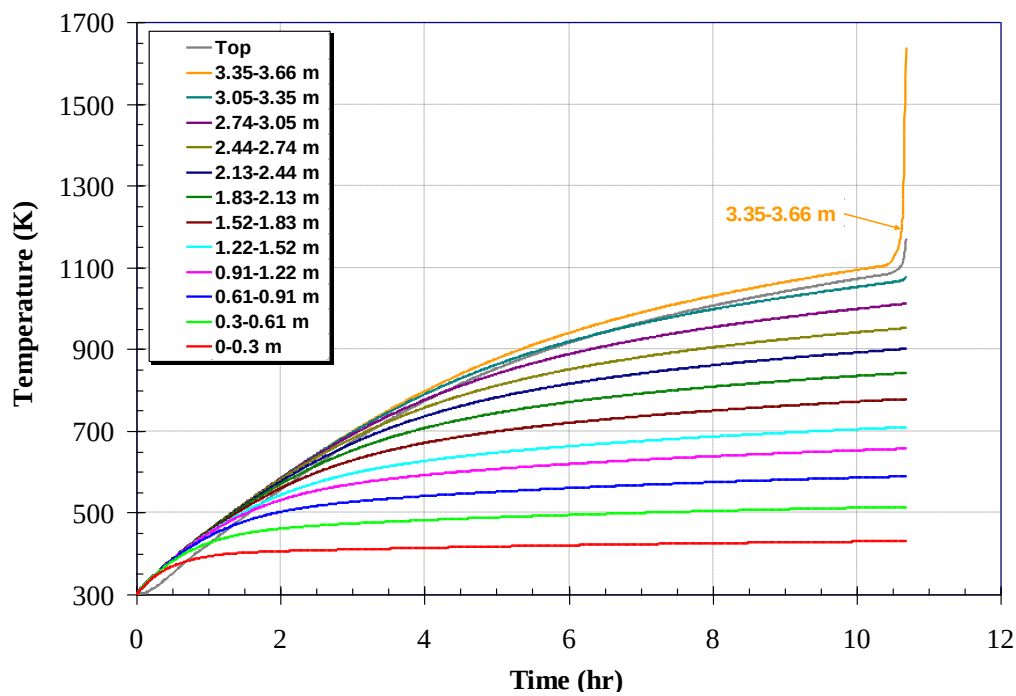

Figure 2.5 **Transient thermal response at different axial levels for a single, insulated assembly at 160 days aging (10 kW).**

2.2 Testing Considerations

2.2.1 Heater Cladding

The Organization for Economic Co-operation and Development – Nuclear Energy Agency / Sandia Fuel Project, Program Review Group (OECD-NEA SFP PRG) requested that Zr-4 be used as the cladding material in the PWR test program so that all members would have access to the material properties for modeling purposes. Zircaloy-4 tubing is not available in an appropriate diameter for heater fabrication, at least 10.72 mm (0.422 in.). In the heater fabrication process the tubing is drawn through a die that swages the diameter down to 9.53 mm (0.375 in.) and compacts the magnesia powder around the nichrome heating element.

The heated assembly in both the Phase I and Phase II experiments must be fabricated from the same material for testing and modeling continuity. ZIRLO and Zr-2 tubing were considered as alternate claddings to fabricate heated assemblies for both Phase I and II. Ultimately, Zircaloy-2 was chosen as the best alternative for the heater cladding. Table 2.1 lists the composition of Zr-2 along with Zr-4 and ZIRLO. The composition of Zr-2 is nearly identical to Zr-4. A comparison of oxygen diffusion coefficients, which is related to the oxidation kinetics, for both Zr-2 and Zr-4 indicate no appreciable differences in the alloys.[3,4] The composition of ZIRLO is significantly different from Zr-4 and the ignition kinetics are known to differ from Zr-4. Zircaloy-2 was used in the BWR ignition study and the use of Zr-4 air oxidation kinetics in the corresponding MELCOR model proved to be valid as discussed next.

Table 2.1 Typical composition of zirconium alloys in wt%.

	Nb	Sn	Fe	Cr	Ni
ZIRLO	1	1	0.2	--	--
Zr-4	--	1.20 - 1.70	0.18 - 0.24	0.07 - 0.13	--
Zr-2	--	1.20 - 1.70	0.07 - 0.20	0.05 - 0.15	0.03 - 0.08

For the previous BWR prototypic scale experiments, the functional equivalence of Zr-2 and Zr-4 was demonstrated within experimental error as shown in Figure 2.6. The timing of the transition to breakaway kinetics has a greater impact on the timing of ignition than the actual parameters of the pre- or post-breakaway oxidation kinetics. Given the absence of a mechanistic understanding of the breakaway phenomena, the PWR ignition project will benefit from the experience earned during the modeling of the Zr-2 cladding in the BWR experiment.

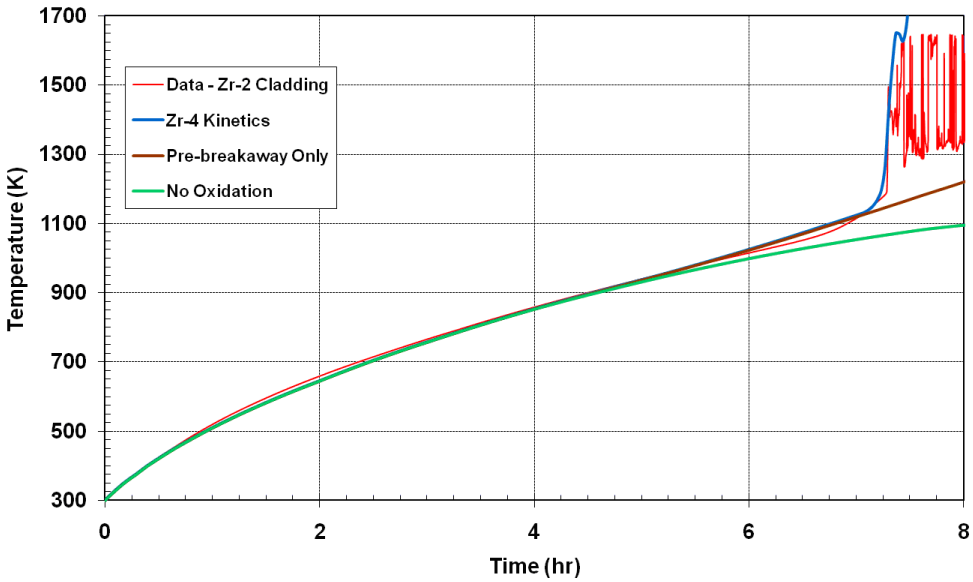

Figure 2.6 **Peak Zr-2 cladding temperature compared with MELCOR simulation using Zr-4 kinetics and special cases of pre-breakaway kinetics only and no Zr oxidation.**

A further advantage of using the Zr-2 tubing is that the heater fabricator has already used this tubing to make 9.53 mm (0.375 in.) heaters for the BWR Heater Design tests. Therefore, the tooling setup for the manufacture of the heaters has already been demonstrated and would require less setup time.

2.2.2 Heater Design

A preliminary design for the heater rods is shown in Figure 2.7. The heated and unheated lengths for the fuel rod simulator and a PWR fuel rod are compared for reference. As shown in Detail A, the lower, unheated length of the heater includes an alumina standoff for electrical isolation 15.9 mm (0.625 in.) and an internal power introduction length 50.8 mm (2 in.). The height of the axial heated zone with respect to the top of the bottom nozzle is preserved as closely as possible between the heater rod 3.680 m (144.875 in.) and the reference PWR fuel rod 3.863 m (145”). Due to the necessary electrical connection at the top, the heater rod design has been extended 0.067 m (2.65 in.) above the prototypic length. Details of the top and bottom electrical connections are given in Section 2.4.

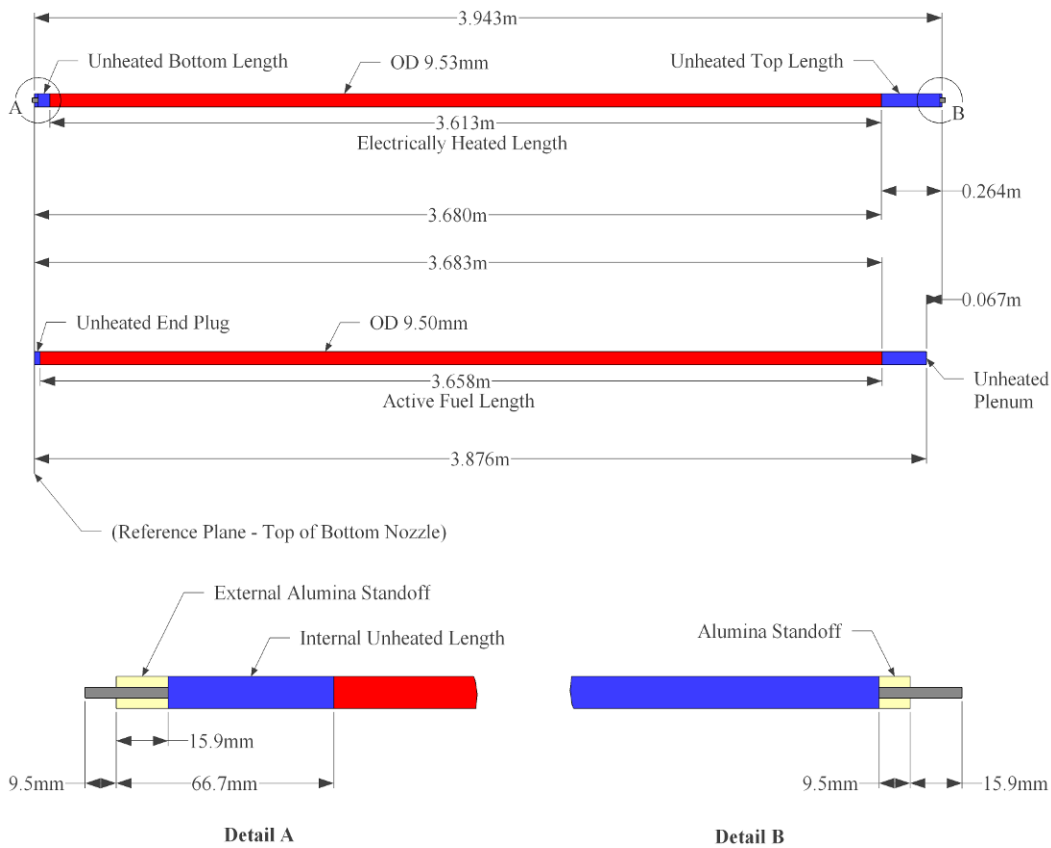

Figure 2.7 Design of the electrically heated fuel simulators.

The vertical dimension in the plan view has been scaled 6:1 to show the heated and unheated zones. PWR fuel layout shown for reference.

2.2.3 Pool Cells

The Holtec pool rack for Westinghouse 17×17 PWR assemblies incorporates pool cells with an inner dimension of 224.5 mm. Therefore, a 224.5 mm pool cell will be used in both the Phase I and Phase II ignition tests. Both will be made from the same 1.91 mm (0.075 in.) thick stainless steel material. The size of the 224.5 mm pool cell is between the 221.8 mm and 226.6 mm pool cells tested in the PWR hydraulic characterization study but is closer to the larger size. Phase I pre-ignition testing will also include a second pool cell of a different size in order to assess the effect of the annular flow region between the pool cell wall and the tube bundle. The 221.8 mm size is recommended for the second pool cell because it provides the greatest contrast in size to the Holtec pool cell.

Consideration was given to using a ceramic material for the Phase I ignition test pool cell but has been dismissed for a number of technical reasons following discussions with the technical staff at Coors Ceramics. The ceramic cell would need to be made in relatively short sections (~0.5 m or less) and fitted together similar to chimney tiles. The dimensional tolerances would only be ±3 mm, which would require that the ceramic cell be made with an ID larger than prototypic (and would not match the Holtec pool rack). The inner surface of the cell wall could not be made continuously smooth but would have gaps at the section joints. The ceramic walls would need to

be relatively thick (~6 mm) so that the ceramic pool cell would have more thermal mass than a prototypic stainless steel pool cell. Finally, at the expected maximum temperatures (~2000 K) alumina would have no structural strength and the cell would slump under its own weight.

The problems of air leakage into the bundle upon pool cell failure will be mitigated by the elimination of penetrations through the pool cell wall. In the full-length BWR ignition test, light pipes, side thermocouples (TCs), and oxygen sensors penetrated the pool cell through fittings welded to the pool cell. When the pool cell melted and slumped, some of the instrumentation attached to the pool cell wall was dragged downward distorting the surrounding insulation and providing new air flow pathways. This was especially true of the large oxygen sensors. For the PWR ignition test the light pipes and side TCs will touch the outside wall of the pool cell but will not be connected to or penetrate through the cell wall. Therefore, the distortion of the PWR pool cell should not open significant air pathways for the PWR ignition test.

2.2.4 Fire Extinguishing

A capability to extinguish the burn will be implemented for the ignition test. The ignition test will be conducted inside of a large stainless steel containment vessel 4.9 m ID × 8 m tall (See Figure 2.8). The hot assembly will cool fastest if it can draft non-reactive gas. Therefore, the experiment will be constructed such that the containment vessel can be flooded with argon gas.

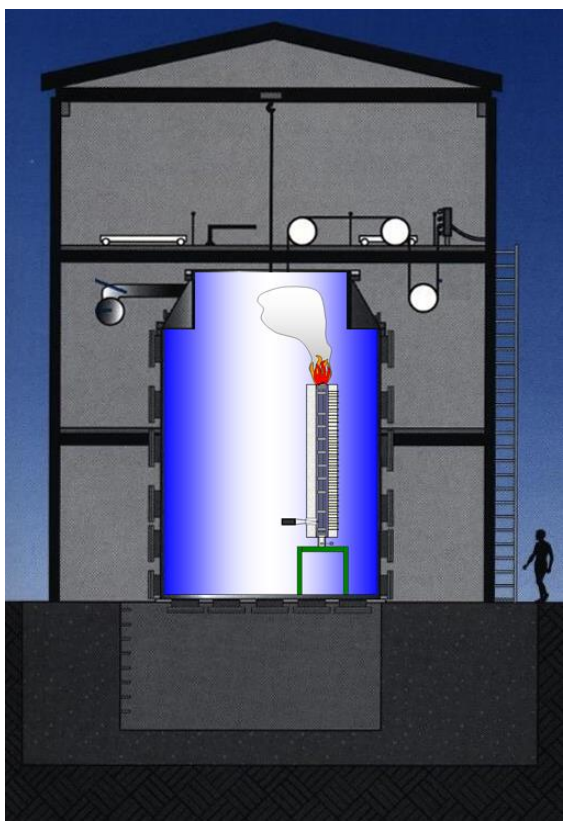

Figure 2.8 Experimental enclosure for the PWR ignition test series.

The facility was originally constructed for the Cylindrical Boiling (CYBL) test series.

2.3 Instrumentation

The instrumentation of the prototypic PWR assembly will be similar to that used in the previous BWR study. Figure 2.9 shows the proposed test assembly. The full-length, electrically heated PWR test assembly will be positioned inside a prototypic storage cell that is surrounded with a thick layer of high temperature insulation. The instrumentation will include hot wire anemometers, oxygen sensors, automated GC for Ar and N_2 quantification, quartz light pipes, and thermocouples (TCs).

The TCs installed inside the heated assembly will be used for testing both pool cells. The optical ports and laser Doppler anemometer measurements will only be included in the first pool cell tests. High-temperature, platinum type TCs (type B) and quartz light pipes will only be installed on the second pool cell. Also, the oxygen sensors and GC analysis of N_2 and Ar will only be available during the ignition test of the second pool cell. Table 2.2 summarizes the instrumentation to be used for each test series.

Table 2.2 Type of instrumentation incorporated into each test series.

	Cell #1 Pre-ignition	Cell #2 Pre-ignition	Cell #2 Ignition
Hot Wire	X	x	x
Bundle TCs	X	x	x
Other TCs	X	x	x
Pt type TCs		x	x
Light pipes		x	x
O_2/N_2/Ar gas			x
LDA	X		

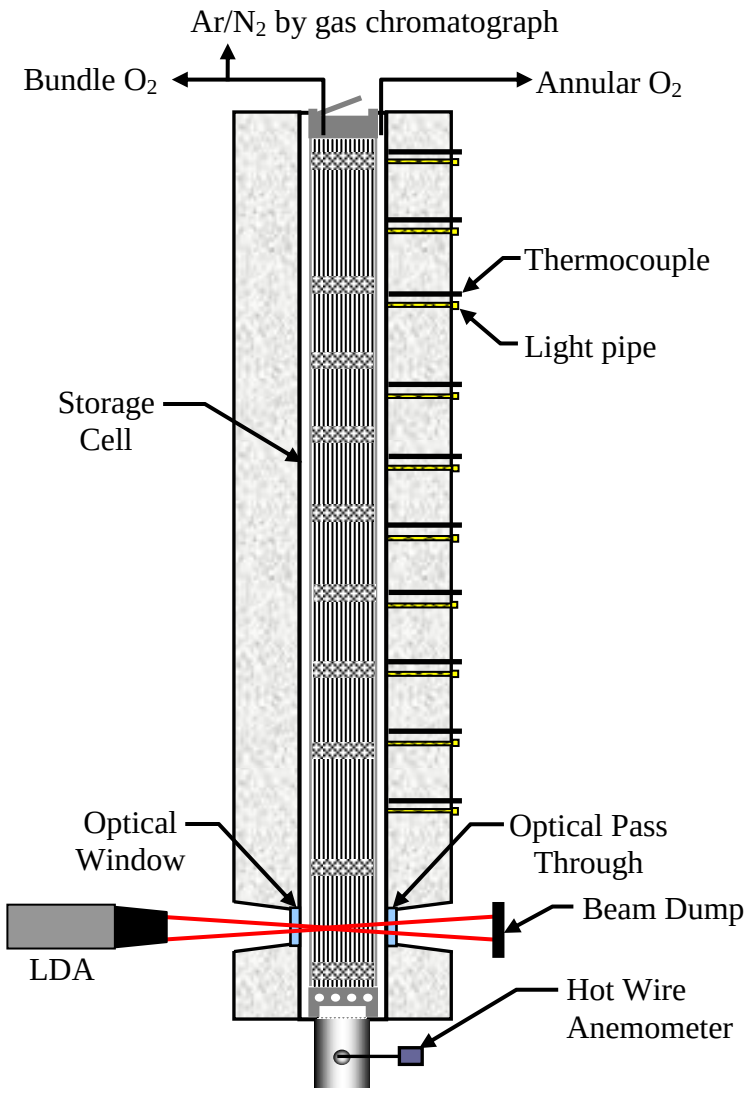

Figure 2.9 PWR test assembly and instrumentation.

2.3.1 Bundle Thermocouples

Approximately 125 TCs will be located within the bundle. The TCs will be attached to the heaters and guide tubes by strapping the tip of the TCs with a small piece Nichrome shim stock to the rod. The shim stock is spot welded to the rod ensuring good thermal contact as shown in Figure 2.10. Figure 2.4 shows the results of preliminary MELCOR modeling. A 10 kW assembly with radial heat loss is expected to reach ignition in just under 11 hours (see Figure 2.5). Unlike the BWR assembly, ignition in the PWR is expected to occur near the top of the assembly. Therefore, most the bundle TCs will be routed out the bottom of the assembly. TCs located in the top no-heat region and the top 15.25 cm (6 in.) of the heated bundle will be routed out the top of the assembly.

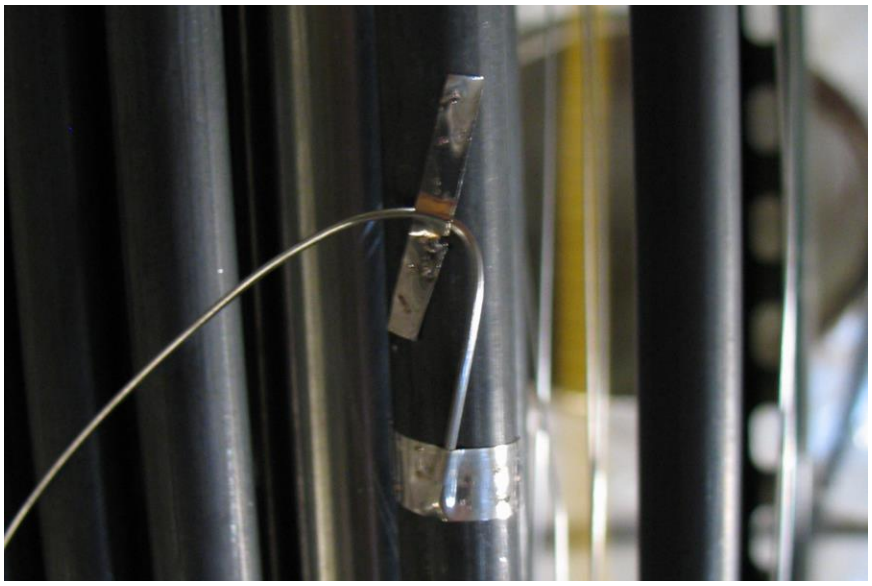

Figure 2.10 Detail view showing TC attachment to a fuel rod.

Figure 2.11 shows the proposed TC layout. Most of the TCs (and all of the interior TCs) will be installed on the outside surface of the guide tubes before any of the heater rods are installed. TCs will also be installed on some outer row heater rods. Three different axial array densities are proposed. Red denotes the location of high density arrays where TCs are located at 15.25 cm (6 in.) intervals. Yellow denotes the location of medium density arrays where TCs are located at 30.5 cm (12 in.) intervals. Green denotes the location of low density arrays where TCs are located at 61 cm (24 in.) intervals. The interior guide tubes are instrumented at low density because these tubes are the most difficult to access.

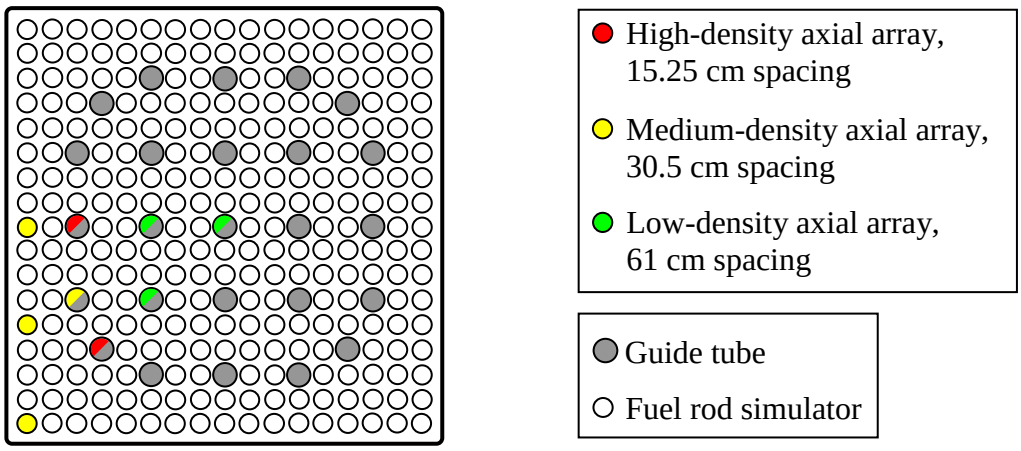

Figure 2.11 TC layout for the Phase I test assembly.

2.3.2 Other Thermocouples

A number of other TCs will be installed on the outer pool cell wall, midway through the high temperature insulation, and on the outer stainless steel thermal radiation shield. These TCs will

allow estimation of heat losses through the insulation. Also, a number of platinum based TCs will be placed along the outer wall of the pool cell and near the assembly exit.

2.3.3 Gas Chromatograph Details

The nitrogen consumption will be monitored in order to determine if nitriding of the zirconium clad is occurring. Tracking a nitrogen deficiency will require simultaneous measurement of nitrogen and argon concentrations. The argon will behave as an inert tracer. If nitrogen is consumed, the ratio of argon to nitrogen will increase. An Alltech Associates Inc. gas chromatograph (GC) method shown in Figure 2.12 is currently under consideration. The method utilizes a basic packed GC column and thermal conductivity detector. The GC column packing is a porous polymer packing at cryogenic temperatures, which can separate nitrogen, oxygen, and argon in less than 4 minutes. Since nothing eludes in the first two minutes, this method can be used to perform the gas analysis at two minute intervals.

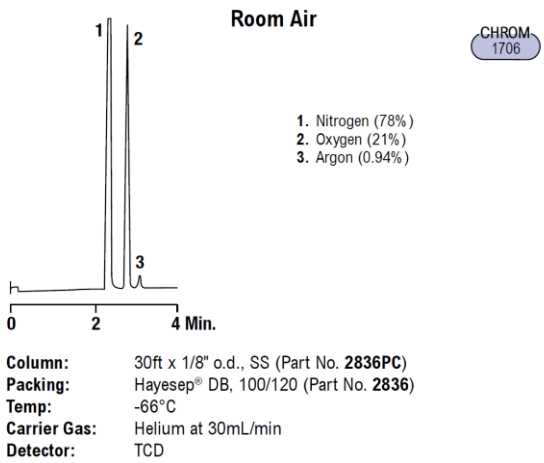

Figure 2.12 Methodology for determining nitriding of the cladding using gas chromatography.

2.4 Heater Rod Electrical Connections

Introducing electrical power into the assembly presents several engineering challenges. An electrical current is fed into the assembly at the top of the assembly by applying voltage, up to 120 V, across the heater rods. The bottom electrical connections terminate in the bottom nozzle, which is tied to the circuit neutral leg. Electrically isolating the heater cladding, guide tubes, and pool cell are crucial to prevent a short circuit in the power loop. In addition, the top electrical connection is expected to reach highly elevated temperatures. Designs have been engineered to address these testing issues.

The peak temperature at the top of the assembly prior to ignition is projected to be 1100K, which is 200 K higher than experienced in the BWR ignition tests. Therefore, the upper heater rod electrical connection requires special attention. The high upper temperatures could lead to loss of electrical connectivity prior to ignition. The upper electrical bus plate and connections are specifically designed to survive at higher temperatures. Figure 2.13 shows a conceptual drawing of the top electrical bus plate design. The bus plate design will be cut from three pairs of nickel-copper alloy 400 (Monel) plates and will replace the top nozzle. The bus plate design is electrically divided into three zones of 88 heater rods each to accommodate the higher power

requirements expected in the Phase II experiment and facilitate installation of the bus plates onto the heater rod power posts. To insure even distribution of power to the heater rods, the power will be introduced into each zone via three 6.4 mm (0.25 in.) Monel threaded rods as shown in Figure 2.13.

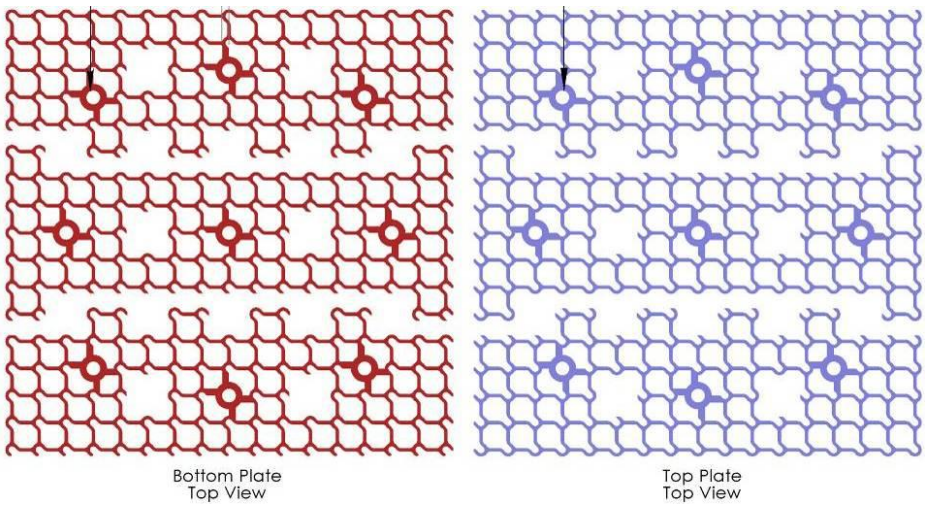

Figure 2.13 Design of the top electrical bus plate.

Each bus plate zone is comprised of a pair of upper and lower plates. The heater rod connection collars for the 88 heater rods are open on the same quadrant corner on a given plate. The connection collars on the mating plate are open on the opposite quadrant. When installed, the 88 heater rod connection pins initially pass through the plate in the larger interstitial area between four pin connection collars. Then, the plate is slid diagonally until all of the heater rod pins are captured in the connection collars. The top and bottom plates are moved in opposite directions so once in position each heater rod pin has 360° contact with the connection collar as shown in Figure 2.14.

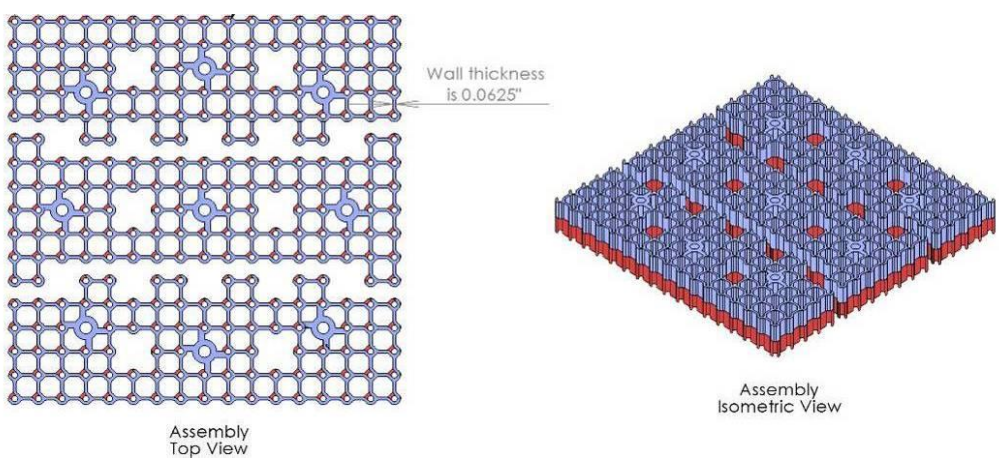

Figure 2.14 Assembly detail of the top electrical bus plate design.

The top of the assembly is represented schematically in Figure 2.15. The top electrical bus plates have been left out of the drawing to avoid confusion. Figure 2.15 shows the top of two heater

rods and a guide tube in cross section. Alumina standoffs and an alumina sphere isolate the cladding and guide tubes from electrical contact with the top bus plates. The additional length of the heater rods over the prototypical value is required to place the electrical connection above the top of the guide tubes. A detailed drawing of the power connection, including the top bus plates, is shown in Figure 2.16.

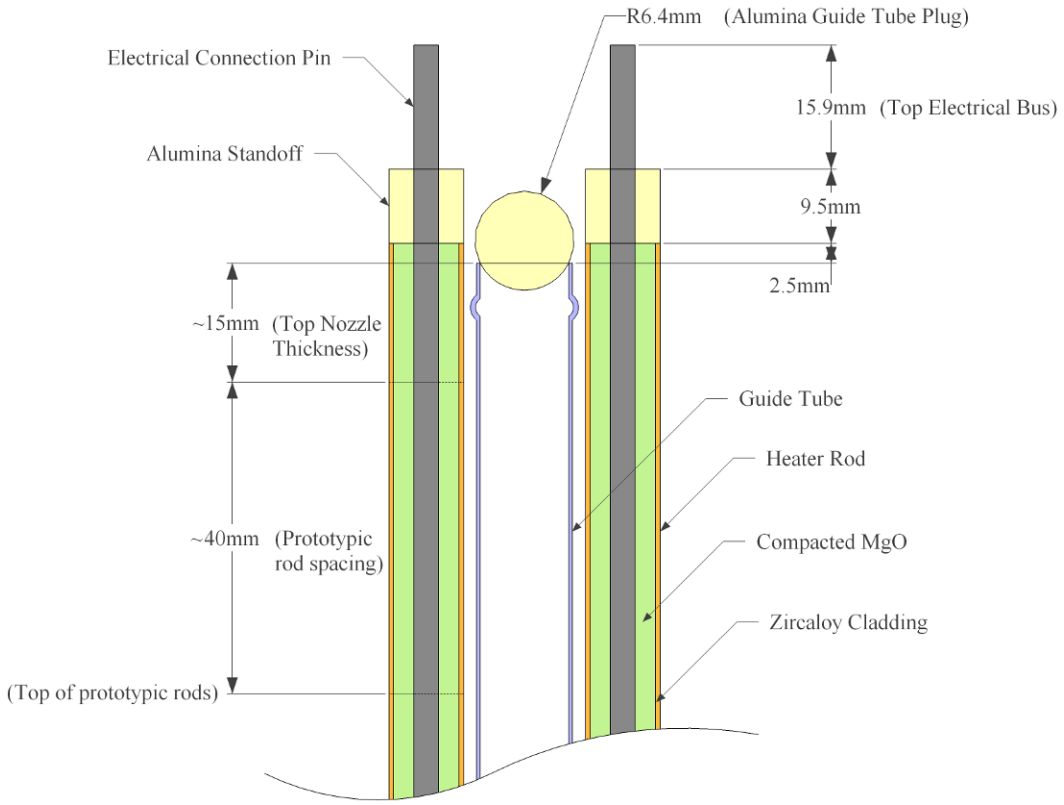

Figure 2.15 Detail drawing of the top of the assembly showing two heater rods and a single guide tube.

The top and bottom plates are held in place by the threaded Monel power rods as shown in Figure 2.16. On the lower plates, the power connection locations are threaded to receive the power rod. The power connection locations on the top plate are slightly oversized, through holes. The power rod is passed through the upper plate and threaded into the lower plate. A Monel nut and washer is tightened down onto the top plate to lock the plate together.

The bottom PWR nozzle will serve as the electrical bus for the neutral connections. Blind holes machined into the bottom nozzle will accept the connection pin of each heater rod as shown in Figure 2.17. High temperature silver contact grease will be placed in each hole to insure good connectivity.

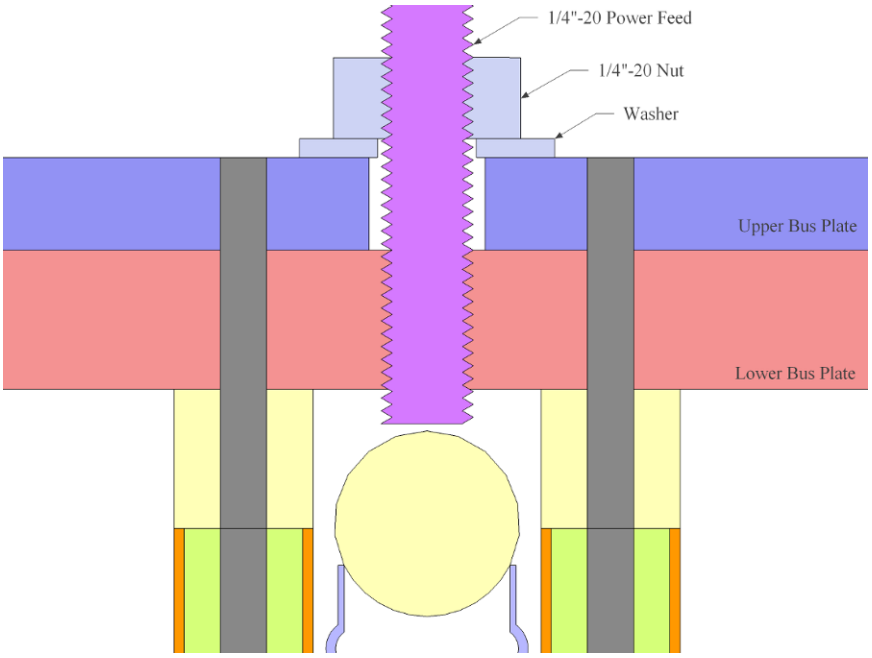

Figure 2.16 Cross-sectional detail drawing of the top electrical connection from the power feed into the heater electrical pins.

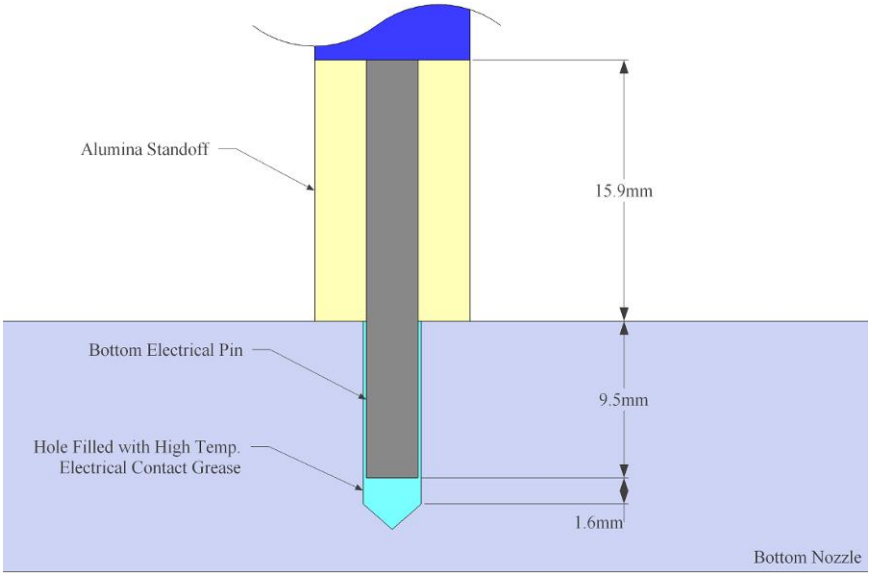

Figure 2.17 Detail drawing of the bottom of the assembly showing the electrical connection of a single heater rod to the bottom nozzle (neutral).

2.5 Experimental Approach

The Phase 1 test matrix will be very similar to the corresponding matrix in the BWR study. For the pre-ignition testing, the assembly will be heated at a given power and the resulting steady state temperatures and induce flow rate determined. The peak temperatures must be kept below 900 K in order to avoid excessive oxidation of the zirconium components. The cumulative temperature history of the zirconium components will be monitored and the resulting oxide layer

produced will be estimated with MELCOR and used as an initial condition for the MELCOR modeling of the final ignition experiment.

The steady state buoyancy driven flow and resulting temperature profile are highly coupled. The thermal gradient inside the bundle creates the buoyancy that drives the flow. The flow in turn convectively cools the bundle such that the flow and the thermal gradients come into balance. The resulting data set provides an excellent validation database for any dynamic thermal-hydraulic numerical model of the assembly.

Figure 2.18, Figure 2.19, and Figure 2.20 show some of the corresponding data generated in the BWR study (in red) along with the MELCOR model calculations (in blue). The applied power ranged from 5 to 50% of the power required for ignition. Assuming the power scaling will be similar for the PWR assembly the pre-ignition power will range from 500 W to 5000 W.

In contrast to the previous BWR project, two series of heated pre-ignition PWR experiments will be conducted using two different size storage cells. The ignition experiment will be conducted with a storage cell the same size that will be used in the Phase-II 3×3 Holtec pool rack. The initial pre-ignition tests will be conducted with a slightly smaller storage cell the same size as the mid-size cell used in the PWR hydraulic characterization.[5] The two different sized storage cells will form two different sized annular gaps between the tube bundle and the storage cell wall. The parallel annular flow path between the bundle and the inner storage cell wall complicates the thermal-hydraulic coupling in the PWR assembly. The partitioning of flow between the annular and bundle regions will be characterized by the laser Doppler anemometer (LDA) used in the recent PWR hydraulic characterization study. The ability and validity of severe accident numerical codes to account for the magnitude of the heat transported to the annular flow will be determined.

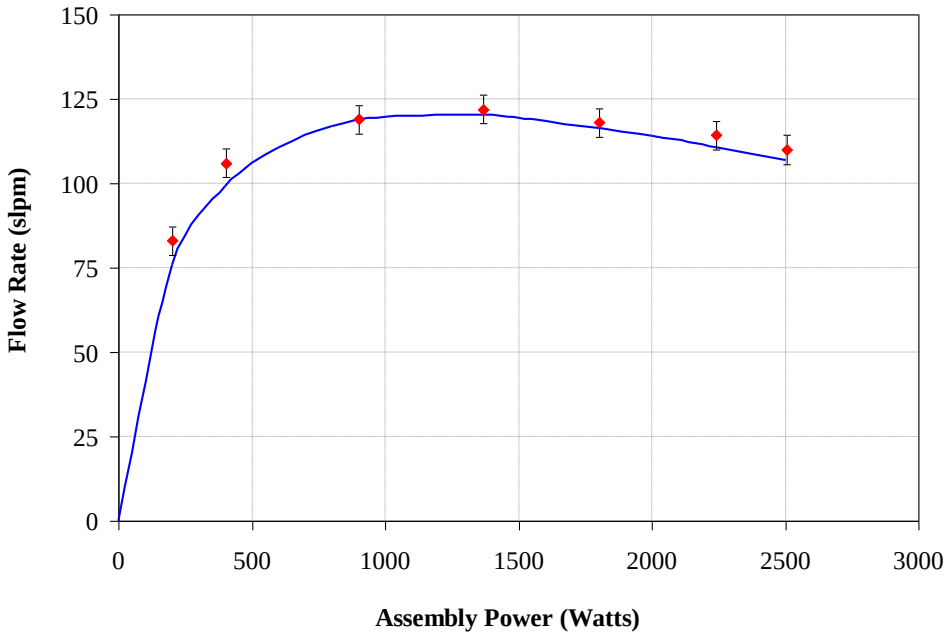

Figure 2.18 Volumetric flow rates as a function of assembly input power for experiment (symbols) and MELCOR (line) from SAND2007-2270.

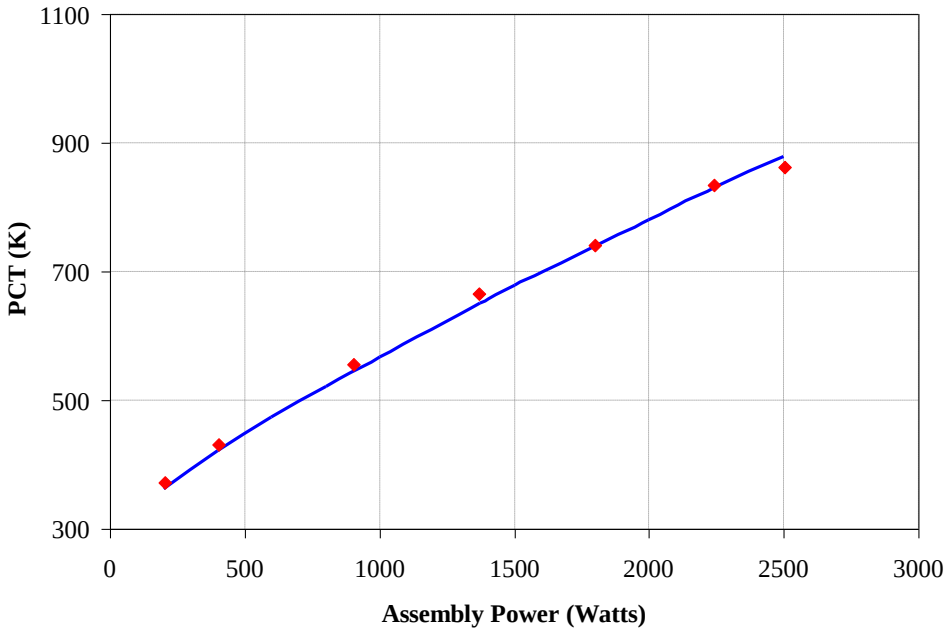

Figure 2.19 Peak cladding temperature as a function of assembly input power for experimental (symbols) and MELCOR (blue line) from SAND2007-2270.

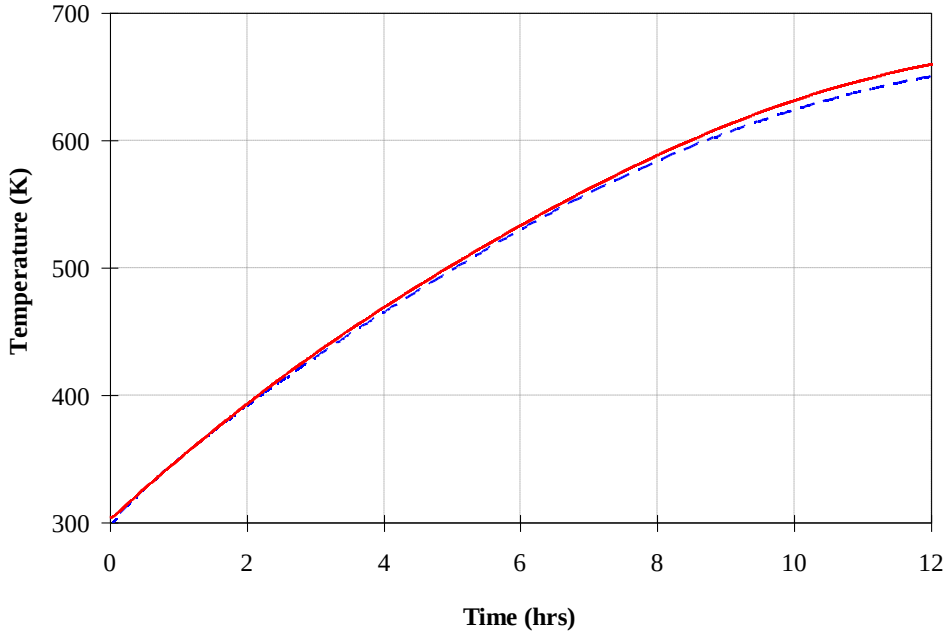

Figure 2.20 Comparison of the experimentally measured thermal transient response (solid red) with the MELCOR code (dashed blue) for an assembly power input of 1370 W from SAND2007-2270.

The Phase I testing will conclude with the ignition of the assembly much like that conducted for the BWR study. The insulated boundary conditions experimentally represented a 100-day old assembly surrounded by 100-day old neighbors. This "hot neighbor" scenario represents an important bounding situation where the oldest, lowest power assembly can heat to ignition. In

the BWR test, ignition initiated about two-thirds the way up the heated length and then burned downwards. Once ignition occurred, the oxygen concentration dropped sharply to zero above the burn front. The downward advance of the burn front was driven by the upward flowing supply of oxygen. All of the zirconium was not consumed as the front moved downward. Once the bottom was reached, the burn front reversed directions and moved back up the length of the assembly consuming the remaining zirconium. The assembly was completely destroyed by the fire as shown in Figure 2.21.

The burn front could not move upwards initially because the burning Zircaloy rods and channel box consumed all the oxygen. The absence of a Zircaloy channel box on a PWR assembly could lead to different burn characteristics. If some oxygen can bypass the burning rods in the annulus, the burn front may proceed further upwards initially, and the burning of the zirconium may be more complete as the burn front moves down. This burn behavior would also likely affect the radial propagation characteristics, which is the focus of the testing in Phase II.

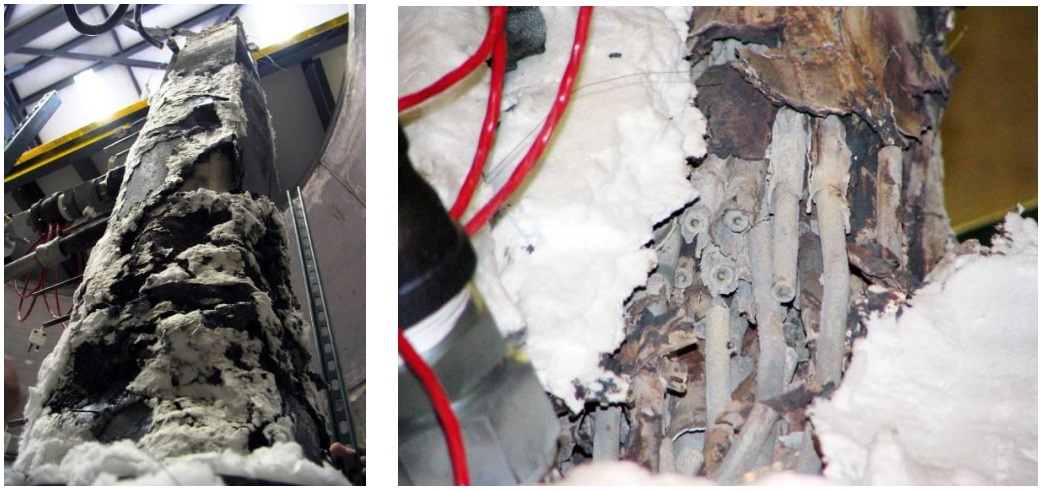

Figure 2.21 Postmortem of the assembly after ignition from SAND2007-2270.

3 PROJECT STATUS AND SCHEDULE

The Sandia Fuel Project (SFP) received chargeable funding on July 7, 2009. Preparatory and scheduling activities followed immediately including the first meeting of the OECD-NEA SFP Program Review Group (PRG) and subsequent meeting of the Management Board (MB) on July 21-22, 2009. Project planning activities were completed on August 7, 2009. This original project plan was predicated on the availability of Zr-4 cladding for the manufacture of the electrically-heated fuel rod simulators. Discussions with the primary hardware vendor, Westinghouse Electric, later indicated that a sufficient quantity of Zr-4 tubing in an appropriate diameter was not available and was not likely to become available in a timeframe or cost acceptable to the project. SNL offered an option of ZIRLO clad heaters to the PRG on August 21, 2009. While the PRG considered the use of ZIRLO for the heater cladding, SNL continued to explore other options. A readily available supply of Zr-2 was identified by SNL and disclosed as a second option on September 22, 2009. The two cladding options have since been debated amongst PRG members. A decision point was set for November 20, 2009, and the project schedule has been updated to reflect this delay in heater cladding selection. Table 3.1 shows the milestones and significant events of the SFP for both the original and the updated schedules. Phase II events have also been included in the table for reference. The two-month delay in tubing selection has created a schedule slip of approximately the same duration through the life of the project.

Table 3.1 Milestones and significant events of the Sandia Fuel Project.

	Milestone / Event	Original	Updated
Phase I	Order heater tubing	9/28/2009	12/1/2009
	Begin pre-ignition (Cell 1)	6/7/2010	7/30/2010
	Begin pre-ignition (Cell 2)	10/12/2010	12/6/2010
	Begin ignition test	11/10/2010	1/17/2011
	Quick look report and data due	12/30/2010	3/8/2011
	Final report and data due	5/20/2011	7/27/2011
Phase II	Order heater tubing	9/28/2009	12/1/2009
	Begin pre-ignition	4/25/2012	6/25/2012
	Begin ignition test	5/24/2012	7/24/2012
	Quick look report and data due	7/2/2012	8/30/2012
	Final report and data due	11/20/2012	1/18/2013

The schedule slip due to the heater tubing selection is within acceptable limits. However, the available slip in the project schedule is now reduced to a marginal value. Efforts to minimize future delays are crucial to the success of the project. Based on previous technical experience and current reports from vendors, no substantial delays are expected.

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4 REFERENCES

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