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July 2, 2010 BW-JAH-2010-217

U.S. Nuclear Regulatory Commission
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Babcock & Wilcox Company, Nuclear Energy
Docket No. PROJ0776
Project No. 776

Subject: Submittal of Technical Report 06-00000392-000(NP), "B&W *mPower*™ Reactor Integrated Systems Test"

On June 30, 2010, Babcock & Wilcox Nuclear Energy (B&W NE) transmitted Technical Report 06-00000392-000(P), "B&W *mPower*™ Reactor Integrated Systems Test". This report contained B&W NE Confidential Commercial Information that was requested to be withheld from public disclosure. At that time, B&W NE committed to provide a non-proprietary version under a separate letter.

Accordingly, enclosed is Technical Report 06-00000392-000(NP), a non-proprietary version of the June 30 report.

Questions concerning this submittal may be directed to T. J. Kim at 434-382-9791 (email: tjkim@babcock.com) or to J. A. Halfinger at 434-316-7507 (email: jahalfinger@babcock.com).

Jeffrey A. Halfinger
Vice President, B&W mPower Development
B&W NE

JHA/

cc: Joelle L. Starefos, NRC, TWFN-6 E4
Stewart L. Magruder, Jr., NRC, TWFN-6 E4

4601
NRR

Add'. J.L Starefos
S.L. Magruder
to ERIDS

Redacted Non-Proprietary Version

babcock & wilcox nuclear energy

B&W *mPower*™ REACTOR INTEGRATED SYSTEMS TEST TECHNICAL REPORT

06-00000392-000 (NP)

June 2010

a progressive energy solution

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

Confidential Commercial Information Is Enclosed in Square Brackets: and Reasons for Withholding the Identified CCI from Public Disclosure Are Provided in an Accompanying Affidavit

Babcock & Wilcox Nuclear Energy, Inc.

B&W *mPower*™ Reactor
Integrated Systems Test Technical Report

SIGNATURES			
Prepared By:	Billy E. Bingham Technical Consultant	Signature *Billy E. Bingham*	*30 Jun 10* Date
Reviewed By:	John Malloy Lead System Engineer	Signature *John Malloy*	*6/30/10* Date
Reviewed By:	Eric Williams Integrated Systems Test Unit Manager	Signature *Eric Williams*	*6/30/10* Date
Approved By:	D. E. Lee Engineer Manager	Signature *[signature]*	*6/30/10* Date

RECORD OF REVISION

Revision	Section(s) or Page(s)	Description of Changes
0	N/A	Initial Issue

Table of Contents

Document No. 06-00000392-000(NP)	Title: B&W *mPower*™ Integrated Systems Test Technical Report

1. OVERVIEW

The B&W *mPower*™ reactor is a simplified, modular and passively safe, pressurized water reactor (PWR) nuclear power plant (Reference 1). It uses an integral design for the nuclear steam supply system, in which the reactor core, control rod drive mechanisms, reactor coolant pumps, pressurizer and steam generator are contained in a single vessel. The reactor is designed to generate approximately 125 MWe with a design life of 60 years.

[

] [CCI per Affidavit 4(a) – 4(e)]

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. The IST facility is being incorporated in the Center for Advanced Engineering Research (CAER) being constructed in Bedford County just west of Lynchburg, Virginia. Figure 1-2 is an architect-engineer's rendition showing the IST loop tower.

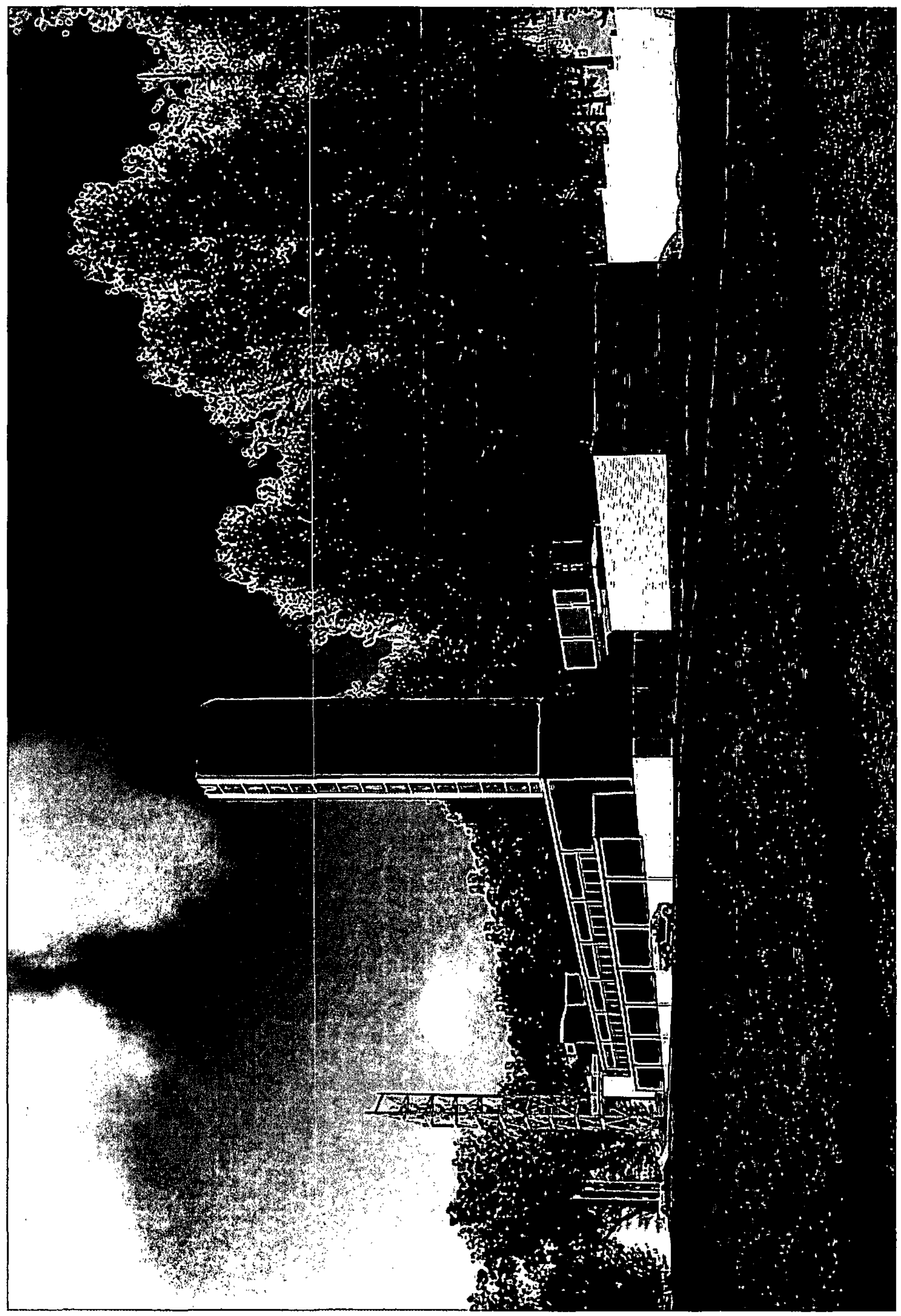
This report describes IST facility functional requirements, systems and test requirements as currently identified. Changes to the facility and/or this report are expected as the B&W *mPower* reactor and IST program designs proceed concurrently.

Figure 1-1 – B&W *mPower* Reactor and IST Loop Side-by-Side

[

] [CCI per Affidavit 4(a) – 4(e)]

Figure 1-2 – Center for Advanced Engineering Research with IST Tower



2. FUNCTIONS AND DESIGN REQUIREMENTS

2.1 Functions

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

2.1.1 Steam Generator Characteristics

[

]
[CCI per Affidavit 4(a) – 4(e)] 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.

2.1.2 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(e)] The reactor core is located at the bottom of the reactor vessel. 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.

2.1.3 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.

2.1.4 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.

2.2 Reactor Coolant System Design Requirements

2.2.1 Scaling

[

]

[CCI per Affidavit 4(a) – 4(e)]

2.2.2 Phenomena Identification

[

] [CCI per Affidavit 4(a) – 4(e)]

2.2.3 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 Virginia, as applicable.

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.

Document No. 06-00000392-000(NP)	Title: B&W *mPower*™ Integrated Systems Test Technical Report

All activities including design, fabrication, procurement, inspection and code stamping are performed to B&W Nuclear Energy Quality Assurance Program (Reference 2) procedures and standards, with ASME Code documents and supporting calculations and documents provided with the equipment.

2.2.4 IST Reactor Loop Design Requirements

[

]

[CCI per Affidavit 4(a) – 4(e)]

2.2.5 Instrumentation Requirements

[

] [CCI per Affidavit 4(a) – 4(e)] The required ranges for the instrumentation are provided in Sections 2.2.5.1 through 2.2.5.5.

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.

2.2.5.1 IST Loop Control and Protection Systems

[

]

[CCI per Affidavit 4(a) – 4(e)]

2.2.5.2 Engineered Safety Features

[

]

[CCI per Affidavit 4(a) – 4(e)]

2.2.5.3 Steam Generator

[

]

[CCI per Affidavit 4(a) – 4(e)]

2.2.5.4 Pressurizer

[

]

[CCI per Affidavit 4(a) – 4(e)]

2.2.5.5 Riser

[

]

[CCI per Affidavit 4(a) – 4(e)]

2.2.6 Reactor Protection System Test Requirements

[

]

[CCI per Affidavit 4(a) – 4(e)]

2.3 Core Simulation

[

]

[CCI per Affidavit 4(a) – 4(e)]

3.0 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(e)]

3.1 Core Simulator

3.1.1 Core and Core Internals/Support

[

] [CCI per Affidavit 4(a) – 4(e)]

3.1.2 Core Simulator Heaters

[

]

[CCI per Affidavit 4(a) – 4(e)]

3.1.3 Reactor Vessel

[

] [CCI per Affidavit 4(a) – 4(e)]

3.1.4 Power Supply

[

] [CCI per Affidavit 4(a) – 4(e)]

3.2 Steam Generator

[

] [CCI per Affidavit 4(a) – 4(e)]

3.2.1 Tubes

[

] [CCI per Affidavit 4(a) – 4(e)]

3.2.2 Shroud

[

] [CCI per Affidavit 4(a) – 4(e)]

3.2.3 Tube Support Plates

[

] [CCI per Affidavit 4(a) – 4(e)]

3.2.4 Tubesheets

[

]

[CCI per Affidavit 4(a) – 4(e)]

3.2.5 Steam Generator Instrumentation

[

] [CCI per Affidavit 4(a) – 4(e)]

3.2.6 Tube Rupture Simulation

[

] [CCI per Affidavit 4(a) – 4(e)]

3.3 Pressurizer

[

] [CCI per Affidavit 4(a) – 4(e)]

3.3.1 Vessel

[

] [CCI per Affidavit 4(a) – 4(e)]

3.3.2 Spray

[

] [CCI per Affidavit 4(a) – 4(e)]

3.3.3 Heaters

[

] [CCI per Affidavit 4(a) – 4(e)]

3.3.4 Instrumentation

[

] [CCI per Affidavit 4(a) – 4(e)]

3.4 Reactor Coolant Pump Region Simulator

[

] [CCI per Affidavit 4(a) – 4(e)]

3.5 Other Reactor Coolant System Pipe Sections

3.5.1 Riser

3.5.1.1 Control Rod Drive Segment

[

] [CCI per Affidavit 4(a) – 4(e)]

3.5.1.2 Steam Generator Segment

[

] [CCI per Affidavit 4(a) – 4(e)]

3.5.2 Steam Generator/Pressurizer/Riser Junction

[

] [CCI per Affidavit 4(a) – 4(e)]

3.5.3 Reactor Coolant Support Loop

[

]

[CCI per Affidavit 4(a) – 4(e)]

Document No.	Title:
06-00000392-000(NP)	B&W *mPower*™ Integrated Systems Test Technical Report

Figure 3-1 – IST Loop and Containment

[

] [CCI per Affidavit 4(a) – 4(e)]

Figure 3-2 – IST Core Simulator Cross-Section inside the Vessel

[

] [CCI per Affidavit 4(a) – 4(e)]

Figure 3-3 – IST Heater Rod

[

] [CCI per Affidavit 4(a) – 4(e)]

Figure 3-4 – IST Axial Power Shape

[

] [CCI per Affidavit 4(a) – 4(e)]

Figure 3-5 – IST Core Simulator Cross-Section Showing Thermocouple Locations

[

] [CCI per Affidavit 4(a) – 4(e)]

Figure 3-6 – IST Reactor Vessel Assembly

[

] [CCI per Affidavit 4(a) – 4(e)]

Figure 3-7 – IST Steam Generator Arrangement

[

] [CCI per Affidavit 4(a) – 4(e)]

Figure 3-8 – IST Tube Support Plate Plan View

[

]

[CCI per Affidavit 4(a) – 4(e)]

Figure 3-9 – IST Tube Support Plate Opening Profile

[

] [CCI per Affidavit 4(a) – 4(e)]

Figure 3-10 – IST Upper Tubesheet, Riser and Pressurizer Junctions

[

] [CCI per Affidavit 4(a) – 4(e)]

Figure 3-11 – IST Pressurizer

[

] [CCI per Affidavit 4(a) – 4(e)]

Figure 3-12 – IST Downcomer in Pump Region

[

] [CCI per Affidavit 4(a) – 4(e)]

4. ENGINEERED SAFETY FEATURE COMPONENTS AND DECAY HEAT REMOVAL

4.1 Emergency Core Cooling System

[ ] [CCI per Affidavit 4(a) – 4(e)]

4.1.1 Emergency Condenser Cooling

[

] [CCI per Affidavit 4(a) – 4(e)]

4.1.2 Secondary Steam Vent

[

] [CCI per Affidavit 4(a) – 4(e)]

4.1.3 Refueling Water Storage Tank and Containment

[

] [CCI per Affidavit 4(a) – 4(e)]

4.1.4 ECCS Piping and Valves

[

] [CCI per Affidavit 4(a) – 4(e)]

4.1.5 Boron Injection

[ ] [CCI per Affidavit 4(a) – 4(e)]

4.2 Reactor Coolant Inventory and Purification Subsystem

[

] [CCI per Affidavit 4(a) – 4(e)]

Figure 4-1 – IST Loop Showing the RWST and Containment Simulation Vessel

[

] [CCI per Affidavit 4(a) – 4(e)]

Document No.	Title:
06-00000392-000(NP)	B&W *mPower*™ Integrated Systems Test Technical Report

5. STEAM, FEEDWATER AND CONDENSATE SYSTEMS

The B&W *mPower* reactor turbine and associated equipment are not included in the IST facility. Rather, the facility incorporates simplified steam, feedwater and condensate systems. [

] [CCI per Affidavit 4(a) – 4(e)]

Feedwater chemistry is based on the EPRI "Reactor Secondary Water Chemistry Guidelines" related to sampling and monitoring requirements for an OTSG during operation (Reference 3). For the purposes of the IST, considering that the chemistry requirements do not need to be as rigorous as for an operating plant with a turbine and the entire balance of plant with a much longer system design lifetime. [

] [CCI per Affidavit 4(a) – 4(e)]

Table 5-1 – IST Water Chemistry Control and Diagnostic Parameters

[

] [CCI per Affidavit 4(a) – 4(e)]

6. INSTRUMENTATION FOR CONTROL AND PROTECTION SYSTEMS

[

] [CCI per Affidavit 4(a) – 4(e)]

7. 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. Figure 7-1 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.

Figure 7-1 – IST Control System Design

[

] [CCI per Affidavit 4(a) – 4(e)]

8. 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 Multi-Loop Integral System Test (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 4). 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.

8.1 Steam Generator Confirmation Testing

[

]

[CCI per Affidavit 4(a) – 4(e)]

8.2 Pressurizer Control Testing

[

] [CCI per Affidavit 4(a) – 4(e)]

8.3 Natural Circulation Testing

[

] [CCI per Affidavit 4(a) – 4(e)]

8.3.1 Steam Generator Cooling

[

] [CCI per Affidavit 4(a) – 4(e)]

8.3.1.1 Normal Single-Phase Cooling

[

] [CCI per Affidavit 4(a) – 4(e)]

8.3.1.2 Saturated Two-Phase Cooling RCS Level in Tube Region

[

] [CCI per Affidavit 4(a) – 4(e)]

8.3.1.3 Boiler Condenser Cooling

[

] [CCI per Affidavit 4(a) – 4(e)]

8.3.2 Emergency Core Cooling System

[

] [CCI per Affidavit 4(a) – 4(e)]

8.3.2.1 Emergency Condenser Subsystem

[

] [CCI per Affidavit 4(a) – 4(e)]

8.3.2.2 Reactor Coolant System Steam and Feed Cooling

[

] [CCI per Affidavit 4(a) – 4(e)]

8.3.3 Reactor Coolant Inventory and Purification System Cooling

[

] [CCI per Affidavit 4(a) – 4(e)]

8.4 Reactor Coolant System Testing

[ ] [CCI per Affidavit 4(a) – 4(e)]

8.4.1 Forced Flow System Testing

[

] [CCI per Affidavit 4(a) – 4(e)]

8.4.2 Transition to Natural Circulation System Testing

[

] [CCI per Affidavit 4(a) – 4(e)]

2.1.3 Control System Testing

[

] [CCI per Affidavit 4(a) – 4(e)]

8.5 Verification of Component, System and Safety Analysis Codes

[

] [CCI per Affidavit 4(a) – 4(e)]

8.6 System and Component Scaling Issues

8.6.1 Stored Energy

[

] [CCI per Affidavit 4(a) – 4(e)]

8.6.2 Heat Losses

[

] [CCI per Affidavit 4(a) – 4(e)]

8.6.3 Reactor Coolant Pump

[

] [CCI per Affidavit 4(a) – 4(e)]

8.6.4 Core/Heaters

[

] [CCI per Affidavit 4(a) – 4(e)]

9. 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 08-00000320-000, dated March 31, 2010 (Reference 2).

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.

10. REFERENCES

1. "B&W *mPower*™ Reactor Design Overview," Technical Report 08-00000341-000(P), May 2010.

2. "Quality Assurance Program for the Design Certification of the B&W *mPower*™ Reactor," Topical Report 08-00000320-000, March 2010.

3. "Reactor Secondary Water Chemistry Guidelines – Revision 6," EPRI Report 1008224, EPRI, Palo Alto, CA, December 2004.

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

11. ATTACHMENTS

1. Integrated Systems Test Primary Loop P&ID, B&W Drawing 04-00000281, Rev. 1, Sheet 1 of 3.

2. Integrated Systems Test Primary Loop P&ID, B&W Drawing 04-00000281, Rev. 1, Sheet 2 of 3.

3. Integrated Systems Test Primary Loop P&ID, B&W Drawing 04-00000281, Rev. 1, Sheet 3 of 3.

4. Integrated Systems Test RWST P&ID, B&W Drawing 04-00000283, Rev. 1, Sheet 1 of 2.

5. Integrated Systems Test RWST P&ID, B&W Drawing 04-00000283, Rev. 1, Sheet 2 of 2.

6. Integrated Systems Test RCIP P&ID, B&W Drawing 04-00000282, Rev. 1, Sheet 1 of 2.

7. Integrated Systems Test RCIP P&ID, B&W Drawing 04-00000282, Rev. 1, Sheet 2 of 2.

8. Integrated Systems Test Secondary Loop P&ID, B&W Drawing 04-00000284, Rev. 1, Sheet 1 of 1.

9. Integrated Systems Test Instrument Air P&ID, B&W Drawing 04-00000280, Rev. 1, Sheet 1 of 1.

Attachment 1 – Integrated Systems Test Primary Loop P&ID, B&W Drawing 04-00000281, Rev. 1, Sheet 1 of 3.

[

] [CCI per Affidavit 4(a) – 4(e)]

Document No.	Title:
06-00000392-000(NP)	B&W *mPower*™ Integrated Systems Test Technical Report

Attachment 2 – Integrated Systems Test Primary Loop P&ID, B&W Drawing 04-00000281, Rev. 1, Sheet 2 of 3.

[

] [CCI per Affidavit 4(a) – 4(e)]

Attachment 3 – Integrated Systems Test Primary Loop P&ID, B&W Drawing 04-00000281, Rev. 1, Sheet 3 of 3.

[

] [CCI per Affidavit 4(a) – 4(e)]

Attachment 4 – Integrated Systems Test RWST P&ID, B&W Drawing 04-00000283, Rev. 1, Sheet 1 of 2.

[

] [CCI per Affidavit 4(a) – 4(e)]

Attachment 5 – Integrated Systems Test RWST P&ID, B&W Drawing 04-00000283, Rev. 1, Sheet and 2 of 2.

] [CCI per Affidavit 4(a) – 4(e)]

Document No.	Title:
06-00000392-000(NP)	B&W *mPower*™ Integrated Systems Test Technical Report

Attachment 6 – Integrated Systems Test RCIP P&ID, B&W Drawing 04-00000282, Rev. 1, Sheet 1 of 2.

[

] [CCI per Affidavit 4(a) – 4(e)]

Attachment 7 – Integrated Systems Test RCIP P&ID, B&W Drawing 04-00000282, Rev. 1, Sheet 2 of 2.

] [CCI per Affidavit 4(a) – 4(e)]

Document No.	Title:
06-00000392-000(NP)	B&W *mPower*™ Integrated Systems Test Technical Report

Attachment 8 – Integrated Systems Test Secondary Loop P&ID, B&W Drawing 04-00000284, Rev. 1, Sheet 1 of 1.

[

] [CCI per Affidavit 4(a) – 4(e)]

Document No.	Title:
06-00000392-000(NP)	B&W *mPower*™ Integrated Systems Test Technical Report

Attachment 9 – Integrated Systems Test Instrument Air P&ID, B&W Drawing 04-00000280, Rev. 1, Sheet 1 of 1.

[

] [CCI per Affidavit 4(a) – 4(e)]