Westinghouse

Westinghouse Electric Company
Nuclear Power Plants
P.O. Box 355
Pittsburgh, Pennsylvania 15230-0355
USA

U.S. Nuclear Regulatory Commission
ATTENTION: Document Control Desk
Washington, D.C. 20555

Direct tel: 412-374-6202
Direct fax: 724-940-8505
e-mail: sisk1rb@westinghouse.com

Your ref: Docket No. 52-006
Our ref: DCP_NRC_002968

July 20, 2010

Subject: Transmittal of Technical Report APP-GW-GLR-079 Revision 8 (TR-026), (Proprietary & Non-Proprietary) "AP1000 Verification of Water Sources for Long-Term Recirculation Cooling Following a LOCA"

Westinghouse is submitting Revision 8 of APP-GW-GLR-079 (Proprietary), "AP1000 Verification of Water Sources for Long-Term Recirculation Cooling Following a LOCA," and the associated Non-Proprietary version (APP-GW-GLR-086 R3).

This information is submitted in support of the AP1000 Design Certification Amendment Application (Docket No. 52-006). This information is provided to support the independent review of the IRWST and CR Screen models by the NRC. The information provided in this report is generic and is expected to apply to all Combined Operating License (COL) applicants referencing the AP1000 Design Certification and the AP1000 Design Certification Amendment Application.

Also enclosed is one copy of the Application for Withholding, AW-10-2887 (non-proprietary) with Proprietary Information Notice, and one copy of the associated Affidavit (non-proprietary).

This submittal contains proprietary information of Westinghouse Electric Company LLC. In conformance with the requirements of 10 CFR Section 2.390, as amended, of the Commission's regulations, we are enclosing with this submittal an Application for Withholding from Public Disclosure and an affidavit. The affidavit sets forth the basis on which the information identified as proprietary may be withheld from public disclosure by the Commission.

Correspondence with respect to the affidavit or Application for Withholding should reference AW-10-2887 and should be addressed to James A. Gresham, Manager, Regulatory Compliance and Plant Licensing, Westinghouse Electric Company LLC, P. O. Box 355, Pittsburgh, Pennsylvania 15230-0355.

Questions or requests for additional information related to the content and preparation of this report should be directed to Westinghouse. Please send copies of such questions or requests to the prospective applicants for combined licenses referencing the AP1000 Design Certification. A representative for each applicant is included on the cc: list of this letter.

DO63
NRO

Very truly yours,

for/ John J DeBlasio

Robert Sisk, Manager
Licensing and Customer Interface
Regulatory Affairs and Strategy

/Enclosures

1. AW-10-2887 "Application for Withholding Proprietary Information from Disclosure," dated July 23, 2010

2. AW-10-2887, Affidavit, Proprietary Information Notice, Copyright Notice dated July 23, 2010

3. APP-GW-GLR-079 Revision 8, (Proprietary) "AP1000 Verification of Water Sources for Long-Term Recirculation Cooling Following a LOCA"

4. APP-GW-GLR-079 Revision 8, (Proprietary) "AP1000 Verification of Water Sources for Long-Term Recirculation Cooling Following a LOCA"

cc:	D. Jaffe	-	U.S. NRC	4E
	E. McKenna	-	U.S. NRC	4E
	P. Donnelly	-	U.S. NRC	4E
	T. Spink	-	TVA	4E
	P. Hastings	-	Duke Power	4E
	R. Kitchen	-	Progress Energy	4E
	A. Monroe	-	SCANA	4E
	P. Jacobs	-	Florida Power & Light	4E
	C. Pierce	-	Southern Company	4E
	E. Schmiech	-	Westinghouse	4E
	G. Zinke	-	NuStart/Entergy	4E
	R. Grumbir	-	NuStart	4E

ENCLOSURE 1

AW-10-2887

APPLICATION FOR WITHHOLDING
PROPRIETARY INFORMATION FROM DISCLOSURE

Westinghouse

Westinghouse Electric Company
Nuclear Services
P.O. Box 355
Pittsburgh, Pennsylvania 15230-0355
USA

U.S. Nuclear Regulatory Commission
ATTENTION: Document Control Desk
Washington, D.C. 20555

Direct tel: 412-374-6306
Direct fax: 724-940-8505
e-mail: sisklrb@westinghouse.com

Your ref: Docket No. 52-006
Our ref: AW-10-2887

July 20, 2010

APPLICATION FOR WITHHOLDING PROPRIETARY
INFORMATION FROM PUBLIC DISCLOSURE

Subject: Transmittal of APP-GW-GLR-079 Revision 8, (Proprietary & Non-Proprietary) "AP1000 Verification of Water Sources for Long-Term Recirculation Cooling Following a LOCA"

The Application for Withholding is submitted by Westinghouse Electric Company LLC (Westinghouse), pursuant to the provisions of Paragraph (b) (1) of Section 2.390 of the Commission's regulations. It contains commercial strategic information proprietary to Westinghouse and is customarily held in confidence.

The proprietary material for which withholding is being requested is identified in the proprietary version of the subject report. In conformance with 10 CFR Section 2.390, Affidavit AW-10-2887 accompanies this Application for Withholding, setting forth the basis on which the identified proprietary information may be withheld from public disclosure.

Accordingly, it is respectively requested that the subject information which is proprietary to Westinghouse be withheld from public disclosure in accordance with 10 CFR Section 2.390 of the Commission's regulations.

Correspondence with respect to this Application for Withholding or the accompanying affidavit should reference AW-10-2887 and should be addressed to James A. Gresham, Manager, Regulatory Compliance and Plant Licensing, Westinghouse Electric Company LLC, P.O. Box 355, Pittsburgh, Pennsylvania, 15230-0355.

Very truly yours,

Robert Sisk, Manager
Licensing and Customer Interface
Regulatory Affairs and Strategy

ENCLOSURE 2

AFFIDAVIT

AW-10-2887
July 20, 20108

AFFIDAVIT

COMMONWEALTH OF PENNSYLVANIA:

ss

COUNTY OF BUTLER:

Before me, the undersigned authority, personally appeared Robert Sisk, who, being by me duly sworn according to law, deposes and says that he is authorized to execute this Affidavit on behalf of Westinghouse Electric Company LLC (Westinghouse), and that the averments of fact set forth in this Affidavit are true and correct to the best of his knowledge, information, and belief:

Robert Sisk, Manager
Licensing and Customer Interface
Regulatory Affairs and Strategy

Sworn to and subscribed
before me this 20th day
of July 2010.

COMMONWEALTH OF PENNSYLVANIA
Notarial Seal
Josette Michelle Colantuono, Notary Public
Cranberry Twp., Butler County
My Commission Expires June 16, 2013
Member, Pennsylvania Association of Notaries

Notary Public

(1) I am Manager, Licensing and Customer Interface, Westinghouse Electric Company LLC (Westinghouse), and as such, I have been specifically delegated the function of reviewing the proprietary information sought to be withheld from public disclosure in connection with nuclear power plant licensing and rule making proceedings, and am authorized to apply for its withholding on behalf of Westinghouse.

(2) I am making this Affidavit in conformance with the provisions of 10 CFR Section 2.390 of the Commission's regulations and in conjunction with the Westinghouse "Application for Withholding" accompanying this Affidavit.

(3) I have personal knowledge of the criteria and procedures utilized by Westinghouse in designating information as a trade secret, privileged or as confidential commercial or financial information.

(4) Pursuant to the provisions of paragraph (b)(4) of Section 2.390 of the Commission's regulations, the following is furnished for consideration by the Commission in determining whether the information sought to be withheld from public disclosure should be withheld.

(i) The information sought to be withheld from public disclosure is owned and has been held in confidence by Westinghouse.

(ii) The information is of a type customarily held in confidence by Westinghouse and not customarily disclosed to the public. Westinghouse has a rational basis for determining the types of information customarily held in confidence by it and, in that connection, utilizes a system to determine when and whether to hold certain types of information in confidence. The application of that system and the substance of that system constitutes Westinghouse policy and provides the rational basis required.

Under that system, information is held in confidence if it falls in one or more of several types, the release of which might result in the loss of an existing or potential competitive advantage, as follows:

(a) The information reveals the distinguishing aspects of a process (or component, structure, tool, method, etc.) where prevention of its use by any of Westinghouse's competitors without license from Westinghouse constitutes a competitive economic advantage over other companies.

(b) It consists of supporting data, including test data, relative to a process (or component, structure, tool, method, etc.), the application of which data secures a competitive economic advantage, e.g., by optimization or improved marketability.

(c) Its use by a competitor would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing a similar product.

(d) It reveals cost or price information, production capacities, budget levels, or commercial strategies of Westinghouse, its customers or suppliers.

(e) It reveals aspects of past, present, or future Westinghouse or customer funded development plans and programs of potential commercial value to Westinghouse.

(f) It contains patentable ideas, for which patent protection may be desirable.

There are sound policy reasons behind the Westinghouse system which include the following:

(a) The use of such information by Westinghouse gives Westinghouse a competitive advantage over its competitors. It is, therefore, withheld from disclosure to protect the Westinghouse competitive position.

(b) It is information that is marketable in many ways. The extent to which such information is available to competitors diminishes the Westinghouse ability to sell products and services involving the use of the information.

(c) Use by our competitor would put Westinghouse at a competitive disadvantage by reducing his expenditure of resources at our expense.

(d) Each component of proprietary information pertinent to a particular competitive advantage is potentially as valuable as the total competitive advantage. If competitors acquire components of proprietary information, any one component may be the key to the entire puzzle, thereby depriving Westinghouse of a competitive advantage.

(e) Unrestricted disclosure would jeopardize the position of prominence of Westinghouse in the world market, and thereby give a market advantage to the competition of those countries.

(f) The Westinghouse capacity to invest corporate assets in research and development depends upon the success in obtaining and maintaining a competitive advantage.

(iii) The information is being transmitted to the Commission in confidence and, under the provisions of 10 CFR Section 2.390, it is to be received in confidence by the Commission.

(iv) The information sought to be protected is not available in public sources or available information has not been previously employed in the same original manner or method to the best of our knowledge and belief.

(v) The proprietary information sought to be withheld in this submittal is that which is appropriately marked in attachment to DCP_NRC_002968, APP-GW-GLR-079 Revision 8, "AP1000 Verification of Water Sources for Long-Term Recirculation Cooling Following a LOCA", to the Document Control Desk. The proprietary information as submitted by Westinghouse for the AP1000 Design Certification Amendment application is expected to be applicable in all license submittals referencing the AP1000 Design Certification and the AP1000 Design Certification Amendment Application in response to certain NRC requirements for justification of compliance of the safety system to regulations.

This information is part of that which will enable Westinghouse to:

(a) Manufacture and deliver products to utilities based on proprietary designs.

(b) Advance the AP1000 Design and reduce the licensing risk for the application of the AP1000 Design Certification

(c) Determine compliance with regulations and standards

(d) Establish design requirements and specifications for the system.

Further this information has substantial commercial value as follows:

(a) Westinghouse plans to sell the use of similar information to its customers for purposes of plant construction and operation.

(b) Westinghouse can sell support and defense of safety systems based on the technology in the reports.

(c) The information requested to be withheld reveals the distinguishing aspects of an approach and schedule which was developed by Westinghouse.

Public disclosure of this proprietary information is likely to cause substantial harm to the competitive position of Westinghouse because it would enhance the ability of competitors to provide similar digital technology safety systems and licensing defense services for commercial power reactors without commensurate expenses. Also, public disclosure of the information would enable others to use the information to meet NRC requirements for licensing documentation without purchasing the right to use the information.

The development of the technology described in part by the information is the result of applying the results of many years of experience in an intensive Westinghouse effort and the expenditure of a considerable sum of money.

In order for competitors of Westinghouse to duplicate this information, similar technical programs would have to be performed and a significant manpower effort, having the requisite talent and experience, would have to be expended.

Further the deponent sayeth not.

AW-10-2887
July 20, 2010

PROPRIETARY INFORMATION NOTICE

Transmitted herewith are proprietary and/or non-proprietary versions of documents furnished to the NRC in connection with requests for generic and/or plant-specific review and approval.

In order to conform to the requirements of 10 CFR 2.390 of the Commission's regulations concerning the protection of proprietary information so submitted to the NRC, the information which is proprietary in the proprietary versions is contained within brackets, and where the proprietary information has been deleted in the non-proprietary versions, only the brackets remain (the information that was contained within the brackets in the proprietary versions having been deleted). The justification for claiming the information so designated as proprietary is indicated in both versions by means of lower case letters (a) through (f) located as a superscript immediately following the brackets enclosing each item of information being identified as proprietary or in the margin opposite such information. These lower case letters refer to the types of information Westinghouse customarily holds in confidence identified in Sections (4)(ii)(a) through (4)(ii)(f) of the affidavit accompanying this transmittal pursuant to 10 CFR 2.390(b)(1).

COPYRIGHT NOTICE

The reports transmitted herewith each bear a Westinghouse copyright notice. The NRC is permitted to make the number of copies of the information contained in these reports which are necessary for its internal use in connection with generic and plant-specific reviews and approvals as well as the issuance, denial, amendment, transfer, renewal, modification, suspension, revocation, or violation of a license, permit, order, or regulation subject to the requirements of 10 CFR 2.390 regarding restrictions on public disclosure to the extent such information has been identified as proprietary by Westinghouse, copyright protection notwithstanding. With respect to the non-proprietary versions of these reports, the NRC is permitted to make the number of copies beyond those necessary for its internal use which are necessary in order to have one copy available for public viewing in the appropriate docket files in the public document room in Washington, DC and in local public document rooms as may be required by NRC regulations if the number of copies submitted is insufficient for this purpose. Copies made by the NRC must include the copyright notice in all instances and the proprietary notice if the original was identified as proprietary.

ENCLOSURE 4

APP-GW-GLR-079 Revision 8, "AP1000 Verification of Water Sources for Long-Term Recirculation Cooling Following a LOCA"

(Non-Proprietary)

RECORD OF REVISIONS

Revision	Date	Description
2	February 2010	A complete reorganization and renumbering of sections was implemented to improve the presentation and continuity of the information in this report. Since these changes did not affect the content of the document, they are not reflected with Revision bars. The report was reorganized in order to present a more complete summary of all of the GSI-191 evaluations performed for the AP1000 design. The current organization of the report sections shows a progression through the various areas of GSI-191 evaluation. Changes to the content of the report are shown with Revision bars in the margin. The content changes include two types; one is information that was submitted to the in previous revisions to AP1000 GSI-191 reports and the other type is new information that being submitted in reports revised in February 2010. Most of these changes consisted of adding information that was already contained in previous revisions of other AP1000 GSI-191 documents, such as APP-PXS-GLR-001, Revision 3 and WCAP-17028-P, Revision 3. This information was presented in these separate reports but not included in TR26 (APP-GW-GLR-079) until now. Therefore these are changes to TR26 but not changes in the AP1000 GSI-191 overall evaluation. Some of the changes in TR26, Revision 7, are new or revised information that is contained in AP1000 GSI-191 documents issued in February 2010. Such information includes additional fuel assembly head loss tests performed (and documented in WCAP-17028-P, Revision 4), a statistical analysis of the fuel assembly test results (documented in APP-GW-GLR-092, Revision 0), and an evaluation of boric acid and trisodium phosphate plate-out on the fuel rods (APP-GW-GLR-110, Revision 0). Some of this information is included in TR26, Revision 7. "Section 2 – Technical Background" was deleted. This section previously provided an overall approach for GSI-191 evaluations. In the new report format, a brief overview of the report is provided in Section 1. And detailed discussions of evaluations and methodologies are found in the individual sections of the report (Sections 2 through 6).

Revision	Date	Description
3	See EDMS	Corrected the COL Information Item number format in Table 1-1 and Table 1-2. Updated coatings debris loadings from within the LOCA ZOI in Section 2.3.2 (related to RAI-SRP6.2.2-SPCV-25, Rev. 1). Coatings debris total updated in Section 2.5. Coatings debris and total debris loadings updated in Section 3.4 and Table 3-4. Discussion of screen head loss testing in Section 5.1.2 updated in regards to new coatings debris loadings. Section 5.2.4 updated in regards to MRI debris becoming lodged in refueling cavity drain check valves and potential backleakage through the valves (related to RAI-SRP6.2.2-CIB1-31, Rev. 1). Discussion of fuel assembly head loss testing in Section 6.1.2 updated in regards to new coatings debris loadings. Table 6-1 and Table 8-7 updated to match the results in Table 9-1 and Table 9-2 of WCAP-17028-P, Revision 6. Table 6-2 with LOCADM results was revised. The row headings for the first two cases were incorrectly reversed. The row headings are now corrected and the numerical results are updated to match the revision of Reference 7. Table 8-1 updated with new coatings debris loading data. Reference list updated with new revisions of references as applicable. One reference was removed and two were added to the list. Revision bars are not shown for minor editorial changes that were made to correct grammar and punctuation and that did not affect the technical content of the report.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

ADS	Automatic Depressurization System
CFR	Code of Federal Regulations
CL	Cold Leg
COL	Combined Operating License
CR	Containment Recirculation
CSS	Containment Spray System
CVS	Chemical and Volume Control
DBA	Design Basis Accident
DCD	Design Control Document
DECL	Double-Ended Cold Leg
DEDVI	Double-Ended Direct Vessel Injection Line
DEHL	Double-Ended Hot Leg
DP	Differential Pressure
DVI	Direct Vessel Injection Line
ECCS	Emergency Core Cooling System
FA	Fuel Assembly
GL	Generic Letter
GSI-191	Generic Safety Issue 191
HL	Hot Leg
I.D.	Inside Diameter
IOZ	Inorganic Zinc
IRWST	In-Containment Refueling Water Storage Tank
LOCA	Loss of Coolant Accident
LOCADM	Loss of Coolant Accident Deposition Model
LTC	Long-Term Cooling
MRI	Metal Reflective Insulation
NRC	Nuclear Regulatory Commission
NUREG	US Nuclear Regulatory Commission Technical Report Designation
OD	Outside Diameter

P&ID	Piping & Instrumentation Diagram
PCS	Passive Containment Cooling System
PRA	Probabilistic Risk Assessment
PRHR HX	Passive Residual Heat Removal Exchanger
PWR	Pressurized Water Reactor
PXS	Passive Core Cooling System
RCS	Reactor Cooling System
RNS	Normal Residual Heat Removal System
RV	Reactor Vessel
RVLIS	Reactor Vessel Level Instrumentation System
sec	seconds (unit of time)
SER	NRC Safety Evaluation Report
SPHSE	Self-Priming High Solids Epoxy
STC	Westinghouse Science and Technology Center
TSP	Trisodium Phosphate Dodecahydrate
WC/T	WCOBRA/TRAC, a LOCA computer code
WGOTHIC	a Containment computer code
ZOI	Zone of Influence (of a LOCA jet)

1 INTRODUCTION

1.1 REPORT CONTENT

The AP1000™[1] Nuclear Power Plant uses natural recirculation for cooling the core following a Loss of Coolant Accident (LOCA). This capability of the AP1000 plant is presented in the Design Control Document (DCD) (Reference 20). This technical report summarizes the evaluations and analyses performed for the AP1000 design to address issues raised in Nuclear Regulatory Commission (NRC) Generic Letter 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized Water Reactors" (Reference 3).

This report summarizes the Nuclear Regulatory Commission (NRC) Generic Safety Issue (GSI)-191 evaluations performed for the AP1000 design in order to respond to NRC Generic Letter (GL) 2004-02 (Reference 3). The areas of GSI-191 resolution discussed in this report include:

- Debris characterization (latent debris and LOCA-generated debris);
- Debris transport;
- Long-term cooling flows;
- Ex-Vessel Effects of Debris (includes screens and other components such as pumps and valves);
- In-Vessel Effects of Debris (includes effects on head loss and chemical deposition in the core).

Section 2 of this report begins by discussing the characteristics and loadings of the latent debris and LOCA-generated debris that is postulated to exist in the AP1000 containment. The debris types are then evaluated to consider the debris sizes and debris quantities that could transport to other locations within containment with the post-LOCA recirculating water. Debris transport is discussed in Section 3. The transported debris can affect long-term core cooling (LTC), since debris can build up at the core inlet and affect the flow of coolant into the core. Section 4 discusses the LTC analyses performed for the AP1000 and the resulting core flows when the core inlet experiences debris-induced pressure drops.

The effects of transported debris on components inside containment are categorized into Ex-Vessel Evaluations and In-Vessel Evaluations. The Ex-Vessel Evaluations discussed in Section 5 include such components as screens, piping, valves, and pumps. Ex-vessel components are evaluated to determine if the presence of debris in the containment recirculation water will adversely affect LTC. The In-Vessel Evaluations discussed in Section 6 focus on several aspects of the debris effects in the reactor vessel including the potential for debris to collect on the core inlet and the impact of debris and chemical precipitates on LTC.

[1] AP1000 is a trademark of the Westinghouse Electric Company.

1.2 COMBINED OPERATING LICENSE INFORMATION ITEMS

This technical report provides the information for closing the following Combined Operating License (COL) Information Item from AP1000 Design Control Document (DCD), Reference 20:

Table 1-1: Summary of COL Information Item 6.3-2

COL Information Item	Design Control Document Section and Title	Description
6.3-2 Verification of Containment Resident Particulate Debris Characteristics	6.3.8.2 Verification of Water Sources for Long Term Recirculation Cooling Following a LOCA	The Combined License applicants referencing the AP1000 will perform an evaluation consistent with Regulatory Guide 1.82, revision 3, and subsequently approved NRC guidance, to demonstrate that adequate long-term core cooling is available considering debris resulting from a LOCA together with debris that exists before a LOCA. As discussed in DCD subsection 6.3.2.2.7.1, a LOCA in the AP1000 does not generate fibrous debris due to damage to insulation or other materials included in the AP1000 design. The evaluation will consider resident fibers and particles that could be present considering the plant design, location, and containment cleanliness program. The determination of the characteristics of such resident debris will be based on sample measurements from operating plants. The evaluation will also consider the potential for the generation of chemical debris (precipitants). The potential to generate such debris will be determined considering the materials used inside the AP1000 containment, the post accident water chemistry of the AP1000, and the applicable research/testing.

In addition, this technical report presents an additional requirement that the containment cleanliness program must provide cleanliness conditions consistent with the conditions used for this evaluation. This is communicated as COL Information Item 6.3-1, shown here as it currently appears in DCD Revision 17:

Table 1-2: Summary of COL Information Item 6.3-1

COL Information Item	Design Control Document Section and Title	Description
6.3-1 Containment Cleanliness Program	6.3.8.1 Containment Cleanliness Program	The Combined License applicants referencing the AP1000 will address preparation of a program to limit the amount of debris that might be left in the containment following refueling and maintenance outages. The cleanliness program will limit the storage of outage materials (such as temporary scaffolding and tools) inside containment during power operation consistent with COL item 6.3.8.2.

Based on this report, the NRC should consider the above COL Information Item closure to be acceptable and applicable to COL applications using the AP1000 design certification as a reference.

2 DEBRIS CHARACTERIZATION

The AP1000 reactor containment building is designed both to contain radioactive material releases and to facilitate long-term core cooling in the event of a LOCA. Water discharged from a break is collected in the lower portion of the containment for recirculation to the core by the Passive Core Cooling System (PXS) as described in DCD Section 6.3.2.1.3. Steam is also condensed on the containment vessel and drains back into the in-containment refueling water storage tank (IRWST). The IRWST has screens that protect the inlets to discharge lines that drain this water back into the Reactor Coolant System (RCS) as described in DCD Section 6.3.2.1.3. The AP1000 Containment Recirculation (CR) Screens and IRWST screens protect the flow paths and components of the PXS from debris that is generated by a postulated pipe break and is then transported in the recirculating water.

The NRC identified its concern regarding maintaining adequate long-term core cooling in Generic Safety Issue 191 (GSI-191) "Assessment of Debris Accumulation on PWR Sump Performance". Generic Letter (GL) 2004-02 (Reference 3), issued in September 2004, identified actions that utilities must take to address the potential for the sump blockage. The NRC position is that plants must be able to demonstrate that debris transported to the sump screens or into the RCS after a LOCA will not lead to unacceptable head loss for the recirculating flow. For the AP1000, this requirement is interpreted as demonstrating that debris transported to CR screens, IRWST screens, or fuel assemblies will not challenge long-term core cooling by either significantly impeding flow through the PXS, impeding flow through the core, or adversely affecting the long-term operation of the PXS. The first step to demonstrate compliance with NRC GL 2004-02 (Reference 3) is to characterize the debris types, sizes, and loadings that can exist in the AP1000 containment.

Three potential sources of debris are evaluated for their impacts on the AP1000 recirculation flow path and long-term core cooling. These debris sources are:

1. Latent containment debris - Latent containment debris, or "resident containment debris" as it is sometimes called, is dirt, dust, lint, and other miscellaneous materials that might be present inside containment before the initiation of a LOCA.

2. ZOI coatings - Coatings located within the ZOI of a LOCA are assumed to fail as fines (small particles) and to transport to the screens or a flooded break location.

3. Post-accident chemical effects - Post-accident chemical effects are the result of containment sump fluid reacting chemically with materials inside containment and producing chemical products (precipitates).

The following sections contain evaluations of the debris characteristics and debris loadings of the three debris sources. [

]a,c

The post-accident chemical products were estimated using a spreadsheet tool generated by the PWR Owners Group and design features and materials of the AP1000.

2.1 AP1000 DESIGN FEATURES IMPACTING GSI-191

The following characteristics of the AP1000 design minimize the potential for a LOCA to generate debris that might challenge the recirculation flow path:

- Because passive safety systems are used and because there is no containment spray system used during a design basis accident (DBA) LOCA, the recirculation flow velocities are low, thereby minimizing the potential for debris transport.[2]

- There is no fibrous debris generated by the LOCA blowdown.

    - Metal reflective insulation (MRI), which contains no fibrous material, is used on components that may be subjected to jet impingement loads from a LOCA jet; MRI is not transported with the low velocities of the recirculating water. (Reference 13, DCD Tier 1, Table 2.2.3-4, Item 8c) Item ix) and Tier 2, Section 6.3.2.2.7.1).

    - Other sources of fibrous debris that might be generated post-LOCA include fire barriers and HVAC filters. Such sources are required to be located outside the zone of influence (ZOI) of a LOCA jet and above the maximum containment flood level during recirculation conditions.

    - Other insulation inside containment, but outside the ZOI, is jacketed in order to reduce the possibility of generating latent fibrous debris during maintenance operations. (Reference 13, DCD Tier 2, Section 6.3.2.2.7.1)

- Epoxy coatings applied to structures or to engineered components are required to have a dry film density $\geq$100 lbm/ft^3 so that the transport of small chips in the AP1000 containment is limited. The use of inorganic zinc (IOZ) inside containment is limited to the containment vessel and to applications where epoxy cannot be used; where IOZ is used it is required to be Safety-Service Level I to prevent detachment during a LOCA. (Reference 13, DCD Tier 2, Section 6.1.2.1.5)

- Protective plates, described in detail in Reference 2, guard the CR Screens against coatings and other debris falling onto or just in front of the CR Screens and being transported into the screens. There is also a 24-inch high weir attached to the floor at a distance 8 inches from the face of each CR screen. The function of this weir is to prevent higher density debris that have settled onto the floor from being swept into the lower level of the screens (Reference 2).

[2] The AP1000 does have a non-safety containment spray capability (injection only), which is available for use in a severe accident (beyond DBA), where core the melts. This capability is manually actuated (requiring a locked-closed manual valve to be opened). Operating procedures prevent the opening of this valve during a DBA LOCA.

- The routing of the gutter return pipe in the IRWST prevents debris from the gutter from entering the IRWST screens. The gutter return pipe extends downward near the bottom of the tank and well away from the IRWST screens so that debris will not be transported to the IRWST screens. The lowest filtering surface of the IRWST screens is located 6 inches above the floor of the IRWST. This design prevents higher density debris that have settled onto the floor of the IRWST from being swept into the lower portion of the IRWST screens (Reference 2).

- The coatings located within the jet impingement ZOI will be assumed to fail as fine particles and to be transported to screens or to the core as discussed in Section 2.3.2.

- Other potential sources of transportable material are caulking, signs, or equipment tags. These items must be made of stainless steel or another metal with a density ≥ 100 lbm/ft^3 when these items are installed inside containment below the maximum flood level or when they are located above the maximum flood level and not inside a cabinet or enclosure. The use of a high-density metal prevents the production of debris that could transport to the CR screens, IRWST screens, or into a double-ended cold leg (DECL) LOCA or double-ended direct vessel injection (DEDVI) LOCA break location that is submerged during recirculation. (Reference 13, DCD Tier 2, Section 6.3.2.2.7.1)

- The CR and IRWST screens use an advanced design and large surface areas to provide for the collection of debris on the screens without impacting recirculation flow. (Reference 9)

- Materials that might corrode and produce large quantities of chemical precipitates have been reduced. The amount of aluminum located inside containment that is located below the post-LOCA flood-up level is limited to 60 lbm. Note that there are some larger sources of aluminum located below the flood level; however, they are enclosed in stainless steel or titanium so that the aluminum is unable to react with post-LOCA recirculating water.

2.2 LATENT CONTAINMENT DEBRIS

[

]a,c

[

]a,c

- Specific consideration of "resident" debris - both fiber-form and particulate debris that accumulates on surfaces during plant construction, testing, and operations.

- [

  ]a,c

- The percentage of the total resident debris that is fiber was determined by laboratory analysis of debris taken from four plants (Reference 21) and test results showing the debris tolerance of the AP1000 fuel assembly (References 14 and 15).
- A containment cleanliness program that limits the types and amounts of resident debris in the AP1000. The AP1000 containment cleanliness program must limit resident debris to be consistent with this evaluation.

Operating PWRs have performed walkdowns in order to determine the amount of latent debris that may exist in their containment as a part of Generic Letter 2004-02 'Supplemental Responses and Close-Out' responses. Please note that these responses can be found on the NRC web site. This information is summarized in Table 2-1. In addition to the latent debris loading results from plant walkdowns, Table 2-1 also presents the latent debris loadings that the plants used in their GSI-191 downstream effects analyses.

Table 2-1: Operating PWR Latent Debris Amounts

a,c

2.2.1 Conservatisms in the AP1000 Latent Debris Assessment

There are several conservatisms inherent to the evaluation and use of the operating PWR latent debris data for the AP1000.

- [

  ]a,c

- AP1000 uses MRI insulation systems or a suitable equivalent. Fiberglass insulation used inside containment will be outside the ZOI and jacketed. Therefore it is expected that the AP1000 fibrous debris would be a small fraction of the total latent containment debris. For conservatism in the determination of the AP1000 latent debris loading, all of the operating PWR latent debris data in Table 2-1 will be utilized, which includes some high fiber plants.

2.2.2 Effect of Containment Size on Latent Debris Loading

In order to assess the applicability of the data in Table 2-1 to the AP1000 design, the effect of containment size on the amount of latent debris is evaluated. It is possible that larger containments might have more latent debris than smaller containments. Table 2-1 lists the containment inside diameter (I.D.) for a number of operating PWR plants, which is taken as a figure of merit for the containment size. The containment IDs range from 105 feet to 150 feet. The total amount of latent debris reported for each of these plants is plotted against their ID in Figure 2-1. The figure shows a wide range of latent debris loadings can exist for each containment size. This suggests that other factors, such as variations in utility cleanliness programs and practices, could have a more significant impact on the latent debris loading than containment size alone.

However, it is noted that there does seem to be a slight dependency of containment size as shown with the trend line displayed on the figure. As shown in Table 2-1, the average for all these plants is approximately 90 lbm of latent debris. The trend line indicates the latent debris varies from about 60 lbm for the smallest containments (105-foot ID) to about 120 lbm for the largest containments (150-foot ID). The AP1000 has a 130-foot ID containment which the trend line indicates would have about 92 lbm, which is close to the average for all of the containments. Review of the relationship between containment size and latent debris loading for operating PWRs does not provide any indications that this data is not applicable to the AP1000.

a,c

Figure 2-1: Operating PWR Latent Debris vs. Containment ID

2.2.3 Effects of Insulation Type on Latent Debris Loading

A comparison of the insulation types between the AP1000 design and the operating PWRs in Table 2-1 was performed in order to assess the applicability of the data in Table 2-1 to the AP1000 design. It is possible that the type of insulation used inside containment might affect the amount of latent debris. There is the possibility of generating some latent debris as insulation is removed and re-installed during shutdown maintenance. Table 2-1 lists the dominant insulation used inside the reactor containment building of thirty-four operating PWRs. For seven of the plants, this information is not listed. Fifteen plants are indicated to be low fiber and twelve plants are indicated to be high fiber. The average latent debris load for the low fiber plants is 94 lbm and the average for the high fiber plants is 73 lbm. This suggests that other factors, such as variations in utility cleanliness programs, have a more significant impact on the latent debris loading than insulation type alone. Review of the relationship between insulation types used in containment and latent debris loading for operating PWRs does not provide any indications that this data is not applicable to the AP1000.

2.2.4 Total Latent Debris Amount for AP1000

The complete latent debris evaluation for the AP1000 is contained in Reference 22. The conclusions from the evaluation are:

- Plants can maintain low total amounts of latent debris.
  - Average total amount is approximately 90 lbm.
  - 8 plants have less than 50 lbm.
- The licensing commitment for these plants is:
  - 18 plants use less than 200 lbm.
  - 16 plants use 150 lbm or less.
- The latent debris walkdown data from the operating PWRs is applicable to the AP1000.
  - The containment size and type of insulation used do not obviate the use of the operating PWR data on the AP1000.

As a result of this evaluation, it will be assumed that the AP1000 containment may contain as much as 130 lbm of total latent debris.

2.2.5 Latent Fiber Evaluation

The data provided in NUREG/CR-6877 (Reference 21), "Characterization and Head-Loss Testing of Latent Debris from Pressurized-Water-Reactor Containment Buildings", supports the position that the amount of latent fiber found in operating PWRs that have performed latent debris walkdowns is small, as opposed to the generic 15% provided in the NRC Safety Evaluation Report (SER) on NEI 04-07. Both NUREG/CR-6877 and the data in the Generic Letter 2004-02 "Supplemental Responses and Close-Out" responses support the fact that the mass of latent debris calculated for the AP1000 (Reference 22) is in line with debris masses found and reported in operating PWRs.

Using the data provided in Table 2 of NUREG/CR-6877 (presented in Table 2-2 below), it is seen that 3 of the 4 plants evaluated in the manner described in the NEI 04-07 SER have less than 7.5% fiber in their latent debris totals. Table 2-2 illustrates that the average fibrous debris load of the four plants is 7% and two of the four plants had less than 4% fiber.

Of thirty-four plants sampled for responses to Generic Letter 2004-02, "Supplemental Responses and Close-Out", only one has proposed a fiber content less than 15%. This plant performed a debris characterization per the NEI 04-07 SER and concluded that an appropriate latent fiber fraction should be 2.7%. Observations from other plant walkdowns included statements such as "dust with no fiber", "visual inspection showed very little fiber content", and "visual examination of the debris showed very little fiber", further indicating that the assumption that 15% of latent debris is fiber is conservative.

Table 2-2: Operating PWR Latent Debris Fiber Concentrations a,c

The amount of fiber in the latent debris proposed for the AP1000 [

][a,c]

2.3 POST-LOCA COATINGS DEBRIS

2.3.1 Coatings Outside the LOCA Zone of Influence (ZOI)

Coatings on the inside surface of the containment shell are either untopcoated inorganic zinc (IOZ) or an epoxy. IOZ will only be used on the containment shell or on surfaces that may be exposed to temperatures that are above the limits of epoxy coatings during normal operating conditions; IOZ coatings used in such applications are required to be Safety – Service Level I to prevent detachment during a LOCA. The coatings inside containment on concrete surfaces and steel surfaces are a self-priming high solids epoxy (SPHSE). These SPHSE coatings are Nonsafety Service Level II. For these coatings outside of the LOCA ZOI, the epoxy coatings are assumed to fail as small chips.

There are several design features which limit the transport of coatings debris and the effects of such debris on the RCS. The epoxy coatings applied inside containment are required to have a dry film density ≥ 100 lbm/ft^3 so that the transport of small chips of epoxy debris to the screens or to the core is limited in the AP1000 post LOCA conditions, including low recirculation velocities, long delays between the accident and the start of recirculation (Reference 13, DCD Tier 2, Sections 6.1.2.1.5 and 6.1.2.1.6). Another AP1000 design feature that prevents the transport of small coatings chips are the protective plates for the CR screens. The CR screens have protective plates that, along with the low flow velocities post-LOCA, prevent coatings debris above the screens from entering the screen. Coatings are not applied to surfaces under the plates in the vicinity of the screens. The low flow velocities and the large floor area of the containment sump, where coatings debris can settle out, limit the coatings debris that could transport into the CR screens.

2.3.2 Coatings Inside the LOCA Zone of Influence (ZOI)

For current operating PWRs, coatings composed of IOZ within a sphere of a radius equal to 10 inside diameters (ID) of the broken pipe will fail as fines (small particles) and as a result will be transported in the recirculating water along with the latent debris. Also, epoxy coatings within a sphere of a radius equal to 4 ID of the broken pipe will be assumed to fail as fines and add to the total debris transported by the recirculating water. These same assumptions are applied to the AP1000. Using those assumptions the quantity of LOCA-generated coatings debris for the AP1000 was determined based upon AP1000 specific materials and surface areas located within ZOIs (Reference 30).

- With an epoxy coating thickness of [ ]^{a,c} mils and a dry film density of [ ]^{a,c}, there would be about [ ]^{a,c} lbm of epoxy debris from the limiting break of a cold leg (CL) pipe which has an ID of 22 inches. Note that the AP1000 is expected to have less coatings inside containment because the plant is simplified such that it has fewer valves, pipes, pipe supports, and snubbers, compared to an operating PWR. Since epoxy coatings have a lower density (by a factor of ~4) than inorganic zinc coatings, the predominance of epoxy coatings also reduces the mass of ZOI coatings in the AP1000.

- The amount of AP1000 IOZ debris was also determined. The amount of post-LOCA IOZ debris is [ ]^{a,c} lbm for the limiting DECL LOCA. This result is consistent with the AP1000 limitations on the use of IOZ which, except for the containment vessel, only allow its use on hot surfaces of components where epoxy coatings are not practical.

- The total amount of coating debris inside the ZOI for the limiting DECL break is selected to be 70 lbm including margin.

The limit of 70 lbm of LOCA-generated coatings debris is applicable for DECL and DEDVI LOCAs. The LOCA-generated coatings debris load for a DEHL LOCA could be larger, upwards of [ ]^{a,c} lbm. Since a DEHL LOCA has been shown to not be limiting for the AP1000, the coatings debris loading of 70 lbm that was established for DECL and DEDVI LOCAs will be utilized as a basis in subsequent GSI-191 evaluations. An explanation why the DEHL LOCA is not limiting for AP1000 GSI-191 is discussed in Section 3.3.3. A more detailed discussion of the application of the coatings debris load is discussed in the sections on screen head loss testing (Section 5.1) and fuel assembly head loss testing (Section 6.1).

2.4 POST-LOCA CHEMICAL EFFECTS

A consideration in evaluating the effects of the debris transported to the sump after a LOCA is the chemical products which may form in the post-LOCA sump environment. Materials present in containment may dissolve or corrode when exposed to the reactor coolant. This reaction would result in oxide particulate corrosion products and the potential for the formation of precipitates due to changes in temperature and reactions with other dissolved materials. These chemical products could become another source of debris loading and could impact sump screen performance and recirculation flow.

An analysis was performed to determine the type and quantity of chemical precipitates which may form in the post-LOCA recirculation fluid for the AP1000 design (Reference 23). The analysis evaluated these post-LOCA chemical effects using the methodology developed in WCAP-16530-NP-A, "Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191" (Reference 6). The purpose of the bench testing and calculation methods documented in WCAP-16530-NP-A was to characterize the type and quantity of precipitates formed using a chemical model evaluation, and to support the downstream effects evaluation using the chemical precipitates predicted in the chemical effects model. These data and methods have been used to evaluate post-accident chemical effects and support sump screen performance testing for operating PWRs. These data and methods are applicable to the AP1000 for the following reasons:

1. The base chemical composition of the containment materials in the AP1000 was determined to be consistent with the classification groups listed in WCAP-16530-NP-A.

2. The sump temperature transient is within the bench test temperature range of [ ]a,c

3. The sump pH transient for the AP1000 is within the range of 4.1 to 12.0 evaluated in WCAP-16530-NP-A.

4. The buffering agent for the PXS in the AP1000 plant is trisodium phosphate dodecahydrate (TSP), which was one of the buffering agents included in the bench testing.

Therefore, considering the above, the data and calculation methods described in WCAP-16530-NP-A are applicable to the AP1000 design.

Table 2-3 lists the predicted chemical precipitates from the AP1000 chemical model evaluation using conservative amounts of containment debris as inputs. The results have been calculated using the minimum post-accident recirculation volume of coolant for the AP1000. Table 2-3 also lists the chemical precipitates in terms of a mass concentration using the minimum recirculation water volume.

a,c

Table 2-3: AP1000 Predicted Chemical Precipitate Formation			

Note that the AP1000 has several features that significantly reduce the amounts of materials that could contribute to the formation of chemical precipitates. The AP1000 containment has little concrete that can come in contact with the post-accident water as a result of the use of structural-steel module construction. The only identified aluminum in the AP1000 containment is in the excore detectors. These detectors are enclosed (in stainless steel or titanium) so that post-accident containment water will not circulate against the aluminum. The AP1000 DCD Tier 1, Table 2.2.3-4 item 8c) xiv) requires inspection of the excore detectors and ensures that they are enclosed in stainless steel or titanium (Reference 20). In addition, the amount of exposed aluminum that is located below the maximum containment flood-up level is limited to 60 lbm. This requirement is contained in DCD subsection 6.1.1.4 (Reference 13).

A sensitivity evaluation was also performed to determine the additional precipitate generation that might occur from zinc materials in containment being exposed to the sump liquid. This sensitivity evaluation determined that less than 1 kg of zinc is released into solution when the limiting case was considered. This amount is relatively small and is determined to be negligible to the overall precipitate generation.

2.5 SUMMARY OF DEBRIS

The latent debris and post-LOCA debris loadings for the AP1000 design are as follows:

- 130 lbm total latent debris.
  - 6.6 lbm of latent debris is fiber.
  - 123.4 lbm of latent debris is particulate.
- LOCA-generated debris:
  - 70 lbm LOCA-generated coatings debris.
  - 57 lbm of post-LOCA chemical precipitates.

3 DEBRIS TRANSPORT

The industry has provided guidance in NEI 04-07 (Reference 18) for the selection of break locations within a PWR and the corresponding effects on debris generation and composition. Westinghouse has reviewed Reference 18 and determined that, considering the design features of the AP1000 and the conservative transport assumptions made for AP1000, this reference is not applicable to the AP1000. It should be noted that many of the criteria in Reference 18 are intended to determine the break locations that produce limiting amounts and compositions of debris that can be generated and transported to the screens. The situation is different for the AP1000 because of its design.

In the AP1000, different LOCA break locations do not generate different amounts and compositions of fibrous debris to be transported to the screens. The reason for this is that AP1000, unlike many other current operating PWRs, does not use a variety of insulation types (such as fiberglass) or other materials that can be damaged by a LOCA jet and subsequently transported to the screens. AP1000 uses metal reflective insulation (MRI) insulation or a suitable equivalent in the locations where insulation may be damaged by LOCA jets. The density of the MRI material combined with the low recirculation velocities ensures that any debris generated by the damage of this insulation material will settle to the containment floor and not be transported to the screens or to a flooded break location.

The bulk of the post-accident particulate debris is due to resident debris; however, some amount of particles may be generated by a LOCA jet impingement on coatings. The coatings particulate debris generated within the ZOI are assumed to be fines and are therefore assumed to transport with the recirculating water.

The requirement to use high-density coatings (dry film density ≥ 100 lbm/ft^3) inside containment, together with the other AP1000 features (including low water velocities and shield plates over the CR screens), results in no epoxy coating debris from outside of the ZOI being transported to the screens. Also, the requirement to use signs and tags made from high-density (≥ 100 lbm/ft^3) materials results in none of this debris being transported to the screens.

The only types of debris assumed to transport with the recirculating water are latent fiber, latent particulate, LOCA-generated coatings debris fines from within the ZOI, and post-LOCA chemical precipitates. In order to provide a simple, bounding set of conditions for evaluating the transport of debris to the AP1000 screens and to the core, the following conservative assumption is made: all of the latent debris, ZOI coatings debris, and post-LOCA chemical precipitates are assumed to transport and none is assumed to settle out.

The following sections describe the methods of debris transport applied to the AP1000 design. For different postulated break locations, different amounts of containment debris can transport to the CR screens, IRWST screens, and the core.

3.1 DEBRIS TRANSPORT TO CONTAINMENT RECIRCULATION SCREENS

Debris present on the various containment surfaces and components can be transported within the AP1000 containment by different mechanisms, including: being carried along by the motion of slowly-moving recirculating water that forms the pool in the reactor containment building basement, jetting of steam/water mixtures expelled through the break, wetting from liquid drops (caused by condensation and not by containment spray) falling from the containment dome (center region), and wetting from water film flowing down the containment walls during passive containment cooling system (PCS) operation. It is important to note that, during a postulated accident, the majority of condensation is returned to the IRWST through filming on the walls and not through drops falling from the dome directly onto the operating deck. For different postulated break locations, the total mass of latent containment debris is divided into three categories: debris that can migrate to the CR Screens, debris that can migrate to the IRWST Screens, and debris that does not transport to either set of screens. It is again noted that the Westinghouse AP1000 design differs from the current PWR designs in that no containment spray can be used during a DBA LOCA.

It is conservatively assumed that 100% of the total latent debris, ZOI coatings debris, and post-LOCA chemical precipitates located inside the AP1000 containment are assumed to transport to the containment recirculation screens.

3.2 DEBRIS TRANSPORT TO IRWST SCREENS

As previously discussed, the majority of post-LOCA condensation inside containment is returned to the IRWST through filming on the walls and not through drops falling from the dome onto the operating deck. The following conservative assumptions are made for debris transport to the IRWST screens.

- 50% of the latent fibrous debris is assumed to transport to the IRWST screens. This assumption is very conservative because :
    - The IRWST is a closed tank and the only way for latent debris to be transported into the tank is through the IRWST gutter. During normal plant operation, the gutter drains to the normal containment sump and not into the IRWST.
    - The IRWST gutter is designed to return steam condensate flowing down the containment shell to the IRWST in an accident. Based on industry and NRC guidance, the vertical surface of the containment shell will have a relatively light load of debris.
    - The IRWST gutter is located at the operating deck elevation; much of the latent debris will be located below this elevation and therefore cannot be transported to the gutter.
    - For the most part, latent debris located on the operating deck will be transported down to the lower parts of the containment and not into the gutter. Reasons for this are:
        - The operating deck is flat.
        - There is a several-inch-high lip around the operating deck that prevents water lying on the operating deck from draining to the gutter.
        - The operating deck has many openings that allow water on the deck to spill down to the lower parts of the containment. The edges of these openings do not have lips.

  - Some latent debris could be transported to the gutter by the discharge of flow from a break located above the operating deck. Such a break would only affect a small portion of the total operating deck area.

- 100% of the particles (i.e., latent particles and post-LOCA coatings debris) and 100% of the post-LOCA chemical precipitates are assumed to transport to the IRWST screens.

  - This is a conservative assumption since it is possible for some of the particles and chemical precipitate loading to collect at the CR screens and core inlet if debris beds of fiber and particulate were to accumulate at those locations.

3.3 DEBRIS TRANSPORT TO THE CORE

For the AP1000, some LOCA break locations will be flooded during long-term recirculation operation because of the relatively high containment flood-up elevation ([ ]a,c Reference 29). During such operation, a portion of the recirculation flow will enter the RCS through the break and will not be screened. The unscreened water can transport debris into the core.

The determination of the percentage of the debris that might be transported into the RCS without screening by the containment recirculation screens is determined by integrating the relative recirculation flows through the break and through the PXS. This calculation is performed for a DEDVI LOCA at the reactor vessel nozzle and for a DECL LOCA at the reactor vessel nozzle (Reference 27). The flow rates in through the break and through the PXS are obtained from WCOBRA/TRAC long-term core cooling cases. [

]a,c

3.3.1 Flow Split for DEDVI LOCA

The DEDVI LOCA is assumed to occur in the loop compartment at the reactor vessel nozzle to maximize the flow into the reactor vessel through the break. This break location also makes all of the fiber in containment available for transport in through the break; a DEDVI LOCA in a PXS room only has access to a small amount of the containment fiber debris, since all of the water that recirculates back into the room is screened by the CR or IRWST screens. Water begins to flow into the reactor vessel through the break at [ ]a,c post-LOCA, when the containment water level has risen above the break location. Containment recirculation through the PXS begins at [ ]a,c post-LOCA when the

IRWST has dropped to the level where the recirculation valves are actuated. At this time [ ]^{a,c}, the estimated flows from WCOBRA/TRAC are [ ]^{a,c} These flows are conservatively held constant for the remainder of the calculation. The calculation is summarized in Table 3-1.

[ ]^{a,c}

Table 3-1: Flow Split Through DEDVI LOCA Break vs PXS Recirculation Paths

a,c

[

]a,c This table should only be used for support of the DEDVI LOCA flow split. An explanation of portions of the calculation are provided below.

- The "total" columns contain the integrated flow from the beginning of the event. These water masses are stepwise integrated as follows:
  - The break flow is [

    ]a,c
  - Repeating this process for the next time step: [

    ]a,c

3.3.2 Flow Split for DECL LOCA

The DECL LOCA is assumed to occur at the inlet nozzle to maximize the flow into the reactor vessel through the break. Water begins to flow into the reactor vessel through the break at [ ]a,c post-LOCA, when the containment water level has risen above the break location. Containment recirculation through the PXS begins at [ ]a,c post-LOCA when the IRWST has dropped to the level where the recirculation valves are actuated. At this time, the estimated flows from WCOBRA/TRAC are [
]a,c These flows are conservatively held constant for the remainder of the calculation. The calculation is summarized in Table 3-2.

[

]a,c

Table 3-2: Flow Split Through DECL LOCA Break vs PXS Recirculation Paths

a,c

[ ]a,c The results from this table should only be used to support the DECL LOCA flow split.

3.3.3 Comparison of Break Location for Flow Split

A DECL LOCA at the inlet nozzle is the most limiting break with regards to debris loading at the core inlet.

1. For a DECL LOCA, the flow split between the [

]^{a,c}

2. For hot leg breaks up to and including a DEHL LOCA, the location of the break makes these breaks less limiting for the transport of debris into the core. There are several reason for this, including:

   a. For a DEHL LOCA, all of the water that enters the core through the downcomer will come from PXS. Water that enters the core through the downcomer from the DVI injection lines will be filtered and will contain essentially no fiber. With the AP1000 flows/velocities and screen design (hole size) the fiber bypass through screen is 1%. With the small amount of fiber in the AP1000, this would result in insignificant fiber transport through the PXS to the core inlet. As a result, there would be insufficient fiber to form a debris bed in the core inlet.

   b. Water can enter the RV through the HL break,. Some of this water is expected to leave the RCS through the HL break as a result of the counter-current flow driven by the RCS pressure fluctuations. Some of this water is expected to leave the RCS through the ADS Stage 4 lines. These discharges would limit the amount of debris able to be transported into the core.

   c. Debris that does enter through the HL and is not discharged from the RCS can enter the upper portion of the core via recirculation that occurs with down flow through outer FAs. Debris that is not captured in the outer FAs can cross over and then up through central FAs. FA debris tests have been conducted for the AP1000 that demonstrate that debris beds will not form in the presence of the two phase flow conditions that will exist in the upper portion of the core where the debris entering the RCS from a flooded HL LOCA might transport (Reference 14). In addition even if a bed did form in outer FAs where down flow circulation could exist, it will be dissolved as soon as up flow of steam occurs. Steam up flow will occur before a debris bed can significantly restrict core cooling. Note that the PXS injection flow path is still available to provide injection to the downcomer to support core cooling.

The results for the DECL LOCA flow split show that the percentage of flow entering the reactor vessel through the flooded broken CL is approximately [ ]^{a,c}. This flow split will be conservatively rounded up to 90%. Therefore it is conservatively assumed that 90% of the debris that could transport to the containment recirculation screens is transported into the RCS through a flooded DECL LOCA break. This assumption will be used in subsequent evaluations of the effects of transported debris on core inlet flow and long-term core cooling.

3.3.4 Minimum Time to Transport Debris to the Core

The flow split calculations were developed to estimate the maximum flow split between recirculation through a break and the PXS. Assumptions were made in the supporting analyses that maximized this flow split but which are not conservative for core cooling. Some of those assumptions include use of a minimum flow resistance through the break and assuming that the single failure was not one of the ADS stage 4 valves. Reference 17 documents LTC analysis sensitivity studies that show the impact of debris-induced pressure drop (DP) on the core and screens on core cooling. These studies use assumptions that are indeed limiting for core cooling.

The purpose of the section is to demonstrate that the maximum core inlet DP due to debris occurs at a time of 9 hours or later following a LOCA. The fuel assembly debris-induced head loss tests, which are described in detail in Section 6.1, serve as the basis for demonstrating when the maximum DP at the core inlet occurs due to the buildup of debris. The test results obtained from the concurrent debris addition tests (CIBAP22, CIBAP24 through CIBAP34, and CIBAP36 and 37) show that the maximum resistance (of the debris bed) DP will occur at a time much later than the 9 hours. Note that the LTC analyses (Reference 17) conservatively used a shorter time (8.6 hours). Table 3-3 shows, for each of the concurrent debris addition tests, the time when the maximum resistance DP occurred in terms of hours after the first debris addition, the quantity of chemicals added before the occurrence of the maximum resistance DP, and the time after the LOCA when the maximum resistance DP occurred. In each of the tests, the fibers and the particles were added in 7 hours, while the additions of chemicals were based on the production rate expected for the plant. The addition rate of the fibers and particles is considered consistent with respect to what the plant is expected to experience.

Table 3-3: Maximum Resistance DP in Concurrent Debris Addition FA Head Loss Tests

a,c

The tests were intended to explore the effect of the debris transport to the core over a period of 30 days after the LOCA. After all of the fibers and particles were added the rate of chemical production was accelerated such that 30 days worth of chemical production was added in less than 1 day. The last column of the table lists the time when the DP due to maximum debris bed resistance would occur in the plant after the LOCA. That quantity of chemicals in the test was compared to the post-accident chemical effects evaluation performed for the AP1000 (Reference 23). Note that even if the fibers and particles were added several hours faster, the earliest maximum resistance DP would remain well beyond the time of 8.6 hours used in the LTC analyses.

3.4 SUMMARY OF DEBRIS TRANSPORT

Based on the previous discussions, Table 3-4 shows the latent debris amounts for the AP1000 for the case in which maximum debris is transported to the core. This table lists the total amounts of debris and how much is transported. This table is based on the limiting LOCA case, a DECL LOCA. The total latent debris in containment is assumed to be [

]a,c

a,c

Table 3-4: AP1000 Debris Summary

4 LONG-TERM CORE COOLING EVALUATIONS

A long-term cooling analysis is provided in the AP1000 Design Control Document (DCD) Revision 17 (Reference 20) to demonstrate that the passive systems provide adequate emergency core cooling system performance during IRWST injection and containment recirculation time period. The long-term cooling analysis is performed using the WCOBRA/TRAC computer code to verify that the passive injection system is providing sufficient flow to the reactor vessel to cool the core and to preclude boron precipitation.

4.1 DCD LTC CASE

The long-term cooling case analyzed in the DCD is a DEDVI line break in one of the PXS valve rooms. This case was selected because it is the most limiting long-term core cooling case; it exhibits the highest decay power and lowest available liquid driving head. The DEDVI break results in one of the IRWST injection lines spilling directly to the containment and as a result, the IRWST drains faster and containment recirculation is initiated earlier with higher core decay power. Because the break location is in one of the PXS rooms, the containment flood volume is greater and the containment water level during recirculation is lower.

In the AP1000 DCD LTC Case, the long-term cooling phase begins after the simultaneous opening of the isolation valves in the IRWST DVI lines and the opening of ADS Stage 4 squib valves when injection flow from the IRWST has been fully established. A continuous analysis of the post-LOCA long-term cooling is provided in the DCD from the time of stable IRWST injection through the time of sump recirculation for the DEDVI break. Maximum design resistances are applied in WCOBRA/TRAC for both the ADS Stage 4 flow paths and the IRWST injection and containment recirculation flow paths.

4.2 LTC SENSITIVITY CASES WITH DEBRIS-INDUCED RESISTANCES

Numerous sensitivity studies were performed based upon the AP1000 DCD LTC case (Reference 17). The objective of the sensitivity studies was to demonstrate that core cooling margins are maintained when large, arbitrary, non-mechanistic head losses are added to the CR screens, IRWST screens, and the core inlet. The head losses applied to the sensitivity studies bound the expected head losses at these locations. WCOBRA/TRAC was used to perform these sensitivity studies. The long-term cooling following a DEDVI break was selected as the basis for the following reasons:

- A DECL LOCA or DEDVI LOCA location results in a significant amount of debris bypassing the CR screens and being transported into the core through the flooded break. Hot leg breaks and elevated breaks would result in much less debris transport to the core inlet.

- A break location in the loop compartment maximizes the amount of debris that can be transported to the core. A DEDVI LOCA in a PXS room would only have available a small portion of the total debris, since all of the water flow that recirculates into the room passes through the CR or the IRWST screens.

- A DEDVI LOCA results in the lowest break elevation on the cold leg side. The elevation of the calculated break is adequate to ensure flow through the core. A DEDVI LOCA maximizes the impact of increased head loss across the core. The lower elevation of the DEDVI break also allows water from containment to flow into the RCS through the break sooner than for a DECL LOCA.

- A DEDVI LOCA results in higher decay heat levels at the time recirculation begins compared to a DECL LOCA. With a DEDVI LOCA, a portion of the IRWST injection flow will spill out of the break into containment, thereby reducing the time of IRWST injection. The start of recirculation for a DEDVI LOCA is sooner than for a DECL LOCA, as is shown in Section 3.3.

- A DEDVI break in a PXS room reduces the final flood-up level compared with a DECL or DEDVI LOCA outside of the PXS rooms.

The sensitivity cases are performed for DEDVI breaks in a PXS room and in the loop compartment adjacent to the DVI line vessel inlet nozzle, in order to identify the potential impact of debris on LTC. Sensitivity Studies 1, 2, and 3 were performed at the start of recirculation (7200 seconds) when a small portion of the debris could have been transported into the RCS. Sensitivity Studies 4 through 10 were performed at a time 8.6 hours post-LOCA. This is a conservative estimate of the time needed to transport the maximum debris load to the core inlet. This assumption maximizes the debris load at the core inlet, thereby maximizing the debris-induced pressure drop and minimizing the core inlet flow.

The Sensitivity Studies will be referred to as cases for the remainder of the discussion in the section. Case 1 considers a moderate increase in the core and screen pressure drops due to debris blockage. Cases 2 and 3 increase these pressure drops. In Case 3, the core inlet pressure drop is assumed to be a resistance (K/A^2) equal to 158.2 ft^{-4}. This is the highest core inlet debris-induced resistance assumed for Cases 1 through 3. The screen pressure drops in Case 3 are the same as in Case 2 and are assumed to be a resistance (K/A^2) of 51.39 ft^{-4} for each set of screens.

The results of Case 3 include a core flow of 111 lbm/sec, comprised of 56 lbm/sec through the intact DVI line and 55 lbm/sec through the broken DVI line. This core inlet flow has a debris-induced pressure drop of 3.5 psi. The results of Case 3 also demonstrate long-term cooling performance comparable to the DCD LTC Case.

Cases 4 through 10 evaluate the LTC of the AP1000 at a time 8.6 hours post-LOCA. This is conservatively estimated to be the time at which all of the debris is transported to the core inlet to create the maximum debris-induced pressure drop. The resistance at the core inlet is varied for each case. Since the objective of these cases is to maximize the debris-induced resistance at the core inlet, the screens resistances are not increased beyond the resistance assumed for the DCD LTC case. Cases 4 through 10 evaluate DEDVI LOCAs in a PXS room and also in the loop compartment close to the RV DVI nozzle. The case with the most limiting core flow is Case 10. Case 10 evaluated a DEDVI LOCA in the loop compartment close to the RV DVI nozzle with a core inlet debris-induced resistance (K/A^2) of 761.8 ft^{-4}. The resulting core inlet flow was 65 lbm/sec with a pressure drop of 4.1 psi. The results of Case 10 also demonstrate long-term cooling performance comparable to the DCD LTC Case.

Sensitivity Case 11 models a DEDVI break in the loop compartment close to the RV DVI nozzle, and the core outlet pressure drop is based on a resistance (K/A^2) of 1.13 ft^{-4}, with no added screen pressure drop. In this case the added debris resistance is applied to the core exit in order to provide insights into the impact of containment debris entering the upper part of the core during a postulated hot leg break LOCA. Because postulated debris would be introduced into the upper plenum during a hot leg break scenario, no increase in the core entrance flow resistance above the value associated with normal plant power operation is modeled. This case is executed at the core power level associated with 31,000 seconds post-LOCA time to transport sump debris into the reactor vessel, using the bounding 10CFR50, Appendix K decay heat assumption. The resulting injection flow rate through the lower resistance broken DVI line (138.5 lbm/sec) is greater than it is through the intact DVI line (76 lbm/sec). The core flow is predicted to be 214.5 lbm/sec with an average pressure loss of 2 psid at the core exit where the added debris resistance was applied. The results of Case 11 also demonstrate long-term cooling performance comparable to the DCD LTC Case.

The results of Case 3 and Case 10 serve as the basis for the acceptance criteria for fuel assembly head loss testing discussed in Section 6.1 of this report. The results of Case 10 provide an acceptable core flow and debris-induced core inlet pressure drop for times after 8.6 hours post-LOCA. The assumed debris-induced resistance at the core inlet is assumed to be caused by the maximum loading of debris that can transport to the core inlet. And the decay heat at 8.6 hours post-LOCA is the highest value of decay heat between 8.6 hours and later times.

The results from Case 3 provide acceptable values of core flow and core inlet debris-induced pressure drop for times less than 8.6 hours post-LOCA. The decay heat at 7200 seconds in Case 3 is the highest decay heat value between the initiation of recirculation (at 7200 seconds) and when Case 10 was analyzed (at 8.6 hours post-LOCA). Therefore the results from Case 3 provide acceptable values of core flow and core inlet debris-induced pressure drop for times less than 8.6 hours post-LOCA.

The results of Case 11 provide acceptable values of core flow and debris-induced pressure drop for application to fuel assembly head loss testing that evaluated DEHL LOCAs, discussed in Section 6.1 of this report.

5 EX-VESSEL EVALUATIONS

Ex-vessel evaluations describe a set of evaluations performed to assess the impact of debris in the post-LOCA recirculating water on components outside of the reactor vessel. AP1000 ex-vessel components evaluated for post-LOCA debris effects include CR screens, IRWST screens, pumps, valves, heat exchangers, orifices, instrumentation tubing, and piping. The methods of evaluating the effects of the debris vary amongst the types of components. Detailed discussions and results of the AP1000 ex-vessel evaluations are provided in the following sections.

5.1 CONTAINMENT RECIRCULATION AND IRWST SCREENS

5.1.1 Screen Design

The AP1000 has two CR Screens and three IRWST Screens. To be consistent with the response of the nuclear industry to NRC guidance on the evaluation of sump screens, the AP1000 screen sizes have been made significantly larger compared to the original AP1000 design. This increase is judged to be prudent because of the standardized approach for the AP1000 design, the potential for additional industry testing and regulatory guidance, and the reduced impact of incorporating larger screens at this time.

The AP1000 screen designs have complex geometries which provide greater screen areas in a given volume and which allow the screens to tolerate larger debris loads with acceptable head losses; the design of these screens is described in detail in Reference 2.

5.1.2 Screen Head Loss Testing

This section summarizes screen head loss experiments that were conducted for AP1000 as part of the response for the AP1000 design to Generic Safety Issue (GSI)-191 and Generic Letter (GL) 2004-02 (Reference 3). The performance of the CR screens and the IRWST screens were confirmed and demonstrated under debris loading conditions (including chemical effects) that address the bounding set of AP1000 specific debris loadings. Debris loadings for the containment screens include particulates and fibrous materials, as well as chemical precipitates that may form in the containment water pool. The screen head loss testing is documented in detail in References 8 and 9.

[

]a,c

Two tests are identified as design basis tests for the AP1000 CR and IRWST screens. Surrogate particulate debris was first introduced to the test flume, followed by the introduction of fiberglass fibers as surrogate fibrous debris. The chemical surrogate was mixed outside of the flume and added to the flume water following the method approved in WCAP-16530-NP-A (Reference 6) for chemical particulate generation for the design basis tests. Negligible pressure drop was observed with these two design basis tests, thus demonstrating acceptable head loss performance for the hydraulic and debris loading conditions for the design basis debris load.

The screen testing for the AP1000 showed that there was no fiber bed formation. This conclusion is based on there being no pressure drop (DP) increase resulting from the addition of debris to the screens. Since there was no fiber bed formation, a small increase in the amount of particles will not impact the screen DP. Therefore the assumption that 70 lbm of the particulate debris load is LOCA-generated coatings debris remains valid. This coatings debris load is applicable to DECL and DEDVI LOCAs. The particle loading [ ]a,c in the two design basis tests was about twice the current licensing limit of 193.4 lbm particles (123.4 lbm latent particles and 70 lbm coatings debris). The margin on the particle debris load [ ]a,c used in these tests also bounds additional coatings debris particles from a DEHL LOCA. No additional screen testing is needed to account for the increase in the coatings debris loading (an approximate [ ]a,c lbm of additional particles) that could be generated from a DEHL LOCA.

Three additional tests were performed as engineering evaluations to examine the sensitivity to the manner in which the chemical constituents might enter the water. In the engineering evaluation tests, water solutions of the ions assumed to be created in solution were added and the influence on the resulting screen pressure differential was recorded. As expected, these engineering evaluation runs showed that the design basis test provides the most conservative manner of loading the recirculation screens and the tests showed acceptable results for all loadings considered.

The testing performed for the AP1000 screen design demonstrates that the collection of debris during post-LOCA recirculation operation on the pocket-design CR and IRWST screens will not cause head losses that will challenge long-term core cooling or the ability to maintain a coolable core geometry under the expected AP1000 debris loading conditions.

5.1.3 Screen Flashing Discussion

The water in the IRWST is normally subcooled throughout most of a LOCA transient. [

]a,c

The minimum water level in the IRWST occurs during recirculation operation. This level can vary from several feet above the top of the IRWST screen to a few inches above the top of the screen. In addition, after a couple weeks post-LOCA, the IRWST level might drop further (below the top of the IRWST screens) if the three unflooded rooms (two passive core cooling system (PXS) rooms and the chemical and volume control system (CVS) room) eventually flood (weeks after a LOCA) due to leakage through walls or back through floor drain check valves.

The minimum water level case considered here [

][a,c] This minimum water level above the IRWST screen, combined with an approximate zero-inch pressure drop across the IRWST screen using design basis flow rates and debris loading, provides added assurance that there will be no voiding of saturated liquid as it passes through the IRWST screen.

5.2 OTHER EX-VESSEL EVALUATIONS

5.2.1 Ex-Vessel Downstream Effects Evaluation Methods

The data and methods used to evaluate ex-vessel downstream effects are outlined in Revision 1 of WCAP-16406-P-A (Reference 10). The evaluation methods identified in Reference 10 that are applicable to long-term core cooling recirculation flow paths associated with the AP1000 passive core cooling system design include valve evaluations for plugging and erosive wear as described in Sections 7 and 8 and Appendix F of Reference 10. The screening criteria for valves identified in Reference 10 are applicable to valves in the long-term core cooling recirculation flow path of PWRs. Only the explosively-actuated (squib) valves in the post-LOCA AP1000 flow path are not covered by the screening criteria. Once the squib valves are open, they exhibit, very closely, the characteristics of a standard gate valve.

Some AP1000 design features eliminate the need for downstream effects evaluations of components that are included in Reference 10. Evaluations of the PXS excluded by the AP1000 design include:

- Pump evaluations, including hydraulic performance, disaster bushing performance, and vibration analysis. There are no safety-related pumps in the AP1000 passive core-cooling flow paths to evaluate.

- Heat exchanger evaluations for both plugging and erosive wear. There are no safety-related heat exchangers in the AP1000 passive core cooling flow paths.

- Orifice evaluations for plugging and erosive wear as described in Sections 7 and 8 and Appendix F of Reference 10. There are no orifices in the post-LOCA PXS recirculation flow path of the AP1000 design.

- Settling of debris in instrumentation lines as described in Section 8 of Reference 10. No instrumentation lines used in the AP1000 post-LOCA PXS flow path design are required to support a safety-related function.

- Containment Spray System (CSS) evaluation from Reference 10. The AP1000 does not have a conventional CSS. The non-safety containment spray function is not permitted to be used during a DBA LOCA. Therefore, this system is excluded from consideration of the AP1000 design.

Therefore only the valve and piping evaluations in Reference 10 were applied to the AP1000 PXS.

The Normal Residual Heat Removal System (RNS) is not a safety-related system, but may also be used to accomplish post-accident long-term core cooling at the discretion of the plant operators if the system and its components are operable; it is a redundant system that provides for "defense in depth" for long-term core cooling. In the DCD Chapter 15 safety analysis, RNS operation is not assumed to be available post-accident because the system is not safety-related. Without RNS operation, the PXS provides the necessary core cooling using natural circulation driven by decay heat and hydrostatic pressure heads. If the RNS is available, the RNS pumps can be used to inject / recirculate water into the RCS and provide cooling through heat exchangers. During this operation, the containment isolation capability of the RNS lines is maintained.

Therefore the evaluation methods in Reference 10 were applied to the RNS valves, pumps, heat exchangers, orifices, instrumentation tubing, and piping.

5.2.2 PXS Downstream Effects

The evaluation included each valve and associated piping in the recirculation path of the PXS. The methodology and acceptance criteria used are described in Reference 10. The complete PXS downstream effects calculation is documented in Reference 24.

The equipment in the post-LOCA PXS flow path was identified using current P&IDs for the AP1000 PXS. The AP1000 PXS P&IDs show no pumps, heat exchangers, orifices, or spray nozzles in the PXS. The following two tables show the components that are in the AP1000 long term core cooling flow path. Table 5-1 describes the containment recirculation flow path and Table 5-2 describes the IRWST injection flow path.

Table 5-1: PXS - Containment Recirculation Flow Path

a,c

Table 5-2: PXS - IRWST Injection Flow Path

a,c

In order to apply erosive wear rate models, the debris size and concentration was first assessed. The debris loadings used for the evaluations were highly conservative quantities determined in Reference 22. These conservative quantities provide a large margin over the debris quantities defined as the design-basis debris loadings in Section 3 of this report.

Each identified valve in the PXS was evaluated [

]a,c

All instrumentation sensors in the PXS recirculation lines are strapped to the outside of the piping. Therefore, there are no instrumentation tubes or sensing lines to evaluate for potential debris collection in the tubes or sensing lines. In addition, no reactor vessel level instrumentation system (RVLIS) or RVLIS-like system is required to be operational post-LOCA for long-term core cooling. Therefore, no evaluation was needed.

For completeness, the potential debris collection in the PXS flow lines is evaluated. Based on the minimum flow rates for the PXS flow lines, it has been determined that the transverse velocity is sufficient to prevent debris settlement in the PXS flow lines.

In summary, the evaluation performed using the applicable methods and models in Reference 10 demonstrates that the AP1000 PXS equipment used in post-LOCA recirculation is acceptable for the expected debris loading in the recirculating fluid resulting from a postulated LOCA.

5.2.3 RNS Downstream Effects

Utilizing methods from Reference 10, downstream effects evaluations were performed for the RNS. The complete RNS downstream effects calculation is documented in Reference 25. Note that the RNS is not a safety-related system, although it is modeled in the Probabilistic Risk Assessment (PRA).

Based on the evaluation criteria of Reference 10, the majority of the valves used in the RNS met the screening criteria and required no further evaluation for erosive wear and plugging. This evaluation demonstrated that the RNS containment isolation valves would not be susceptible to plugging or erosion damage that would prevent them from performing their containment isolation function should that become necessary during RNS operation. Four of the AP1000 RNS valves used in the post-LOCA RNS recirculation required further plugging and wear evaluations. These evaluations showed that these four valves, throttle globe valves V006A/B and V008A/B, are not susceptible to plugging or failure by erosive wear, confirming that their RNS throttling function would not be compromised.

For the two RNS pumps, the effect of debris ingestion was evaluated on three aspects of operability, including hydraulic performance, mechanical shaft seal assembly performance, and mechanical performance (vibration). The hydraulic and mechanical performances of the AP1000 RNS pumps were determined to not be affected by the recirculating sump debris. The mechanical shaft seal assembly performance evaluation resulted in a change to the procurement specification so that the RNS pumps' backup seal bushings use a more wear resistant material, such as bronze.

The AP1000 RNS heat exchangers and orifices were evaluated for the effects of erosive wear for a mission time of 30 days. The erosive wear on these components was determined to be insufficient to affect the system performance. The smallest clearance found for the AP1000 heat exchangers and orifices is 0.620 inches for the heat exchangers; therefore, no blockage of the RNS flow paths is expected with the current sump screen hole size of 0.0625 inches.

The RNS piping, including relevant instrumentation tubing, was evaluated. There is no reactor vessel level instrumentation system (RVLIS) in the AP1000 RNS. The RNS flow lines were evaluated for debris settlement and it was determined that the minimum flow through the RNS greatly exceeded the minimum flow that would allow settlement. Therefore any instrumentation tubing on the RNS piping is not susceptible to blockage.

5.2.4 AP1000 Refueling Cavity Drain Lines

NEI 04-07 (References 18 and 19) provides the methodology guidance to perform a baseline sump performance evaluation. The types of insulation found in the AP1000 containment dictate the direction in which the evaluation is performed. The AP1000 is highly compartmentalized and insulated with MRI in the zone of influence (ZOI) and has two 6-inch drain connections (Figure 9.1-6 sheet 1, Reference 20) located in the refueling cavity. The drain line splits into two lines outside the cavity and separately penetrates the refueling cavity wall. Inside the refueling cavity, the lines end with a downward-facing 90° elbow which prevents debris that might enter the cavity from falling directly into the drain lines.

Section 3.4.3.2 of Reference 19 provides a discussion of the debris size distributions that have been used in various studies and specifies a two-size distribution for material inside the zone of influence (ZOI) of a postulated break for the baseline evaluation. [

]^{a,c} Small fines are defined as any material that could transport through gratings, trash racks, and/or radiological protection fences by blowdown, containment sprays, or post-accident pool flows. Furthermore, small fines are assumed to be the basic constituent of the material for latent debris and coatings (in the form of individual fibers, particles, and pigments, respectively). Reference 18, Section 3.4.3.2, assumes the largest openings of the gratings, trash racks, or radiological protection fences to be less than a nominal 4 inches (less than 20 square inches total open area) and classifies the remaining material that cannot pass through gratings, trash racks, and radiological fences as large pieces. The MRI is sufficiently dense and the flow rates are also sufficiently small that the MRI debris is not transported to the AP1000 CR screens.

Reference 19, Sections 3.6.3.1, 3.6.3.2, and 3.6.3.3, which address the highly compartmentalized, mostly uncompartmentalized, and ice condenser containments, respectively, primarily contain compartmental-specific debris transport assumptions. Table 3-4 of Reference 19 summarizes these assumptions for the small fines debris generated within the ZOI. The baseline guidance recommends that all debris generated outside the ZOI be treated as small fines debris that is subsequently transported to the sump screens (i.e., 100% transports to the sump pool and no transport into the inactive pools). The baseline guidance recommends the assumption that all of the large piece debris deposits onto the containment bottom floor, where it remains. The NEI 04-07 (Reference 18) guideline adopts the value of 75% for small fines and

25% for large pieces as the size distribution of any type of MRI inside a pipe break ZOI. For highly compartmentalized containments such as the AP1000, 25% of the MRI debris generated is large pieces and 75% of the MRI debris generated is in the form of small fines. 25% (~18% of the total MRI destroyed) of the small fines is assumed to be ejected to upper containment and 75% (~56% of the total MRI destroyed) of the small fines are deposited directly to the sump pool floor.

Since only a small percentage of MRI in the ZOI may be ejected to the upper containment and even less into the refueling cavity, MRI debris is not expected to block the 6-inch refueling cavity drain lines or to be transported into the drain lines. In the unlikely event that some MRI debris is transported into the refueling cavity drain lines, the transported debris would not be flat sheets, but rather small pieces of deformed metal that would pass through the pipe and check valves. Thus, the coolant that is spilled into the refueling canal would drain into the lower compartment of the AP1000 reactor containment building. In addition, when the containment water level rose above the drain pipe elevation, the back pressure applied to the check valves would cause them to close.

Even though it is considered unlikely for latent debris to be trapped inside both of the series drain check valves and to interfere with their ability to close, such a possibility has been evaluated as a sensitivity study (Reference 31). This study determined that gross back leakage through both check valves of [ ]^{a,c} gpm could be tolerated and still provide adequate long-term core cooling. Both of the long-term cooling cases (Case 3 and Case 10 from Reference 17) were evaluated. Case 3 was determined to be limiting. In this case, the check valve leakage reduced the containment level from its minimum initial level of [ ]^{a,c} ft to a value greater than the level used in the Case 3 LTC analysis (107.8 ft) at the time Case 3 was analyzed (2.6 hr). The containment level would eventually drop to [ ]^{a,c} ft (when the containment and the refueling cavity equilibrated at the same level) about [ ]^{a,c} hours after the LOCA. When the containment level drops to this lower level the containment recirculation rate is estimated to decrease by about [ ]^{a,c} percent. With the long time required for the level to decrease (> [ ]^{a,c} hr) and the small decrease in flow, the recirculation flow rate is able to remove decay heat even with the large check valve leakage assumed.

Another part of the study estimated how far open the disc in these swing disc check valves would have to be blocked open in order to allow such a large leak. That opening was estimated to be about [ ]^{a,c} inch. In addition it was estimated that there would be a significant force (about [ ]^{a,c} lb_f) working to close the check valves.

The conclusion i reached is that even with a gross back leakage of about [ ]^{a,c} gpm through the two series refueling cavity drain check valves that LTC would still be provided. In addition, the possibility of such a leak occurring is not considered credible considering the likelihood of transporting debris into the check valves, having debris be trapped in both valves, and having both valves be blocked more to create a [ ]^{a,c} inch unimpeded flow opening that can withstand such a large closing force.

6 IN-VESSEL EVALUATIONS

In-vessel evaluations describe a set of evaluations performed to assess the impact of debris in the post-LOCA recirculating water on components inside of the reactor vessel. AP1000 in-vessel components evaluated for post-LOCA debris effects include the core inlet and fuel assemblies. Fuel assembly head loss testing was performed to evaluate the effects of debris in the post-LOCA recirculating water on flow through the fuel assemblies. The ability of the fuel rods to become scaled with chemicals in the post-LOCA recirculating coolant was evaluated to determine the effects on maintaining effective heat transfer from the fuel rods to the coolant.

6.1 FUEL ASSEMBLY HEAD LOSS TESTING

6.1.1 Fuel Assembly Testing Discussion

Westinghouse has performed a series of experiments to quantify the effect of latent debris and post-LOCA debris, including containment chemical effects, on the head loss across the fuel assemblies of an AP1000 during a postulated LOCA. The fuel assembly debris bed head loss experiments that were conducted for the AP1000 design in consideration of Generic Safety Issue (GSI)-191, "Assessment of Debris Accumulation on PWR Sump Performance" are documented in WCAP-17028 (References 14 and 15).

The experiments, performed at the Westinghouse Science and Technology Center (STC) in Churchill, PA, used a fuel assembly design consistent with that described in Section 4.2.2.2 of the AP1000 DCD (Reference 20). The flow rates and debris loadings were selected to conservatively bound those conditions expected following a postulated LOCA for the AP1000 as defined in the DCD (References 13 and 20). The debris load for the AP1000, including both particulate, fiber, and chemical effects, has been significantly reduced by design (Reference 14 and 15). The fuel assembly, debris loads, and flow rates are directly applicable to the AP1000 as described in Sections 4.0, 5.0, and 7.0 of WCAP-17028 (References 14 and 15).

The data from this test program demonstrates the ability of the AP1000 to provide assurance of long-term core cooling under debris loading conditions expected for the AP1000 following a postulated LOCA. Thirty-nine head loss experiments were performed that investigated a spectrum of fibrous and particulate debris loads and chemical effects. The experiments investigated sensitivities to:

- Variations in the debris loads (Particulate, fiber, and chemical precipitates).
- Different fiber lengths and materials (fiberglass and others).
- Flow oscillations (simulating cyclic flow variations seen in AP1000 LTC testing and analysis), as well as flow decreases from the beginning to the end of tests (simulating the impact of debris head loss increase on the natural circulation flow process of the AP1000 passive systems).
- Sequence of debris additions, including sequential (all particles then all fibers, then all chemicals) and concurrent (simultaneous particle, fiber, and chemical additions).
- Water temperature and other chemicals [ ]a,c

Most of the tests were conducted to simulate DEDVI and DECL LOCA conditions, however three of the tests simulated DEHL LOCA conditions.

6.1.2 Fuel Assembly Testing Summary of Results

The thirty-nine assembly head-loss experiments that were performed for the AP1000 design investigated a spectrum of fibrous and particulate debris loads and chemical effects. Data from thirty-five of these experiments indicate that the design basis amount of debris that might exist in an AP1000 containment resulted in [

]a,c Thus, results from thirty-five of these experiments demonstrate the ability of the AP1000 to provide reasonable assurance of long term core cooling under the fibrous and particulate debris loading and chemical effects conditions expected for the AP1000 following a postulated LOCA. Four of the thirty-nine tests were evaluated to be invalid tests due to either a deviation from the approved test procedure or an equipment malfunction during the performance of the test.

Based upon the test results, Test CIBAP27 was selected as the limiting test for DEDVI and DECL LOCAs. The test procedure of the limiting test was used as a basis for further testing. The further testing included several repeat tests, tests with an increased water temperature and other chemicals [

]a,c

Considering the entire FA test program, all of the tests met the acceptance criteria. The repeat tests showed that there was considerable variation from test to test, using the same test procedure (e.g. flows, debris amounts, and debris addition timing). The variations included non-uniform debris bed buildup within the FA and gaps that sometimes developed in the debris bed during the test. This characteristic indicates that considering an AP1000 core with 157 FAs, that the debris bed in one FA will be different from the debris bed in another FA. In addition, the FA tests showed that the FA debris-induced head loss was concentrated across the bottom nozzle and P-grid. In some of the concurrent debris tests, the DP measured at upper locations in the FA was always less than the DP across the inlet nozzle and P-grid. The debris is not expected to distribute uniformly across the entire core inlet and therefore some FAs will have more debris buildup than other FAs. The FAs with less debris buildup will experience less debris-induced DP across the FA and will be able to pass more flow. The higher flows through these low-DP FAs would cross over to assist cooling FAs that have a higher DP and lower flow at the core inlet.

A statistical analysis of the test program results determined that the probability for a single fuel assembly to exceed the acceptance criteria of 4.1 psi is less than [ ]a,c (Reference 26).

Therefore, there is a low probability that a few of the 157 FAs in the AP1000 core could build up a debris bed that could exceed the acceptance criteria. However, many of the FAs in the core will have debris beds that have lower resistances than the acceptance criteria. The results of the statistical analysis of the AP1000 FA debris testing (Reference 26) show that the effective core inlet adjusted DP would be [

]a,c, which demonstrates considerable margin to the acceptance criterion of 4.1 psi.

The NRC has performed TRACE analyses (Reference 28) which show that crossflow through and around the rod bundles can exist in core areas where blockages do not exist. Crossflow in the reactor core downstream of the blocked inlet area provides sufficient flow and cooling to adequately maintain acceptable clad temperatures for all cases analyzed. The TRACE analysis was performed for a double ended cold leg break (DECLB) for the periods before and after the start of recirculation. The analysis results using the TRACE computer code show that the PWR core can be sufficiently cooled in the recirculation phase with inlet blockage conditions up to 94.8%.

The FA head loss testing included an extra 20 lbm of particles, above the previously estimated 50 lbm from LOCA-generated coatings debris. Sensitivity tests performed during the AP1000 FA testing program determined that the limiting DP across the FA was caused with fewer particles in the recirculating water. Therefore the assumption that 70 lbm of the particulate debris load is LOCA-generated coatings debris remains valid. This coatings debris load is applicable to DECL and DEDVI LOCAs. No additional testing is needed to account for the increase in the coatings debris loading (an approximate 30 lbm of additional particles) that could be generated from a DEHL LOCA. FA testing for a DEHL break has shown that debris transported into the core through the flooded HL break [

]^{a,c}

The testing performed for the AP1000 fuel assembly demonstrates that the collection of debris during post LOCA recirculation operation will not cause head losses that will challenge long-term core cooling or maintenance of a coolable core geometry under the expected AP1000 debris loading conditions.

As noted above, these experiments demonstrate that the AP1000 design provides for [

]^{a,c} A summary of results from the test program is presented in Table 6-1.

Table 6-1: Summary of Results from Fuel Assembly Head Loss Tests

a,c

6.2 FUEL ROD CHEMICAL DEPOSITION

6.2.1 Boric Acid and Trisodium Phosphate Evaluation

During a LOCA, the AP1000 PXS design utilizes automatic depressurization (ADS) valves connected to the hot legs (HL) to reduce the reactor coolant system (RCS) pressure in a controlled fashion to allow continued injection of water into the RCS from passive water supplies. Once open, this flow path vents considerable quantities of water as well as steam from the RCS. The water that leaves through these valves carries boron and other chemicals out of the RCS which automatically and effectively limits the buildup of these chemicals in the core. For AP1000 the maximum concentration of boron in the core has been determined to be less than 7400 ppm boron. The solubility temperature of boron at this concentration is only 50°F and as a result there is no concern with precipitation in the lower plenum during LTC following a LOCA.

A series of bench-scale test were conducted by Westinghouse to investigate the nucleate boiling heat transfer characteristics of unbuffered and buffered boric acid solutions. These tests included concentrations of boric acid and trisodium phosphate (TSP) that were equal to and greater than those concentrations that will occur in the AP1000 following a LOCA. However, the [

]^{a,c} Therefore additional PWR heated rod testing in the presence of boric acid solution with decay heat level heat input and low pressure was reviewed, and can be applied to AP1000. Additional heated rod testing includes rod-bundle geometries and multi-rod full-height slab core geometry. These tests generally show the following precipitation behavior in the heated rod region:

- No bulk precipitation in the heated rod region.
- No local precipitation observed in the non-boiling region of the heated rods.
- Some local precipitation may be observed in the boiling region near the two-phase mixture level if the core would become uncovered. The boric acid precipitation form is usually amorphous however and can be redissolved in the presence of a continuous liquid phase.

These more prototypical geometries of the multi-rod and rod bundle tests displayed precipitation behavior in the heated rod region that was consistent with the single heated rod testing for un-buffered boric and boric acid buffered with TSP. All tests showed that solute deposition on the heated rods could only be achieved by deliberately reducing the two-phase mixture level into the heated region. Deposition was not observed on the heated rods when they were covered by either a single or two-phase mixture at decay heat power levels.

Deposition of boric acid or boric acid buffered with TSP is not expected to occur during post-LOCA conditions in the AP1000 since the heated core region has been shown to always be covered by a two-phase mixture. (Reference 11)

6.2.2 LOCADM Evaluation

With respect to downstream effects associated with the core, the potential for deposition of post-LOCA chemical products on the fuel cladding and the consequential effects on clad temperatures can be addressed using the methods developed and documented in WCAP-16793-NP, Revision 1 (Reference 12). This evaluation method was developed to be generically applicable to all PWRs.

There is a concern that debris could also collect at the fuel assembly grids. The Nuclear Regulatory Commission (NRC) identified its concern regarding maintaining adequate long-term core cooling in GSI 191. Generic Letter (GL) 2004-02 (Reference 3), issued in September 2004, identified actions that utilities must take to address the sump screen blockage issue. The NRC's position is that plants must be able to demonstrate that debris transported to the sump screen after a LOCA will not lead to unacceptable head loss for the recirculation pumps, will not impede flow through the Emergency Core Cooling System (ECCS), and will not adversely affect the long-term operation of the ECCS.

To demonstrate acceptable AP1000 long term core cooling performance, an evaluation was performed to account for chemical reactions within the coolant that could lead to deposition of material within the core. The evaluation for the AP1000 accounted for the unique features of the AP1000 design. These features include those that significantly reduce the amounts of materials that could contribute to the formation of chemical precipitates, as well as the absence of containment spray during a LOCA and safety injection pumps to provide long term core cooling.

As noted in this report, the AP1000 has several features that significantly reduce the amounts of materials that could contribute to the formation of chemical precipitates. The AP1000 containment has little concrete that can come in contact with the post accident water as a result of the use of structural steel module construction. The only identified aluminum in the AP1000 containment is in the excore detectors. These detectors are enclosed in stainless steel or titanium so that post accident containment water will not circulate against the aluminum. Therefore, this mass of aluminum is excluded from the post-LOCA chemical reaction. However, for conservatism, an aluminum mass of 60 lbm is used to assess the post-LOCA chemical reactions in the calculations.

6.2.2.1 LOCADM Method and Assumptions

The calculation method of the LOCADM spreadsheet is described in WCAP-16793-NP, Revision 1 (Reference 12). The AP1000 LOCADM evaluation makes some simplifications to the required inputs that are conservative. These data and methods are applicable to the AP1000 for the following reasons:

- This evaluation effectively increases the aluminum surface area to conservatively account for the zinc release from galvanized steel. It is conservative to increase the aluminum amounts because the aluminum release rate is greater than that of any other material used in this evaluation. Although the rate of core deposition for both aluminum and zinc are different, a bounding thermal conductivity for the chemical deposition on the fuel cladding is evaluated regardless of the material being deposited in the core.

- This evaluation uses what is called "The Pre-Filled Reactor and Sump Option". Use of this option assumes that the entire sump volume is present in the sump at time t = 0, precluding the need to specify individual break flow rates. This is also conservative, because modeling the sump as full at the start of the transient allows the chemical reactions to begin at time t = 0 and provides for the calculation of a greater amount of chemical precipitate deposition on the fuel.

- Although the AP1000 design precludes large amounts of aluminum from making contact with post accident containment recirculation fluids, a mass of 60 lbm of aluminum is used for conservatism.

- This evaluation uses a method to modify aluminum release rate to satisfy NRC concerns about the trend of the predicted aluminum corrosion. Including this method effectively doubles the release rate during the initial portion of the event, yet holds fixed the total aluminum mass release. This is also conservative, because the release rate of aluminum is increased early in the transient when the deposition on the fuel is greatest due to high core decay heat rates and the boiling associated with the removal of that decay heat.

- This evaluation determines the impact of chemical precipitate deposition on fuel rods resulting from the formulation of chemical precipitates in the post-LOCA recirculation pool environment. The LOCADM calculation method conservatively assumes that all of the chemical precipitates generated in the post-LOCA environment are transported into the core and that the chemical precipitates produced can only be depleted through core deposition over the thirty-day length of the calculation. The calculation conservatively assumes that there is no deposition of chemical precipitates anywhere else in the recirculation pool, such as on the CR screens.

- This evaluation accounts for the AP1000 plant design, which has automatic depressurization system (ADS) stage 4 valves in the hot-leg that, once actuated, vent significant quantities of water along with steam from the core to the containment throughout the LOCA event. This behavior was modeled in the LOCADM spreadsheet by defining core injection flow rates that exceeded the boiloff rate by an amount that was less than the amount calculated in the AP1000 long term core cooling accident analysis (Reference 20, DCD Tier 2, Section 15.6.5.4C).

Fibrous Debris in LOCADM

In addition to the chemical precipitates, the fibrous debris that may transport into the core is also considered in the LOCADM calculation. This consideration is done through a "bump-up" factor which adds scale buildup on the fuel related to the amount of fiber transported into the core. The "bump-up" factor in LOCADM is "independent of the type, diameter, or length of the fiber" and independent of the source of the fiber (screen pass-through or break bypass). The "bump-up" factor is set such that the total mass of deposits on the core after 30 days is increased by the best estimate of the mass of the fiber that may reach the core.

It is conservative to use the "bump-up" factor method that was developed for current operating PWRs to address the possibility that fiber debris may bypass the sump screens and be available for deposition on the fuel cladding in the AP1000.

Including fibers in the AP1000 LOCADM evaluation provides for a plant-specific effect that is based on the screen design and debris mix of that plant. The application of the "bump-up" factor to the AP1000 is consistent with current operating PWRs and accounts for fibrous material in the recirculating coolant that may reach the fuel.

The AP1000 plant design precludes the use of un-jacketed fiberglass insulation and therefore it does not have a source of post-accident-generated fiberglass debris. A quantitative estimate of the effect of the latent fibrous debris on chemical-deposit thickness and fuel temperature is accounted for in the AP1000 LOCADM calculation by use of the "bump-up" factor applied to the initial debris inputs. The use of the "bump-up" factor in the AP1000 LOCADM calculation is appropriate because, although the amount of fibrous and particulate debris is small and the fibrous component of that amount is smaller still, it is possible that some of the fibrous debris in the AP1000 containment may bypass the fuel bottom nozzle and protective grid and enter the core.

The "bump-up" factor for the AP1000 accounts for this postulated bypass of latent fibrous debris by increasing the mass of chemical precipitates that may be deposited on the fuel. In effect, the mass of latent fibrous-debris bypass is treated as post-accident chemical precipitates for the purpose of evaluating deposition in the core. This allows the bypassed material to be deposited on the fuel in the same manner as the chemical-reaction products with the same low thermal conductivity as those chemical reaction products.

The "bump-up" factor is implemented in the LOCADM calculation on a mass basis. The basis for the "bump-up" factor is the assumption that all of the latent fibrous debris mass will pass through the bottom nozzles and protective grids of the fuel and enter the core. To implement the "bump-up" factor, all materials that contribute to the formation of chemical precipitates are increased by a uniform percentage so that the resulting precipitates available for deposition have increased by approximately the amount of latent fibrous debris assumed for the AP1000. This conservative method is independent of the type, diameter, or length of the fiber.

Conservatisms in the "Bump-up" Factor Specific to AP1000

The application of the "bump-up" factor to the AP1000 LOCADM evaluation is conservative for several reasons. The quantity of latent fiber that is assumed in calculating the "bump-up" factor is based upon a conservatively high debris loading calculated in Reference 22. This is the same debris loading used in the ex-vessel downstream effects to evaluate the effects of debris in the recirculating water on pumps, valves, and other components in the post-LOCA recirculation flow paths. This conservative amount of fiber, 22.5 lbm, bounds the expected latent fiber quantity of 6.6 lbm.

The thermal conductivity assumed for the scale buildup on the fuel rods is also conservative when considering the latent fiber as part of the fuel rod post-LOCA scale. Typical types of fibers that might be found inside a currently operating reactor containment building include fiberglass, cotton, nylon, polyester, and human hair. The thermal conductivity of dry natural fibers such as cotton (0.02 BTU/ft-h-°F) and manmade fibers such as nylon and polyester (0.144 and 0.13, BTU/ft-h-°F) is compromised when the fibers become saturated with water, as is the case in a post-LOCA environment. The thermal conductivity of these saturated fibers rises significantly, trending towards the value of water at the ambient conditions saturating the fibrous material (~0.40 BTU/ft-h-°F) (Reference 16). The conclusion is that these fibers have a heat conductivity when wet that is much higher than the heat conductivity used for the chemical scale in the LOCADM evaluation (0.11 BTU/ft-h-°F). This is conservative for the

LOCADM evaluation. One of the acceptance criteria is that the fuel cladding temperature after the start of recirculation must not exceed 800 °F. Using a value of heat conductivity for the scale on the fuel rods that is lower than the heat conductivity of wet fibers conservatively estimates higher fuel cladding temperatures since less heat will be transferred through the scale buildup.

As previously mentioned, it is conservative to assume that the entire fibrous latent debris load can reach the fuel rods and deposit on the rods with chemical precipitates. It is possible for fibers to be caught in other locations upstream of the fuel rods. The latent fiber in the AP1000 containment may include a variety of fiber materials that may be longer and thicker than fiberglass fibers. Because the bottom nozzle and the protective grid present a limiting hole size similar to the six mesh holes in the recirculation screens, it is expected that the fiber-capture capability of the bottom nozzle and the protective grid would allow fewer longer and thicker fibers to penetrate the "strainer" than the shorter thinner fibers.

Long fibers would tend to be captured and retained by the debris filter bottom nozzle and protective grid of the fuel located at the core entrance. Thus, the fuel design inhibits the passage of long fibers into the active core itself. Short small-diameter fibers are considered more conservative than the thick large-diameter fibers that are the constituents of fibrous debris for the following reasons:

- A given fiber, regardless of diameter, has only one point of contact.
- NUREG/CR-6877 (Reference 21) suggests that the diameter of latent fibrous debris is greater than that of fiberglass by as much as 2 to 1.
- A single fiber, in and of itself, will not impact heat transfer from the fuel. Therefore groups of fibers must be considered to evaluate their potential to impact heat transfer.

Consider first that the fibers configure themselves in a parallel orientation to the fuel rod with square or hexagonal packing (these are the most efficient packing configurations, allowing the least amount of space between fibers).

The packing ratio for these configurations will be equal to the ratio of "occupied" cross-sectional area to total cross-sectional area for a given configuration. As the fiber diameters increase, the area of unoccupied space must also increase. As the area of unoccupied space increases, the amount of water available to fill in the unoccupied space also increases, allowing for greater heat transfer. The larger the fiber diameter, the greater the interstitial free space, and the greater the heat transfer.

Longer, thicker fibers will tend to be trapped in the fuel assembly inlet nozzle and not be transported to the fuel rods. For smaller thinner fibers transported to the fuel rods, the best packing of the fibers would result in significant voids that would result in better heat transfer than the amount assumed in the LOCADM code. Considering all the locations upstream of the fuel rods where fibers could be caught, it is highly conservative to assume that the entire fibrous latent debris load transports into the core and deposits on the fuel rods with the chemical precipitates.

6.2.2.2 AP1000 Conditions for LOCADM

The evaluation was performed with the LOCADM spreadsheet using AP1000 plant-specific data. The purpose of this evaluation was to use the LOCADM spreadsheet to predict the growth of fuel cladding deposits and to determine the clad/oxide interface temperature that results from coolant impurities entering the core following a LOCA. Three scenarios were evaluated with LOCADM for the AP1000 design (Reference 7):

1. Maximum sump volume – maximum water volume results in lower concentrations of post-accident chemical products.

2. Minimum sump volume – minimum water volume results in higher concentrations of post-accident chemical products.

3. Minimum sump volume with fibrous debris "bump-up" – minimum water volume and implementation of a "bump-up" factor results in the highest concentration of post-accident chemical products.

The AP1000 is expected to have results similar to, or less severe, than those of operating PWRs with similar post-accident chemical loading, chemical concentrations, flow rates, and core power profiles.

6.2.2.3 Acceptance Criteria

As noted in WCAP-16793-NP, Revision 1 (Reference 12), the stated acceptance criterion is that the maximum cladding temperature maintained during periods when the core is covered will not exceed a core average clad temperature of 800°F (426.7°C). This acceptance basis is applied after the initial quench of the core and is consistent with the long-term core cooling requirements stated in 10 CFR 50.46 (b)(4) and 10 CFR 50.46 (b)(5).

An additional acceptance criterion is to demonstrate that the total debris deposition on the fuel rods (oxide + crud + precipitate) is less than 50 mils (1270 μm). The 50 mil thickness is the maximum acceptable deposition thickness before bridging of adjacent fuel rods by debris is predicted to occur. The 50 mils of solid precipitation described here include the clad oxide, crud layer and debris deposition. The oxide and crud are buildup on the fuel rods from normal operating conditions and are present before the LOCA occurs. The results of this evaluation are presented in Table 6-2 below and discussed in the following text.

6.2.2.4 Results

Maximum sump volume

For the maximum sump water volume case, use of the LOCADM spreadsheet predicted a maximum
[

]^{a,c} (Reference 7).

Minimum sump volume

For the minimum sump water volume case, use of the LOCADM spreadsheet predicted a maximum [

]^{a,c} (Reference 7).

Limiting Case - Minimum sump volume with fibrous debris "bump-up"

For the minimum sump water volume case, the LOCADM spreadsheet was also run with increased quantities of debris – in accordance with the "bump-up" factor methodology described in Reference 12. For the limiting case, the LOCADM spreadsheet predicted a maximum LOCA scale thickness of 1.25 mils (31.69 μm). When added to the pre-accident oxide thickness of 5.984 mils (152 μm) and pre-accident crud thickness of 5.512 mils (140 μm), this yields a total of 12.74 mils (323.69 μm). Again, this predicted deposition is significantly less than the acceptance criteria of 50 mils (1270 μm).

For conservatism, the "bump-up" factor considered 22.5 lb (12.5% of 180 lb) of fibrous material and neglected any screen capture. The 22.5 lb of latent fiber was uniformly distributed to each of the materials contributing to chemical-precipitate generation. The "bump-up" factor had a minor impact on the total deposition thickness as shown in Table 6-2.

Cladding Temperatures

In all three cases evaluated, the maximum temperature calculated for the outside diameter (OD) of the fuel cladding (at the fuel/oxide interface) at the onset of recirculation was 309.58 °F (154.21 °C). In all three cases evaluated, the temperature at the fuel/oxide interface was calculated to then decrease throughout the remainder of the event.

Table 6-2: Results of LOCADM Cases

a,c

The LOCADM calculations performed for the AP1000 demonstrate that both acceptance criteria for long-term core cooling identified previously in this report are achieved. Specifically, for the three cases evaluated:

1. The maximum clad temperature calculated for the AP1000 of 309.58 °F (154.21 °C) is significantly less than the acceptance value of 800 °F (426.7 °C).

2. The total thickness of deposition calculated for the AP1000 fuel cladding is significantly less than the 50 mil (1270 μm) thickness at which bridging of deposited debris between adjacent fuel rods by further debris is predicted to occur.

Thus, the conservative calculation of deposition of post-accident chemical products on the fuel rods does not challenge long-term core cooling for the AP1000 design.

7 REGULATORY IMPACT

Design Function

The changes to the DCD in regards to GSI-191, presented in Reference 13, do not represent an adverse change to the design function or to the way in which design functions are performed or controlled. The changes to the DCD do not involve revising or replacing a DCD-described evaluation methodology, nor do they involve a test or experiment not described in the DCD. The DCD change does not require a license amendment per the criteria of VIII.B.5.b of Appendix D to 10 CFR Part 52.

Severe Accident Change Criteria

The DCD changes do not result in a negative impact on features that mitigate severe accidents. Therefore there is no increase in the probability or consequences of a severe accident.

Security

The closure of the COL Information Items will not alter barriers or alarms that control access to protected areas of the plant. The closure of the COL Information Items will not alter requirements for security personnel. Therefore, the closure of the COL Information Item does not have an adverse impact on the security assessment of the AP1000.

8 SUMMARY OF RESULTS

This report summarizes the NRC GSI-191 evaluations performed for the AP1000 design. This report shows the success of the AP1000 in reducing the sources of debris and also the robustness of the design in tolerating the debris that is applicable to the design. The areas of GSI-191 discussed in this report are:

- Debris characterization (latent debris and LOCA-generated debris);
- Debris transport;
- Long-term cooling flows;
- Ex-Vessel Effects of Debris (includes screens and other components such as pumps and valves);
- In-Vessel Effects of Debris (includes effects on head loss and chemical deposition in the core).

The results from each evaluation are summarized in this section. Where applicable, the acceptance criteria for an evaluation are also provided for comparison with the results.

Table 8-1: AP1000 Debris Characterization Summary

a,c

Table 8-2: AP1000 Debris Transport Summary

a,c

a,c

Table 8-3: AP1000 Long-Term Core Cooling Acceptance Criteria

a,c

Table 8-4: AP1000 Screen Head Loss Testing

a,c

Table 8-5: AP1000 PXS Downstream Effects Evaluations

Table 8-6: AP1000 RNS Downstream Effects Evaluations

a,c

Table 8-7: AP1000 Fuel Assembly Head Loss Test Results

a,c

a,c

Table 8-8: AP1000 Statistical Evaluation of Fuel Assembly Head Loss Tests		

a,c

Table 8-9: AP1000 LOCADM Results for Post-LOCA Scale Deposition on Fuel Rods				

9 REFERENCES

1. Nuclear Regulatory Commission Regulatory Guide 1.82, Rev.3, "Water Sources for Long-Term Recirculation Cooling Following a Loss-of-Coolant Accident," November 2003.

2. APP-GW-GLN-147, Revision 3, Technical Report 147, "AP1000 Containment Recirculation and IRWST Screen Design," November 2009.

3. Nuclear Regulatory Commission Generic Letter GL 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation during Design Basis Accidents at Pressurized-Water Reactors," September 2004. (ADAMS Accession Number: ML042360586)

4. NEI 02-01, Rev. 1, "Condition Assessment Guidelines: Debris Sources Inside PWR Containments," September 2002.

5. This reference was deleted in Revision 8 of this document.

6. WCAP-16530-NP-A, Revision 0, "Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191," April 2008.

7. APP-PXS-M3C-057, Revision 2, "Lost of Coolant Accident Deposition Model (LOCADM) Analysis for AP1000 Plant Design," May 2010.

8. WCAP-16914-NP, Revision 5, "Evaluation of Debris Loading Head Loss Tests for AP1000 Recirculation Screens and In Containment Refueling Water Storage Tank Screens," June 2010.

9. WCAP-16914-P, Revision 5, "Evaluation of Debris Loading Head Loss Tests for AP1000 Recirculation Screens and In Containment Refueling Water Storage Tank Screens," June 2010.

10. WCAP-16406-P-A, Revision 1, "Evaluation of Downstream Sump Debris Effects in Support of GSI-191," March 2008.

11. APP-GW-GLR-110, Revision 0, Boric Acid Precipitation Tests During Post-LOCA Conditions, February 2010.

12. WCAP-16793-NP, Revision 1, "Evaluation of Long-Term Cooling Considering Particulate, Fibrous and Chemical Debris in the Recirculating Fluid," April 2009.

13. APP-GW-GLE-002, Revision 6, "Impacts to the AP1000 DCD to Address Generic Safety Issue (GSI)-191," February 2010.

14. WCAP-17028-P, Revision 6, "Evaluation of Debris Loading Head Loss Tests for AP1000 Fuel Assemblies During Loss of Coolant Accidents," June 2010.

15. WCAP-17028-NP, Revision 6, "Evaluation of Debris Loading Head Loss Tests for AP1000 Fuel Assemblies During Loss of Coolant Accidents," June 2010.

16. "Thermal Conductivity of Wet Fabrics," Saburo Naka and Yoshinobu Kamata, Members, TMSJ, Journal of the Textile Machinery Society of Japan, Vol. 23, No. 4, pp. 114-119 (1977).

17. APP-PXS-GLR-001, Revision 4, "Impact on AP1000 Post-LOCA Long Term Cooling of Postulated Containment Sump Debris," February 2010.

18. NEI 04-07, "Pressurized Water Reactor Sump Performance Evaluation Methodology", Revision 0, Volume 1, December 2004.

19. NEI 04-07, "Pressurized Water Reactor Sump Performance Evaluation Methodology", Revision 0, Volume 2, "Safety Evaluation by the Office of Nuclear Reactor Regulation Related to NRC Generic Letter 2004-02, Revision 0," December 2004.

20. APP-GW-GL-700, AP1000 Design Control Document, Revision 17, November 2008.

21. NUREG / CR-6877, "Characterization and Head-Loss Testing of Latent Debris from Pressurized-Water-Reactor Containment Buildings," July 2005.

22. APP-PXS-M3C-053, Revision 2, "AP1000 Latent Debris Calculation," November 2009.

23. APP-PXS-M3C-052, Revision 1, "AP1000 GSI-191 Chemistry Effects Evaluation," May 2009.

24. APP-PXS-M3C-056, Revision 3, AP1000 Passive Core Cooling System Downstream Effects Calculation, December 2009.

25. APP-RNS-M3C-202, Revision 2, AP1000 Normal Residual Heat Removal System Downstream Effects Calculation, December 2009.

26. APP-GW-GLR-092, Revision 0, Statistical Evaluation of AP1000 Fuel Assembly Debris-Loading Head-Loss Tests, February 2010.

27. APP-PXS-M3C-011, Revision 0, Flow Split Calculation between LOCA Break Location and PXS during Post-LOCA Containment Recirculation, February 2010.

28. NRC Analysis Report, "Post-LOCA PWR Core Inlet Blockage Assessment," February 2007. (ADAMS Accession No. ML070860521)

29. APP-PXS-M3C-034, Revision 1, Containment Flood-Up Level, February 2010.

30. APP-PXS-M3C-013, Revision 0, Post LOCA Coatings Debris from Zone of Influence, May 2010.

31. APP-PXS-M3C-012, Revision 1, POST-LOCA Refueling Canal Drain Check Valve Leak Evaluation, May 2010.