Attachment 2

babcock & wilcox nuclear energy

B&W mPower™ Reactor
Integrated Systems Test Technical Report
06-00000392-001(NP)
Revision 001
November 2011

a progressive energy solution

B&W mPower™ Reactor Program
Babcock & Wilcox Nuclear Energy, Inc.
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Lynchburg, VA 24501

Document No.	Title	Rev. No.
06-00000392-001(NP)	**B&W mPower™ Reactor Integrated Systems Test Technical Report**	**001**

SIGNATURES			
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RECORD OF REVISION

Revision	Section(s) or Page(s)	Description of Changes
0	N/A	Initial Issue
1	All Sections	Revision updates information about the IST design, test plan, analysis, and provides new information about scaling of the IST.

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1. OVERVIEW

The Babcock & Wilcox (B&W) mPower™ reactor is a simplified, modular and passively safe, pressurized water reactor (PWR) nuclear power plant. It uses an integral design for the nuclear steam supply system, in which the reactor core, control rod drive mechanisms, reactor coolant pump impellers (not motors), pressurizer, and steam generator are contained in a single vessel. The original target power level for the reactor was 425 MWt (125 MWe), but is currently being optimized to 500 MWt (160 MWe).

The B&W mPower reactor core utilizes fuel assemblies that are shortened versions of the standard commercial 17-by-17 fuel assembly, and an integral steam generator that is an evolutionary version of the once through steam generators (OTSGs) used in existing B&W-designed operating power reactors.

The integral design of the B&W mPower reactor provides for a large inventory of reactor coolant, no large external reactor coolant system (RCS) piping, and no reactor vessel penetrations below the top of the core. The key benefit of these features is the retention of reactor coolant in the core region of the RCS, such that the reactor core is not uncovered through all design basis events, including loss of coolant accidents (LOCAs).

The B&W mPower reactor design has its roots in integral reactor concepts developed for shipboard applications in the 1960s through the 1970s and secure military power systems developed in the mid-1980s. The design most closely resembles the reactor system utilized in the nuclear merchant ship Otto Hahn.

The purpose of the Integrated Systems Test (IST) program is to extend the existing PWR database to confirm B&W mPower reactor design methodology and to demonstrate that the passive engineered safety systems and features of the B&W mPower reactor design are adequate to protect the plant and public health and safety. The program is intended to expand and enhance the existing PWR database and add confidence for its application to an integral system design. The program is also intended to enhance the database as it relates to component design, build confidence in the nuclear steam supply system and its operation, and demonstrate the adequacy of plant control systems, engineered safety features, and protection systems. Test program data is expected to improve the analytical methodology for, and the understanding of, facility design and operation, as well as the application of incorporated safety features for design basis events. The test facility is expected to provide an understanding of the application of abnormal operating procedures and the emergency operating procedures. It may also be used in the initial phases of operator training.

IST test procedures are developed based on the analysis of the B&W mPower reactor and the system model of the IST simulation using RELAP5. Post-test analyses are used to evaluate the correlations selected and the system models used, and to identify whether any new correlations may be needed. This also permits an evaluation of the methods available and the ability to apply such methods as the test program advances.

Figure 1-1 is a side-by-side, scale comparison of the B&W mPower reactor and the IST loop at the original design power level of 425 MWt. However, as noted above, as the initial design progressed, it was determined to increase the power level to 500 MWt, with a commensurately higher electrical power output (160 MWe versus 125 MWe).

The IST facility is installed in the Center for Advanced Engineering Research (CAER) located in Bedford County just west of Lynchburg, Virginia. Figure 1-2 is a picture of the facility. The IST loop and emergency core cooling systems are located in the tower except for the ultimate heat sink that has been located on the roof of the tower. The roof is located about 100 feet above the first floor. Figure 1-3 is a picture of the operator control panel showing three control stations. The third station has no control capability; however, it will allow the test engineer or others to observe the test program. The control room is on the ground floor level. The picture was taken from the data analysis room. Figure 1-4 is a picture of the operations staff office area in the main facility on the second level or the main facility level based on the front entry to the facility. Offices are provided for the operators, the test engineers, and the IST maintenance staff.

This report describes IST facility functional requirements, systems, the scaling to the 425 MWt design, test requirements as currently identified, and a comparison with the power upgrade design that is in progress. Changes to the facility and/or this report are expected as the B&W mPower reactor design matures and IST program proceeds concurrently. Finally, an overview of the test plans is provided concentrating on the first six months of testing.

Figure 1-2. Center for Advanced Engineering Research with IST Tower in the Foreground

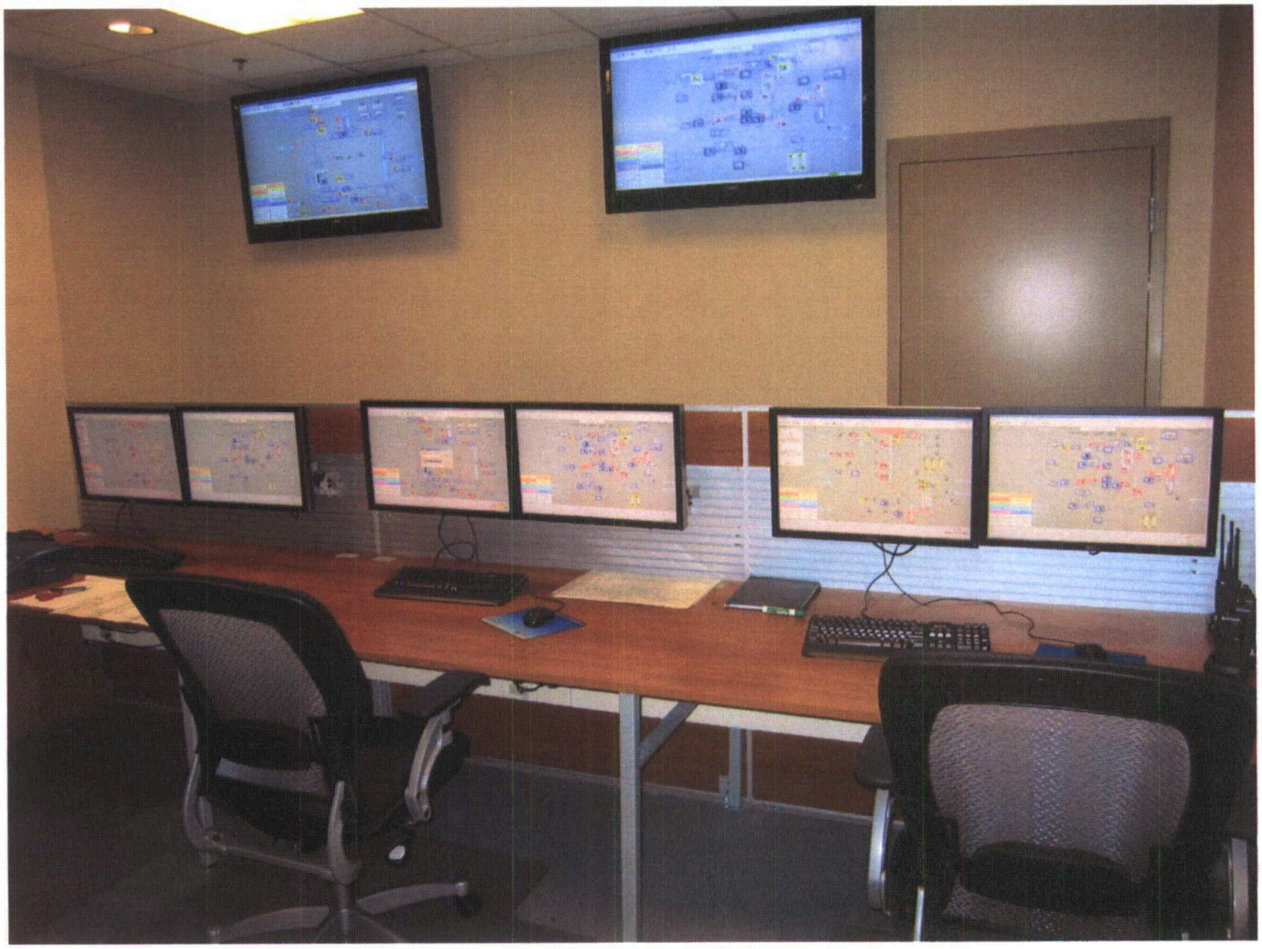


Figure 1-3. Control Room Panel as viewed through the Window in Data Analysis Room

Figure 1-4. Operations Staff Office Area

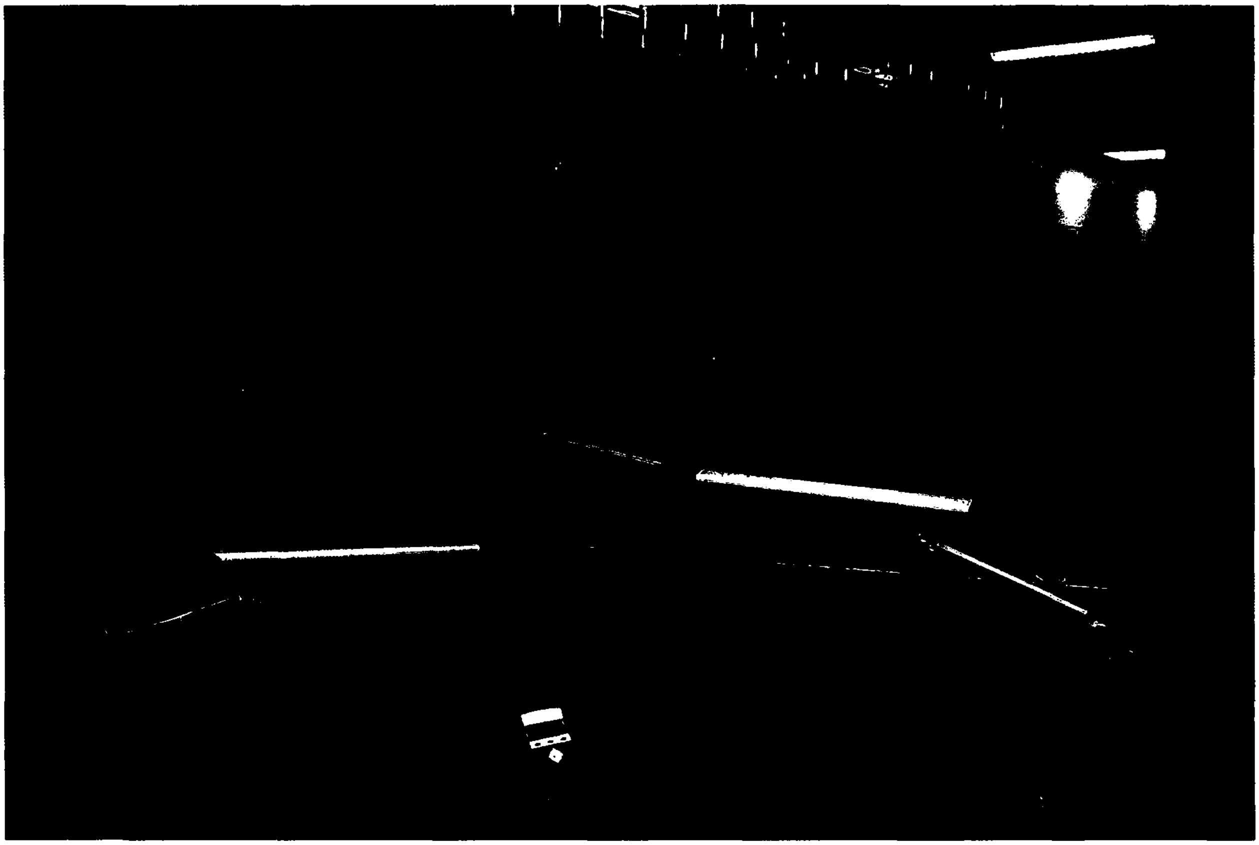


Figure 1-4. Operations Staff Office Area

2. SCALING

The original IST scaling was based on a 425 MWt B&W mPower integral reactor design. [

]

[CCI per Affidavit 4(a) – 4(d)]

2.1 IST – B&W mPower Reactor Design Features at 425 MWt Power Level

Important features of the B&W mPower reactor design include the following:

[

] [CCI per Affidavit 4(a) – 4(d)]

2.2 IST – B&W mPower Comparison

The IST primary loop and the scaled B&W mPower reactor at 425 MWt are shown side by side in Figure 1-1. [

] [CCI per Affidavit 4(a) – 4(d)]

2.3 Top – Down Scaling at 425 MWt

The IST test loop has many objectives, as addressed in Section 3.1. These include confirmation of the design and analysis technology associated with the steam generator and verification of the analyses associated with design basis accidents, especially the design basis LOCA. [

] [CCI per Affidavit 4(a) – 4(d)]

Due to the diversity of the potential modes that the loop would encounter a simplified top-down approach was taken based on the paper by Ishii and Kataoka, Reference [1].

2.3.1 Single Phase Natural Convection

[

] [CCI per Affidavit 4(a) – 4(d)]

2.3.2 Scaling Anomalies

[

] [CCI per Affidavit 4(a) – 4(d)]

2.3.3 Top down Scaling Conclusions

[

] [CCI per Affidavit 4(a) – 4(d)]

2.3.4 Assessment of Applicability of IST to Power Upgrade

The design power level of the B&W mPower reactor has been increased from the initial 425 MWt to 500 MWt with the continued plant optimization. A side by side comparison of the 425 MWt reactor, the IST loop, and the power upgrade level are shown in Figure 2-2. Along with the increase in power level, several other changes have been made. These changes include:

[

] [CCI per Affidavit 4(a) – 4(d)]

2.3.4.1 IST Scale Factor Change for Power Upgrade

[

] [CCI per Affidavit 4(a) – 4(d)]

2.3.4.2 Core & System Upgrades

[

] [CCI per Affidavit 4(a) – 4(d)]

2.3.4.3 IST Power Upgrade Scaling Conclusions

[

] [CCI per Affidavit 4(a) – 4(d)]

2.4 Bottom-Up Scaling at 425 MWt

As part of the conceptual design process, a phenomena identification and ranking table (PIRT) was developed for the design basis LOCA for the B&W mPower reactor system. [

] [CCI per Affidavit 4(a) – 4(d)]

A Figure of Merit (FOM) is the criterion against which the Relative Importance of each "phenomenon" is judged. Successful figures of merit have distinct characteristics as follows:

- directly related to the issue (Step1)
- directly related and explicit to the phenomena identified
- easily comprehended
- measurable

The FOMs determined to be most appropriate for the objectives of this PIRT are shown in Table 2-3.

2.4.1 Safety Related Risk Perspective

In the context of the PIRT, a Risk Perspective relates to the relative uncertainty in understanding the combined Relative Importance and State of Knowledge (SOK) of a phenomenon. For example, a phenomenon which is controlling in the reactor response to a postulated accident scenario (high Relative Importance) and has a large or undetermined SOK (low SOK) poses the highest level of risk in understanding the safety significance of that phenomenon. Further, a phenomenon having a high Relative Importance and moderate SOK poses the next relative level of risk, and so on through decreasing levels of risk. The generic risk perspective applicable to this PIRT is described in Table 2-4.

The risk perspective of most interest to the B&W mPower safety related licensing and regulation activities adequately captured by considering the PIRT results for the first three risk levels. Those results are summarized in Table 2-5, including <u>potential</u> research that may have promise in further reductions in the risk.

2.4.2 Components that Dominate Each LOCA Phase

The components that dominate the various phases have been identified and delineated in Table 2-5. The characteristics of the components that contribute to this dominance are discussed in this section.

- Subcooled Blow Down – Phase 1

[

] [CCI per Affidavit 4(a) – 4(d)]

- Saturated Two-Phase Blow Down – Phase 2

[ ] [CCI per Affidavit 4(a) – 4(d)]

- Saturated Steam Blow Down to ADS Actuation – Phase 3

[ ] [CCI per Affidavit 4(a) – 4(d)]

- Depressurization to Passive RWST Makeup – Phase 4

[ ] [CCI per Affidavit 4(a) – 4(d)]

- Long Term Cooling to 72 Hours – Phase 5

[ ] [CCI per Affidavit 4(a) – 4(d)]

2.4.3 Recommendations for B&W mPower Reactor Use of PIRT Results

The ECCS design is in the process of being finalized and the analyses of the selected design basis LOCA is ongoing. On this basis the PIRT may need to be revisited when the design is finalized. Based on the state of the design an analysis through November 2010 and the review by the team of experts the following conclusions can be made:

[

] [CCI per Affidavit 4(a) – 4(d)]

2.4.4 Assessment of PIRT Recommendation Relative to Power Upgrade

A review of the phenomena identified and evaluated during the LOCA PIRT process was reviewed, resulting in these observations:

[

] [CCI per Affidavit 4(a) – 4(d)]

[

]

[CCI per Affidavit 4(a) – 4(d)]

Figure 2-1. Simplified IST Emergency Core Cooling System Line Diagram

[

]

[CCI per Affidavit 4(a)-4(d)]

Figure 2-2. B&W mPower 425 MWt – IST Loop – 500 MWt Reactor

[

]

[CCI per Affidavit 4(a)-4(d)]

Figure 2-3. Upgrade System to be Installed with Steam Generator T/C Removal

Table 2-1. IST Elevations Relative to B&W mPower Reactor, Relative to Containment Floor

Component	IST	B&W mPower Reactor
Bottom heated length	[	
Top of heated Length		
Riser Flow over elevation		
Top of upper tubesheet		
Bottom of upper tubesheet		
Top of lower tubesheet		
Bottom of lower tubesheet		
Bottom pressurizer separator plate		
Normal pressurizer water level		
Top pressurizer stand pipe(s)		
Bottom Pressurizer head		
Centerline break		
Break inlet elbow		
Water level in RWST		
Centerline emergency condenser		
Bottom of ultimate heat sink (UHS) tanks		
Water Level in UHS		]

[CCI per Affidavit 4(a)-4(d)]

Table 2-2. Top-Down Scaling Summary

Scaling Group	Single-Phase	Two-Phase
[		
		]

[CCI per Affidavit 4(a)-4(d)]

Scaling Group	Single-Phase	Two-Phase
[		
		]

[CCI per Affidavit 4(a)-4(d)]

Table 2-3. Figures of Merit for B&W mPower Reactor Design Basis LOCA PIRT

PHASE	Figure of Merit	Interval
[		
		]

[CCI per Affidavit 4(a)-4(d)]

Table 2-4. Generic Risk Perspective

Risk Level	Phenomena Relative Importance	Phenomena State Of Knowledge	Probable Response To Reduce Risk
[			
			]

[CCI per Affidavit 4(a)-4(d)]

Table 2-5. B&W mPower Reactor PIRT Risk Perspective Results

Risk Level	System Component Phenomena	Phase & Phase-Importance Rank	SOK Rank	Comments Related To Potential Risk Reduction
[				
				]

[CCI per Affidavit 4(a)-4(d)]

Risk Level	System Component Phenomena	Phase & Phase-Importance Rank	SOK Rank	Comments Related To Potential Risk Reduction
[				
				]

[CCI per Affidavit 4(a)-4(d)]

Risk Level	System Component Phenomena	Phase & Phase-Importance Rank	SOK Rank	Comments Related To Potential Risk Reduction
[				
				]

[CCI per Affidavit 4(a)-4(d)]

3. FUNCTIONS AND DESIGN REQUIREMENTS

3.1 Functions

The IST program is designed to evaluate the inherent safety margins associated with the B&W mPower integral reactor design and associated passive engineered safety features.

3.1.1 Steam Generator Characteristics

[

] [CCI per Affidavit 4(a) – 4(d)] The IST program is intended to extend the existing database and provide confidence in the correlations used to cover the operating range of the B&W mPower reactor steam generator.

3.1.2 Design Basis Event Testing

The B&W mPower reactor contains all the RCS components in a single vessel, which enhances the reactor response to operational transients and design basis events, including taking advantage of passive engineered safety features. [

] [CCI per Affidavit 4(a) – 4(d)] The reactor core is located at the bottom of the reactor vessel and the pressurizer is at the top of the reactor vessel. The steam generator surrounds the central riser within the reactor vessel, below the pressurizer. The reactor coolant pumps are located in the downcomer annulus just below the steam generator. The IST program is intended to develop the required data to support the safety analysis methodology used in the design certification application for the B&W mPower reactor and to demonstrate that the B&W mPower reactor protection systems and engineered safety features are sufficient to protect the plant and public health and safety.

3.1.3 Operational Testing

The IST program is intended to confirm the operational characteristics of the B&W mPower reactor systems and the associated control and protection systems.

3.1.4 Flow Characteristics

The IST program is intended to confirm the methodology used in the design of the B&W mPower reactor system and transitions to the various states associated with natural circulation cooling and reactor coolant makeup.

3.2 Reactor Coolant System Design Requirements

3.2.1 ASME Code Design Requirements

IST loop vessels are designed and stamped based on ASME Boiler and Pressure Vessel Code (ASME Code), Section VIII UG-99, 2007 Edition, up to and including 2009 Addenda, and IST loop piping to ASME B31.1.

The IST loop also incorporates additional requirements as required by ASME Code Section I and any other unique requirements for installation in the state of Virginia.

The IST loop is protected with one or more ASME Code approved safety valves.

The steam generator steam outlet is protected with one or more ASME Code approved safety valves inside the steam line isolation valve, taking into account the rupture of a steam generator tube.

All activities including design, fabrication, procurement, inspection and code stamping are performed to B&W Nuclear Energy Quality Assurance Program procedures and standards, with ASME Code documents and supporting calculations and documents provided with the equipment.

3.2.2 IST Reactor Loop Design Requirements

The IST design was based on scaling the B&W mPower integral reactor producing 425 MWt. Subsequently, the B&W mPower integral reactor thermal output has been optimized to 500 MWt. IST design parameters for the scaled optimized power level are shown in parenthesis.

]

[CCI per Affidavit 4(a) – 4(d)]

3.2.3 Instrumentation Requirements

[

] [CCI per Affidavit 4(a) – 4(d)] The required ranges for the instrumentation are provided in Sections 3.2.3.1 through 3.2.3.5.

System and component instrumentation for the IST facility is more extensive than that for the B&W mPower reactor systems instrumentation for several reasons:

1. For testing of the control system and any new algorithm that may be used in normal operation to allow an expansion in the normal operational boundaries and reactor applications.
2. To allow component design related testing.
3. To cover protection system and engineered safety feature testing.
4. For methodology development and testing for design and analysis of the integral reactor systems and components.
5. For operator training and system behavior understanding, including abnormal operation and emergency operation.
6. The controls for the pump will allow both constant speed and constant mass flow.

3.2.3.1 IST Loop Control and Protection Systems

[

]
[CCI per Affidavit 4(a) – 4(d)]

3.2.3.2 Engineered Safety Features

Emergency Core Cooling System

[

]
[CCI per Affidavit 4(a) – 4(d)]

3.2.3.3 Steam Generator

[

]
[CCI per Affidavit 4(a) – 4(d)]

3.2.3.4 Pressurizer

[

]
[CCI per Affidavit 4(a) – 4(d)]

3.2.3.5 Riser

[

]
[CCI per Affidavit 4(a) – 4(d)]

3.2.4 Reactor Protection System and Engineered Safety Feature Activation Test Requirements

[

]
[CCI per Affidavit 4(a) – 4(d)]

3.3 Core Simulation

[

]
[CCI per Affidavit 4(a) – 4(d)]

4. SYSTEM DESCRIPTION

The IST facility is designed to confirm B&W mPower reactor design basis methodology and demonstrate that the passive engineered safety systems of the B&W mPower reactor are adequate to protect the plant and public health and safety.

[

] [CCI per Affidavit 4(a) – 4(d)]

4.1 Core Simulator

4.1.1 Core and Core Internals/Support

[

] [CCI per Affidavit 4(a) – 4(d)]

4.1.2 Core Simulator Heaters

[

]
[CCI per Affidavit 4(a) – 4(d)]

4.1.3 Reactor Vessel

The IST reactor vessel is constructed from [

] [CCI per Affidavit 4(a) – 4(d)]

4.1.4 Power Supply

[

] [CCI per Affidavit 4(a) – 4(d)]

4.2 Steam Generator

[

] [CCI per Affidavit 4(a) – 4(d)]

4.2.1 Tubes

[

] [CCI per Affidavit 4(a) – 4(d)]

4.2.2 Shroud

[

] [CCI per Affidavit 4(a) – 4(d)]

4.2.3 Tube Support Plates

[

] [CCI per Affidavit 4(a) – 4(d)]

4.2.4 Tubesheets

[

] [CCI per Affidavit 4(a) – 4(d)]

4.2.5 Steam Generator Instrumentation

[

] [CCI per Affidavit 4(a) – 4(d)]

4.2.6 Tube Rupture Simulation

[

] [CCI per Affidavit 4(a) – 4(d)]

4.3 Pressurizer

[

] [CCI per Affidavit 4(a) – 4(d)]

4.3.1 Vessel

[

] [CCI per Affidavit 4(a) – 4(d)]

4.3.2 Baffle Plate and Surge Arrangement

[

] [CCI per Affidavit 4(a) – 4(d)]

4.3.3 Spray

[

] [CCI per Affidavit 4(a) – 4(d)]

4.3.4 Heaters

[

] [CCI per Affidavit 4(a) – 4(d)]

4.3.5 Instrumentation

[

] [CCI per Affidavit 4(a) – 4(d)]

4.3.6 Code Safety Valves

[

] [CCI per Affidavit 4(a) – 4(d)]

4.4 Reactor Coolant Pump Region Simulator

[

] [CCI per Affidavit 4(a) – 4(d)]

4.5 Other Reactor Coolant System Pipe Sections

4.5.1 Riser

4.5.1.1 Control Rod Drive Segment

[

] [CCI per Affidavit 4(a) – 4(d)]

4.5.1.2 Steam Generator Segment

[

] [CCI per Affidavit 4(a) – 4(d)]

4.5.2 Steam Generator/Pressurizer/Riser Junction

[

] [CCI per Affidavit 4(a) – 4(d)]

4.5.3 Pump-Steam Generator to Reactor Vessel

[

] [CCI per Affidavit 4(a) – 4(d)]

4.5.4 Reactor Coolant Support Loop

[

] [CCI per Affidavit 4(a) – 4(d)]

4.6 Loop Insulation

[

] [CCI per Affidavit 4(a) – 4(d)]

[

]
[CCI per Affidavit 4(a) – 4(d)]

Figure 4-1. IST Loop

[

]

[CCI per Affidavit 4(a) – 4(d)]

Figure 4-2. IST Core Simulator Cross-Section inside the Vessel

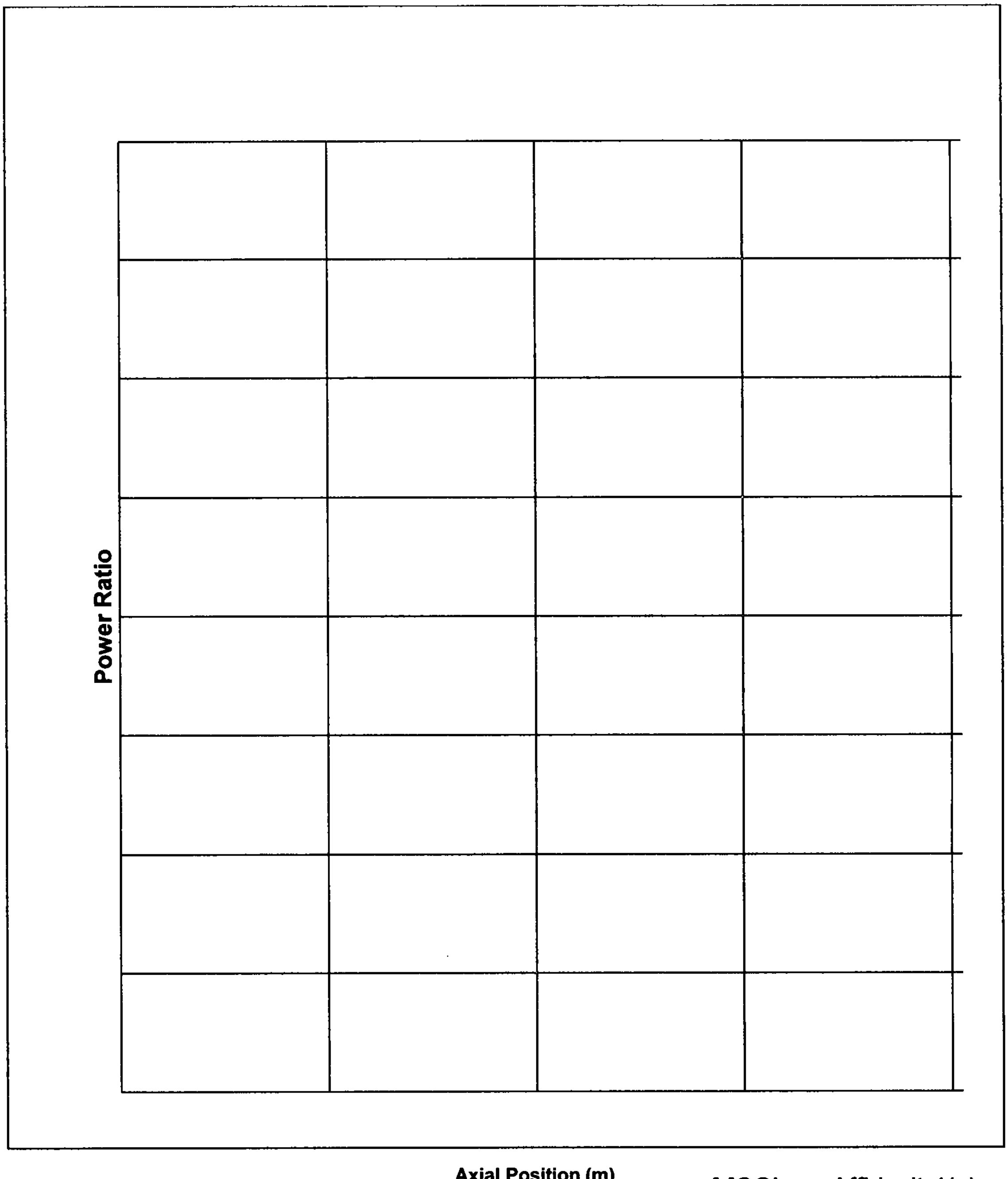
[

]

[CCI per Affidavit 4(a) – 4(d)]

Figure 4-3. IST Heater Rod

[



] [CCI per Affidavit 4(a) – 4(d)]

Figure 4-4. IST Axial Power Shape

[

] [CCI per Affidavit 4(a) – 4(d)]

Figure 4-5. IST Core Simulator Cross-Section Showing Thermocouple Locations as Viewed from the Insertion Flange

[

] [CCI per Affidavit 4(a) – 4(d)]

Figure 4-6. IST Reactor Vessel Assembly

[

]
[CCI per Affidavit 4(a) – 4(d)]

Figure 4-7. IST Steam Generator Arrangement

[

]

[CCI per Affidavit 4(a) – 4(d)]

Figure 4-8. IST Tube Support Plate Plan View

[

]

[CCI per Affidavit 4(a) – 4(d)]

Figure 4-9. IST Tube Support Plate Opening Profile

[

]

[CCI per Affidavit 4(a) – 4(d)]

Figure 4-10. IST Upper Tubesheet, Riser and Pressurizer Junctions

[

]

[CCI per Affidavit 4(a) – 4(d)]

Figure 4-11. Steam Generator Temperature as a Function of Power Level

[

]

Figure 4-12. IST Pressurizer

[CCI per Affidavit 4(a) – 4(d)]

[

] [CCI per Affidavit 4(a) – 4(d)]

Figure 4-13. IST Downcomer in Pump Region

[

]

[CCI per Affidavit 4(a) – 4(d)]

Figure 4-14. Loop Forced Circulation Pump

[

]

[CCI per Affidavit 4(a) – 4(d)]

Figure 4-15. MIST Guard Heater Application

Table 4-1. Vagen Analyses of the Expected Steam Generator Test Points

[

]
[CCI per Affidavit 4(a) – 4(d)]

Table 4-2. Forced Circulation Pump Information

[

]
[CCI per Affidavit 4(a) – 4(d)]

5. ENGINEERED SAFETY FEATURE COMPONENTS AND DECAY HEAT REMOVAL

5.1 Emergency Core Cooling Trains

[

] [CCI per Affidavit 4(a) – 4(d)]

5.1.1 Emergency Condenser Cooling

[

] [CCI per Affidavit 4(a) – 4(d)]

5.1.2 Separator at Emergency Condensed Condensate Outlet

[

] [CCI per Affidavit 4(a) – 4(d)]

5.1.3 Automatic Depressurization Valves

[

] [CCI per Affidavit 4(a) – 4(d)]

5.1.4 ECC Piping & Valves

[

] [CCI per Affidavit 4(a) – 4(d)]

5.1.5 ECCS Insulation

The ECC trains are covered with insulation and trace heating to limit the loss of energy to the environment for long term cooling events

5.1.6 Ultimate Heat Sink

[

] [CCI per Affidavit 4(a) – 4(d)]

5.1.7 UHS - Emergency Condenser Feedwater Pipe

[ ] [CCI per Affidavit 4(a) – 4(d)]

5.1.8 UHS - Emergency Condenser Return Piping

[ ] [CCI per Affidavit 4(a) – 4(d)]

5.1.9 ECCS Spargers

[ ] [CCI per Affidavit 4(a) – 4(d)]

5.1.10 Pipe Insulation and Support

[ ] [CCI per Affidavit 4(a) – 4(d)]

5.2 Emergency Boron System

[

] [CCI per Affidavit 4(a) – 4(d)]

5.3 Steam Generator Steam Vent

[

]

[CCI per Affidavit 4(a) – 4(d)]

5.4 RWST and Containment

The RWST containment simulation is illustrated in Figure 5-10. The IST RWST is [

] [CCI per Affidavit 4(a) – 4(d)]

Attachments 4 and 5 are the P&IDs for the RWST system.

5.5 Steam and Feed Component

The ability to steam and feed for core cooling is provided in the IST. [

] [CCI per Affidavit 4(a) – 4(d)]

5.6 Reactor Coolant Inventory and Purification Subsystem

[

]

[CCI per Affidavit 4(a) – 4(d)]

Attachments 6 and 7 are the P&IDs for the RCIPS.

[

]
[CCI per Affidavit 4(a) – 4(d)]

Figure 5-1. Emergency Condenser Vendor Drawing

[

]

[CCI per Affidavit 4(a) – 4(d)]

Figure 5-2. B&W mPower Reactor Emergency Condenser Heat Flux

[

]

[CCI per Affidavit 4(a) – 4(d)]

Figure 5-3. IST Emergency Condenser Simulator Heat Flux

[

]
[CCI per Affidavit 4(a) – 4(d)]

Figure 5-4. Emergency Condenser Outlet Separator

[

]

[CCI per Affidavit 4(a) – 4(d)]

Figure 5-5. Configuration for Emergency Condenser E-5001

[

]

[CCI per Affidavit 4(a) – 4(d)]

Figure 5-6. Configuration for Emergency Condenser E-5003

[

]

[CCI per Affidavit 4(a) – 4(d)]

Figure 5-7. IST Ultimate Heat Sink Tank

[

]
[CCI per Affidavit 4(a) – 4(d)]

Figure 5-8. Horizontal Sparger

[

]

[CCI per Affidavit 4(a) – 4(d)]

Figure 5-9. Vertical Sparger

[

]

[CCI per Affidavit 4(a) – 4(d)]

Figure 5-10. IST Loop Showing the RWST and Containment Simulation Vessels

Table 5-1. IST Emergency Condenser Design Information

[

]

[CCI per Affidavit 4(a) – 4(d)]

Table 5-2. Emergency Condenser Performance

[

]

[CCI per Affidavit 4(a) – 4(d)]

Table 5-3. Pipe and Fittings

[

]

[CCI per Affidavit 4(a) – 4(d)]

6. COMPONENT COOLING WATER SYSTEM

[

] [CCI per Affidavit 4(a) – 4(d)]

6.1 RCIPS Heat Exchangers Cooling

Cooling water is provided [

] [CCI per Affidavit 4(a) – 4(d)]

6.2 Loop Pump Cooling

[

] [CCI per Affidavit 4(a) – 4(d)]

6.3 Heater Rod Seal Cooling

[

] [CCI per Affidavit 4(a) – 4(d)]

6.4 Feedwater Purification Heat Exchanger Cooling

[

] [CCI per Affidavit 4(a) – 4(d)]

7. STEAM, FEEDWATER, AND CONDENSATE SYSTEMS

[

] [CCI per Affidavit 4(a) – 4(d)]

Attachment 8 is the P&ID for the steam, feedwater, and condensate systems.

Table 7-1. IST Water Chemistry Control and Diagnostic Parameters

[

]
[CCI per Affidavit 4(a) – 4(d)]

8. INSTRUMENTATION FOR CONTROL, PROTECTION, AND DATA ACQUISITION

[

] [CCI per Affidavit 4(a) – 4(d)]

9. CONTROL, PROTECTION, AND DATA ACQUISITION SYSTEMS

The IST uses a DeltaV PlantWeb control system. The architecture of the DeltaV system provides integration of "smart" bus technology, including Foundation FieldBus, ProfiBus DP, DeviceNet, AsiBus, Ethernet and serial connections. The system includes integrated time synchronization and the ability to time-stamp data at the lowest level of the architecture.

The DeltaV software is used for field device calibrations, replacement, record keeping, diagnostics and testing. The DeltaV global database includes security, historian with data "status," event capture, process alarm management, field device alerts and system diagnostics. The DeltaV configuration and version control audit trail allows version control and change management to the global database. The offline simulation environment of the DeltaV system provides the ability to build medium- to high-process models with the DeltaV configuration as is employed in the test environment.

The IST facility control system incorporates a secure engineering and operational environment, including services for communications, alarming, operator graphics, system diagnostics, plant historian and engineering. The system consists of a dedicated process controller; and provides a streamlined flow of diagnostic information and communication. The system also has the capability of supporting basic and advanced process control functions and any combination of input/output subsystems, including conventional, digital and wireless. Data from instruments throughout the IST are recorded at a 1-sec sampling rate. Figure 9-1 illustrates the architecture for the control, protection and data acquisition system.

A reliable air system using two full-capacity compressors supplies the instrument air to the control devices.

Attachment 9 is the P&ID for the instrument air system.

9.1 Loop Inventory Control – RCIPS

9.1.1 Fixed Level Band Control

[

] [CCI per Affidavit 4(a) – 4(d)]

9.1.2 Level Band Floats with Power Level

[

] [CCI per Affidavit 4(a) – 4(d)]

9.2 Loop Pressure Control

[

] [CCI per Affidavit 4(a) – 4(d)]

9.3 Loop Flow Control

[

] [CCI per Affidavit 4(a) – 4(d)]

9.4 Heater/Core Power Control

[

] [CCI per Affidavit 4(a) – 4(d)]

9.5 Trace Heater Control

[

] [CCI per Affidavit 4(a) – 4(d)]

The region breakdown for the primary loop heat tracing is shown in Figure 9-2, and the breakdown for the ECCS are given in Figure 9-3.

9.6 Reactor Protection and Engineered Safety Feature Activation Systems

[

] [CCI per Affidavit 4(a) – 4(d)]

9.6.1 Reactor Protection System Setpoints for 425 MWt Equivalent Testing

[

]

[CCI per Affidavit 4(a) – 4(d)]

9.6.2 Engineered Safety Feature Activation System Setpoints

[

]

[CCI per Affidavit 4(a) – 4(d)]

9.6.3 Additional Loop Protection

The ASME Code B&W mPower requirements are spelled out in Section 3.2.1 under code requirements. The minimum ASME Code sections I and VIII are required for IST. The ASME Code approved pressure relief valves for IST are large compared to the loop design flows and volumes. [

] [CCI per Affidavit 4(a) – 4(d)]

[

]
[CCI per Affidavit 4(a) – 4(d)]

Figure 9-1. IST Control System Design

[

]

[CCI per Affidavit 4(a) – 4(d)]

Figure 9-2. IST primary LOOP Trace Heating Regions

[

]

[CCI per Affidavit 4(a) – 4(d)]

Figure 9-3. ECCS Trace Heating Regions

Table 9-1. IST Inventory Control Logic

[

Table 9-2. Pressure Control Logic

]

[CCI per Affidavit 4(a) – 4(d)]

10. IST – B&W MPOWER REACTOR RELAP5 ANALYSES AT 425 MWT

B&W NE is developing RELAP5 models of the IST. These models will be used for comparing RELAP5 results with data collected from the IST test. [

] [CCI per Affidavit 4(a) – 4(d)]

This section is divided into three topics. The first summarizes the IST RELAP5 model. The second documents the steady-state comparisons of the IST and B&W mPower model. The third documents the transient comparisons of the IST and B&W mPower model. Currently, both the IST and the B&W mPower RELAP5 models are in a state of development so these results should be considered preliminary.

10.1 IST Modeling for RELAP5

The purpose of this section is to provide a description of the IST model used for preliminary scaling comparisons. The model presented here is preliminary based on information available at the time. However, the model has been documented and checked for accuracy and is adequate for the purposes of this preliminary scaling comparison. Prior to making pre-test predictions, it is expected that a number of changes will be made to reflect the as-built plant and to align with best practices for PWR plant modeling.

The objective of this section is to provide a description of the RELAP5 modeling of IST components. A detailed description of IST systems and components has been provided in Sections 4, 5, 6, and 7. Figures provided are representative of the relationship between systems and components of the IST and corresponding RELAP5 models. The following parts of the IST have been incorporated into this preliminary model.

[

] [CCI per Affidavit 4(a) – 4(d)]

10.1.1 Reactor Pressure Vessel

[

] [CCI per Affidavit 4(a) – 4(d)]

10.1.2 Steam Generator

[

] [CCI per Affidavit 4(a) – 4(d)]

10.1.3 Pressurizer

[

] [CCI per Affidavit 4(a) – 4(d)]

10.1.4 Riser

[

] [CCI per Affidavit 4(a) – 4(d)]

10.1.5 Downcomer

[

] [CCI per Affidavit 4(a) – 4(d)]

10.1.6 Emergency Core Cooling Systems

[

] [CCI per Affidavit 4(a) – 4(d)]

10.1.7 Heat Structures

Heat structure models are solid structures that generate heat, conduct heat between liquid/vapor volumes, and stores/releases energy with changes in system temperatures. [

] [CCI per Affidavit 4(a) – 4(d)]

10.1.7.1 Heater Rods

[

] [CCI per Affidavit 4(a) – 4(d)]

10.1.7.2 Heat Transfer Structures

[

] [CCI per Affidavit 4(a) – 4(d)]

10.2 <u>Confirmation of Scaling Factors at Steady State Conditions</u>

[

] [CCI per Affidavit 4(a) – 4(d)]

10.3 Confirmation of Scaling Factors for Transient Conditions

[

] [CCI per Affidavit 4(a) – 4(d)]

10.4 Scaling Factor Conclusions

This section has shown that the scaling approach and the various design compromises to reduce atypicalities in the IST have resulted in similar SS and transient performance between B&W mPower and the IST. This is an important step in the overall testing and safety analysis code qualification program. The next stage of the RELAP5 model development will further enhance the model with as-built design dimensions and prepare the model to make pre-test predictions of the IST transient performance.

[

]

[CCI per Affidavit 4(a) – 4(d)]

Figure 10-1. IST Reactor Pressure Vessel Nodalization

[

]

[CCI per Affidavit 4(a) – 4(d)]

Figure 10-2. Cross-section of IST Pressure Vessel Lower End

[

]

[CCI per Affidavit 4(a) – 4(d)]

Figure 10-3. IST Riser and Pressurizer Nodalization

[

]

[CCI per Affidavit 4(a) – 4(d)]

Figure 10-4. IST Steam Generator Nodalization

[

]

[CCI per Affidavit 4(a) – 4(d)]

Figure 10-5. Steam Generator Cross Section

[

]

[CCI per Affidavit 4(a) – 4(d)]

Figure 10-6. IST Downcomer Nodalization

[

]

[CCI per Affidavit 4(a) – 4(d)]

Figure 10-7. IST ECCS Primary Side and RWST Nodalization

[

]

[CCI per Affidavit 4(a) – 4(d)]

Figure 10-8. IST ECCS Secondary Side Nodalization

[

]

[CCI per Affidavit 4(a) – 4(d)]

Figure 10-9. IST Heater Rod Heat Structure Nodalization

[

]

[CCI per Affidavit 4(a) – 4(d)]

Figure 10-10. IST vs. B&W mPower Comparison of Single Sided Break LOCA Break Mass Flow Rates

[

]

[CCI per Affidavit 4(a) – 4(d)]

Figure 10-11. IST vs B&W mPower Comparison of Single Sided Break LOCA Pressurizer Pressures

[

]

[CCI per Affidavit 4(a) – 4(d)]

Figure 10-12. IST vs B&W mPower Comparison of Single Sided Break LOCA Collapsed Water Levels

Table 10-1. Achieved Ratio of B&W mPower to IST for 100% Power Steady-State Conditions

[

]

[CCI per Affidavit 4(a) – 4(d)]

Table 10-2. Achieved Ratio of B&W mPower to IST for 5% Natural Circulation Steady-State Conditions

[

]

[CCI per Affidavit 4(a) – 4(d)]

11. SYSTEM AND COMPONENT TESTING REQUIREMENTS

IST program system and component testing supports computer software development and verification, component and system model development and verification, and control and protection system development. The testing supports safety analysis, licensing and development of abnormal and emergency operating procedures. The testing provides supporting data for system transients associated with various operational occurrences and design basis events as they transition from various operating points to a stable long-term cooling state. The tests are also broad in scope, to provide a better overall understanding of component performance, system performance, systems interaction, control system design, and protection system design.

The B&W MIST program was a set of tests conducted in the mid-1980s, following the TMI-2 accident, which related largely to the understanding of small break LOCAs (Reference 6). The IST program is patterned after the MIST program, with an expanded scope to document B&W mPower reactor integral plant performance over a full spectrum of normal and transient operating conditions.

11.1 Steam Generator Confirmation Testing

[

]

[CCI per Affidavit 4(a) – 4(d)]

11.2 Pressurizer Control Testing

[

] [CCI per Affidavit 4(a) – 4(d)]

11.3 Natural Circulation Testing

[

] [CCI per Affidavit 4(a) – 4(d)]

11.3.1 Steam Generator Cooling

[ ] [CCI per Affidavit 4(a) – 4(d)]

11.3.1.1 Normal Single-Phase Cooling

[ ] [CCI per Affidavit 4(a) – 4(d)]

11.3.1.2 Saturated Two-Phase Cooling RCS Level in Tube Region

[ ] [CCI per Affidavit 4(a) – 4(d)]

11.3.1.3 Boiler Condenser Cooling

[ ] [CCI per Affidavit 4(a) – 4(d)]

11.3.2 Emergency Core Cooling System

[ ] [CCI per Affidavit 4(a) – 4(d)]

11.3.2.1 Emergency Condenser Subsystem

[

] [CCI per Affidavit 4(a) – 4(d)]

11.3.2.2 Reactor Coolant System Steam and Feed Cooling

[

] [CCI per Affidavit 4(a) – 4(d)]

11.3.3 Reactor Coolant Inventory and Purification System Cooling

The B&W mPower reactor RCIPS serves a number of functions, as described in Section 5.6.

[

[CCI per Affidavit 4(a) – 4(d)]

11.4 Reactor Coolant System Testing

Sections 11.4.1 through 11.4.3 summarize planned IST testing for the RCS.

11.4.1 [ ] [CCI per Affidavit 4(a) – 4(d)]

] [CCI per Affidavit 4(a) – 4(d)]

11.4.2 [ ] [CCI per affidavit 4(a) – 4(d)]

] [CCI per Affidavit 4(a) – 4(d)]

11.4.3 [ ] [CCI per Affidavit 4(a) – 4(d)]

] [CCI per Affidavit 4(a) – 4(d)]

11.5 Verification of Component, System and Safety Analysis Codes

[

] [CCI per Affidavit 4(a) – 4(d)]

11.6 System and Component Scaling Issues

11.6.1 Stored Energy

[

] [CCI per Affidavit 4(a) – 4(d)]

11.6.2 Heat Losses

[

] [CCI per Affidavit 4(a) – 4(d)]

11.6.3 Reactor Coolant Pump

[

] [CCI per Affidavit 4(a) – 4(d)]

11.6.4 Core/Heaters

[

] [CCI per Affidavit 4(a) – 4(d)]

12. COMPONENT AND SYSTEMS TESTING PROGRAM

The existing fleet of commercial reactors was based on a large number of component tests that were integrated analytically. The B&W Multi Loop Integral Systems Test (MIST) [11] was a set of follow on tests that related largely to the understanding of the small break loss of coolant accident. [

] [CCI per Affidavit 4(a) – 4(d)]

12.1 Introduction

[

] [CCI per Affidavit 4(a) – 4(d)] Each section of testing will be described below. The projected test sequence is shown as Table 12-1.

12.2 IST Testing Section One

[

] [CCI per Affidavit 4(a) – 4(d)]

12.3 IST Testing Section Two

[

] [CCI per Affidavit 4(a) – 4(d)]

12.4 IST Testing Section Three

[

] [CCI per Affidavit 4(a) – 4(d)]

12.5 IST Testing Section Four

[

] [CCI per Affidavit 4(a) – 4(d)]

12.7 IST Testing Section Six

[

] [CCI per Affidavit 4(a) – 4(d)]

] [CCI per Affidavit 4(a) – 4(d)]

12.6 IST Testing Section Five

[

Table 12-1. Projected Testing Sequences

[

]

[CCI per Affidavit 4(a) – 4(d)]

13. QUALITY ASSURANCE

The IST program is a significant part of the B&W mPower reactor design verification program. The IST program is conducted in accordance with the "Quality Assurance Program for the Design Certification of the B&W mPower Reactor™," as described in B&W Topical Report (Reference 9).

Key quality assurance elements of the IST program include design verification by testing, test control, and control of measuring and test equipment. The IST program is conducted in accordance with written procedures, and the IST facility is operated by trained operators pursuant to approved procedures.

A RELAP5 model of the integral reactor test loop and supporting systems is used to verify scaling and to predict the results of the tests for comparison to expected plant performance, and to provide a basis for establishing acceptance criteria. Means to verify the accuracy of data are established, such as redundant instrumentation or related instrumentation. Judgment as to the quality of the data is made prior to signing off on test completion.

It is recognized that plant design, IST systems design, and test program design are being conducted concurrently. Wherever possible, flexibility in the IST program design is incorporated.

14. REFERENCES

1. Ishii, M. and I. Kataoka, "Scaling Criteria for LWR's under Single-Phase and Two-Phase Natural Circulation." Presented at Joint NRC/ANS Meeting on Basic Thermal Hydraulic Mechanisms in LWR Analysis, September, 1982, Bethesda, MD

2. Marks' Standard Handbook for Mechanical Engineers, Eighth Edition, McGraw-Hill Book Co., New York, 1978, p. 13-79.

3. Handbook of Hydraulic Resistance, 3rd Edition, I.E. Idelchik, Jaico Publishing House, Delhi, 2008.

4. Flow of Fluids Through Valves, Fittings and Pipe, Technical Paper 410, Crane Co., Stamford, CT, 2009.

5. Two-Phase Flow, Boiling and Condensation in Conventional and Miniature Systems, Ghiaasiaan, S. Mostafa, Cambridge University Press, New York, 2008, p. 233.

6. "Multiloop Integral Systems Test (MIST): Final Report, Summary," Gloudemans, James R., NUREG/CR-5395, EPRI/NP-6480, BAW-2023 Volume 1, April 1991.

7. Heat Transfer Research Institute, Inc. (HTRI) HTRI Xchanger Suite 6.

8. PWR Primary Water Guidelines, Volume 1, Revision 4. TR-105714-V1R4.

9. "Quality Assurance Program for the Design Certification of the B&W mPower™ Reactor Topical Report," 08-00000320-000-A, Revision 2, N-R0015, January 2011.

15. ATTACHMENTS

1. Integrated Systems Test Primary Loop P&ID, Sheet 1 of 3.
2. Integrated Systems Test Primary Loop P&ID, Sheet 2 of 3.
3. Integrated Systems Test Primary Loop P&ID, Sheet 3 of 3.
4. Integrated Systems Test RWST P&ID, Sheet 1 of 2.
5. Integrated Systems Test RWST P&ID, Sheet 2 of 2.
6. Integrated Systems Test RCIP P&ID, Sheet 1 of 2.
7. Integrated Systems Test RCIP P&ID, Sheet 2 of 2.
8. Integrated Systems Test Secondary Loop P&ID, Sheet 1 of 1.
9. Integrated Systems Test Instrument Air P&ID, Sheet 1 of 1.
10. Integrated Systems Test Demin & Component Cooling Water P&ID, Sheet 1 of 1.
11. Integrated Systems Test ECCS P&ID, Sheet 1 of 1.

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Attachment 1 – Integrated Systems Test Primary Loop P&ID, Sheet 1 of 3

[

] [CCI per Affidavit 4(a) – 4(d)]

Attachment 2 – Integrated Systems Test Primary Loop P&ID, Sheet 2 of 3

[

] [CCI per Affidavit 4(a) – 4(d)]

Attachment 3 – Integrated Systems Test Primary Loop P&ID, Sheet 3 of 3

[

] [CCI per Affidavit 4(a) – 4(d)]

Attachment 4 – Integrated Systems Test RWST P&ID, Sheet 1 of 2

[

] [CCI per Affidavit 4(a) – 4(d)]

Attachment 5 – Integrated Systems Test RWST P&ID, Sheet 2 of 2

[

] [CCI per Affidavit 4(a) – 4(d)]

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Attachment 6 – Integrated Systems Test RCIP P&ID, Sheet 1 of 2

[

] [CCI per Affidavit 4(a) – 4(d)]

Attachment 7 – Integrated Systems Test RCIP P&ID, Sheet 2 of 2

[

] [CCI per Affidavit 4(a) – 4(d)]

Attachment 8 – Integrated Systems Test Secondary Loop P&ID, Sheet 1 of 1

[

] [CCI per Affidavit 4(a) – 4(d)]

Attachment 9 – Integrated Systems Test Instrument Air P&ID, Sheet 1 of 1

[

] [CCI per Affidavit 4(a) – 4(d)]

Attachment 10 – Integrated Systems Test Demin & Component Cooling Water P&ID, Sheet 1 of 1

[

] [CCI per Affidavit 4(a) – 4(d)]

Attachment 11 – Integrated Systems Test ECCS P&ID, Sheet 1 of 1

[

] [CCI per Affidavit 4(a) – 4(d)]