Enclosure 3
B&W mPower™ GSI-191 Technical Report
11111-000-3TR-MECC-00009
(Redacted)

babcock & wilcox mPower

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Minor Change ☒

B&W mPower™ a progressive energy solution

B&W mPower™ Reactor Program
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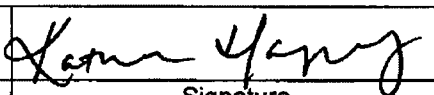
Prepared By:	Katherine Haggerty		6/19/13
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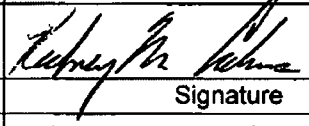
Reviewed By:	Rodney Adams		6/19/2013
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RECORD OF REVISION

Revision No.	Date	Preparer	Description of Changes
000	06/14/2013	K. Haggerty	Initial Revision
001	06/19/2013	K. Haggerty	Minor Editorial Changes

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Abstract

The objective of this report is to describe how the Babcock & Wilcox (B&W) mPower ™ Reactor design addresses Generic Safety Issue (GSI) 191 "Assessment of Debris Accumulation on PWR Sump Performance." GSI-191 concerns the potential for post-accident debris blockage and interference with the capability of emergency core cooling system (ECCS) recirculation during long-term core cooling. NRC Regulatory Guide (RG) 1.82 describes acceptable methods and guidelines for evaluating the adequacy of plant design features and ECC performance, including a framework for licensees to develop, demonstrate, and implement a comprehensive resolution to GSI-191.

This report demonstrates that the B&W mPower Reactor provides long-term cooling after a postulated accident with reactor coolant quality water [

] Further, this report shows that there is [

]

The information in this report provides a basis for a determination that [

]

Disclaimer

The design and engineering information contained in this document has been prepared by B&W mPower in connection with pre-application reviews of the B&W mPower Reactor design. Changes to final design information which affect the conclusions pertinent to GSI-191 will be provided in a revision to this technical report.

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

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List of Acronyms

ADV—Automatic Depressurization Valve
CFR—Code of Federal Regulations
CSS—Containment Spray System (NRC)
DBA—Design Basis Accident
ECC—Emergency Core Cooling System (mPower)
ECCS—Emergency Core Cooling System (NRC)
GSI—Generic Safety Issue
HELB—High-Energy Line Break
IIV—Integral Isolation Valve
IPIT—Intermediate Pressure Injection Tank
LOCA—Loss-of-Coolant Accident
NEI—Nuclear Energy Institute
NPSH—Net Positive Suction Head
NRC—Nuclear Regulatory Commission
PSV—Pressrizer Safety Valve
PWR—Pressurized Water Reactor
RCI—Reactor Coolant Inventory and Purification System (mPower)
RCS—Reactor Coolant System (mPower)
RG—Regulatory Guide
RWST—Refueling Water Storage Tank
ZOI—Zone of Influence

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1. INTRODUCTION

The purpose of this report is to discuss how features of the B&W mPower ™ Reactor design address the safety concerns associated with Generic Safety Issue (GSI) 191 "Assessment of Debris Accumulation on PWR Sump Performance." The Nuclear Regulatory Commission (NRC) initiated GSI-191 to address safety concerns associated with long-term recirculation cooling following a loss-of-coolant accident (LOCA), including the transport of LOCA-generated and latent debris materials to emergency core cooling system (ECCS) sump screens, downstream components in the ECCS, the containment spray system (CSS), and the reactor core. This potentially results in low heat transfer, potential blockage of core cooling flow, and wear on downstream components and challenges the plant's ability to meet long-term cooling requirements in accordance with 10 CFR 50.46(b) (5). This report highlights the features of the B&W mPower design, describes an overall approach for long-term cooling, and incorporates guidance from NRC documents to demonstrate the resolution of GSI-191 concerns for design basis LOCAs.

As a result of NRC research, industry research, and past operating experience, the NRC requested licensees provide sufficient information to assess the potential for debris blockage of flow paths during design basis accidents requiring recirculation. The B&W mPower design approach to GSI-191 employs the evaluation guidance for long-term recirculation cooling following a LOCA contained in NRC Regulatory Guide (RG) 1.82, Revision 4.

Feedback from NRC staff on a proposed B&W mPower GSI-191 Plan, (MPWR-EPP-005009 (Reference 6.5), "B&W mPower Approach to Satisfy GSI-191"), was received at a November 27, 2012 meeting. Several questions associated with the B&W mPower plan to address GSI-191 were raised. These include:

- addressing the insulation and coatings to be used in containment
- defining the B&W mPower design approach to long-term cooling and recirculation and demonstrating how the design conforms to GSI-191 requirements
- identifying the need and potential design of strainers
- determining basis for or justification for not performing screen or specific fuel testing

2. BACKGROUND

In 1979 the NRC opened Unresolved Safety Issue (USI) A-43, "Containment Emergency Sump Performance." The NRC sponsored an extensive research program, the technical findings of which are summarized in NUREG-0897, "Containment Emergency Sump Performance," dated October 1985. The resolution of USI A-43 was subsequently documented in Generic Letter (GL) 85-22, "Potential for Loss of Post-LOCA Recirculation Capability Due to Insulation Debris Blockage," dated December 3, 1985.

Although the staff's regulatory analysis concerning USI A-43 did not support imposing new sump performance requirements upon licensees of operating Pressurized Water Reactors (PWR)s or boiling-water reactors (BWRs), the staff found in GL 85-22 that the 50-percent blockage assumption (under which most nuclear power plants had been licensed) identified in Regulatory Guide (RG) 1.82, "Sumps for Emergency Core Cooling and Containment Spray Systems," Revision 0, should be replaced with a more comprehensive requirement to assess debris effects on a plant-specific basis. The 50-percent screen blockage assumption did not require a plant-specific evaluation of the debris-blockage potential and could result in a non-conservative analysis for screen blockage effects.

Following the resolution of USI A-43 in 1985, several events challenged the conclusion that no new requirements were necessary to prevent the clogging of ECCS debris screens at operating BWRs:

- On July 28, 1992, at Barsebäck Unit 2, a Swedish BWR, the spurious opening of a pilot-operated relief valve led to the plugging of two containment vessel spray system suction debris screens with mineral wool and required operators to shut down the spray pumps and backflush the debris screens.

- In 1993, at Perry Unit 1, two events occurred during which ECCS debris screens became plugged with debris. On January 16, ECCS debris screens were plugged with suppression pool particulate matter, and on April 14, an ECCS debris screen was plugged with glass fiber from ventilation filters that had fallen into the suppression pool. On both occasions, the affected ECCS debris screens were deformed by excessive differential pressure created by the debris plugging.

- On September 11, 1995, at Limerick Unit 1, following a manual scram due to a stuck-open safety/relief valve, operators observed fluctuating flow and pump motor current on the A loop of suppression pool cooling. The licensee later attributed these indications to a thin mat of fiber and sludge which had accumulated on the suction debris screen.

In response to these ECCS suction debris screen plugging events, the NRC issued several generic communications, including Bulletin 93-02, Supplement 1, "Debris Plugging of Emergency Core Cooling Suction Strainers," dated February 18, 1994; Bulletin 95-02, "Unexpected Clogging of a Residual Heat Removal (RHR) Pump Strainer While Operating in Suppression Pool Cooling Mode," dated October 17, 1995; and Bulletin 96-03, "Potential Plugging of Emergency Core Cooling Suction Strainers by Debris in Boiling-Water Reactors," dated May 6, 1996. These bulletins requested that BWR licensees implement appropriate procedural measures, maintenance practices, and plant modifications to minimize the potential for the clogging of ECCS suction debris screens by debris accumulation following a LOCA.

The NRC staff concluded that all BWR licensees had sufficiently addressed these bulletins by installation of large capacity debris screens. Findings from research to resolve the BWR debris screen clogging issue, however, raised questions concerning the adequacy of PWR sump designs. In comparison to the technical findings of the earlier USI A-43 research program on PWRs, the BWR research findings demonstrated that the amount of debris generated by a high-energy line break (HELB) could be greater, finer (and thus more easily transportable), and that certain combinations of debris (e.g., fibrous material plus particulate material) could result in a substantially greater head loss than an equivalent amount of either type of debris alone.

These research findings prompted the NRC to open GSI-191, "Assessment of Debris Accumulation on PWR Sump Performance." The objective of GSI-191 is to ensure that post-accident debris blockage will not impede or prevent the operation of the ECCS and CSS in recirculation mode at PWRs during LOCAs or other HELB accidents for which sump recirculation is required.

On June 9, 2003, having completed its technical assessment of GSI-191, the NRC issued Bulletin 2003-01, "Potential Impact of Debris Blockage on Emergency Recirculation during Design-Basis Accidents at Pressurized-Water Reactors." In developing Bulletin 2003-01, the NRC staff recognized that it may be necessary for addressees (current licensees) to undertake complex evaluations to determine whether regulatory conformance exists in light of the concerns identified in the bulletin and that the methodology needed to perform these evaluations was not currently available.

To provide the necessary methodology, the NRC staff prepared Generic Letter (GL) 2004-02: "Potential Impact of Debris Blockage on Emergency Recirculation during Design Basis Accidents at Pressurized-Water Reactors." GL 2004-02 describes areas of concern for PWRs and requests specific information from addressees to confirm the suitability of ECCS recirculation capability. Regulatory Guide 1.82, Revision 3 was endorsed as suitable guidance for purposes of sump and debris screen design and evaluation.

Subsequent to issuance of GL 2004-02, the NRC provided guidance for the content of responses to GSI-191 and guidance for review of the responses. The content guidance is contained in a letter from the NRC to the Nuclear Energy Institute (NEI), "Content Guide for Generic Letter 2004-02 Supplemental Responses," dated August 15, 2007. The review guidance is contained in a letter from the NRC to the NEI, "Revised Guidance for Review of Final Licensee Responses to Generic Letter 2004-02, 'Potential Impact of Debris Blockage of Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors,'" dated March 28, 2008.

In December 2004 the NEI Sump Performance task group developed a methodology document, NEI 04-07 Vol 1. "Pressurized Water Reactor Sump Performance Evaluation Methodology," to

be used as a guideline to address the issue of GL 2004-02. The NRC subsequently reviewed NEI 04-7 Volume 1 and issued a response of the document called NEI-04-07 Volume 2 "Safety Evaluation by the Office of Nuclear Reactor Regulation Related to NRC Generic Letter 2004-02" (Reference 3). The proposed evaluation methodology for pressurized water reactors is an overall acceptable guidance methodology for the plant specific evaluation of ECCS or CSS performance following postulated design basis accidents.

In March 2012 the NRC issued a Revision 4 to RG 1.82 (Reference 1) endorsing the methodology published in NEI 04-07. RG 1.82, "Water Sources for Long-Term Recirculation Cooling Following a Loss-of-Coolant Accident," describes acceptable methods for implementing requirements of sumps that provide water sources for emergency core cooling, containment heat removal, or containment atmosphere systems. RG 1.82 provides guidelines for evaluating the adequacy and availability of sump inventory for long-term recirculation cooling following a LOCA.

3. DESIGN OVERVIEW

3.1 B&W mPower Reactor Features

3.1.1 Reactor Design

The B&W mPower Reactor design is a simplified, passive, modular Advanced Light Water Reactor (ALWR) that uses an integral arrangement in which the reactor core, steam generator, pressurizer, control rod drive mechanisms, and reactor coolant pumps are combined into a common unit. The integrated design of the B&W mPower Reactor eliminates large piping connections between the reactor vessel, pressurizer, and steam generator typical of existing, larger PWRs. Eliminating the large connecting pipes reduces the inventory discharge rate during a LOCA and the insulation associated with these large pipes. The insulation on these large connecting lines typically provides the largest source of post-LOCA debris in operating PWRs.

3.1.2 ECC Design

The primary safety system in the B&W mPower design, the emergency core cooling system (ECC), is designed to provide passive, long-term, core decay heat removal using a source of cooling water, the refueling water storage tank (RWST), located high in containment.

The ECC is [

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Figure 1 illustrates one train of the ECC process flow, and Figure 2 depicts the location of the reactor vessel, RWST, ADVs, and Injection lines inside containment.

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Figure 1: ECC Process Flow Illustration

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[

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Figure 2: Elevation View of B&W mPower ECC in Containment

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

3.1.3 RWST Design

Design features of the RWST [
]are summarized in Table 1. [

]

Table 1: RWST Design Features

Protective Feature	Implications
[	[
]	]

These features include [

]

3.1.4 Water Quality

During normal power operation, water chemistry of the RWST and IPIT is controlled and monitored to ensure water quality is within water chemistry specifications derived from EPRI Primary Water Chemistry Guidelines (Reference 6.4). The water contained in the RWST and IPIT is [
]

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

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[

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Figure 3: Refueling Cavity to RWST Flow Path

[

]

3.2 ECC Operation

In the event of a design basis accident such as a LOCA, the ECC passively performs a series of functions that result in complete depressurization of the RCS and injection of cooling water from the [ ] After sufficient RCS depressurization through the ADVs, the [

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[

]

The [ ] cooling capability for the ECC is outlined in Table 2.

Table 2: ECC Long-Term Cooling Capability

Time Frame	Objective	Source
[		
		]

The ECC response and potential GSI-191 impact for several break scenarios are outlined below.

3.2.1 [

] listed in

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Table 1 [

]

3.2.2 [

]

[

]

Figure 4: ECC and RCI Connections to the Reactor Vessel

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3.2.3 [

]

4. B&W mPOWER REGULATORY GUIDE 1.82 CONFORMANCE

Features of the B&W mPower plant differ significantly from current operating plants and typical, larger PWRs, especially with regard to the approach to containment and long-term core cooling. In current operating PWRs, the response to DBAs such as a LOCA requires cooling water to be recirculated from the containment sump and relies on containment spray systems to cool containment. The B&W mPower Reactor, however, [

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4.1 Regulatory Positions Common to All Water-Cooled Reactors (Item C.1.1)

4.1.1 ECCS Sumps, Suppression Pools, Suction Strainers, and Debris Interceptors (Item C. 1.1.1)

[

]

4.1.2 Minimizing Debris (Item C.1.1.2)

The B&W mPower design does not have an [

] because of the design features outlined in Section 3.1.

Latent debris concerns and containment cleanliness for the B&W mPower design are discussed in Section 4.3.6 below.

4.1.3 Instrumentation and Operator Actions (Item C.1.1.3)

The B&W mPower design [

]

4.1.4 Active Systems (Item C.1.1.4)

The B&W mPower design [

]

4.1.5 Inspection (Item C.1.1.5)

The B&W mPower design [

]

4.2 Evaluation of Alternative Water Sources (Item C. 1.2)

The RWST is the [

]

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[

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4.3 Evaluation of Long-Term Recirculation Capability (Item C. 1.3)

4.3.1 Net-Positive Suction Head (NPSH) of the Emergency Core Cooling System and Containment Heat Removal Pumps (Reg. Guide 1.82, Item C.1.3.1)

The ECC is a passive system and does not contain any pumps, and, thus, the concerns regarding adequate NPSH are not applicable to B&W mPower design.

4.3.2 Pipe Break Characterization (Item C.1.3.2)

The objective of the break selection and characterization process is to identify the break size and locations that present the greatest challenge to post-LOCA sump performance. Only breaks in high-energy systems that could impact long-term cooling or reactor cavity recirculation need to be considered.

The function of long-term core cooling and containment cooling for the B&W mPower design [ ] These functions are performed as described in section 3.2. Therefore, the [

]

4.3.3 Debris Generation/ Zone of Influence (Item C.1.3.3)

The objective of the debris generation/zone of influence (ZOI) evaluation process is to determine for each postulated break location the zone within which the break jet forces would be sufficient to damage materials and create debris, and the amount and characteristics of debris generated. The evaluation of debris generation and characteristics is significant in determining the transportability of the debris to the containment sump strainers.

Because of the RWST design features described in section 3.1, and the description of the conformance to RG 1.82, Item C. 1.3.2 provided in section 4.3.2, [

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[

]

4.3.4 Debris Transport (Item C.1.3.4)

The B&W mPower design [

] of previously described design features.

4.3.5 Coating Debris (Item C.1.3.5)

The failures of coatings post-accident contribute to the debris generated and often react with containment spray systems to form harmful precipitates. Because of the previously described RWST design features, [

]

4.3.6 Latent Debris (Item C.1.3.6)

Latent debris in the B&W mPower design is [

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4.3.7 Upstream Effects (Item C.1.3.7)

Because all water required for post-accident core cooing is [

]

4.3.8 Downstream Effects (Item C.1.3.8)

GSI-191 evaluations consider the impact of debris on the components downstream of the ECCS strainer. This debris carried downstream causes wear, abrasion, and blockage in narrow passages and fuel assemblies. Because there are [

]

4.3.9 Strainer Structural Analysis (Item C.1.3.9)

In typical PWRs, the ECCS relies on sump recirculation through safety-related strainers for long-term cooling requiring. The adequacy of the strainer design must be validated through testing and analysis. The B&W mPower design [

]

4.3.10 Chemical Reaction Effects (Item C.1.3.10)

Because of the nature of the B&W mPower ECC design, chemical reaction effects are not an issue for the B&W mPower design. Post-LOCA debris materials in the zone of influence (ZOI) may transport to the sump area and react with spray chemicals, insulation, corroding metals, and other submerged materials. In the sump, chemical substances could form and impede flow of water through sump strainers or affect ECC or RCS downstream components (Reference 6.6). The B&W mPower design [

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4.3.11 Debris Accumulation, Head Loss, and Vortexting (Item C.1.3.11) and Prototypical Head Loss Testing (Item C.1.3.12)

The recommended testing of strainer designs are intended to determine acceptable limits for head loss and vortexing without negatively impacting long-term cooling. Testing of these scenarios should reflect plant-specific conditions and yield conservative results. There are [

]

5. CONCLUSIONS/RECOMMENDATIONS

The design features of the B&W mPower Reactor, such as the integrated reactor vessel, protected RWST, and the ECC long-term core cooling approach [

]

The information in this report provides a basis for a determination [

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6. REFERENCES

6.1	Regulatory Guide 1.82, Revision 4	Water Sources for Long-Term Recirculation Cooling Following a Loss-of-Coolant-Accident
6.2	NRC Generic Letter 2004-02	Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors
6.3	WCAP-16793 (ML 11292A021	Evaluation of Long-Term Cooling Considering Particulate, Fibrous, and Chemical Debris in the Recirculating Fluid
6.4	EPRI TR-105714, Revision 4	PWR Primary Water Chemistry Guidelines
6.5	MPWR-EPP-005009	B&W mPower Approach to Satisfy GSI-191
6.6	WCAP-16530-MP-A (ML08115037)	Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191