US-APWR Sump Strainer Performance

Non-Proprietary Version

September 2008

Revision History (Sheet 1 of 3)

Revision	Page (Section)	Description
0 (Feb-2008)	All	Original issued
1 (Sept-2008)	1	Section 1.0, second paragraph: - Summary of Chapter 3 was changed.
	3	Section 2.1, forth paragraph: - Added second paragraph to clarify for debris sources in the RWSP. - MHI document, "4CS-UAP-20080045" was referred.
	3	Section 2.1, fifth paragraph: - PCI strainer system was selected as standard design of the US-APWR. - Strainer mesh size was changed as per design progress. - Appendix-A was provided to describe details of PCI strainer system.
	3	Section 2.1, sixth paragraph: - Strainer submergence was changed as per design progress.
	3 to 4	Section 2.1, seventh paragraph: - Clarification for strainer head loss was provided, and strainer system was resized as per design progress.
	5	Section 2.2, seventh paragraph: - Use of fibrous debris was reduced further as per design progress.
	5	Section 2.2, eighth paragraph: - Clarification for blanket type fiber insulation was provided.
	5	Section 2.3, first paragraph: - Clarifications for coating details were provided.
	6	Figure 2-1: - Replace with PCI strainer system as per design progress.
	7	Section 3.1, fifth paragraph: - Limitation of use of particulate insulation was corrected to avoid confusing.
	8	Section 3.1, ninth paragraph: - Clarification for use of fibrous insulation was provided, and reference figures in the DCD were supplemented.
	8	Section 3.1, tenth paragraph: - Location of fiber insulation was identified to be inside "SG compartment (A)"..
	9	Section 3.1, fourteenth paragraph: - Clarification for "TBE" observed in the past PCI tests was provided.
	9	Section 3.2, first paragraph: - Clarification for miscellaneous debris was provided.

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Revision	Page (Section)	Description
1 (Sept-2008)	10	Section 3.2, seventh paragraph: - Clarification for miscellaneous debris was provided.
	11 to 13	Section 3.4, second paragraph to last paragraph: - Additional details of plant layout associated with debris transportation analysis were provided. - Evaluation of debris allocation on one sump was provided.
	13 to 14	Section 3.5: whole section was changed: - Replaced previous head loss calculation using NUREG-CR6224 and CR6808 with “bounding evaluation” using existing test data of US operating PWR plant. - PCI document describing details of bounding evaluation was provided in Appendix-B. - Future activities were summarized at the end of the section.
	14	Section 3.6.1, first paragraph: - Replace “Figure 3-5” with “Figure 3-6”.
	14	Section 3.6.2, first paragraph: - Editorial improvements were made.
	14 to 16	Section 3.6.2.1, first paragraph, a) and d): - Editorial improvements were made.
	16	Section 3.6.2.1, e): - Upper limit of strainer head loss was specified as per application of “bounding evaluation” described in section 3.5.
	17	Section 3.6.2.2, second paragraph: - Replace “Figure 3-6” with “Figure 3-7”.
	18	Section 3.7.1, third paragraph: - Replace “Figure 3-7” with “Figure 3-8”.
	19	Section 3.7.1, forth paragraph: - Clarification for drain pipes was provided.
	20	Section 3.7.2, third paragraph: - Replace “Figure 3-8” with “Figure 3-9”.
	21	Section 3.8, whole section was changed: - Incorporate the summary of chemical effects test plan, “MUAP-08006 US-APWR Sump Debris Chemical Effects Test Plan, June 2008”.
	22 to 23	Section 3.9, second paragraph: - Summary of bounding evaluation was provided.
	23	Section 3.9, third paragraph: - Current schedule of relative technical reports submittals was incorporated.

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Revision	Page (Section)	Description
1 (Sept-2008)	28	Figure 3-5 was added. (Subsequent figures were re-numbered accordingly.)
	34	Table 3-3 was revised as per further reduction of use of fibrous insulation as discussed in section 2.2.
	34	Table 3-4, the amount of fibrous insulation was revised as per further reduction of use of fibrous insulation as discussed in section 2.2.
	35	Table 3-5, material density of latent fiber was corrected to avoid inconsistency.
	36	Table 3-6 and Table 3-7 were deleted, because bounding evaluation was applied instead of head loss calculations as discussed in section 3.5.
	39	Section 4.1.2, first paragraph: - Incorporate strainer mesh size as discussed in section 2.1.
	39	Section 4.2.1, second paragraph: - Incorporate strainer mesh size as discussed in section 2.1.
	46	Section 5.0, “Conclusion” was revised as per the revision of the technical report.
	47	Section 6.0: Four references were added.
	-	“Appendix-A” and “Appendix-B” were attached.

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List of Acronyms

APWR	Advanced Pressurized Water Reactor
ARL	Alden Research Laboratory
CO/L	Cross Over Leg
CPNPP	Comanche Peak Nuclear Power Plant
CSS	Containment Spray Systems
CVCS	Chemical and Volume Control System
DBA	Design Basis Accident
DCD	Design Control Document
ECCS	Emergency Core Cooling Systems
ECC/CS	Emergency Core Cooling and Containment Spray
GR	Guidance Report
HELB	High Energy Line Break
HVAC	Heating, Ventilation, and Conditioning
LOCA	Loss of Coolant Accident
LBLOCA	Large Break LOCA
MCP	Main Coolant Pipe
MHI	Mitsubishi Heavy Industries, LTD.
MS/FW	Main Steam and Feed Water
NPSH	Net Positive Suction Head
NEI	Nuclear Energy Institute
NRC	Nuclear Regulatory Commission
PCI	Performance Contracting Inc,.
PWR	Pressurized Water Reactor
PZR	Pressurizer
RCP	Reactor Coolant Pump
RG	Regulatory Guide
RHR	Residual Heat Removal
RMI	Reflective Metal Insulation
RWSP	Refueling Water Storage Pit
RV	Reactor Vessel
SBLOCA	Small Break LOCA
SE	Safety Evaluation
SFS	Sure-Flow Strainer

SG	Steam Generator
SI	Safety Injection
TBE	Thin Bed Effect
ZOI	Zone of Influence

1.0 INTRODUCTION

This technical report summarizes the design and evaluation of the standard US-APWR sump strainer, and supports the US-APWR Design Control Document (DCD), Chapter 6, Subsections 6.2 “Containment Systems”, and 6.3 “Emergency Core Cooling Systems (ECCS). (Reference [1]) The design and evaluation described herein were in accordance with the Regulatory Guide 1.82 Rev.3. (Reference [2])

In this report, Chapter 2 contains a description of the strainer, its type, location, and a summary of design features relative to the insulation and coating systems which are generally considered as the potential debris sources. Chapter 3 provides bounding evaluation by comparison of the US-APWR design basis to the Comanche Peak Nuclear Power Plant (CPNPP) 1 & 2 design basis with the intent to demonstrate the postulated design is bounded by the head loss test results of CPNPP 1 & 2, without US-APWR head loss testing. Chapter 4 discusses the downstream effect of the strainer. Finally, Chapter 5 presents the conclusions of the US-APWR sump strainer performance.

2.0 DESIGN DESCRIPTION

2.1 ECC/CS strainer

The US-APWR emergency core cooling and containment spray (ECC/CS) strainers are designed to be consistent with Regulatory Guide (RG) 1.82 as follows:

- Four independent sets of strainer system are provided
- The strainers are installed on the bottom floor of the containment to collect the blowdown water during the accident
- The design precludes the drain water impinging directly on the strainers
- The strainers are well isolated from postulated pipe break jets and missiles
- The strainer's large surface provides low flow rate on the strainer surface and mitigates debris head loss
- The perforate plates are designed to prevent blockage of core cooling
- The strainers are constructed of corrosion resistant materials
- The strainers are sized to maintain the performance of the safety-related pumps
- The strainers are designed to meet seismic category I requirements
- The strainers are inspected periodically, during plant shutdown

As shown in the US-APWR DCD Figures 6.2.2-8 and 6.2.2-9, four independent sets of ECC/CS strainers are provided inside the in-containment refueling water storage pit (RWSP). The ECC/CS strainers prevent debris from entering the safety systems that are required to maintain the post-LOCA long-term cooling performance. The RWSP is located at the lowest part of the containment in order to collect containment spray water and blowdown water by gravity. The RWSP is compartmentalized by a concrete structure against the upper containment area, and connecting pipes that drain the collected water from the upper containment are provided in the ceiling of the RWSP. The RWSP protects the ECC/CS strainers from missiles. The ECC/CS strainers are installed on the bottom floor of the RWSP, and are designed to be fully submerged during all postulated events requiring the actuation of the ECCS.

The fully submerged strainers, in combination with the Safety Injection (SI) pump and the Containment Spray/Residual Heat Removal (CS/RHR) pump elevation, provide sufficient NPSH to ensure continuous suction availability without cavitation. The strainer sizing accommodates the estimated amount of debris potentially generated in containment.

There is no debris source (i.e. insulation, paints, concrete wall) in the RWSP. All debris is generated outside the RWSP. The debris will be transported to the RWSP by return water through drain pipes that are dispersed in upper containment floor. The drain pipes are positioned not to impinge the strainer system by drain water. Vent pipes are also provided to equalize the atmospheric pressure between the RWSP and the upper containment. Detail information of drain/vent pipes are provided in 4CS-UAP-20080045 "US-APWR Technical Information and Requirements for ECC/CS Sump Strainer". (Reference [3])

The standard US-APWR design utilizes a passive disk layer type of strainer systems, "Sure-Flow Strainer (SFS)", supplied by Performance Contracting Inc. (PCI)". Figure 2-1 shows a typical plan view of the disk type strainer system of one safety train used in the US-APWR. The strainer is principally constructed of perforated plate with a square flange at the bottom for attachment to the supporting plate, which is covered on the sump pit. A manifold core tube connected to the flange penetrates near the center of the layer disks, and guides the clean water filtered by the layer disks into the sump pit. The joint gap between the components of the strainer is controlled to preclude debris from bypassing the perforate plates. The strainers and supporting plates will be constructed of corrosion-resistant stainless steel. The nominal diameter of holes is designed to be equal or less than 0.066", consistent with the narrow gap in the downstream systems of the strainer. The downstream narrow gap is discussed in Section 4.0 of this report. Technical description and detailed drawings of strainer are provided in Appendix-A.

The RWSP is filled by 651,000 gallons of borated water during normal operation, and is designed to hold a sufficient water volume during a loss of coolant accident (LOCA). An adequate water level is maintained to submerge the strainer in case of a LBLOCA. The strainers are installed so as to submerge the top of the layer disk 3.67" under the minimum water level. The water balance of the RWSP is summarized in US-APWR DCD Table 6.2.1-3, and its calculation is discussed in Section 3.7 of this report.

The specification requires the strainers to be designed for a 4.7 feet of water of the head loss during accident. This requirement was set with sufficient margin for NPSH evaluation as summarized in Section 3.6. The strainer was sufficiently sized to meet the requirement, and each SFS module contains 27 stacked disks and 9 modules per safety train providing nominal 3,510 ft^2 of strainer surface area. In the evaluation of the debris head loss in Section 3.5, only two of four safety trains are conservatively operable during accident, and approximately total 7,000 ft2 of strainer surface area is provided to cope with postulated debris load.

2.2 Insulation

The standard US-APWR design utilizes the zone of influence (ZOI) method for the evaluation of debris generation, as discussed in Section 3.1 and Section 3.2 of this report. The ZOI represents the zone where a given high-energy line break (HELB) will generate debris that may be transported to the strainer. The size of the ZOI is defined in terms of pipe diameters and determined based on the pressure contained by the piping and the destruction pressure of the insulation surrounding the break site. The ZOI for specific insulation types are provided in the approved methodology, NEI 04-07 Guidance Report (GR) amended by NRC Safety Evaluation (SE). (Reference [3])

In the Section 3.3.4.2.1 (Table 3-2) of the SE, the reflective metal insulation (RMI) is seen to require a largest destruction pressure among the types of insulation made of fibrous and particulate materials. Therefore, the application of RMI for the pipe lines and components subject to jet impingement from a HELB will minimize the generation of insulation debris, rather than the use of fibrous/particulate material insulations.

The US-APWR design considers that the pipe breaks in the primary coolant system piping have the potential need for reliance on ECCS sump recirculation. In addition, the secondary side system, i.e. main steam and feed water (MS/FW) pipe breaks also require sump operation.

As a result, the US-APWR design utilizes the RMI, to the greatest extent practicable, for the pipe lines and components subject to jet impingement from a HELB, in order to mitigate the generation of insulation debris.

Following is the design of the insulation applying for the US-APWR equipment and pipe lines:

Equipment

RMI is applied to the reactor vessel (RV), the reactor coolant pumps (RCP), the steam generators (SG), and the pressurizer (PZR) in the areas that have large amount of insulation to be potentially subject to jet impingement from a HELB.

There is no other equipment to be insulated inside containment of the US-APWR. In addition, the heating, ventilation, and air conditioning (HVAC) of the US-APWR requires no insulation, nor even the ventilation filters, which are considered as the potential debris sources caused by HELB.

Pipe lines

RMI is applied for the main coolant pipes (MCP) connecting the RV, the SG, and the RCP, and MS/FW pipe lines. RMI is applied on the pipe lines located inside the ZOI which are subject to the jet impingement of HELB. The use of fibrous insulation is practically minimized and applied only for 1 inch excess letdown line of chemical and volume control system (CVCS).

Others

Blanket type of fibrous insulation is applied to fill a gap at support for RMI insulated pipe, and root SG support legs. This insulation is also applied for small vales equal or less than 3/4 inches nominal. These are potential fibrous debris sources when they are located in the ZOI of HELB.

2.3 Coatings

The standard US-APWR utilizes a DBA qualified and acceptable coating system in containment. The coating systems in containment are met with the requirement of Service Level-I coatings categorized in USNRC Regulatory Guide 1.54 Revision 1 (Reference [5]) and relative ASTM requirement described in R.G 1.54. The criteria for those coating systems are contained in ANSI N101.2, “Protective Coatings (Paints) for Light Water Nuclear Reactor Containment Facilities (Reference [6]),” and its successor document, ASTM D 3911, “Standard Test Method for Evaluating Coatings Used in Light-Water Nuclear Power Plants at Simulated Design Basis Accident (DBA) Conditions (Reference [7]).” Only the epoxy type coatings (including primer and top coated) are used. The inorganic zinc coating systems are not used.

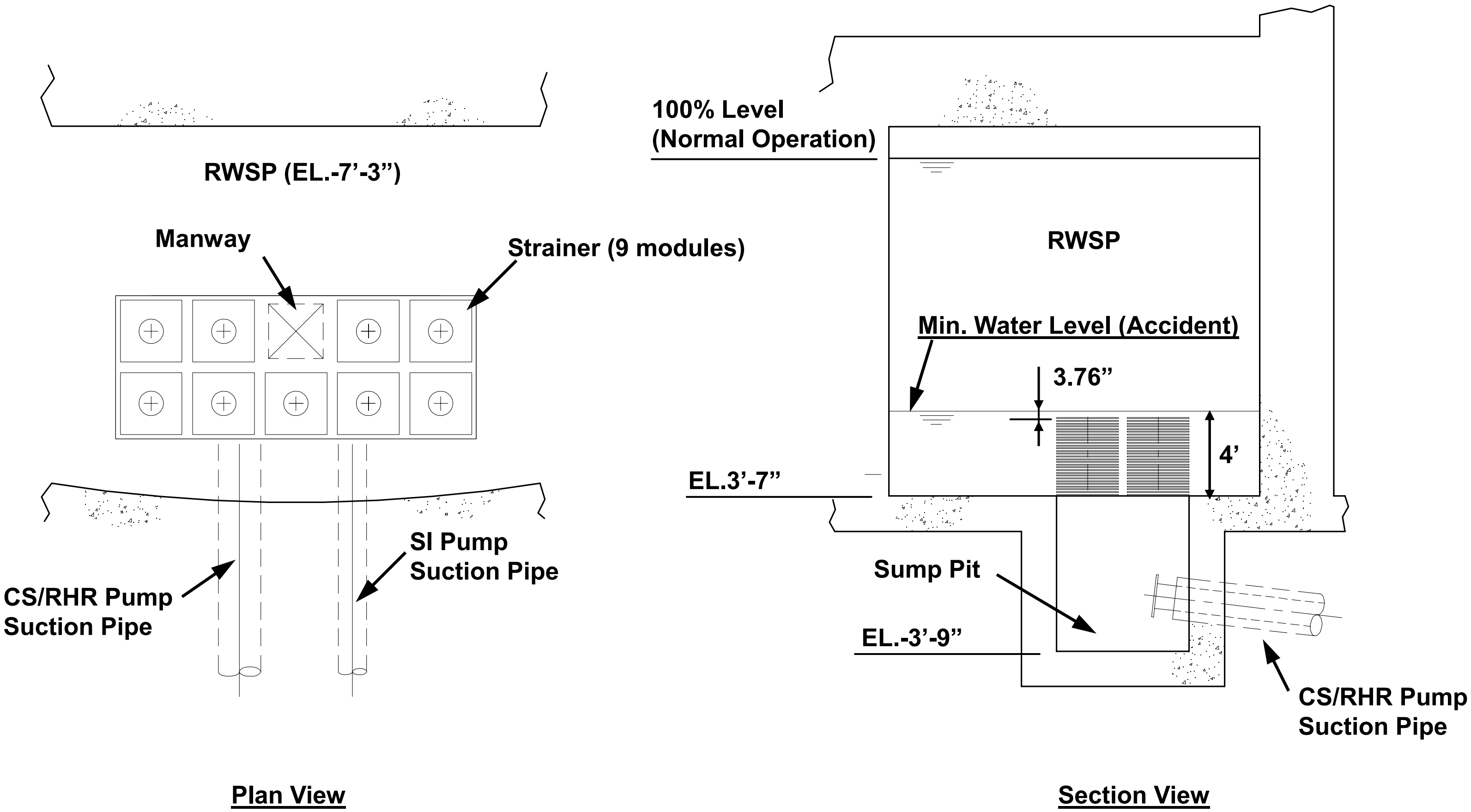


Figure 2-1 ECC/CS Strainer Arrangement

3.0 EVALUATION OF STRAINER PERFORMANCE

3.1 Break Selection

The US-APWR design considers that the pipe breaks in the primary coolant system piping have the potential need for reliance on ECCS sump recirculation. A reactor coolant system (RCS) piping large break loss of coolant accident (LBLOCA) and certain RCS piping small break LOCAs (SBLOCAs) would also require ECC/CS sump recirculation. In addition, the secondary side system, i.e. Main Steam and Feed Water (MS/FW), pipe breaks require sump operation.

For the break selection, the following break location criteria, which are recommended in the SE (Reference [3]) and comply with RG 1.82, are considered:

<u>Break Criteria</u>

1. Pipe break in the RCS or MS/FW with the largest potential for debris
2. Large breaks with two or more different types of debris
3. Breaks with the most direct path to the sump
4. Large breaks with the largest potential particulate debris to insulation ratio by weight
5. Breaks that generate a “thin-bed” - high particulate with 1/8" fiber bed

According to Section 3.3.4.1 of the SE, the breaks are considered for selection only for 2" in diameter and larger HELB pipes. Based on the criteria, the pipe lines considered to be break for sump strainer performance of the US-APWR are listed in Table 3-1.

Section 3.3.5 of the SE describes an approach to the break selection process which includes beginning the evaluation at an initial location along a pipe and stepping along in equal increments (5 foot increments) considering breaks at each sequential location. However, it is not necessary to consider 5-ft increments for the US-APWR evaluation, because of the following conservative considerations:

As discussed in Section 2.2 of this report, the RMI is used for the equipment and pipe lines located in the ZOI to the greatest extent practicable. The use of fibrous insulation is minimized, so that only a small amount of fibrous debris will be generated from small diameter pipe line insulation. Particulate insulations are not used inside the containment. Therefore, only the RMI debris and fibrous debris are considered as the potential insulation debris for the US-APWR.

The amounts of RMI and fibrous insulation debris are estimated conservatively for the US-APWR. In addition, the generation of RMI debris and fibrous debris are combined conservatively, regardless of the location of pipe break.

As shown in Table 3-2, the diameter of the ZOI for RMI is defined as 2 inside diameters of the broken pipe. Therefore, most of RMI debris is generated from broken pipe itself. In order to maximum RMI debris generation, the MCP which has a largest inner diameter is selected as the location of the pipe break, which generates largest amount of RMI debris inside containment.

Figures 3-1 and 3-2 show a spherical region within a distance equal to 2 inside diameters of the MCP when the cross over leg (CO/L) nozzle of the SG is broken. As shown, only a small portion of the RMI installed on CO/L and SG is included in the ZOI, so that the generation of RMI debris is relatively limited. Even if the break selection process which includes stepping along in equal increments (5 foot increments) and considering breaks at each sequential location is utilized, the amount RMI debris generated will never exceed all amount of RMI installed on a CO/L. In other words, if all amount of RMI installed on a CO/L is considered as debris, it is not necessary to consider 5-ft increments for break selection. As a result, the standard US-APWR design considers conservatively that all the RMI installed on a CO/L is considered as debris in the evaluation.

For the fibrous insulation debris generation, a conservative evaluation is performed. As discussed in Section 2 of this report, only 1 inch excess letdown line equips fibrous insulation within the ZOI of HELB. The excess letdown line is connected to CO/L (A) and routed lower portion in SG compartment (A). The line runs toward excess letdown heat exchanger room which is located adjacent to SG compartment (A). The general arrangements of containment were provided in the DCD Chapter 1 Figure 1.2-14 to Figure 1.2-25.

The diameter of the ZOI for fibrous (NUKON) is defined 17 inside diameters of the broken pipe (Table 3-2), the Figures 3-3, and 3-4 show a spherical region within a distance equal to 17 inside diameters of the MCP when the CO/L nozzle of SG is broken. As shown, all of region inside a SG compartment is enveloped horizontally by the ZOI. Therefore, the worst case of fibrous debris generation is that all of fibrous insulation inside SG compartment (A), is considered to become debris. Further discussion about the worst case of fibrous debris generation of the US-APWR is provided in the Section 3.2 of this report.

The maximum amounts of RMI debris and fibrous insulation debris are estimated and combined in the debris head loss evaluation, regardless the location of pipe break. This conservative design assumption envelops the break criteria No.1 and No.2.

For Break Criterion 3, it is not necessary for the US-APWR to identify the most direct path to the RWSP, because of the conservative assumption regarding debris transport ratio, as discussed in Section 3.4 of this report.

Since particulate insulation is excluded from the ZOI of HELB, any particulate debris will be generated from coatings and latent debris. As discussed in Section 3.2 of this report, the coatings debris and latent debris of the US-APWR are conservatively considered constant volumes, regardless of the break location. Therefore, the US-APWR does not require identifying the specific break location which generates maximum volume of particulate debris.

For the evaluation of “thin-bed effect (TBE)” associated with the Break Criterion 5, it is well known that the head loss due to TBE depends on the amount of particle debris. As discussed in Section 3.5.3, the worst case of particulate debris generation is considered in the evaluation. For the US-APWR, PCI SFS has been selected. PCI has never observed any evidence of the thin bed effect in vendor’s large flume testing facilities in the past, because of its three-dimensional geometry and very low approach velocities. The TBE may occur only under such very controlled conditions where the fibrous debris is very carefully prepared as individual fibers that are slowly added to a closed vertical pipe loop test apparatus. This configuration is not applicable for the US-APWR strainer design and configuration in the RWSP of the post-LOCA conditions.

3.2 Debris Generation

The sources of debris at the US-APWR are the insulation debris, coatings debris, latent debris, and miscellaneous debris (i.e. tags, signs, stickers, etc.). For the insulation debris, the US-APWR evaluation concluded that the RMI and fibrous insulation were the potential debris sources following a HELB.

The US-APWR design defines a ZOI for the evaluation of debris generation. The damage pressures and corresponding volume-equivalent spherical ZOI of each insulation type are extracted from the guidance of the SE, and are provided in Table 3-2.

In estimating the US-APWR insulation debris generation, a more conservative evaluation rather than ZOI methodology was applied. As discussed in Section 3.1, all of RMI insulation installed on a CO/L was assumed to become debris. In addition, all fibrous insulation inside the ZOI would become fibrous debris, excluding that outside robust barriers. Figures 3-3 and 3-4 show the robust barriers, such as primary and secondary shield walls, which protect components behind them from jet impingement. The estimated amount debris was conservative and enveloped the amount of debris generated at any pipe break locations.

Table 3-3 provides the location of fibrous insulation in each area inside containment. As shown, SG compartment (A) includes largest amount of fibrous insulation. Therefore, the amount of fibrous insulation debris of the US-APWR was estimated assuming that all fibrous insulation inside SG compartment (A) would be broken by jet impingement.

As for the coating debris of the US-APWR, the ZOI for qualified coatings is a sphere with a radius 10 times the MCP inner diameter, which generates largest amount of coating debris. In the evaluation, the volume of coating debris was calculated by multiplying the surface area of the ZOI sphere by the thickness of the coating film. The thickness of the coating film was defined based on the past experience, and was conservatively assumed to be 650 (μm). As a result, the maximum volume of coating debris was established as 0.51 (m^3).

Latent debris is defined as unintended dirt, dust, paint chips, and fibers, which principally consist of fiber and particle debris. The evaluation used a conservative assumption of 200 (lbm) as the upper bound amount of latent debris. The particulate and fiber mix of the latent debris was assumed to be 15% fiber as per the guidance of the SE.

The standard US-APWR does not define specific type of materials for miscellaneous debris, such as tapes, tags or stickers, because these are controlled by foreign material control program established by plant owner. To deal with this uncertainty, a 200 ft^2 penalty of sacrificial strainer surface area per sump is applied as a margin for future detail design and installation of the US-APWR.

The amount of insulation, coating and latent debris assumed for the US-APWR is provided in Table 3-4.

3.3 Debris Characteristics

The debris characteristics used in the US-APWR evaluation are presented in Table 3-5. The size distribution is not required for the analysis, because all of generated debris is considered to be small, and is assumed all the debris is transported to the RWSP.

3.4 Debris Transport

Debris transport is the estimation of the fraction of debris that is transported from debris sources (break location) to the sump strainer. NEI GR provides the generic transport logic tree to evaluate the fraction of debris for the typical conventional PWR plants.

NEI GR methodology reasonably reduces the fraction of debris that is transported to the sump pool. Since the US-APWR has a similar layout feature to the conventional 4 loop PWR plants, the reduction of transported debris can be considered. However, for conservative assumption, the US-APWR assumes that all the generated debris will be transported to the RWSP. This assumption gives a most conservative upper limit for the debris transport evaluation. The layout features of the US-APWR associated with debris transportation from pipe break location to the RWSP is described below, and it demonstrates that the assumptions in the US-APWR debris transportation contain a lot of conservatisms. The general arrangements of containment were provided in the DCD Chapter 1 Figure 1.2-14 to Figure 1.2-25. A set of engineering drawings relative to the RWSP was provided in 4CS-UAP-20080045 "US-APWR Technical Information and Requirements for ECC/CS Sump Strainer". (Reference [3])

The US-APWR is a four main coolant loop plant, and a SG and RCP is located in four independent SG compartments. As discussed in Section 3.1, worst case debris generation occurs by a main coolant pipe break. This was considered to be the worst case for debris transportation because the debris was generated at the lower portion of the SG compartment, close to the RWSP.

Each SG compartment is enclosed horizontally by primary and secondary shield walls. The bottom floor of the compartment is at elevation 25'-3", and supports the SG and RCP legs. Each compartment is isolated by a concrete wall, and access opening at floor level is provided between the loop compartments to allow access. A labyrinth access from outside the secondary shield wall is provided for each SG compartment, and slope is provided in the labyrinth. The top of slope in the labyrinth is at elevation 25'-5", and two inches higher than nominal floor level. In each SG compartment, seven layers of intermediate grating floors are provided for various maintenance purposes during plant shutdown.

When the debris is generated by a pipe break in the compartment, some amount of debris might be trapped at layered grating floors, but it was conservatively assumed in the evaluation that all of the debris would drop to the floor bottom. Then the debris would be transported to outside the secondary shield walls thru the labyrinth access. The debris would be finally transported to the RWSP thru 10 of the 18 inch drain pipes that are dispersed at five locations outside the secondary shield walls.

It was assumed that the dropped debris on the floor would be retained within the secondary shield walls, until the return water overflows the two inch high slope at the labyrinth access. Before overflowing, the debris would be distributed over the floor of the four SG compartments, and some debris might be trapped at, or flow through the 4 inch floor drain pipes to the containment drain sump pit that is one of ineffective pools as discussed in Section 3.7.1. Two floor openings (39” square) located at corridor between B-loop compartment and C-loop compartment may lead the debris to the reactor cavity area where there is also an ineffective pool. However, it was conservatively assumed in the evaluation that the debris would not be trapped, and all of the debris would be transported to outside secondary shield walls.

When the overflowing starts, the debris will be discharged outside of the secondary shield walls through four labyrinth access paths. Then, the debris will be spread over the containment floor, until the return water overflows the two inch slope provided around the RWSP drain pipes. During this, some of debris might be trapped at, or flow through the 4 inch floor drain pipes, or directly flow through the floor opening for the stairs to the containment sump pit area that is also one of ineffective pools as discussed in Section 3.7.1. However, it was conservatively assumed in the evaluation that all debris would be transported to the RWSP.
As mentioned above, a lot of conservatisms were considered in the evaluation. All generated debris was assumed to be transported to the RWSP. It was assumed that the debris would be spread over the containment floor, and equivalently allocated to all RWSP drain pipes. Figure 3-5 shows schematics of debris distribution of RWSP drain pipes, and debris allocation patterns for operable sump strainers. As shown, it was assumed that 20% of the debris would be equivalently allocated to each of the five drain pipe locations. It also shows that the debris allocation for two operable sumps would follow three patterns:

1) 70% debris on one sump, and 30% on the remaining (Worst case)

2) 60% debris on one sump, and 40% on the remaining
3) 50% debris on one sump, and 50% on the remaining

Therefore, the worst case of debris allocation pattern was selected, and defined as design basis that 70% of generated debris would be allocated to one sump strainer.

As described previously, latent debris is defined as unintended fiber and particles that are potentially accumulated on various surfaces over the whole area of the containment. During an accident, containment spray water and the subsequent water stream on the floor will wash down the latent debris, and will lead it to floor drains of each containment floor. While most of the latent debris will be lead into containment drain sump pit that is an ineffective pool, it was conservatively considered in the evaluation that all of latent debris would be transported to the RWSP. Since the latent debris will come from the whole area inside containment, it was assumed that it would be spread equivalently over the bottom floor of containment, then transported to the RWSP. Therefore, the allocation patterns of the latent debris were considered to be the same as to those of debris generated by the pipe break.

3.5 Debris Head Loss

The standard US-APWR utilizes PCI's SFS technology that has been selected by US-APWR operating plants as described in Appendix-A. PCI was contracted by the US-APWR to provide a qualified SFS that should be specifically designed for the standard US-APWR, and provide associated qualification reports. PCI has considerable experience for existing plants to evaluate debris head losses of the SFS, as well as performing debris head loss tests using scaled a SFS with the flume test facility at the Alden Research Laboratory (ARL). The test for Comanche Peak Nuclear Power Plant Units 1 & 2 (CPNPP-1/2) was conducted under plant specific design parameters and estimated debris, including chemical debris, in February, 2008. These tests were conducted, audited by the NRC at ARL, and successfully completed.

For the debris head loss evaluation of the US-APWR, PCI has performed an analysis to demonstrate that the US-APWR design basis was bounded by the CPNPP-1/2 tests and design parameters. The intention of this "bounding evaluation" was that if the postulated design of the US-APWR is bounded by the head loss test results of CPNPP 1 & 2, US-APWR head loss testing may not be necessary. The bounding evaluation is the comparative evaluation between the US-APWR and CPNPP-1/2 using both plant specific design parameters. The details and results are discussed in Appendix-B.

In the evaluation, an assumption was made for the type and quantity of chemical debris specific to the US-APWR that it would be same as to that of CPNPP-1/2. Under this assumption, the bounding evaluation concluded that the CPNPP1/2 tests results bound the US-APWR design basis. Accordingly, the US-APWR debris head loss will be sufficiently lower than specified limit of 4.7 feet of water.

In order to confirm that an assumption made for chemical debris in fact bounds the US-APWR specific chemical debris type and quantity, ongoing chemical effects test will be examined. A summary of chemical effects test plan is discussed in Section 3.8. The test results and confirmatory assessment for this bounding evaluation will be provided by the end of December, 2008.

3.6 Net Positive Suction Head

3.6.1 System Operation

The US-APWR engineered safety features (ESF) include safety injection (SI) pumps and containment spray/residual heat removal (CS/RHR) pumps. These pumps are normally aligned to the refueling water storage pit (RWSP) inside the containment. Figure 3-6 shows a schematic flow diagram of ECC and CSS. The SI pumps are automatically initiated by the safety injection signal and the CS/RHR pumps are automatically initiated by the containment spray signal. These pumps take suction directly from the RWSP. Four ECC/CS strainers are installed in the RWSP and each ECC/CS strainer is for one of four trains.

3.6.2 NPSH Available Calculation

Net-positive suction head available (NPSH available) calculations were performed to determine the NPSH available for the ECCS and CS pumps.

3.6.2.1 Assumptions

For the NPSH available calculation, the most limiting conditions were assumed to be applicable to all events.

a) Single Failure

The SI pumps and CS/RHR pumps of the US-APWR consist of four trains. A single ECC/CS strainer is installed in each train (e.g., one ECC/CS strainer supplies one SI pump and one CS/RHR pump). Therefore, a single failure in any single train does not affect flow rate through any other strainer or ECC/CS train.

The containment spray system has a common spray ring header. Therefore, if the number of operating pumps is smaller, the flow in any one pump is greater. The minimum number of operating CS/RHR pumps is two (one pump is assumed out of service, a second one is assumed to experience a single failure, and the remains two are operating).

In the NPSH available calculation, the maximum (assumed runout) pump flow rates were conservatively used thus minimizing NPSH available. The calculated NPSH available is therefore greater than would be expected in the case of a single failure.

b) Containment Pressure

For the minimum NPSH available calculation, no containment overpressure is credited (i.e., containment pressure is assumed to equal the saturation pressure corresponding to the sump water temperature).

c) Water Level

RWSP water level for NPSH available calculation is the minimum RWSP water level. The details of the calculation of minimum water level are given in Section 3.7. The water level used in NPSH available calculation includes a 5% uncertainty.

d) Head loss

Head loss calculations for NPSH available are prepared based on hydraulic models of the systems aligned to take suction from the RWSP. The system configurations of SI pump suction and CS/RHR pump suction are not changed during an accident. Therefore this system configuration results in the highest sump flow rate, which is used for sizing the ECC/CS strainers. The flow rate for the NPSH available calculation is conservatively based on the maximum pump flow rate. These calculations use Equations 3-5, 3-14 and 3-15 of Crane Technical Paper No. 410, “Flow of Fluids Through Valves, Fittings, and Pipe” (Reference [9]) to determine the head loss due to frictional resistance in the piping and line losses due to other components. The water temperature for head loss calculation (Pipe, fitting, and so on) is conservatively set as 32 deg F to maximize fluid density and the resulting head loss. The head loss used in NPSH calculation includes a 5% uncertainty.

e) Debris head loss

Upper limit of strainer head loss is specified to be 4.7 feet of water at 70 degree F in order to sufficiently satisfy the NPSH requirement of SI pumps and CS/RHR pumps.

3.6.2.2 Calculation Results

The NPSH available is calculated based on the equation below;

$$NPSH_{available} = h_{statichead} - h_{lineloss} - h_{ECC/CSstrainerloss}$$

$h_{statichead}$	Static head (RWSP minimum water level – pump center elevation)
$h_{lineloss}$	Head loss (Suction piping and valve pressure loss)
$h_{ECC/CSstrainerloss}$	Debris head loss (Due to debris clogging and chemical effect)

For static head, the relationship between RWSP minimum water level and pump center elevation is shown in Figure 3-7. In this calculation, the water level is used 3.8’, which includes a minus 5% margin for uncertainty.

The NPSH available for the SI pump and the CS/RHR pump are shown in Tables 3-8 and 3-9.

3.7 Upstream Effect

3.7.1 Hold-up Volumes

The evaluation of upstream effect is a review of the flow paths leading to the RWSP, identifying those flow paths which could result in blocking the return water that could challenge the RWSP minimum water level evaluation. The evaluation also includes identifying the hold-up volumes, such as recessed areas and enclosed rooms, for which trapped water will not return to the RWSP. The evaluation of the US-APWR was performed, and all of the hold-up volumes were taken account into the minimum water level calculation. The description of the US-APWR flow paths was discussed in the DCD Chapter 6, Section 6.2.1.1.2, and is summarized as follows:

"Figure 6.2.1-9 through Figure 6.2.1-15 also shows containment drainage paths into the RWSP. Piping is provided through several partitions above the RWSP where water could otherwise be trapped. In particular, piping that allows free communication and drainage is installed between the refueling cavity and the pressure equalizing chamber, as shown in Figure 6.2.1-9. These communication pipes are closed with a flange at both ends during refueling. Drain piping also is provided between the pressure equalizing chamber and the RWSP. Figure 6.2.1-16 and Figure 6.2.1-17 present the plan and sectional view of the RWSP, while Table 6.2.1-3 presents RWSP design and containment-related features."

Figure 3-8 shows a schematic of containment spray/blowdown return pathways of the US-APWR, and is provided to supplement the information in the DCD. Containment spray water is showered on the operating floor, SG compartments, and refueling cavity. The water on the operating floor easily spills out from a number of large floor openings to the area downstairs. In addition, a number of floor drain funnels lead the spray water to bottom portion of the containment. The water sprayed into the SG compartments will easily reach to the bottom floor of the containment, because only the layered intermediate grating floors are installed inside the compartment. In the refueling cavity, there are two 8 inches drain pipe which are communicated to bottom portion of the containment. As discussed in Section 2, the use of RMI is maximized and it is quite unlikely that a large amount of fibrous debris will blow down on the cavity, and block the drain path.

In a LOCA, the blowdown water spills out from reactor coolant pipe located inside the secondary shield wall. Since four large personnel entrances leading into the secondary shield wall are provided, the debris will not entirely clog these entrances. Then, water will be spread at the floor outside the secondary shield walls, and return into the RWSP though ten (10) drain pipes (18 inches) as discussed in Section 3.2. These large drain pipes are equipped with debris interceptors in order to prevent the drain pipe from being covered by large debris and plate-like materials, and allow water and debris smaller than inner diameter of drain pipe to enter the RWSP. Details of drain pipe is provided in 4CS-UAP-20080045, "US-APWR Technical Information and Requirements for ECC/CS Sump Strainer". (Reference [3]) The interceptors consist of a solid cover plate and vertical bars. The cover plate is provided to prevent unexpected materials from entering to the RWSP during refueling and other normal operations. The pitch of the vertical bars is designed to be smaller than inner diameter of the drain pipe to prevent the drain pipe from choking. Since these large drain pipes are well distributed at five locations in containment floor, it is very unlikely that all of the drain pipes will be completely blocked by debris. As a result, no choke points which may block the flow paths of return water are identified. Therefore, only the hold-up volumes may challenge the minimum water level of the RWSP.

The US-APWR hold-up volumes are categorized into two groups, "Return water on the way to the RWSP", and "Ineffective pools". The calculated values described in the DCD Table 6.2.1-3 *"RWSP Design Features"*. The followings are the definitions of the groups:

<u>Return water on the ways to the RWSP</u>

In a LOCA, the RWSP water returns from containment spray nozzle and broken pipe. The water on the way to the RWSP will decrease the initial RWSP water level. The following are the source of return water to the RWSP.

a. Containment spray water droplets and saturated steam (includes the empty spray header rings and pipes)
b. Condensate water on all of the containment surfaces (includes equipment, walls and ceiling, etc.)
c. Water stream on the containment floors (includes refueling cavity floor)

<u>Ineffective pools</u>

An ineffective pool is defined as a hold-up volume that entraps return water which will not contribute to recovering the RWSP water level. The following are considered as the US-APWR ineffective pools:

a. Reactor cavity
b. Containment recirculation air distribution chamber (includes ducts)
c. Containment reactor coolant drain pump room (includes containment drain sump)
d. Recessed pits in the refueling cavity

In addition to the above, a further hold-up volume was conservatively included, and assumed to be 90 m^3 using engineering judgement. The calculated hold-up volumes of the US-APWR are provided in Table 3-10.

3.7.2 Minimum Water Level

The minimum water level of the RWSP forms the basis for estimating pump water head in the NPSH evaluation, as discussed in Section 3.7. It was conservatively calculated as follows:

During normal operation, the RWSP contains 2300 (m^3) of borated water (the water volume from 0 (%) to 100 (%) water level), as shown in Figure 3-8. The RWSP allows the water evaporation and when the water surface reaches the 96 (%) water level, the makeup operation is activated and continued until 100 (%) water level is recovered. This level is defined as “below nominal water level” of the RWSP, and is used as the initial water level for the postulated accidents. In case of LBLOCA, the water mass in the accumulator tanks can contribute to recover the RWSP, but this source was conservatively disregarded in the calculation.

The minimum water level of the RWSP during a LOCA was calculated by subtracting the hold-up volume from the initial water volume in the RWSP. The minimum water level is calculated as shown in Figure 3-9, and it is determined that it will be settled at 4.5 feet above the RWSP floor. It was then conservatively set at 0.5 feet lower than the calculated level. The minimum water level of the US-APWR was therefore set at 4.0 feet above the RWSP floor, and this value was used in the NPSH evaluation.

3.8 Test Plan for Chemical Effect

The PWR post-LOCA environment creates several challenges to containment materials and debris sources based on temperature, chemical reactions, and effects from sprayed and pooled water. The combination of spray chemicals, insulation, corroding metals, and submerged materials create a potential condition for the formation of chemical substances that may impede the flow water through the recirculation sump strainers or affect downstream components in the emergency core cooling or reactor coolant systems.

The US-APWR is a low fiber plant that uses sodium tetra-borate as a buffer. Based on a review of the results presented for ICET Test #5 (Reference [10]), the US-APWR is expected to have minimal corrosion and reaction products. However, in order to further understand the plant specific interactions between the containment materials and post-LOCA debris with the recirculation sump fluid chemistry, MHI has elected to perform a chemical effects test for the US-APWR. (Reference [11])

3.8.1 Test Objectives

The objective for the chemical effects test is to obtain experimental data under simulated plant conditions on the corrosion products that may form in a post-LOCA environment. This data will then used to determine compositions, characterize properties, and quantify masses of chemical reaction products that may develop in the containment under a representative post-LOCA environment.

The test results are used for the downstream chemical effects evaluation to confirm their minimal impact on long term cooling. The results are also used for supporting the evaluation of their impact on post-accident strainer head loss evaluations as discussed in Section 3.5.

3.8.2 Test Parameters

The chemical effects test entails two separate tests:

- An autoclave test that simulates the temperature transient of the first 100 hours of the post-LOCA and,
- A recirculation test that simulates the post-LOCA long term environment from 100 hours to 30 days.

Both of the tests will be conducted using scaled quantities of non-metallic, metallic, and cementitious materials exposed to the warm, slightly basic pH liquid of the pool and spray environment. The specific parameters identified in the test plan are based on the evaluation for the US-APWR plant condition.

3.8.3 Test Duration

Maximum duration of recirculation test is limited to 30 days. Maximum duration of autoclave test will be limited to 100 hours.

3.8.4 Sampling and Examination

Since the purpose of the test program is to identify the type and mass of corrosion products that may form in the post-LOCA environment, it is essential that all masses of all species are accounted for in the experiment. The locations of these species can be on the surface of the metallic coupons, on the surface of the fiberglass samples, as precipitate in the tanks and in solution. Following examinations are performed in the tests:

- Test coupon examination
- Fiberglass sample examination
- Precipitate/Sediment examination
- Fluid sample examination

3.9 Evaluation Summary

The US-APWR sump strainer performance was evaluated in accordance with the RG 1.82 Rev.3 requirements. The break selection, debris generation, and debris transport were analyzed to identity the potential debris which may reach to the strainers in the RWSP assuming a number of conservative considerations. The characteristics of potential debris were set, identified, and referred appropriately, and used in the debris head loss evaluations, as well as the NPSH evaluation of vital pumps of the US-APWR.

A bounding evaluation was performed to demonstrate that debris head loss of the US-APWR strainer is bounded by existing head loss test data conducted by CPNPP-1/2. The evaluation concluded that postulated debris head loss would satisfy the specified requirements of the standard US-APWR, and have sufficient suction head to operate plant safely following a post-LOCA event. In the evaluation, an assumption was made of the type and quantity of chemical debris of the US-APWR. This assumption will be justified by analyzing ongoing chemical effects test results.

The chemical tests will be conducted through the end of November, 2008. The tests reports will be submitted to the NRC as the tests progress, and a summary of the test results will be incorporated into this technical report at the end of December, 2008.

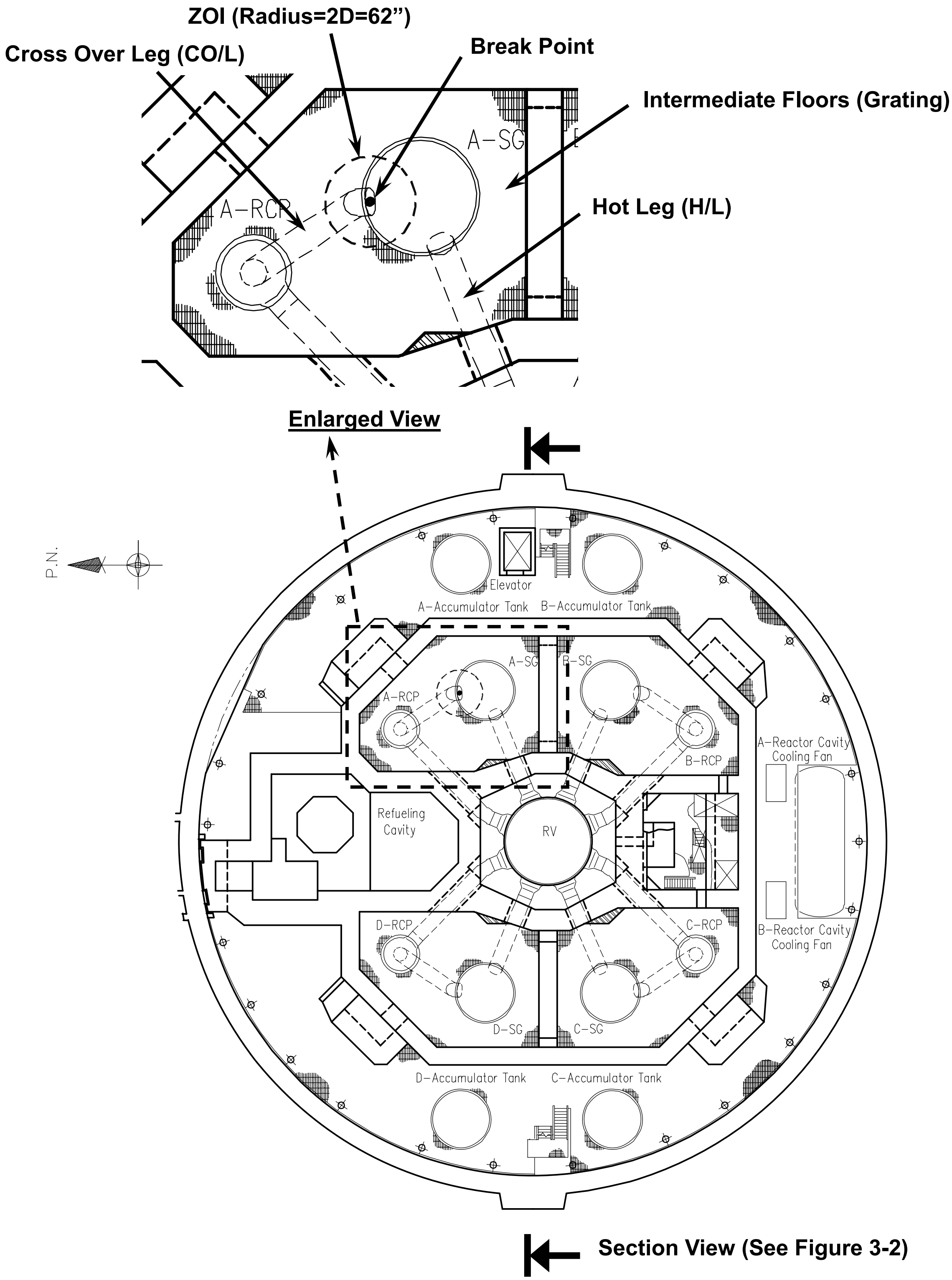


Figure 3-1 Plan View of Zone of Influence (RMI, L/D=2.0)

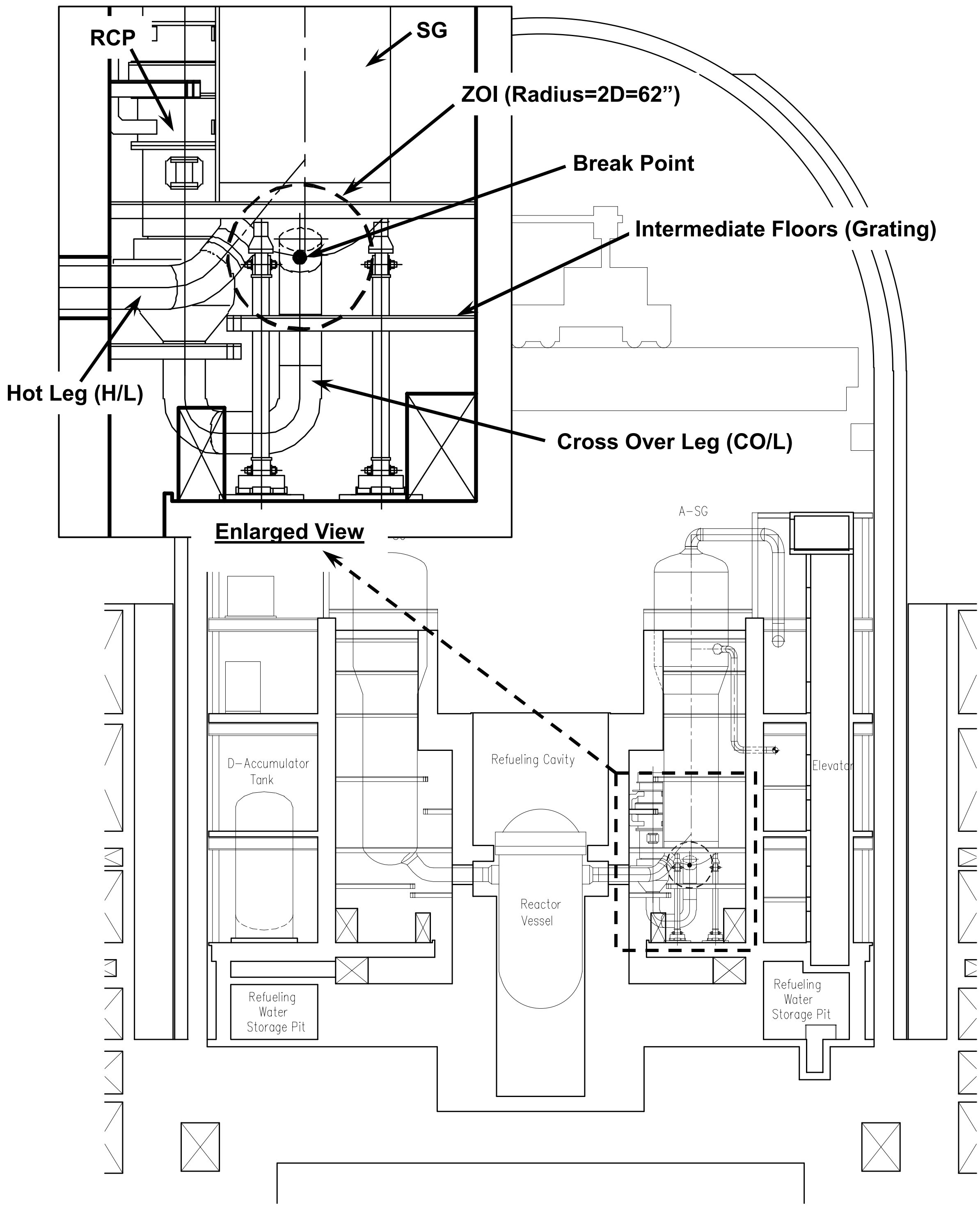


Figure 3-2 Section View of Zone of Influence (RMI, L/D=2.0)

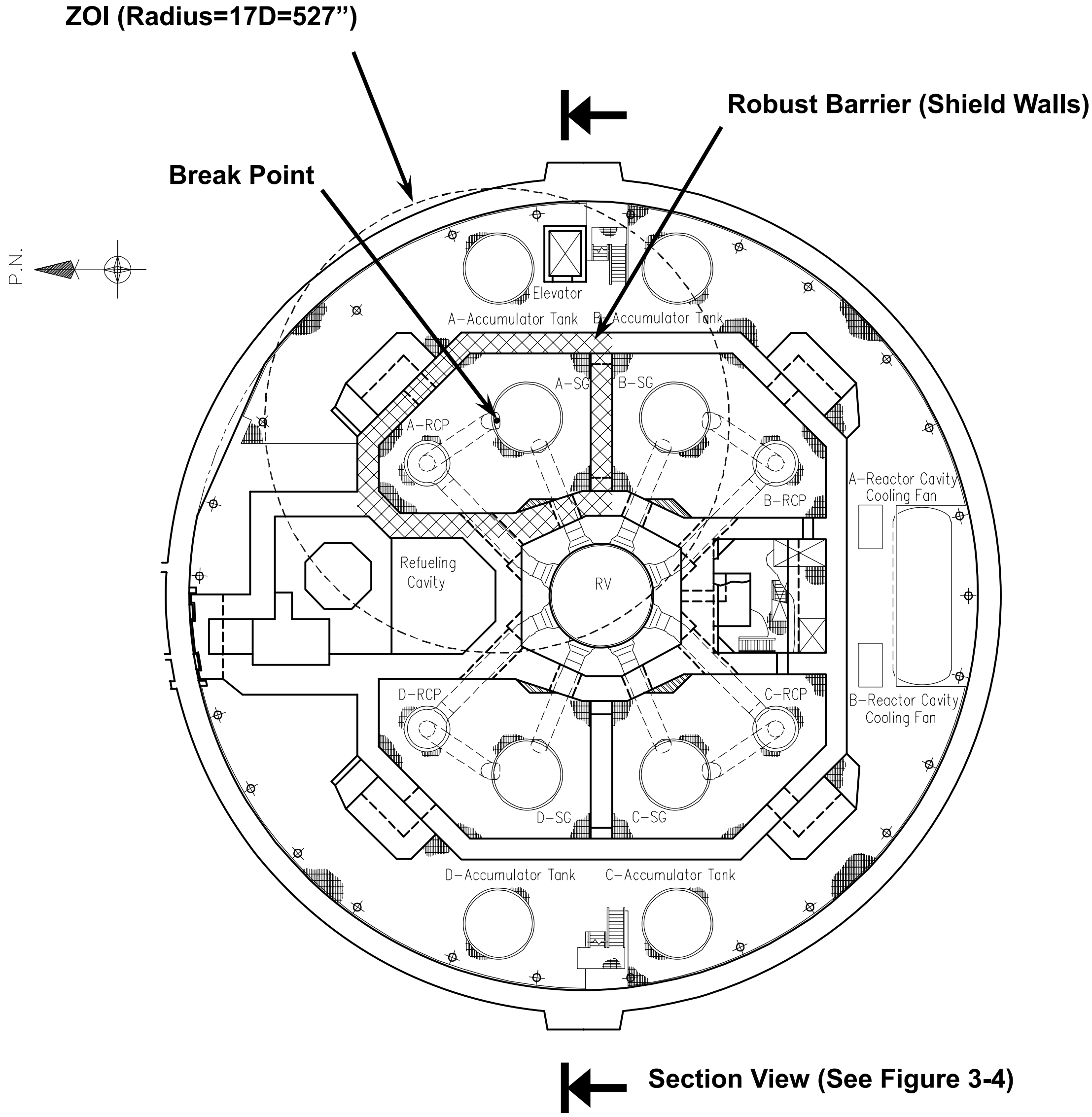


Figure 3-3 Plan View of Zone of Influence (Nukon, L/D=17)

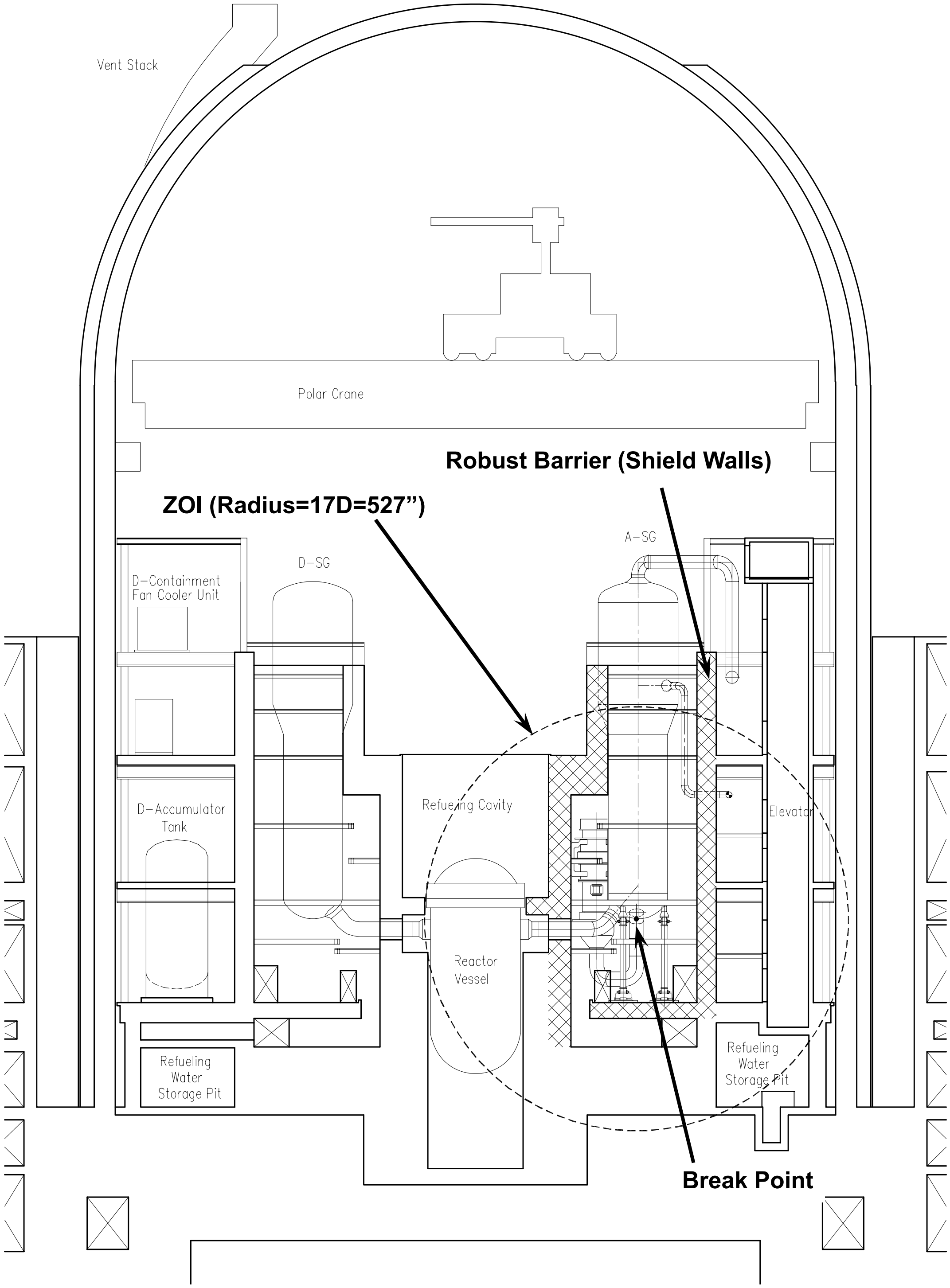
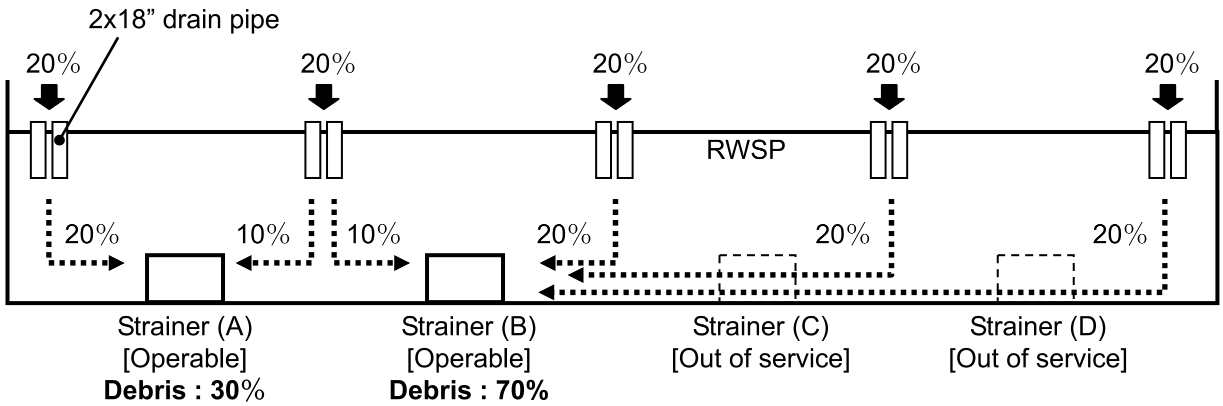
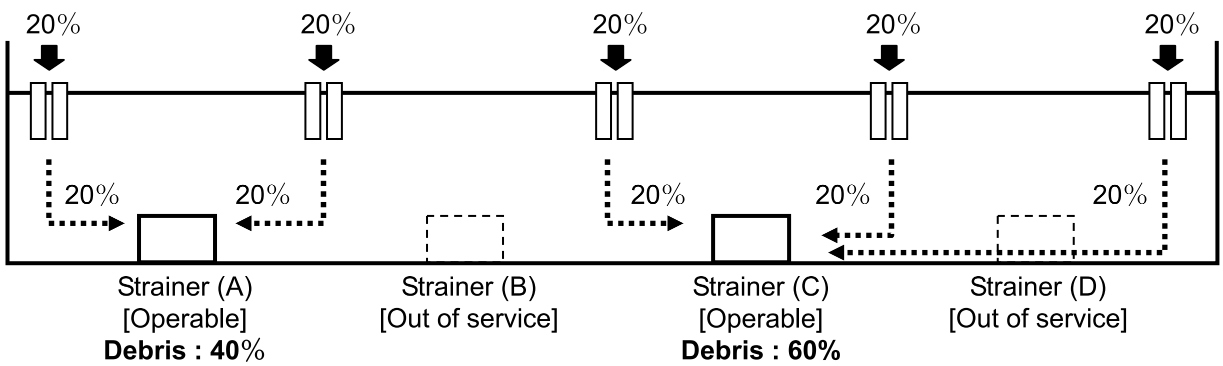


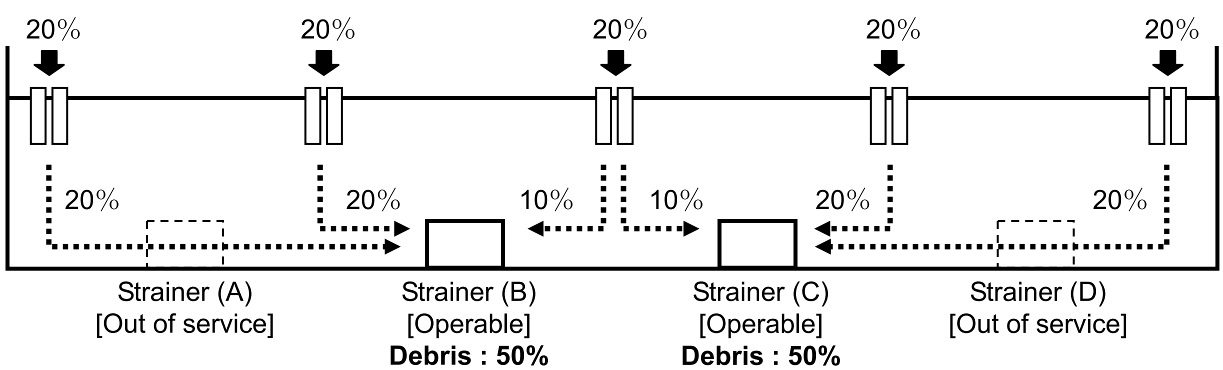
Figure 3-4 Section View of Zone of Influence (Nukon, L/D=17)



Pattern-[1] 70% Debris Allocation on Sump Strainer (Worst case)



Pattern-[2] 60% Debris Allocation on Sump Strainer



Pattern-[3] 50% Debris Allocation on Sump Strainer

Figure 3-5 Schematics of Debris Allocation on Operable Sumps

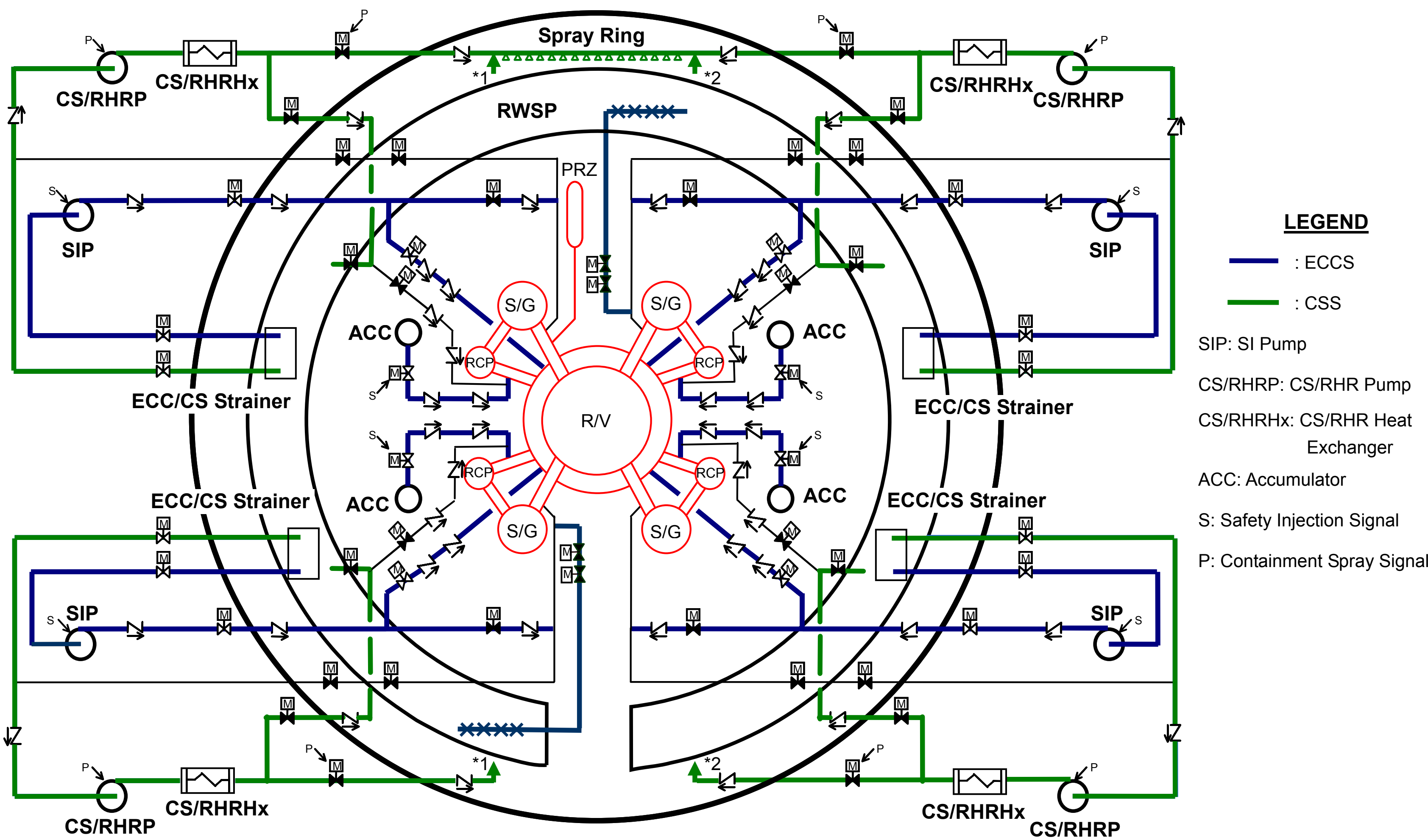


Figure 3-6 Schematic Flow Diagram of ECCS/CSS

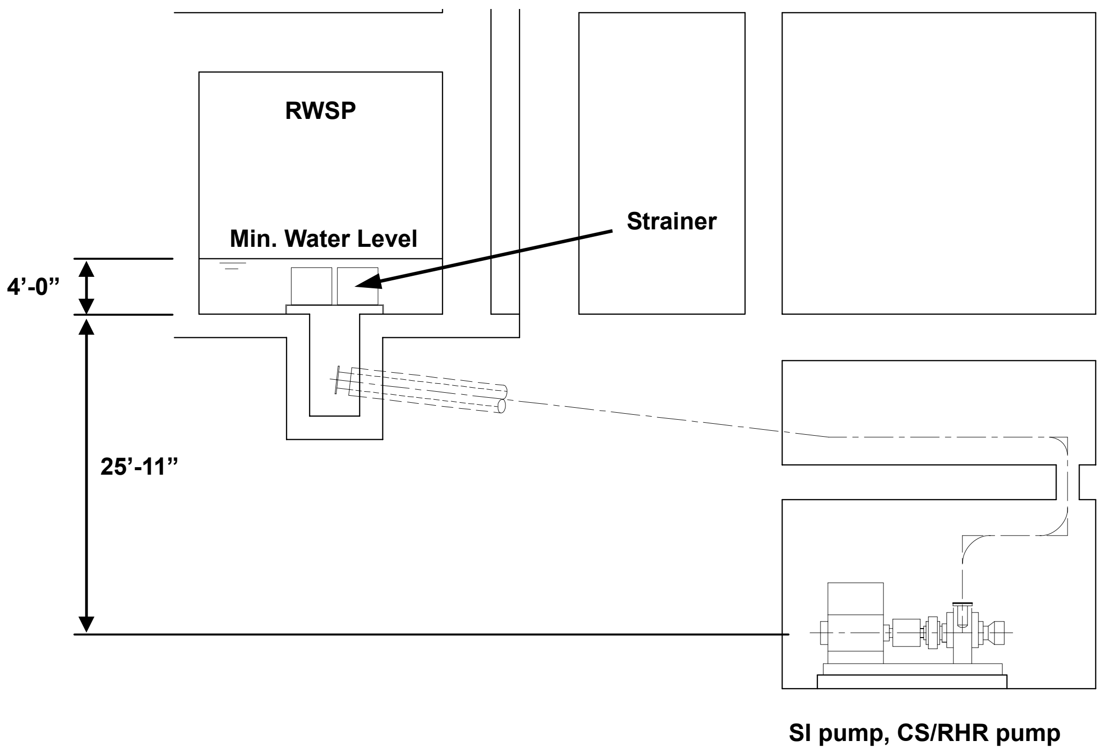


Figure 3-7 Elevation between Minimum Water Level and the Pumps

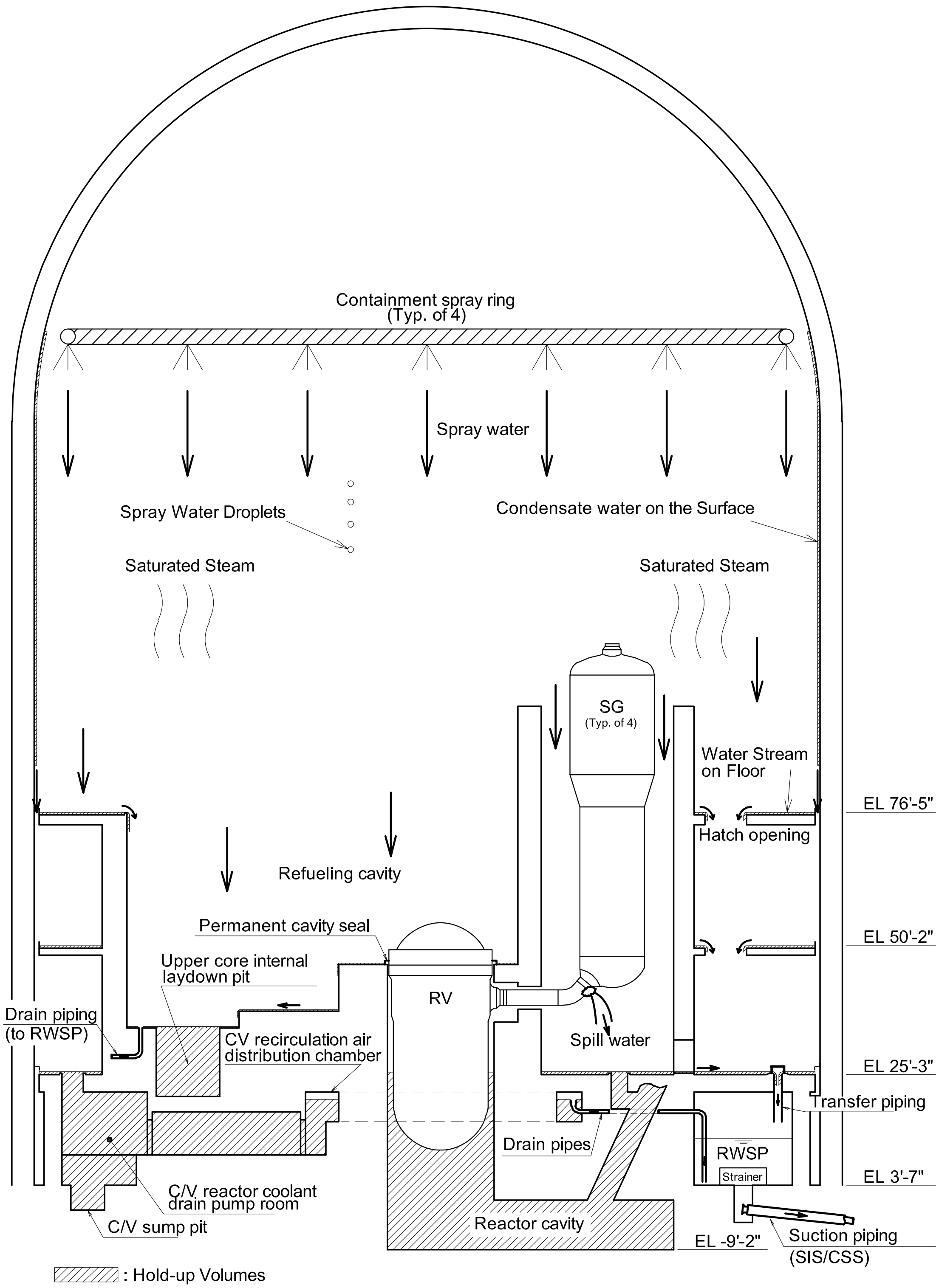


Figure 3-8 Schematic of Return Water and Hold-up Volumes

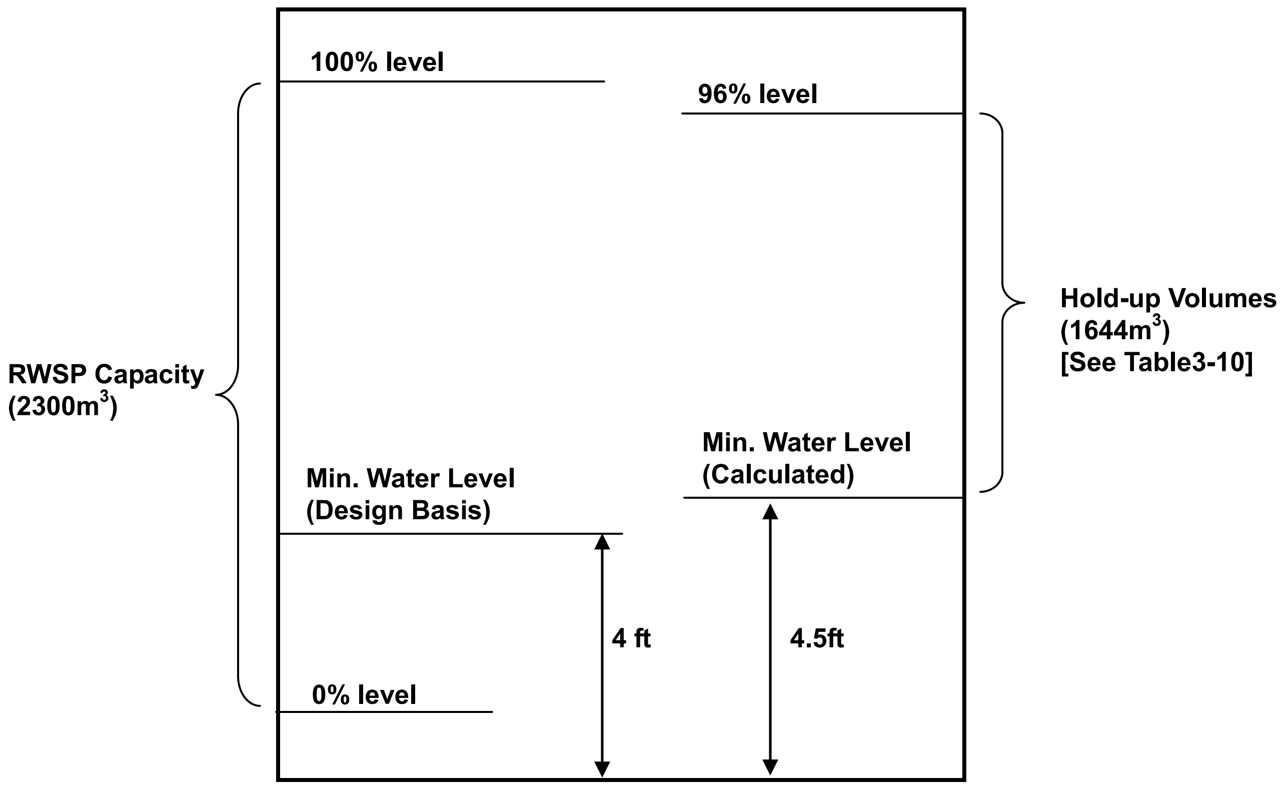


Figure 3-9 Minimum Water Level of the RWSP

Table 3-1 The US-APWR Postulated Break Pipe Lines

<table>
<tr><th rowspan="4">Pipe lines</th><th>Size</th><th colspan="6">Location</th></tr>
<tr><th rowspan="3">Inner Diameter (in)</th><th colspan="5">Inside secondary shield wall</th><th rowspan="3">Outside secondary shield wall</th></tr>
<tr><th colspan="4">SG compartment</th><th rowspan="2">PZR compartment</th></tr>
<tr><th>A</th><th>B</th><th>C</th><th>D</th></tr>
<tr><td>Main coolant pipes</td><td>31</td><td>X</td><td>X</td><td>X</td><td>X</td><td></td><td></td></tr>
<tr><td>PZR surge line</td><td>12.81</td><td></td><td>X</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Accumulator injection lines</td><td>11.19</td><td>X</td><td>X</td><td>X</td><td>X</td><td></td><td></td></tr>
<tr><td>RHR pump inlet lines</td><td>8.5</td><td>X</td><td>X</td><td>X</td><td>X</td><td></td><td></td></tr>
<tr><td>RHR pump outlet lines</td><td>6.81</td><td>X</td><td>X</td><td>X</td><td>X</td><td></td><td></td></tr>
<tr><td>PZR spray line</td><td>5.19</td><td></td><td>X</td><td>X</td><td></td><td>X</td><td></td></tr>
<tr><td>Direct Vessel Injection lines</td><td>3.44</td><td>X</td><td>X</td><td>X</td><td>X</td><td></td><td></td></tr>
<tr><td>Charging line</td><td>3.44</td><td>X</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Let down line</td><td>2.62</td><td></td><td></td><td></td><td>X</td><td></td><td></td></tr>
<tr><td>Safety injection (SI) lines</td><td>3.44</td><td>X</td><td>X</td><td>X</td><td>X</td><td></td><td></td></tr>
<tr><td>PZR aux. spray line</td><td>2.62</td><td></td><td></td><td></td><td></td><td>X</td><td></td></tr>
<tr><td>PZR safety valve inlet line</td><td>5.19</td><td></td><td></td><td></td><td></td><td>X</td><td></td></tr>
<tr><td rowspan="4">PZR safety depressurizeation lines</td><td>6.81</td><td></td><td></td><td></td><td></td><td>X</td><td></td></tr>
<tr><td>5.19</td><td></td><td></td><td></td><td></td><td>X</td><td></td></tr>
<tr><td>3.44</td><td></td><td></td><td></td><td></td><td>X</td><td></td></tr>
<tr><td>2.62</td><td></td><td></td><td></td><td></td><td>X</td><td></td></tr>
<tr><td>Main steam lines</td><td>14.31</td><td></td><td></td><td></td><td></td><td></td><td>X</td></tr>
<tr><td>Feed water lines</td><td>29.01</td><td>X</td><td>X</td><td>X</td><td>X</td><td></td><td>X</td></tr>
</table>

Table 3-2 Damage Pressure and Corresponding Volume-Equivalent Spherical ZOI Radii

Type	Destruction Pressure (psig)	ZOI Radius / Break Diameter
Transco RMI Darchem DARMET	114	2.0
Unjacketed Nukon, Jacketed Nukon with standard bands	6	17.0

Table 3-3 Location of Fibrous Insulation

Pipe lines	Size	Location					
	Diameter (in)	Inside secondary shield wall					Outside secondary shield wall
		SG compartment				PZR compartment	
		A	B	C	D		
CVCS excess let down lines	1	X					X
Others(small valves, supports)	-	X	X	X	X	X	X

Table 3-4 Debris Generation

Type		Amount	
		English unit	Metric unit
RMI (Transco)		106 (ft^3) [foil surface area 11,442(ft^2)]	3.0 (m^3) [foil surface area 1063(m^2)]
Fibrous Insulation (Nukon)		46 (ft^3)	1.3 (m^3)
Coating (Epoxy)		1.8 (ft^3)	0.51 (m^3)
Latent Debris (200 lbm)	Fiber (15%)	30 (lbm)	-
	Particle (85%)	170 (lbm)	-

Table 3-5 Debris Characteristics

Description	Symbol	Values
RMI debris		
Inter-foil gap thickness	Kt	0.003 (ft)
Fibrous Insulation debris (Nukon)		
Diameter of fiber	D_{f1}	7 (μm)
Fabricate density	C_{f1}	2.4 (lbm/ft^3)
Material density	ρ_{f1}	159 (lbm/ft^3)
Specific surface volume	S_{vf1}	1.742×10^5 (ft^{-1})
Coating		
Diameter of particle	D_{p1}	10 (μm)
Sludge density	C_{p1}	19 (lbm/ft^3)
Material density	ρ_{p1}	94 (lbm/ft^3)
Specific surface volume	S_{vp1}	1.829×10^5 (ft^{-1})
Latent Debris (Fiber) Note		
Fabricate density	C_{f2}	Assumed same as to Nukon
Material density	ρ_{f2}	Assumed same as to Nukon
Specific surface volume	S_{vf2}	Assumed same as to Nukon
Latent Debris (Particulate) Note		
Sludge density	C_{p2}	75 (lbm/ft^3)
Material density	ρ_{p2}	168.6 (lbm/ft^3)
Specific surface volume	S_{vp2}	1.06×10^5 (ft^{-1})

Table 3-6 [Not used]

Table 3-7 [Not used]

Table 3-8 SI Pump NPSH Evaluation

$h_{statichead}$	29.7 ft
$h_{lineloss}$	3.1 ft
$h_{ECC\,/\,CSstrainerloss}$	4.7 ft
NPSH available	21.9 ft
NPSH required	15.7 ft

Table 3-9 CS/RHR Pump NPSH Evaluation

$h_{statichead}$	29.7 ft
$h_{lineloss}$	7.1 ft
$h_{ECC\,/\,CSstrainerloss}$	4.7 ft
NPSH available	17.9 ft
NPSH required	16.4 ft

Table 3-10 Upstream Effect Hold-up Volumes

[1] Return water on the way to the RWSP	(m^3)
Containment spray droplets & saturated steam (including the empty spray header rings & pipes)	249.7
Condensate water on the various surfaces	85.0
Water stream on the floor (including reactor cavity floor)	185.0
Subtotal [1]	519.7 (approx. 137,000 gallons)
[2] Ineffective pools	
Reactor cavity	491.7
Containment recirculation air distribution chamber (Including ducts)	128.1
Containment reactor coolant drain pump room (Including containment drain sump)	343.5
Recessed pits in the refueling cavity	70.7
Additional hold-up volume	90.0
Subtotal [2]	1124.1 (Approx. 297,000 gallons)

4.0 DOWNSTREAM EFFECT

4.1 Downstream Effect (Outside Reactor Vessel)

The systems which take suction from RWSP sump are the safety injection system and the containment spray system. These systems include pumps, heat exchangers, valves, piping, fittings and other components. These components may be affected by debris that comes through the strainers. This section describes the evaluation of potential downstream effects outside the reactor vessel.

4.1.1 System Operation

The SI pumps are automatically initiated by the safety injection signal and supply boric acid water from the RWSP to the reactor vessel through direct vessel injection lines. Then SIS is realigned to shift the RCS injection from the direct vessel injection line to the hot leg injection line after a LOCA in order to prevent boron precipitation. Therefore, both injection lines are in the flow paths of the water through the ECC/CS strainers. Safety injection pump minimum flow lines are also in these flow paths, which are always used when the pumps are operating.

The CS/RHR pumps are automatically initiated by the containment spray signal and spray into the containment from the RWSP through the containment spray lines. Then, after the containment pressure is sufficiently decreased, the CSS is realigned to shift from the containment spray line to the CS/RHR pump full–flow test line to remove the heat from the containment. Therefore, both lines are in the flow paths of the water through the ECC/CS strainers. The CS/RHR pump minimum flow lines are also in these flow paths, which are always used when the pumps are operating.

4.1.2 Evaluation

The strainer hole size is 0.066”. Therefore, when the gap of the components is less than this value, the flow path may be blocked. Components that are in the flow paths during accidents are listed in Table 4-1.

The evaluation results for the potential clogging of each component are described below;

Pumps: most flow areas are sufficiently larger, so the potential of plugging by debris is very low.

Valves: The valve types that are used in the flow path during an accident are gate, check, globe and butterfly.

Gate valves

Gate valves are used full-open or full-close. In the US-APWR, gate valve sizes are above 4'', so they have a sufficient flow area. Therefore the potential of gate valve plugging is very low.

Check valves

Check valves in the US-APWR are used with sufficient flow rate, and check valve sizes are above 4''. Therefore the potential of check valve plugging is very low.

Globe valves

Globe valves may be used for throttling. When an expected difference pressure of globe valve is larger, the gap between valve body and seat may be very small. In the US-APWR design, the expected differential pressure is normally achieved by a combination of valve and orifice settings. Therefore the gap can be controlled not to be too small. Moreover, since the high head safety injection system of the US-APWR is designed to be completely independent, each train does not affect the other trains. So, ineffective injection water does not need to be considered. This means that high injection line resistance is also not needed. Therefore, the expected differential pressure of globe valves and orifices are not too large and the gap is not likely to be small.

Butterfly valves

Butterfly valves in the US-APWR are used at the outlet of CS/RHR heat exchanger. These valves are used full open and valve sizes are 8''. Therefore the potential of butterfly valve plugging is very low.

Heat exchangers: the smallest portion of the CS/RHR heat exchanger is a tube. The tube size is 3/4'' and is sufficiently larger than the strainer hole size. Therefore the potential of the CS/RHR heat exchanger plugging is very low.

Orifice: the hole diameter of an orifice is determined by the expected differential pressure. As described for globe valves, since the expected differential pressure of orifices is not too large and the hole is not too small, the potential of orifices plugging is very low.

Spray Nozzles: The containment spray nozzle has an inlet orifice 0.375” in diameter. This orifice is the smallest portion of spray nozzle and is larger than the strainer hole size. Therefore the potential of spray nozzle plugging is very low.

Instrumentation tubing: These lines are water-solid and designed to remain water-solid. This design precludes the direct introduction of debris-laden fluid into the instrumentation tubing. Therefore, the potential of instrumentation tubing plugging is very low.

Piping: Pipe diameters are sufficiently larger than the strainer hole size. Therefore the potential of piping plugging is very low.

Small particles of debris that come through the ECC/CS strainers may adversely affect components experience in the downstream of the strainers. Some parts of components such as valves or pumps may wear by contact with debris particles. This means that the components may be affected by particles. Therefore, the effects of the small particles should be evaluated

In the US-APWR design, the amount of the particle debris is expected to be small since compartment walls are consist of steel concrete which surfaces are covered by steel mold plate. This design decreases amount of concrete sludge during accidents. Materials that com in contact with water through the strainers have high resistance to erosion. Therefore, the potential for asverse effects from debris particles is very low.

4.2 Downstream Effect (Inside Reactor Vessel)

4.2.1 Blockage of Core Inlet

The following sequence is the US-APWR core cooling path flows in the reactor vessel downstream of the sump strainer. Cooling water will:

1. Come in from ECCS nozzle
2. Pass through the downcomer which is annulus between the reactor vessel and the core barrel
3. Pass through the lower plenum
4. Pass through the flow holes of the lower core support plate
5. Pass through the fuel assemblies
6. Pass through the holes of the upper core plate
7. Flows out from outlet nozzle

The smallest flow in the core internals is that of the flow holes of the lower core support plate whose size is [ ] The flow hole of the bottom nozzle in the fuel assembly is [ ] This is the narrowest gap downstream of the strainer to core inlet, and dictates that the nominal diameter of the strainer holes shall be sufficiently smaller than the gap. [ ] percent margin was considered to limit the debris which may pass through the gap, and no larger than 0.071” (1.8mm) of debris are blocked at the strainer. Finally, the strainer supplier’s standard perforate plate with 0.066” (1.67mm) was selected to the US-APWR strainer specification.

The flow hole of the lower core support plate is over [ ] times the size of the strainer holes. Therefore it is not necessary to consider piling up the downstream debris at any flow paths in the reactor internals. The flow hole of the fuel assembly bottom nozzle is [ ] times the size of of the strainer holes. Therefore, it is quite unlikely that the downstream debris may pile up at the fuel assembly bottom nozzle.

4.2.2 Trapping Debris in Fuel Assemblies

Debris passing through the flow holes of the bottom nozzle is interrupted by the bottom grid spacer in the fuel assembly. Since the debris passing through the strainer and the bottom

nozzle is very small, most of the debris can flow out through clearances among adjacent fuel assemblies or inside the grid spacer. Thus, a small remaining amount of debris may be trapped by springs of the grid spacer.
The trapped debris is built up to about an inch height in the grid spacer, because the spring capturing the debris is located in the center of the grid spacer and has approximately two inches height. Such built up debris does not have significant influence on cooling of the fuel rod cladding at around the bottom grid spacer, because the corresponding region of the US-APWR fuel rod is at the lower plenum with no heat generation.
There is possibility that the debris passing through the bottom grid spacer will be trapped by the grid spacers at an upper elevation. Even if it happens, the channel closure by the locally built-up debris is less significant for core cooling in general, because heat removal is achieved by the coolant flow which can be supplied from such channels as exist among the fuel assemblies.

4.2.3 Boric Acid Precipitation

The US-APWR design uses boron as a core reactor reactivity control method, and there is a procedure that instructs the operators to switch operating DVI lines over to the hot leg injection line (simultaneous reactor vessel and hot leg injection) no sooner than about four (4) hours after the postulated large LOCA to prevent the core region boric acid concentration from reaching the precipitation point. The switchover time is determined by a simplified method, as described in the DCD Chapter 15, based on assumptions regarding mixing in the reactor vessel.

The debris ingested into the core region through the strainers may have some impact on the assumed mixing volume for the evaluation of boric acid concentration during the post-LOCA long term cooling. The debris in the coolant in the reactor vessel would displace water volume that would otherwise dilute the boric acid in the core region. However, the displaced volume of debris would be a small fraction of the liquid mixing volume used for the evaluation of US-APWR boric acid concentration, which is of the order of many hundreds of cubic feet. Therefore, debris ingested into the reactor vessel would not significantly affect the estimation of boric acid concentration in the core region.

4.2.4 Hot Leg Injection

The US-APWR design adopts ECCS hot leg injection no sooner than about four (4) hours after occurrence of the postulated LBLOCA. At this switchover time, the coolant in the RWSP is expected to have been circulating through the ECCS and CSS several times. Therefore, particulate and fibrous debris, which is generated by the initial RCS break flow and CS water and then transferred to the RWSP, is expected to be depleted either by capture on the strainer or by settle-out in low flow rate regions, such as the lower plenum. Thus, the amount of debris injected during the hot leg injection mode is expected to be small enough that the core cooling is not significantly affected by the debris.

Table 4-1 Components List in the Flow Path during an Accident

Components	Remark
Pumps	
SIS-RPP-001A,B,C,D	Multi-stage centrifugal type
RHS-RPP-001A,B,C,D	Centrifugal type
Heat Exchangers	
RHS-RHX-001A,B,C,D	Shell & tube type
Valves	
SIS-MOV-001A,B,C,D	Gate, 10”
SIS-VLV-004A,B,C,D	Check, 4”
SIS-MOV-009A,B,C,D	Gate, 4”
SIS-VLV-010A,B,C,D	Check, 4”
SIS-MOV-011A,B,C,D	Globe, 4”
SIS-VLV-012A,B,C,D	Check, 4”
SIS-VLV-013A,B,C,D	Check, 4”
SIS-MOV-014A,B,C,D	Globe, 4”
SIS-VLV-015A,B,C,D	Check, 4”
SIS-VLV-023A,B,C,D	Globe, 2”
CSS-MOV-001A,B,C,D	Gate, 14”
CSS-VLV-002A,B,C,D	Gate, 10”
CSS-MOV-004A,B,C,D	Gate, 8”
CSS-VLV-005A,B,C,D	Check, 8”
RHS-VLV-004A,B,C,D	Check, 16”
RHS-VLV-013A,B,C,D	Globe, 3”
RHS-HCV-603	Butterfly, 8”
RHS-HCV-633	Butterfly, 8”
RHS-MOV-021A,B,C,D	Gate, 8”
RHS-VLV-022A,B,C,D	Check, 8”
RHS-MOV-025A,B,C,D	Globe, 8”
Orifice	
SI pump outlet flow instrument orifice	
SI pump minimum flow orifice	
Direct vessel injection line orifice	
Hot leg injection line orifice	
CS/RHR pump outlet flow instrument orifice	
CS/RHR pump minimum flow instrument orifice	
CS/RHR pump minimum flow line orifice	
Containment spray ring orifice	
Spray Nozzle	
Containment Spray Nozzle	Orifice size 0.375 in.

5.0 CONCLUSION

This technical report describes the design and the evaluation of the US-APWR sump strainer. The US-APWR sump strainer design is intended to consistent with the requirements in RG 1.82 Rev.3. The break selection, debris generation, and debris transport were analyzed to identity the potential debris which may reach to the strainers in the RWSP assuming a number of conservative considerations. The characteristics of potential debris were set, identified, and referred appropriately, and used in the debris head loss evaluations, as well as the NPSH evaluation of vital pumps of the US-APWR. A bounding evaluation was performed to demonstrate that debris head loss of the US-APWR strainer is bounded by existing head loss test data conducted by CPNPP-1/2. The evaluation concluded that postulated debris head loss would satisfy the specified requirements of the standard US-APWR, and have sufficient suction head to operate plant safely following a post-LOCA event. In the evaluation, an assumption was made of the type and quantity of chemical debris of the US-APWR. This assumption will be justified by analyzing ongoing chemical effects test results.

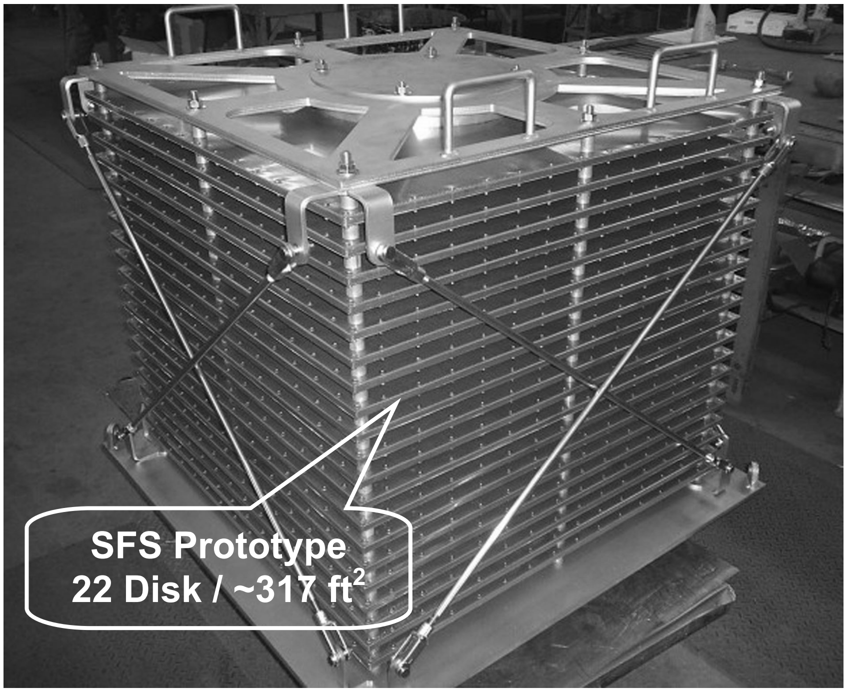
The chemical tests will be conducted through the end of November, 2008. The tests reports will be submitted to the NRC as the tests progress, and a summary of the test results will be incorporated into this technical report at the end of December, 2008.

6.0 REFERENCES

1. "Design Control Document for the United States Advanced Pressurized Water Reactor", Mitsubishi Heavy Industries, Ltd., 2007
2. "Water Sources for Long-Term Recirculation Cooling Following a Loss-of-Coolant Accident," Revision 3", U.S NRC, Regulatory Guide 1.82 Rev.3, November, 2003
3. "US-APWR Technical Information and Requirements for ECC/CS Sump Strainer", 4CS-UAP-20080045 Mitsubishi Heavy Industries, Ltd., August 2008.
4. "Pressurized Water Reactor Sump Performance Evaluation Methodology", amended by NRC, NEI 04-07 Revision 0, December 2004.
5. "Service Level I, II, and III Protective Coatings Applied to Nuclear Power Plants", Regulatory Guide 1.54 Revision 1, July, 2000, USNRC.
6. "Protective Coatings (Paints) for Light Water Nuclear Reactor Containment Facilities", ANSI N101.2
7. "Standard Test Method for Evaluating Coatings Used in Light-Water Nuclear Power Plants at Simulated Design Basis Accident (DBA) Conditions", ASTM D 3911
8. "Characterization and Head-Loss Testing of Latent Debris from Pressurized Water Reactor Containment Buildings", NUREG/CR-6877, U.S NRC.
9. Crane Technical Paper No. 410, "Flow of Fluids Through Valves, Fittings, and Pipe"
10. "Integrated Chemical Effect Test Project: Consolidated Data Report, Volume 1", NUREG-6914, U.S NRC.
11. "US-APWR Sump Debris Chemical Effects Test Plan", MUAP-08006 Mitsubishi Heavy Industries, Ltd., June 2008.

Appendix-A

PCI Sure Flow Strainer Technical Description and Drawings



The prototype **Sure-Flow® Strainer** (SFS) shown on the left was built in the PCI factory to proof the installation ease of our SFS modular concept.

This is very similar to the 27 disk SFS PCI is proposing to supply herein for the MHI U.S. APWR.

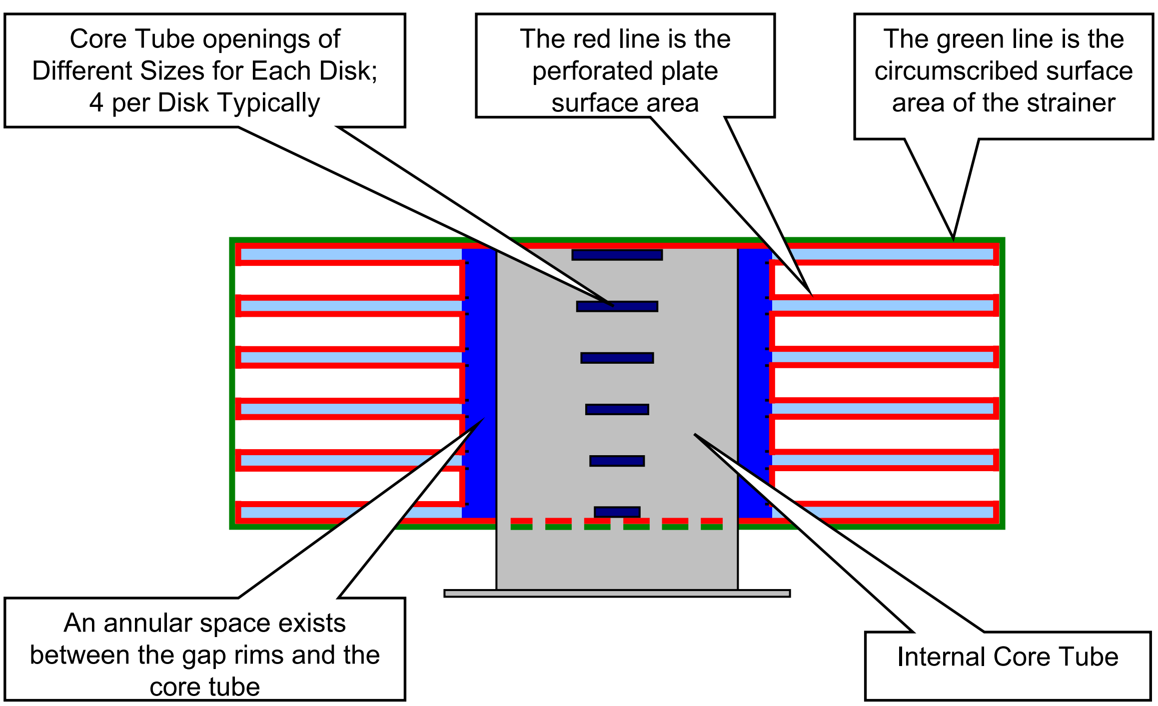
As shown to the left, this 22 disk strainer can be assembled by two men in less than one hour.

The sizes of the disks are approximately 36" x 36".

Basic Design Components of SFS

The illustration in Figure 1 below identifies the basic concept of the components and terms applicable to Sure-Flow Strainers.

FIGURE 1



The following describes and defines the PCI **Sure-Flow® Strainer** (SFS) major component elements, features and benefits as proposed for the MHI U.S. APWR.

SFS Module Components and Assembly

The following major components are described below and identified in Figure 2.

1. Base Plate – The SS plate upon which a core tube is attached containing a hole to within the perimeter of the core tube to allow water to communicate with the plenum or sump opening below. Also attaching to this plate are brackets for cross braces and a solid gap rim between the base plate and first perforated disk.

2. Core Tube – A stainless steel cylinder with openings enlarging in locations upstream of the suction source specifically designed to create uniform flow axially along the length of the core tube. This is a patented feature of all Sure-Flow Strainers. The benefits of a uniform suction pressure to each disk and gap are as follows:

   - Results in lower "actual" approach velocities to each disk and gap. A lower approach velocity means the debris bed will form under lower compression than screens without flow control resulting in a lower head loss than same size screens without flow control.
   - Control of the approach velocity justifies the use of reduced scale testing in lieu of testing the entire SFS screen arrangement. A single, full scale module will be used to test the debris bed head loss performance of the entire SFS arrangement.
   - The core tube discourages and prevents vortex formation and air ingestion.
   - The core tube provides design flexibility so that disks and modules can be positioned further from a central suction source to increase the size of screens provided within a given special limitation.

3. Disk – A rectangular chamber fabricated from stainless steel perforated plate to form nominal ½" thick disks. All disks are reinforced to prevent collapse against specified suction pressures using an innovative wire frame design that allows low head loss flow through the disk to its center where water exists into an annulus chamber that exists around the core tubes. The wire frames can be designed to work with light weight sheets; which allows PCI to offer perforated plate designs with holes as small as 0.037" in diameter. The hole size specified by MHI for the US APWR is 0.066" diameter.

4. Gap Rim – A "hoop" made from stainless steel perforated plate to form nominal 1" high rim with a diameter 3.5" greater than the core tube to provide an annulus chamber between the gap rims and core tube. Gap rims serve to connect the surface area formed by disks together and to provide additional surface area. Gap rims all have solid edge margins so as to not form openings larger than holes at the interface between disks and gap rims. Gap rims are also designed to withstand the specified suction pressures of the system with internal hoops and pipe spacers held in place with tension rods.

5. Tension Rods and Pipe Spacers – There are normally 12 tension rods to a SFS module. Pipe spacers are positioned inside each disk and between disks to provide a continuous tube for the tension rod to pass through the assembly and to assure the components align precisely. The pipe spacers provide a bearing surface when tension is applied to the rods by nuts or couplings. Eight (8) tension rods are positioned along the outside perimeter and four (4) are positioned just

inside the gap rims. Tension rods are used to squeeze the disks, gap rims and pipe spacers together into a single assembly without openings that would allow debris larger than the size of holes to enter the internal chamber. They also provide an important structural component to the assembly.

6. Top Frame – At the top of the SFS module assembly is a thick stainless steel plate with flow openings to which tension rods are terminated under torque to complete the assembly. A solid gap rim is usually positioned between the top disk surface and Top Frame to provide additional openings for water to enter the top surface of the top disk.

7. Cross Bracing – To comply with twisting and lateral structural forces cross bracing is added external to the disks between base plates and top frames; and / or connect to intermediate stiffener plates as shown in Figure 1. When an intermediate stiffener plate with flow openings is used gap rims of ½" height are used instead of 1" high gap rims to increase surface area and protect submergence to the specified water level. The cross braces connect via threaded connections so as to allow a secure and firm fit during assembly.

All components of the SFS module is fabricated from stainless steel to provide worry free service inside nuclear containment environments.

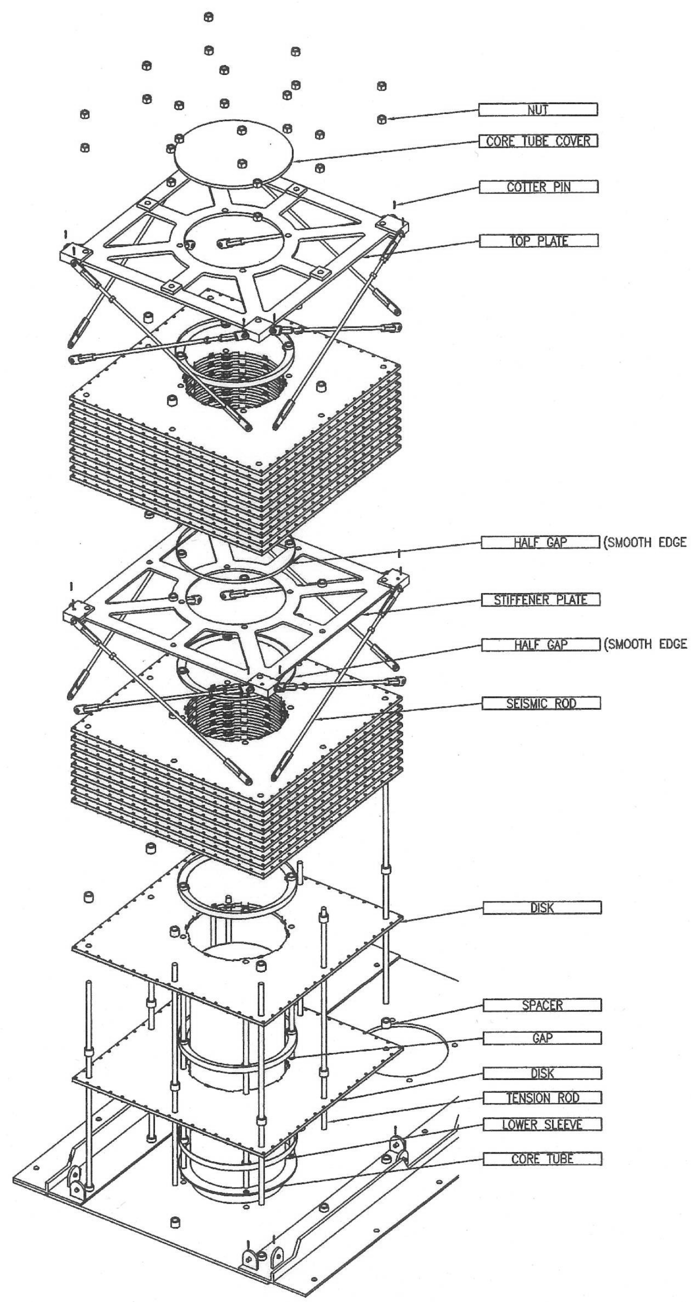
Design Reference History

The following U.S. PWR plants contracted PCI to supply our Sure-Flow Strainers to them for operation. PCI will be applying the same design principles to this design as we have implemented in the following plants.

No.	Plant Name	NSSS Supplier / Loops
1	Callaway	Westinghouse / 4 loops
2	Wolf Creek	Westinghouse / 4 loops
3	Comanche Peak Units 1 & 2	Westinghouse / 4 loops
4	South Texas Project Units 1 & 2	Westinghouse / 4 loops
5	Palisades	CE / 2 loops
6	Point Beach Units 1 & 2	Westinghouse / 2 loops
7	Prairie Island Units 1 & 2	Westinghouse / 2 loops
8	Kewaunee	Westinghouse / 2 loops
9	TVA – Watts Bar 1	Westinghouse / 4 loop Ice Condenser
10	TVA – Sequoyah Units 1 & 2	Westinghouse / 4 loop Ice Condenser
11	FPL - St. Lucie Unit 2	CE / 2 loops
12	FPL – Turkey Point Unit 4	Westinghouse / 3 loops
13	TVA – Watts Bar 2	Westinghouse / 4 loop Ice Condenser

- 17 of the 18 units have been fabricated; shipped and installed as of June 2008.

FIGURE 2 – TYPICAL SURE-FLOW STRAINER ASSEMBLY



REV.	DESCRIPTION	DRWN	CHKD	APPD	DATE

SCANNED

[ ]

NOTES:

1. SUBJECT TO FINAL STRUCTURAL AND HYDRAULIC QUALIFICATION.

PCI PERFORMANCE CONTRACTING INC ENGINEERED SYSTEMS

ENGINEERED SYSTEMS GROUP
16047 West 110th Street
Lenexa, Kansas 66219
Phone: (913) 928-2800
Fax: (913) 307-0453

Unless otherwise noted tolerances are:
± 3mm for metric
± 1/8" for fractions
± 0.0625" for decimals
± 2° for angles

Customer's Purchase Order: MNP-0458

MHI APWR
SURE-FLOW® STRAINER
GENERAL ARRANGEMENT

Scale: NTS	Job No.: 01-02-90-6032	Size: D	Drawing Number: US-APWR-GA-00	Rev: 0
Date: 9/24/08	Chkd: FRD			
Drwn: JCS	Appd:			

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REV.	DESCRIPTION	DRWN	CHKD	APPD	DATE

SCANNED

[ ]

NOTES:

1. SUBJECT TO FINAL STRUCTURAL AND HYDRAULIC QUALIFICATION.

NUCLEAR SAFETY RELATED

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ENGINEERED SYSTEMS

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Unless otherwise noted tolerances are:
± 3mm for metric
± 1/8" for fractions
± 0.0625" for decimals
± 2° for angles

Customer's Purchase Order: MNP-0458

MHI APWR
SURE-FLOW® STRAINER
GENERAL ARRANGEMENT

Scale: NTS	Job No.: 01-02-90-6032	Size: D	Drawing Number: SFS-APWR-GA-03	Rev: 0
Date: 9/24/08	Chkd: FRD			
Drwn: JKD	Appd:			

REV.	DESCRIPTION	DRWN	CHKD	APPD	DATE

[ ]

NOTES:

1. SUBJECT TO FINAL STRUCTURAL AND HYDRAULIC QUALIFICATION.

NUCLEAR SAFETY RELATED

BILL OF MATERIAL

PCI PERFORMANCE CONTRACTING INC
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Unless otherwise noted tolerances are:
± 3mm for metric
± 1/8" for fractions
± 0.0625" for decimals
± 2° for angles

Customer's Purchase Order: MNP-0458

MHI APWR
SURE-FLOW® STRAINER
STRAINER ISO

Scale: NTS	Job No.: 01-02-90-6032	Size: D	Drawing Number: SFS-APWR-GA-10	Rev: 0
Date: 9/24/08	Chkd: FRD			
Drwn: JKD	Appd: KD			

SCANNED

Appendix-B

Debris Allocation & Testing Bounding Analysis

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TABLES

1.0 Purpose and Summary Results

The US Nuclear Regulatory Commission (USNRC) in generic safety issue (GSI) 191 identified it was possible that debris in pressurized water reactors (PWR) containments could be transported to the emergency core cooling system (ECCS) sump(s) following a loss of coolant accident (LOCA). It was further determined that the transported debris could possibly block the sump screens/strainers and impair the flow of water. This could directly affect the resultant operability of the various ECCS pumps (i.e., Safety Injection (SI) and Residual Heat Removal (RHR)) and the Containment Spray (CS) system pumps, and their ability to meet their design basis function(s). In order to address and resolve the various issues identified by the USNRC in GSI-191, utilities have implemented a program of replacing the existing ECCS sump screens or strainers with new and improved designs.

In order to address and resolve the specific issues associated with USNRC GSI-191 for the Mitsubishi Heavy Industries, Ltd. (MHI) United States – Advanced Pressurized Water Reactor (US-APWR) Nuclear Power Plant, MHI entered into a contract with Performance Contracting, Inc. (PCI). The primary objective of the contract was for PCI to provide a qualified Sure-Flow® Suction Strainer that has been specifically designed for the US-APWR in order to address and resolve the USNRC GSI-191 ECCS sump blockage issue.

PCI has prepared a Qualification Report specifically for the subject strainer. The Qualification Report is a compilation of the various documents and calculations that support the strainer qualification. As part of the US-APWR Qualification Report, PCI will perform a number of calculations in support of the postulated Sure-Flow® Suction Strainer. This calculation TDI-6034-08, *Debris Allocation & Testing Bounding Analysis – MHI US-APWR* is one of a number of calculations that specifically supports the design and qualification of the subject strainer.

The purpose of this document is to demonstrate that the US-APWR design basis is bounded by the existing Comanche Peak Nuclear Power Plant Units 1 & 2 (CPNPP-1/2) debris and by-pass tests performed at the Alden Research Laboratory (ARL). If the CPNPP-1/2 tests in fact bound the US-APWR design basis, then US-APWR specific tests may not have to be performed for the US-APWR postulated debris types and quantities.

The proposed US-APWR has four (4) separate safety trains each with its own sump that supply water to one (1) train of the Emergency Core Cooling System (ECCS), that is the Residual Heat Removal (RHR)/Containment Spray (CS) and the Safety Injection (SI) pumping systems. The total maximum design flow rate is 5,200 gpm per train. The train flow rate is the total of the Residual Heat Removal (RHR)/Containment Spray (CS) and Safety Injection (SI) pumps for each specific train. The new Sure-Flow® Suction Strainer consists of four (4) separate strainer module assemblies designated as A, B, C and D **[Reference 9.1]**.

Each of the four (4) sumps shall have in place nine (9) Sure-Flow® Strainer vertical modules. Vertical modules have vertical core tubes with horizontal disks. Each module has twenty-seven (27) disks. All disks are 35 inches x 35 inches with a nominal one-half (1/2) inch thickness. Each disk is separated by a perforated 1-inch high gap resulting in twenty-one (26) gaps for each module. Each of four sumps will have a strainer assembly with a total strainer surface area of 3,512.8 ft^2 / sump; without reduction for sacrificial areas.

The nine (9) SFS modules are located over the sump, minimizing the clean strainer head loss of the strainer assembly system. The A, B, C and D sumps shall have a combined total strainer surface area of 14,051.2 ft^2. PCI drawing SFS-MHI APWR-GA-00, Revision 0 **[Drawing 10.1]** provides details of the subject configuration.

This Acceptance Criteria associated with this calculation is defined and discussed in Section 6.0. The primary acceptance criterion is that the US-APWR has more NPSH available than that of CPNPP-1/2. An evaluation and analysis was performed herein to compare the US-APWR and CPNPP-1/2 design basis specification loss-of-coolant-accident (LOCA) generated debris allocations.

This document concludes that based on the comparative evaluation results associated with the US-APWR and based on the specific LOCA generated debris types and quantities, **the CPNPP-1/2 ARL tests bound the Design Basis of the US-APWR with respect to debris laden strainer head loss.**

This conclusion is based on the following:

- US-APWR is bounded by CPNPP-1/2 testing performed at ARL (i.e., March 2008) **[References 9.2 & 9.3]**,
- CPNPP-1/2 has a significantly greater volume of particulate debris than the US-APWR , and therefore the US-APWR is bounded by the CPNPP-1/2 test program and associated test results for LOCA generated particulate debris **[References 9.1, 9.2, 9.3 & 9.5]**,

- CPNPP-1/2 has less fiber debris on a mass per strainer unit of area than the US-APWR under a beyond Design Basis condition wherein all (i.e., 100%) fiber debris is collected by one sump.

  However, for design conditions evaluated where only 70% or 50% of the fibers are collected on one (1) of two (2) operating sumps, CPNPP-1/2 has more fiber debris on a mass per strainer unit of area than the US-APWR. Furthermore, the US-APWR Design Basis is the 70% / 30% loading of the Design Basis debris types and quantities on one (1) of two (2) operating strainer trains per **ATTACHMENT 2** as specified by **[Reference 9.1]**.

  Accordingly, CPNPP-1/2 testing will bound the US-APWR for all cases except the beyond Design Basis case where 100% of the US-APWR Design Basis debris is collected on one of two operating sumps. In this scenario, the fiber bed is slightly thicker for the US-APWR due to the greater fibrous debris volume than CPNPP-1/2, however, the difference is so small to negate any concern that the US-APWR would perform differently under this operating condition. Therefore, PCI concludes the CPNPP-1/2 fiber bed would be just as efficient as the US-APWR in trapping particulate debris in the fiber bed for this design condition **[References 9.1, 9.2 & 9.3, and ATTACHMENTS 2 & 3]**.

- PCI concludes the US-APWR is bounded by CPNPP-1/2 testing on the basis of "debris" per unit area of strainer screen (i.e., perforated plate area) for all types of debris as specified in NEI 04-07 **[References 9.1, 9.2 & 9.3, and ATTACHMENTS 2 & 3]**.

PCI has made a conservative estimate in this analysis with regard to the total quantity of chemical precipitates to be evaluated. The quantity estimated herein is based on a slightly greater quantity than that specifically associated with CPNPP-1/2, which based on engineering judgment is reasonable. The specific chemical particulate debris of the US-APWR will be tested, assessed, and quantified by an on-going MHI chemical effects testing program. After the completion of the chemical effects test program and evaluation of the test results, it will be re-confirmed that the CPNPP-1/2 chemical precipitate debris will bound that of the US-APWR.

The logic to estimate a quantity substantially higher than the US-APWR design basis warrants is due to the assumption a fiber bed is not expected to form in the actual US-APWR large flume testing at ARL. If no debris bed forms, it will not matter what quantity of chemical precipitates are tested; the head loss should be acceptable.

The overall conclusion of PCI's assessment and evaluation herein is that the CPNPP-1/2 design basis conditions with respect to LOCA generated debris, subsequent debris allocation for testing, and the ARL test results of the CPNPP-1/2 specified debris allocations bounds the expected final Design Basis (**ATTACHMENT 2**) of the US-APWR design conditions.

It is also concluded that this calculation, an integral portion of the Qualification Report completely supports the qualification, installation, and use of the PCI Sure-Flow® Suction Strainer for the US-APWR.

2.0 Definitions & Terminology

The following Definitions & Terminology are defined and described as they are utilized in this calculation.

Sure-Flow® Suction Strainer – Strainer developed and designed by Performance Contracting, Inc. that employs Sure-Flow® technology to reduce inlet approach velocity.

Emergency Core Cooling System (ECCS) – The ECCS is a combination of pumps, piping, and heat exchangers that can be combined in various configurations to provide either safety injection or decay heat cooling to the reactor.

Mitsubishi Heavy Industries Ltd. (MHI) United States Advanced Pressurized Water Reactor (US-APWR) – also know as MHI US-APWR. The US-APWR is an advanced NSSS design that MHI has submitted to the USNRC for design certification (DC). The US-APWR design certification is on behalf of the licensees.

Comanche Peak Nuclear Power Plant Unit 1 & 2 - also known as CPNPP-1/2, Comanche Peak 1/2, and Comanche Peak. CPNPP-1/2 is an existing two-unit PWR utilizing a Westinghouse based NSSS.

Containment Spray System – also known as CSS or CS. The system is utilized to address a LOCA.

Loss-Of-Coolant-Accident – also known as a LOCA. A LOCA is the result of a pipe break or inadvertent leak that results in the discharge of primary reactor coolant from the normal nuclear steam supply system (NSSS) boundary. A LOCA can be classified as a large break LOCA (LBLOCA) or a small break

LOCA (SBLOCA). Classification is directly dependent upon the nominal size of the affected pipe that is associated with the LOCA.

Proprietary

Proprietary

Proprietary

Proprietary

Proprietary

PCI PERFORMANCE CONTRACTING INC ENGINEERED SYSTEMS

Proprietary

Proprietary

Proprietary

Proprietary

8.0 Conclusions

In simple terms, this calculation concludes that the PCI Sure-Flow® Strainers proposed for the MHI US-APWR will have enough suction head to operate safely following a post-LOCA event.

Based upon the information and discussion presented in the previous sections, it can be concluded that the CPNPP-1/2 debris allocation types and quantities, the ARL testing program for CPNPP-1/2, subsequent CPNPP-1/2 test results, and analysis of the CPNPP-1/2 test results bound the US-APWR design basis debris allocation.

With regard to chemical precipitate debris, the quantity of the US-APWR chemical debris is assumed in this bounding evaluation to be slightly more than that of CPNPP-1/2. The specific chemical particulate debris of the US-APWR will be tested, assessed, and quantified by an on-going MHI chemical effects testing program. After the completion of the chemical effects test program and evaluation of the test results, it will be re-confirmed that the CPNPP-1/2 chemical precipitate debris will bound that of the US-APWR.

9.0 References

9.1 Mitsubishi Heavy Industries Ltd., *US-APWR Technical Information and Requirements from ECC/CS Sump Strainer*, 4CS-UAP-20080045, Revision 1

9.2 Luminant, *Comanche Peak Nuclear Power Plant Units 1 and 2 Specification Emergency Sump Suction Strainers,* CPSES-M-2044, Revision 5

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9.15 *PCI TDI-6004-06 Revision 2 - Total Head Loss – Comanche Peak Steam Electric Station*

10.0 Drawings

10.1 SFS-MHI USAPWR-GA-00, Revision 0, MHI US-APWR , *Sure-Flow® Strainer, General Arrangement*

ATTACHMENT 1 - Comparison Summary CPNPP-1/2 to US-APWRBeyond Design Basis – 100% of Total Design Basis Debris to One (1) Strainer

MHI US APWR Design Basis from Table 4.1 of MHI Tech Spec No. 4CS-UAP-20080045-Rev 1

Proprietary

ATTACHMENT 2 - Comparison Summary CPNPP-1/2 to US-APWR Design Basis – 70% / 30% of Total Design Basis Debris to Two (2) Strainers

MHI US APWR Design Basis from Table 4.1 of MHI Tech Spec No. 4CS-UAP-20080045-Rev 1

Proprietary

ATTACHMENT 3 - Comparison Summary CPNPP-1/2 to US-APWR Normal Allocation Basis – 50% / 50% of Total Design Basis Debris to Two (2) Strainers

Proprietary

MHI US APWR Design Basis from Table 4.1 of MHI Tech Spec No. 4CS-UAP-20080045-Rev 1