6C Containment Debris Protection for ECCS Strainers

The information in this appendix of the reference ABWR DCD is subject to several changes due to the adoption of ~~a stacked disk ECCS strainer design~~a complex ECCS strainer design (e.g. Cassette Type Strainer). Consequently, for clarity it is presented in its entirety with the following departures incorporated. ~~One subsection and two tables are deleted and replaced with references and information incorporated from the stacked disk Licensing Topical Report, "Application Methodology for the General Electric Stacked Disk ECCS Suction Strainer," NEDC-32721P-A (Reference 6C-4).~~This strainer design has been used at numerous BWRs in Japan and numerous PWRs in the United States. The strainer is described in Reference 6C-9. Departure STD DEP Vendor changes General Electic (GE) to Toshiba in Section 6C.1.

STD DEP 6C-1

STD DEP Vendor

The original DCD text is presented in *italics*, deletions are shown as ~~strikethroughs~~, and new text in underlined regular font.

6C.1 Background

NRC Bulletin No. 93-02, "~~ƒ~~Debris Plugging of Emergency Core Cooling Suction Strainers,~~≈~~" (Reference 6C-1) *NRC guidance and highlights the need to adequately accommodate debris in design by focusing on an incident at the Perry Nuclear Plant.* ~~*GE*~~Toshiba *reviewed the concerns addressed by NRC Bulletin 93-02*, including complying with Generic Letters GL 97-04 on NPSH requirements for ECCS pumps and GL 98-04 blockage from foreign materials and paint debris (References ~~6C-6 and 6C-7~~6C-7 and 6C-8)*, and has reviewed the design of the ABWR for potential weaknesses in coping with the bulletin's concerns.* ~~*GE*~~Toshiba *has determined that the ABWR design is more resistant to these problems for a number of reasons as discussed in the following.*

The ultimate concern raised by the Perry incident was the deleterious effect of debris in the suppression pool and how it could impact the ability to draw water from the suppression pool during an accident. The ABWR design has committed to following the guidance provided in Regulatory Guide 1.82 (Reference 6C-2), Utility Resolution Guidance (URG) for ECCS Suction Strainer Blockage, NEDO-32686-A (Reference 6C-3) *and the additional guidance described below.*

The ABWR is designed to accommodate debris present in the suppression pool prior to Loss-of-Coolant Accident (LOCA) and *to inhibit debris generated during a LOCA from preventing operation of the Residual Heat Removal (RHR), Reactor Core Isolation Cooling (RCIC) and High Pressure Core Flooder (HPCF) system.*

6C.2 ABWR Mitigating Features

The ABWR has substantially reduced the amount of piping in the drywell relative to earlier designs and consequently the quantity of insulation required. Furthermore, there is no equipment in the wetwell spaces that requires insulation or other fibrous *materials. The ABWR design conforms with the guidance provided by the NRC for maintaining the ability for long-term recirculation cooling of the reactor and containment following a LOCA.*

The Perry incident was not the result of a LOCA but rather debris entering the Suppression Pool during normal operation. The arrangement of the drywell and wetwell/wetwell airspace on a Mark III containment (Perry) is significantly different from that utilized in the ABWR design. In the Mark III containment, the areas above the suppression pool water surface (wetwell airspace) are substantially covered by grating with significant quantities of equipment installed in these areas. Access to the wetwell airspace (containment) of a Mark III is allowed during power operations. In contrast, on the ABWR the only connections to the suppression pool are 10 drywell connecting vents (DCVs), and access to the wetwell or drywell during power operations is prohibited. The DCVs will have horizontal steel plates located above the openings that will prevent any material falling in the drywell from directly entering the vertical leg of the DCVs. This arrangement is similar to that used with the Mark II connecting vent pipes. Vertically oriented trash rack construction will be installed around the periphery of the horizontal steel plate to intercept debris. The trash rack design shall allow for adequate flow from the drywell to wetwell. In order for debris to enter the DCV it would have to travel horizontally through the trash rack prior to falling into the vertical leg of the connecting vents. Thus the ABWR is resistant to the transport of debris from the drywell to the wetwell.

In the Perry incident, the insulation material acted as sepia to filter suspended solids from the suppression pool water. The Mark I, II, and III containments have all used carbon steel in their suppression pool liners. This results in the buildup of corrosion products in the suppression pool, which settle out at the bottom of the pool until they are stirred up and resuspended in the water following some event (SRV lifting). In contrast, the ABWR liner of the suppression pool is fabricated from stainless steel which significantly lowers the amount of corrosion products which can accumulate at the bottom of the pool.

A further mitigating feature for the ABWR is that the insulation installed on the ASME Section III, Class 1 piping ($\geq$ 80 mm) in the drywell, i.e., the large bore piping, is reflective metal insulation type (RMI). Use of RMI minimizes the fibrous insulation source term used in the suction strainer design. This is a significant factor in design that reduces the potential suction strainer debris load and further reduces the potential for suction strainer blockage. In addition, inspections will ensure that there is no evidence of excessive build-up of debris around the ECCS suction strainers and any abnormalities that could affect the mechanical functioning of the suction strainers.

Since the debris in the Perry incident was created by roughing filters on the containment cooling units, a comparison of the key design features of the ABWR is necessary. In the Mark III design more than 1/2 of the containment cooling units are effectively located in the wetwell airspace. For the ABWR there are no cooling fan units in the wetwell air space. Furthermore the design of the ABWR Drywell Cooling Systems does not utilize roughing filters on the intake of the containment cooling units.

Temporary filters are used during post construction systems testing ~~and refueling outages~~ in accordance with plant housekeeping and foreign material exclusion procedures further reducing the potential for introducing debris to the suppression pool.

In the event that small quantities of debris enter the suppression pool, the Suppression Pool Cleanup System (SPCU) will remove the debris during normal operation. The SPCU is described in Section 9.5.9 and shown in Figure 9.5-1. The SPCU is designed to provide a continuous cleanup flow of 250 m^3*/h. This flow rate is sufficiently large to effectively maintain the suppression pool water at the required* ~~*purity*~~ cleanliness*. The SPCU system is intended for continuous operation and the suction pressure of the pump is monitored and provides an alarm on low pressure. Early indication of any deterioration of the suppression pool water quality will be provided if significant quantities of debris were to enter the suppression pool and cause the SPCU strainer to become plugged resulting in a low suction pressure alarm.*

The suction strainers design *at* Perry preceded and *did not meet the current regulatory requirements. The ABWR ECCS suction strainers will utilize* ~~*a “ƒT≈” arrangement with conical strainers on the 2 free legs of the “ƒT≈”*~~ the state-of-the art ~~Optimized Stacked~~ cassette type strainer design. ~~Disk ECCS Suction Strainer Design developed by General Electric or equivalent.~~ ~~*This design separates the strainers so that it minimizes the potential for a contiguous mass to block the flow to an ECCS pump.*~~ The design of the strainers will be based on ~~the Licensing Topical Report (LTR), Application Methodology for the General Electric Stacked Disk ECCS Suction Strainer, NEDC-32721P-A, or equivalent and the Utility Resolution Guidance, NEDO-32686-A.~~ Regulatory Guide 1.82, NUREG/CR-6224 (Reference 6C-4), NUREG/CR-6808 (Reference 6C-5) and the Utility Resolution Guidance, NEDO-32686-A. ~~The stacked disk strainer design is based on a set of disks whose internal radius and thickness vary over the height of the strainer.~~ The cassette type strainer design is based on a set of cassette modules with U-shaped filter pockets attached to their exterior. As a result, the cassette type strainer has increased available suction surface area without increasing the overall size of the strainer. ~~The selected variation in these parameters provides an increased surface area.~~ The holes in each ~~disk~~ pocket filter are sized to prevent a deleterious quantity of debris from passing through strainer, but allow fluid to pass through. A key feature in the design of these strainers is to collect debris where velocity is low, since the pressure drop across the debris bed is known to be proportional to the velocity through the bed. This minimizes head loss across the strainer. Further technical details and methodologies are used to determine the head loss across the strainer for design debris loadings and to determine the structural loads on ECCS penetrations, piping and strainers caused by LOCA induced hydrodynamic forces. ~~The LTR was reviewed and accepted by the NRC as described in the NRC Safety Evaluation Report (Reference 6C-5).~~ *The ABWR design also has additional features not utilized in earlier designs that could be used in the highly improbable event that all suppression pool suction strainers were to become plugged. The alternate AC (Alternating Current) independent water addition mode of RHR allows water from the Fire Protection System to be pumped to the vessel and sprayed in the wetwell and drywell from diverse water sources to maintain cooling of the fuel and containment. The wetwell can also be vented at low pressures to assist in cooling the containment.*

6C.3 RG 1.82 Improvement

All ECCS strainers will at a minimum be sized to conform with the guidance provided in Reg. Guide 1.82, for the most severe of all postulated breaks.

The following clarifying assumptions will also be applied and will take precedence:

(1) *The debris generation model will utilize* ~~*right angle cones acting in both directions;*~~ ~~the stacked disk ECCS suction strainer design in accordance with Licensing Topical Report NEDC 32721P-A, or equal and the Utilities Resolution Guidance, NEDO-32686-A.~~the Utility Resolution Guidance, NEDO-32686-A.

(2) *The* ~~*amount of*~~ design *insulation debris* load that is *generated* ~~*will be assumed to be 100% of the insulation in a distance of 3 L/D of the postulated break within the right angle cones including targeted insulation;*~~ and transported to the suppression pool is based on ~~the referenced LTR and the URG.~~the Utility Resolution Guidance, NEDO-32686-A.

(3) The strainer design is based on the Debris Load Fraction that accumulates on a given strainer for the LOCA case being considered. The debris load fraction is defined as the fraction of the total flow that is attributed to a given strainer.

(4) ~~*All (100%) of the insulation debris generated will be assumed to be transported to the suppression pool.*~~*Transportation of insulation debris to the suppression pool will be in accordance with NEDO-32686-A.*

(5) *The debris in the suppression pool will be assumed to remain suspended until it is captured on the surface of a strainer.*

~~*The sizing of the RHR suction strainers will assume that the insulation debris in the suppression pool is evenly distributed to the 3 pump suctions. The strainer size will be determined based on this amount of insulation debris and then increased by a factor of 3. The flow rate used for calculating the strainer size will be the runout system flow rate.*~~

Suction strainer sizing criteria is based on meeting NPSH requirements at run out system flow, ~~plus margin,~~ and the design basis debris load including consideration of chemical effects, in the suppression pool that is considered to accumulate on the suction strainers after a number of pool volume turnovers.

The sizing of the RHR*, RCIC and HPCF suction strainers will conform to the guidance of Reg Guide 1.82 and* ~~*will assume*~~ assumes *that* all *the* ~~*insulation*~~ *debris in the suppression pool,* including insulation debris, corrosion sludge, dust and dirt, *is proportionally distributed to the pump suctions based on the flow rates of the systems at run out conditions* considering the most limiting system failures*. The strainers available for capturing insulation debris will include 2 RHR suction strainers and a single HPCF or RCIC suction strainer* in accordance with single failure criteria. The assessment of chemical effects will be in accordance with RG 1.82, and will include evaluation of the suppression pool post-LOCA chemistry, identification of potentially reactive material in the drywell, benchtop testing to identify types and amounts of chemical precipitates, and small-scale testing of strainer elements, if required. Downstream effects of material predicted to pass through the suction strainers will be evaluated in accordance with RG 1.82.

6C.4 Discussion Summary

In summary, the ABWR design includes the necessary provisions to prevent deleterious *debris from entering the ECCS and impairing the ability of the RCIC, HPCF, and RHR systems to perform their required post-accident functions. Specifically, the ABWR does the following:*

(1) The design is resistant to the transport of debris to the suppression pool.

(2) The suppression pool liner is stainless steel, which significantly reduces corrosion products.

(3) The SPCU system will provide early indication of any potential problem. Low SPCU pump suction pressure can provide early indication of debris present in the suppression pool and permit the plant operator to take appropriate corrective action.

(4) The SPCU System operation will maintain suppression pool cleanliness. Plant housekeeping and Foreign Material Exclusion (FME) procedures assure pool cleanliness prior to plant operation and over plant life such that no significant debris is present in the suppression pool.

(5) Visual inspection of the suction strainers is performed each refueling outage.

(6) ~~*(5)*~~ *The equipment installed in the drywell and wetwell minimize the potential for generation of debris.*

(7) ~~*(6)*~~ ~~*The*~~ ~~stacked disk~~ ~~*ECCS suction strainers*~~ The complex ECCS strainers *meet the current regulatory requirements* ~~and are designed in accordance with NRC approved LTR, NEDC-32721P-A (or equivalent),~~ *unlike the strainers at the incident plants.*

~~*(7) The RHR suction strainers will apply an additional factor of 3 design margins.*~~

~~The information regarding the ECCS strainers design calculations along with input data, methodology, analysis, discussion and examples is contained in Licensing Topical Report, Application Methodology for the General Electric Stacked Disk ECCS Suction Strainer, NEDC-32721P-A.~~

~~*6C.5 Strainer Sizing Analysis Summary*~~

~~*A preliminary analysis was performed to assure that the above requirements could be satisfied using strainers compatible with the suppression pool design as shown by*~~

~~*Figure 1.2-13i. The following summarizes the results, which indicate strainer sizes that are acceptable within the suppression pool design constraints.*~~

~~*Each loop of an ECCS system has a single suppression pool suction strainer configured in a T shape with a screen region at the two ends of the T cross member. Analysis determined the area of each screen region. Thus, RHR with three loops has six screen regions. The HPCF with two loops has four screen regions, and the RCIC has two screen regions. The characteristic dimension given for the screens in the*~~

6C.5 Strainer Sizing Analysis Summary

~~*A preliminary analysis was performed to assure*~~ The strainer sizing analysis assures *that the above requirements* ~~*could be*~~ are *satisfied using strainers compatible with the suppression pool design as shown by Figure 1.2-13i. The following summarizes* ~~*the results, which indicate strainer sizes that are acceptable within the suppression pool design constraints.*~~ the strainer sizing analysis.

Each loop of an ECCS system has a single suppression pool suction strainer configured in a T shape with a screen region at the two ends of the T cross member. Analysis determined the area of each screen region. Thus, RHR with three loops has six screen regions. The HPCF with two loops has four screen regions, and the RCIC has two screen regions. ~~*The characteristic dimension given for the screens in the results below indicates a surface area consisting of a circle with a diameter of the dimension plus a cylinder with a diameter and length of the dimension.*~~ The characteristic dimensions to calculate a surface area for cassette type strainer are given as follows,

(1) Depth of filter pocket

(2) Width of filter pocket

(3) Length of strainer

(4) Diameter of strainer

By the requirements above, all of the debris deposits on the strainers. The distribution of debris volume to the strainer regions was determined as a fraction of the loop flow splits based on runout flow. Debris on the screen creates a pressure drop as predicted by ~~*NUREG-0897*~~ NUREG/CR-6224 and NUREG/CR-6808, *which is referenced by R.G. 1.82.* ~~*The equation for NUKONTM insulation on page 3-59 of NUREG-0897 was used for this analysis. The NUKONTM debris created pressure drop equation is a function of the thickness of debris on the screen (which is a function of debris volume), the velocity of fluid passing through the screen (runout flow used), and the screen area.*~~ Pressure drop caused by the mixed particulates and fiber bed is calculated by the equation shown on NUREG/CR-6224, Appendix B. The following parameters play an important part in the function of this equation for pressure drop caused by mixed bed.

(1) Thickness of debris on screen

(2) Characteristic shape of debris type

(3) Rate of particulate mass to fiber debris mass

(4) Velocity of fluid passing through the screen (runout flow used)

On the one hand, pressure drop is calculated by the equation shown on NUREG/CR-6808 for RMI. *The debris created pressure drop was applied in an equation as follows; the static head at the pump inlet is equal to the hydraulic losses through the pipe and fittings, plus the pressure drop through the debris on the strainers, plus the hydraulic loss through the unplugged strainer, plus a margin equal to approximately 10% of the static head at the pump inlet, and plus the required NPSH. The static head takes into account the suppression pool water level determined by the draw down calculated as applicable for a main steam line break scenario. A summary provided in Table 6C-1, and a summary of the analysis results is provided in Table 6C-2.*

By making realistic assumptions, the following additional conservatisms are likely to occur, but they were not applied in the analysis. No credit in water inventory was taken for water additions from feedwater flow or flow from the condensate storage tank as injected by RCIC or HPCF. Also, for the long term cooling condition, when suppression pool cooling is used instead of the low pressure flooder mode (LPFL), the RHR flow rate decreases from runout (1130 m^3/h) to rated flow (954 m^3/h), which reduces the pressure drop across the debris.

results below indicates a surface area consisting of a circle with a diameter of the dimension plus a cylinder with a diameter and length of the dimension.

By the requirements above, all of the debris deposits on the strainers. The distribution of debris volume to the strainer regions was determined as a fraction of the loop flow splits based on runout flow. Debris on the screen creates a pressure drop as predicted by NUREG-0897, which is referenced by R.G. 1.82. The equation for NUKONTM insulation on page 3-59 of NUREG-0897 was used for this analysis. The NUKONTM debris created pressure drop equation is a function of the thickness of debris on the screen (which is a function of debris volume), the velocity of fluid passing through the screen (runout flow used), and the screen area. The debris created pressure drop was applied in an equation as follows; the static head at the pump inlet is equal to the hydraulic losses through the pipe and fittings, plus the pressure drop through the debris on the strainers, plus the hydraulic loss through the unplugged strainer, plus a margin equal to approximately 10% of the static head at the pump inlet, and plus the required NPSH. The static head takes into account the suppression pool water level determined by the draw down calculated as applicable for a main steam line break scenario. A summary provided in Table 6C-1, and a summary of the analysis results is provided in Table 6C-2.

By making realistic assumptions, the following additional conservatisms are likely to occur, but they were not applied in the analysis. No credit in water inventory was taken for water additions from feedwater flow or flow from the condensate storage tank as injected by RCIC or HPCF. Also, for the long term cooling condition, when

~~suppression pool cooling is used instead of the low pressure flooder mode (LPFL), the RHR flow rate decreases from runout (1130 m3/h) to rated flow (954 m3/h), which reduces the pressure drop across the debris.~~

6C.6 References

6C-1 Debris Plugging of Emergency Core Cooling Suction Strainers, NRC Bulletin No. 93-02, May 11, 1993.

6C-2 Water Sources for Long-Term Recirculation Cooling Following a Loss-of-Coolant Accident, NRC Reg. Guide 1.82.

6C-3 Utility Resolution Guidance for ECCS Suction Strainer Blockage, NEDO-32686-A.

~~6C-4 Licensing Topical Report, Application Methodology for the General Electric Stacked Disk ECCS Suction Strainer, NEDC-32721P-A.~~

6C-4 Parametric Study of Potential for BWR ECCS strainer Blockage Due to LOCA Generated Debris, NUREG/CR-6224.

~~6C-5 Safety Evaluation Report (SER) by the Office of Nuclear Reactor Regulation GE Nuclear Energy Licensing Topical Report NEDC-32721P, "Application Methodology for GE Stacked Disk Suction Strainer, Part I," TAC No. MB3311, dated February 3, 1999; and Part 2, TAC No. M98500, dated June 28, 2002.~~

6C-5 Knowledge Base for Effect of debris on Pressurised Water Reacter Emergency Core Cooling Sump Performance, NUREG/CR-6808

6C-6 NOT USED

6C-7 ~~6C-6~~ NRC Generic Letter (GL) 97-04, Assurance of Sufficient Net Positive Suction Head for Emergency Core Cooling and Containment Heat Removal Pumps, dated October 7, 1997

6C-8 ~~6C-7~~ NRC Generic Letter (GL) 98-04, Potential for Degradation of the Emergency Core Cooling System and the Containment Spray System After a Loss-Of-Coolant Accident because of Construction and Protective Coating Deficiencies and Foreign Material in Containment, dated July 14, 1998.

6C-9 Application Methodology for the ECCS Strainer, Toshiba Corporation, PDR-2008-100575, Rev 0, June 3, 2008.

~~Table 6C-1 Debris Analysis Input Parameters~~Not Used

~~Estimated debris created by a main steam line break~~	~~2.6 m^3~~
~~RHR runout flow (Figure 5.4-11, note 13)~~	~~1130 m^3/h~~
~~HPCF runout flow (Table 6.3-8)~~	~~890 m^3/h~~
~~RCIC controlled constant flow (Table 5.4-2)~~	~~182 m^3/h~~
~~Debris on RHR screen region, 3 RHR loops operating~~	~~0.434 m^3~~
~~Debris on HPCF screen region~~	~~0.369 m^3~~
~~Debris on RCIC screen region~~	~~0.097 m^3~~
~~RHR required NPSH (Table 6.3-9)~~	~~2.4 m~~
~~HPCF required NPSH (Table 6.3-8)~~	~~2.2 m~~
~~RCIC required NPSH (Table 5.4-2)~~	~~7.3 m~~
~~RHR pipe, fittings and unplugged strainer losses1~~	~~0.60 m~~
~~HPCF pipe, fittings and unplugged strainer losses*~~	~~0.51 m~~
~~RCIC pipe, fittings and unplugged strainer losses*~~	~~0.39 m~~
~~Suppression pool static head above pump suction~~	~~5.05 m~~

~~*] Calculated hydraulic losses*~~

~~Table 6C-2 Results of Analysis~~Not Used

~~RHR screen region area/characteristic dimension~~	~~5.66 m^2/1.20 m~~
~~HPCF screen region area/characteristic dimension~~	~~1.46 m^2/0.61 m~~
~~RCIC screen region area/characteristic dimension~~	~~0.27 m^2/0.26 m~~
~~Total ECCS screen region area~~	~~40.0 m^2~~