U.S. EPR Design Features to Address GSI-191

ANP-10293NP
Revision 3

Technical Report

March 2011

AREVA NP Inc.

Nature of Changes

Item	Section(s) or Page(s)	Description and Justification
1	All	Revision 1 incorporates new design bases for the U.S.EPR GSI-191 Design Features. Revision 1 revises ANP-10293 in its entirety.
		Revision 2
2	Appendix F	Added
3	All	Miscellaneous editorial changes
		Revision 3
4	All	Miscellaneous editorial changes
5	3.1.2	Updated debris source term
6	3.2.5	Added section to discuss water holdup in the Reactor Building
7	Appendix A	Updated discussion of conformance for items 1.3.1.1 and 1.3.1.9
8	Appendix B	Added discussion for items 2.d(v) and 2.d(vi)
9	Appendix C	Updated based on latest design input
10	Appendix D	Updated to incorporate IRWST design change
11	Appendix E	Complete revision based on latest test results
12	Appendix F	Complete revision
13	Appendix G	Added to discuss Ex-Vessel downstream effect

Contents

Page

1.0 INTRODUCTION 1-1

2.0 U.S. EPR DESIGN FEATURES 2-1

2.1 IRWST 2-1

2.2 Defense-in-Depth Strategy 2-1

2.3 Details of the U.S. EPR ECCS Sump Blockage Mitigation Design Features 2-4

2.3.1 Weirs and Trash Racks 2-7

2.3.2 Retaining Baskets 2-8

2.3.3 IRWST (ECCS) Sump Strainers 2-9

2.4 RCS Insulation 2-10

3.0 APPLICABLE U.S. EPR DESIGN BASES 3-1

3.1 Technical Basis for the ECCS Sump Recirculation Design Features 3-1

3.1.1 Debris Transport 3-1

3.1.2 Debris Source Term 3-2

3.1.3 Chemical Effects 3-3

3.1.4 ECCS Strainer Performance 3-4

3.2 Other Considerations 3-5

3.2.1 NPSH Assessment 3-5

3.2.2 Strainer Vortexing, Submergence, Flashing, and Deaeration Assessment 3-5

3.2.3 IRWST Cleanliness 3-7

3.2.4 Strainer Mechanical Integrity 3-7

3.2.5 Water Holdup 3-7

4.0 REGULATORY OVERVIEW 4-1

4.1 Generic Safety Issue 191 4-1

4.2 Regulatory Guide 1.82 Rev. 3 4-1

4.3 RG 1.82 Conformance Assessment 4-3

4.4 Generic Letter 2004-02 4-3

5.0 CONCLUSION 5-1

6.0 REFERENCES 6-1

APPENDIX A RG 1.82 CONFORMANCE ASSESSMENT A-1
A.1 Regulatory Guide 1.82 .... A-1
APPENDIX B GENERIC LETTER 2004-02 INFORMATION MATRIX B-1
B.1 GL 2004-02 .... B-1
APPENDIX C DEBRIS GENERATION EVALUATION FOR THE U.S. EPR C-1
C.1 Introduction C-1
C.2 Assumptions C-2
C.3 Computer Software C-5
C.4 Technical Approach C-5
C.5 Evaluation Technique C-14
C.6 Results C-25
C.7 References C-32
APPENDIX D CHEMICAL EFFECTS EVALUATION FOR THE U.S. EPR D-1
D.1 Chemical Effects Evaluation D-1
D.2 Chemical Effects Testing D-2
D.3 IRWST Sump Chemistry Modeling D-53
APPENDIX E ECCS STRAINER PERFORMANCE TESTING FOR THE U.S. EPR E-1
E.1 Introduction E-1
E.2 Scope and Objective E-2
E.3 Test Apparatus E-5
E.4 Debris Description E-28
E.5 Debris Quantities and Introduction Sequence E-32
E.6 Test Results E-41
E.7 Conclusions E-66
E.8 Conclusions E-68
E.9 References E-68
APPENDIX F DOWNSTREAM EFFECTS EVALUATION FOR THE U.S. EPR F-1

F.1 Introduction F-1
F.2 Background F-3
F.3 Debris Accumulation at Core Inlet or Intermediate Spacer Grids F-12
F.4 Deposition of Chemical Precipitates and Debris on Fuel Rods (EPRDM) F-47
F.5 Summary and Conclusion F-74
APPENDIX G EX-VESSEL DOWNSTREAM EFFECTS EVALUATION G-1
G.1 Introduction G-1
G.2 Assumptions and Design Information G-2
G.3 ECCS Component Evaluations G-9
G.4 Conclusions G-13

List of Tables

Page

Table 3.1-1 Total Debris Source 3-3

Table 3.2-1 Maximum Water Holdup 3-14

Table A.1 RG-1.82 Conformance Assessment Matrix A-1

Table B.1 GL 2004-02 Information Matrix B-1

Table C.4-1 Pipe Break Selections C-8

Table C.5-1 Basis for Pipe Break Selections C-18

Table C.5-2 L/D Values for Each Insulation Type C-19

Table C.5-3 Pipe Break Inputs C-19

Table C.5-4 Section Descriptions of the Steam Generator Model C-20

Table C.5-5 Vertical Center Line of Steam Generators C-21

Table C.5-6 Section Descriptions of the Reactor Coolant Pump Model C-22

Table C.5-7 Vertical Centerline of Reactor Coolant Pumps C-22

Table C.5-8 Section Descriptions of the Pressurizer Model C-23

Table C.5-9 Vertical Centerline of Pressurizer C-23

Table C.5-10 Size and Distribution of Debris Within the ZOI C-25

Table C.6-1 Break 1 Insulation Totals C-26

Table C.6-2 Break Debris Generation Totals C-26

Table C.6-3 Break 2 Insulation Totals C-27

Table C.6-4 Break 2 Debris Generation Totals C-27

Table C.6-5 Break 3 Insulation Totals C-28

Table C.6-6 Break 3 Debris Generation Totals C-28

Table C.6-7 Break 4 Insulation Totals C-29

Table C.6-8 Break 4 Debris Generation Totals C-29

Table C.6-9 Break 5 Insulation Totals C-30

Table C.6-10 Break 5 Debris Generation Totals C-30

Table C.6-11 Break 6 Insulation Totals C-31

Table C.6-12 Break 6 Debris Generation Totals C-31

Table C.6-13 Break 7 Insulation Totals C-32

Table C.6-14 Break 7 Debris Generation Totals C-32

Table D.2-1 Summary of the Autoclave Pre-Test Rinse Analysis Results........ D-5

Table D.2-2 Elemental Composition of the Aluminum Coupon D-7

Table D.2-3 Pre-Test EDS Data of Pulverized Concrete Sample........ D-8

Table D.2-4 Elemental Composition of Microtherm Powder by EDS........ D-12

Table D.2-5 Summary of Autoclave Debris Loading D-16

Table D.2-6 Comparison of NUKON® Post-Test EDS Results D-32

Table D.2-7 Final Mass of all Recovered Materials........ D-51

Table D.3-1 Chemical Effects Ratio – Material Quantity versus IRWST Volume........ D-55

Table D.3-2 Measured Release Rate for Concrete in Borated Water at pH 10........ D-56

Table D.3-3 Pretest SEM/EDS Composition of Pulverized Concrete........ D-59

Table D.3-4 Chemical Composition of NUKON® Fiber Insulation........ D-63

Table D.3-5 Pretest SEM/EDS Composition of Microtherm D-68

Table D.3-6 Measured Weight Losses of Materials........ D-71

Table D.3-7 Estimated Chemical Releases during Autoclave Test D-72

Table D.3-8 Debris Generation for RCS Crossover Leg Break at the SG3 Outlet Nozzle D-78

Table D.3-9 Estimated Chemical Release for the RCS Crossover Leg Break at the SG3 Outlet Nozzle D-80

Table D.3-10 Total Elements Released and Solids Formed from the RCS Crossover Leg Break at the SG3 Outlet Nozzle........ D-81

Table E.2-1 U.S. EPR Strainer Performance Tests - Phase 1 ....E-4

Table E.2-2 U.S. EPR Strainer Performance Tests - Phase 2 ....E-4

Table E.3-1 Scaling Summary for Phase 1 Testing........E-8

Table E.3-2 Scaling Summary for Phase 2 Testing........E-12

Table E.3-3 Strainer Filter Media E-24

Table E.3-4 Retaining Basket (RB) Scaling Summary and Modeled Parameters E-27

Table E.3-5 Retaining Basket Filter Media E-28

Table E.5-1 Debris Allocation and Flume Flow Rate for the Debris Transport Test....E-33

Table E.5-2 Debris Allocation and Flume Flow Rate for Head Loss Tests E-37

Table E.5-3 Chemical Debris Additions and Flume Flow Rate for the Head Loss Tests E-38

Table E.5-4 Fibrous Debris Only Test Batching E-39

Table E.5-5 Debris Allocation and Flume Flow Rate for the Fibrous Debris Only Sample Bypass Test....E-40

Table E.6-1 Clean Strainer Head Loss Test Results E-41

Table E.6-2 Maximum and Average Measured Head Loss for the Design Basis Debris Loaded Strainer Head Loss Test E-42

Table E.6-3 Head Loss Data for Fibrous Debris Only Sample Bypass Test No. 2A....E-44

Table E.6-4 Bypass Test Results E-45

Table E.6-5 Debris Transport Test Results E-47

Table E.6-6 Clean Strainer Head Loss Test Results E-48

Table E.6-7 Test 2A Pre and Post Filter Bag Weights....E-61

Table E.6-8 Test 2A Fiber Bypass E-62

Table E.6-9 Test 2E Pre and Post Filter Bag Weights....E-63

Table E.6-10 Test 2E Fiber Bypass E-64

Table E.6-11 Test 2F Pre and Post Filter Bag Weights....E-65

Table E.6-12 Test 2F Fiber Bypass....E-66

Table E.7-1 Head Loss Testing Summary....E-67

Table E.7-2 Bypass Testing Summary E-67

Table F.3-1 Minimum Flow Required for DHR with Time F-26

Table F.3-2 Core Boron for Cold Leg Breaks with Cold Side Injection F-30

Table F.3-3 Loop Pressure Drops for Cold Leg Breaks with Cold Leg Injection F-35

Table F.3-4 Cold Leg Breaks with Hot Leg Injection, K/A^2 Calculation F-40

Table F.3-5 Hot Leg Breaks with Hot Leg Injection, K/A^2 Calculation F-42

Table F.3-6 K/A^2 Calculation Summary F-43

Table F.3-7 Sample Test Acceptance Criteria F-44

Table F.3-8 Summary of Maximum Debris Generated from All Break Locations F-46

Table F.4-1 Debris Inputs F-64

Table F.4-2 Inputs for IRWST Temp and Mass Releases F-65

Table F.4-3 Coolant/Miscellaneous Material Inputs F-66

Table F.4-4 Reactor Core Parameters F-66

Table F.4-5 EPRDM Output For Each Time Step F-68

Table F.4-6 EPRDM Output For Core Elevations 1-13 .... F-69

Table F.4-7 EPRDM Output For Core Elevations 14-26 .... F-70

Table F.4-8 EPRDM Output For Core Elevations 27-39 .... F-71

Table F.4-9 EPRDM Output For Core Elevations 40-52 .... F-72

Table G.2-1 Components in the ECCS Flow Path during a LB LOCA G-5

Table G.2-2 Total Debris Generated during the LB LOCA G-8

Table G.2-3 Post-LOCA Fluid Constituents G-9

List of Figures

Page

Figure 2-1 U.S. EPR ECCS Sump Blockage Mitigation Design Features ... 2-2

Figure 2-2 Elevation View of ECCS Sump Blockage Mitigation Features ... 2-4

Figure 2-3 IRWST Cut-away View ... 2-5

Figure 2-4 Weir and Trash Rack Locations Above the Heavy Floor ... 2-6

Figure 2-5 ECCS Trash Rack Structure (typical of 4) ... 2-6

Figure 2-6 ECCS Sump Strainer Structure (typical of 4) ... 2-7

Figure 3-1 20" Berm around SGBD Tank ... 3-10

Figure 3-2 Openings that Communicate to the Heavy Floor Area ... 3-11

Figure 3-3 Profile of the 4 openings ... 3-12

Figure C.5-1 Debris Generation Analysis Process ... C-15

Figure C.5-2 Pipe Coordinate System ... C-16

Figure D.2-1 Schematic of the Autoclave System ... D-4

Figure D.2-2 NUKON® Insulation before Heat Treatment ... D-9

Figure D.2-3 NUKON® Insulation after Heat at 600°F for 24 Hours ... D-10

Figure D.2-4 SEM Micrograph of NUKON® Fibers before Testing ... D-10

Figure D.2-5 Optical Micrograph of Microtherm on SEM Sample Stub ... D-12

Figure D.2-6 SEM Micrograph of Microtherm Insulation Prior to Testing ... D-13

Figure D.2-7 SEM Micrograph and EDS Spectrum of Microtherm Prior to Testing ... D-14

Figure D.2-8 Assembled Autoclave Internals ... D-17

Figure D.2-9 pH and Temperature Trend for Chemical Effects Test ... D-19

Figure D.2-10 Boron, Sodium, and Phosphorous Concentrations during Chemical Effects Test ... D-20

Figure D.2-11 Graphical Summary of Calcium, Aluminum, and Silicon Concentrations during Chemical Effects Test ... D-21

Figure D.2-12 Potassium and Magnesium Concentration during Chemical Effects Test ... D-23

Figure D.2-13 Aluminum Coupon after Removal from Autoclave ... D-24

Figure D.2-14 SEM Micrograph and EDS Spectrum of Post-Test Aluminum Coupon prior to Cleaning D-25

Figure D.2-15 Aluminum Coupon after Cleaning D-26

Figure D.2-16 Concrete Coupon after Removal From Autoclave D-27

Figure D.2-17 Concrete Coupon after Test D-27

Figure D.2-18 Optical Micrograph of NUKON® Fibers after Test D-28

Figure D.2-19 SEM Micrograph of NUKON® after Testing D-29

Figure D.2-20 SEM Micrograph of NUKON® Fibers Showing Bridging D-30

Figure D.2-21 Backscattered Electron Image of NUKON® Fibers after Testing D-31

Figure D.2-22 NUKON® Fiber Post-Test − EDS Location #1 .... D-33

Figure D.2-23 NUKON® Fiber Post-Test − EDS Location #2 .... D-34

Figure D.2-24 Microtherm Insulation Recovered from the Autoclave D-35

Figure D.2-25 Optical Micrograph of Microtherm after Testing − Overview D-36

Figure D.2-26 Close-up of Microtherm Showing Deposit D-36

Figure D.2-27 SEM Micrograph of Microtherm Fibers after Testing D-37

Figure D.2-28 SEM Micrograph of Microtherm Particulate after Testing D-38

Figure D.2-29 EDS Spectrum of Microtherm Particulate after Testing D-39

Figure D.2-30 SEM Micrograph and EDS Spectra of Silicon Phase D-40

Figure D.2-31 SEM Micrograph and EDS Spectra of Titanium Phase D-41

Figure D.2-32 Latent Debris Recovered after Testing D-42

Figure D.2-33 Latent Debris − Close-up D-42

Figure D.2-34 Autoclave Internals after Testing D-43

Figure D.2-35 Final Solution from Test D-44

Figure D.2-36 SEM Micrograph and EDS Analysis of Sample #1 − Location 1 .... D-45

Figure D.2-37 SEM Micrograph and EDS Analysis of Sample #1 − Location 2 .... D-46

Figure D.2-38 SEM Micrograph and EDS Analysis of Sample #1 − Location 3 .... D-47

Figure D.2-39 SEM Micrograph and EDS Analysis of Sample #2 .... D-48

Figure D.2-40 SEM/EDS Analysis of Residual Material from Test #1 .... D-49

Figure D.2-41 SEM/EDS Analysis of Residual Material from Test #2 .... D-50

Figure D.3-1 Estimated Solid Concrete Release Rate at pH 8 .... D-58

Figure D.3-2 Mass Release versus Time for Nukon® Fiber at pH 7 .... D-60

Figure D.3-3 Mass Release Rate versus Time for NUKON® Fiber at pH 7 .... D-61

Figure D.3-4 Post-test Appearance of NUKON® Fiber D-62

Figure D.3-5 Corrosion of Aluminum A1100 .... D-65

Figure D.3-6 Measured Concentration of Aluminum in Solution D-66

Figure D.3-7 Measured Silica Concentration D-69

Figure D.3-8 Comparison of Aqueous Concentrations Calculated with *StreamAnalyzer* with Measured Values (Aluminum Precipitation Turned Off) D-73

Figure D.3-9 Comparison of Aqueous Concentrations Calculated with *StreamAnalyze* with Measured Values (Aluminum allowed to Precipitate) D-74

Figure D.3-10 Methodology for Determining the Exposed Concrete Surface Area D-79

Figure D.3-11 Plot of Total Solids vs. Time for the RCS Crossover Leg Break at the SG3 Outlet Nozzle D-82

Figure E.3-1 Test Configuration for Phase 1 Testing (Side View, - inches) E-6

Figure E.3-2 Test Configuration for Phase 1 Testing (Top View, - inches) E-7

Figure E.3-3 Test Configuration for Phase 2 Testing E-10

Figure E.3-4 Test Configuration for Phase 2 Testing (Recirculation Loop and Make-up Water Tank) E-11

Figure E.3-5 Strainer, Retaining Basket, and Miniflow Lines Within the Phase 2 Test Flume E-13

Figure E.3-6 Strainer, Retaining Basket, and Components Within the Phase 2 Test Flume E-14

Figure E.3-7 Debris Introduction Nozzle E-17

Figure E.3-8 Debris Injection Hopper E-17

Figure E.3-9 Dirt and Dust Introduction E-18

Figure E.3-10 Filter Housing Units E-19

Figure E.3-11 Aft End of Flume Tank E-20

Figure E.3-12 Overflow Weir Filter bags E-20

Figure E.3-13 Water Addition E-21

Figure E.3-14 Modeled Portion of Strainer E-22

Figure E.3-15 Strainer Support and Sump Cover (overhead view) E-23

Figure E.4-1 RMI Test Debris E-29

Figure E.4-2 Coating Chips E-31

Figure E.6-1 Strainer and Retaining Basket Head loss Data for the Design Basis Debris Loaded Strainer Head Loss Test E-43

Figure E.6-2 Strainer and Retaining Basket Head Loss Data for the Thin Bed Test E-46

Figure E.6-3 Test 1 Raw Data E-49

Figure E.6-4 Test 1A Raw Data E-51

Figure E.6-5 Test 1B Raw Data E-53

Figure E.6-6 Test 1C Raw Data E-55

Figure E.6-7 Test 1D Raw Data E-57

Figure E.6-8 Test 1E Raw Data E-59

Figure E.7-1 Bypass Fraction per Fuel Assembly E-68

Figure F.2-1: Core Flow Patterns Following a Cold Leg Break During Cold Leg Injection F-8

Figure F.2-2: Core Flow Patterns Following a Cold Leg Break During Cold Leg Injection (Another View) F-9

Figure F.2-3: Core Flow Patterns Following a Hot Leg Break During Cold Leg Injection F-10

Figure F.2-4 Core Flow Patterns Following a Cold Leg Break During Simultaneous Injection F-11

Figure F.3-1 Flow Loss Network for a CLPD Break F-31

Figure F.4-1 Flows During a LOCA Cold Leg Break F-52

Figure F.4-2 Boiling Chimney Deposition Effect F-53

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Nomenclature

Acronym	Definition
BWR	Boiling Water Reactor
CSS	Containment Spray System
ECCS	Emergency Core Cooling System
FME	Foreign Material Exclusion
FPPS	Fuel Pool Purification System
GL	Generic Letter
GSI	Generic Safety Issue
HELB	High Energy Line Break
IRWST	In-Containment Refueling Water Storage Tank
LBLOCA	Large Break Loss of Coolant Accident
LHSI	Low Head Safety Injection
LOCA	Loss Of Coolant Accident
LWR	Light Water Reactor
MHSI	Medium Head Safety Injection
NPSH	Net Positive Suction Head
PWR	Pressurized Water Reactor
RCS	Reactor Coolant System
RG	Regulatory Guide
RMI	Reflective Metal Insulation
TSP	Tri-Sodium Phosphate
ZOI	Zone Of Influence

1.0 INTRODUCTION

This report describes the U.S. EPR™ design with respect to Generic Safety Issue (GSI) 191. GSI-191 is concerned with the potential for post-accident debris blockage that could interfere with the capability of the recirculation mode of the emergency core cooling system (ECCS) during long-term reactor core cooling. NRC Regulatory Guide (RG) 1.82 (Reference 1) describes acceptable methods and guidelines for evaluating the adequacy of plant design features and ECCS performance, including a framework for licensees to develop, demonstrate, and implement a comprehensive resolution to GSI-191. Nuclear Energy Institute (NEI) 04-07 (Reference 3) provides methodology and guidance for addressing and resolving GSI-191 issues. This report assesses the U.S. EPR design with respect to RG 1.82, NEI 04-07, and the related generic letter (GL), 2004-02 (Reference 2).

Specifically, this report:

1. Describes the design features of the U.S. EPR that limit the impact of post-accident debris accumulation on ECCS sump performance.
2. Describes the U.S. EPR debris source and generation.
3. Describes the chemical effects and head loss testing associated with debris transport.
4. Presents the supporting bases for the U.S. EPR design relative to GSI-191.
5. Presents an overview of related regulations and guidance.
6. Provides a review of RG 1.82 and GL 2004-02 conformance.

The U.S. EPR sump design is robust with respect to post-accident debris accumulation and ECCS recirculation sump strainer blockage because of the following features:

1. The U.S. EPR will have limited post-accident debris relative to current light water reactors (LWR). Reactor coolant system (RCS) piping and components will be insulated with reflective metal insulation (RMI). There will be no fibrous or micro-porous insulation and no calcium-silicate insulation used on the RCS.

2. The three-tiered debris retention design of the U.S. EPR ECCS recirculation system, including the safety injection system (SIS) and the in-containment refueling water storage tank (IRWST), is an effective solution to post-accident ECCS pump strainer clogging. The combination of weirs, trash racks and retaining baskets are effective in retaining most of the debris. As a result, very little debris will reach the ECCS strainers. The ECCS strainers have large screen surface areas to accommodate the small amount of debris that will reach them.

The U.S. EPR design conforms to the applicable RG 1.82 requirements as detailed in Table A.1 of Appendix A.

The features of the U.S. EPR that mitigate the risk of post-accident debris clogging the ECCS strainers are:

- A general layout of the plant that reduces the zone of influence (ZOI).
- The absence of a containment spray system (CSS) for design basis accident mitigation that would contribute to debris transport.
- Judicious selection of insulating materials. The insulated piping within the ZOI will be RMI. (ZOI = 2D)
- Multiple barriers that significantly limit the amount of post-accident debris reaching the ECCS strainers:
  - Weirs around the heavy floor openings that promote settling of debris.
  - Trash racks above the heavy floor openings to prevent large debris from being transported to the IRWST.

- Retaining baskets below the heavy floor openings that capture the remaining debris contained in weir overflow.
- Large volume and large area IRWST that results in relatively low flow velocities, which permits settling of the debris.
- Large surface area ECCS strainers with small screen mesh sized to minimize debris bypass that may potentially affect any downstream clogging of fuel or critical equipment.

The U.S. EPR sump system design has been validated by a comprehensive testing program which demonstrated:

- Retention capacity and effectiveness of the retaining baskets.
- Strainer retention capacity and large margins relative to the head losses across the strainers, for a given volume of debris.

In summary, this report concludes that the U.S. EPR reactor design provides an innovative and comprehensive solution to post-accident debris blockage that addresses the concerns of GSI-191. The U.S. EPR design conforms to RG 1.82 as detailed in Table A.1 of Appendix A.

2.0 U.S. EPR DESIGN FEATURES

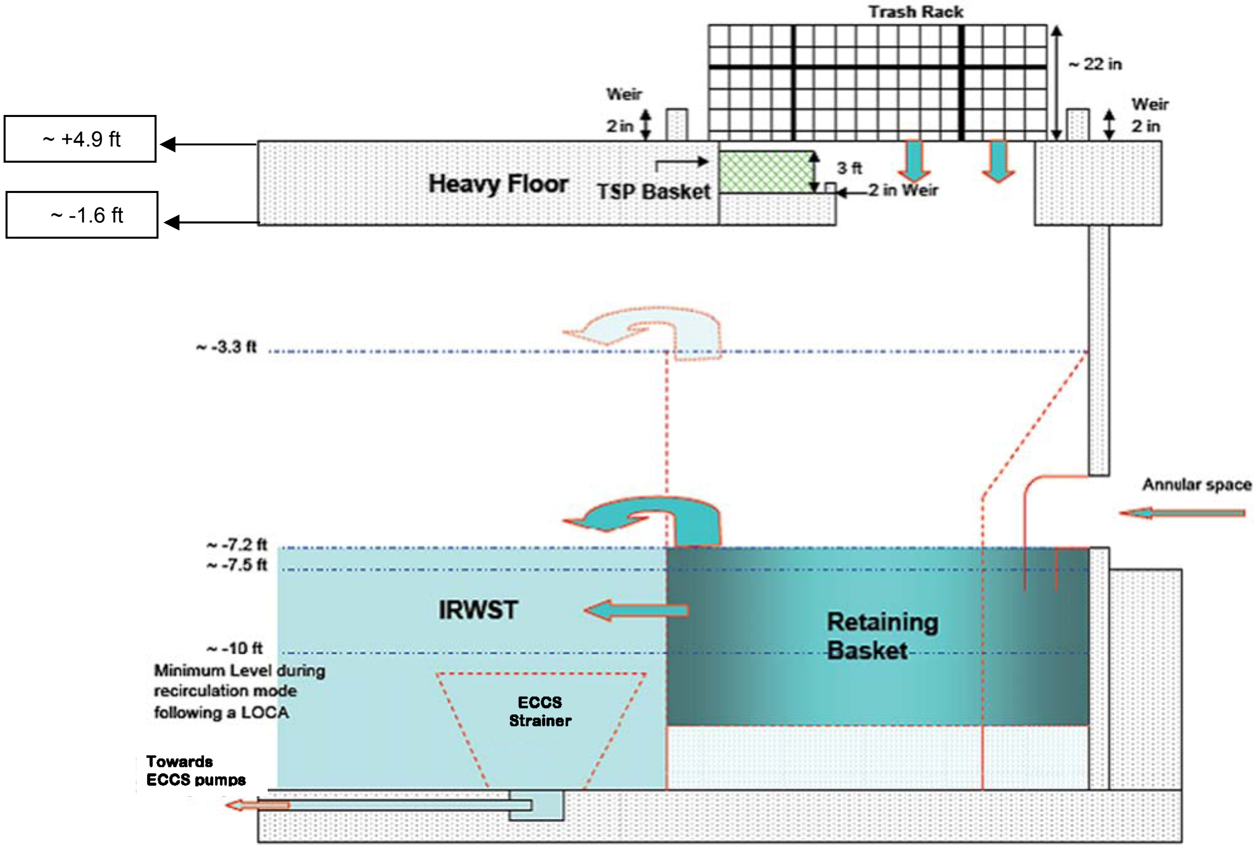
2.1 *IRWST*

A key feature of the U.S. EPR design important to resolving post-accident debris blockage is the IRWST. The IRWST is functionally equivalent to the external refueling water storage tank found in the current fleet of PWRs. The IRWST contains a large volume of borated water that is monitored for a homogeneous concentration, level, and temperature. The IRWST serves as a water source, heat sink, and return reservoir for ECCS. The IRWST is an open pool within a partly immersed building structure. The walls of the IRWST have an austenitic stainless steel liner covering the immersed region of the building structure. The liner prevents interaction of the boric acid and concrete structure and provides water tightness. Locating the IRWST inside containment and immediately below the RCS loop vaults permits integrating design features that collectively represent an effective solution for preventing post-accident debris blockage and ECCS sump clogging.

2.2 *Defense-in-Depth Strategy*

The U.S. EPR design takes advantage of the in-containment physical arrangement to develop a tiered “defense-in-depth” strategy against ECCS sump suction clogging as shown in Figure 2-1. The return water discharged from a loss of coolant accident (LOCA) drains to the containment heavy floor and flows to the IRWST.

Figure 2-1 U.S. EPR ECCS Sump Blockage Mitigation Design Features



This tiered “defense-in-depth” strategy includes:

- A large area, low flow velocity region in each of the four RCS loop vaults that promotes debris settling.
- A set of four protective weir/trash rack structures to retain large debris in the RCS loop vault.
  - The weir (curb) is approximately 2 inches high, to facilitate water pooling and debris settling in the RCS loop vault areas.

   - The trash rack is a 4x4 inch heavy-duty screen that fully encompasses the floor opening and prevents large debris from entering the retaining basket below.

- Four retaining baskets in the IRWST. Each retaining basket is located under each weir/trash rack port to catch and retain any small debris that is carried through the trash racks by ECCS recirculation flow.
- Large area, low flow velocity region within the IRWST promotes settling of fine debris that passes through the retaining baskets.
- Four large surface area three-dimensional flat screen sump strainers in the IRWST, each protecting one of the four ECCS pump suction sumps located in the floor of the IRWST.

Additional features associated with these barriers that contribute to the overall effectiveness of the system include:

- Retaining basket area sized to overlap trash rack portal area so that ECCS recirculation flow falls within the retaining basket.
- An approximately 1.6 ft gap between the top of the retaining basket and the bottom heavy floor permits the retaining basket to overflow into the IRWST should the retaining basket be filled with debris.
- Retaining basket screen mesh size is equivalent to the strainer screen mesh size; both are sized to minimize fine debris that may bypass the strainer and obstruct downstream clearances in the ECCS flow path.
- Inverted side screens on the sump suction strainers to promote gravitational release of debris beds in low flow or no flow conditions.
- Retaining baskets and ECCS strainers sized so that each set is sufficient to accommodate the anticipated debris load resulting from the worst-case LOCA.

- RCS insulation materials selected to minimize the quantity of insulation debris known to be highly deleterious to post-loss of coolant accident (LOCA) ECCS function.

2.3 *Details of the U.S. EPR ECCS Sump Blockage Mitigation Design Features*

Figure 2-2, Figure 2-3, and Figure 2-4 show the locations of the weir/trash rack structures, the retaining baskets, and the sump strainers in relation to the RCS and the IRWST. Figure 2-5 and Figure 2-6, respectively, show the design of the trash rack structure and the sump strainer structure.

Figure 2-2 Elevation View of ECCS Sump Blockage Mitigation Features

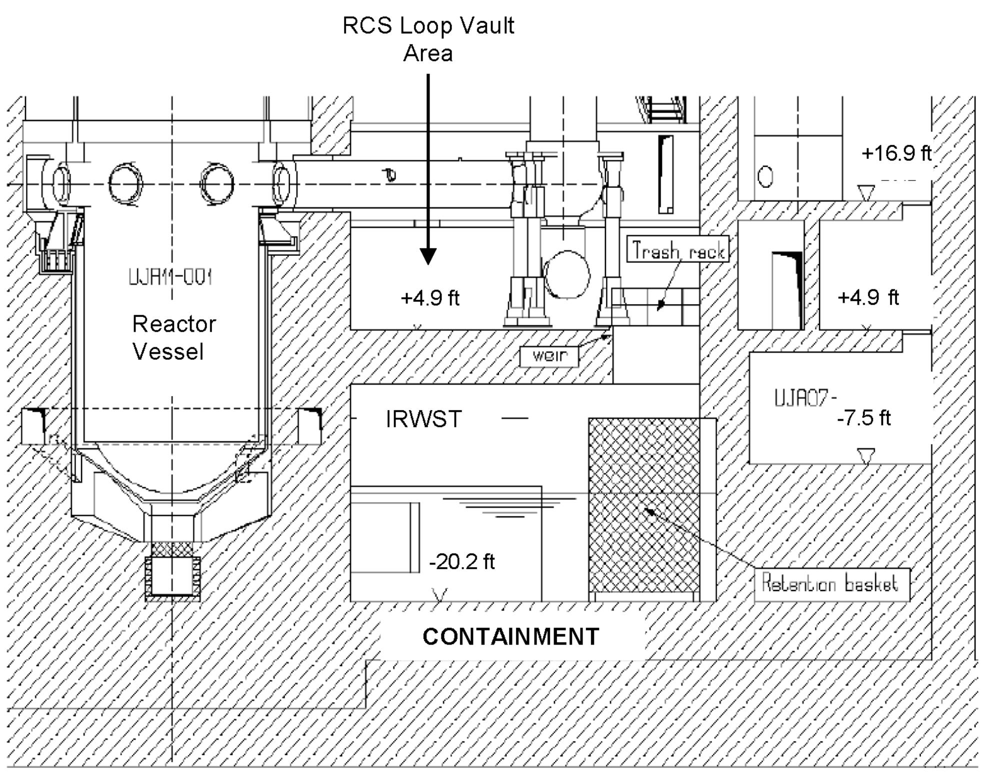


Figure 2-3 IRWST Cut-away View

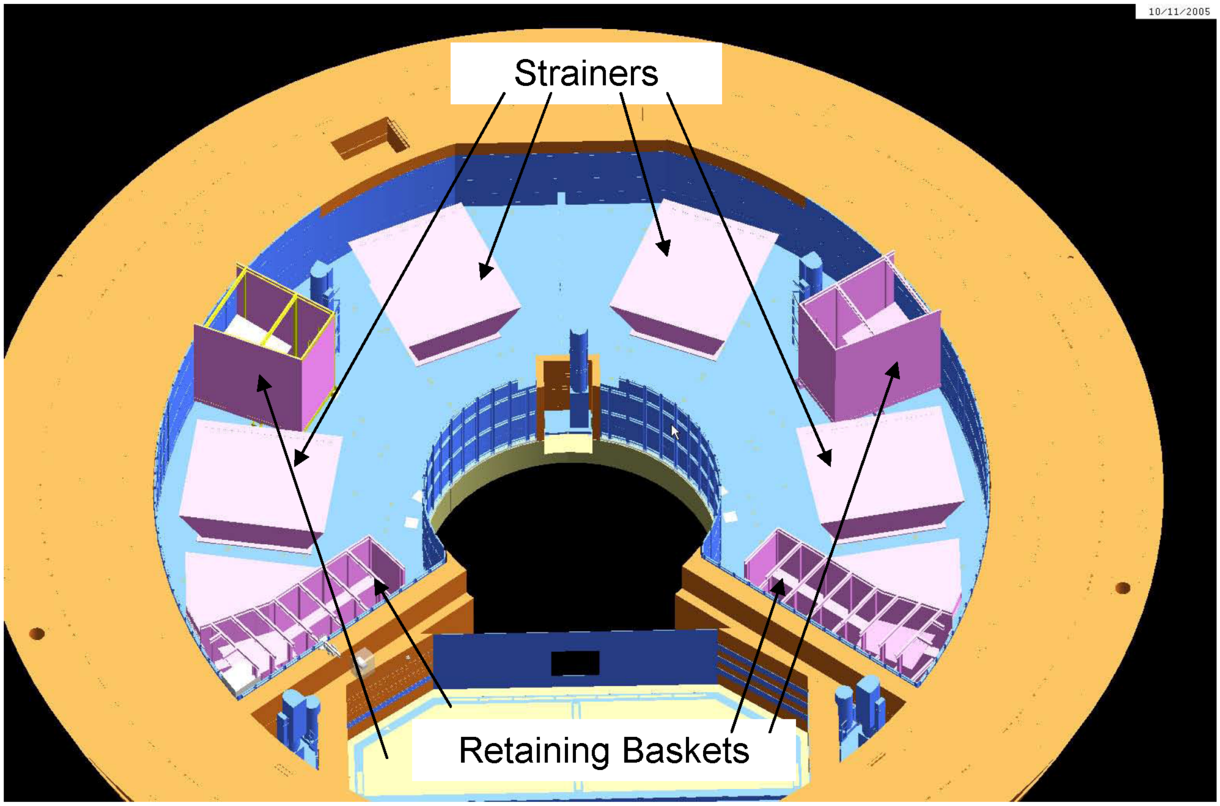


Figure 2-4 Weir and Trash Rack Locations Above the Heavy Floor

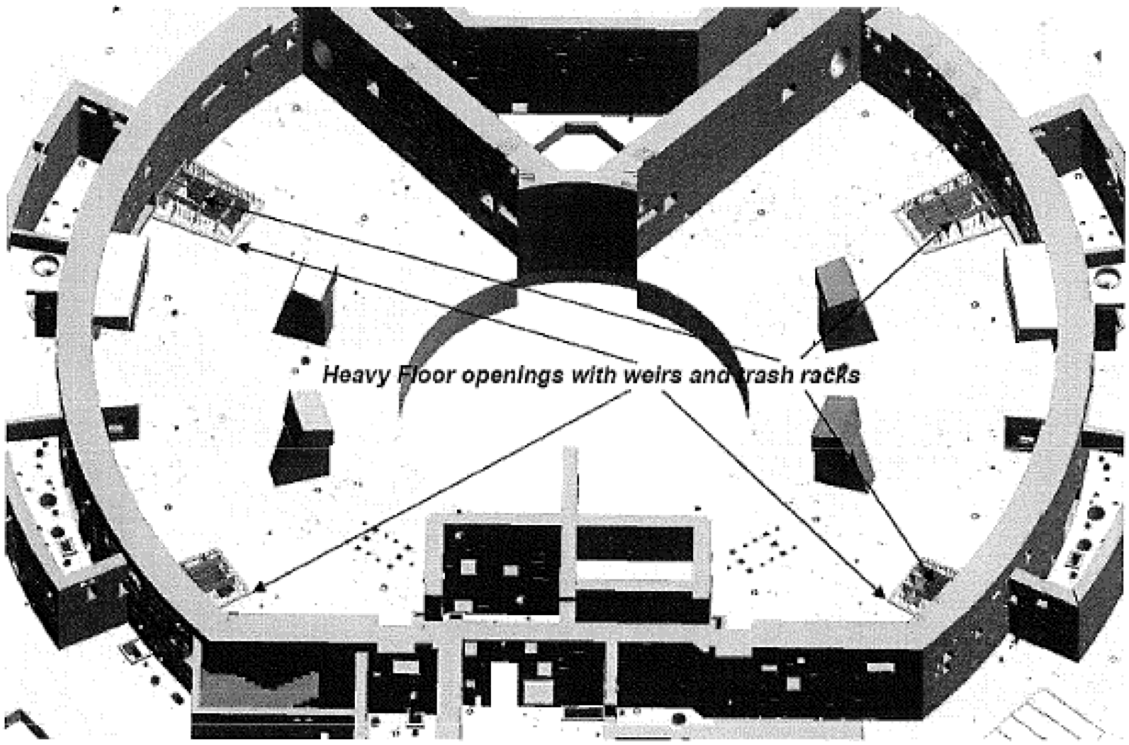


Figure 2-5 ECCS Trash Rack Structure (typical of 4)

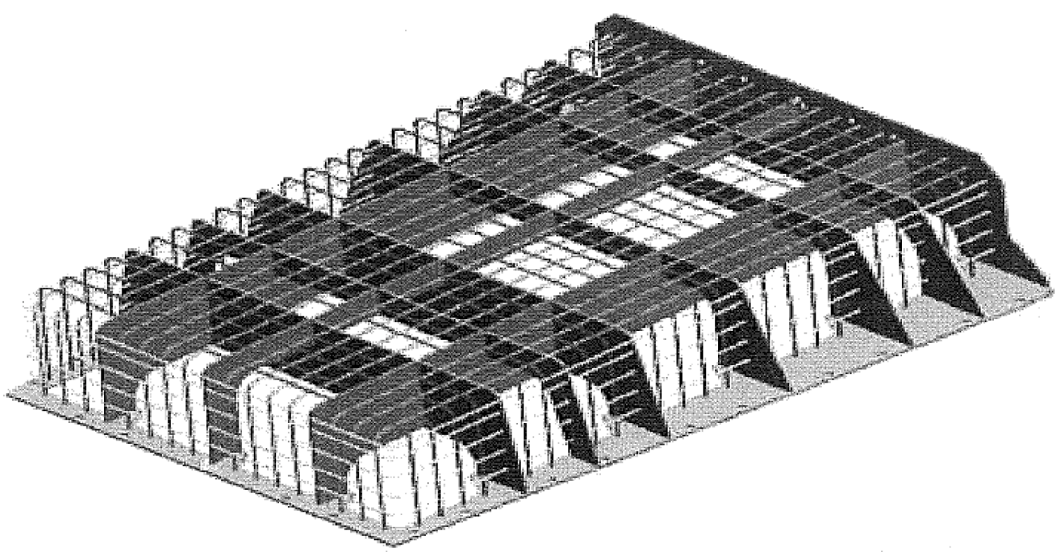
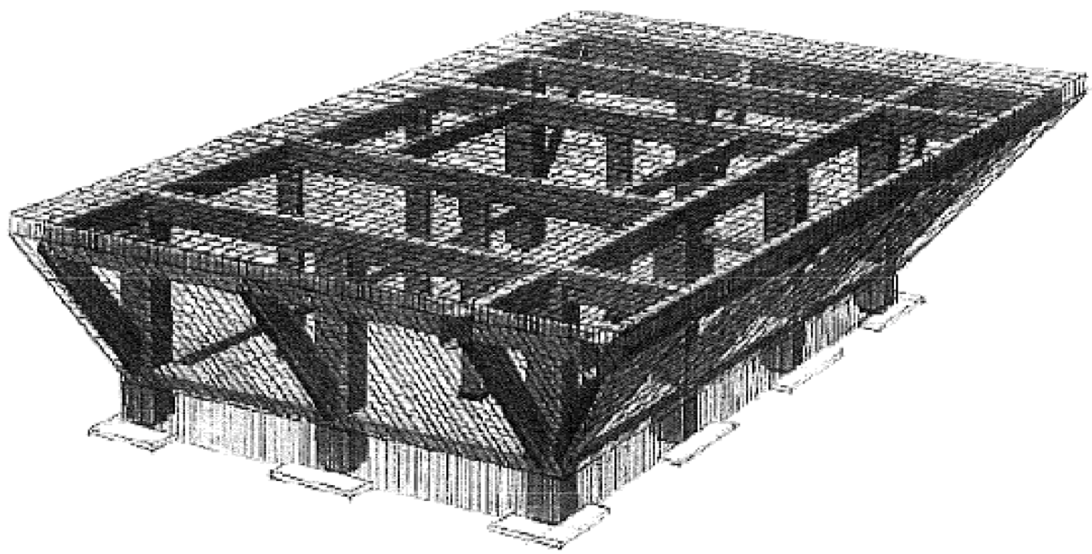


Figure 2-6 ECCS Sump Strainer Structure (typical of 4)



2.3.1 *Weirs and Trash Racks*

There are four openings in the RCS loop area “heavy” floor that open to the IRWST below. Each opening is approximately 50 ft^2 in area and is protected by a weir and trash rack assembly. The weir is a 2-inch high concrete curb around the perimeter of the floor opening that permits pooling of LOCA return water and promotes debris settling in the RCS loop vault area. The trash rack is a box-like mesh structure approximately 22 inches tall that consists of a 4x4 inch rigid metal grid that envelopes the floor opening. Each of the floor openings is aligned with the retaining basket located below. In addition to the protection offered by the trash racks, the 6.6 ft depth of the floor openings also provides jet impingement protection by limiting the angle of any jet that could pass through the opening unimpeded.

The weirs and trash racks prevent most of the LOCA-generated debris from passing through the four heavy floor openings to the IRWST below. LOCA-generated debris that passes through each trash rack will fall into a retaining basket.

2.3.2 *Retaining Baskets*

A retaining basket is positioned under each of the four heavy floor openings. The retaining baskets collect and retain debris that pass through the trash racks. The retaining baskets are constructed of austenitic stainless steel. The mesh size of the retaining baskets (nominal opening 0.08 x 0.08 inches) is the same size as the down stream ECCS sump strainer mesh size.

The perimeter of the upper portion of the retaining basket extends approximately 1.5 ft beyond the perimeter of the heavy floor opening. This extension prevents debris that passes through the trash racks from bypassing the retaining basket and reaching the sump strainers. There is a gap of approximately 1.6 ft between the top of each basket and the heavy floor to provide a flow path for return water in the event the basket becomes filled with debris.

The volume of each retaining basket can accommodate the debris generated from the limiting break. Water level in the basket is self-regulating and increases as the lower portion of the basket becomes filled with debris. Water overflow over the top of the retaining basket would occur after the debris have been captured.

Two of the four retaining baskets are split into two compartments: a large one (minimum volume of approximately 1589 ft^3 and minimum surface area of approximately 721 ft^2) dedicated to the flow from the heavy floor, a smaller one (minimum volume of approximately 530 ft^3 and minimum surface area of approximately 269 ft^2) dedicated to the flow from the annular space. The latter compartment is lower and its height is designed to minimize water retention in the annular space. The minimum volume of the two other baskets is approximately 1589 ft^3 each with a minimum surface area of approximately 721 ft^2.

2.3.3 *IRWST (ECCS) Sump Strainers*

The ECCS sump strainers are arranged above each of their respective sumps. The following aspects are taken into account to size the IRWST strainers:

- Nature of the debris (e.g., fiber, RMI, particulates, paint chips).
- Maximum quantity of debris that can reach one strainer during the recirculation phase after a large break loss of coolant accident (LBLOCA) when considering the effectiveness of the retaining basket.
- A conservative head loss across the strainer of approximately 2.18 psi at 104°F.
- The zone of influence of the break.
- ECCS recirculation flow.
- Maximum head loss across the strainer with consideration of ECCS pump NPSH margin and the mechanical strength of the strainer.
- Ample strainer surface area to prevent excessive strainer head loss.

A conservative approach is used for sizing the ECCS strainer. Based on the above conservative input and assumptions, the minimal design surface area of approximately 690 ft^2 is selected for the ECCS strainer. The installed strainers will have about 10% more surface area (approximately 760 ft^2) to provide additional margin. The strainer sizing has been validated by testing.

The screen filters retain debris to prevent pump/equipment malfunction and clogging of the smallest restrictions in the core. The screen design reflects a flat grid configuration with a nominal opening size of 0.08 x 0.08 inches to limit passage of debris through the strainer.

Strainer testing demonstrated conservatism in the dimensioning of the strainer. Because most of the debris is trapped in the retaining basket, a limited amount of debris will reach the ECCS strainers. The small amount of debris reaching the strainer results in a very small head loss through the strainer.

2.4 *RCS Insulation*

The judicious selection of insulating materials for piping and equipment inside containment is important in limiting post-accident debris. The U.S. EPR design approach is to extensively use RMI for the RCS piping and major components, including the reactor vessel, the steam generators, reactor coolant pump casings, and the hot, cold, and crossover legs. Insulated piping in the zone of influence will be insulated with RMI. (ZOI =2D)

3.0 APPLICABLE U.S. EPR DESIGN BASES

The design of the U.S. EPR ECCS recirculation system coupled with the judicious selection of and control of insulating materials and other debris generating material effectively addresses strainer clogging. This conclusion is based on U.S. EPR evaluations and substantiated by physical testing that demonstrates the overall system effectiveness.

The design is such that for the postulated event, the LOCA transported debris will not cause a significant loss of NPSH for the ECCS pumps. This is based on the following assumptions:

1. a conservative LOCA debris estimate developed from the guidance of RG 1.82 Rev. 3 and NEI 04-07.

2. all LOCA related debris is transported to the IRWST and all of this material is deposited into one retaining basket.

These assumptions form the underlying technical basis for the U.S. EPR strainer design.

Results of the strainer test program validate the design of the U.S. EPR ECCS recirculation system.

3.1 *Technical Basis for the ECCS Sump Recirculation Design Features*

The technical basis for the ECCS sump recirculation design features is provided by the studies, summarized below. The results of these studies demonstrate the effectiveness of the sump recirculation design features.

3.1.1 *Debris Transport*

Though the U.S. EPR design incorporates multiple LOCA return flow paths and a tiered defense-in-depth debris retention system, a conservative approach is applied in the debris transport evaluation, in that credit is not taken for all design features. For evaluation purposes all LOCA related debris is assumed to be transported to one heavy floor opening (with weir and trash rack) and is assumed to all enter one retaining basket. No credit is taken for debris settling prior to entering the retaining basket. The debris entering the retaining basket is filtered by the retaining basket screen. Some debris passes through the retaining basket filter and is transported to one strainer where it is filtered. The ECCS strainer head loss is based on the accumulation of debris on the single strainer, as shown by testing.

3.1.2 *Debris Source Term*

A debris generation evaluation was performed to establish the debris source term for the U.S. EPR. The details of this evaluation are documented in Appendix C. The evaluation utilizes the guidance of NRC Regulatory Guidance 1.82 Rev. 3 and information presented in Nuclear Energy Institute (NEI) 04-07. This assessment analyzes seven break locations for a postulated LOCA, tabulates the debris generation totals for each break, and identifies the limiting breaks with respect to the most debris generated. The debris generation totals for the limiting pipe breaks serve as a basis for development of the U.S. EPR sump performance program and validation testing.

The debris source term is based on the maximum amount of debris generated by the limiting breaks. For the U.S. EPR design, seven break locations were evaluated for potential limiting debris loads. The following limiting break is identified for the U.S EPR:

- RCS hot leg 3 at pressurizer surge line connection

The RCS hot leg 3 at the pressurizer surge line connection produces the most RMI debris. This debris amount serves as input to the debris source term. Table 3.1-1 summarizes the total debris source term for the U.S. EPR.

Table 3.1-1 Total Debris Source

Material	Amount
RMI (ft^2)	2119.03
Microtherm® (ft^3)	1.00
Qualified Epoxy Coatings (lb_m)	126.30
Qualified IOZ Coatings (lb_m)	958.70
Unqualified Coatings (lb_m)	250.00
Latent Debris (lb_m)	150.00
Miscellaneous (ft^2)	100.00

The bases and assumptions for the debris types and amounts are explained in Appendix C and serve as input to the U.S. EPR Chemical Effects Evaluation and the U.S. EPR ECCS Strainer Performance Testing as detailed in Appendix D and Appendix E, respectively.

3.1.3 *Chemical Effects*

Generic Letter 2004-02 requests the maximum head loss across the ECCS sump strainers postulated from debris accumulation be evaluated. This evaluation requires assessment of chemical effects. As part of the evaluation of IRWST strainer clogging for the U.S. EPR plant, the chemical effects were evaluated to identify specific compounds and quantities of materials that may precipitate within the containment sump pool following a LOCA. This evaluation is comprised of the following integrated studies:

- Chemical Effects Testing

  Chemical Effects Testing involves testing of simulated post-break conditions to identify chemical effects arising from the interaction of debris materials and buffering agents used to raise the pH of the fluid in the IRWST. The test results provide the data required to calculate the chemical debris generated as a result of a design basis LOCA. The calculation of the chemical debris quantities is performed in the IRWST Sump Chemistry Modeling study.

- IRWST Sump Chemistry Modeling

Using the data and results from Chemical Effects Testing, IRWST Sump Chemistry Modeling calculates and identifies the specific compounds and quantities of materials that may precipitate within the U.S. EPR reactor containment sump pool following a LOCA.

Appendix D details the methodology and results of the U.S. EPR Chemical Effects Evaluation. The results of this evaluation serve as a basis for development and input to the U.S. EPR ECCS Strainer Performance Testing as detailed in Appendix E.

Based on chemical effects studies and ECCS strainer performance testing, the amount of chemical precipitate formation will not result in significant impact to strainer head loss and ECCS operation.

3.1.4 *ECCS Strainer Performance*

ECCS strainer testing was conducted to demonstrate strainer performance following a postulated loss of coolant accident (LOCA). Testing is based on guidance specified in NEI 04-07 Volumes 1 and 2 (Reference 3) and the March 2008 testing guidance (Reference 4). The U.S. EPR Debris Generation Evaluation (Appendix C) and the U.S. EPR Chemical Effects Evaluation (Appendix D) serve as a basis and input to the strainer testing.

ECCS strainer testing conservatively challenged the “defense in depth” design of the U.S. EPR IRWST design by using only one of the four sets of retaining basket/strainer combinations that exist in the IRWST design. Testing determined the strainer head loss based on prototypical water flow and debris mix conditions expected in the U.S. EPR containment following a postulated LOCA. Testing also evaluated strainer response to thin bed conditions, debris transport response, and provided bypass sampling for downstream analysis. A total of five tests were performed. These tests include:

- Debris Transport Test
- Clean Strainer Head Loss Test

- Design Basis Debris Loaded Strainer Head Loss Test
- Fibrous Debris Only Sample Bypass Test
- Debris Loaded Strainer Head Loss Thin Bed Test

ECCS strainer performance testing demonstrated the effective and reliable performance of the U.S. EPR design for GSI-191. The strainer design, complimented by the design mitigation features of the retaining basket, provides an abundance of head loss margin for the ECCS strainer. Testing concludes the strainer head loss is conservatively limited to less than 0.5 feet of water as compared to a strainer design head loss of approximately 5.0 feet. The observed head loss was zero feet because of debris. In addition, testing revealed no thin bed formation on the strainer. Fiber-only bypass testing also yielded acceptable results.

The details of U.S EPR ECCS strainer performance testing are provided in Appendix E.

3.2 *Other Considerations*

3.2.1 *NPSH Assessment*

An NPSH assessment of the ECCS system was performed. Results of this assessment conclude the system will satisfactorily function with the strainer design head loss of approximately 5 feet. Based on the results of strainer testing, the actual strainer head loss for the design basis LOCA is less than 0.5 feet with a water temperature of 120°F. The strainer testing head loss of approximately 1/10th of the design strainer head loss ensures adequate NPSH margin for the ECCS pumps.

3.2.2 *Strainer Vortexing, Submergence, Flashing, and Deaeration Assessment*

Vortexing

An evaluation was performed of the potential for IRWST vortexing using the methodology of ANSI Standard 9.8-1998 (Reference 5), Sections 9.8.6 and 9.8.7. To minimize free surface vortices for the U.S. EPR inlet sump for the low head safety injection (LHSI) and medium head safety injection (MHSI) pumps, the recommendation in ANSI Standard 9.8-1998 was followed, which recommends a minimum submergence of ~50 in. The U.S. EPR-designed submergence is ~147 in., so there is no vortexing potential for the U.S. EPR sump design. The calculated minimum submergence is based on maximum LHSI/MHSI combined flow and higher-than-expected fluid temperature, both of which are conservative and provide additional vortexing margin.

Submergence / Flashing

The strainer height is 7.8 feet. The IRWST minimum level for ECCS pump NPSH is 10.0 feet. This results in a strainer submergence of 2.2 feet under LOCA conditions. The maximum strainer head loss is 0.88 psi at 212°F. This converts to an equivalent head of 2.1 feet of head loss. The strainer submergence level exceeds the associated head loss. If the surface pressure is conservatively assumed at the saturation pressure of the IRWST water temperature, the local static pressure after the strainer will not be less than the saturation pressure, and flashing will not occur across the strainer surface.

During testing, the maximum observed head loss across the strainer is less than 0.5 feet, which provides additional margin to flashing.

Deaeration

The strainer submergence post LOCA is greater than the observed head loss under loss of coolant conditions. Since solubility of gas in water is directly proportional to the fluid pressure, the increase in solubility of air due to the static pressure increase of the water above the strainer is more than enough to compensate for the decrease in solubility of air due to the head loss across the strainer. Therefore, deaeration of fluid will not occur. The design head loss value is a conservative value aimed primarily at minimizing the calculated NPSH for the ECCS pumps, and does not imply deaeration even though it may be greater than the strainer submergence.

3.2.3 *IRWST Cleanliness*

The IRWST serves as a water source, heat sink, and return reservoir and contains a large volume of borated water that is monitored for a homogeneous concentration, level, and temperature. The IRWST is an open pool within a partly immersed building structure. The walls of the IRWST have an austenitic stainless steel liner covering the immersed region of the building structure. The liner prevents interaction of the boric acid and concrete structure and provides water tightness.

During normal operations and refueling, there is the potential for debris to enter the IRWST and settle on its submerged surfaces. This “latent, resident” debris could become re-entrained post-accident. To maintain the cleanliness of the IRWST, the IRWST water inventory and access to the IRWST areas will be controlled and monitored. The fuel pool purification system (FPPS) is utilized to maintain the purity of the IRWST water inventory. IRWST programmatic controls for foreign material exclusion (FME) and tank cleaning will be implemented. A cleanliness control program will limit debris within containment.

3.2.4 *Strainer Mechanical Integrity*

The ECCS strainers are designed to accommodate an approximate 5.0 feet pressure differential. The maximum pressure drop across the strainers is less than 0.5 feet as shown by strainer performance testing. The strainers are Seismic Category I, safety-related components.

3.2.5 *Water Holdup*

The water holdup mass in the Reactor Building is examined during various phases of the LBLOCA transient, including time of blowdown, refill/reflood, post-reflood, peak containment pressure, and half peak containment pressure time. There are different categories analyzed for water holdup, including condensate on walls and ceilings, water retained in steam and droplet phase in the containment atmosphere, and water retained on floors. Water is also retained in a retaining basket assumed to be clogged and in the RCS.

Condensation on vertical walls and ceilings is assumed to be at a uniform film thickness and distribution throughout the Reactor Building. For a LBLOCA, the mass of droplets in the containment atmosphere is only significant early in the transient during blowdown. Steam mass inside the containment atmosphere is evenly distributed throughout the containment free volume and is based on containment vapor partial pressure and saturation temperature.

The mass of retained water on the heavy floor and lower annular area is based on the height of each respective weir plus an additional dynamic head height based on the flow rate onto each floor. The flow on the heavy floor consists of condensation from rooms above the heavy floor and liquid break flow leaving the RCS. Water on the heavy floor returns to the IRWST via the four trash racks.

Wall openings are provided in the SGBD room walls at four locations, two in each wall, to route the surge line break fluid out of the SGBD tank room and onto the heavy floor. During a LBLOCA, water may flow from the heavy floor into the SGBD and PRT rooms. In the water retention analysis, the SGBD and PRT rooms (UJA11018 and UJA11019) are considered to be flooded at the same depth as the heavy floor.

The four openings between the SGBD and PRT rooms and the loop areas are free openings (0.618 feet^2 each) (Figure 3-2). The minimum opening height from the floor for each 0.618 feet^2 opening is approximately 1.05 feet (Figure 3-3). There are no devices contained in the openings, allowing bidirectional flow. A 20 inch (1.67 feet) (Figure 3-1) high berm around the SGBD system tank prevents flooding into the compartment below. The two doors leading into the annular regions from room UJA11018 will contain a flooding berm of at least 20 inches (1.67 feet) high to preclude flooding into the annular area. Obstructions to drainage of water such as toe-plates will be specifically designed to allow drainage to the IRWST.

Debris generation is limited to reflective metallic insulation (RMI) and latent debris. There is no fibrous insulation in the ZOI in the U.S. EPR containment design. However, fibrous insulation may be used outside the ZOI.

The maximum level of flooding on the heavy floor and the floors of the SGBD and PRT rooms in the water retention analysis is 0.7855 feet, which occurs during blowdown of a LBLOCA. The flooding level for a pressurizer surge line break was not evaluated because the LBLOCA is more limiting for water retention. The maximum level of water retention (0.7855 feet) is lower than the level of berms (1.67 feet), and no water will flood out to the annular space or to the room below the SGBD tank room. Door operation in the SGBD tank room is not required to release or contain the water level because the flooding level, 0.7855 feet, from the LBLOCA is below the 1.67 feet height of the berms at each door.

Figure 3-1 20" Berm around SGBD Tank

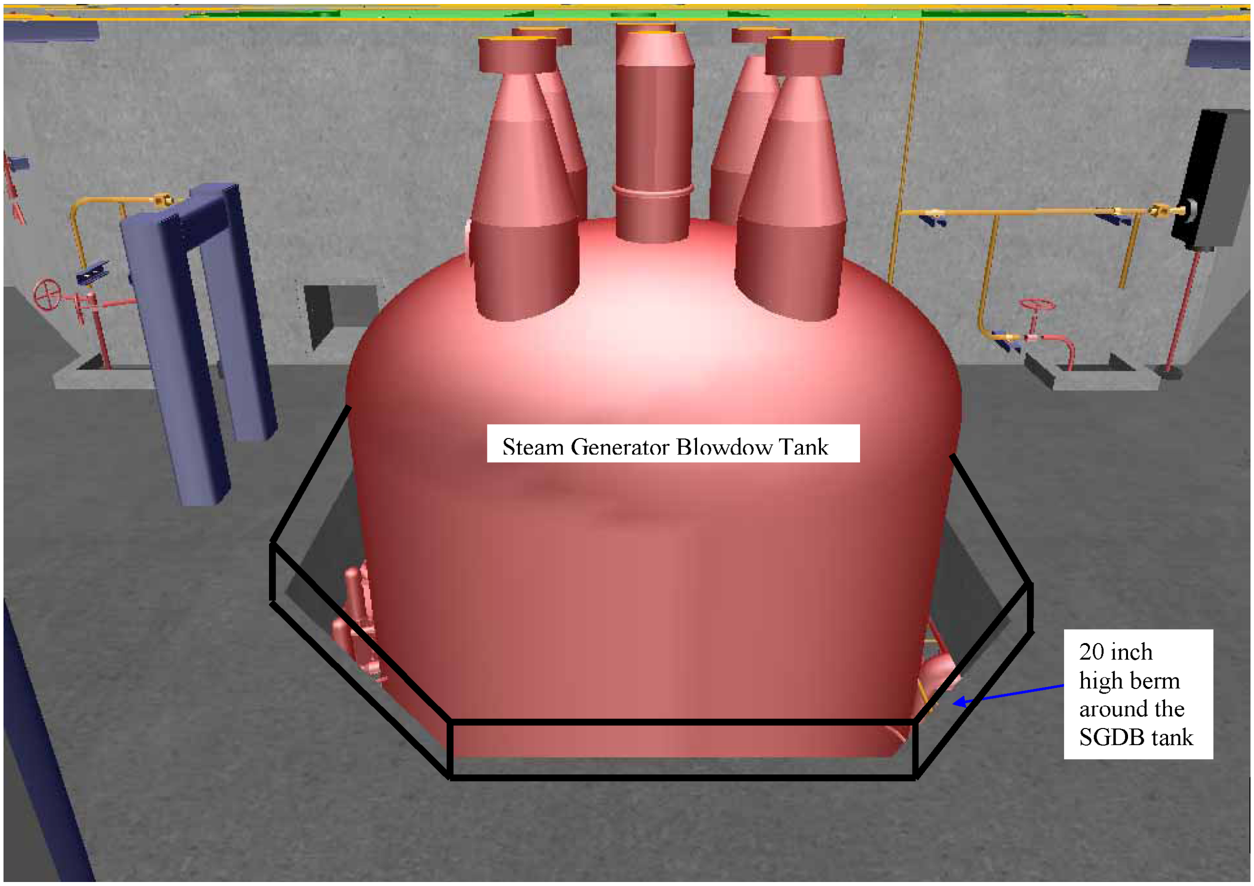


Figure 3-2 Openings that Communicate to the Heavy Floor Area

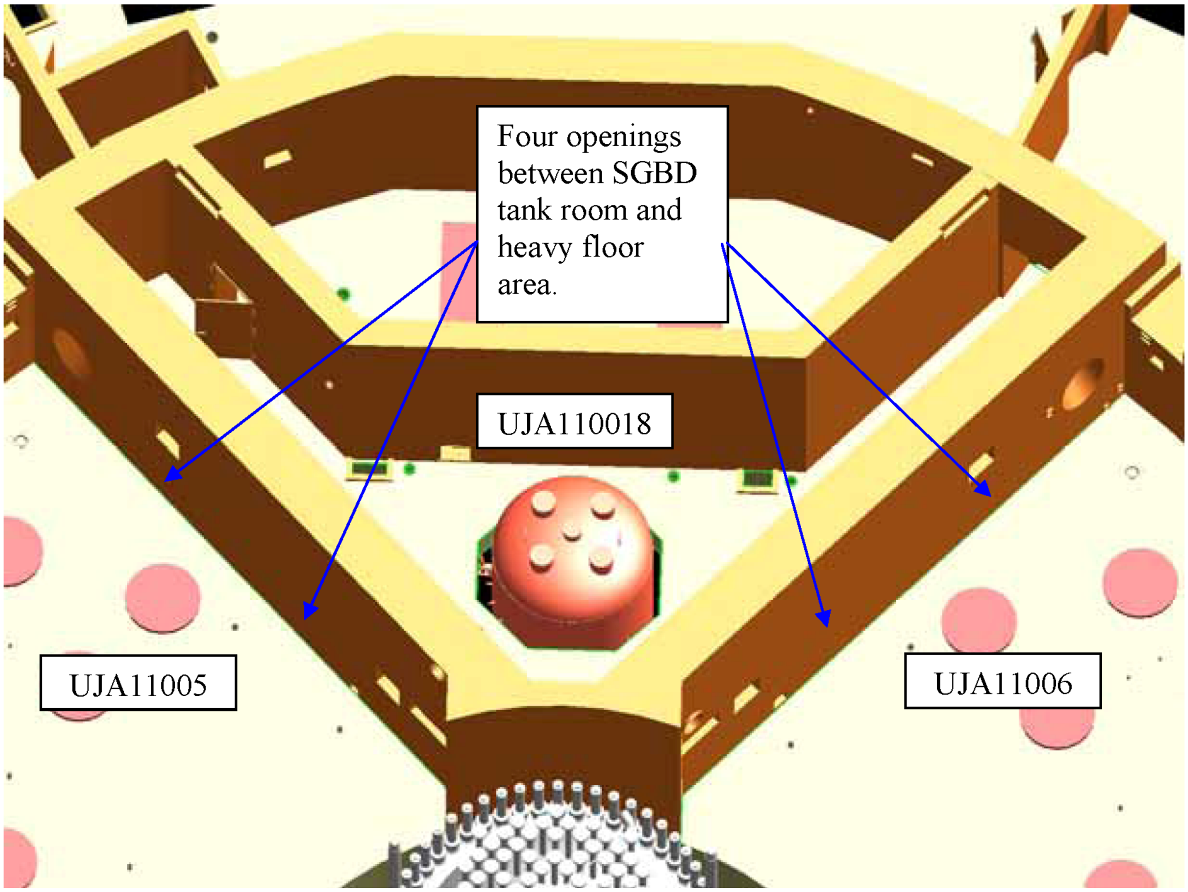
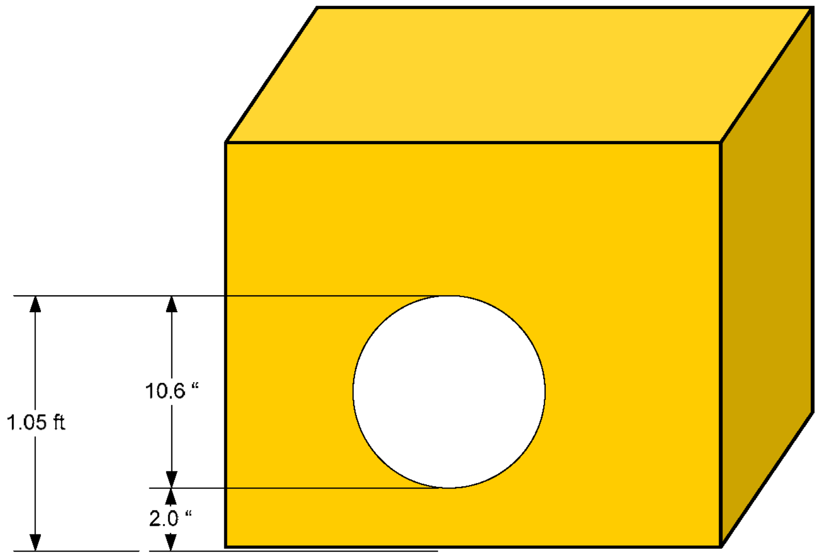


Figure 3-3 Profile of the 4 openings



The flow to the lower annular area consists only of condensation flow, although it is possible for the pressure during blowdown to force water from the IRWST into the lower annular service area. The exact amount of IRWST water that could be displaced depends on different, interrelated factors for each break scenario. The water retention analysis was a worst-case evaluation, assuming that the annular area would instantly fill to the weir height with IRWST liquid. This worst-case scenario only impacts the early phases of the transient, which are not limiting regarding the ECCS pumps.

The lower annular area communicates with the IRWST through seven openings via gutters. These gutters seal off the two areas with a water seal in the IRWST to maintain a two-zone containment. The gutters are attached to the IRWST wall at the openings by anchoring bolts to the frame. The gutters protrude out from the wall approximately 12 inches, and then turn 90° down into the IRWST water to a level of -2.8 (-9.2 ft) meters. The minimum IRWST level during normal operating conditions is -2.59 (-8.5 ft) meters, keeping the annular space separated from the IRWST (see Figure 2-1). The gutters are stainless steel, including the anchoring material.

There are no RCS breaks outside the equipment compartment that can affect the annular area. The only high-energy line breaks that will affect the annular area are a feedwater line break and a main steam line break, but in those cases, ECCS recirculation is not required for event mitigation.

In addition to the heavy floor and the lower annular area, water is retained on the floors of several rooms where condensation will occur but will not return to IRWST. These rooms contain walls or curbs that completely hold up water, or doors that partially hold up water.

The total amount of water holdup is used to calculate the IRWST level for evaluation of NPSH requirements and for the debris distribution evaluation for GSI-191 requirements. The maximum amount of water holdup for a LBLOCA occurs at one hour into the transient. It is possible for the holdup value to be greater during the initial blowdown phase, and the ECCS pumps are not needed. Table 3.2-1 summarizes water holdup in the Reactor Building at one hour. Table 3.2-1 shows that after accounting for the water held up in containment, the IRWST has a margin to ECCS pump NPSH of 197,158 pounds.

Table 3.2-1 Maximum Water Holdup

Time (s)	3,600
Steam Phase (lbm)	317,245
Droplets (lbm)	81
Wall Condensate (lbm)	16,318
Ceiling Condensate (lbm)	25,983
Retention on RB Floors (lbm)	396,146
Retention in Clogged Basket (lbm)	68,064
Re-injected into RCS (lbm)	363,825
Total Mass of Retained Water (lbm)	**1,187,662**
Accumulator Injection (lbm)	-228,614
RCS Inventory (lbm)	-604,170
Total IRWST Water Loss (lbm)	**354,878**
Allowable IRWST Loss (lbm)	552,036
Margin (lbm)	**197,158**

4.0 REGULATORY OVERVIEW

The purpose of this section is to provide a brief overview of the related regulatory issues and an evaluation of the U.S. EPR conformance.

4.1 *Generic Safety Issue 191*

GSI-191, “Assessment of Debris Accumulation on PWR Sump Performance,” was initiated by the NRC in 1996 in response to a number of plant events and subsequent follow-on research regarding the adequacy of ECCS sump designs.

The issue of post-accident debris blockage arising from a LOCA or high energy line break (HELB) for which sump recirculation is required could potentially impact the plant’s ability to demonstrate compliance with General Design Criterion 38, “Containment Heat Removal,” and 10 CFR 50.46 (b) (5) as it relates long term post-LOCA core cooling requirements. The objective of GSI-191 is to prevent post-accident debris blockage that could impede the operation of the emergency core cooling system (ECCS) and the containment spray system (CSS) in the recirculation mode at PWRs during LOCAs or other HELB accidents for which sump recirculation is required.

4.2 *Regulatory Guide 1.82 Rev. 3*

Regulatory Guide 1.82 Rev. 3, “Water Sources for Long-Term Recirculation Cooling Following a Loss-Of-Coolant Accident,” provides guidelines for evaluating the adequacy of the availability of the sump and suppression pool for long-term recirculation cooling following a LOCA.

The primary safety concerns regarding long-term recirculation cooling following a LOCA are:

1. LOCA-generated and pre-LOCA debris materials transported to the debris interceptors (i.e., trash racks, debris screens, suction strainers) resulting in adverse blockage effects.

2. Post-LOCA hydraulic effects, particularly air ingestion.

3. The combined effects of items (1) and (2) on long-term recirculation pumping operability (i.e., NPSH available at the pump inlet).

The above safety concerns extend to the CSS for plants with containment designs where the CSS draws suction from the recirculation sump. In some cases, the CSS would draw from the recirculation sump significantly earlier than would the ECCS. However, the U.S. EPR design basis does not rely on a CSS.

Debris resulting from a LOCA, together with debris that exists before a LOCA, could block the ECCS debris interceptors and result in degradation or loss of NPSH margin. Such debris can be divided into the following categories:

1. Debris that is generated by the LOCA and is transported by blowdown forces (e.g., insulation, paint).

2. Debris that is generated or transported by washdown.

3. Other debris that existed before a LOCA (e.g., corrosion material, sludge in a BWR suppression pool) and that may become suspended in the containment sump or suppression pool.

Debris can be further subdivided as follows:

1. Debris that have a high density and could sink but are still subject to fluid transport if local recirculation flow velocities are high enough.

2. Debris that have an effective specific gravity near 1.0 and tend to remain suspended or sink slowly and will nonetheless be transported by very low velocities or local fluid turbulence phenomena.

3. Debris that will float indefinitely by virtue of low density and will be transported to and possibly through the debris interceptors.

Debris generation, early debris transport, long-term debris transport, and attendant blockage of debris interceptors should be evaluated to show that the ability of the ECCS to provide long-term post-LOCA core cooling is not jeopardized. All potential debris sources should be evaluated, including but not limited to, the fire barrier material, insulation materials (e.g., fibrous, ceramic, and metallic), filters, corrosion material, and paints or coatings.

Regulatory Guide 1.82 provides separate guidance for PWR and BWR plants based on the design features of currently operating reactors. However, advanced PWR or BWR designs may employ design features that this regulatory guide only associates with the opposite reactor design (e.g., an advanced PWR design that employs an IRWST similar to the suppression pool of a current BWR design, or an advanced BWR design that employs a large dry containment similar to a current PWR design).

Therefore, for advanced PWR and BWR designs, the guidance provided in both the PWR and BWR sections of RG 1.82 that is appropriate and consistent with the plant's design features should be considered.

4.3 *RG 1.82 Conformance Assessment*

An assessment of U.S. EPR conformance to RG 1.82 is provided in Appendix A. All 53 PWR-related guidance and five potentially applicable BWR guidance items were reviewed.

4.4 Generic Letter 2004-02

GL 2004-02 was issued to licensees of operating plants requesting that they demonstrate that corrective actions taken to address GSI-191 are adequate.

Additionally, GL 2004-02 requested the licensee provide information to assess the potential impact of debris blockage on emergency recirculation during design basis events.

Table B.1 of Appendix B provides U.S. EPR sump recirculation information as applicable to requested information outlined in GL 2004-02.

5.0 CONCLUSION

The U.S. EPR sump design has advanced and redundant features with respect to post-accident debris accumulation and ECCS recirculation sump strainer blockage. The U.S. EPR's ECCS recirculation system has multiple levels of debris removal and filtration that provide an effective system for preventing LOCA-generated debris from degrading ECCS performance or impeding core cooling. The conclusion is supported by the following information presented in this report:

1. The U.S. EPR has a minimal post-accident debris source term relative to current LWRs. RCS piping and components will be insulated with RMI; there will be no fibrous or micro-porous insulation within the ZOI, and no calcium-silicate insulation within containment.

2. The three-tiered debris retention design of the U.S. EPR ECCS recirculation system is an effective solution to post-accident ECCS pump strainer clogging. The combination of weirs/trash racks and retaining baskets are effective in retaining most of the debris. As a result, very little debris will reach the ECCS strainers. The ECCS strainers have a large screen surface area to accommodate the small amount of debris that will reach them.

3. The U.S. EPR design conforms to the applicable RG 1.82 requirements as detailed in Table A.1 of Appendix A.

4. Test results using a conservative debris source term validate the performance of the U.S. EPR ECCS recirculation system features to prevent sump/strainer clogging.

6.0 REFERENCES

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

2. GL 2004-02, “Potential Impact of Debris Blockage on Emergency Recirculation during Design Basis Accidents at Pressurized-Water Reactors,” U.S. NRC, September 2004.

3. NEI 04-07, “Pressurized Water Reactor Sump Performance Evaluation Methodology,” Volumes 1 (Methodology) and 2 (Safety Evaluation), December 2004.

4. “NRC Staff Review Guidance Regarding Generic Letter 2004-02 Closure in the Area of Strainer Head Loss and Vortexing,” March 2008.

5. ANSI Standard 9.8-1998, “Pump Intake Design.”