# Critical Heat Flux Test Program Technical Report

January 2014

Revision 0

Docket: PROJ0769

Nonproprietary

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## CONTENTS

## TABLES



## FIGURES



 

# 1.0 Introduction

## 1.1 Overview

The NuScale Power, LLC (NuScale) small modular reactor (SMR) uses natural circulation to drive the flow in the reactor coolant system, providing reliable core heat removal during normal plant operation and for accident conditions. These unique primary coolant flow conditions and the geometric configuration of the NuScale design do not permit the direct application of existing critical heat flux (CHF) correlations. As a result, a test program to obtain CHF test data for the NuScale reactor fuel design has been conducted.

## 1.2 Test Program Summary

To obtain CHF test data suitable for CHF correlation development for use in fuel bundle design and safety analysis codes, NuScale has completed a test program using a full-length, full-power, electrically heated fuel assembly simulation with spacer grids. Testing was conducted over a wide range of flow rates and pressures with multiple test bundle configurations utilizing both uniform and cosine axial power shape profiles. This testing was performed at Stern Laboratories in Hamilton, Ontario, Canada from September 2012 through March 2013, with an overall program duration of approximately 24 months beginning in October of 2011.

## 1.3 Purpose

This document presents an overview of the test program and objectives. Details are provided on the planning, execution and results of this effort, including descriptions of the programmatic and technical requirements, test bundle, facility, instrumentation and data acquisition system, test procedures and test uncertainties.

## 1.4 Abbreviations and Definitions

Table 1-1. Abbreviations

| Term | Definition |
|---|---|
| 95/95 | at least a 95% probability at the 95% confidence level |
| AECL | Atomic Energy of Canada Limited |
| AOO | anticipated operational occurrence |
| APS | axial power shape |
| B&W | Babcock and Wilcox |
| BHL | beginning of heated length |
| CCW | counterclockwise |
| CFR | Code of Federal Regulations |
| CHF | critical heat flux |
| CHFR | critical heat flux ratio |
| DAS | data acquisition system |
| DCA | design certification application |

| Term | Definition |
|---|---|
| DNB | departure from nucleate boiling |
| EHL | end of heated length |
| EPRI | Electric Power Research Institute |
| FRS | fuel rod simulator |
| GDC | general design criterion |
| LOCA | loss-of-coolant accident |
| LWR | light water reactor |
| MCHFR | minimum critical heat flux ratio |
| NF | NuScale fuel |
| NRC | United States Nuclear Regulatory Commission |
| PWR | pressurized water reactor |
| QA | quality assurance |
| RTD | resistance temperature detector |
| SL | Stern Laboratories, Inc. |
| SMR | small modular reactor |
| SRP | Standard Review Plan |
| SSC | structures, systems and components |
| T/C | thermocouple |
| TH | thermal-hydraulic |
| W | Westinghouse |

Table 1-2. Definitions

| Term | Definition |
|---|---|
| critical heat flux | The limit in boiling heat transfer characterized by the sudden decrease in heat transfer efficiency because of either a departure from nucleate boiling or dryout. |
| critical heat flux ratio | The ratio of the predicted critical heat flux to the actual operating heat flux. |
| minimum critical heat flux ratio | The minimum critical heat flux ratio value throughout a reactor core. |

 

### 1.5 Referenced Documents

1.5.1 Critical Heat Flux Test Development Plan, NP-TSD-0712-001.

1.5.2 CHF Testing Statement of Work, NP-SW-0811-013.

1.5.3 Gellerstedt, J.S., Lee, R.A., Oberjohn, W.J., Wilson, R.H., Stanek, L.J., "Correlation of Critical Heat Flux in a Bundle Cooled by Pressurized Water," Two-Phase Flow and Heat Transfer in Rod Bundles, pp. 63-71, *Winter Annual Meeting of the American Society of Mechanical Engineers*, Los Angeles, CA, November 18, 1969.

1.5.4 Tong, L.S., "Prediction of Departure from Nucleate Boiling for an Axially Non-uniform Heat Flux Distribution," *Journal of Nuclear Energy*, Vol. 21, pp. 241-248, 1967.

1.5.5 Reddy, D.G., Fighetti, C.F., "Parametric Study of CHF Data, Volume 2: A Generalized Subchannel CHF Correlation for PWR and BWR Fuel Assemblies," EPRI NP-2609, Volume 2, Electric Power Research Institute, Palo Alto, CA, January 1983.

1.5.6 Groeneveld, D.C., Leung, L.K.H., Kirillov, P.L., Bobkov, V.P., Smogalev, I.P., Vinogradov, V.N., Huang, X.C., Royer E., "The 1995 Look-up Table for Critical Heat Flux in Tubes," Nuclear Engineering and Design, Vol. 163, pp. 1-23, 1996.

1.5.7 Overview of the NuScale Power Module and 12-Unit Reference Plant Arrangement, NP-DEM-RP-PLOV-001, Revision 0.

1.5.8 Technical Specification for NuScale Fuel Simulators - 4.2.5Fuel Simulator Specification, NP-TS-0112-923-R1.

1.5.9 Corradini, Michael L., "Fundamentals of Multiphase Flow," 1997.

1.5.10 U.S. Nuclear Regulatory Commission, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition," NUREG-0800, March 2007.

1.5.11 *U.S. Code of Federal Regulations*, "General Design Criteria for Nuclear Power Plants," Appendix A, Part 50, Chapter I, Title 10, "Energy," (10 CFR 50, Appendix A).

1.5.12 *U.S. Code of Federal Regulations*, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants," Appendix B, Part 50, Chapter I, Title 10, "Energy," (10 CFR 50, Appendix B).

1.5.13 American Society of Mechanical Engineers, *Quality Assurance Requirements for Nuclear Facility Applications*, ASME NQA-1-2008 and NQA-1a-2009 addenda, New York, NY.

1.5.14 Collier, J.G., "Convective Boiling and Condensation," McGraw Hill, 1972.

1.5.15 Stern Laboratories, Inc., "Uniform Series Results of Thermal Mixing, CHF and Transient Experiments for NuScale Power," SL-250-R1.

1.5.16 Stern Laboratories, Inc., "Cosine Series Results of Thermal Mixing, CHF and Transient Experiments for NuScale Power," SL-252-R0.

1.5.17 Stern Laboratories, Inc., Uncertainty Analysis of Thermal Mixing, CHF and Transient Experiments for NuScale Power," SL-253-R0.

1.5.18 Stern Laboratories, Inc., "Final Report on Thermal Mixing, CHF and Transient Experiments for NuScale Power," SL-254-R0.

# 2.0 Critical Heat Flux Test Program—Requirements and Background

As an applicant for new reactor design approval and certification, NuScale must demonstrate that fuel design limits are not exceeded during normal operation or anticipated operational occurrences (AOOs) and that fuel temperature does not exceed the allowable limits established in 10 CFR 50.46 for LOCA events. The ability to accurately predict CHF over the full range of operation is of paramount importance to establishing these fuel limits and has traditionally been done by the development of an empirical correlation applicable to the operational range of interest.

Critical heat flux refers to the heat flux at which continuous liquid contact with the heated surface of the fuel rods cannot be maintained, due to phenomena called departure from nucleate boiling (DNB) or dryout. This results in a sudden decrease in heat transfer performance and an associated temperature excursion at the heated surface which can lead to a failure of the fuel rod.

CHF is highly dependent on the fuel geometry, flow parameters and fluid properties so, due to the unique operating conditions of the NuScale reactor, existing CHF correlations are not applicable to this design. {{

}}3(a)(c) A high level overview of the thermal design process, NuScale CHF correlation methodology and CHF test program basis is discussed in this section to provide the context within which the test program was developed. Additional details and reference material can be found in the CHF Test Development Plan (Reference 1.5.1), and Statement of Work (Reference 1.5.2).

## 2.1 Thermal Design and CHF Correlation Overview

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## 2.2 Applicable Ranges of Existing CHF Correlations

Table 2-1 summarizes the applicable ranges for some of the existing CHF models in the public domain. The Babcock and Wilcox B&W-2 and Westinghouse W-3 CHF correlations were developed for their specific fuel assembly applications, and the Electric Power Research Institute

EPRI-1 CHF correlation and the Atomic Energy of Canada Limited AECL CHF look-up table were developed for general applications.

Most of the CHF correlations for specific applications could not be accessed because they are proprietary. {{

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Table 2-1. Applicable ranges of existing CHF models

| Parameter | B&W-2 (Reference 1.5.3) | W-3 (Reference 1.5.4) | EPRI-1 (Reference 1.5.5) | AECL CHF Look Up Table (Reference 1.5.6) |
|---|---|---|---|---|
| Pressure (MPa) | 13.8–16.5 | 6.9–15.9 | 1.4–16.9 | 0.1–20.0 |
| Mass flux (kg/s-m$^2$) | 1017–5425 | 1356–6781 | 271–5561 | 0–8000 |
| Thermodynamic quality | -0.03–0.20 | -0.15–0.15 | -0.25–0.75 | -0.50–1.00 |
| Heated length (mm) | 1829 | 254–3658 | 762–4267 | 312–6000 |
| Hydraulic diameter (mm) | 5.1–12.7 | 5.1–17.8 | 8.9–14.0 | 3.0–25.0 |
| *All ranges are approximate* | | | | |

## 2.3 NuScale Reactor Fuel Design Background

The fuel assembly, core layout, and overall thermal design parameters for the NuScale reactor provided the basis for specifying the fuel simulators and hardware for the test program.

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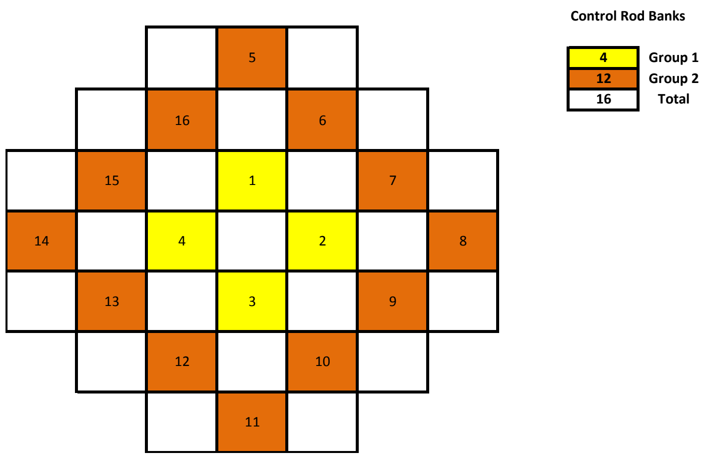


Figure 2-3. NuScale control rod location map (Reference 1.5.7)

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| B | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| C | 3 | 3 | 3 | 3 | 4 | 2 | 3 | 3 | 2 | 3 | 3 | 2 | 4 | 3 | 3 | 3 | 3 |
| D | 3 | 3 | | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 3 | 3 | 3 |
| E | 3 | 3 | 4 | 3 | 3 | 3 | 3 | 5 | 3 | 5 | 3 | 3 | 3 | 3 | 4 | 3 | 3 |
| F | 3 | 3 | 2 | 3 | 3 | 2 | 3 | 3 | 2 | 3 | 3 | 2 | 3 | 3 | 2 | 3 | 3 |
| G | 3 | 3 | 3 | 3 | 3 | 3 | 5 | 3 | 3 | 3 | 5 | 3 | 3 | 3 | 3 | 3 | 3 |
| H | 3 | 3 | 3 | 3 | 5 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 5 | 3 | 3 | 3 | 3 |
| I | 3 | 3 | 2 | 3 | 3 | 2 | 3 | 3 | 1 | 3 | 3 | 2 | 3 | 3 | 2 | 3 | 3 |
| J | 3 | 3 | 3 | 3 | 5 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 5 | 3 | 3 | 3 | 3 |
| K | 3 | 3 | 3 | 3 | 3 | 3 | 5 | 3 | 3 | 3 | 5 | 3 | 3 | 3 | 3 | 3 | 3 |
| L | 3 | 3 | 2 | 3 | 3 | 2 | 3 | 3 | 2 | 3 | 3 | 2 | 3 | 3 | 2 | 3 | 3 |
| M | 3 | 3 | 4 | 3 | 3 | 3 | 3 | 5 | 3 | 5 | 3 | 3 | 3 | 3 | 4 | 3 | 3 |
| N | 3 | 3 | 3 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 3 | 3 | 3 |
| O | 3 | 3 | 3 | 3 | 4 | 2 | 3 | 3 | 2 | 3 | 3 | 2 | 4 | 3 | 3 | 3 | 3 |
| P | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Q | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |

| Rod ID | Rod Type | U235 w/o | Gd w/o | # of Rods |
|---|---|---|---|---|
| 1 | Instrument Tube | | | 1 |
| 2 | Guide Tube | | | 24 |
| 3 | UO2 | 3.25 | 0.0 | 244 |
| 4 | $UO_2 + Gd_2O_3$ | 3.12 | 4.0 | 8 |
| 5 | $UO_2 + Gd_2O_3$ | 3.06 | 6.0 | 12 |

Figure 2-4. Fuel assembly map (Reference 1.5.7)

The fuel development activities are ongoing and include efforts for the detailed fuel assembly and fuel rod design, fuel performance code development and licensing support. {{

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Prototypic core thermal and geometric parameters were established early in the design process and the critical heat flux test program was initiated at that point in order to generate test data in sufficient time to support the CHF correlation and associated code development prior to DCA submittal.

## 2.4 Test Program Fuel Simulation and Bundle Configurations

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## 2.5 Reactor Operating Conditions and Selection of Test Conditions

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As a natural circulation reactor, the flow rate generated by the buoyant forces is much lower than in a pumped primary coolant system. In addition, the operating pressure of the NuScale reactor is at the lower range of typical PWRs. {{

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# 3.0 Test Requirements

Descriptions of the fuel simulation, bundle configurations and test matrix requirements noted in Section 2.0 were translated into specifications necessary for the execution of the test program. Details for the basis for each set of tests is outlined in this section and a discussion of how the test data are used in the CHF correlation development and the subchannel analyses is provided.

## 3.1 Test Input and Output Parameters

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Figure 3-1. Key test inputs and outputs

## 3.2 Steady-State CHF Tests

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### 3.3 Transient CHF Tests

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### 3.4 Thermal Mixing Tests

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### 3.5 Pressure Drop Tests

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# 4.0 Test Program Overview

The test program was conducted at the facilities of Stern Laboratories and developed around the technical, quality assurance (QA), and programmatic requirements discussed in this document. Stern Laboratories was selected as the test supplier because of their recognized expertise and 45 years of experience performing CHF tests for the nuclear industry. Stern maintains a quality assurance program that complies with the requirements of 10 CFR 50 Appendix B (Reference 1.5.12). Additionally, Stern Laboratories communicated a willingness to adapt their facilities and processes to accommodate NuScale’s stringent technical requirements. Stern worked extensively with NuScale to extend the low flow capabilities of the test loop and make technical and QA improvements to their processes and procedures necessary to meet the requirements of NuScale’s program.

A general description of the program QA requirements, test facility, test section, and data acquisition system can be found in this section, along with a brief overview of the test procedures and operations.

## 4.1 Program Quality Assurance Requirements

The data generated in this test program will be used in the development of the NuScale CHF correlation used to define the limiting conditions for fuel performance, and as such, the services provided by Stern Laboratories were considered safety-related. As a result, NuScale qualified Stern to the applicable requirements of NQA-1 2008/2009a (Reference 1.5.13) and placed them on the NuScale Qualified Suppliers List.

Stern conducted testing and test preparations in accordance with the project specific quality plan based on input from NuScale identifying which elements of the program are considered safety-related, as reflected in the program inspection and test plan.

## 4.2 Facility Overview—Test Loop

The Stern project engineer and qualified loop operators were responsible for the proper setup and configuration of the hydraulic test loop for performing these tests, and for operation of the loop during the tests. The stainless steel test loop, rated at 20.8 MPa and 371°C, consists of a main circulating pump, a 250 kW preheater, mixers, a pressurizer, heat exchangers, a storage tank, condenser, interconnect piping and various valves and controllers to control flow, pressure, and inlet temperature subcooling in order to deliver high temperature, high pressure water to the test section. The loop is shown schematically in Figure 4-1.

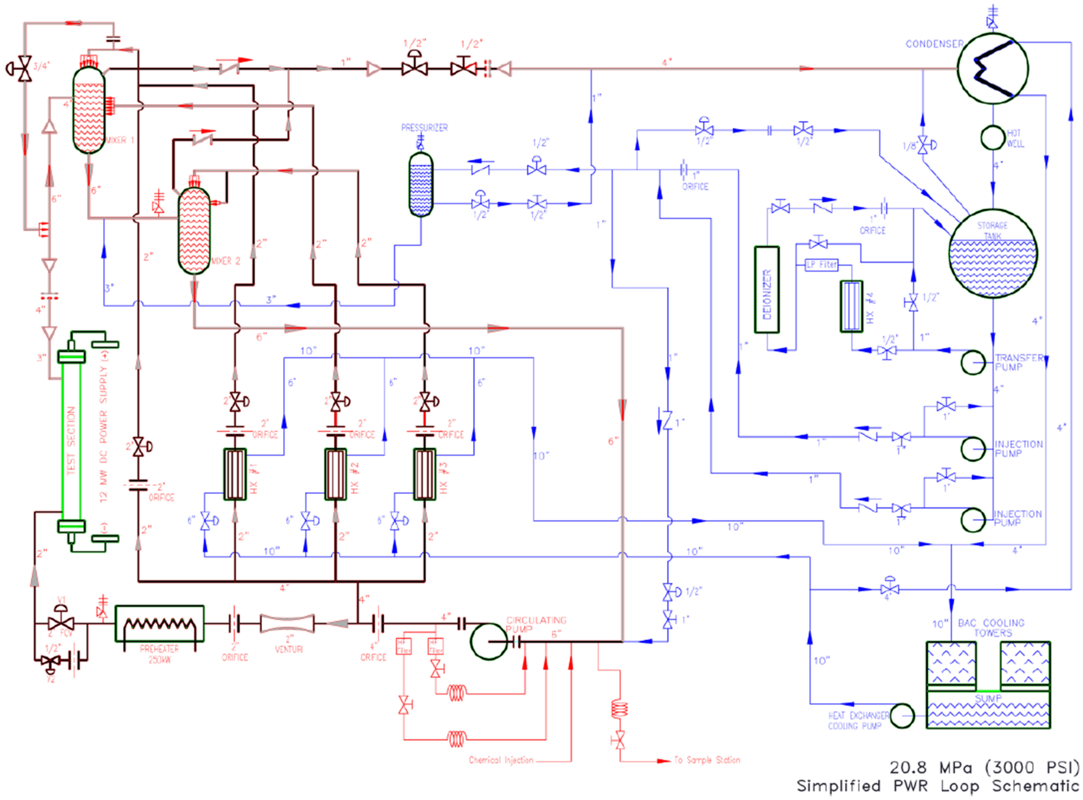


Figure 4-1. PWR test loop schematic

The loop coolant circulation flow is provided by a high head, high capacity pump with flow adjusted by control valves at the inlet to the test section. Pressure is maintained at the test section outlet, downstream end of heated length, using a pressurizer partially filled with nitrogen or air through an electronic regulator. Loop water passing through the bypass valve and through heat exchangers is used to condense the two-phase mixture in the mixer. Additional subcooling is controlled by injecting loop water passing through heat exchanger and mixers. Fine temperature control is achieved with a small amount of bypass loop water through heat exchanger that is injected into the main loop piping near the main pump suction. During mixing and adiabatic pressure drop tests, the preheater is utilized for most cases to control the inlet temperature subcooling. A small amount of loop water is bled from the top of the mixers to ensure that noncondensable gases are removed.

The water chemistry is controlled by the injection of hydrazine into the coolant at the circulating pump inlet to maintain the oxygen content of the coolant as low as reasonably possible. The makeup water in the storage tank is maintained at a very low electrical conductivity by use of a deionizer which provides the initial water in the storage tank and through which the water is continuously recirculated during testing. The oxygen content, electrical conductivity and pH of the coolant are monitored continuously during testing. The oxygen content is normally maintained less than 5 ppm after hot conditions are reached each day.

## 4.3 Test Section

The test section, shown schematically in Figure 4-2, consists of a pressure housing fabricated from 200 mm (approximately 8 in), schedule 160, 316 stainless steel pipe and a square flow channel fabricated from 410 stainless steel with a 68.4 mm inside width (cold). The flow channel has pressure taps installed along the wall on one side for the measurement of pressure drop. The pressure tap sense lines are routed through the annulus between the flow channel and the pressure housing to a central flange. The flow channel is attached to the central flange to prevent

bypass flow in the annulus. This results in the flow channel being subjected to external pressure in the lower (upstream) portion and internal pressure in the upper (downstream) portion.

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Figure 4-2. Schematic of test section

The test section inlet and outlet sections provide calming regions with re-entrant geometry designed to minimize flow mal-distributions. The top (outlet) end flange incorporates fixed packing gland seals to support the fuel simulators. The bottom (inlet) end flange has cooled o-ring seals to allow for the differential thermal expansion between the fuel simulators and the pressure housing.

Provision is made at both ends for connection of the simulator electrode extensions to the power supply bus and cooling of the extensions.

The test section is thermally insulated and supported at the top and guided at the bottom by a steel structure. Two thermal wells are provided at both the inlet and outlet of the test section piping for platinum resistance temperature detectors (RTD's) to measure the coolant temperature.

### 4.4 Fuel Simulators and Test Bundle Configurations

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## 4.5 Power Supplies

The electrical power to the fuel simulators was provided by various combinations of the laboratory DC power supplies to produce the radial peaking patterns. Five 2500 kW power supplies, three 1000 kW power supplies and five 250 kW power supplies were available. Three of the 2500 kW power supplies were used in reversed polarity to minimize the magnetic forces due to electric current. The power supplies were low ripple, twelve pulse design and employ current feedback for stable control and were controlled by a custom program on the data acquisition system which outputs control signals to the power supply controllers. The total current from each power supply was measured using a calibrated shunt. The current to each fuel simulator was measured using a Hall effect transducer. The primary and redundant voltages were measured across the test section using voltage taps on the power bus. Signal isolators were used to attenuate and filter the current and voltage measurement signals. The total power was calculated using the current and voltage measured from each power supply. The power was also calculated using the voltages and the individual current measurements for each fuel simulator.

Appropriate cabling arrangements were derived for the power connections from power supplies to the fuel simulators that provided the desired radial peaking pattern with the magnetic forces minimized and to allow for easy adjustments to the peaking pattern as needed while testing. For the experiment, power supplies #9 and #10 were connected with reversed polarity. The cable connections are verified using checklists that are stored in the project master binder.

## 4.6 Critical Instrumentation and Data Acquisition System

The general layout of the data acquisition system including the instruments, the scanners, the main data acquisition control and monitoring, the power control and the fail-safe system are shown schematically in Figure 4-8.

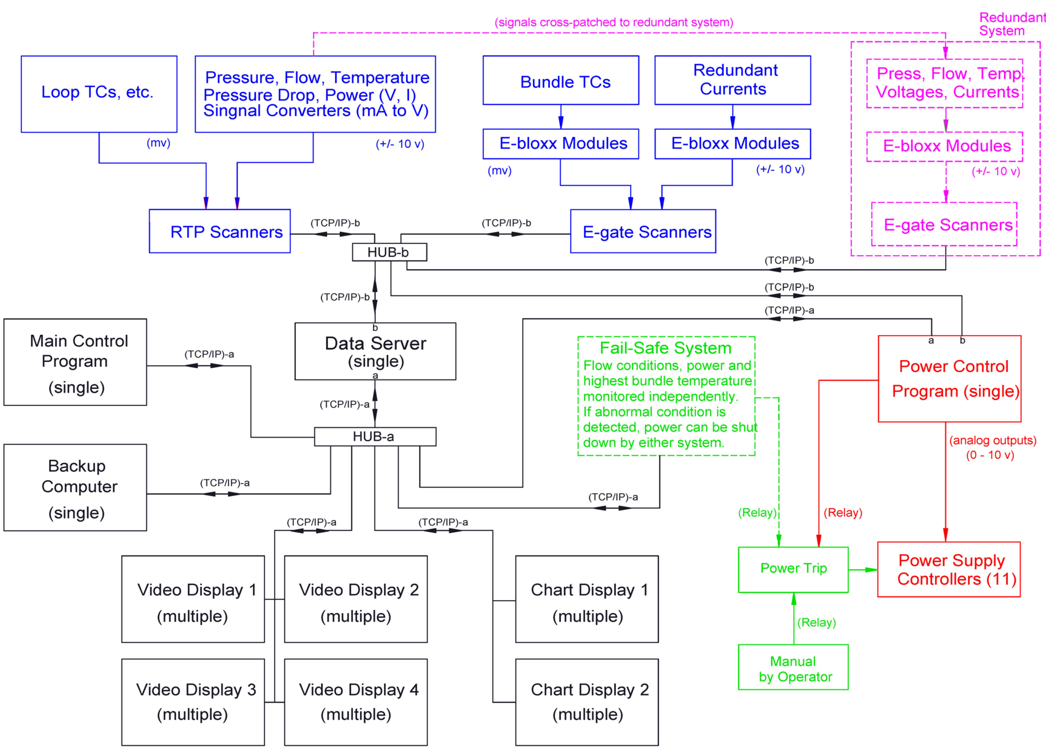


Figure 4-8. DAS schematic

 

The data acquisition system (DAS) was used to scan the instruments and convert the signals to engineering units and perform various calculations. The DAS consists of a central computer (data server with LINUX operating system) which is connected via network connections to scanners which digitize the analog signals from the various instruments and provides calculated data to various networked computers which display and/or control the test parameters for the test operators.

The DAS control program on the data server computer scanned the instrument signals at a predetermined rate and converted the values to engineering units. A computer operator selected the type of data recording and started and stopped data recording as requested by the test engineer, and also changed the test label, the nominal test setup conditions, the recording rates and periods, and updated instrument calibration constants or modified program parameters, such as the setup tolerances, when required. The instrument signals were scanned continuously at the rate of ten samples per second per channel and selected channels were displayed on video monitors. For CHF tests, when the operator initiated a data recording event, a 20-second pre-event data buffer and a 20-second post-event data recording were stored. A separate data summary file was also recorded that includes 10 seconds of pre-event averaged data. If the power control program initiated a power step down due to a sudden simulator temperature rise at CHF conditions then the data were automatically stored by the DAS in the same manner as the critical power data recording.

### 4.6.1 Instrumentation

The instrumentation included RTDs for measuring the coolant temperatures, pressure transmitters for measuring differential and absolute pressures, orifice and venturi meters for measuring flow rates, shunts, Hall effect transducers and voltage transducers for measuring power, thermocouples installed in the fuel simulators for detection of critical power and thermocouples installed on the outlet spacer grid to measure the fluid temperature in subchannels.

The instruments were calibrated, installed, connected to the data acquisition system utilizing rigorous verification procedures. Installation and connection checks were completed by connecting each instrument one at a time to the data acquisition system and checking to ensure the corresponding data acquisition channel responds. Checks were also conducted to ensure that all measurement devices were in current calibration and the correct conversion constants were being used.

### 4.6.2 Main Control Program

A main control program running on the data server computer was used by the computer operator to control the system for scanning and recording the experimental data. The data server scans the instrument signals at the rate of ten samples per second per channel and provided selected values, averaged over five seconds and converted to engineering units, to the various video displays and other computers in the network.

The main test parameters (test section flow rate, inlet temperature, outlet pressure) were displayed on the main display screen as running averages updated about every two seconds with an indication if they were at the nominal values within preset tolerances. {{

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The computer operator selected the type of data recording and started and stopped recording, as instructed by the test engineer. The computer operator was also required to change test labels, change the nominal test setup conditions, change recording rates and periods, update instrument calibration constants and modify various program parameters, such as setup tolerances, as authorized or instructed by the test engineer.

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Monitors were available for graphic display of selected fuel simulator thermocouple signals in real time, as plotted lines simulating strip chart recorders. Normally, 15 thermocouple signals were displayed on each of two monitors and additional monitors were used as desired. Four monitors were used for text display of selected test data during testing. Additional instances of any of these displays were also used as desired.

Control and verification of the data acquisition system software calculations were performed in accordance with Stern Laboratories quality procedures. Various checks were performed on a regular basis to ensure the data acquisition system functions satisfactorily.

### 4.7 Test Section Installation and Facility Commissioning

The fuel simulators were installed in the flow channel within the test section, and the test section installed into the loop facility in accordance with approved fabrication and acceptance procedures. The installation and setup was documented in pretest inspection reports which include the applicable checklists used to record the setup activities.

# 5.0 Test Program Execution

## 5.1 Overview of Program Schedule

The CHF test program began in October of 2011 with the final project deliverable received in October of 2013. Testing commenced in September of 2012 and continued until March of 2013. The program was organized around the three main objectives listed below, with major completion milestones summarized.

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## 5.2 Test Operations

The loop operation and test procedures for {{ }}3(a)-(c) A summary of each is found below.

### 5.2.1 Loop Operation

With the test section installed, the loop was filled with deionized water and pressurized to the operating pressure by adjusting the gas pressure in the pressurizer. The loop and test section were checked for any leaks in the piping or test section fittings and repaired as necessary and appropriate.

At loop start-up, the computer data acquisition programs were started to monitor loop conditions. The meters for monitoring oxygen level, pH and conductivity were turned on and checked that they were working satisfactorily with the appropriate flow through the water sample line. The oxygen content, conductivity and pH level of the loop water were monitored continuously during operation and maintained at acceptable levels. Hydrazine was injected into the loop water as necessary to control the dissolved oxygen content to less than 2 ppm and maintain the water conductivity less than 10 μS/cm.

The auxiliary cooling water to the test equipment was turned on and set to the required flows. The oil cooling system which is used for electrode cooling, was turned on with the required flow. The cooling systems were checked for leaks and repaired as necessary. The hardware and software protective devices and limits, such as the low flow power trip, the fuel simulator over-temperature alarms and the manual power shut-off were checked to ensure that they are operating correctly and were enabled.

### 5.2.2 Steady-State CHF Testing

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### 5.3 NuScale Testing and Program Oversight

To ensure that technical and programmatic requirements were implemented and testing executed correctly for this design certification test program, NuScale conducted test witnessing and program oversight at Stern Laboratories. For the CHF test program, multiple test witness trips were made to verify that test activities were conducted in compliance with program requirements.

Test witnessing was integrated into the overall progression of the test program and was conducted by the responsible test engineer or designee. The responsible test engineer served as the technical focal point and project manager for the test program, so they were well positioned to evaluate the execution of a test program against the broader project objectives and procedural requirements. For the CHF test program, the following activities were the primary focus for test witnessing.

- test section final assembly
- test loop and facility commissioning
- start-up of test activities
- daily test execution
- posttest disassembly and evaluation of hardware

In addition to verifying procedural compliance throughout the noted test activities, an important aspect of the test witness role was to provide real-time technical direction and data evaluation during daily test execution. This technical direction was provided both during on-site test witnessing and by using remote, near real time support when on-site support was not possible.

## 5.4 NRC Inspection

In March of 2013, the U.S. Nuclear Regulatory Commission (NRC) performed a design certification inspection of NuScale focused on testing activities conducted at Stern Laboratories. The purpose of the inspection was to verify proper implementation of NuScale's QA program as required to conduct the test program.

The inspection resulted in the issuance of a single, severity level IV violation related to the initial procurement and supplier evaluation activities. This violation had no impact to the test data and the inspection team concluded that both NuScale and Stern Laboratories QA processes and procedures complied with applicable federal regulations and were implemented effectively in support of the CHF test program.

## 6.0 Test Uncertainties

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## 7.0 Test Results

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# 8.0 Conclusion

All program objectives were achieved and the test data generated are acceptable for use for the development of the NuScale CHF correlation. As a result, the test data have been released within NuScale for development of the CHF correlation. The NuScale CHF correlation development effort is ongoing and will be documented in an upcoming topical report.