ENCLOSURE 2

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Class I (Public)

Licensing Topical Report

BOILING WATER REACTOR EMERGENCY CORE COOLING SUCTION STRAINER IN-VESSEL DOWNSTREAM EFFECTS

(NUCLEAR FUEL)

IMPORTANT NOTICE REGARDING THE CONTENTS OF THIS REPORT
Please Read Carefully

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EXECUTIVE SUMMARY

The Boiling Water Reactor Owners Group (BWROG) developed resolution guidance, referred to as the Utility Resolution Guide (URG) in 1996 to address the issues raised in NRC Bulletin (NRCB) 95-02, "Unexpected Clogging of a Residual Heat Removal Pump Strainer While Operating in Suppression Pool Cooling Mode," dated October 17, 1995, and NRCB 96-03, "Potential Plugging of Emergency Core Cooling Suction Strainers by Debris in Boiling-Water Reactors," dated May 6, 1996. These bulletins provided industry Operation Experience regarding effects from suppression pool debris, and requirements to ensure that any debris generated during a Loss-of-Coolant Accident (LOCA) would not affect required Emergency Core Cooling System (ECCS) performance. Licensees evaluated their suction strainers and implemented required modifications and procedures to ensure reliable ECCS operation following a LOCA. In October 2001, the NRC staff concluded that generic and plant-specific activities associated with NRCB 95-02 and NRCB 96-03 were complete on the basis that licensees had designed their ECCS suction strainers with sufficient margin to remain operable even with the debris loads anticipated during a LOCA.

The NRC issued a Generic Safety Issue (GSI) 191, "Experimental Studies of Loss-of-Coolant-Accident-Generated Debris Accumulation and Head Loss with Emphasis on the Effects of Calcium Silicate Insulation" in 1996 to examine whether the events and research associated with the Boiling Water Reactor (BWR) strainers warranted similar evaluations and/or changes for Pressurized Water Reactors (PWRs). The results of that analysis have led to new information regarding the previous analysis of the downstream effect of debris on BWR fuel.

This report provides the results of the updated analysis of the downstream effects of debris on GNF BWR fuel. This report provides a bounding approach for all reactor types, BWR/2 through 6, as well as all LOCAs, large and small including liquid and steam pipe breaks, based on sensitivity studies and analytical techniques. A detailed testing plan is described to verify the results of the analysis and assumptions.

Subsequent submittals will present the results of the testing described in this report as well as provide the equivalent analysis and testing criteria for both Areva and Westinghouse fuel.

REVISION SUMMARY

Rev. No.	Remarks
0	Initial Issue
1	Incorporated comments from BWROG reviewers.
2	Incorporated comments on page 52 from BWROG reviewers.

ACRONYMS AND ABBREVIATIONS

BWR	Boiling Water Reactor
BWROG	Boiling Water Reactor Owners Group
BYP	Bypass Region
CCFL	Counter Current Flow Limiting
CST	Condensate Storage Tank
DBA	Design Basis Accident
ECCS	Emergency Core Cooling System
EPU	Extended Power Uprate
GEH	GE-Hitachi Nuclear Energy LLC
GNF	Global Nuclear Fuel LLC
GSI	Generic Safety Issue
GT	Guide Tube
HB	Hot Bundle
HPCI	High Pressure Coolant Injection
HPCS	High Pressure Core Spray
HR	Hot Rod
LEAK	Leakage Pathways
LOCA	Loss of Coolant Accident
LP	Lower Plenum
LPCI	Low Pressure Coolant Injection
LPCS	Low Pressure Coolant Spray
LTP	Lower Tie Plate
LTR	Licensing Topical Report
NEI	Nuclear Energy Institute
NRC	Nuclear Regulatory Commission
NRCB	Nuclear Regulatory Commission Bulletin
OLTP	Original Licensed Thermal Power
ΔP	Pressure Differential
PCT	Peak Cladding Temperature
PWR	Pressurized Water Reactor
PWROG	Pressurized Water Reactor Owners Group
SEO	Side Entry Orifice
SER	Safety Evaluation Report
UP	Upper Plenum
URG	Utility Resolution Guide

UTP	Upper Tie Plate
ZOI	Zone Of Influence

1. <u>Introduction – Background and Objective</u>

1.1. Background

Mr. John A. Grobe, Associate Director for Engineering and Safety Systems Office of Nuclear Reactor Regulation, sent a letter to Mr. Richard Anderson, BWROG Executive Chairman, dated April 10, 2008, entitled "Potential Issues Related to Emergency Core Cooling Systems Strainer Performance At Boiling Water Reactors." The letter requested assistance from the BWROG in addressing these potential issues.

The letter described the work performed between 1992 and 2001, by both the Nuclear Regulatory Commission (NRC) and the industry, to resolve the issues of debris blockage of ECCS Suction Strainers in BWRs. Upon learning of the problem, the NRC issued Generic Safety Issue (GSI) 191 in 1996 to determine if any of the events that occurred in BWRs warranted an evaluation by PWRs. The results of that evaluation did confirm that appropriate corrective actions should be undertaken by the PWRs. This was communicated by the NRC to the industry via Generic Letter 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation during Design Basis Accidents at Pressurized-Water Reactors." Nuclear Energy Institute (NEI) implementing guidance, with certain exceptions, was endorsed via issuance of a Safety Evaluation on December 6, 2004 (NEI 04-07 Volume 2). Issues evaluated by the PWRs led to increased knowledge of the effects of debris on suction strainers and downstream components. The letter explained that chemical effects have been more problematic than expected and a thin bed of debris on a strainer may cause a more limiting head loss than a much thicker bed developed under different conditions. The letter encouraged the BWROG to develop a comprehensive evaluation plan integrated with the efforts of the NRC to address these issues regarding BWR strainer performance

The letter's attachment discusses the subject areas requiring additional evaluation by the BWRs. These areas are:

- Chemical effects,
- In-vessel downstream effects,
- Head loss evaluation,
- Latent debris,
- Zone-of-Influence (ZOI) adjustment for air jet testing,
- ZOI for coatings, and
- Debris characteristics.

This Licensing Topical Report (LTR) will address in-vessel downstream effects.

The BWROG agrees additional analysis is required for downstream effects related to debris intrusion in the reactor vessel because BWRs use channeled fuel assemblies. The channels inhibit crossflow among fuel assemblies in the fuel rod region versus open cores in PWRs. The evaluation of potential downstream effects of debris on BWR fuel is contained in this report.

1.2 Objective

The US NRC requested additional information regarding the technical basis supporting adequate post-LOCA cooling of BWR fuel considering the potential for downstream effects of debris on fuel blockage. Specifically, it is postulated that debris generated during a LOCA in a BWR may pass through the ECCS suction strainers, and affect the performance of the fuel by restricting flow through the fuel bundles.

This is the first of three LTRs, which generically analyzes blockage effects for determination of limiting conditions and critical fuel cooling parameters throughout the LOCA transient to support development of acceptance criteria for testing of GNF fuel designs. Similar reference analyses and criteria will be developed for testing of the two other BWR fuels. This work will be presented in separate LTRs similar to this report for the Areva and Westinghouse fuel designs. This report also presents an outline of the proposed testing plan.

The objective of this report is to obtain NRC concurrence of the analysis technique, results, and proposed test plan.

1.3 References

1.3.1 "Summary of Public Meeting with the Boiling Water Reactor Owners Group (BWROG) to Discuss the Treatment of Generic Safety Issue (GSI)-191 Technical Issues as Applied to Boiling Water Reactor (BWRs)," dated November 27, 2007. ADAMS Accession Number: ML073540021.

1.3.2 Letter from Mr. John A. Grobe, Associate Director for Engineering and Safety Systems Office of Nuclear Reactor Regulation, to Mr. Richard Anderson, BWROG Executive Chairman, "Potential Issues Related to Emergency Core Cooling Systems (ECCS) Strainer Performance At Boiling Water Reactors," dated April 10, 2008. ADAMS Accession Number: ML080500540.

1.3.3 SECY-09-0156, "Status of Applying Lessons Learned from Pressurized Water Reactors to Emergency Core Cooling System Suction Strainer Performance for Boiling Water Reactors," dated October 23, 2009. ADAMS Accession Number: ML092600377.

2. Initial NRC Questions Incorporated in the Analysis

The NRC and the BWR Owners Group have met on a number of occasions to discuss an overall approach to produce a single test plan using different test criteria (e.g., debris source terms, bypass fraction, chemical effect, etc.) for the different BWR fuel types for the purpose of addressing in-vessel downstream effects. During these meetings some important questions regarding the analytical evaluation were raised.

The analysis herein incorporates application of the NRC approved licensing methodology SAFER. It also addresses the question of Long Term Oxidation by demonstrating that there is no significant PCT for the entire transient under blockage conditions including the very long term cooling condition. The analysis incorporates a limiting blockage scenario addressing the question limited cross flow between channeled fuel assemblies in a BWR by assuming that the average channel remains "clean" (i.e. no blockage simulated) which minimizes cooling the blocked hot channel. If necessary, local debris effects will be evaluated by an appropriate thermal calculation based on test results.

3. Analytical Evaluation Summary

The analysis establishes a baseline LOCA scenario for a limiting BWR configuration by analyzing reactor vessel size, penetrations, feedwater systems, main steam line geometries, ECCS, reactor recirculation systems, control rod drive systems, and reactor water cleanup systems for the various BWR product lines. In addition, the different types of LOCAs were analyzed to determine the limiting break size and location with respect to fuel bundle effect on PCT. The BWR product line database is provided in Section 4.

From this starting point, a Reference Scenario is developed to provide detailed long-term LOCA BWR fuel temperature predictions based on limiting blockage conditions for complete or partially restricted hot fuel bundle inlet and outlet paths.

The analysis also examines other blockage conditions to illustrate critical aspects of BWR LOCA event and the in-vessel downstream effects of potential debris. Table 3-1 presents a summary where critical blockage evaluation questions are addressed:

Table 3-1 Locations of Answers to Critical Blockage Evaluation Questions

No.	Question	Section
1	Postulated transport path of debris to fuel	3.3.5 & 4.e
2	Postulated fuel blockage degree history and location	3.4.2 Case 04
3	Analytical basis for LOCA long-term cooling evaluation	3.3.4
4	Fuel cooling consequences of assumed blockage	3.5

No.	Question	Section
5	Boundary conditions on hot fuel subjected to blockage	3.6
6	Testing criteria for fuel blockage locations and periods	5
7	Blockage acceptance criteria	Table 5-1
8	Application of assumed blockage to BWR/2 through 6	4

Parameters critical to fuel cooling that follow the SAFER/GESTR-LOCA analytical results for the Reference Scenario are used to establish test conditions and test acceptance criteria for the following four (4) tests:

i. Bypass lower tie plate leakage flow hole refill,

ii. Lower tie plate filter short-term re-flood,

iii. Lower tie plate filter long-term cooling, and

iv. Top core post re-flood cooling, and spray cooling post top core uncovery.

The analysis supporting the proposed fuel assembly blockage test program description is presented herein.

3.1 SAFER/GESTR LOCA Methodology and Evaluation Model

The analysis is performed with the SAFER/GESTR-LOCA evaluation model with the GEH engineering computing program, SAFER04A. SAFER04A is used to analyze the long-term, thermal-hydraulic behavior of the coolant inventory including the ECCS behavior in the vessel. SAFER04A calculates the uncovery and re-flooding of the core, the Peak Cladding Temperature (PCT), and the local oxidation. For a detailed description of the model refer to References 3.8.1 through 3.8.8.

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3.2 Analysis Procedure

3.2.1 Licensing Criteria

The acceptance criteria for the ECCS-LOCA analyses are based on requirements of the Code of Federal Regulations, 10 CFR 50.46. Characteristics will be defined that will preclude exceeding the 10 CFR 50.46 acceptance criteria.

3.2.2 Base SAFER/GESTR-LOCA Analysis

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3.3 Analysis Inputs and Assumptions

3.3.1 Standard Inputs

The standard input required for SAFER04A includes: specification of the vessel geometry, power peaking factors, initial operating conditions, makeup water system characteristics, external flows, and recirculation system characteristics. For a discussion regarding sources of input to the model, refer to Reference 3.8.3.

3.3.2 Plant Parameters

The initial core thermal power and core flow from a recent BWR 3 SAFER EPU licensing LOCA analysis is used in the evaluation. [[

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3.3.3 General Assumptions

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3.3.4 Selection of Limiting LOCA Plant/Break/ECCS

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3.3.5 Simulation of Debris Blockage

SAFER04A solves the overall loop momentum equations for the flows entering and leaving the lower plenum through the three available paths; i.e., the core and either of the two banks of jet pumps. Once these flows are determined, continuity and energy balances are used to calculate sequentially the flows and masses in the other regions. The pressure drops in the core and bypass regions are used to drive the leakage flows. The flows to the hot fuel assembly are calculated by imposing the core average plenum-to-plenum pressure drop on that assembly.

There are numerous leakage paths in a BWR between the bypass/guide tube region and the core/lower plenum region.

During normal operation, these flows are from the active core to the bypass region and they keep the bypass moderator from boiling. During a postulated LOCA, these leakage paths help to refill the lower plenum and re-flood the core region.

The SAFER04A leakage flow correlations consider all of the leakage paths between the core/lower plenum and bypass/guide tube regions [Figure 3-5 of Reference 3.8.8]. [[

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3.4 Analysis

3.4.1 Limiting Baseline LOCA Scenario

A detailed understanding of the limiting baseline LOCA scenario and relevant thermal-hydraulic processes that govern the core thermal response is necessary to assess the downstream fuel effects of LOCA generated debris. Debris is potentially transported to the reactor by the injection of ECCS. The LOCA blowdown phase starts at the event initiation and ends when the first low-pressure ECCS initiates. The refill/re-flood phase covers the remaining part of the transient subsequent to low pressure ECCS actuation. Specifically, the refill phase commences after LPCS initiation at 38 seconds. Lower plenum refill completion is defined as the lower plenum being full and subcooled. When the lower plenum has filled, core re-flood begins. The re-flood phase is

The detailed discussion of the limiting baseline LOCA scenario (Calculation identifier **24F31** in PCT figure) focuses primarily on the refill/re-flood phase.

The sequence and timing of the key events relevant to debris effects are summarized in Table 3-1.

Fundamentally, vessel inventory sets the boundary conditions for the fuel heatup and the subsequent cooldown of the fuel rods. The PCT and reactor water level response pertaining to the limiting hot bundle is illustrated in Figures 3-1 and 3-2.

Table 3-1 Sequence of Key Events for the Baseline LOCA Scenario

Event	Time (sec)
Recirculation Suction Line Break (2 LPCI, 1 LPCS available)	[[
Jet pump suction uncovers	
Recirculation pump suction begins to uncover	
Lower plenum (LP) flashing starts, First peak PCT	
Level in Guide Tube (GT) and LP regions start to lower	
LP level below recirculation suction line elevation	
LPCI/LPCS low pressure permissive met	
First uncovery of PCT node	
Upper plenum (UP) reaches minimum water level, Bypass region (BYP) water level starts to lower	
LPCS flow begins, Commence Refill Phase	
LPCI flow begins, LP fill rate increases	
LP refilled above recirculation suction, BYP region level restored	
LP level restored to bottom of active fuel (BAF), GT level lowering	
GT reaches minimum, BYP level drops rapidly	
Fluid level collapses in all regions (Condensation due to ECCS)	
Level in LP and GT regions start to rise	
Refill Phase complete, Commence Re-flood Phase	
Second peak PCT, GT level restored, BYP level starts to rise	
Last covering of PCT node, hot bundle Re-flood Phase is complete	
Hot & average bundles refilled, two-phase level at top of active fuel	
BYP region refilled	
Net Flow through hot bundle SEO ceases	
Last restoration of nucleate boiling to hot node	
LPCI off (core spray injection alone remains)	]]

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3.5 Proposed Analytical Test Criteria Basis

3.5.1 Test #1: Lower Plenum Refilling from Fuel Bypass (Re-flood Backflow)

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3.5.2 Test #2: Core Re-flood Rate Test (Re-flood Rate)

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3.5.3 Test #3: Long-Term Lower Tie Plate Blockage Test (Inlet Blockage)

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3.6.4 Test #4: Upper Tie Plate Blockage (Outlet Blockage)

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3.6.5 Summary of Proposed Test Criteria

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3.7 Analysis Conclusions

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3.8 References

3.8.1 NEDE-23785-1-PA Rev. 1, *The GESTR-LOCA and SAFER Models for the Evaluation of the Loss-of-Coolant Accident.* Vol. 1, "GESTR-LOCA – A Model for the Prediction of Fuel Rod Thermal Performance," dated October 1984.

3.8.2 NEDE-23785-1-PA Rev. 1, *The GESTR-LOCA and SAFER Models for the Evaluation of the Loss-of-Coolant Accident.* Vol. 2, "SAFER – Long-term Inventory Model for BWR Loss-of-Coolant Analysis," dated October 1984.

3.8.3 NEDE-23785-1-PA Rev. 1, *The GESTR-LOCA and SAFER Models for the Evaluation of the Loss-of-Coolant Accident.* Vol. 3, "SAFER/GESTR Application Methodology," dated October 1984.

3.8.4 NEDE-20566-P-A, *General Electric Company Analytical Model for Loss-of-Coolant Analysis in Accordance with 10 CFR 50 Appendix K*, Volumes I, II, and III, dated September 1986.

3.8.5 NEDE-20566-4-P, *General Electric Company Model for Loss-of-Coolant Accident Analysis in Accordance with l0 CFR 50 Appendix K Amendment No. 4, Saturated Counter-Current Flow Characteristics of a BWR Upper Tieplate*, July 1978.

3.8.6 NEDE-20566-5-P, *General Electric Company Model for Loss-of-Coolant Accident Analysis in Accordance with l0 CFR 50 Appendix K* Amendment No. 5, "Backflow Leakage from the Bypass Region for ECCS Calculations," dated June 1978.

3.8.7 NEDC-32950P, *Compilation of Improvements to GENE's SAFER ECCS-LOCA Evaluation Model,* January 2000, as reviewed by letter from S. A. Richards (NRC) to J. F. Klapproth (GE), "General Electric Nuclear Energy (GENE) Topical Reports NEDC-32950P and NEDC-32084P Acceptability Review," dated May 24, 2000.

3.8.8 NEDE-30996P-A, "SAFER Model for Evaluation of Loss-of-Coolant Accidents for Jet Pump and Non-Jet Pump Plants, Volumes I and II," dated October 1987.

4. BWR Product Line Distinctions

This section describes the BWR fleet characteristics with respect to vessel size, piping penetrations, ECCS configuration and LOCA long-term cooling requirements. This review establishes that debris from the ECCS strainers may enter the fuel assemblies under one or two phenomena, depending on the LOCA type. These phenomena are either natural circulation when the water level is above the fuel channel or coolant downflow when the water level is below the fuel channel. When debris is postulated to accumulate within the fuel assembly, the two phenomena remain the same, except for the high water level condition with 100% inlet blockage. For this highly unlikely condition, the coolant flow will revert to that of the low water level and become downflow as described in the LOCA analysis Section 3. Therefore, the reference bounding long-term cooling calculation is applicable to the BWR fleet described here.

a. Reactor Vessel Size

The BWR product type and vessel size is given in Table 4-1. The BWR type will generally determine both the piping penetrations and ECCS configurations. The BWR size determines, along with penetration piping size and ECCS capacity, the rate of coolant loss and refill.

b. Reactor Vessel Penetrations

The piping penetrations considered as potential LOCA sources are listed in Items i through vi below, and in Table 4-2. The non-recirculation pipe breaks will always lead to a fully covered core for long-term cooling. The recirculation line breaks for BWR/2 plants will generally lead to an uncovered core for long-term cooling. The recirculation line breaks for BWR/3 through 6 plants will generally lead to short-term core uncovery, followed by fully covered core for several hours. These plants would also uncover the top portion of the core once decay heat decreases and is unable to sustain a two-phase mixture. Therefore, all BWR plants are susceptible to both long-term covered or uncovered core depending on break type.

i. Feedwater (6 nozzles all BWRs except 4 nozzles in one BWR/3)

ii. Main Steam Lines (4 nozzles all BWRs except 2 nozzles BWR/2)

iii. ECCS Systems (Table 4-2)

iv. Reactor Recirculation System (Table 4-2)

v. Reactor Water Cleanup System (All BWRs, suction from vessel drain and recirculation piping, discharge to recirculation or feedwater piping)

vi. Isolation Condenser (BWR/2 and Dresden, suction from steam piping, discharge to feedwater piping)

c. ECCS Availability and Performance

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d. LOCA Response By Product Line

The LOCA response will vary widely depending on BWR type and specific break size, location and available ECCS. [[

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e. Debris transport and deposition for steamline and recirculation breaks

The debris transport and deposition during ECCS injection following a postulated LOCA will generally occur from low inlet velocity flow when water level is above the fuel channel top. [[

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Table 4-1 BWR Type and Vessel Size

BWR Type	Name	Vessel Size inches	BWR Type	Name	Vessel Size inches
2	Nine Mile Point 1	213	4	Browns Ferry 1 2 and 3	251
2	Oyster Creek	213	4	Vermont Yankee	205
3	Dresden 2 and 3	251	4	Peach Bottom 2 and 3	251
3	Monticello	205	4	FitzPatrick	218
3	Quad Cities 1 and 2	251	4	Cooper	218
3	Pilgrim	224	4	Hatch 1 and 2	218
5	LaSalle 1 and 2	251	4	Brunswick 1 and 2	218
5	Columbia	251	4	Duane Arnold	183
5	Nine Mile Point 2	251	4	Fermi 2	251
6	Grand Gulf	251	4	Limerick 1 and 2	251
6	Perry	238	4	Hope Creek	251
6	River Bend	218	4	Susquehanna 1 and 2	251
6	Clinton	218			

Table 4-2 BWR Vessel Penetrations

BWR Type	Name	ECCS			Recirculation	
		Core Spray	LP Core Injection	HP CI or CS	Suction	Discharge
2	Nine Mile Point 1	2	-	-	5	5
2	Oyster Creek	2	-	-	5	5
3	Dresden 2 and 3	2	a[1]	-	2	10
3	Monticello	2	a	b[2]	2	10
3	Quad Cities 1 and 2	2	a	b	2	10
3	Pilgrim	2	a	b	2	10
4	Browns Ferry 1 2 and 3	2	a	b	2	10
4	Vermont Yankee	2	a	b	2	10
4	Peach Bottom 2 and 3	2	a	b	2	10
4	FitzPatrick	2	a	b	2	10
4	Cooper	2	a	b	2	10
4	Hatch 1 and 2	2	a	b	2	10
4	Brunswick 1 and 2	2	a	b	2	10
4	Duane Arnold	2	a	b	2	8
4	Fermi 2	2	a	1 CI	2	10
4	Limerick 1 and 2	2	4	1 CI	2	10
4	Hope Creek	2	4	1 CI	2	10
4	Susquehanna 1 and 2	2	a	1 CI	2	10
5	LaSalle 1 and 2	1	3	1 CS	2	10
5	Columbia	1	3	1 CS	2	10

BWR Type	Name	ECCS			Recirculation	
		Core Spray	LP Core Injection	HP CI or CS	Suction	Discharge
5	Nine Mile Point 2	1	3	1 CS	2	10
6	Grand Gulf	1	3	1 CS	2	12
6	Perry	1	3	1 CS	2	10
6	River Bend	1	3	1 CS	2	10
6	Clinton	1	3	1 CS	2	10

NOTES:

1 a = Injected in recirculation pipe,

2 b = Injected in feedwater pipe.

Table 4-3 Minimum ECCS Available for Break Type

BWR Type	Name	Recirculation		Main Steam	Feed Water	Core Spray	LP CI	HP CI or CS
		Suction	Discharge					
2	Nine Mile Point 1	2CS	2CS	2CS	2CS	1CS	-	-
2	Oyster Creek	2CS	2CS	2CS	2CS	1CS	-	-
3	Dresden 2 & 3	2CS	2CS	2CS	2CS	2LPCI	-	-
3	Monticello	2CS	2CS	2CS	2CS	2LPCI	-	-
3	Quad Cities 1 & 2	2CS	2CS	2CS	2CS	2LPCI	-	-
3	Pilgrim	2CS	2CS	2CS	2CS	2LPCI	-	-
4	Browns Ferry 1 2 & 3	2CS 2LPCI	2CS	1CS 2LPCI	1CS 2LPCI	2LPCI	-	-
4	Vermont Yankee	2CS	2CS	2CS	2CS	2LPCI	-	-
4	Peach Bottom 2 & 3	2CS 2LPCI	2CS	1CS 2LPCI	1CS 2LPCI	2LPCI	-	-
4	FitzPatrick	2CS 2LPCI	2CS	1CS 2LPCI	1CS 2LPCI	2LPCI	-	-
4	Cooper	2CS 2LPCI	2CS	1CS 2LPCI	1CS 2LPCI	2LPCI	-	-
4	Hatch 1 &2	2CS 2LPCI	2CS	1CS 2LPCI	1CS 2LPCI	2LPCI	-	-
4	Brunswick 1 & 2	2CS 2LPCI	2CS	1CS 2LPCI	1CS 2LPCI	2LPCI	-	-
4	Duane Arnold	2CS 2LPCI	2CS	1CS 2LPCI	1CS 2LPCI	2LPCI	-	-
4	Fermi 2	2CS 2LPCI	2CS	1CS 2LPCI	1CS 2LPCI	2LPCI	-	-

BWR Type	Name	Recirculation		Main Steam	Feed Water	Core Spray	LP CI	HP CI or CS
		Suction	Discharge					
4	Limerick 1 & 2	2CS 3LPCI	2CS 3LPCI	1CS 3LPCI	1CS 3LPCI	3LPCI	1CS 3LPCI	1CS 3LPCI
4	Hope Creek	2CS 3LPCI	2CS 3LPCI	1CS 3LPCI	1CS 3LPCI	3LPCI	1CS 3LPCI	1CS 3LPCI
4	Susquehanna 1 & 2	2CS 2LPCI	2CS	1CS 2LPCI	1CS 2LPCI	2LPCI	-	-
5	LaSalle 1 & 2	1CS 2LPCI	1CS 2LPCI	1CS 2LPCI	1CS 2LPCI	2LPCI	1CS 1LPCI	1CS 1LPCI
5	Columbia	1CS 2LPCI	1CS 2LPCI	1CS 2LPCI	1CS 2LPCI	2LPCI	1CS 1LPCI	1CS 1LPCI
5	Nine Mile Point 2	1CS 2LPCI	1CS 2LPCI	1CS 2LPCI	1CS 2LPCI	2LPCI	1CS 1LPCI	1CS 1LPCI
6	Grand Gulf	1CS 2LPCI	1CS 2LPCI	1CS 2LPCI	1CS 2LPCI	2LPCI	1CS 1LPCI	1CS 1LPCI
6	Perry	1CS 2LPCI	1CS 2LPCI	1CS 2LPCI	1CS 2LPCI	2LPCI	1CS 1LPCI	1CS 1LPCI
6	River Bend	1CS 2LPCI	1CS 2LPCI	1CS 2LPCI	1CS 2LPCI	2LPCI	1CS 1LPCI	1CS 1LPCI
6	Clinton	1CS 2LPCI	1CS 2LPCI	1CS 2LPCI	1CS 2LPCI	2LPCI	1CS 1LPCI	1CS 1LPCI

5. BWR Fuel Bundle Test and Validation Information

This section documents the basis for application of the reference bounding LOCA scenario to specific fuel designs and fuel blockage test criteria.

a. Limiting Reference Scenario LOCA Test Requirements

Section 3 documents the reference bounding LOCA blockage case that forms the basis for the test criteria. The validation of the analysis is accomplished by simulating the four key phenomena that may be affected by the presence of debris in the coolant. These four phenomena, in order of progression during the postulated LOCA, are listed below in Table 5-1 with their applicable boundary conditions and acceptance criteria. [[

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b. Critical Fuel Aspects of Limiting Scenario

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c. GNF/GEH Fuel Selection Basis

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1. Evaluation of Full Blockage Bounding Condition

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2. Evaluation of Limited Blockage Condition

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3. Proposed Confirmatory Fuel Bundle Testing

The overview of the proposed tests is documented in Appendix A. The four key short-term and long-term LOCA phenomena potentially affected by ECCS strainer debris will be directly tested so that the interaction of the debris and flow through the fuel bundle is determined. The specific criteria originated with the reference bounding LOCA analysis, with expanded parameter ranges that conservatively address small plant unique differences, such as inlet flows and water level responses.

4. Planned Testing Schedules

The GNF fuel testing will be performed following receipt of the SER for this report. The subsequent test results will be submitted in a supplement to this report. Analysis results and testing criteria for Areva and Westinghouse fuel will be submitted following GNF. Testing of Areva and Westinghouse fuel will follow completion of satisfactory confirmatory testing of GNF fuel.

5. Subsequent Submittals

a. Addendum to this LTR: GNF Limiting Fuel Bundle Design Test Results

b. Areva LTR with vendor specific LOCA analysis, followed by an addendum with Areva Limiting Fuel Bundle Design Test Results, and

c. Westinghouse LTR with vendor specific LOCA analysis, by an addendum with Westinghouse Limiting Fuel Bundle Design Test Results, maybe separate LTR aligned.

6. Conclusion

This LTR presents a reference bounding LOCA evaluation that assures an insignificant effect on calculated PCT for a conservative fuel blockage assumption. The approach taken in this evaluation is twofold, first the blockage must not affect the limiting licensing LOCA evaluation that the limiting fuel temperatures are not exceeded with sufficient margin, and second the blockage criteria are set sufficiently conservative such that the tests can readily confirm criteria. The potentially debris affected flow conditions through the fuel were examined and blockage simulated to assess the adequacy of the cooling mechanisms should some flow be reduced due to debris deposition in the fuel assembly components. The results of both the LOCA analysis and test criteria should fully demonstrate that the BWR plant and fuel design are exceedingly amenable to cooling even with significant flow area blockage.

Appendix A – BWROG Fuels Testing Program Summary

The US NRC has requested additional information regarding the technical basis supporting adequate post-LOCA cooling of BWR fuel considering the potential for downstream effects of debris on fuel blockage (see, for example, References 1 through 4). Specifically, it is postulated that debris generated during a loss of coolant accident (LOCA) in a BWR may pass through the emergency core cooling system (ECCS) suction strainers and affect the performance of the fuel by restricting flow through the fuel bundles. Debris passing through the ECCS suction strainers can persist throughout the accident scenario from the initial "chugging" phase (unsteady oscillation of the vapor-water interface in the downcomers to the suppression pool) through long-term core cooling. However, it is expected that, for plants with debris bed formation across all available suction strainer screen area, the downstream debris load will diminish with time due to suction strainer debris bed filtering. The BWROG ECCS Suction Strainer Source Term Subcommittee will define: 1) the debris characteristics, 2) the debris concentration history, and 3) the total quantity of bypassed debris to be used in the tests described in this section. Appropriate surrogates will be selected to model the debris types observed in-plant that could be drawn into the suction strainers during a LOCA event including fibrous, particulate, microporous, dust, dirt, latent debris, etc. Although chemical compounds and their characteristics are uncertain at this time, appropriate surrogates will be tested if necessary. In all cases, conservative and bounding concentrations of the surrogates will be tested to ensure applicability to the full BWR fleet.

The debris material that passes through the ECCS suction strainers and eventually reaches the fuel bundles can arrive from different flow paths depending on the stage of the accident progression. The proposed test program considers the LOCA event progression, available debris, debris types, coolant flow paths in the core and debris transport into the fuel. A fuel vendor-independent scenario has been defined that follows the progression of a BWR LOCA event. This common scenario considers the effect of debris-induced fuel blockage during the lower plenum refill, core re-flood and long-term cooling phases of the LOCA event. Each fuel vendor will determine a Peak Clad Temperature (PCT) without blockage for that defined common LOCA scenario. Each vendor will also analytically establish blockage acceptance criteria such that it can be demonstrated that the base PCT is not affected. The objective of testing is to show that the actual flow restrictions resulting from debris introduced from the suppression pool and entrained in the safety injection flow are bounded by the analytical acceptance criteria.

In advance of the development of the subject test scope, GE-Hitachi conducted LOCA blockage analyses to identify the limiting plant design and limiting break scenario from the fuel blockage perspective as described in Section 3.4.1. From this analysis the BWR 3 configuration with an associated double-ended guillotine break in a recirculation loop was identified as the limiting scenario for fuels testing. The available ECCS equipment for a limiting BWR 3/4 event includes one train of core spray and one train of low-pressure coolant injection. However, consideration is also given in the preparation of the proposed test program to LOCA response sequences and systems for the BWR 2, 4 and 5/6 geometries to achieve the most conservative test results.

Summarizing the event progression following a LOCA event, the low-pressure coolant injection (LPCI) is directed downstream of the recirculation pump discharge valves. From there, the LPCI flow fills the discharge line and flows through the jet pump nozzles, into the jet pump throat and then into the lower plenum. The core spray is discharged into the upper plenum via the core spray spargers located just above the top of the core and flows into the top of the fuel bundles and into the bypass region surrounding each fuel channel. The core spray water that flows into the bypass region first accumulates in the control rod guide tubes. Once the guide tubes are filled, the water flows into the lower plenum via holes in the transition piece at the bottom of each fuel bundle (i.e., the lower tie plate bypass flow holes) and several other leakage flow paths. The core refills until the collapsed water level in the core corresponds to the head of water in the jet pumps. Further ECCS injection makes up for boil-off in the core or spills into the downcomer via the jet pumps. From there, the water flows back through the jet pump nozzles and into the broken recirculation pump suction line and out the break. For BWR 5/6 plants, LPCI is injected into the vessel through the shroud.

The test program outline described below considers this basic event progression in defining a series of laboratory tests using representative test assemblies for each US BWR fuel vendor. The results will be used to evaluate the effect of the debris-laden water on the flow performance of each vendor's fuel bundle, LOCA event results, or other licensing parameters. All proposed tests will be conducted at room temperature and atmospheric pressure. While these tests are not designed to replicate the prototypical LOCA transient (at prototype thermodynamic conditions), the proposed tests are meant to conservatively bound the effect of LOCA-generated debris on fuel blockage.

The test bundles to be used in the tests will be full height and representative of commercial designs that implement production components with the exception of fuel rods (individual rods will not contain UO_2 pellets). The core bypass region associated with one bundle will be simulated. With the exception of Test 4, the bundle configuration will be representative of production bundles – for conservatism in Test 4, the channel will be raised off the lower tie plate to ensure that only upper tie plate and upper spacer blockage is evaluated. A fuel support piece and simulated core support plate will be provided to interface with the bundle.

The acceptance criteria for the tests will be based on the 10 CFR 50.46(b) cladding criteria as evaluated by each fuel supplier using their licensed methods in modeling the limiting LOCA event with fuel component blockage explicitly modeled using a conservative blockage function (i.e., blockage extent as a function of time). If the blockage function based on the BWR test program results is more limiting than that used in the LOCA event analysis, suggesting a significant adverse cladding response, the fuel supplier may demonstrate compliance of the cladding temperature response by performing LOCA analyses implementing the following changes:

- Implement the test-derived blockage function in the bounding reference LOCA analysis,
- Reduce conservatisms on input parameters applicable to the specific plant, and/or
- Perform a complete plant-specific limiting LOCA analysis.

In the event that cladding criteria are still not met with these re-analyses, plant physical changes can be considered to reduce the source term available to the fuel including: a) cleaning the drywell, b) changing containment insulation types, and/or c) changing the ECCS suction strainer type/design.

Test 1: Lower Plenum Refilling from Fuel Bypass

Purpose:

The purpose of this test is to confirm that the time for reactor vessel lower plenum refilling is acceptable given potential debris entrapment in bypass flow pathways.

Basis:

During early refilling of the lower plenum (LP) of a BWR from the core spray flow through the fuel bypass channels, following a LOCA, it has been postulated that some degree of blockage of the flow paths between the bypass channel and the lower plenum (bypass holes and other clearances) may occur. Flow from the bypass region between the fuel bundles to the LP would be reduced if the two approximately ¼-inch diameter bypass flow holes in the lower tie plate and/or other small clearance gaps became partially or totally blocked by debris passing through the ECCS pump suppression pool suction strainers. A reduction in bypass channel flow might reduce the filling rate of the LP and thus potentially delay the time for core re-flood.

Key Test Bundle Features (Figure A-1):

1) Height of Fuel Bundle: An indicator of the potential blockage is the time-varying water column height in the fuel bypass region during the time flow is injected from the top of the bundle with debris, compared to the case with no debris. Because the water level height with blockage is unknown, the full height of the bundle will be included in the test.
2) Components of Fuel Bundle: Because this and subsequent testing requires the use of an actual (full height) fuel bundle, one-quarter of the bypass region associated with the typical core cell containing four fuel bundles and the associated bypass flow paths will be simulated. The top of the bundle will have a flow diverter to ensure that the water/debris mixture flows into the bypass region and that none enters the bundle. This top flow diverter will not be airtight so that air pressure will not build up in the bundle. Thus, the actual bundle geometry, bypass flow paths and lower tie plate with its specific features (e.g., debris filter, bypass flow holes and other clearances) will be used (see Figure A-2). The bundle will sit on a mock-up of the core support plate and associated fuel support piece to simulate all of the prototypic leakage paths between the bypass and lower plenum. The top guide will be simulated because this represents the minimum flow area for core spray to enter the bypass region. Control blade geometry will be simulated to

account for the reduced area of the flow path due to the presence of the blade geometry. Surrounding the test fuel bundle will be a watertight chamber providing one-half the clearances to the adjacent fuel bundles (note that the adjacent fuel bundles are not included in the test setup). All sides of this chamber will be transparent to facilitate viewing of the bypass region flow and possible blockage.

3) Interface with Lower Plenum: The reactor vessel lower plenum geometry will not be included, being unnecessary for the proposed scope of the test and because room needs to be provided for the measurement of the bypass flow versus time using a water/debris receiving tank and electronic scale (digital balance).

Test Loop Components: (Figure A-1 and A-2)

1) Flow Control: Flow will be withdrawn from a water supply/debris mixing tank by gravity (or a pump, if required) and measured versus time. Piping size and length shall be selected to minimize any settling of debris in the inflow system. The volume of water in the water supply/debris mixing tank shall be the total volume to be introduced during one test.

2) Debris: The total mass of debris to be used in each test shall be mixed in the same water supply tank described above. Mixing shall be by a mechanical device so that no additional flow is introduced into the tank and no debris is lost from the tank.

3) Setting: To make room for the mass per time flow measurement (water/debris receiving tank and digital balance) below the test module, the test rig shall be raised sufficiently off the test lab floor.

4) A computer data acquisition system will be used to control the test loop and collect data.

Test Operating Conditions:

1) Flow and Debris Injection: The top of the fuel channel will be covered and water with fully mixed debris (characteristics to be provided by BWROG ECCS Suction Strainer Source Term Subcommittee) will only be introduced into the bypass region between the fuel channels from the water supply/mixing tank located above the test rig (Figure A-1). The rate of water and total debris mass flux (concentration) shall be controlled by the use of a computer actuated valve to simulate a conservative ECCS flow rate prorated by total bypass area to total area of the entire core and prorated on a per bundle basis for five (5) minutes (approximate LP fill time). The flow and debris will not be recirculated; this is a once-through test.

2) Debris Constituents: The debris constituents and the total mass per constituent to be used during the duration of LP filling, averaged on a per bundle basis, will be provided by the BWROG ECCS Suction Strainer Source Term Subcommittee. If required, debris components may be added in stages to more closely simulate the time history of material passing through the ECCS suction strainers in the suppression pool.

Parameters to be Measured:

1) Water Level in Bypass Region: This water level should be measured in at least two locations versus time with instrumentation that includes high frequency response sensors.
2) Flow measurement for the injected flow may be by the volumetric method (drop in average water level in the mixing tank versus time) or an equivalent method (orifice plate or similar) that is accurate for the debris/water mix.
3) Flow Rate from Bypass Region into the Lower Plenum: Flow and debris draining from the bypass holes and other openings should be collected and weighed versus time (or using some equivalent system to determine the mass flow versus time). An energy distribution grid should be used to dissipate the energy from the falling water to minimize oscillations in the weight measurement.
4) Total Mass of Debris: For each constituent of the debris mix, the total debris mass to be introduced during each test is to be measured (weighed). The total quantity of each constituent to be tested will be provided by the BWROG ECCS Suction Strainer Source Term Subcommittee.
5) Total Mass of Debris Bypassed: Water that drains from the bypass openings into the mass per time measuring system is to be collected, strained and dried at the end of each test to obtain the total mass of debris bypassed versus that introduced. The difference indicates the mass of debris held up in the bypass region.
6) Photographs will be taken when practical to document each test.

Repeatability:

1) Water Level versus Time: Five tests should be conducted with clean water to characterize the repeatability of making flow and water level measurements. Five tests are deemed sufficient based on experience; however, statistical relevance of the collected data should be analyzed to determine if a larger number of tests are required.
2) Water Level versus Time: Three tests should be conducted with each given debris mix to determine potential debris effects on LP filling.
3) Debris Mix: Each constituent of the debris mix shall be weighed and introduced into the mixing tank in the desired time history.
4) Cleaning: After each debris test, the mixing tank, flow system including the water/debris receiving tank and bundle bypass region is to be cleaned using appropriate methods (including disassembly of bundle components, if needed, and thorough power washing, as necessary) and new "clean" test data (tests conducted with a clean test flow loop, clean bundle, and water only) should subsequently be obtained. Without the variability of debris effects, experience indicates that water level measurements can have an uncertainty of 2 to 3% based on the various instruments involved. To find a true difference between clean tests among this uncertainty suggests that deviations from prior

average clean test should not vary by more than 5%. Greater differences would indicate the need for re-cleaning and a repeat of the clean tests.

The debris test matrix associated with the Test 1 scope of work is to be determined based on input from the BWROG ECCS Suction Strainer Source Term Subcommittee and the expected quantity of material passing through the ECCS suction strainers in the suppression pool.

Acceptance Criteria

The acceptance criteria for this test will be based on the results of the limiting base LOCA event and fuel bundle blockage analyses performed by each fuel supplier (Section 3.4 summarizes the GEH analyses, Section 3.6 provides proposed test criteria). It is expected that the basis for the criteria will be the differential rate of drainage from the bypass region for clean water versus debris-laden water. A differential in bypass drainage rate can, through analysis, affect the calculated PCT. The acceptable variation is based on the vendor specific analytical relationship between the bypass drainage rate differential and the peak cladding temperature increase allowance.

Test 2: Core Re-flood Rate Test

Purpose:

The purpose of Test 2 is to confirm that the time for bundle re-flood is acceptable given the potential for debris entrapment in the lower tie plate and bypass region flow paths.

Basis:

During early refilling of the lower plenum and fuel bundles of a BWR following a LOCA, it has been postulated that some degree of blockage of the lower tie plate debris filter and lower spacers may occur. Blockage of this filter and spacers might impede the flow of water from the lower plenum into the fuel bundles and could consequently affect the calculated PCT margin by delaying the re-flood time. The results of Test 2 will identify the difference (if any) in core re-flood time using clean water in comparison to debris-laden water. While the total time to recover the core to a two-phase cooling condition after filling the lower plenum can vary from a few seconds to approximately 2 minutes, the test will apply a wide range of flow rates to conservatively assess the effect of debris using flow rates representative of the analysis.

Key Test Bundle Features (Figure A-3):

1) Height of Fuel Bundle: An indicator of the potential blockage at the lower tie plate and associated effect on core re-flood is the rate of change of the water column height in the fuel bundle with debris, compared to the case with no debris. Using the same general test rig developed for Test 1, the full height of the bundle shall be included, although the test will be terminated when the water level in the bundle, at a minimum, reaches an elevation equal to two-thirds of the total height of the fuel bundle.

2) Components of Fuel Bundle: Testing requires the use of an actual (full height) fuel bundle and one-quarter of the bypass region associated with the typical core cell containing four fuel bundles and the associated bypass flow paths will be simulated. This includes the actual bundle geometry, bypass flow paths and the lower tie plate with the debris filter. As in Test 1, the bundle shall sit on a fuel support piece and a mock-up of the core support plate and a sealed lower plenum tank. Surrounding the test fuel bundle will be a watertight chamber providing one-half the clearances to the adjacent fuel bundles (note that the adjacent fuel bundles are not included in the test setup). All sides of this chamber will be transparent to facilitate viewing of the bypass region flow and possible blockage.

3) Interface with Lower Plenum: Components other than the simulated core support plate, the fuel support piece and bypass region gaps associated with the core support plate will not be simulated. However, a sealed lower plenum tank will be used with a total plan view area equivalent to the prorated per bundle net area to give the correct rate of water rise. Inflow will be upward from the bottom to help maintain the debris in suspension.

4) Interface Above Fuel Bundle: An inlet hopper will be fitted above the upper tie plate to provide an inflow path for water to the bypass region. The fuel bundle channel will be

extended up past the inlet hopper to ensure that no bypass flow introduced into the top of the test rig enters the fuel bundle and that the bundle is open to atmospheric pressure.

Test Loop Components: (Figure A-3)

1) Flow Control: Flow will be pumped from the water supply/debris-mixing tank into a pipe, which supplies water to both the upper and lower test rig inflow regions. Flow rate will be measured in each supply line with an orifice flow meter (or equivalent) and controlled by a computer-actuated valve. Piping size and length shall be selected to minimize any settling of debris in the supply system. The volume of water in the tank shall be total volume to be introduced during one test.

2) Debris: The total mass of debris to be used in each test shall be mixed in the same water source tank described above. Mixing shall be by a mechanical device so that no additional flow is introduced into the tank and no debris is lost from the tank. The total debris mass and water tank volume should provide the proper debris concentration.

3) Test rig shall be instrumented with pressure gages to measure water level rise as a function of time in the lower plenum, the bypass region (four points) and the fuel bundle. A differential pressure measurement with respect to time shall also be made across the lower tie plate.

4) A computer data acquisition system will be used to control the test loop and collect the required data.

5) A flow distributor will be used in the lower plenum tank to ensure uniform, upward flow across the lower plenum cross section.

Test Operating Conditions:

1) Flow and Debris Injection: Flow will be introduced into the test rig from two locations: the hopper at the top of the rig which supplies water to the bypass region and the lower plenum tank which simulates water entering the fuel bundle from below the lower tie plate. At the top of the test rig, the exit of the fuel channel will be isolated from the bypass flow as described previously and water with fully mixed debris (characteristics to be provided by the BWROG ECCS Suction Strainer Source Term Subcommittee) will be introduced into the bypass region from a mixing tank using a pump. The rate of water and total debris mass flux (concentration) shall be controlled by the use of a computer-actuated valve to simulate the target total bypass flow (to be determined from the fuel supplier-specific limiting base LOCA event and fuel bundle blockage sensitivity analyses). At the bottom of the test rig, water with fully mixed debris at the proper concentration will be introduced into the lower plenum from the mixing tank. The rate of water and total debris mass flux (concentration) shall be controlled by the use of a computer-actuated valve to simulate the target total plenum flow (to be specified from the fuel supplier-specific limiting base LOCA event and fuel bundle blockage sensitivity analyses).

2) The flow and debris will not be recirculated; this is intended to be a short (less than 2 minutes), once-through test. It is expected that the filling rate of the lower plenum tank will preclude settlement of debris in the lower plenum tank.

3) Debris Constituents: The debris constituents, their concentration in the injection flow, and the total mass per constituent to be used during the duration of core re-flood will be provided by the BWROG ECCS Suction Strainer Source Term Subcommittee. If required, debris components may be added in stages to more closely simulate the time history of material passing through the ECCS suction strainers in the suppression pool.

Parameters to be Measured:

1) Debris Mix: Each constituent of the debris mix shall be weighed and introduced to the mixing tank.

2) Water Level in Bypass Region: This water level should be measured versus time with instrumentation that includes high frequency response sensors.

3) Water Level in Fuel Bundle: This water level should be measured within the bundle versus time with instrumentation that includes high frequency response sensors.

4) Water Level in Lower Plenum: This water level should be measured at two locations versus time with instrumentation that includes high frequency response sensors.

5) Debris filter (integral with the lower tie plate) and lower spacer(s) differential pressure change as a function of time: This differential pressure measurement shall be made with an appropriately ranged differential pressure cell connected upstream and downstream of the lower tie plate.

6) Flow measurement for the injected flows shall be by the differential pressure method or an equivalent method that is accurate for the debris/water mix.

7) Bypass Region Flow Rate: Flow injected into the bypass region should be specified from the fuel supplier-specific limiting base LOCA event and fuel bundle blockage sensitivity analyses.

8) Flow Rate into Lower Plenum: Flow into the lower plenum should be specified from the fuel supplier-specific limiting base LOCA event and fuel bundle blockage sensitivity analyses.

9) Photographs will be taken when practical to document each test.

The expected duration of Test 2 is short (less than 2 minutes) based on fuel supplier-specific limiting base LOCA event and fuel bundle blockage sensitivity analyses.

Repeatability:

1) Water Level versus Time: Five tests should be conducted with clean water to characterize the repeatability of making flow and water level measurements and to set a baseline for the subsequent tests. Five tests are deemed sufficient based on experience; however, statistical relevance of the collected data should be analyzed to determine if a larger number of tests are required.

2) Water Level versus Time: Three tests should be conducted with each given debris mix to determine potential debris effects on core re-flood.

3) Cleaning: After each debris test, the mixing tank, the lower plenum tank, flow system and bundle bypass region is to be cleaned using appropriate methods (including disassembly of bundle components, if needed, and thorough power washing, as necessary) and new "clean" test data (tests conducted with a clean test flow loop, clean bundle, and water only) should subsequently be obtained. Without the variability of debris affects, experience indicates that averaged pressure loss coefficients can have an uncertainty of 2 to 3% based on the various instruments involved. To find a true difference between clean tests among this uncertainty suggests that deviations from prior average clean test loss coefficients should not vary by more than 5%. Greater differences would indicate the need for re-cleaning and a repeat of the clean tests. The test matrix, specific debris characteristics and concentration associated with the Test 2 scope of work is to be determined based on input from the BWROG ECCS Suction Strainer Source Term Subcommittee and the expected quantity of material passing through the ECCS suction strainers in the suppression pool.

Acceptance Criteria

The acceptance criteria for this test will be based on the results and requirements of the fuel supplier-specific limiting base LOCA event and fuel bundle blockage sensitivity analyses (Section 3.4 summarizes the GEH analyses, Section 3.6 provides proposed test criteria). It is expected that the basis for the criteria will be the differential rate of fuel bundle flood up for clean water versus debris-laden water. A differential in the fuel bundle re-flood rate can, through analysis, affect the calculated PCT. The acceptable variation is based on the vendor specific analytical relationship between the fuel bundle re-flood rate differential and the peak cladding temperature increase allowance.

Test 3: Lower Tie Plate Blockage Test

Purpose:

The purpose of Test 3 is to establish the experimental blockage function for the fuel bundle lower tie plate and lower spacers when exposed to debris.

Basis:

During long-term core cooling of a BWR following a LOCA, it has been postulated that some degree of blockage of the lower tie plate debris filter and lower spacers may occur. Blockage of this filter and spacers may impede the flow of water from the lower plenum into the fuel bundle and could affect the available make-up coolant to balance the core-steaming rate. The results of Test 3 will identify the time rate-of-change of head loss across the debris filter and lower spacers using clean water and debris-laden water. This is a recirculation flow loop test with termination to be defined by the limiting debris filter/lower spacer blockage requirements as determined from the fuel supplier-specific limiting base LOCA event and fuel bundle blockage sensitivity analyses.

Key Test Bundle Features (Figure A-4):

1) Height of Fuel Bundle: An indicator of the extent of blockage as a function of time of the lower tie plate and lower spacers is the differential pressure across these components measured with debris, compared to the case with no debris. Using the same general test rig developed for Tests 1 and 2, the full height of the bundle shall be included.
2) Components of Fuel Bundle: Testing requires the use of an actual fuel bundle as configured in Tests 1 and 2. This includes the actual bundle geometry and lower tie plate debris filter. The bundle shall sit on a fuel support piece and a mock-up of the core support plate. This test does not require flow in the bypass region and thus the bypass flow paths shall be blocked from the top with an airtight seal.
3) Interface with Lower Plenum: Test 3 will utilize the same sealed lower plenum tank used in Test 2.
4) Interface Above Fuel Bundle: The bundle channel extension used in Test 2 will be connected to the return flow line and pass flow back to the water supply/mixing tank.

Test Loop Components: (Figure A-4)

1) Flow Control: Flow will be pumped from a debris-mixing tank into a pipe, which supplies water to the lower plenum. Flow rate will be measured in the supply line with an orifice flow meter (or equivalent) and controlled by a computer-actuated valve. Piping size and length shall be selected to minimize any settling of debris in the inflow system. The volume of water in the tank shall be selected based on target debris concentrations as per BWROG ECCS Suction Strainer Source Term Subcommittee specifications. It is expected that the upward flow in the lower plenum tank will preclude settlement of debris; however, mechanical mixers may be required in the lower plenum tank to keep debris suspended.

2) Debris: The total mass of debris to be used in each test shall be mixed in the same water source tank described above. Mixing shall be by a mechanical device so that no additional flow is introduced into the tank and no debris is lost from the tank.

3) The test rig shall be instrumented with the same pressure gages installed in Test 2 to measure the differential pressure across the lower tie plate/debris filter assembly and lower spacers.

4) A computer data acquisition system will be used to control the test loop and collect the required data.

5) A flow distributor will be used in the lower plenum tank to ensure uniform, upward flow across the lower plenum cross section.

Test Operating Conditions:

1) Flow and Debris Injection: Water with fully mixed debris will be introduced into the lower plenum from the mixing tank. The rate of water and total debris mass flux (concentration) shall be controlled by the use of a computer-actuated valve to simulate the target total plenum flow specified from the fuel supplier-specific limiting base LOCA event and fuel bundle blockage sensitivity analyses.

2) The flow and debris will be re-circulated. Test 3 is intended to be a closed loop test with test termination criteria to be determined based on the fuel supplier-specific limiting base LOCA event and fuel bundle blockage sensitivity analyses.

3) Debris Constituents: The debris constituents, their concentration, and the total mass per constituent to be used during the duration of core re-flood will be provided by the BWROG ECCS Suction Strainer Source Term Subcommittee. If required, debris components may be added in stages to more closely simulate the time history of material passing through the ECCS suction strainers in the suppression pool.

Parameters to be Measured:

1) Debris Mix: Each constituent of the debris mix shall be weighed and introduced into the mixing tank to achieve proper concentration.

2) Change in differential pressure across the debris filter (integral with the lower tie plate) and lower spacers as a function of time: These differential pressure measurements shall be made with an appropriately ranged differential pressure cell connected upstream and downstream of the lower tie plate and spacers.

3) Flow measurement for the plenum inflow shall be by the differential pressure method (orifice plate) or an equivalent method that is accurate for the debris/water mix. Total flow for this test will be specified from the fuel supplier-specific limiting base LOCA event and fuel bundle blockage sensitivity analyses.

4) Photographs will be taken when practical to document each test.

Repeatability:

1) ΔP versus Time: Five tests should be conducted with clean water to characterize the repeatability of making flow and water level measurements and to set a baseline for the subsequent tests. Five tests are deemed sufficient based on experience; however, statistical relevance of the collected data should be analyzed to determine if a larger number of tests are required.

2) ΔP versus time: Three tests should be conducted with each given debris mix to determine potential debris effects on core re-flood.

3) Cleaning: After each debris test, the mixing tank, lower plenum tank, flow system and bundle bypass region is to be cleaned using appropriate methods (including disassembly of bundle components, if needed, and thorough power washing, as necessary) and new "clean" test data (tests conducted with a clean test flow loop, clean bundle, and water only) should subsequently be obtained. Without the variability of debris affects, experience indicates that averaged pressure loss coefficients can have an uncertainty of 2 to 3% based on the various instruments involved. To find a true difference between clean tests among this uncertainty suggests that deviations from prior average clean test loss coefficients should not vary by more than 5%. Greater differences would indicate the need for re-cleaning and a repeat of the clean tests. The test matrix, debris characteristics and concentrations associated with the Test 3 scope of work is to be determined based on input from the BWROG Source Term Subcommittee and the expected quantity of material passing through the ECCS suction strainers in the suppression pool.

Acceptance Criteria

The acceptance criteria for this test will be based on the results and requirements of the fuel supplier-specific limiting base LOCA event and fuel bundle blockage sensitivity analyses (Section 3.4 summarizes the GEH analyses, Section 3.6 provides proposed test criteria). It is expected that the basis for the criteria will be the pressure differential and its effect on the calculated makeup water required based on core steaming. The relationship between pressure differential and the peak cladding temperature increase can be developed although it may be fuel supplier specific.

Test 4: Upper Tie Plate Blockage

Purpose:

The purpose of Test 4 is to establish the experimental blockage function of the fuel bundle upper tie plate and upper spacers when exposed to debris during long term cooling. The test will also quantify local debris accumulation at, for example, interfaces with spacer grids and tie plates.

Basis:

During long-term cooling of a BWR core after a LOCA, it has been postulated that some blockage of the fuel bundle (UTP and upper spacers may occur. It may take several days for the steam bubble in the upper one-third of the core to collapse and for the flow injected at the top of the core to fully penetrate downward into the fuel bundle. Prior to full penetration, a water pool remains above the steam bubble with limited down flow that assists core cooling. A countercurrent flow regime exists at this time: debris-laden water flows down fuel rod surfaces and flashes to steam, which flows upward and exits the top of the bundle. The downward flowing water may contain debris that has passed through the suction strainers in the suppression pool and this debris could accumulate on the upper tie plate and upper spacers. The upward steam flow limits the amount of water and associated debris that is able to flow into the bundle and may dislodge debris that would otherwise accumulate at the upper tie plate and upper spacers. A reduction in water flowing down into the fuel bundles due to blockage of the upper tie plate and spacers might decrease the rate of core cooling.

As essentially all of the water flowing downward into a given fuel bundle is converted into steam by the hot fuel, very little of the debris-laden water flows through the lower tie plate. As the objective of this particular test is to evaluate the blockage characteristics of the upper tie plate and upper spacers only, the fuel channel will be raised off of the lower tie plate to ensure no impediment to axial flow exists in the upper part of the test bundle due to blockage of the lower tie plate.

Testing of potential blockage of the upper tie plate and upper spacers is divided into two-phases: Test 4a will be conducted using only water with debris entering from the top of the fuel channel and Test 4b will be conducted using water with debris entering from the top *and* countercurrent air flow to simulate upward steam flow. Test 4b will *only* be conducted if the more conservative Test 4a results in more rapid debris accumulation during the early part of the transient, when significant steam updraft exists and is expected to prevent debris accumulation when the fuel requires more downflow. Note that the blockage criteria are given for long-term, but are applied in early conditions of the analysis, which is more conservative.

Test 4a: Water Test

Key Test Bundle Features (Figures A-5 and A-6):

1) Height of Fuel Bundle: Although only the upper one-third of the fuel bundle is affected by this issue, the entire bundle length will be used in the tests as a full-length bundles is available from Tests 1-3. However, effects of the lower tie plate will not be considered because the droplets from core spray water do not flow down to the lower region of the bundle. The fuel channel will be raised to ensure that the lower tie plate does not become blocked and impede axial flow in the upper part of the bundle.

2) Components of Fuel Bundle: The test rig used in Tests 1-3 will be used for Test 4a. As such, actual fuel bundles will be tested. The upper part of the bypass channel geometry in the test rig will be modified so that all the flow and debris is conservatively introduced only into the fuel channel and onto the upper tie plate. Surrounding the test fuel bundle will be the same watertight chamber used previously providing one half the clearances to the adjacent fuel bundles (the adjacent fuel bundles will not be included in the test setup). All sides of this chamber will be transparent.

3) Interface with Lower Plenum: A water collection tank will be used to capture water and debris injected into the top of the channel.

Test Loop Components (Figures A-5 and A-6):

1) Flow Control: Water mixed with debris will be withdrawn from a debris-mixing tank and measured while discharging to the top of the bundle. The flow rate used in the test will be based on fuel supplier-specific limiting base LOCA event and fuel bundle blockage sensitivity analyses. Piping size and length shall be selected to minimize any settling of debris in the inflow system. A low-pressure sparger system with relatively large holes (so no debris is trapped) will distribute the flow to the bundle above the upper tie plate. Water and debris that passes through the fuel bundle will be collected below the bundle in a tank with mechanical mixers and pumped back to the supply tank. This recirculation system will be designed to operate for a few days, if needed.

2) Debris: The total mass of debris to be used in each test shall be mixed in the water source tank described above. Mixing shall be by a mechanical device so that no additional flow is introduced into the tank and no debris is lost from the tank. Total debris mass and tank volume shall be selected to reproduce the target debris concentration expected during long-term cooling.

3) Air Flow Pressure Loss Testing: Subsequent to operating the test loop for the time period needed to establish asymptotic (i.e., essentially steady state) results, estimated to be approximately one or two days but to be quantified as described below under Test Operating Conditions, the water flow system will be removed from the bundle and the head loss coefficient of the upper tie plate and upper spacers will be determined using a separate air flow system (see Figure A-6). For these tests the bypass region will be blocked so that the airflow is only through the fuel channel. Air is used as the test fluid

rather than water as water flow could compress or dislodge any debris deposited on/in the fuel bundle components. For these reasons, the airflow would be controlled to limit the pressure drop across the upper tie plate and upper spacers to a relatively low value, such as about 10 mm of water column as measured with a differential pressure cell. These tests will provide a way to quantify the extent of blockage, in addition to visual observations of blockage, and provide results that can be compared against the analysis criteria.

4) Instrumentation: In addition to the sparger flow measurement, pressure taps will be installed just above the upper tie plate, between the upper tie plate and the upper spacer and below the upper spacers to the liquid water level in the core associated with long-term core cooling. Differential pressure transducers connected to these taps will be used mainly during the airflow tests to determine the head loss (coefficient) of the upper tie plate and upper spacers as they may be affected by the accumulation of debris. The difference in loss coefficients with a clean system in comparison to those with debris accumulation may be used to confirm criteria established from fuel supplier-specific limiting base LOCA event and fuel bundle blockage sensitivity analyses. A differential pressure type flow meter will be used to measure the airflow to allow determination of a loss coefficient (differential pressure/dynamic head).

5) Photographs will be taken as practical to document each test.

Test Operating Conditions:

1) Flow and Debris Injection: Water with fully mixed debris will be pumped into the low-pressure sparger above the fuel channel. The rate of injection of the water and debris mixture shall be controlled to simulate a wide rate range from approximately 0.5 to as high as 10 gpm to conservatively assess the effect of debris using flow rates representative of the vendor specific analysis. The flow and debris will be recirculated.

2) Initial Testing to Establish Test Duration: Trial testing will be conducted for an initial period of approximately one to two days. Differential pressure measurements across the upper tie plate and upper spacers will be made during this time to estimate when steady conditions have been reached. At that point, the water test will be stopped to: a) measure loss coefficients across the upper tie plate and upper spacers using the airflow system (Figure A-6), and b) photograph any visible blockage. The water flow test will then be resumed and the cycle repeated until the differential pressure measurements with airflow become repeatable (i.e., are close to the same value as the previous airflow measurement) indicating the total time needed to run the water test.

3) Actual Testing: Water tests to determine the possible effects of debris blockage on the loss coefficient for the upper tie plate and upper spacers will be run for the total time established above and the air flow system will be used only once at the end of that time to determine the change in loss coefficient. As indicated above, the airflow will be controlled to produce only a small differential pressure to minimize any effects on the debris bed.

4) Debris Constituents: The debris components, their characteristics, concentrations and the total mass per component to be used during long-term cooling will be provided by the BWROG ECCS Suction Strainer Source Term Subcommittee. If required, debris components may be added in stages to more closely simulate the time history of material passing through the ECCS suction strainers in the suppression pool.

Parameters to be Measured:

1) Pressure measurements will use pressure cells. Depending on location and related access, they may be flush mounted or use tubing to static ports in the fuel bundle.
2) Flow measurement for the injected water flow will be by an orifice plate or an equivalent method that is accurate for the debris/water mix.
3) The air flow rate will be measured by an orifice meter in the fan discharge duct. Air temperature will also be recorded to allow calculation of the air density and the dynamic head.
4) Total Mass of Debris: For each constituent of the debris mixture, the total debris mass to be introduced during each test is to be measured (weighed) to achieve the desired initial concentration.
5) Mixed Debris Concentration: Water samples will be taken during the test from the injection line to verify the debris concentration.
6) Where practical, photographs of debris accumulation will be taken after the water injection test but before the air test to determine the loss coefficient. Additionally, photographs of debris on and about fuel rods will be taken to characterize local deposition at, for example, interfaces with spacer grids and tie plates.

Repeatability:

1) Air Flow Tests with a Clean System: Five air flow rates shall be used to determine the loss coefficient for the upper tie plate and upper spacers with a clean system and to characterize the repeatability of making air flow and pressure measurements. Five tests are deemed sufficient based on experience; however, statistical relevance of the collected data should be analyzed to determine if a larger number of tests are required. The average value of these five loss coefficients will establish the clean system loss coefficient.
2) Air Flow Test with Debris Accumulation: Five air flow rates (limited in magnitude as described above) shall be used to determine the loss coefficient for the upper tie plate and upper spacers with blockage.
3) Cleaning: After each debris test and the determination of the corresponding (average) loss coefficient, the mixing tank, collection tanks, the flow system and the fuel bundle shall be cleaned using appropriate methods (including disassembly of bundle components, if needed, and thorough power washing, as necessary) and new "clean" test data (tests conducted with a clean test flow loop, clean bundle, and five air flows) should subsequently be obtained. Without the variability of debris affects, experience indicates

that averaged pressure loss coefficients can have an uncertainty of 2 to 3% based on the various instruments involved. To find a true difference between clean tests among this uncertainty suggests that deviations from prior average clean test loss coefficients should not vary by more than 5%. Greater differences would indicate the need for re-cleaning and a repeat of the clean tests.

4) The cycle of three tests would be repeated for each debris mix.

Acceptance Criteria

The acceptance criteria for this test will be based on the results and requirements of the fuel supplier-specific limiting base LOCA event and fuel bundle blockage sensitivity analyses (Section 3.4 summarizes the GEH analyses, Section 3.6 provides proposed test criteria). It is expected that the basis for the criteria will be the increase in loss or differential pressure coefficient at the upper tie plate and upper spacers compared to a clean system. This increase in pressure differential can be compared to the calculated increase obtained by assuming a certain percent blockage in flow area. It is postulated that blockage at these locations could affect the calculated makeup water required based on core steaming. The relationship between any pressure differential and the peak cladding temperature increase can be developed although it may be fuel supplier specific.

Test 4b: Water Down-Flow with Countercurrent Air Flow

Note: The following Test 4b will *only* be conducted if the more conservative Test 4a produces unexpected debris deposition during the early portion of the test that is considered unrealistic for fuel bundles with upward steam flow.

Key Test Bundle Features (Figures A-7 and A-6):

1) Height of Fuel Bundle: Although only the upper one-third of the fuel bundle is affected by this issue, the entire bundle length will be used in the tests because a full-length bundle is available from Tests 1-3. However, effects of the lower tie plate will not be considered because the droplets from core spray water do not flow down to the lower region of the bundle. The fuel channel will be raised to ensure that the lower tie plate does not become blocked and impede axial flow in the upper part of the bundle.

2) Components of Fuel Bundle: The test rig used in Test 1-3 will be used for Test 4b. As such, actual fuel bundles will be tested. The upper part of the bypass channel geometry in the test rig will be modified so that all the water and debris is conservatively introduced only into the fuel channel and onto the upper tie plate. Surrounding the test fuel bundle will be the same water and air tight chamber used previously providing one half the clearances to the adjacent fuel bundles (the adjacent fuel bundles will not be included in the test setup). All sides of this chamber will be transparent.

3) Interface with Lower Plenum: The lower end of the fuel channel and lower tie plate will be immersed in a water collection tank. This ensures that air injected into the fuel bundle can only flow upward.

Test Loop Components (Figures A-7 and A-6):

1) Flow Control: Water mixed with debris will be withdrawn from a debris-mixing tank and measured while discharging to the top of the bundle. The flow rate used in the test will be based on the fuel supplier-specific limiting base LOCA event and fuel bundle blockage sensitivity analyses. Piping size and length shall be selected to minimize any settling of debris in the inflow system. A low-pressure sparger system with relatively large holes (so no debris is trapped) will distribute the flow to the bundle above the upper tie plate. Water and debris that passes through the fuel bundle will be collected below the bundle in a tank with mechanical mixers and pumped back to the supply tank. This recirculation system will be designed to operate for a few days, if needed.

2) Debris: The total mass of debris to be used in each test shall be mixed in the water source tank described above. Mixing shall be by a mechanical device so that no additional flow is introduced into the tank and no debris is lost from the tank. Total debris mass and tank volume shall be selected to reproduce the maximum debris concentration expected in the plant spray flow.

3) Air Flow: A separate air flow injection system will be used to introduce a measured air flow into the fuel bundle to simulate the countercurrent steam flow leaving the top of the bundle. Air flow rate will be set to establish the same dynamic head as calculated for the

expected conservative, long-term cooling steam flow, thus producing similar affects on redistribution of the debris. A filter will be placed above the sparger ring to capture any debris lost from the system due to the injected air flow. Any debris caught on that filter will be rinsed off periodically to re-suspend the debris and any debris deposited at the end of the test will be measured and added to the total mass used for each test thereafter.

4) Air Flow Pressure Loss Testing: Subsequent to operating the test loop for the time period needed to establish asymptotic (i.e., essentially steady state) results, estimated to be approximately one or two days but to be quantified as described below under Test Operating Conditions, the water/air injection flow systems will be removed from the bundle and the head loss coefficient of the upper tie plate and upper spacers will be determined using a separate air flow system, see Figure A-6. For these tests, the bypass region will be blocked so that the air flow is only through the fuel channel. Air is used as the test fluid rather than water because: a) the upper region of the fuel bundle is in steam (similar density to air), and b) water flow could compress or dislodge any debris. For these reasons, the air flow would be controlled to limit the pressure drop across the upper tie plate and upper spacers to a relatively low value, such as about 10mm of water column as measured with a differential pressure cell. These tests will provide a way to quantify the extent of blockage, in addition to visual observations, and provide results that can be compared against the analysis criteria.

5) Instrumentation: In addition to the sparger water flow and air injection flow measurements, pressure taps will be installed just above the upper tie plate, between the upper tie plate and the upper spacer and below the upper spacers. Differential pressure transducers connected to these taps will be used mainly during the subsequent air flow tests to determine the head loss (coefficient) of the upper tie plate and upper spacers as they may be affected by any accumulation of debris. The difference in loss coefficients with a clean system in comparison to those with debris accumulation may be used to confirm criteria established from fuel supplier-specific limiting base LOCA event and fuel bundle blockage sensitivity analyses. A differential pressure type flow meter will be used to measure the air flow to allow determination of a loss coefficient (differential pressure/dynamic head).

6) Photographs will be taken as practical to document each test. Additionally, photographs of debris on and about fuel rods will be taken to characterize local deposition at, for example, interfaces with spacer grids and tie plates.

Test Operating Conditions:

1) Water Flow and Debris Injection: Water with fully mixed debris will be pumped into the low-pressure sparger above the fuel channel. The rate of injection of the water and debris mixture shall be controlled to simulate a wide rate range from approximately 0.5 gpm to as high as 10 gpm to conservatively assess the effect of debris using flow rates representative of the vendor specific analysis. The flow and debris will be recirculated.

2) Air Injection: Using a suitable air source such as a compressor or blower, a measured air flow will be injected into the upper part of the fuel bundle to simulate the upward flow of steam leaving the top of the fuel bundle. The injected air flow rate will be set to produce the same dynamic head at the fuel bundle outlet as would the calculated steam flow.

3) Initial Trial Testing to Establish Test Duration: Trial testing will be conducted for an initial period of approximately one to two days. Differential pressure measurements will be made across the upper tie plate and upper spacers during this time to estimate when steady conditions have been reached. At that point, the water/air injection test will be stopped to measure the loss coefficients of the upper tie plate and upper spacers using the air flow system (Figure A-6) and to photograph any visible blockage. The water/air injection test will then be resumed and the cycle repeated until the differential pressure measurements with air flow become repeatable (i.e., are close to the same value as in the previous air flow measurement), indicating the total time needed to run the water/air injection test.

4) Actual Testing: Water/air injection tests to determine the possible effects of debris blockage on the loss coefficients of the upper tie plate and upper spacers will then be run for the total time established in the trial testing and the air flow system will be used only once at the end of that time to determine the change in loss coefficients. As indicated above, the air flow rate will be controlled to produce only a small differential pressure to minimize any affects on the debris bed.

5) Debris Constituents: The debris components, their characteristics, concentrations and the total mass per fuel component to be used during long-term cooling will be provided by the BWROG ECCS Suction Strainer Source Term Subcommittee. If required, debris components may be added in stages to more closely simulate the time history of material passing through the ECCS suction strainers in the suppression pool.

Parameters to be Measured:

1) Pressure measurements will use pressure cells. Depending on location and related access, they may be flush mounted or use tubing to static ports in the fuel bundle.

2) Flow measurement for the injected water flow will be by an orifice plate or an equivalent method that is accurate for the debris/water mixture used.

3) The air flow injected into the fuel bundle will be measured with an orifice plate or an equivalent method.

4) The air flow rate to determine the loss coefficients across the upper tie plate and upper spacers will be measured by an orifice meter in the fan discharge duct. Air temperature will also be recorded to allow calculation of the air density and the dynamic head.

5) Total Mass of Debris: For each constituent of the debris mix, the total debris mass to be introduced during each test is to be measured (weighed) to achieve the desired initial concentration.

6) Mixed Debris Concentration: Water samples will be taken four or five times during the test from the injection line to verify the debris concentration.

7) Where practical, photographs of debris accumulation will be taken after the water/air injection test but before the air test to determine loss coefficients.

8) Any debris caught on the filter located above the sparger ring will be dried and weighed.

Repeatability/Uncertainty:

1) Air Flow Tests with a Clean System: Five air flow tests shall be used to determine the loss coefficients of the upper tie plate and upper spacers with a clean system and to characterize the repeatability of making air flow and pressure measurements. Five tests are deemed sufficient based on experience; however, statistical relevance of the collected data should be analyzed to determine if a larger number of air flow tests are required. The average value of these five loss coefficients will establish the clean system loss coefficient.

2) Air Flow Test with Debris Accumulation: Five air flow rates, limited in magnitude as described above, shall be used to determine the loss coefficients for the upper tie plate and upper spacers with blockage and to characterize the repeatability of making air flow and pressure measurements.

3) Cleaning: After each debris test and the determination of the corresponding average loss coefficient, the mixing and collection tanks, the flow system and the fuel bundle shall be cleaned using appropriate methods (including disassembly of bundle components, if needed, and thorough power washing, as necessary) and new "clean" test data (tests conducted with a clean test flow loop, clean bundle, and five air flows) should subsequently be obtained. Without the variability of debris affects, experience indicates that averaged pressure loss coefficients can have an uncertainty of 2 to 3% based on the various instruments involved. To find a true difference between clean tests among this uncertainty suggests that deviations from prior average clean test loss coefficients should not vary by more than 5%. Greater differences would indicate the need for re-cleaning and a repeat of the clean tests.

4) The above-described cycle of water/air injection tests, subsequent air tests to determine loss coefficients and cleaned bundle tests should be repeated twice for a total of three tests with each debris mix.

5) The cycle of three tests would be repeated for each debris mix.

Acceptance Criteria

The acceptance criteria for this test will be based on the results and requirements of the fuel supplier-specific limiting base LOCA event and fuel bundle blockage sensitivity analyses (Section 3.4 summarizes the GEH analyses, Section 3.6 provides proposed test criteria). It is expected that the basis for the criteria will be the increase in loss or differential pressure coefficient at the upper tie plate and the upper (and possibly additional) spacer grid(s) compared to a clean system. This increase in pressure differential can be compared to the calculated increase obtained by assuming a certain percent blockage in flow area. It is postulated that blockage at these locations could affect the calculated makeup water required based on upper core steaming. The relationship between any pressure differential and the peak cladding temperature increase can be developed although it may be fuel supplier specific.

Test Debris Preparation (Applicable to all Tests)

Work relative to debris characterization, concentration, total mass and possible time history is being performed by the BWROG ECCS Suction Strainer Source Term Subcommittee. Therefore, the characterization of each debris type to be considered in evaluating the effect of coolant flow on downstream components is expected to be provided as a design level input from work being conducted by that subcommittee. It is also expected that the form of each debris type will be specified as well as the time history of its concentration per unit volume of water. Surrogates for material such as coatings may be identified for testing and should be consistent with surrogates used in the ECCS suction strainer head loss testing program. Some information is available from data obtained for the PWROG downstream effects evaluation and subsequent fuels testing, however, it should be noted that the ECCS suction strainer hole sizes and velocities are different between PWR and BWR plants and this could influence the downstream debris characteristics. Although the presence of any chemical compounds and their characteristics are uncertain at this time, appropriate surrogates will be tested, if necessary. In all cases, conservative and bounding concentrations of the surrogates will be tested to ensure applicability to the full BWR fleet.

Once the characteristics of the debris are identified, details of a suitable methodology for preparing the debris for introduction into the mixing tanks for Tests 1 through 4 can be developed.

References for Appendix A

1. "Differences in Treatment of Containment Strainer/Sump Clogging Technical Issues for Boiling Water and Pressurized Water Reactors," presentation by R. Architzel (NRC) to BWR Owners Group, dated November 27, 2007. ADAMS Accession Number: Number ML073320414.

2. Letter, J.A. Grobe (NRC) to R. Anderson (BWROG), "Potential Issues Related to Emergency Core Cooling Systems (ECCS) Strainer Performance at Boiling Water Reactors," dated April 10, 2008. ADAMS Accession Number: ML080500540.

3. Memorandum, J.A. Golla (NRC) to M.L. Scott (NRC), 'Summary of June 5, 2008, Public Meeting with the Boiling Water Reactor Owner's Group (BWROG) to Discuss BWROG Proposed Activities Regarding Strainer Clogging Issues', dated June 24, 2008. ADAMS Accession Number: ML081620552.

4. Memorandum, M.C. Honcharik (NRC) to S.L. Rosenberg (NRC), "Summary of November 5, 2008, Open Meeting with the Boiling Water Reactor (BWR) Owner's Group (BWROG) with Senior Management (TAC No. MB5757)," dated November 28, 2008. ADAMS Accession Number: ML083260102.

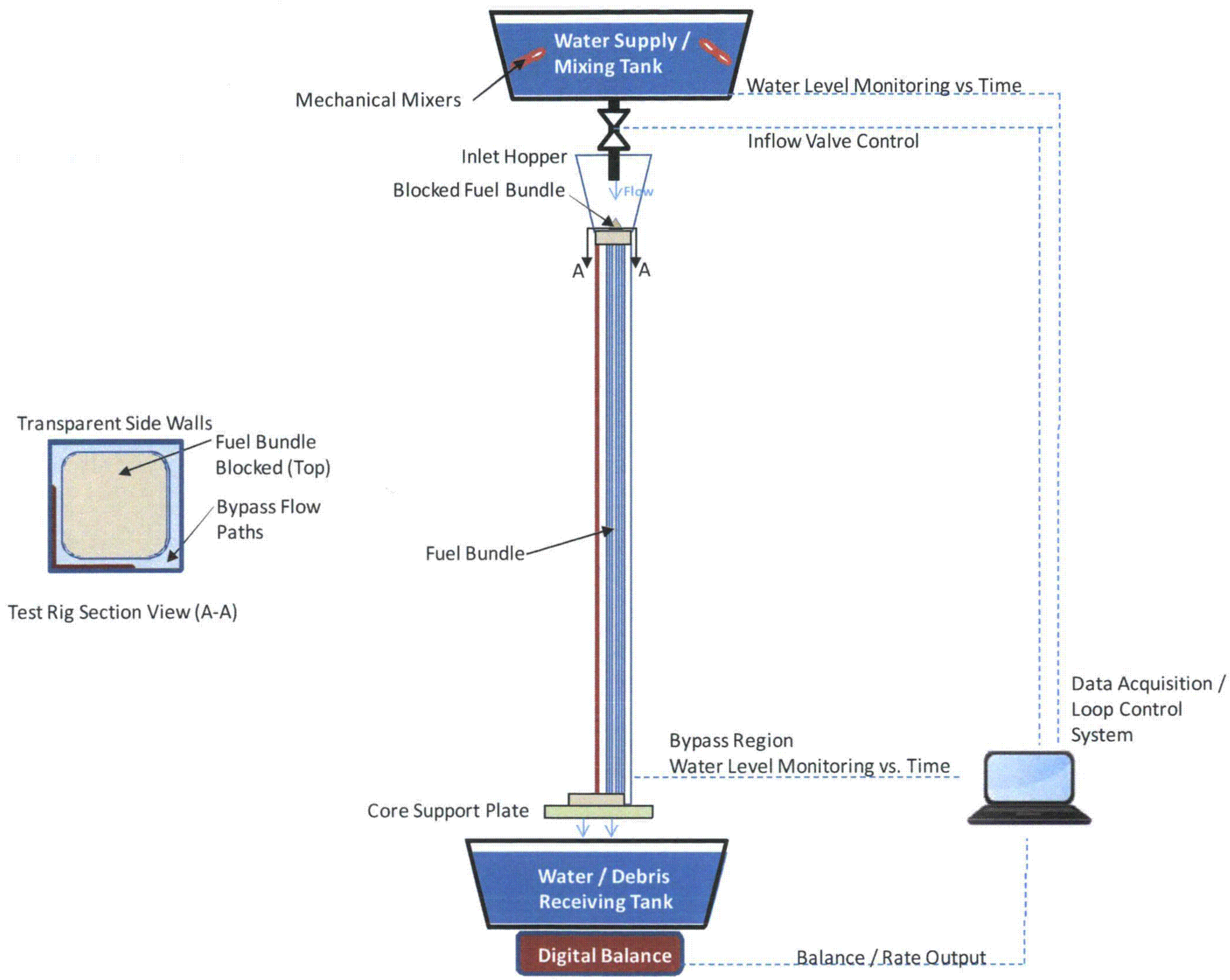

Figure A-1 TEST 1 - Bypass Region Refill Test Rig

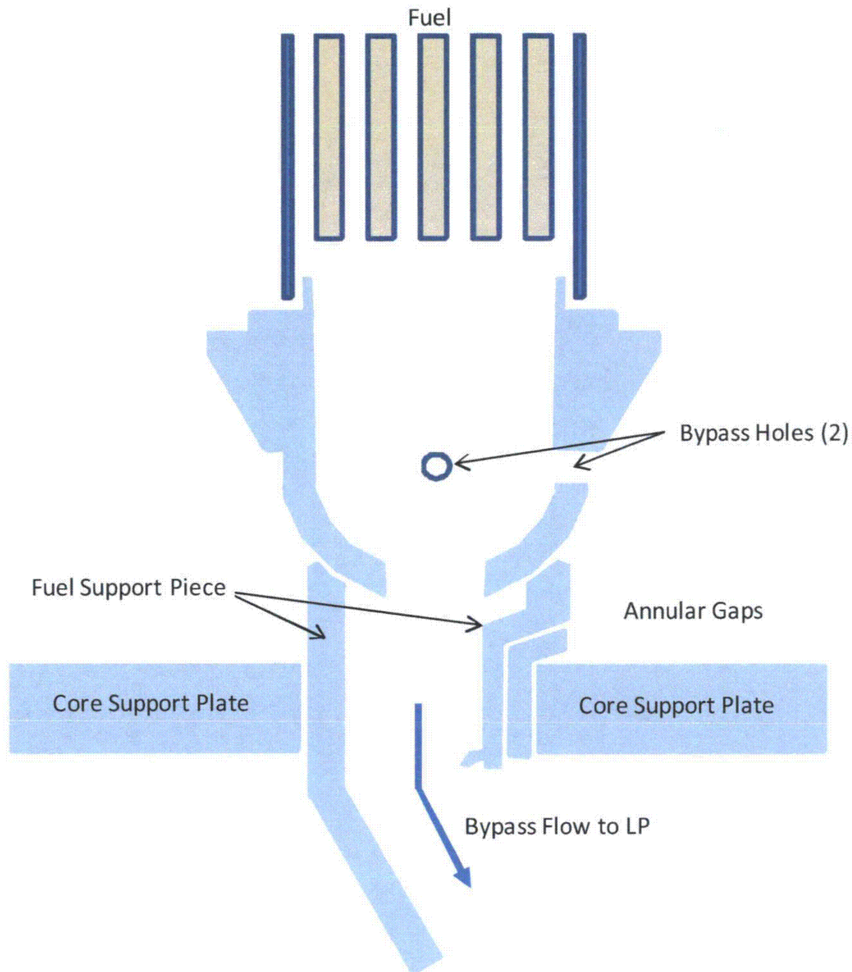

Figure A-2 Fuel Bundle Lower Region and Support Assembly Schematic Showing Bypass Holes and Selected Bypass Region Gaps

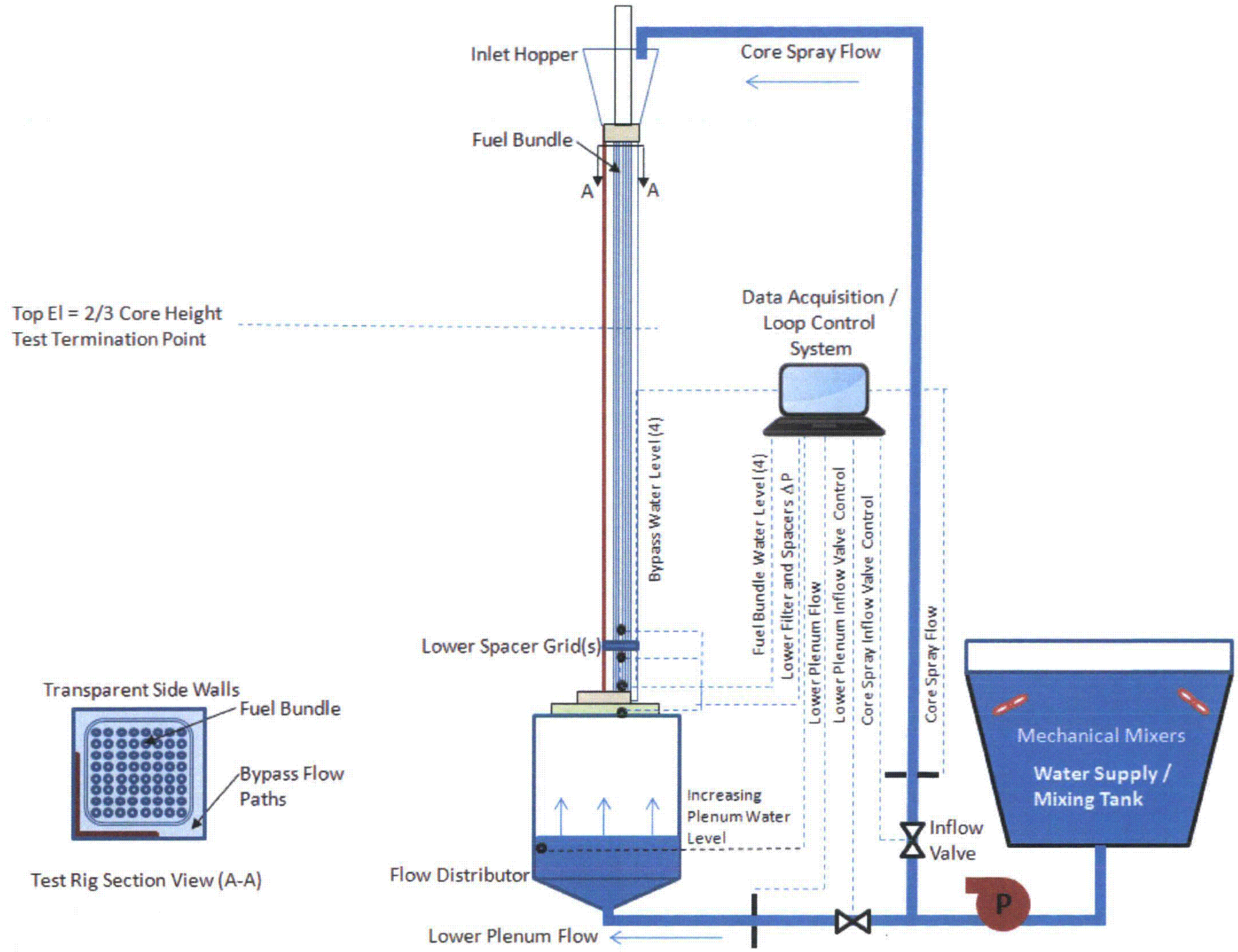

Figure A-3 TEST 2 - Core Re-flood Rate Test Rig

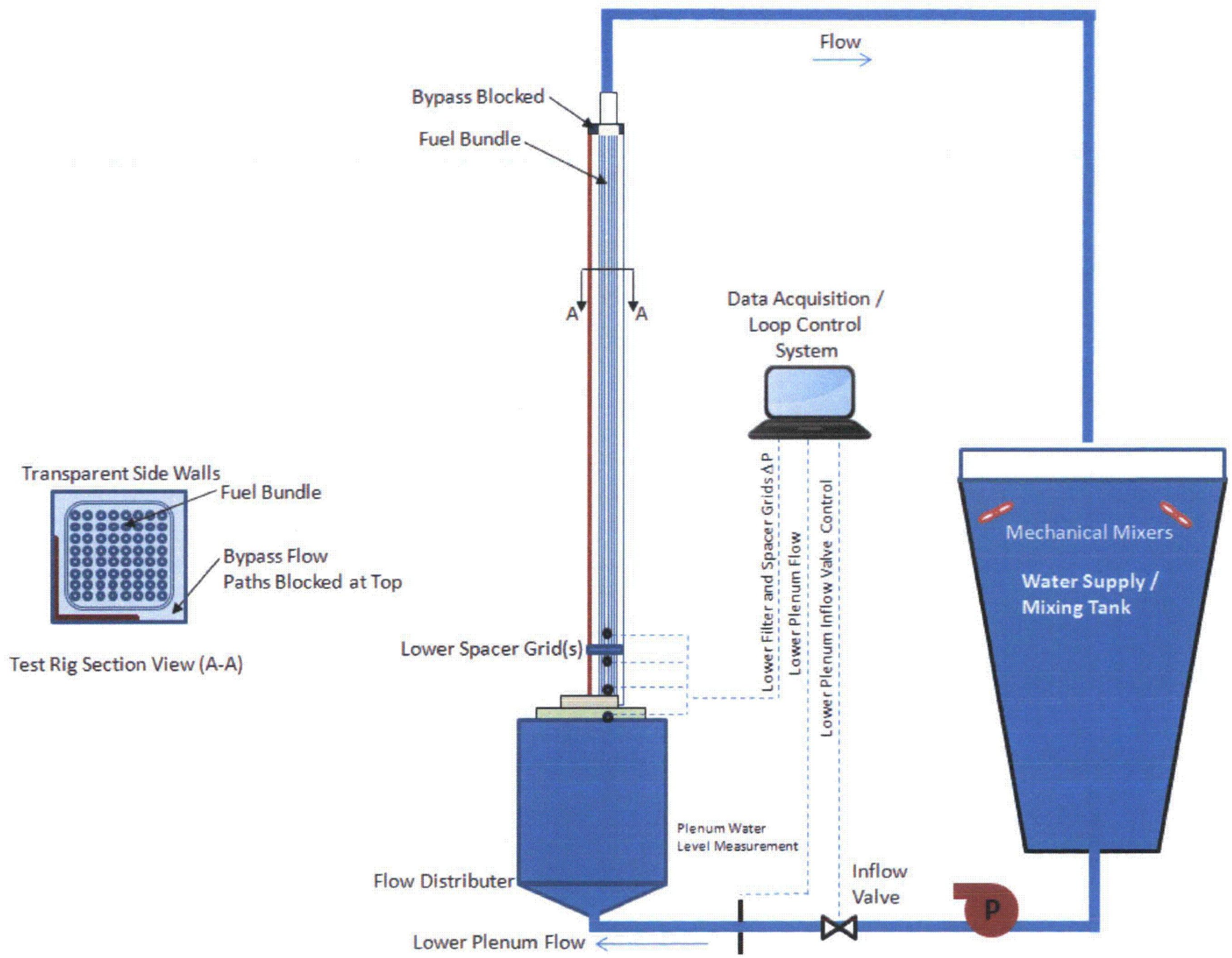

Figure A-4 TEST 3 - Lower Tie Plate Blockage Test Rig

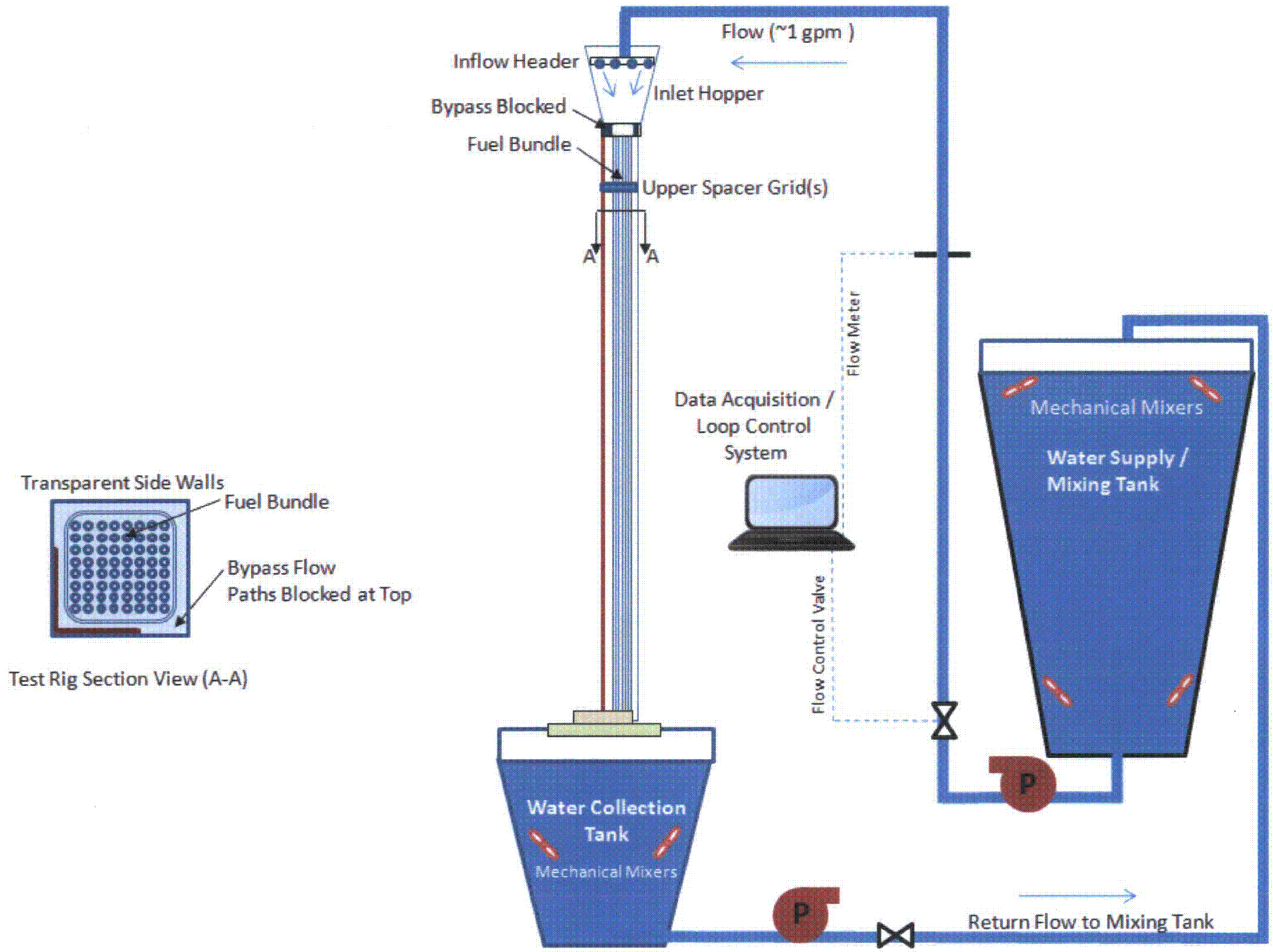

Figure A-5 TEST 4a - Upper Tie Plate Blockage Test Rig #1

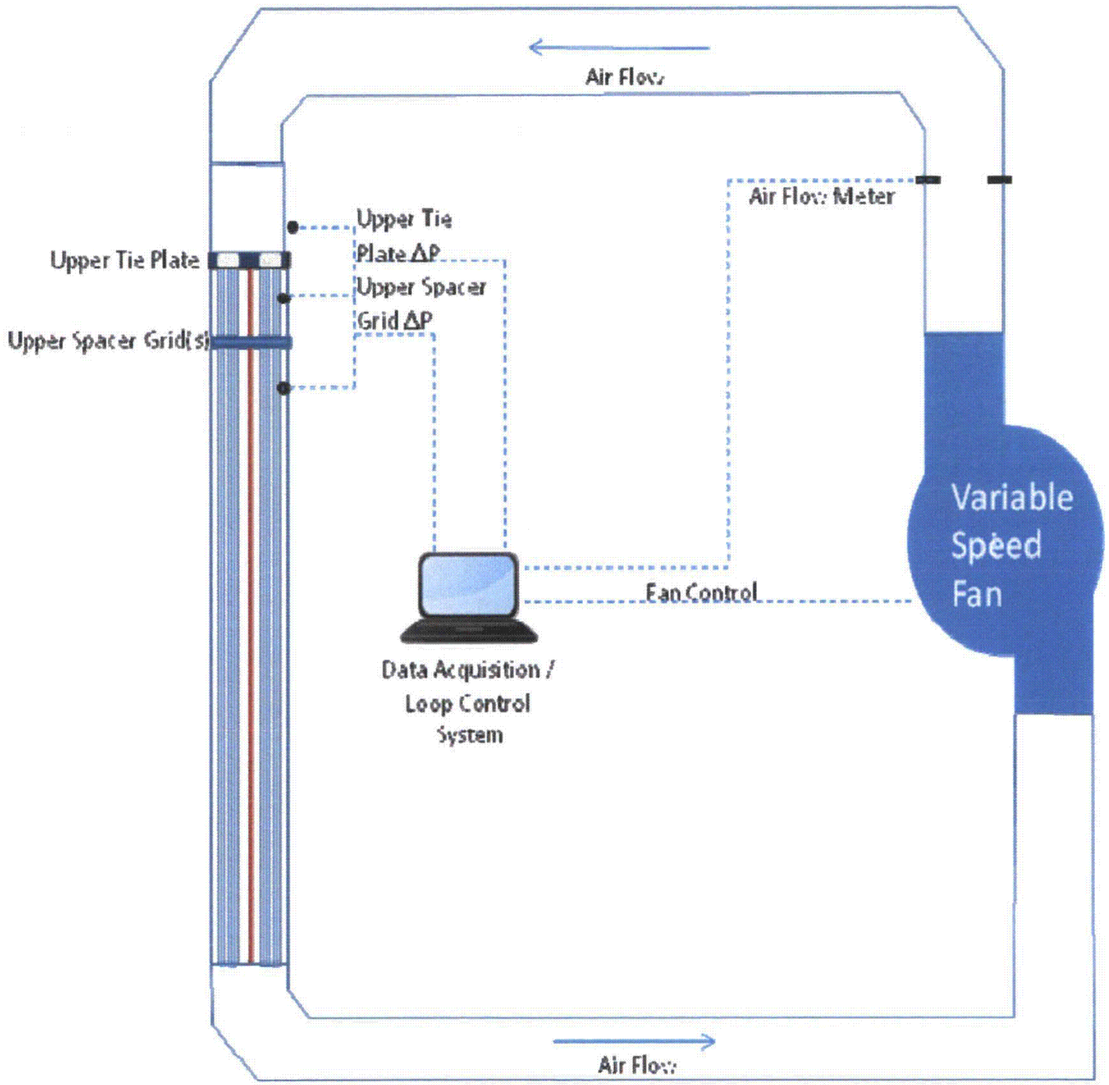

Figure A-6 TEST 4a - Upper Tie Plate Blockage Test Rig #2

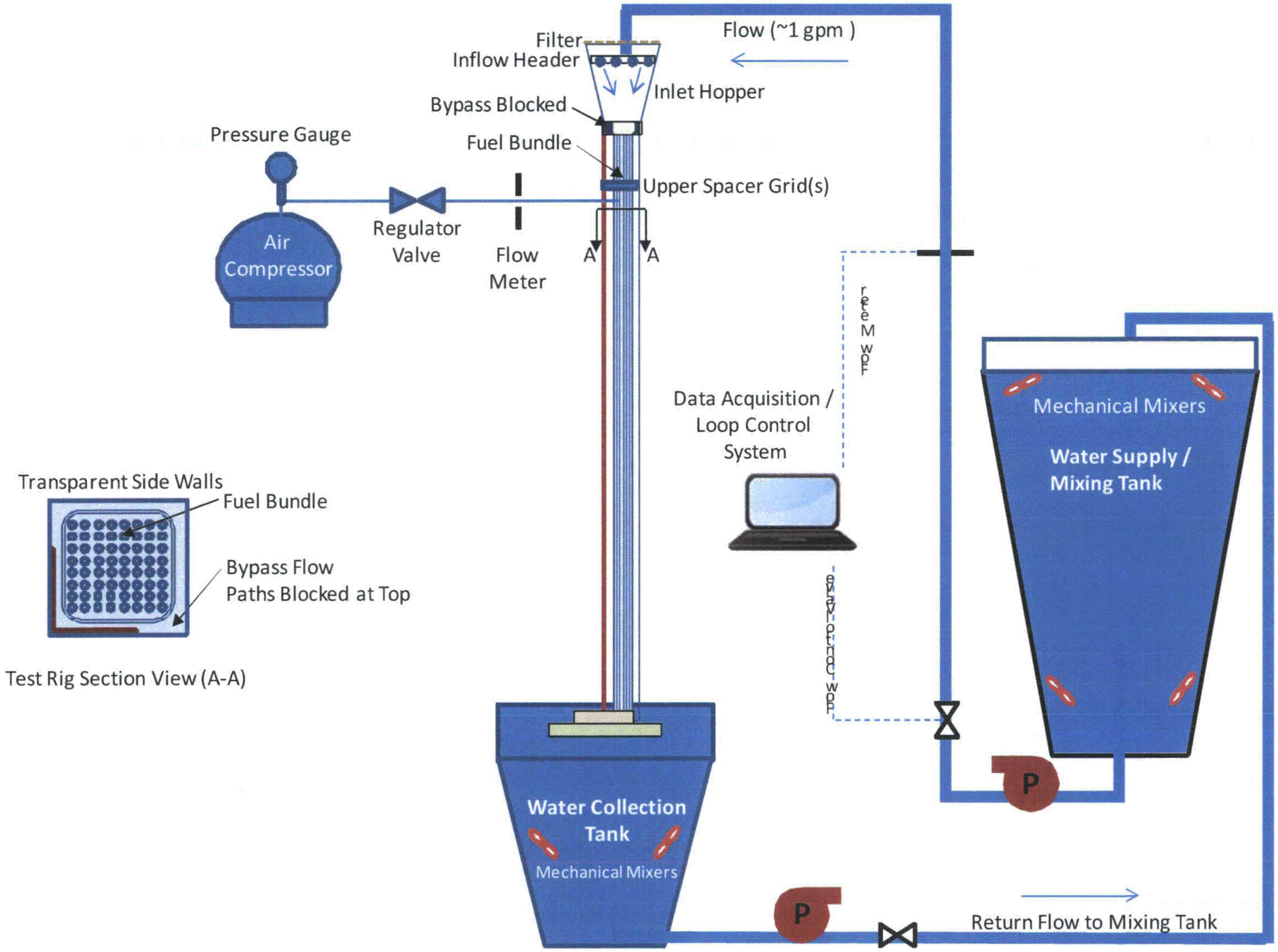

Figure A-7 TEST 4b - Upper Tie Plate Blockage Test Rig