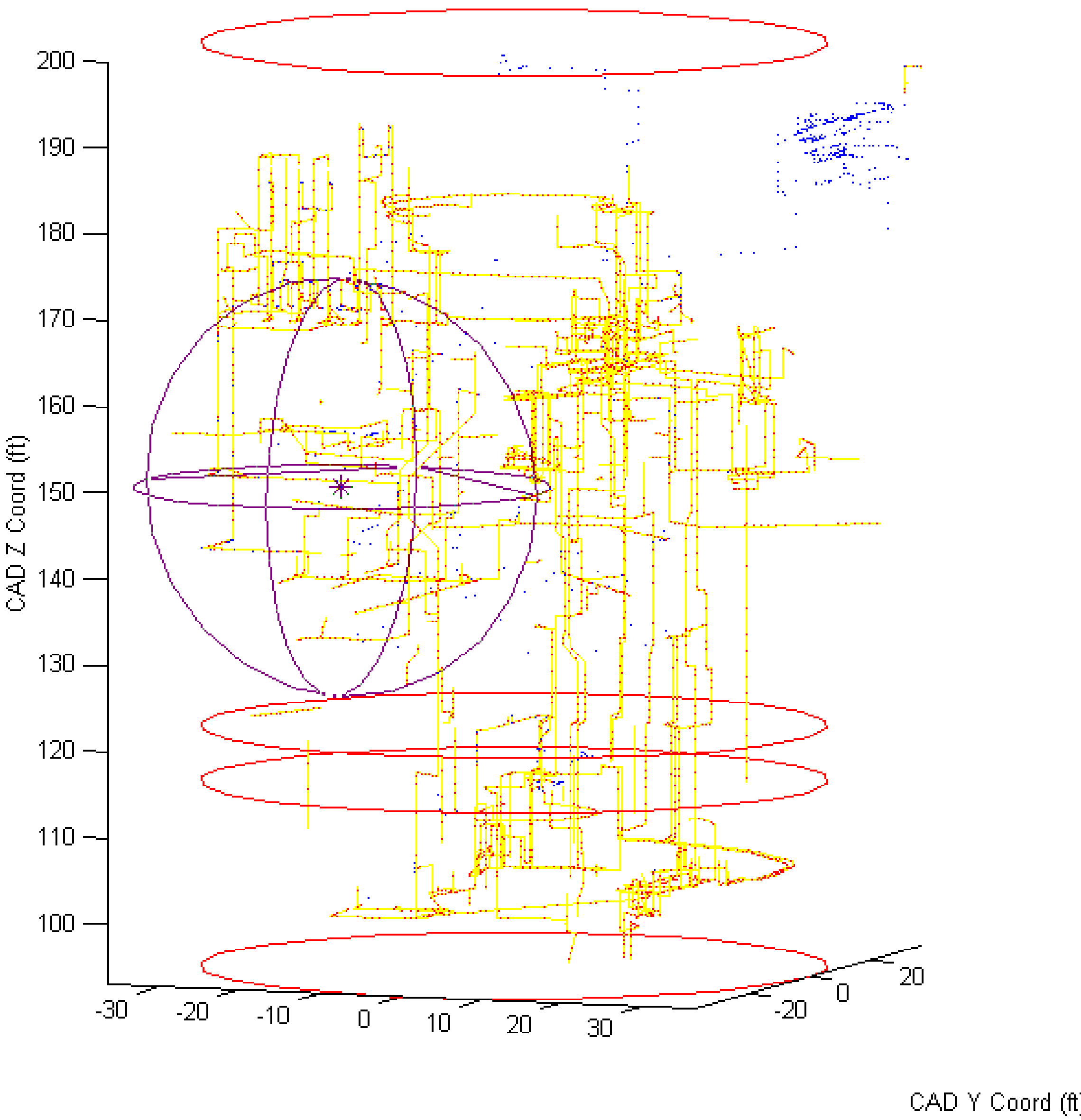
LOS ALAMOS TECHNICAL EVALUATION REPORT

On-Site Audit of the Grand Gulf Nuclear Station Emergency Core Cooling System Strainer-Blockage Resolution



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LIST OF ACRONYMS

BWROG	Boiling Water Reactor Owners' Group
DBA	Design-Basis Accident
ECCS	Emergency Core Cooling System
FME	Foreign Material Exclusion
GGNS	Grand Gulf Nuclear Station
HEPB	High-Energy Pipe Break
HPCS	High-Pressure Core Spray
HVAC	Heating, Ventilating, and Air Conditioning
LOCA	Loss-of-Coolant Accident
LPCI	Low-Pressure Core Injection
LPCS	Low-Pressure Core Spray
NPSH	Net Positive Suction Head
NRC	Nuclear Regulatory Commission
RCIC	Reactor Core Isolation Cooling
RG	Regulatory Guide
RHR	Residual Heat Removal
RMI	Reflective Metal Insulation
RWCU	Reactor Water Clean-Up
SER	Safety Evaluation Report
SPC	Suppression Pool Cooling
SPCP	Suppression Pool Cleanliness Program
URG	Utility Resolution Guidance
ZOI	Zone of Influence

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by

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1.0 INTRODUCTION

Grand Gulf Nuclear Station (GGNS) is a BWR/6 plant with a Mark III containment. In response to US Nuclear Regulatory Commission (NRC) Bulletin 96-03, replacement strainers were installed at GGNS during the 1998 outage. NRC staff performed an on-site audit at Grand Gulf of the analyses that formed the basis for the design and installation of the replacement strainers. Included in the audit were the licensee's (Entergy) implementations of programs related to the general issue of Emergency Core Cooling System (ECCS) strainer blockage, such as the Foreign Material Exclusion (FME) Program and the Suppression Pool Cleanliness Program (SPCP). Los Alamos National Laboratory analysts assisted the NRC in this effort.

The on-site audit focused primarily on reviewing documents related to the design and installation of the replacement strainers. Appendix A contains the completed checklist used by Los Alamos and NRC staffs during the on-site review. This checklist provides a brief summary of all aspects of the review. This report documents the supporting analyses conducted by Los Alamos during the on-site review.

1.1 Plant Familiarization

Grand Gulf Unit 1 uses predominantly Mirror™-brand reflective metal insulation (RMI) cassettes[1] to insulate reactor system piping. Smaller inventories of Kaowool,[2] Calcium-Silicate[3] (Cal-Sil), and fiberglass are also present. The licensee estimates that 676 ft^3 of Kaowool (including miscellaneous fiberglass) and 908 ft^3 of Cal-Sil insulation are present in the containment. The Cal-Sil insulation is protected by aluminum jackets, and some of the preformed fiberglass also is encased in a metal jacket. The licensee conducted extensive quarter-scale pool-transport and head-loss testing for their complete replacement strainer design and small-scale testing for a segment of the design. No simulated RMI debris was observed to accumulate or remain attached to the strainer under design approach velocities (~0.02 ft/s), and therefore, RMI was not considered in their debris-generation, debris-transport, or head-loss calculations. Los Alamos has reviewed the licensee's position regarding RMI and concurs.

[1]Mirror is a trademark insulation manufactured and installed by Diamond Power Specialty Company. It contains 2.5-mm stainless-steel foils enclosed in a welded stainless-steel cassette.
[2]Kaowool is a spun mineral-fiber material with a manufactured density in the range of 7.4 to 8.4 lbm/ft^3 that is formed in blankets supported with wire mesh.
[3]Calcium-silicate is a formed particulate material with fiber binding and a manufactured density in the range of 13 lbm/ft^3 that is encased in a metal covering.

Therefore, for the purpose of this audit, the primary concern is estimating the combined effects of damaged fibrous (Kaowool and fiberglass) and damaged particulate (Cal-Sil) insulation.

Before 1998, Grand Gulf Unit 1 used truncated-cone strainers with 3/32-in. perforations on 5/32-in. centers to protect against plugging of core-spray nozzles and damage of ECCS pump seals and bearings. The net surface area of the strainers was 170 ft^2, and each strainer was 40 in. long, 23.25 in. in diameter at the base, and 6 in. in diameter at the top. The total licensing-basis ECCS flow is 44,895 gal./min.

The licensee's resolution of the potential strainer-blockage issue was installation of *passive, large-capacity* suction strainers designed and manufactured by Enercon Services, Inc. The replacement strainers have a combined surface area of 6253 ft^2 (an increase of approximately 3700% compared with the old design). This very large strainer is located on the suppression-pool floor as shown in Fig. 1. It serves as a common header for all six ECCS pumps (RHR-A, RHR-B, RHR-C, HPCS, LPCS, RCIC) so that any combination of operating systems can draw recirculation water through the same large screen area.

The licensee estimated the maximum debris loading on the strainer following a postulated LOCA using methodologies discussed by the Boiling Water Reactors Owners' Group (BWROG) in the Utility Resolution Guidance (URG) document (Ref. 1). Estimates for quantities of insulation debris generated were evaluated using a modified version of URG Method 1 while maintaining its intent of conservatively bounding the amount of debris that may be generated. No credit was taken by the licensee for capture of debris in the drywell. The quantity of sludge used to size the strainer (500 lbm) was chosen to bound the estimated generation rate. The URG also was used to estimate quantities of other particulate debris, including qualified paint chips, foreign material, dust and dirt, rust from unpainted structures, and unqualified or indeterminate coatings. The FME program and the SPCP were implemented to limit the quantities of foreign materials (e.g., anticontamination clothing and plastic bags) and suppression pool sludge.

Because the replacement strainer serves as a common header, the limiting condition for operation is licensing-basis flow through all ECCS pumps. The strainer was sized to handle the licensing-basis flow. The strainer also was designed such that a sufficient net positive suction head (NPSH) margin exists to accommodate any uncertainties in the estimation of debris volume or head loss. Available NPSH was calculated conservatively assuming a wetwell pressure of 14.7 psia and a suppression pool temperature of 185°F.

1.2 Objectives

The focus of the Los Alamos review of supporting documentation was to identify any concerns relative to the licensee's strainer design criteria and strainer performance analyses. In particular, the review was to do the following.

- Evaluate how the licensee estimated the quantity of debris used for sizing the strainer
- Determine if the process used for selecting postulated breaks was consistent with the guidance in Regulatory Guide (RG) 1.82, Rev. 2
- Determine if the debris generation method used by the licensee was consistent with that of the URG and therefore provided reasonable estimates for drywell and wetwell debris transport

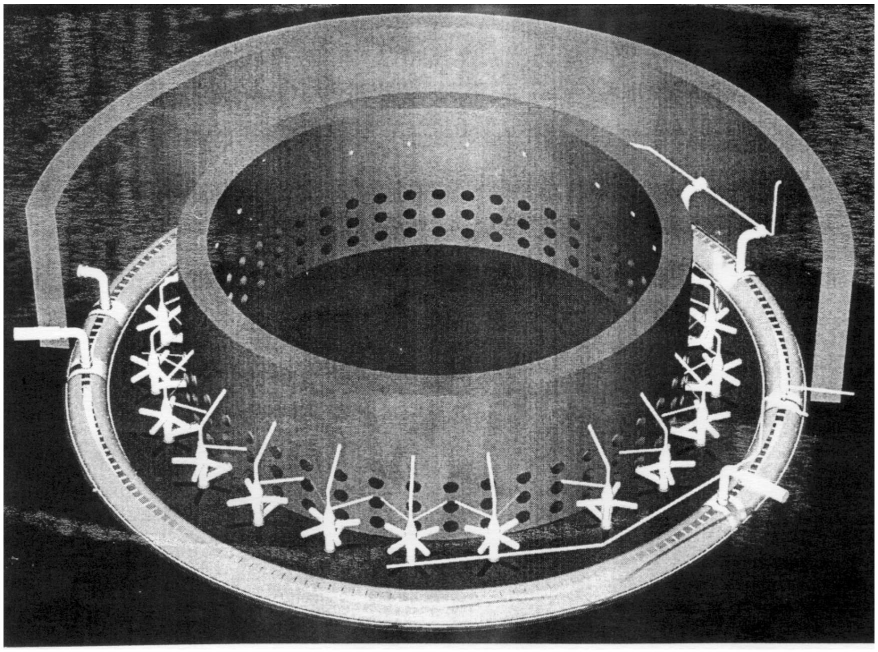

Figure 1. Annular arrangement of Grand Gulf ECCS strainer in Mark III containment. (Design drawing reproduced from licensee presentation.)

- Evaluate the licensee's strainer design criteria and strainer performance testing
- Examine if the licensee's rationale for scaling data from quarter-scale testing to the actual GGNS plant is appropriate

To achieve these objectives, Los Alamos performed three sets of analyses. The first set independently calculated the debris loading on the strainer using methods approved by the NRC. The second set of analyses (1) compiled information relevant to the Grand Gulf Unit 1 ECCS design and operation and (2) calculated clean-strainer head loss to determine available NPSH margin. The final set of analyses examined the application of quarter-scale testing to GGNS plant analyses. The following sections present and discuss the significant findings of these tasks.

1.3 Supporting Documents Reviewed During the On-Site Audit

Grand Gulf Nuclear Station, "Evaluation of Insulation Debris From HEPB," GGNS-94-0028, Rev. 0 (G/C Report 3030).

Grand Gulf Nuclear Station Unit 1, "Suppression Pool Strainer Surface Area and Approach Velocity Determination," MC-Q1M24-97027, Rev. 0 (October 1997).

Grand Gulf Nuclear Station Unit 1, "ECCS Suppression Pool Suction Strainer Head Loss Evaluation," MC-Q1M24-97014, Rev. 0 (November 1997).

Grand Gulf Nuclear Station Unit 1, "Perforated Plate Pressure Drops," MC-Q1M24-97015, Rev. 0.

Grand Gulf Nuclear Station Unit 1, “NPSH Calculations – RHR Pumps,” 1.1.1-Q, Supplement 1, Rev. 0 (November 1997).

Licensing Document Change Request 97-074, Attachment 60 to ER 97/0089-00-00, November 1997.

Grand Gulf Nuclear Station Unit 1, “Changes, Test or Experiments Safety Evaluation Form,” Attachment 3 to ER 97/0089-00-00, SE No. 97-0016-01 (August 1999).

Grand Gulf Nuclear Station Unit 1, “ECCS Pumps NPSH Calculation,” 1.1.53-Q, Supplement 1, Rev. 0 (November 1997).

Grand Gulf Nuclear Generating Station Unit 1, “NPSH Calculation – HPCS Pump (Q1E22C001),” MC-Q1E22-91124, Rev. 1 (November 1997).

Grand Gulf Nuclear Station Unit 1, “ECCS Pump Surveillance Criteria,” MC-Q1111-84016, Rev. 1 (September 1998).

Bechtel, “Mississippi Power and Light Company Grand Gulf Nuclear Station Units 1 and 2: NPSH Calculations – RHR Pumps,” Job #9645, Calc. # 1.1.1D (August 1980).

Bechtel, “Grand Gulf Nuclear Station Units 1 and 2 Strainer Data Sheet,” Appendix Q, Spfc. 9645-M-187.0, March 1977 (original strainer specification).

Bechtel, “Mississippi Power and Light Company Grand Gulf Nuclear Station Unit1: ECCS Pumps – NPSH Calculation,” Job #9645, Calc. # 1.1.53-Q, DCA #NPE-4-112 (May 1984).

Enercon Services, “ECCS Suction Strainer Testing: Test Flows and Strainer Locations,” Job #MT-102, Calc. #MT1-CALC-001, Rev. 1 (October 1996).

2.0 CONTRACTOR FINDINGS

2.1 Selection of Break Location

To estimate the debris loading on the replacement strainers, the licensee assumed that 50% of the nonmetallic insulation in the drywell would be affected by the limiting break. This assumption is similar to URG Method 1, which suggests that 100% of the inventory be considered within the zone of influence (ZOI). The licensee stated that this approach eliminates the need to select for analysis a specific break size and location by conservatively calculating a quantity of debris that bounds the maximum from any postulated break. Los Alamos confirmatory analyses have found that no single break could generate or transport half of the containment inventory of nonmetallic insulation. Hence, the Los Alamos staff concurs with the licensee approach and concludes that it very conservatively maximizes the quantity of insulation debris generated.

One of the recommendations of Regulatory Position 2.3.1.5 of RG 1.82, Rev. 2, is that the licensee should consider “the medium and large breaks with the largest potential particulate-to-insulation ratio by weight.” The primary reason for this regulatory position is to identify the potential for a thin layer of fiber to effectively filter particulates and induce high head losses, i.e., the “thin-bed effect,” which has been observed by the BWROG and the NRC in testing of cylindrical and truncated-cone strainers (Refs. 1 and 2). The licensee did not specifically address this issue in the documents provided for review. During the audit, the licensee stated the following.

- The GGNS strainer design is based on a debris loading that maximizes particulate debris (Cal-Sil and suppression-pool sludge) by weight. The only means by which one could arrive at a sludge-to-fiber ratio that is larger than the base case is if one were to hypothesize a break that generated the same quantity of Cal-Sil but a lower quantity of Kaowool. Earlier debris generation estimates had shown that to be physically impossible for large breaks because Kaowool and Cal-Sil are distributed fairly uniformly.
- Even if such a break occurred, the quantity of Kaowool would be so low that uniform deposition of debris on the strainer would not be possible because the strainer surface area ($\approx$ 6500 ft^2) is very large.
- Finally, the strainer design is such that sufficient operational margin ($\approx$ 10 ft-water) exists to incorporate any uncertainties.

To resolve the question of potential thin-bed effects, Los Alamos computed the distribution of particulate-to-fiber ratios for all postulated breaks (ranging from small to large breaks). Cal-Sil debris from each break and suppression-pool sludge contribute to particulate material, whereas Kaowool and fiberglass debris from breaks contribute to fiber material. In the Los Alamos analysis, Cal-Sil and fibrous debris transport estimates were obtained using URG Method 3 and combined transport factors as approved by the NRC Safety Evaluation Report (SER) (Ref. 1). Figure 7 shows the results of the Los Alamos independent analysis. This analysis clearly establishes that likely particulate-to-fiber ratios could be far in excess of those used in the licensee's design basis ($\approx$ 2.5). These large values are due mostly to the fact that Los Alamos calculations estimated considerably smaller quantities of fibrous debris (15 ft^3) transport compared with the licensee estimate (350 ft^3). The Los Alamos estimate of Cal-Sil debris transport (110 ft^3) is also smaller than the licensee's estimate (450 ft^3), but the magnitude of difference here is much smaller than that for fibrous debris. In spite of these differences, Los Alamos believes that the licensee's position on the thin-bed effect is acceptable because

1. The estimates for fibrous debris deposited on the strainer made by Los Alamos are very small. The theoretical fiber-bed thickness for 15 ft^3 deposited on a 6500-ft^2 strainer is 0.02 in. At such low loadings, uniform fiber beds are not expected to form, nor would they have the strength to filter out sludge particles.

2. Additional testing by the licensee using small-scale facilities has shown that even at conditions representative of the design basis (350 ft^3 of Kaowool on 6500 ft^2 of strainer), head loss is driven by thin-bed effects, i.e., head loss is driven mostly by the quantity of Cal-Sil insulation used in the test, not by the particulate-to-fiber ratio. Considering that the licensee maximized Cal-Sil volume in the design basis, it also maximized head loss.

<u>Based on the review, the Los Alamos staff concludes that the method used by the licensee to select a postulated break will bound the limiting break of interest, and it meets the intent of the guidance provided in RG 1.82, Rev. 2. The limiting break assumed by the licensee does maximize the estimated head loss across the strainer.</u>

2.2 Debris Generation

2.2.1 Licensee Analysis

GGNS uses Mirror™ RMI on most of the containment piping systems, so a large volume of RMI debris would be generated regardless of the postulated break location. The licensee screened out RMI from analysis because they considered RMI debris not transportable given the Mark III wetwell and strainer geometry. The licensee has quarter-scale testing data in support of their position. In those tests, the licensee dropped sizable quantities of RMI in the wetwell, but they found that it deposited preferentially on the sides of the strainer. Very few, if any, RMI pieces actually remained attached to the strainer surface. On this basis, the licensee concluded that RMI debris would not affect strainer head loss.

Los Alamos agrees with the licensee's rationale because their quarter-scale tests are prototypical and have shown that RMI would not accumulate on the strainer surface. Note that BWROG tests have shown that approach velocities higher than 0.2 ft/s would be needed to retain RMI fragments on the strainer surface. The approach velocities in the GGNS case are much lower ($\approx$ 0.02 ft/s).

GGNS also uses significant volumes (1600 ft^3) of nonmetallic insulation on the piping. Of that, the licensee estimates that approximately 900 ft^3 is Cal-Sil and 700 ft^3 is Kaowool. They assumed that 450 ft^3 of Cal-Sil and 350 ft^3 of Kaowool would be destroyed by the limiting break, i.e., 50% of the total inventory. This approach is similar in intent to the guidance provided in URG Method 1.

2.2.2 Los Alamos Analysis

Los Alamos used detailed spatial information provided by the licensee to conduct an independent assessment of debris generation and transport. The GGNS data base included approximately 730 possible break locations in high-energy pipes of different sizes and approximately 3100 cylindrical insulation targets. All potential break locations and debris combinations were examined systematically. This calculation maps spherical ZOIs at every postulated break location that are sized by the pipe diameter and by the damage pressure of each insulation type. In this regard, the Los Alamos analysis is analogous to URG Method 3, and it provides a somewhat more physical prediction of debris volume to confirm the safety margin inherent to the strainer design criteria.

The extensive licensee database of insulation inventories and potential high-energy pipe break (HEPB) locations is well-documented. The systems within containment that serve as HEPB sources and/or insulation targets are provided in Table 1. The GGNS database postulates breaks at every fitting, and conservatively assumes that every piping stress-analysis data point serves as a fitting as well. Approximately 730 potential HEPBs are located inside containment; most of these are located on the Reactor Water Clean-Up (RWCU) System. The postulated HEPBs are concentrated inside the drywell. However, breaks in the drywell head, the RWCU heat exchanger, the pipe chase, the filter demineralizer/backwash tank rooms, and the steam tunnel also are included in the database. Other areas of containment not mentioned here are free from potential HEPBs.

Approximately 3100 insulation target elements are included in the GGNS data base, including four pipe-whip restraints on the main steam lines in addition to the systems mentioned in Table 1. They conservatively included as insulation targets all small piping that is indicated as insulated on either form MS-02 or the specific piping isometric. Some conflicts in type and/or location were noted between these two references, but resolution was not required to preserve conservatism in the total inventory estimate.

Using spreadsheet tables of insulation targets provided by the licensee, Los Alamos analysts estimated the total containment insulation inventories listed in Table 2. As noted in this table, there are four types of nonmetallic insulation in the GGNS drywell.

1. Cal-Sil
2. Kaowool
3. K/C (a combination of Kaowool and Cal-Sil)
4. preformed fiberglass

Based on inspection, the licensee concluded that (1) K/C insulation is made up of 25% Kaowool and 75% Cal-Sil and (2) preformed fiberglass is essentially the same as Kaowool. Using such a partitioning, Los Alamos arrived at an estimate of 908 ft^3 of Cal-Sil material and 676 ft^3 of Kaowool. This estimate agrees well with the licensee's verbal estimate of 900 ft^3 of Cal-Sil and 700 ft^3 of Kaowool.

Table 1. High-Energy Pipe and/or Insulated Systems within the Grand Gulf Containment.

System	HEPB Source	Insulation Target
Electrical		X
Equipment		X
Heating and Ventilation		X
Recirculation (A/B)	X	Note 1
Recirculation Drain	X	X
Feedwater – Loop A	X	Note 1
Feedwater – Loop B	X	Note 1
Main Steam A/B/C/D	X	Note 1
Main Steam Drains	X	X
RX Head Vent to MS	X	X
LPCI A/B/C	X	X
RHR Suction	X	X
RX Head Spray	X	X
HPCS	X	X
LPCS	X	X
RCIC	X	X
RWCU	X	X
RWCU Filt/Demin	X	X Note 2
Fuel Pool C and CU		X
Standby Liq. Con.	X	X
Drywell Cooling		X
Cont. and DW Cooling		X
Comp. Cooling		X
Chilled Water		X
Dirty Radwaste		X

Note 1: Insulation is RMI. However, Kaowool convection seals may be used at the joints.
Note 2: Only two of these lines are insulated.

Table 2. Grand Gulf Total Containment Nonmetallic Insulation Inventory.

Insulation Type	Total Volume (ft^3)
Calcium-Silicate	309.7
Kaowool	315.5
K/C[1]	798.0
Preformed Fiberglass	161.3
Total	1584.5

[1]Denotes a possible combination of Kaowool and Cal-Sil in close proximity that could not be distinguished from each other.

Features of conservatism in the licensee database include the following.

- All insulation targets were modeled as cylindrical tubes wrapped in insulation. This includes equipment; electrical conduits; and heating, ventilating, and air conditioning (HVAC) ducts.
- Electrical conduits were modeled as cylinders 10 ft in diameter and 10 ft long centered on the best available location.
- One Kaowool convection seal (0.44 ft^3) on Mirror™ RMI was assumed to be a target for each HEPB to account for the possible presence of RMI joints within the ZOI.
- Additional lengths were added to equipment to account for insulation on the ends of the cylindrical approximation.

The Los Alamos analysis of many potential pipe breaks was automated by using a computer program written in the Matlab™ macro language. Electronic files of insulation (described by endpoint coordinates, insulation thickness, and pipe diameter) and break locations (described by coordinates and pipe diameter) were read into the program and evaluated for debris generation and transport. To obtain better resolution, every insulation target was interpolated into 1-ft-long or smaller segments. Every subsegment that lay within a spherical ZOI was included in the damage inventory for a given event. No credit was given for shielding by adjacent pipes or structures.

Further assumptions and approximations include the following. The Grand Gulf Unit 1 insulation-target data base contained many entries with nonzero insulation thickness that were designated as “bare” pipes. Most of these entries were for HVAC ducts and equipment such as heat exchangers and tanks that are not present inside the drywell; therefore, they were removed from the debris generation analysis. All entries for Mirror™ insulation also were removed, as were entries with zero insulation thickness. The process of removing bare and zero-thickness entries left only five or six objects with apparently rectangular dimensions. These included four pipe-whip restraints and some electric cable trays, but conservative cylindrical approximations were provided consistent with the licensee documentation. The Los Alamos analysis conservatively used the outside pipe diameter to scale the ZOI according to URG formulas. The URG damage pressures assumed for each insulation type are 40 psi for Kaowool, 160 psi for Cal-Sil, 40 psi for the indeterminant combination of K/C, and 10 psi for preformed fiberglass, which was assumed to have properties similar to jacketed NUKON. Finally, one convective-seal volume of Kaowool (0.44 ft^3) was added to each break.

Figures 2 and 3 show a perspective and a plan view, respectively, of all pipes insulated with nonmetallic insulation. Pipes are shown in yellow; blue dots denote potential break locations; red dots denote insulation-target center points; and red lines provide visual references for the drywell radius (36.5 ft) at the elevation of the suppression pool (93 ft), the lowest grating (114.5 ft), an operations platform (121 ft), and the roof (170 ft). One potential ZOI is shown in magenta to show the large volume that can affect material with a 10-psi damage pressure. Note that many of the break locations reside in large RMI-insulated pipes that are not shown in these figures. Also, recall that the licensee postulated HEPB in areas outside of the drywell, so piping systems may extend beyond the drywell radius shown in the figures.

All 730 break locations were evaluated for debris generation and transport. Figure 4 shows that most of the break locations fall in smaller pipes of less than 0.5-ft diameter, so it is not surprising that the distribution of total debris volume for all possible breaks also is skewed to low values less than 10 ft^3 (see Fig. 5). Almost half of these pipe breaks are too small to generate any nonmetallic debris other than a possible convective seal. The single largest event is capable of generating 167.5 ft^3 of total debris, which includes 13.2 ft^3 of Kaowool, 2.9 ft^3 of preformed fiberglass, and 113.4 ft^3 of Cal-Sil. (Here 150.2 ft^3 of mixed K/C has been partitioned as 75% Cal-Sil and 25% Kaowool.) This is also the single event that generates the most Cal-Sil debris, but other individual events are capable of generating maximum debris inventories of 70.5 ft^3 of Kaowool and 18.3 ft^3 of fiberglass.

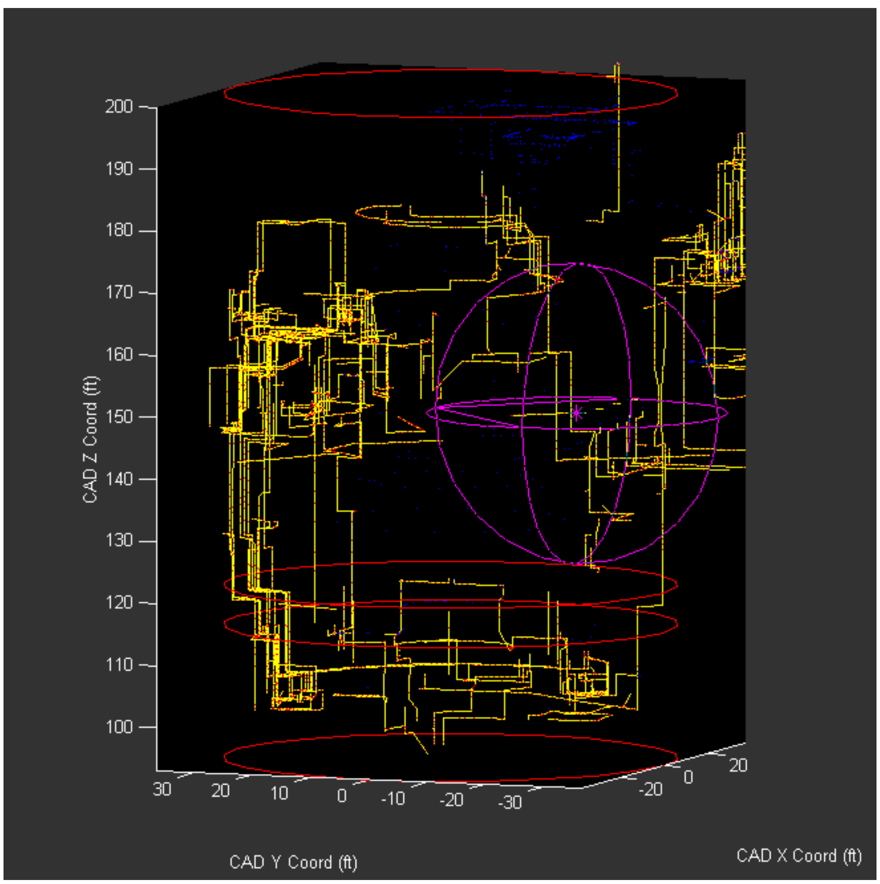

Fig. 2. Perspective view of piping with nonmetallic insulation (yellow) and postulated ZOI (magenta) within Mark III containment drywell (red).

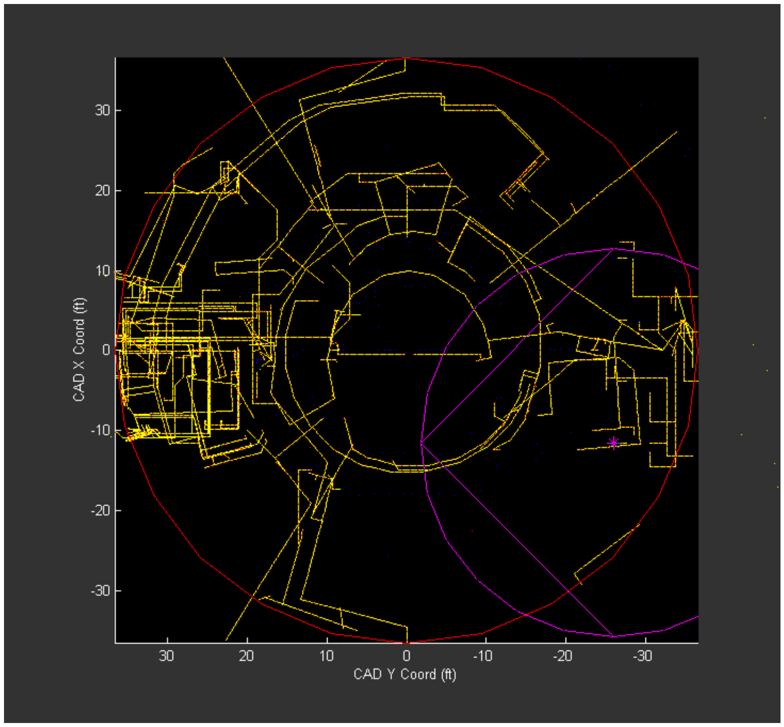

Fig. 3. Plan view of piping with nonmetallic insulation (yellow) and postulated ZOI (magenta) within Mark III containment drywell (red).

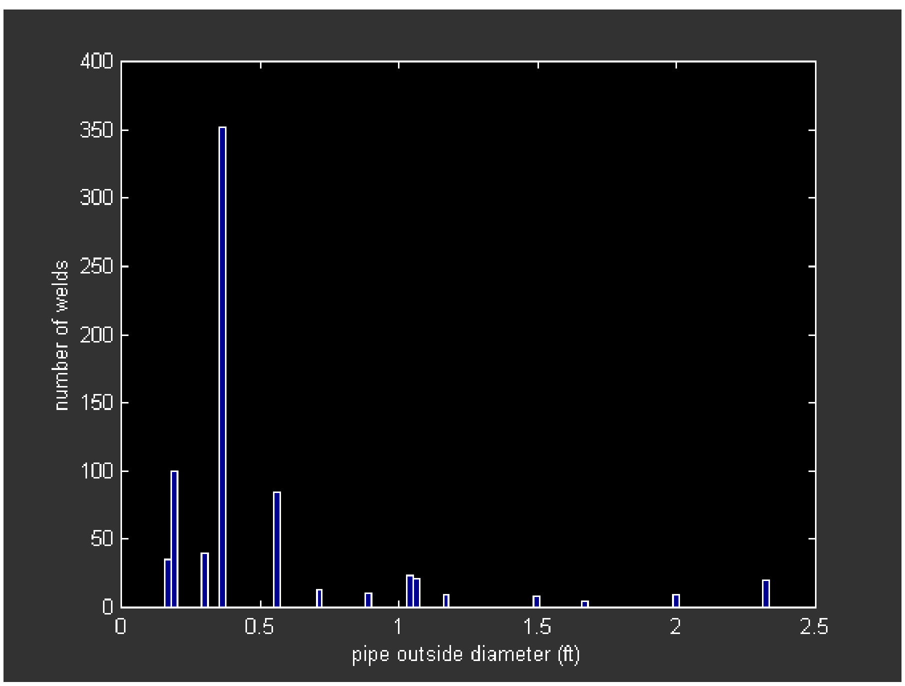

Fig. 4. Distribution of postulated pipe breaks by piping diameter.

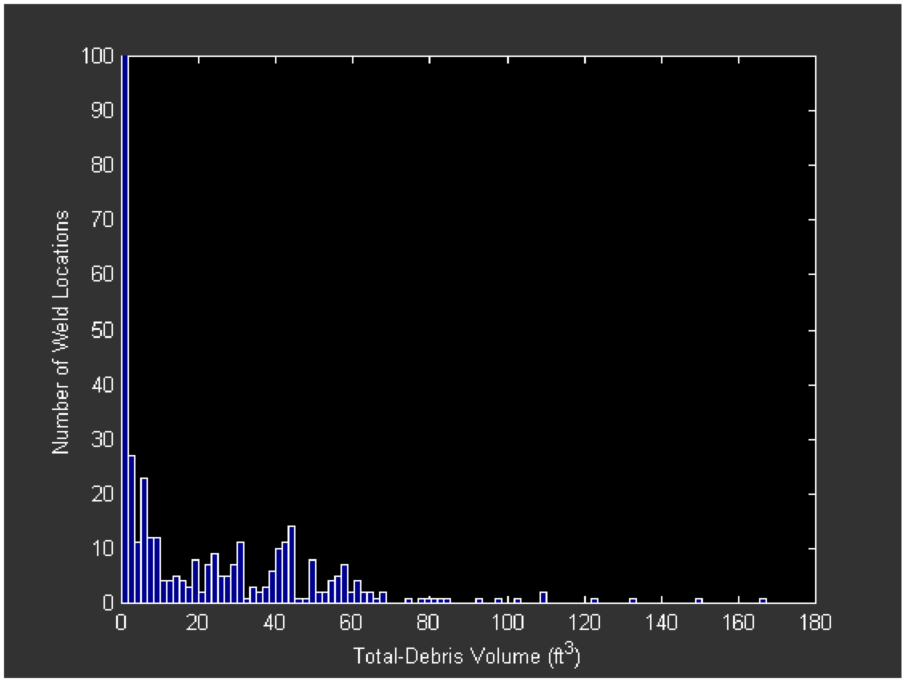

Fig. 5. Distribution of postulated pipe breaks by the total insulation debris that they generate.

The Los Alamos estimate of the largest debris volume generation is approximately 5 times lower than that assumed by the licensee. Based on independent verification using a detailed, physically defensible approach, Los Alamos concludes that the licensee estimate of debris used to size the strainers (50% of total nonmetallic inventory) is conservative and meets the intent of RG 1.82, Rev. 2, and the NRC Safety Evaluation Report (SER) on the URG (URG SER).

2.3 Debris Transport

GGNS used a nonmetallic-debris transport factor of 1.0 for drywell transport. This assumption is conservative compared with the URG. Los Alamos applied the URG-recommended drywell transport factors of 0.78 for Kaowool debris generated below the level of the lowest grating and 0.28 for Kaowool debris generated above the level of the lowest grating. A drywell transport factor of 1.0 was used for Cal-Sil debris regardless of its location. Both analyses assumed a suppression-pool (wetwell) transport factor of 1.0.

Figure 6 shows that grating is effective at reducing the volume transported to the suppression pool. In comparison with Fig. 5, the distribution has shifted to much lower debris volumes. The break transporting the largest total volume (128.9 ft^3) to the wetwell included 14.7 ft^3 of Kaowool, 113.4 ft^3 of Cal-Sil, and 0.8 ft^3 fiberglass. Thus, the strainer must accommodate 15.5 ft^3 of fiber and 113.4 ft^3 of Cal-Sil from the break in addition to any other material already present in the pool. There is no reason why the event that leads to the highest transport must correspond to the event that generates the maximum volume of debris, but in this case, they are the same.

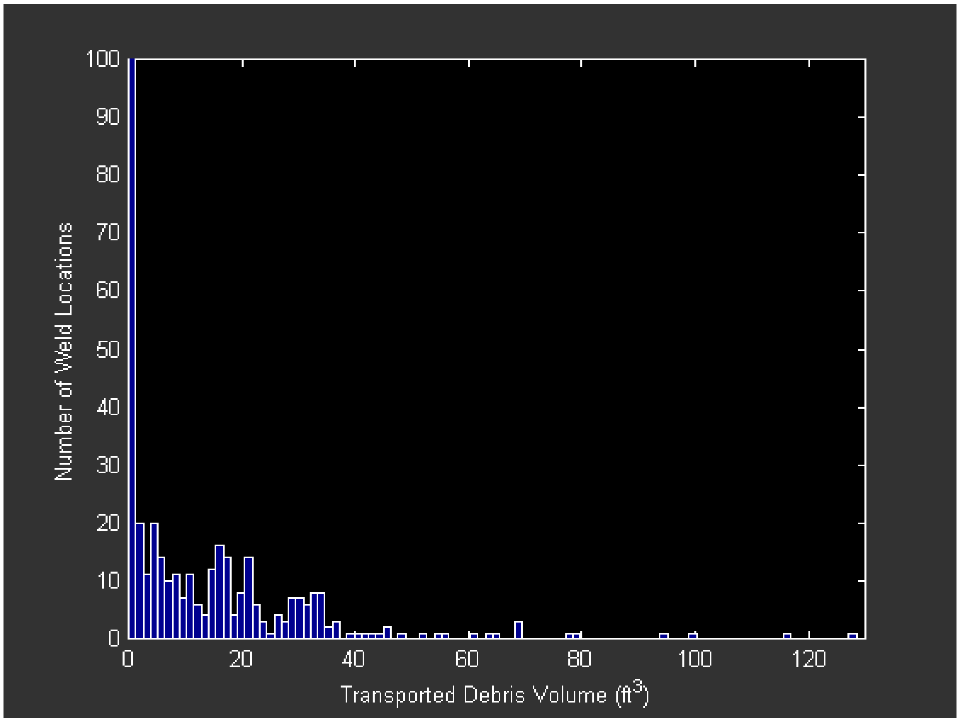

Fig. 6. Distribution of postulated pipe breaks by the amount of debris transported to the ECCS strainer.

Figure 7 shows the particulate-to-fiber mass ratios for the debris estimated to reach the suppression pool. The particulate debris consists of Cal-Sil and sludge. The fibrous debris consists of Kaowool. The boundary volume for this ratio for large breaks is about 16, which corresponds to a Kaowool volume of 15.5 ft^3, a Cal-Sil volume of 113 ft^3, and a sludge mass of 512 lbm. The maximum particulate-to-fiber ratio can be much larger for some extreme cases (small breaks) where the expected quantities of fibrous debris are very small. These estimates reflect the effect of the following conservative assumption: the volume of Cal-Sil reaching the strainer was estimated using a drywell transport factor of 1.0. Most likely, not all Cal-Sil generated in the drywell would be transported to the strainer.

Los Alamos analysts conclude that the licensee assumptions for debris transport were conservative and that they bound estimates obtained using URG Method 2. This method is also conservative and was approved by NRC.

2.4. Debris Loading on the Strainer

Table 3 compares the debris loading used by the licensee for the strainer design basis with the independent Los Alamos estimate. The licensee debris loading of 50% of the plant inventory of Cal-Sil (450 ft^3) and Kaowool (350 ft^3) is judged to be very conservative. This comparison highlights the magnitude of conservatism in the licensee strainer design.

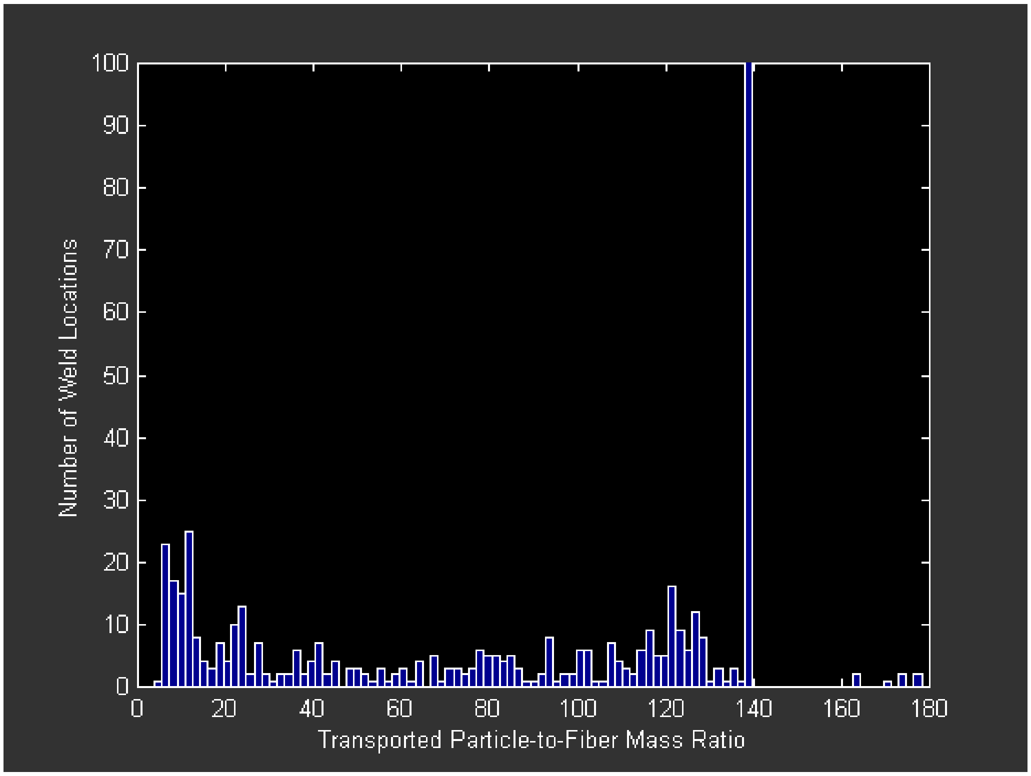

Fig. 7. Distribution of postulated pipe breaks by the mass ratio of particulate and fiber debris transported to the ECCS strainer.

Table 3. Comparison of Strainer Debris Loading Estimates.

	Debris Quantity		
Debris Type	**GGNS**	**Los Alamos**	**Comment**
Kaowool and Fiberglass	350 ft^3	15.5 ft^3	Los Alamos Method 2, Licensee Method 1
Cal-Sil	450 ft^3	113.4 ft^3	Los Alamos Method 2, Licensee Method 1
Sludge (black oxide)	512 lbm	512 lbm	GGNS Survey + 3 cycles
Rust	50 lbm	50 lbm	BWROG URG
Paint	624 lbm	624 lbm	GGNS Unqualified Paint
Adhesive Labels	9 ft^2	9 ft^2	GGNS FME
Duct Tape	0.3 ft^2	0.3 ft^2	GGNS FME
Tie Wraps	17.2 ft^2	17.2 ft^2	GGNS FME
Plastic Tags	32	32	GGNS FME
Fe_2O_3	150 lbm	150 lbm	BWROG URG

Los Alamos believes that the debris loading and the licensee's rationale for its use in sizing the strainer are conservative. Such a conservative approach provides assurance that uncertainties in estimation of any individual debris species will not invalidate the overall design. For example, this margin probably will be sufficient to accommodate any findings from the coatings/paints study.

2.5 Strainer-Design Considerations

2.5.1. ECCS Operating Parameters

The Grand Gulf Unit 1 ECCS consists of the following: (a) three pumps in the low-pressure core injection (LPCI) system [Residual heat removal (RHR) -A, -B, and –C], each pump with a runout flow of 8940 gal./min; (b) one train of the low-pressure core spray (LPCS) system with a runout flow of 9100 gal./min; (c) one train of the high-pressure core spray (HPCS) system with a runout flow of 8175 gal./min; and (d) one train of the reactor core isolation cooling (RCIC) system with a rated flow of 800 gal./min (see Table 4). These systems take suction from the replacement strainer at different azimuthal locations.

For the GGNS, the limiting case for ECCS operation is assumed to be continuous operation of all ECCS components at runout flow. This is the licensing-basis case analyzed by the licensee. The total licensing basis ECCS flow is 44,895 gal/min. Many licensees take credit for (a) the design flow of the ECCS pumps being lower than the runout flow and (b) the operators ability to throttle the ECCS pumps to flows even lower than the design flow. By not crediting any of these factors, GGNS is very conservative.

Table 4. GGNS ECCS Licensing-Basis Flow (Long-Term).

System	Condition	Flow (gal./min)
RHR-A	Runout	8940
RHR-B	Runout	8940
RHR-C	Runout	8940
HPCS	Runout	8175
LPCS	Runout	9100
RCIC	Design	800
Total	Licensing basis	44,895

Based on our review, Los Alamos agrees with the licensee's choice of the limiting condition for ECCS operation. Los Alamos recognizes that the licensee's choice to use runout flow in the design and performance assessment of the strainers is conservative and voluntary.

2.5.2. Licensee $NPSH_{Margin}$ Estimates

The licensee committed to follow NRC regulatory guidance provided in NRC RG 1.1. RG 1.1 recommends that the licensee use maximum credible wetwell temperature and no containment overpressure while estimating $NPSH_{Margin}$. In the past (i.e., pre-NRC 96-03 ECCS configuration) to be conservative, the licensee assumed that the suppression pool would reach a temperature of 212°F, which is the saturation temperature at a pressure of 14.7 psia. The licensee recognized that this assumption is "most conservative" and not necessary because the Updated Final Safety Analysis Report bounding analyses showed that the limiting suppression-pool temperature would not exceed 185°F. The licensee's Safety Evaluation Report provided a detailed description of the rationale for lowering the suppression-pool temperature to 185°F. On this basis, the licensee revised its NPSH calculations to reflect the lower pool temperature[4] and lower atmospheric drywell pressure.

The $NPSH_{margin}$ for each ECCS pump was estimated using

$$NPSH_{margin} = (P_{wetwell} - P_{vp})(144/\rho) + \Delta H_{static} - \Delta H_{Line\text{-}losses} - \Delta H_{strainer} - NPSH_{required} \ ,$$

where

$P_{wetwell}$ = containment pressure in the wetwell (14.7 psia),
P_{vp} = vapor pressure of water at reference temperature (psia),
ρ = density of water at reference temperature (lbm/ft^3),
ΔH_{static} = water height above reference point[5] (ft-water),
$\Delta H_{Line\text{-}losses}$ = frictional losses in the piping connecting strainer to pump (ft-water),
$NPSH_{required}$ = NPSH required at the reference point (ft-water),
$\Delta H_{strainer}$ = head loss across the strainer (ft-water).

The parameters used in the Los Alamos independent analyses are listed in Table 5. These values were derived from the licensee calculation documents. The last column of Table 5 shows the $NPSH_{margin}$ available for each pump. This is the operational margin.

Table 5. Parameters Used in the Licensee GGNS $NPSH_{Margin}$ Calculations

System # pump	Flow Rate (gal./min)	$NPSH_{req}$ ($ft\text{-}H_2O$)	ΔH_{static} ($ft\text{-}H_2O$)	ΔH_{Line} ($ft\text{-}H_2O$)	P_{vp} ($ft\text{-}H_2O$)	$\Delta H_{strainer}$ ($ft\text{-}H_2O$)	$NPSH_{Margin}$ ($ft\text{-}H_2O$)
RHR-A	8,940	2.0	12.1	3.92	19.58	**XXXXX**	10.1
RHR-B	8,940	2.0	12.1	4.29	19.58	**XXXXX**	10.1
RHR-C	8,940	2.0	12.1	4.18	19.58	**XXXXX**	6.1
HPCS	8,175	2.0	12.1	3.48	19.58	**XXXXX**	9.4
LPCS	9,100	1.6	12.1	3.09	19.58	**XXXXX**	9.1

Based on the review, Los Alamos concludes that the licensee followed a logical process for estimating $NPSH_{margin}$. Other conclusions are listed below.

- Los Alamos performed several spot-checks to examine the accuracy of the licensee estimates of line losses (ΔH_{Line}). In all cases, Los Alamos estimates for ΔH_{Line} are slightly lower (10%-15%) than the licensee estimates. It is likely that the licensee estimated fouling of the piping using a more conservative representation than that applied by Los Alamos.
- Los Alamos believes that the licensee's use of 185°F as a water temperature is reasonable and appears to be consistent with the plant licensing basis. The licensee's decision not to credit containment over-pressure is conservative.

[4]The licensee used 185°F to estimate the liquid vapor pressure only. The licensee estimated all strainer head losses (including those by debris) at 75°F. This approach is very conservative.
[5]The reference elevation at which GGNS ECCS $NPSH_{required}$ was estimated was at point 3 ft above the pump flange.

- Los Alamos agrees with the licensee's approach for handling possible uncertainties in the suppression-pool height as a result of drawdown by the ECCS pumps. The licensee also carried out a separate calculation that examined the effect of a lower suppression-pool temperature (125^{o}F vs 185^{o}F) and a lower pool height (9.7 ft vs 12.1 ft). As expected, the limiting case corresponds to 185^{o}F.

The following sections summarize how the licensee estimated $\Delta H_{strainer}$ in Table 5.

<u>2.5.3 Strainer Design Criteria and Geometrical Description</u>

The utility's solution to potential strainer blockage was to replace truncated cone strainers with a single large passive strainer. The objectives of the strainer design were as follows.

- Accommodation of 100% of the fiber, particulate, and miscellaneous-debris drywell inventories without affecting ECCS operability, i.e., $NPSH_{Margin}$ greater than zero
- Independence of the ECCS function groups so that loss of one does not affect the effective strainer area
- Connection of the RCIC to the strainer without affecting head loss
- Design, fabrication, and installation costs comparable with other replacement options

After exploring several strainer designs, GGNS settled on a single, shared, large-capacity, passive strainer. The plate of the replacement strainer is constructed of 14-gauge steel plate with 3/32-in. hole diameters spaced on 5/32-in. centers.

This strainer is constructed of 51 segments that are arranged in a contiguous circle in the Mark III suppression pool as shown in Figure 1. These segments can be divided broadly into 10 types (Types A through J), mainly based on their geometrical detail. Table 6 provides a list of the various segments used and their respective surface areas. Figure 8 presents a photograph of a Type-A segment, which make up about 85% of the total strainer surface area. The strainer has the following salient features.

- Although the strainer is located on the suppression floor, a significant portion of the strainer surface is vertical. (See Figure 8.) Coupled with very small approach velocities, this design allows for sedimentation of heavy debris.
- The strainer allows for traps where debris can settle out. This reduces the potential for buildup of uniform debris beds. This feature has been shown to result in lower head losses from nonuniform debris buildup and bypass flow.

The suction lines of the RHR-A, RHR-B, RHR-C, HPCS, and LPCS are connected to the strainer at azimuthal angles of 30, 330, 190, 310 and 170 degrees, respectively. This mode of connection forms three natural divisions. In reality, these divisions are interconnected, but when all ECCS trains are operating at the runout flow, interdivisional flow is expected to be negligible. Therefore, one could interpret these divisions as being similar to separate strainers. The net surface area for flow is between 5852 and 6253 ft^2. There is some difference between the Los Alamos estimate of 5852 ft^2 and the licensee estimate of 6253 ft^2. This difference is of minor significance and is probably a reflection of the fact that Los Alamos relied on engineering drawings, whereas the licensee estimates are based on CAD analyses.

It is important to note that the new strainer represents a substantial increase (3700%) in the strainer area from the pre-NRCB 96-03 design. This extremely large plate area acts to reduce the approach velocity to a design value of about 0.016 ft/s.

Table 6. Grand Gulf Replacement Strainer Areas Given by Segment Type.

Segment Type	Quantity	Area/Segment (ft^2)	Total Area (ft^2)
A	38	130	4940
B	4	64	256
C	1	93	93
D	1	77	77
E	1	117	117
F	1	110	110
G	1	63	63
H	1	105	105
I	1	91	91
J	2	50	100
Total	**51**		**5852**

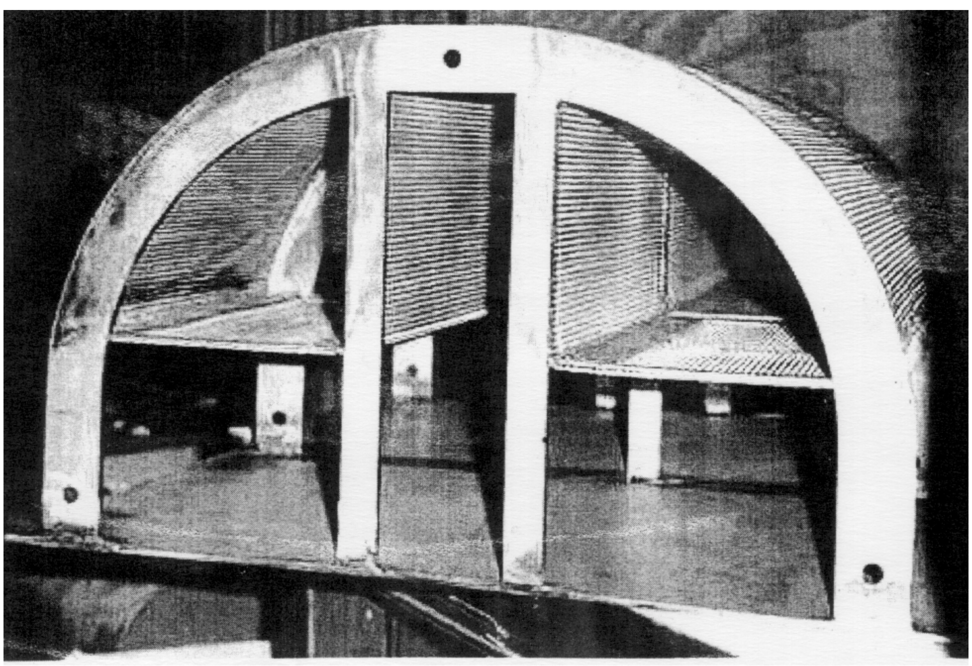

Figure 8. Prototypical section of the Grand Gulf ECCS suction strainer. (Photograph reproduced from licensee presentation).

2.5.4 Strainer Qualification Testing

Mark III containment owners sponsored a combined research program to study the head-loss performance of the replacement strainer.[6] A quarter-scale strainer was built and installed in the Mark III quarter-scale test facility. Table 7 compares quarter-scale geometric and operational parameter values with the GGNS plant values. This comparison clearly establishes that the quarter-scale testing adequately simulated important flow parameters. In particular, the licensee ensured that (a) the approach velocity at the strainer surface is the same as the approach velocity in the plant and (b) the debris loadings per unit area of the strainer in the tests are the same or greater than those expected in a real plant. By monitoring the same flow velocity and debris-bed thickness, the tests ensured that measured head loss caused by debris buildup can be used directly in the licensee NPSH analysis. The comparison also shows that the strainer tested is actually a 1/5-scale representation rather than 1/4-scale as indicated by the name. (It is 1/4 scale for some other Mark III containments but not for GGNS.)

There are two geometrical differences between the quarter-scale test setup and the plant: (1) the quarter-scale tests use a significantly lower number of strainer sections compared with the plant and (2) the construction of these strainer segments is different (for example, the number of ribs used in the quarter-scale tests is lower and the plate thickness is different). These differences mean that clean-strainer head losses measured in the quarter-scale test setup are not directly scalable to the GGNS plant application. The licensee performed very detailed analyses to “correct” for these differences, and Los Alamos reviewed their results.

There is one major difference in the operating parameters. All tests were conducted at 75°F compared with the expected wetwell temperature of 185°F. The licensee used the results directly in the $NPSH_{Margin}$ evaluation. This is conservative because, due to viscous effects, low temperatures are known to result in higher head loss.

The licensee sponsored a total of five tests that are specifically applicable to GGNS. Table 8 presents the experimental parameters investigated in each of these tests. The objectives and results of these tests can be summarized as follows. Test G-0.1 was designed to measure the clean-strainer head loss for the quarter-scale geometry. The measured head losses were about 3 in. of water at the conditions representing runout ECCS flow. The licensee recognized that these head losses were specific to the quarter-scale geometry and scaled (or corrected) them to account for geometrical differences between the test geometry and the real strainer. The licensee analyses showed, after correction for these differences, that the full-scale, clean-strainer head loss might be as high as 4 ft of water.

Licensee tests G-5A, G-6, G-6/SPC, and G-7 used a debris loading of 175 lbm of Kaowool, 337.5 lbm of Cal-Sil, 32 lbm of sludge, and additional quantities of miscellaneous debris (e.g., rust, paint, adhesive labels). For the real plant, this corresponds to debris volumes significantly larger than the licensing-basis debris loading listed in Table 3.[7] The licensee conducted an additional test (G-5) in which they added 175 lbm of Kaowool and 675 lbm of Cal-Sil to the suppression pool and measured the resulting head loss. This case corresponds to 100% of the

[6]The same strainer also is being used by two other Mark III owners, Clinton and Perry. River Bend, which is another sponsor of the strainer testing, decided to install GE strainers instead.

[7]The licensee actually intended to match the Table 3 values and determined the test loads by dividing the Table 3 values by 16. However, the actual test strainer was 27 times smaller, not 16 as suggested by “quarter-scale” geometry. As a result, the tests resulted in significantly larger bed buildup than expected for the real strainer.

Table 7. Comparison of 1/4-Scale Test Parameters with GGNS Plant Values.

Parameter	1/4-Scale Facility	Plant Value	Comments
Temperature	75°F	185°F	Makes measured ΔH conservative
Strainer Geometric Details			
Division 1 Details			
Number of Section	13	34	
Area of Section (ft^2)	7.35	69.49	
Total Area (ft^2)	95.6	2571	
Division Flow (gal./min)	671	18,040	RHR-A and LPCS runout flow
Flow Velocity (ft/s)	0.01563	0.01563	Velocities are same in both cases
Division 2 Details			
Number of Section	18 (10 +08)	53 (34+19)	Tests and plant use outside and whole sections
Area of Section (ft^2)	3.78; 7.35	35.7; 69.5	
Total Area (ft^2)	96.6	2534.5	
Division Flow (gal./min)	713	18, 705	RHR-B, RHR-C, and RCIC runout flow
Flow Velocity (ft/s)	0.01644	0.01644	Velocities are same in both cases
Division 3 Details			
Number of Section	10	34	
Area of Section (ft^2)	3.57	33.78	
Total Area (ft^2)	35.7	1148.5	
Division Flow (gal./min)	255	8,175	HPCS runout flow; used in all tests
Flow Velocity (ft/s)	0.01586	0.01586	Velocities are same in both cases
Debris Loads (Used and Scaled)			
Kaowool (lbm/ft^3)	175 lb	600 ft^3	Plant = 175 x 27.43[8] (A_{plant}/A_{test})/8.4 (den[9])
Cal-Sil (lbm/ft^3)	338 lb	713 ft^3	Plant = 338 x 27.43 (A_{plant}/A_{test})/13 (den)
Sludge (lbm)	32	864	Plant = 32 x 27.43
Rust (lbm)	3.13	85	Plant = 3.13 x 27.43
Paint (lbm)	39	1070	Plant = 39 x 27.43
Adhesive Labels (ft^2)	0.54	14.81	Plant = 0.54 x 27.43
Duct Tape (ft^2)	0.019	0.52	Plant = 0.019 x 27.43
Tie Wraps (ft^2)	1.075	29.5	Plant = 1.075 x 27.43
Plastic Tags (#)	2	55	Plant = 2 x 27.43
Fe_2O_3 (lbm)	9.38	257	Plant = 9.38 x 27.43
Black Oxide (lbm)	32	878	Plant = 32 x 27.43

[8] The strainer surface-area ratio is 27.43, indicating that the facility is close to 1/5-scale.
[9] The material densities of Kaowool and Cal-Sil are 8.4 lbm/ft^3 and 13 lbm/ft^3.

Table 8. Quarter-Scale Test Data for GGNS Strainer at Different Debris Loads.

TEST ID / Test Description	Head Loss Measured for Pump (inch-water)				
	LPCI-A	LPCS	LPCI-B	LPCI-C	HPCS
G-0.1 (No Debris Loading; Clean Strainer Head Losses)					
5 ECCS at Low Flow[10]	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX
Loose Division 1	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX
Loose Division 2	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX
Division 1 Only	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX
Five ECCS @ High Flow	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX
G-5 (Kaowool: 350 lb, Cal-Sil: 675 lb, Sludge: 32 lb)					
5 ECCS at Low Flow	XXXXX	XXXXX	XXXXX	XXXXX	XXXXXX
Loose Division 1	XXXXX	XXXXX	XXXXX	XXXXX	XXXXXX
Loose Division 2	XXXXX	XXXXX	XXXXX	XXXXX	XXXXXX
Division 1 Only	XXXXX	XXXXX	XXXXX	XXXXX	XXXXXX
Five ECCS @ High Flow	This test was not done because plexiglass suction broke				
G-5A (Kaowool: 175 lb, Cal-Sil: 338 lb, Sludge: 32 lb)					
5 ECCS at Low Flow	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX
Loose Division 1	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX
Loose Division 2	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX
Division 1 Only	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX
Five ECCS @ High Flow	This test was not done because plexiglass suction broke				
G-6 (Kaowool: 175 lb, Cal-Sil: 338 lb, Sludge: 32 lb, Recipe: Per Table 7)					
5 ECCS at Low Flow	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX
Loose Division 1	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX
Loose Division 2	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX
Division 1 Only	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX
Five ECCS @ High Flow	This test was not done because plexiglass suction broke				
G-6/SPC (Kaowool: 175 lb, Cal-Sil: 338 lb, Sludge: 32 lb, Recipe: Per Table 7)					
B - SPC / 4 ECCS	XXXXX	XXXXX	XXXXX	XXXXX	XXXXXX
B – SPC / RHR C and HPCS	XXXXX	XXXXX	XXXXX	XXXXX	XXXXXX
A – SPC/ LPCS, HPCS	XXXXX	XXXXX	XXXXX	XXXXX	XXXXXX
A – SPC / LPCS	XXXXX	XXXXX	XXXXX	XXXXX	XXXXXX
G-7 (Kaowool: 175 lb, Cal-Sil: 338 lb, Sludge: 32 lb)					
5 ECCS at Low Flow	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX

[10] Low flow corresponds to runout flow: net flow of 44,895 gal./min. High flow is a nonprototypical flow for the purpose of testing only.

drywell inventory. The licensee did not use data from test G-5 in the licensing basis calculations. The licensee stated that this test was done purely to demonstrate that the strainer can accommodate significantly larger quantities of debris than those listed in Table 3.

In tests G-5A, G-6, and G-7, the debris was first added to the suppression pool, and then licensing-basis ECCS flow (scaled to quarter-scale) was established through all five trains. These tests simulated regular operation of ECCS in that they took suction from the suppression pool and delivered the flow upstream of the vent pipes. This configuration allowed for the flow to enter the suppression pool through vent pipes, as expected following a DBA. After head loss reached steady state, the ECCS pumps attached to Division 1 (RHR-A and LPCS) were turned off, and the resulting head loss was measured. Next, pumps attached to Division 2 (RHR-B and RHR-C) were turned off, and the head loss corresponding to Division 1 and 3 flows was measured. The final configuration allowed flow through pumps attached to Division 1 only and the head loss was measured. In these tests, the maximum head losses measured were for Test G7.

In Test G-6/SPC, the ECCS was configured to operate in suppression pool cooling mode. In this case, the ECCS pumps delivered flow through suppression pool cooling return lines, which induced intense turbulent mixing of the suppression pool water and debris. Based on visual examinations, the licensee noted that there was little (if any) debris sedimentation in this configuration. As a result, the measured head losses corresponding to G-6/SPC were markedly higher than those measured in any of the other tests.

Table 8 provides the head-loss data measured in each test. Based on the review of the testing program and its results, Los Alamos' conclusions are as follows.

- The licensee's test program is extensive. Good attention to detail was shown by the licensee. It also should be noted that the licensee is continuing some of the tests to better understand the head-loss implications of Cal-Sil insulation debris.
- The data repeatability is acceptable. For example, variations in head losses measured between G-5A, G-6 and G-7 are less than 2 ft-water. The plant has sufficient margin to account for these uncertainties.
- The head-loss tests indicate that some of the tests might not have reached steady state before termination. The licensee accounted for this apparent shortcoming by extrapolating to a steady value.
- Cal-Sil and Kaowool combinations result in high head losses, even though the approach velocity is very small (0.016 ft/s). This finding is significant because such data were previously not available.

In Los Alamos' opinion, the licensee adequately simulated the strainer performance. Use of these data in ECCS strainer NPSH analyses is appropriate.

2.5.5 Licensee Use of Test Data in the NPSH Evaluations

The licensee used the test data to estimate (a) head loss induced by flow through the clean strainer and (b) strainer head loss as a result of debris bed buildup. The licensee did not use the test data directly because the licensee recognized that there is some nonprototypicity involved in the quarter-scale testing. Additional steps were undertaken by the licensee to "correct" for these differences between quarter-scale geometry and the strainer installed in the plant. The "corrected" data used by the licensee are given in Table 9. The scaling analyses (or correction) performed by the licensee and their results are as follows.

Table 9. Application of Test Data in the Licensee NPSH Calculations.

System	Flow (gal./ min))	$\Delta H_{Clean\text{-}Str}$ (in.-H_2O)	Test Data $\Delta H_{Debris\text{-}Max}$ (in.-H_2O)	Extrapolated $\Delta H_{Debris\text{-}Max}$ (in.-H_2O)	Design $\Delta H_{strainer}$ (in.-H_2O)	Design $\Delta H_{strainer}$ (ft-H_2O)
HPCS	8175	**XXXXX**	**XXXXX**	**XXXXX**	**XXXXX**	**XXXXX**
LPCS	9100	**XXXXX**	**XXXXX**	**XXXXX**	**XXXXX**	**XXXXX**
RHR-A	8940	**XXXXX**	**XXXXX**	**XXXXX**	**XXXXX**	**XXXXX**
RHR-B	8940	**XXXXX**	**XXXXX**	**XXXXX**	**XXXXX**	**XXXXX**
RHR-C	8940	**XXXXX**	**XXXXX**	**XXXXX**	**XXXXX**	**XXXXX**

- The licensee noted that clean-strainer head losses must be corrected to account for differences between the quarter-scale geometry and the real strainer. Important differences between the quarter-scale tests and the plant geometry are (a) the quarter-scale tests use a significantly smaller number of strainer sections, (b) the number of ribs used to construct strainer model is lower than the actual number of ribs used in the plant strainer, and (c) the strainer plate thickness is different. The licensee performed various analyses to conservatively estimate clean-strainer head losses. The corrected range is shown in Column 3 of Table 9. The licensee stated that the actual head losses were measured after installing the strainer and were shown to have been bounded by the correction values given in Table 9.
- The licensee used the test data to estimate increase in head loss as a result of debris buildup. For this purpose, the licensee identified the maximum head loss measured for each pump. They were listed in Column 4 of Table 9. These head losses did not necessarily correspond to a single test configuration. For example, in the case of HPCS, the maximum head loss occurred in Test G-6/SPC (B-SPC/RHR-C&HPCS). This value is shown bold and boxed in Table 8. For other pumps, the maximum head loss occurred in Test G-6/SPC (B-SPC/4 ECCS).
- The licensee observed that some of the head-loss traces might not have reached steady state even after several hours of continuous operation. To eliminate potential errors, the licensee extrapolated measured head losses to obtain steady values. In many cases, the difference is only a few inches-water. Column 5 of Table 9 has the extrapolated head losses.
- The final values, which are sums of Columns 3 and 5, are shown in Columns 6 and 7. These values were used in the licensing basis $NPSH_{margin}$ estimates.

Based on the review and on independent calculations, Los Alamos believes that the licensee estimates of strainer head loss are conservative as follows.

- The head-loss measurements were made at 75°F, compared with an anticipated suppression pool temperature of 185°F. This means that measured head loss is higher than the head losses anticipated following a DBA. The licensee could have performed analyses to take credit for this difference as recommended by the URG. The licensee decision not to take credit for this introduced voluntary conservatism.
- The bounding head loss measured by the licensee occurred for the case when the entire ECCS was operated in the suppression pool cooling mode (G-6/SPC). Apparently, it is because the Suppression Pool Cooling (SPC) System induced turbulent mixing of the

debris and water and did not allow for any settling. Considering that the SPC mode is not expected to be operated until late in the accident, the licensee could have used the head loss measured for other ECCS operational configurations. As shown in Table 8, all other configurations resulted in markedly lower head losses. The licensee's decision to use bounding head-loss measurements is conservative.

- The debris loading used by the licensee is very conservative. As discussed in the previous sections, the Table 3 values are significantly higher than those calculated independently by Los Alamos scientists.

Table 10 provides a comparison between the licensee estimates for head loss and those of Los Alamos. Los Alamos estimates were presented for two cases: (a) the same debris loading as that used in the licensee tests and (b) a debris loading consistent with Los Alamos independent calculations. The following conclusions can be drawn from Table 10.

- The licensee estimates for strainer head losses are very conservative. Los Alamos believes that actual head losses would be significantly lower than the licensee estimates.
- In spite of the conservatisms noted above, the licensee has sufficient operational margin. This highlights the success of the licensee strainer design approach.

Table 10. Comparison of Licensee and Los Alamos Strainer Head-Loss Estimates.

System	Flow (gal./min)	Design $\Delta H_{strainer}$ (ft-H_2O)	Los Alamos - 50% inventory[11] (ft-H_2O)	Los Alamos – Method 2[12] (ft-H_2O)
HPCS	8175	**XXXXX**	6.55	< 4.5
LPCS	9100	**XXXXX**	7.78	< 5.8
RHR-A	8940	**XXXXX**	5.71	< 3.8
RHR-B	8940	**XXXXX**	5.54	< 3.7
RHR-C	8940	**XXXXX**	7.13	< 4.4

[11]This calculation assumes that 50% of drywell inventory of nonmetallic insulation and other debris would reach the strainer. See Table 3 for composition of the debris. The differences between the Los Alamos and utility calculations are (a) water temperature and (b) debris scaling.

[12]Los Alamos Method 2/3 calculations suggest that a much smaller amount of Kaowool and Cal-Sil would reach the strainer. The resulting head losses are presented here. Because it is likely that actual bed might be highly nonuniform, Los Alamos estimates are bounding (Los Alamos estimates assume uniform deposition).

3.0 DEFICIENCIES AND RECOMMENDATIONS

No deficiencies were found.

4.0 CONCLUSIONS

The licensee employed conservative methods to estimate the quantity of insulation debris that would be generated in the drywell and transported to the ECCS suction strainer. The licensee's assumptions for noninsulation debris also appear reasonable. Similarly, the licensee calculation of resulting head loss is conservative and is significantly larger than the independent estimates of Los Alamos staff. The licensee analyses have the following voluntary conservatisms imbedded in them.

- The licensee used a very conservative debris source term to size and test the strainers. Using URG Method 2, the Los Alamos staff estimated that the licensee debris loading is conservative by up to 300% in the case of Cal-Sil and up to 2000% in the case of Kaowool.

- The licensee measured head loss at 75°F and used the data directly in the NPSH evaluations. The licensee could have taken credit for elevated suppression pool temperature as described in the URG. This would have reduced net head loss by a factor of 2.5 (the ratio of dynamic viscosity at 75°F and 185°F.

5.0 REFERENCES

1. BWROG, "Utility Resolution Guidance for ECCS Suction Strainer Blockage," NEDO-32686 (November 20, 1996).

2. Science and Engineering Associates, Inc., "Parametric Study of the Potential for BWR ECCS Suction Strainer Blockage due to LOCA-Generated Debris," US Nuclear Regulatory Commission report NUREG/CR-6224 (October 1995).

APPENDIX A:
CHECKLIST USED DURING GRAND GULF ON-SITE REVIEW

Plant Name:	**Grand Gulf Generating Station**
Containment Type:	**Mark III**
Vendor for Strainer:	**Transco Products, Inc.**
Vendor for ΔH Analysis:	**EnerCon 1/4-Scale Testing**
Vendor for Loads Analysis:	**EnerCon (Testing & Analysis)**

Inventory of Major Insulations In the Plant

	Fibrous *(Type/ft^3)*	**Particulate** *(Type/lbm)*	**RMI** *(Type/ft^2)*	**Other** *(Type/ft^3)*
Primary Piping	**Kaowool /900**	**Cal-Sil /700**	**Mirror (2.5-mil S/S)**	
Reactor Shielding Cavity			**Mirror (2.5-mil S/S)**	
Special Structure/Component				
Miscellaneous (Anti-Sweat)	Preformed Fiber Glass			

(Units: Volume in ft^3 and Foil Area in ft^2)

Debris Generation Model Used in the Study		
Method #1 -- All Debris In the Containment	☒	**(50% of debris transported)**
Method #2		
Method #3		
Method #4 -- Not approved for use by Staff		

Drywell Transport Factors Used in the Study	
Transport Factor is assumed equal to 1	☒
Used URG Transport Factors	
Plant Specific Calculations	

Suppression Pool Transport Factors Used in the Study		
Transport Factor is assumed equal to 1		
Used BLOCKAGE Calculations		
Plant Specific Calculations	☒	**Whatever happended in the 1/4-scale testing**

Miscellaneous Debris	**Location**	**Basis for Estimates**
Duct Tape	Drywell	Plant Specific
Tie Wraps	Dry Well	Plant Specific
Rust	Sup_Pool	50 lbm from URG
Paint-Chips (Epoxy)	Drywell	85 lbm fom plant estimate
Dirt and Dust	Drywell	150 lbm rom URG
Sludge	Pool	Measured 370 lb in Outage 13 (2 year cycle)
Other (Plastic Tags)	Drywell	Plant Specific

Head Loss Estimation		
Vendor Correlation and Analysis Used		
Vendor LTR Enclosed		
Vendor LTR Previously Reviewed by Staff		
Vendor tested Exact Strainers with Insulation	**Yes**	**1/4-scale which has 1/16th surface area**
Plant Specific Analysis (e.g., URG Correlations)	Yes	**Used analyses to scale 1/4-scale test**

NPSH Estimation (Comparison with GL 97-04 Response)		
Operator Throttling of ECCS Assumed	**No**	
Time at which throttled	**N/A**	**minutes**
Percentage Flow Reduction from Rated Flow	**N/A**	
Maximum Pool Temperature	**185 °F**	
Assumed Containment Overpressure	**No**	
Staff reviewed the licensing basis (GL 97-04 Res.)		
Reference No:		
Date of Approval:		

Codes and Standards (Comparison with Licensing Basis/UFSAR)	
Quality Assurance Requirements	
10 CFR Appendix-B	☒
ASME Certificate Required	
Materials	
Conform to ASTM Specifications	☒
Certified Material Test Reports are Provided	☒
Design/Fabrication	**Not pressure stamped/pressure tested**
Qualified ASME Section III, Subsection NC	☒
Qualified ASME Section III, Class 2	
Other (Bolts per Sub-section NF_)	☒
Welding	
Qualified to ASME Section IX	☒
Other (Qualified Welder)	☒
NDE per ASME Section III	
Critical welds examined by liquid penetrant	☒
All Other Welds Visually Examined	☒
Other (____________________)	

Structural Evaluation addressed	
Loads on strainer components and welds evaluated	☒
Loads on torus penetrations reevaluated	☒
Added strainer supports to the torus	☒
Effect on structures in close proximity	☒
Effect on increased water level in supp-pool	**Yes (No effect)**
Seismic Loads	**Yes**
Hydrodynamic loads method basis	
Vendor analyses	**Yes**
Methods and Assumptions same as original	**Drag coefficients decreased by 15%**
Substantial changes in methods	**No**

Debris Estimates (Plant and Staff Evaluations)

(If saturation thickness assumption is used got to end)

A) Destruction Pressures Used (in psi)

Insulation Type	Plant	Staff	Comment
Transco RMI		190	
Cal-Sil with Al Jacket	1	160	50% Destruction and Transport
K-Wool	1	40	50% Destruction and Transport
Temp-Mat with ss wire retainer		17	
Knaupf		10	
Jacketed Nukon		10	
Unjacketed Nukon		10	
Koolphen-K		6	
MIRROR from Diamond	4	4	Screened out because of low Vel
Min-K		4	
Other:			
(Anti Sweat)			Ignore because low volume. Bound with K-Wool
( )			
( )			

B) Volume of Zone of Influence Used (ft^3 or Equivalent L/D Value for Sphere Radius)

Insulation Type	Break #1		Break #2		Break #3		Break #4	
	Plant	Staff	Plant	Staff	Plant	Staff	Plant	Staff
Transco RMI	--	--						
Cal-Sil with Al Jacket	N/A	6.2						
K-Wool	N/A	7.7						
Temp-Mat with ss wire retainer	--	--						
Knaupf	--	--						
Jacketed Nukon	--	--						
Unjacketed Nukon	--	--						
Koolphen-K	--	--						
MIRROR from Diamond	N/A	11.6						
Min-K	--	--						
Other:	--	--						
(Anti Sweat)	--	--						
( )	--	--						
( )	--	--						
( )	--	--						

C) Volume of Debris Generated by Break (in ft^3)

Insulation Type	Grand Gulf		Staff Estimate	
	Above Grate	Below Grate	Above Grate	Below Grate
Transco RMI	--	--	--	--
Cal-Sil with Al Jacket	450	0		
K-Wool	350	0		
Temp-Mat with ss wire retainer	--	--	--	--
Knaupf	--	--	--	--
Jacketed Nukon	--	--	--	
Unjacketed Nukon	--	--	--	--
Koolphen-K	--	--	--	--
MIRROR from Diamond	Screened Out			
Min-K	--	--	--	--
Other:	--	--	--	--
(Anti Sweat)	--	--	--	--
( )	--	--	--	--
( )	--	--	--	--
( )	--	--	--	--

If breaks < 2, then

Vendor Data supports screening out rest of breaks ☒

Plant has undocumented analyses reviewed by staff

D) Drywell Debris Transport Fractions Used in the Analysis

Insulation Type	Grand Gulf		Staff Estimate	
	Above Grate	Below Grate	Above Grate	Below Grate
Transco RMI	--	--	--	
Cal-Sil with Al Jacket	1	1	1	1
K-Wool	1	1	0.27	0.78
Temp-Mat with ss wire retainer	--	--	--	
Knaupf	--	--	--	--
Jacketed Nukon	--	--	--	
Unjacketed Nukon	--	--	--	
Koolphen-K	--	--	--	
MIRROR from Diamond	N/A	N/A		
Min-K	--	--	--	
Other:				
(Anti Sweat)	N/A	N/A	0.27	0.78
( )	--	--	--	--
( )	--	--	--	--
( )	--	--	--	--

E) Wetwell Debris Transport Fractions Used in the Analysis

Insulation Type	Grand Gulf		Staff Estimate	
	Above Grate	Below Grate	Above Grate	Below Grate
Transco RMI	--		--	
Cal-Sil with Al Jacket	1.00	1.00	1	1
K-Wool	1	1	1	1
Temp-Mat with ss wire retainer	--	--	--	--
Knaupf	--	--	--	--
Jacketed Nukon	--	--	--	--
Unjacketed Nukon	--	--	--	--
Koolphen-K	--	--	--	--
MIRROR from Diamond	--	--	--	--
Min-K	--	--	--	--
Other:	--	--	--	--
(Anti Sweat)	1	1	1	1
( )	--	--	--	--
( )	--	--	--	--
( )	--	--	--	--

F) ***Net Insulation Debris Volume on the Strainer (ft^3)***

Insulation Type	Grand Gulf		Staff Estimate
	Above Grate	Below Grate	Above Grate
Transco RMI	--	--	--
Cal-Sil with Al Jacket	450	0	15.5
K-Wool	350	0	113.5
Temp-Mat with ss wire retainer	--	--	--
Knaupf	--	--	--
Jacketed Nukon	--	--	--
Unjacketed Nukon	--	--	--
Koolphen-K	--	--	--
MIRROR from Diamond	**Screened Out Low Velociy**		
Min-K	--	--	--
Other:	--	-	-
(Anti Sweat)	**Same as Kaowool**		
( )	-	-	-
( )	-	-	-
( )	-	-	-

G) *Miscellaneous Debris*

Debris Type	*Grand Gulf*		*Staff Estimate*		*Units*	*Status*
	Gen	**T.F**	**Gen**	**T.F.**		
Duct Tape	0.3	1	N/A	1	**ft^3**	**Not**
Tie Wraps	17.2	1.00	**N/A**	1	**ft^2**	**O.K.**
Rust	50	1.00	**50**	1	**lbm**	**O.K.**
Paint-Chips (Epoxy)	624	1.00	**None**	1	**lbm**	**O.K.**
Dirt and Dust	150	1.00	**150**	1	**lbm**	**O.K.**
Sludge	**512**	**1.00**	**450**	1	**lbm**	**O.K.**
Other (Plastic Tags)	32		N/A	1	**ft^3**	**Not**
Adhesive Labels	**9**		**N/A**		**ft^2**	**Not**

Enter Qualified Coatings Type for Containment **Epoxy**

What is Done about Unqualified Coating **Plant estimated approximately 85 lbm.**

Enter Number of Years for Suppression Pool Clean-Up = **1 outage**

ECCS Flow Rate and Design Details

	RHR-A	RHR-B	RHR-C	LPCS	HPCS	RCIC	Total
Before Throttling							
Flow Rate (GPM)	8,940	8,940	8,940	9,100	8,175	800	44,895
Pool Temperature (oF)	185	185	185	185	185	185	
Wetwell Pressure (psia)	14.7	14.7	14.7	14.7	14.7	14.7	
Vapor Pressure (ft-water)	19.58	19.58	19.58	19.58	19.58	19.58	
Static Height (ft-watrer)	12.1	12.1	12.1	12.1	12.1		
$NPSH_{Required}$ (ft-water)	2.0	2.0	2.0	1.6	2.0	0.0	
$DH_{Strainer}$ (ft-water)	[redacted]						
Piping Frictional (ft-water)	3.9	4.3	4.2	3.5	3.1		
NPSHmargin (ft-water)	10.0	10.1	6.1	9.8	8.8		
After Throttling (Time:	**N/A**	***min)***					
Flow Rate (GPM)							0
Pool Temperature (oF)							
Wetwell Pressure (psia)							
$NPSH_{Required}$ (ft-water)							
DHStrainer (ft-water)							
Piping Frictional (ft-water)							
NPSH Margin (ft-water)							
	N/A	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	

Strainer Flow Rates and Design Details

	RHRA	RHRB	RHRC	LPCS	HPCS	RCIC	Total
Previous Strainer							
Flow Rate Data							
Licensing/Runout (GPM)	8,940	8,940	8,940	9,100	8,175	800	44,895
Single Failure (GPM)	N/A	N/A	N/A	N/A	N/A		
Throttle Design (GPM)	N/A	N/A	N/A	N/A	N/A		
Throttle Sing Fail (GPM)	N/A	N/A	N/A	N/A	N/A		
Bottom Diameter (in.)	6	6	6	6	6	2	
Active Length (in)	40.0	40.0	40.0	40.0	40.0	8.0	
Flange Diameter (in.)	23.25	23.25	23.25	23.25	23.25	6	
Plate Area (ft^2)	25.5	25.5	25.5	25.5	25.5	1.4	129
Clean ΔH (ft-water)	[redacted]						

	Div-1	Div-2	Div-3	Total
Replacement Strainer				
Flow Rate Data				
Full Design	18,040	18,680	8,175	44,895
Full Single Failure	N/A	N/A	N/A	
Throttle Design	N/A	N/A	N/A	
Throttle Single Failure	N/A	N/A	N/A	
Plate Area (ft^2)	2400.0	2400.0	1050.0	5,850
Gap Volume (ft^3)	xx	xx	xx	
Circumscribed Area (ft^2)	xx	xx	xx	
Circum+ends Area (ft^2)	xx	xx	xx	

Strainer Performance Results

	Div-1	Div-2	Div-3	Total
Plate Area Increase	47.0	47.8	41.2	45.4
A_{circ} Increase	[redacted]			0.0
Hole Dimension Change	**N/A**	**N/A**	**N/A**	**N/A**
Volume of Gap	xx	xx	xx	0.0
Loading (Design-Full Flow)				
Load Factor	**0.40**	**0.42**	**0.18**	**1.00**
K-Wool Volume (ft^3)	**141**	**146**	**64**	**350.0**
Volume Outside Gap	141	146	64	350
Thickness Outside Gap	0.06	0.06	0.06	0.06
Cal-Sil Volume (ft3)	**181**	**187**	**82**	**450.0**
Cal-Sil+Sludge Mass (lbm)	**2556.4**	**2647.1**	**1158.5**	
Part-to-Fiber Ratio	**2.2**	**2.2**	**2.2**	
Plate Velocity (ft/s)				
Design Full	0.017	0.017	0.017	0.017
Throttled Flow	N/A	N/A	N/A	-
CircumScribed Velocity (ft/s)				
Design Full	0.020	0.020	0.020	N/A
Throttled Flow	N/A	N/A	N/A	-

Head Loss Estimates for Strainer

	RHR-A	RHR-B	RHR-C	LPCS	HPCS
Plat Estimates					
Flow Rate (GPM)	8,940	8,940	8,940	9,100	8,175
Pool Temperature (oF)	185	185	185	185	185
Clean Strainer (ft-water)	1.79	1.78	1.70	3.83	2.46
Debris Bed Head Loss					
Test Data (in-water)	[redacted]				
Extrapolated Test Data					
$DH_{Strainer}$ (ft-water)					

LANL Estimates

Temperature Correction (185 0F versus 75 0F)

$DH_{Strainer}$ (ft-water)	5.8	5.5	7.1	7.8	6.5

Debris Correction

$DH_{Strainer}$ (ft-water)	3.8	3.7	4.4	5.8	4.5