GE Nuclear Energy

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Licensing Topical Report

Application Methodology for the General Electric Stacked Disk ECCS Suction Strainer

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**Important Notice Regarding
Contents of this Report**

Please Read Carefully

The purpose of this report is to document the application methodology for the General Electric Stacked Disk ECCS Suction Strainer. This report addresses hydraulic performance design methods and provides procedures for the calculation of hydraulic loads for new strainer installations. The use of this information for any purpose other than that for which it is intended, is not authorized; and with respect to any unauthorized use, GE makes no representation or warranty, express or implied, and assumes no liability (for example, no liability related to nuclear damage) as to the completeness, accuracy, or usefulness of the information contained in this document, or that its use may not infringe privately owned rights.

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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

February 3, 1999

MFN:99-049

Thomas A. Green, Project Manager
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SUBJECT: SAFETY EVALUATION CONCERNING GENERAL ELECTRIC TOPICAL REPORT NEDC-32721P, "APPLICATION METHODOLOGY FOR THE GENERAL ELECTRIC STACKED DISK ECCS SUCTION STRAINER," PART I (TAC NO. M98500)

Dear Mr. Green:

By letters dated April 3, 1997, and November 21, 1997, General Electric Company (GE) submitted General Electric Topical Report NEDC-32721P, "Application Methodology for the General Electric Stacked Disk ECCS Suction Strainer," to the Nuclear Regulatory Commission (NRC, the staff) for review. The methodologies described in this report are being used by multiple boiling-water reactor (BWR) licensees (i.e., 12 plants) as part of their resolution of the BWR emergency core cooling system (ECCS) suction strainer clogging issue. BWR licensees were requested in NRC Bulletin 96-03, "Potential Plugging of Emergency Core Cooling Suction Strainers by Debris in Boiling Water Reactors," to implement hardware and programmatic modifications, as necessary, to minimize the potential for clogging of ECCS suction strainers during a loss-of-coolant accident (LOCA). By facsimile dated August 18, 1997, and letter dated March 10, 1998, the staff transmitted requests for additional information (RAIs) to GE. GE responded to the staff RAIs in letters dated November 21, 1997, and April 29, 1998.

The GE topical report encompasses methodologies for two different types of analyses. The first methodology is used to determine the head loss across the strainer for estimated debris loadings. The second methodology is used to determine the structural loads on the ECCS penetrations, piping and strainers caused by hydrodynamic forces during an accident. These two methodologies are separate and distinct. Therefore, the staff has broken its review into two parts. The Enclosure to this letter provides Part I of the staff's safety evaluation (SE) of topical report NEDC-32721P. Part I of this SE provides the staff's evaluation of the methodology used to determine strainer performance (i.e., head loss across the strainer with assumed debris loadings) only. Part II of this safety evaluation will address the methodology to determine the structural loadings due to hydrodynamic forces during an accident, and will be provided when that part of the staff's review is complete.

GE's topical report and RAI responses were evaluated by the staff's contractor, Los Alamos National Laboratory (LANL) and LANL's findings relative to GE's methodology for determining the head loss across GE stacked disk strainers are documented in a LANL Technical Evaluation Report (TER) entitled "Technical Review of GE LTR NEDC-32721P: Application Methodology for GE Stacked-Disk ECCS Suction Strainer," dated December 23, 1998. LANL's TER is an attachment to the staff's SE. The staff reviewed GE's submittals and LANL's TER, and agreed with the contractor's findings. Based on the staff's review of all relevant information, including the LANL report, the staff has concluded that the test program used by GE for verifying the hydraulic performance of the prototype strainer and validating GE's head loss correlation is acceptable. Further, the staff has concluded that extending the test results over a narrow parametric range outside the test range is reasonable. However, the staff believes that in one case (a plant with a sludge-to-fiber mass ratio in excess of those tested), the application of GE test data (or the correlation) would be inappropriate without additional testing. GE is conducting an additional test to address this concern.

GE adopted an empirical means for correlating the test data. Because GE chose to correlate head loss in terms of superficial parameters (such as circumscribed velocity) that are easy to determine in plant applications, concerns were identified regarding the generic applicability of the GE correlation, especially application beyond the test range. However, upon further review, the staff believes that GE introduced sufficient margin to compensate for any deficiencies in the correlation. Therefore, the staff concluded that this margin would allow GE to apply its correlation within a narrow range beyond the range for which the test data was obtained. LANL also conducted independent analyses to evaluate the applicability of GE methodology to each of the plant applications cited in GE's submittals. Based on the results of these calculations, the staff concluded that the use of GE's hydraulics design method is acceptable for all the plants, with the exception noted above.

The staff has identified the following specific concerns relative to the use of the GE correlation for the one exception noted above. First, neither the GE nor the NUREG/CR-6224 correlations were ever tested to sludge-to-fiber ratios approaching the value for this plant (i.e., thin-bed effects) and second, the controlling insulation in this case may be a different type of fibrous insulation for which no head loss data has previously been obtained. The staff concludes, therefore, that GE's approach of validating its hydraulics methodology using head loss data from GET-1 is the most prudent approach.

The staff also reached the following conclusions:

(1) GE's use of bump-up factors, consistent with the guidance of NEDO-32686A "Utility Resolution Guidance for ECCS Suction Strainer Blockage" (URG), to account for miscellaneous debris is acceptable.

(2) GE's approach to estimate head loss contribution from reflective metallic insulation (RMI) debris appears reasonable; however the staff notes that GE should ensure that NRC comments provided in Appendix K to the staff's safety evaluation report on the URG are

properly reflected in any GE plant-specific analyses. Specifically, GE should not neglect the contribution of RMI debris without suppo[r]ting analyses establishing that RMI contri[b]ution is negligible. The staff was unable to verify the contribution to strainer head loss from RMI debris because GE did not provide information relative to the assumed RMI loadings for any of the plants using GE strainers.

Sincerely,

Michael J. Davis, Project Manager
Generic Issues and Environmental Projects Branch
Division of Reactor Program Management
Office of Nuclear Reactor Regulation

Enclosure: As stated

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

Attachment

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION RELATED TO TOPICAL REPORT NEDC-32721P, ENTITLED "APPLICATION METHODOLOGY FOR THE GENERAL ELECTRIC STACKED DISK ECCS SUCTION STRAINER" GENERAL ELECTRIC COMPANY PART I

EVALUATION OF GENERAL ELECTRIC'S METHODOLOGY TO DETERMINE STRAINER HYDRAULIC PERFORMANCE

1.0 INTRODUCTION

By letters dated April 3, 1997, and November 21, 1997, the General Electric Company (GE) submitted topical report NEDC-32721P, "Application Methodology for the General Electric Stacked Disk ECCS Suction Strainer," to the Nuclear Regulatory Commission (NRC, the staff) for review. The methodologies described in this report are being used by multiple boiling-water reactor (BWR) licensees (i.e., 12 plants) as part of their resolution of concerns identified in NRC Bulletin 96-03, "Potential Plugging of Emergency Core Cooling Suction Strainers by Debris in Boiling Water Reactors." By facsimile dated August 18, 1997, and letter dated March 10, 1998, the staff transmitted requests for additional information (RAIs) to GE. GE responded to the staff RAIs in a letters dated November 21, 1997, and April 29, 1998.

The GE topical report encompasses methodologies for two different types of analyses. The first methodology is used to determine the head loss across the strainer for estimated debris loadings. The second methodology is used to determine the structural loads on the ECCS penetrations, piping and strainers caused by hydrodynamic forces during an accident. These two methodologies are separate and distinct. Therefore, the staff has broken its review into two parts. This safety evaluation (SE) is Part I of the staff's evaluation of topical report NEDC-32721P. Part I provides the staff's evaluation of the methodology used to determine strainer performance (e.g., head loss across the strainer with assumed debris loadings) only. Part II of this safety evaluation will address the methodology to determine the structural loadings due to hydrodynamic forces during a accident. The hydrodynamic load methodology is still undergoing staff review.

2.0 DISCUSSION

GE's topical report and RAI responses were evaluated by the staff's contractor, Los Alamos National Laboratory (LANL) and LANL's findings relative to GE's methodology for determining the head loss across GE stacked disk strainers are documented in a proprietary Technical Evaluation Report (TER) entitled "Technical Review of GE LTR NEDC-32721P: Application Methodology for GE Stacked-Disk ECCS Suction Strainer," dated December 23, 1998. This SE does not contain proprietary information; however, LANL's TER (attached) does. LANL's TER is accordingly being withheld from the public document room.

3.0 CONCLUSIONS

Based on the staff's review of all relevant information including LANL's TER and GE's submittals, the staff has concluded that the testing program used by GE for verifying the hydraulic performance of the prototype GE strainer and validating GE's head loss correlation is acceptable. The staff notes that some of the test procedures are not considered to be prototypical because they do not exactly replicate post-LOCA conditions; however, the overall impact of these procedures on the measured head loss is considered to be insignificant. The staff concludes that GE has taken adequate measures to ensure that test results are conservative. The test program provided valuable data that can be used to correlate the effect of flow velocity, strainer shape, debris loading and particulate-to-fiber ratio on head loss. The only drawback of the GE test program noted by the staff is that it did not envelope the parametric range that covers all the plant applications. In particular, much of the test data were obtained for low fiber loadings where the gaps between the strainer disks were not completely filled. This comment is applicable to all insulation types, especially when tested in conjunction with sludge debris. This, in itself, is not a deficiency, and in fact, is often the case for many test programs where practical considerations influence the parametric range selected for testing. Extending the test results over a narrow parametric range outside the test range is reasonable. However, the staff believes that for one case (a plant with a sludge-to-fiber mass ratio in excess of those tested), the application of GE test data (or the correlation) would be inappropriate without additional testing. GE is conducting an additional test to address this concern.

GE adopted an empirical means for correlating the test data. GE's choice was to correlate head loss in terms of superficial parameters (such as circumscribed velocity) that are easy to determine in plant applications. This approach raised questions regarding the generic applicability of the GE correlation, especially application of the correlation beyond the test range. However, the staff believes that GE introduced margin which is sufficient to compensate for any deficiencies noted in the correlation. For example, GE recommended use of 1.0 (the maximum value it can reach) for the compression factor (f_2) irrespective of flow rate. According to the test data, at a flow rate of 10,000 GPM the actual compression factor is approximately 0.75, which is 25% lower than the design value of 1.0. The staff concluded that this margin would allow GE to apply its correlation within a narrow range beyond the range for which the test data obtained. LANL also conducted independent analyses to evaluate the applicability of GE methodology to each of the plant applications cited in GE's submittals. These analyses used an updated version of the NUREG/CR-6224 head loss correlation which was modified to better predict the characteristics of the GE strainer geometry. The modified NUREG/CR-6224 correlation was then applied to each plant specified in the GE submittals. Based on the results of these calculations, the staff concluded that the use of GE's hydraulics design method is acceptable for all the plants, with the one exception noted above. For the one exception, the staff identified specific concerns relative to the application of the GE correlation. The staff is concerned about the applicability of the GE correlation to this plant because:

(1) neither the GE correlation nor the NUREG/CR-6224 correlations were tested to sludge-to-fiber ratios approaching the value for this plant (i.e., thin-bed effects), and

(2) the controlling insulation in this case may be a different type of fibrous insulation for which no head loss data have previously been obtained. The staff concludes, therefore, that

GE's approach of validating its hydraulics methodology using head loss data from an additional test is the most prudent approach.

The staff also reached the following conclusions:

(1) GE's use of bump-up factors, consistent with the guidance of NEDO-32686A "Utility Resolution Guidance for ECCS Suction Strainer Blockage" (URG), to account for miscellaneous debris is acceptable.

(2) GE's approach to estimate head loss contribution from reflective metallic insulation (RMI) debris appears reasonable; however, the staff notes that GE should ensure that NRC comments provided Appendix K to the staff's safety evaluation report on the URG are properly reflected in any GE plant-specific analyses. Specifically, GE should not neglect the potential contribution of RMI debris to strainer head loss without supporting analyses establishing that RMI contribution is negligible. The staff was unable to verify the contribution to strainer head loss from RMI debris because GE did not provide information relative to the assumed RMI loadings for any of the plants using GE strainers.

Principal contributors: Rob Elliott, NRC
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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

June 28, 2002

MFN:02-039

Mr. James F. Klapproth, Manager
Engineering & Technology
GE Nuclear Energy
175 Curtner Ave
San Jose, CA 95125

SUBJECT: REVIEW OF GE NUCLEAR ENERGY LICENSING TOPICAL REPORT, NEDC-32721P, "APPLICATION METHODOLOGY FOR GE STACKED DISC SUCTION STRAINER," PART II (TAC NO. MB3311)

Dear Mr. Klapproth:

By letters dated April 3, 1997, November 21, 1997, and October 30, 2001, GE Nuclear Energy (GENE) submitted Topical Report NEDC-32721P, "Application Methodology for GE Stacked Disk Suction Strainer," to the NRC for review. On February 3, 1999, the staff issued Part I of its safety evaluation of GENE's methodology for determining strainer performance. The NRC staff has completed its review of the GENE methodology for determining the hydrodynamic load inputs to the structural analyses of the new emergency core cooling system (ECCS) strainers. Based on the review, we have concluded that the proposed scaling factors are acceptable for use in the determination of the hydrodynamic load inputs to the structural analyses. Therefore, the NRC staff concluded that licensees with GE stacked disk strainers will not exceed the strainer and containment penetration design loads following a safety/relief valve (SRV) discharge or loss-of-coolant accident event using the proposed methodology.

The staff finds that the subject topical report is acceptable for referencing in licensing applications to the extent specified under the limitations delineated in the report and in the associated NRC safety evaluation. The enclosed safety evaluation defines the basis for acceptance of the topical report.

The NRC requests that GENE publish an accepted version of the revised Topical Report NEDC-32721P within 3 months of receipt of this letter. The accepted version shall incorporate this letter and the enclosed safety evaluation between the title page and the abstract, and add a "-A" (designating accepted) following the report identification number (i.e., NEDC-32721P-A).

Document transmitted herewith contains sensitive unclassified information.
When separated from Enclosure 1, this document is decontrolled.

If the NRC's criteria or regulations change so that its conclusion in this letter that the topical report is acceptable is invalidated, GENE and/or the applicant referencing the topical report will be expected to revise and resubmit its respective documentation, or submit justification for the continued applicability of the topical report without revision of the respective documentation.

Pursuant to 10 CFR 2.790, we have determined that the safety evaluation provided as Enclosure 1 contains proprietary information. We have prepared a non-proprietary version of the safety evaluation (Enclosure 2) that we have determined does not contain proprietary information. However, we will delay placing Enclosure 2 in the public document room for a period of ten (10) working days from the date of this letter to provide you with the opportunity to comment on the proprietary aspects only. If you believe that any information in Enclosure 2 is proprietary, please identify such information line by line and define the basis pursuant to the criteria of 10 CFR 2.790.

If you have any questions, please contact Alan Wang, GENE Project Manager, at (301) 415-1445.

Sincerely,

Cornelius F. Holden, Jr., Acting Director
Project Directorate IV
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

Project No. 710

Enclosures: 1. Proprietary Safety Evaluation
2. Non-Proprietary Safety Evaluation

cc w/encl. 2: See next page

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cc w/encl 2:

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SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

GE NUCLEAR ENERGY LICENSING TOPICAL REPORT

NEDC-32721P, "APPLICATION METHODOLOGY FOR GE STACKED DISK SUCTION STRAINER," PART 2 OF 2

PROJECT NO. 693

1.0 OVERVIEW

1.1 Introduction

On October 30, 2001, GE Nuclear Energy (GENE) submitted to the NRC Licensing Topical Report (LTR) entitled, "Application Methodology for GE Stacked Disk Suction Strainer," NEDC-32721P, Revision 2, dated October 2001 (Reference 1). This report contained the methodology developed by GENE and used by all boiling water reactor (BWR) plant owners that use emergency core cooling system (ECCS) suction strainers from GENE to resolve the strainer plugging issue in accordance with NRC Bulletin 96-03 (Reference 2).

Bulletin 96-03 was issued on May 6, 1996, to all holders of operating licenses or construction permits for BWRs. The purpose of this bulletin was to request the above holders to implement appropriate procedural measures and plant modifications to minimize the potential for clogging of ECCS suppression pool suction strainers by debris generated during a loss-of-coolant accident (LOCA).

GENE provided the referenced LTR in response to Bulletin 96-03. The LTR provided the design of a larger strainer, which was intended to replace the existing smaller cylindrical strainers that were originally installed in all BWR plants. This new design is referred to as the GE optimized stacked disk ECCS suction strainer. The design utilizes disks whose internal radius and thickness vary over the height of the strainer. The selected variation in these parameters achieves an increased surface area compared to existing strainers of the same size. When properly designed, the new strainer is expected to perform with a minimum head loss for the range of possible amounts of debris while fitting into a minimum volume.

This LTR addresses two major areas of the strainer design. The first is related to the hydraulic performance of the strainer under a range of both amount and type of debris. The second pertains to the procedures or methodologies used for the calculation of the hydrodynamic load inputs for the installation of the new strainers. The values of these load inputs are used in the structural analysis of the torus penetration that supports the strainer as well as the strainer itself. This evaluation will only address the second area. The hydraulic performance of this new strainer was documented in an NRC safety evaluation (SE) dated February 3, 1999, entitled "Safety Evaluation Concerning General Electric Topical Report NEDC-32721P, 'Application Methodology for the General Electric Stacked Disk ECCS Suction Strainer', Part 1 (TAC NO. M98500)," (Reference 3).

1.2 Background

The need to perform hydrodynamic load calculations was first recognized during the original suppression pool hydrodynamic program undertaken by GENE during the design of the Mark III containment. During this program, calculations of hydrodynamic forces were necessary since it was found that these forces could be substantial. This finding was also of particular importance to the design of the Mark I containment. The Mark I containment designs were the only operating BWR containments at the time. The Mark II containment plants were in the construction phase and the Mark III design was still in the design stage. It was found that the original design basis for the Mark I design had not accounted for these newly found hydrodynamic forces. As a result, the owners of Mark I plants organized into an owners group in an effort to resolve this issue in a timely fashion. Similarly, the owners of Mark II plants also formed into an owners group. These two groups formulated programs which consisted of experimental and analytical efforts, that resulted in the development of methodologies which would compute the values of these hydrodynamic loads.

Documentation of these hydrodynamic loads as applicable to Mark I and II containment designs can be found in various topical reports generated by GENE and others as part of short and long term pool dynamic load programs. An important document was the GENE report, "Mark I Containment Program Load Definition Report," NEDO-21888, dated December 1978 (Reference 4) and later revised in November 1981. Its importance was the fact that the report provided the methodology to calculate the complete array of pool dynamic loads produced by either LOCA or safety relief valve (SRV) events. The generic GENE Load Definition Report (LDR) was further supported with plant unique reports called Plant Unique Analysis Reports (PUARs). The combination of these reports formed the basis for any individual changes in both hardware and procedures. The Mark II owners group prepared similar reports.

The staff prepared a SE that evaluated the entire Mark I program undertaken by the Mark I owners group. The staff's SE was documented in NUREG-0661 entitled, "Safety Evaluation Report, Mark I Containment Long-Term Program," dated July 1980 (Reference 5). As part of the SE, the NRC provided acceptance criteria for the long-term program. For the most part, the staff accepted the load methodology as proposed by the Mark I owners group. However, there were exceptions as noted in NUREG-0661. For each exception, the staff provided an acceptable alternative to the methodology provided by the owners group. Similarly, the staff prepared an SE for the Mark II program which was documented in NUREG-0487 entitled, "MARK II Containment Lead Plant Program Evaluation and Acceptance Criteria," dated October 1978 and supplemented in September 1980 (Reference 6).

The acceptance criteria for the hydrodynamic load methodology has been in effect since its issuance date of July 1980 and September 1980, respectively. The staff has maintained that as long as the licensee follows the entire approved methodology for a particular load, no further staff review is necessary. As a result, the staff needs only to verify that the acceptance criteria have been properly applied.

2.0 TOPICAL REPORT METHODOLOGY

Fluid forces acting on the strainer can result from air and steam discharges into the suppression pool. These air and steam discharges, or bubble sources, can be from the downcomers, vents, or SRV quenchers. The total fluid force is a combination of two components, acceleration drag and standard drag. The acceleration drag is caused by acceleration of the flow field, whereas standard drag results from the instantaneous fluid velocity. The methodology which determines the fluid forces in the LTR is the same as the previously approved methodology. Additionally, the hydrodynamic loads on the new disk strainer will be calculated identically to the previously approved Mark I (Reference 5) and Mark II (Reference 6) programs discussed above. However, these loads will also be modified by scaling factors to account for the larger and more complex shape of the new ECCS strainers.

Since the new GE ECCS strainers have increased in length and diameter, the methodology previously established in the LDR and the Dynamic Forcing Functions Information Report (DFFR) (Reference 7) for calculating the drag loads on the new stacked disk strainer would yield unreasonably high acceleration and standard drag forces acting on the strainer. GENE reviewed the previous approach to determine where excess margin existed. It was found that the acceleration drag forces acting on the stacked disk strainer were the most significant source of excess margin. Further, the most important parameter needed to calculate the drag forces acting on the stacked disk strainer was the hydrodynamic mass coefficient, C_m. It is noted that the LTR does not discuss C_m, per se, only the acceleration drag volume (ADV). The hydrodynamic mass coefficient is defined as the ADV multiplied by water density.

Previous calculations used in the LDR/DFFR used a bounding value of 2.0 for C_m and assumed that the strainer was a solid cylinder with an infinite length. To continue to use this same C_m value for the much larger stacked disk strainer would impose very large forces on the new device that would not be realistic. The assumption that the strainer is a solid cylinder with an infinite length was also very conservative.

Additionally, standard drag is generally considered to be small in comparison with acceleration drag, but it can represent about 10 percent of the combined load. Previous calculations used in the LDR/DFFR were made using a conservative value of 1.2 for the standard drag coefficient (C_d). Similar to C_m, GENE felt that it could be demonstrated by analysis and test that a value of 1.2 for C_d was too conservative for the new strainer application. GENE had conducted several standard drag air tests at the University of Maryland to support their conclusions.

2.1 Scaling Factors

As stated above, the changes that were under consideration involved only input value changes to a methodology that had been previously approved by the staff. The GENE approach was to account for both the finite size as well as crediting for the presence of the perforated plate on the strainer surface. Each individual LOCA and SRV load defined by the previously installed strainer will be modified by scaling factors which account for the new larger strainers. Scaling factors will be applied to four areas which account for the strainer location to the bubble source, the strainer porosity, the strainer proximity to the torus wall and other structures, and the shape of the strainer. These scaling factors were developed and applied separately to the acceleration and standard drag loads. As such, the load applied to the new strainer is the existing strainer load modified by the combined scaling factors.

2.1.1 Location Scaling Factor

Scaling factors associated with strainer location to the bubble source are the result of the significant increase in strainer size and volume. The larger strainer size brings the surface of the strainer into regions of the suppression pool not seen by the much smaller original strainer design. Since the acceleration field caused by a bubble is proportional to the inverse square of the distance from the bubble source to the center of gravity of the strainer, the location scaling factor for the acceleration drag is the ratio of the square of the distance to the existing strainer over the square of the distance to the new strainer. For the standard drag, the location scaling factor is the ratio of the distance to the existing strainer to the 4^{th} power over the distance to the new strainer to the 4^{th} power.

2.1.2 Shape Scaling Factor

Scaling factors associated with strainer shape are also the result of the significant increase in strainer size and volume. The shape scaling factor accounts for the differences between the existing strainer and the new strainer, and not the porosity (or perforations) of the strainers. For simple geometries, there are approved methods available for obtaining the unsteady flow fields imposed by LOCA discharge of drywell air, condensation oscillation, chugging, and the fluid-structure interaction response of the flexible pool wall. However, the new strainer geometry is different from standard geometric forms in that it has a complex configuration. This complication requires reasonable estimates of the acceleration drag volume and the hydrodynamic mass coefficient of the new strainer. These estimates were determined based on the application of approved analytical methods for Mark I and IIs.

The shape scale factors for acceleration drag is based on the ratio of the ADV for the new GE strainer over the ADV of the existing strainer. Additionally, the design values of ADV for the new GE strainer are different for the cross-flow and axial flow directions. As described in Appendix B of the LTR, GENE employed an analytical method called a fast panel analysis to predict the ADVs in both flow directions of three GE stacked disk strainer designs, i.e., three different diameter/length (D/L) values, placed in an in viscid flow field. It was then used to compare the predicted ADVs and hydrodynamic mass coefficients for solid surfaced cylinders of the same corresponding dimensions. The actual calculations were performed using a Continuum Dynamics, Inc. (CDI) proprietary fast panel analysis and a commercially available computer program. This program was originally developed to analyze lift on airplane wings and adapted to a water media instead of air. GENE used the fast panel analysis to develop the ADV as a function of D/L for all of the fabricated GE strainers.

The shape scaling factor for the standard drag is the ratio of the area of the new GE strainer over the area of the existing strainer. GENE performed tests that combined the effects of the shape and porosity for the standard drag load only. This test is discussed in the porosity scaling factor section of this SE.

The analytical efforts, as described in Appendix B of the GENE LTR, have demonstrated that significant reductions are possible in the calculated forces. However, it must also be acknowledged that the available technology would not allow the direct analytical modeling of the complex configuration of the stacked disk geometry with perforated plates. Therefore, a porosity scaling factor was required to account for the perforated plates of the new ECCS strainer design.

2.1.3 Porosity Scaling Factor

The porosity scaling factor for the acceleration and standard drag loads accounts for the perforated plate of the GE stacked disk ECCS suction strainer. All GE stacked disk ECCS suction strainers are fabricated from stainless steel perforated plate with an approximate open area of 40 percent. The effect of porosity on the acceleration and standard drag loads can only be evaluated by tests. Tests performed by GENE have concluded that the acceleration drag porosity scaling factors [ ] respectively, compared to identical structures without perforations.

As stated before, GENE performed tests which accounted for the combined effects of the shape and porosity on the standard drag. The tests were preformed on the GE prototype strainer at the Glenn L. Martin Wind Tunnel in College Park, Maryland. Based on the bounded test data, the standard drag coefficients for the new GE ECCS suction strainer [ ]. Using this information, the porosity scaling factor is the ratio of the standard drag coefficient of the new GE strainer over the standard drag coefficient of the existing strainer.

2.1.4 Proximity Scaling Factor

The wall proximity and proximity to other structures effects are calculated using the same methodology (that is, LDR) and adjusted for the dimensions of the new strainer. This accounts for the increased load due to local pool velocity and acceleration due to the presence and proximity of walls and other structures. According to the LTR, the calculation is performed assuming a solid body. The load increase is then reduced to account for the space between the disks and the porosity of the suction strainer. This method does not induce a wall proximity load. The wall proximity effects are accounted for by applying the approved Mark I, II, and III program criteria.

3.0 STAFF EVALUATION OF GENE PROGRAM

The staff evaluation concentrated on obtaining additional information on specific elements of the overall approach. The staff was interested in the value of the hydrodynamic mass coefficient and ADV and the manner in which GENE was determining the forces acting on submerged structures like the strainer. Previously, the accepted methodology identified specific events, such as LOCA, SRV actuation, unstable condensation oscillation (CO), and chugging, in which submerged structure loads were calculated for each event. The staff believed that a similar approach should be selected for the new stacked disk strainers. During a meeting with the staff held on January 27, 1998, GENE confirmed that the approach outlined by the staff is exactly what was being done for the strainer analysis (Reference 8).

The staff conducted a rather extensive literature search to identify any additional experimental data on drag measurements of various body configurations. The search produced texts relating to methods used for calculating the drag forces on various submerged bodies. The staff found several references that directly related to the issue under discussion. The predominate work was found to have been conducted mainly by Dr. J. R. Morison and his associates. The results of their efforts were published in 1950 (Reference 9) and 1953 (Reference 10). Dr. Morison's work formed the technical basis used by GENE in NEDO-21471 (Reference 11). NEDO-21471 provided the methods needed to calculate the drag forces which act on a body submerged in the suppression pool during a postulated SRV or LOCA event. These efforts focused on the consideration of only solid bodies. However, it provided a methodology to determine the flow fields interacting with the strainer.

The methodology established in NEDO-21471 has been approved by the NRC staff in NUREG-0661 and continues to represent an acceptable method to calculate submerged structure loads during a hydrodynamic event. In order for a user to calculate the submerged structure drag loads using the approved methods in NEDO-21471, several coefficients must be known about the submerged body under evaluation. NEDO-21471 provides tables of coefficients from which the user can select. However, these coefficients are highly geometry dependant and do not address the perforation of the surface. As a result, the tables could not be used in obtaining the coefficients for the new GE stacked disk strainer. Hence, it was necessary for GENE to find the appropriate hydrodynamic mass coefficient and ADV for a porous stacked disk strainer.

As stated before, the GENE LTR provides a revised methodology in the form of scaling factors to account for the complex configuration and perforated plate of the GE ECCS stacked disk suction strainer. The staff evaluated the proposed scaling factors for both the acceleration and standard drag loads. For the proposed location scaling factor, the staff concluded that the ratios of the new and existing strainers appropriately account for changes in the location of the new strainer for both the acceleration and standard drag loads. Therefore, the staff finds the use of the location scaling factor as described in the GENE LTR to be acceptable.

For the proximity scaling factor, the methodology to calculate the acceleration and standard drag loads has not changed. The calculation to account for the dimensions of the new GE stacked disk ECCS suction strainer appears reasonable for both acceleration and standard drag load recalculation purposes. Therefore, the staff finds the use of the proximity scaling factor as described in the GENE LTR to be acceptable.

The shape scaling factor and the porosity scaling factor for the standard drag loads were bounded by tests performed at the Glenn L. Martin Wind Tunnel at the University of Maryland. The wind tunnel tests accounted for the effects of the shape and porosity of the strainer on the standard drag load and were used to determine the standard drag coefficients for the porosity scaling factor. These coefficients were used in the ratio to determine the porosity scaling factor. The shape scaling factor was the ratio of the area of the new and existing strainer. The staff has reviewed the wind tunnel test report and has concluded that the results are reasonable for the shape and porosity scaling factors on the standard drag load. Therefore, the staff finds the use of the shape and porosity scaling factors for the standard drag load as described in the GENE LTR to be acceptable.

For the shape scaling factor for acceleration drag, the parametric results of the computer-based fast panel analysis of the stacked disk geometry showed the effect of each parameter (strainer hydraulic length and diameter) on the value of the acceleration drag volume. The calculated ADV for a strainer with a given diameter/length is then used in the ratio of the calculated ADV over the ADV of the existing strainer to calculate the shape scaling factor. However, the fast panel analysis could not directly model the complex configuration of the stacked disk geometry with perforated plates. Since the ADV calculated by the fast panel analysis does not account for the perforated plates, the shape scaling factor for the acceleration drag load would be conservative. Therefore, the staff finds the use of the shape scaling factor for the acceleration drag load, as described in the GENE LTR, to be acceptable.

With regard to the porosity scaling factor for the acceleration drag load, analysis of the effect of the perforated plate is dependent on the open area of the perforated plate and the adequacy of the tests. Since the determination of the effect of the perforated plate on the acceleration drag load is a difficult task without the ability to perform confirmatory tests, the staff contracted the services of Professor T. Sarpkaya of the Naval Postgraduate School in Monterey, California. Dr. Sarpkaya is an internationally recognized expert in the field of hydrodynamics. His text, "Mechanics of Wave Forces on Offshore Structures," (Reference 12), was a valuable resource to the staff during this review. Dr. Sarpkaya was commissioned to provide an expert opinion of typical values of the hydrodynamic mass coefficient for structures similar to the GE stacked disk strainers under the conditions expected following a LOCA and SRV discharge.

Based on the conclusions of Dr. Sarpkaya's technical evaluation report, the staff met with GENE on August 21, 2001, to discuss the hydrodynamic load issue (Reference 15). As a result of the meeting, GENE agreed to submit a revised LTR to correct contradictory and sometimes incorrect information in the previous revision of the LTR. Revision 2 of the GENE LTR was submitted on October 30, 2001.

In his technical evaluation report (Reference 13), Dr. Sarpkaya conjectured that typical values of the hydrodynamic mass coefficient for structures with similar geometry and open area as the GE stacked disk strainers would not be smaller than 0.20 to 0.25. In fact, based on tests performed by D. Osgood at the Naval Postgraduate School (Reference 14), Dr. Sarpkaya believes that the hydrodynamic mass coefficient of a perforated cylinder with a porosity of 40 percent lies within the range of 0.12 to 0.30 for all values of the frequency parameter (from about 6,000 to 1,200,000). As stated above, GENE determined that the effect of the porosity of the GE stacked disk strainer is bounded by taking a reduction to either 13 percent (axial direction) or 30 percent (cross flow direction) of the value for an identical structure without perforations. These reductions, or porosity scaling factor for acceleration drag, are consistent with Dr. Sarpkaya's conclusions. Additionally, the staff reviewed other test data from tests on strainers which are very similar in design to the GE stacked disk strainers. The staff concluded that these tests were performed in conditions that were representative of the actual conditions seen by the ECCS suction strainer. The hydrodynamic mass coefficients from these tests were the same order of magnitude as those used by GENE and conjectured by Dr. Sarpkaya. Based on the above information, the staff finds the use of the porosity scaling factor for the acceleration drag load, as described in the GENE LTR, to be acceptable.

4.0 CONCLUSION

The staff has completed its review of the GENE LTR relative to the application methodology for the GE stacked disk strainer. In particular, this review has focused on the methodologies used for the calculation of loads for the installation of the disk strainer.

GENE has stated that the hydrodynamic loads on the new disk strainer will be calculated identically to the previously approved Mark I and Mark II programs. Since the calculation of a particular load will use one of these previously approved Mark I and II methodologies without any deviations, the staff finds the approach acceptable. However, these loads will also be modified by scaling factors to account for the larger and more complex shape of the new ECCS strainers. The staff has reviewed the scaling factors with the assistance of Dr. T. Sarpkaya. The staff has concluded that the use of the scaling factors applied individually to the acceleration and standard drag loads is acceptable. Additionally, the staff concludes that the methodology in the LTR ensures that ECCS strainers are designed, using the methodology, to handle the worst case loads in the suppression pool such that containment penetrations remain intact, and that General Design Criteria 4, "Environmental and Dynamic Effects Design Basis," of Appendix A to 10 CFR Part 50 is met with respect to the design of the strainers. Therefore, the staff finds it is acceptable to use the methodology in NEDC-32721P.

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ABSTRACT

The GE stacked-disk ECCS suction strainer utilizes disks whose internal radius and thickness vary over the height of the strainer. The selected variation in these parameters achieves an increased surface area compared to conventional strainers of comparable size, and this optimizes strainer performance by generating minimum head loss for any assumed debris loading in the smallest possible volume. This licensing topical report documents the application methodology for the General Electric stacked disk ECCS suction strainer, including (1) hydraulic performance design methods and (2) procedures for calculation of loads for new strainer installation that can be used in the structural analysis of the torus penetration(s), the strainer supports, and the strainer itself.

1.0 INTRODUCTION

The BWR Owners' Group (BWROG) has developed Utility Resolution Guidance [Ref. 1] to assist utilities in resolving the ECCS suction strainer plugging issue and, in particular to provide guidance to BWR operators in responding to NRC Bulletin 96-03 [Ref. 2].

Section 3.2.6.2.3 of the Utility Resolution Guidance documents the methodology for calculating the head loss across specific strainers tested by the BWROG after the limiting quantity of debris present on each strainer has been established. These calculation procedures are described in Appendices A and B of the alternate strainer test report [Ref. 3]. The alternate strainer test report also describes the basis for which the head loss correlations were developed and their application requirements.

The GE stacked-disk strainer design is based on a patented innovation that utilizes disks whose internal radius and thickness vary over the height of the strainer. The selected variation in these parameters achieves an increased surface area compared to conventional stacked-disk strainers of comparable size tested by the BWROG. This optimizes strainer performance by generating minimum head loss for any assumed debris loading in the smallest possible volume. GE has thoroughly tested the optimum stacked-disk strainer design at the EPRI NDE Center, and the resulting test data are included as Appendix A. This testing included evaluation of strainer performance for very high fibrous debris loadings. The hydraulic performance data correlation presented in Section 3.3 is based on earlier BWROG test data [Ref. 3], as well as the specific GE optimized strainer data (Appendix A). Section 3.5 describes the GE strainer sizing calculation methodology, and an example calculation is included in Section 3.6.

Section 4 of this Licensing Topical Report provides the calculation procedures to be followed to provide hydrodynamic load inputs to the structural analyses of the new strainers, the torus penetrations, and the strainer supports, if employed. The load calculation procedures are based on scaling of the previously calculated loads by applying scale factors that account for changes in size, geometry, and location of the new strainers. These scale factors are applicable for Mark I, II, and III containment designs.

2.0 DESCRIPTION OF GE STACKED-DISK STRAINER

The patented GE stacked-disk ECCS pump suction strainer is optimally designed to have minimum head loss and to accumulate a maximum quantity of debris, within a given volume. The strainer has a central core of varying radius such that the flow through the entire central region is maintained at constant velocity. The constant velocity core minimizes head loss where velocities are the greatest. A number of perforated disks of varying internal diameter and whose thickness may vary with radius surround the central core. Figure 2-1 is an isometric view of a typical GE stacked-disk strainer with a quarter segment removed to illustrate the internal design. The holes in each disk are sized to prevent a significant quantity of debris from passing into the strainer, but allow fluid to pass through the strainer. For BWR application, the strainer hole size will vary to assure that the design is compatible with specific containment spray nozzles and/or with the ECCS pump seal cooling flow orifices. The spacing between the disks is maintained constant at 1.75 inches. The outer diameter of the disks is typically constant, but can vary and still maintain the constant velocity core. The prototypical optimum stacked-disk strainer tested by GE is shown in Figure 2-2.

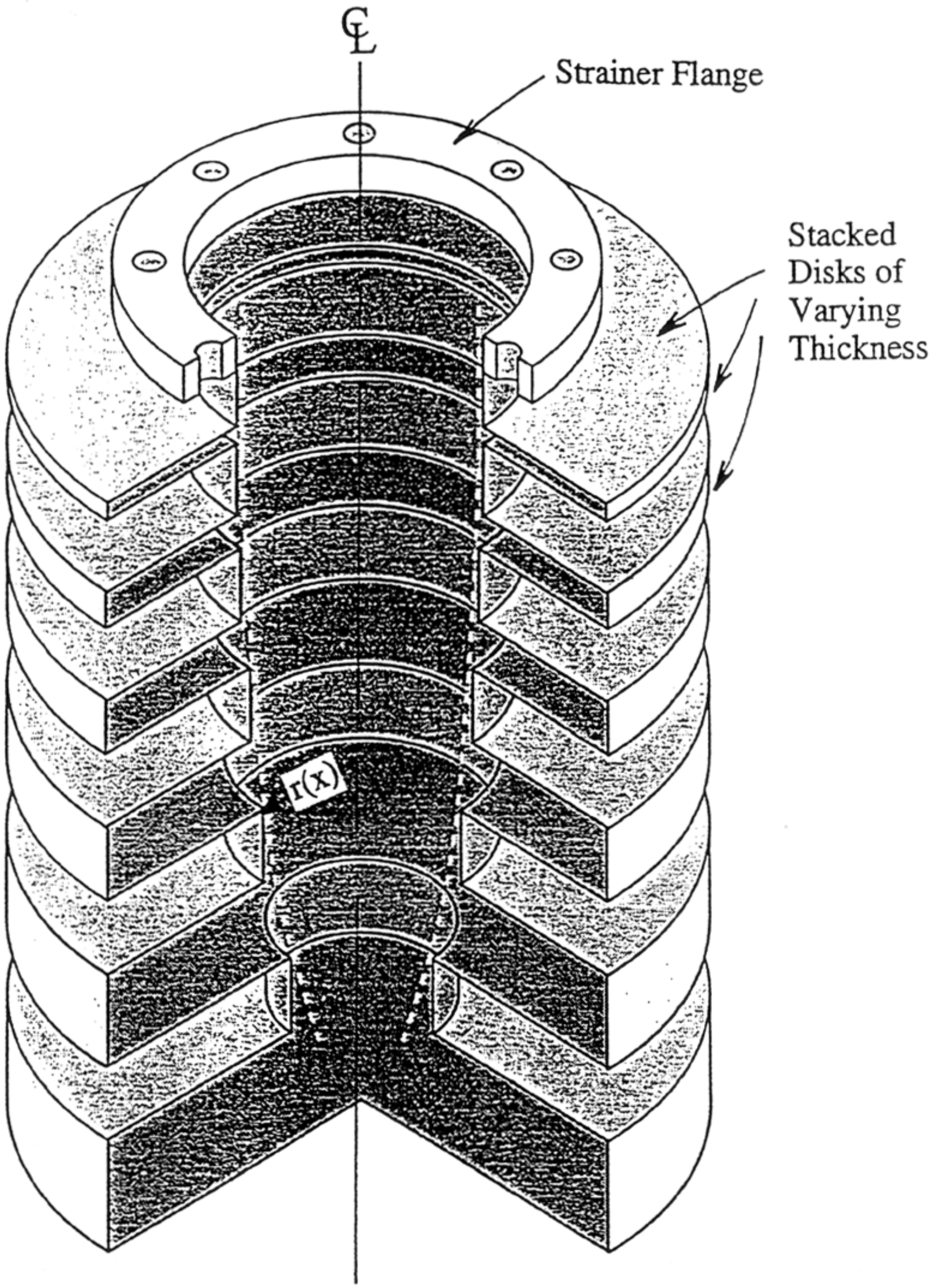

Figure 2.1. Typical GE Stacked-Disk Strainer with a Quarter Segment Removed to Illustrate the Internal Design

Figure 2-2. Protypical GE Stacked Disk Strainer

3.0 HYDRAULIC DESIGN METHODOLOGY

3.1 Overview of Hydraulic Design Methodology – Basic Principles

The methodology used for hydraulic design of the GE stacked-disk suction strainer is described in this section. This methodology is employed to calculate the strainer head loss and the detailed shape of the strainer such as the number of the disks, the thickness and the radii of the disks, and the overall size of the strainer (outer diameter and length). The head loss calculation includes the head losses without debris (clean head loss) and with debris. The head loss with debris considers the effects of the fiber debris and the corrosion products first. Then effects of other miscellaneous debris are considered in terms of a bump-up factor as outlined in Appendix A of Reference 3. The detailed sizing calculation estimates the perforated plate area based on the total debris load, and then determines the inner radius and thickness of each disk assuming an estimated outer diameter. If the strainer dimensions do not meet the design requirements, the same calculation may be repeated for a different outer diameter. The head loss calculation and the sizing calculation are iterated until all design requirements are met.

Sections 3.2, 3.3, and 3.4 describe the details on the head loss calculation. Section 3.2 describes the hydraulic testing performed on the GE prototype strainer, including the clean head loss as well as the debris head loss. Section 3.3 describes the test data correlations developed from the GE prototype hydraulic testing, as well as the BWROG testing of the 60-point star strainer and the stacked-disk strainer No. 2. Section 3.4 describes the bump-up factor calculation procedure for miscellaneous debris.

Section 3.5 describes the basic fluid mechanics and the equations used for the strainer sizing. Section 3.6 provides an example strainer sizing calculation that also includes the head loss calculation.

For the head loss correlation, the following head loss equation is used:

$$\Delta h = K_h \cdot \frac{\mu U t}{\rho g d^2}$$

where

Δh = the head loss in ft
K_h = the dimensionless head loss coefficient
μ. = the dynamic viscosity in lbm/ft-sec
U = the approach velocity in ft/sec, defined as

$$U = \frac{Q}{\pi D L}$$

Q = the pump flow rate applied to the strainer in ft^3/sec
D = the outer diameter of the strainer in ft
L = the active length of the strainer in ft

t = the fiber bed thickness in ft, defined as

$$t = \frac{M_f}{\rho_f \cdot \pi DL}$$

M_f = mass of fiber debris in lbm
ρ_f = uncompressed density of the fiber debris in lbm/ft^3

ρ = the density of the water in lbm/ft^3
g = the gravitational acceleration, 32.2 ft/sec^2
d = the interfiber distance in ft

The definitions of these terms and symbols are consistent with Reference 3.

3.2 Hydraulic Test

A prototype GE strainer was fabricated with the hydraulic design optimized as described in Section 3.5 and with proper internal structural supports so that the strainer can withstand the postulated hydrodynamic loads. A hydraulic test was performed on the GE prototype strainer to:

- Ascertain the head loss performance of the GE strainer design compared with other designs available in the industry.
- Evaluate strainer debris load conditions not addressed in Reference 3, in particular the high fiber load conditions and the performance with Tempmat fiber insulation.

The applicable test data from Reference 3, along with the GE prototype test data, are used in developing the design correlation for the GE strainers.

Appendix A provides the descriptions of the GE prototype strainer, the test facility, the test procedures, and the test data obtained. Table 3-1 is the test matrix.

3.3 Correlation of Test Data

The main focus of this section is to obtain an appropriate correlation for K_h. Appendix B of Reference 4 provides an overview of available literature related to the head loss data, and also a sound theoretical model. The testing and the modeling work in Reference 4 are applicable to flat perforated plate geometries, and, therefore, some phenomena that could exist in complex suction strainer configurations are not addressed. Reference 3 provides test data for a variety of strainer designs, for which the test data has been empirically correlated.

Table 3.1. Test Matrix for GE Prototype Stacked-Disk Strainer Testing

Test ID	Flow, gpm	M_f, lbm	M_c, lbm	RMI, ft^2	Remarks
GE1	2500 -10,000				Clean head loss
GE2	2500 -10,000	25	100		Performance comparison
GE3	2500 - 10,000	50	100		Performance comparison
GE4	2500 - 10,000			640	Performance comparison
GE6	1250 - 3750	100 - 600			High fiber Load
GE7	2500 - 7500	17 - 100	85 - 500		M_c/M_f = 5
GE8	2500 - 4000	118.5 - 237	32 - 64		TempMat
GE9	2500 - 10,000 5000	25 - 75 75	125 - 375 375	160 - 480 640	M_c/M_f =5 RMI/Mf = 6.4 ft^2/lbm Additional RMI
GE10	5000	50	1568		High M_c/M_f

The strainer head loss can theoretically be calculated by the Darcy equation for porous media for the given strainer geometry and debris loading profile. This problem is, however, not easily solvable because it is difficult to define the debris load profile and the corrosion-to-fiber mass ratio (M_c/M_f) profile in a complex geometry in a three-dimensional flow field. Therefore, the following more practical approach has been employed:

From the review of References 3 and 4, it is found that K_h is expected to be a primary function of the following four parameters for a given strainer design:

The following procedure is used to define the GE optimum stacked-disk strainer geometry:

1. Determine U_p/U_c. The total perforated area, A_s, is estimated considering the total debris to be collected by the strainer. The pump suction flange inner radius is given as part of the existing conditions for the each plant, and wb is determined as part of the strainer design. The strainer outer diameter, R, is determined based on the strainer envelope requirements. Equation 8 is used to calculate U_p/U_c.

   To calculate the head loss from RMI debris, the methodology described in Reference 3 shall be employed. The BWROG test results showed that RMI has a negligible or very small effect on overall strainer head loss when a substantial quantity of fibrous debris is present.

2. Calculate r; from Equation 7. Start from r_L and sequentially calculate r_i. Adjust U_p/U_c slightly until r_0 shows a reasonable value.

3. Use the minimum allowable disk thickness (e.g., 3/8 or 0.4 inch) to calculate (U_p /U_d); for each disk using Equation 9 where (U_d/U_c); remains below 1.0. When (U_d/U_c); exceeds 1.0, set the value of (U_d/U_c); equal to 1.0 and calculate t; for each disk using Equation 9.

4. Calculate other design parameters such as the strainer length (L), and the total perforated plate area (A_s) based on the calculation of r_i and t_i.

3.6 Example Strainer Size Calculation

The head loss correlations and the strainer sizing methodology developed above are programmed into an EXCEL spreadsheet. The strainer design input parameters include:

- NPSH available for the ECCS suction strainer
- Suppression pool temperature at which the above NPSH is calculated
- Debris loads - fiber debris, sludge, RMI, and other miscellaneous debris
- Pump flow rate
- Suction flange inner diameter and the maximum outside diameter of the strainer

Based on these inputs, an approximate strainer size is determined and the calculation is iterated between the head loss and strainer sizing until all the design requirements are met. After the finalized strainer design is selected, detailed geometric information is produced as an output for the hardware designer. This design information includes:

- Strainer D (outside diameter) and L (active length)
- Number of disks
- The thickness and the inner radius of each disk
- The total perforated plate area
- Other miscellaneous geometric details

An example calculation is provided in Appendix C.

4.0 CALCULATION OF LOADS FOR NEW STRAINER APPLICATIONS

4.1 Purpose and Overview

4.1.1 Process Overview

This section provides methods for calculation of suppression pool hydrodynamic loads on the new strainer installation that are to be used as input to the structural analysis of the suppression pool penetrations, the strainer attachment, and the strainer itself.

Hydrodynamic loads on structures submerged within suppression pools, caused by postulated Loss of Coolant Accidents (LOCA) and Safety Relief Valve (SRV) actuations have been extensively studied, and load definition methodologies have previously been approved by the NRC (e.g. Ref. 10). The purpose of this approach is to provide a simple and straightforward process for load definition of the new strainers such that all of the margin inherent in the original strainer load definitions is maintained.

4.1.2 Definitions and Nomenclature

For consistency with previous load definitions, the GE methodology for ECCS Suction Strainer submerged structure loading uses the relationships:

$$F_A(t) = \rho V_a \frac{a}{g_0}$$

and

$$F_V(t) = C_D A \rho \frac{U^2}{2g_0}$$

for the acceleration and standard drag loads, respectively, where:

$F_A(t)$ = the acceleration drag force as a function of time (lbf)

ρ = the density of water (lbm/ft^3)

V_a = the “acceleration drag volume” (ft^3)

a = the local acceleration of the flow field surrounding the submerged structure (ft/sec^2)

$F_V(t)$ = the velocity drag force as a function of time (lbf)

C_D = the velocity drag coefficient (dimensionless)

A = the cross sectional area of the structure in the direction of the flow (ft^2)

U = the local velocity of the flow field surrounding the submerged structure (ft/sec)

g_0 = Newton’s constant (32.2 lbm-ft/lbf-sec^2)

5.0 SUMMARY

This Licensing Topical Report documents the application methodology for the General Electric optimum stacked-disk ECCS suction strainer.

Section 3.0 documents the hydraulic design methodology employed. Applicable test data has been compiled and an empirical design correlation for the GE optimum stacked-disk strainer has been developed. This design correlation considers the methodology described in NUREG/CR-6224 [Ref. 4] and includes the mass of corrosion products to mass of fiber ratio, Reynolds number based on the local velocity across the perforated plate surfaces and the fiber diameter of the insulation, a flow rate factor (bed compaction factor), and the bed thickness to strainer diameter ratio. It has been demonstrated that the correlation between the design methods and the test data is realistic and conservative.

Section 4.0 provides methods for calculation of submerged structure loads for the new strainer installation that can be used in the structural analysis of the torus penetrations, the new strainers, and the strainer supports, if applicable. The load calculation procedures involve the development of scale factors that modify the original strainer loads to account for changes in size, geometry, porosity and location of the new strainers.

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Appendix A

"General Electric Company Stacked Disk Strainer Report"
(CDI Report, December 1996)

General Electric Company

Stacked Disk Strainer Data Report

Revision 0

December 1996

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ABSTRACT

A General Electric Company (GE) stacked disk strainer was tested under a variety of debris and flow conditions in the Boiling Water Reactor Owners' Group (BWROG) test facility at the EPRI facility in Charlotte, North Carolina. This report documents the head loss results from the tests conducted in October and November 1996.

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1. INTRODUCTION

In the event of a Loss of Coolant Accident (LOCA) in a Boiling Water Reactor (BWR) nuclear power plant, insulation installed on piping can reach the wetwell which supplies water to the Emergency Core Cooling System (ECCS). This insulation combined with corrosion products and other debris can migrate and block strainers installed on suction lines supplying the ECCS pumps. An alternate suction strainer design, the GE stacked disk strainer, was provided by the General Electric Company to evaluate its performance under different flow and debris loads. From October into November 1996, Continuum Dynamics, Inc. conducted a series of tests on this strainer. Tests were conducted at the Electric Power Research Institute (EPRI) Non Destructive Evaluation Center in Charlotte, North Carolina.

Testing was conducted following the Plan for Testing GE Strainer, Revision 1, 31 October 1996 (Ref. 1). Test procedures and materials essentially duplicated BWROG procedures and materials for strainer testing (Refs. 2 and 3).

2. TEST FACILITY

A schematic of the test facility is shown in Figure 2-1. The strainer was mounted horizontally to a 24 inch tee in a nominally 50,000 gallon vessel. Two centrifugal pumps capable of producing 10,000 GPM were used to provide system flow controlled by valves on the pump outlets. The flow returned to the vessel through a venturi and then through a pipe whose exit was centered in the vessel and directed down toward the floor. This pipe orientation prevented material from settling on the vessel floor.

Instrumentation

A schematic illustrating the instrument locations is shown in Figure 2-2. The head loss across the strainer and debris bed is measured by a Rosemount 1151 smart differential pressure transmitter that is connected to the blind flange of the strainer tee. The flow rate is measured by the venturi in the return leg of the piping and another a Rosemount 1151 smart differential pressure transmitter. The outputs of these transmitters were connected through Sensotec GMA displays and amplifiers (0.2% accuracy) to a computer controlled DATAQ DI-220 12 bit data acquisition system. Test debris was weighed on an Ohaus model DS10L scale and water temperature was measured with a thermometer. Table 2-1 lists the instruments used in the test program.

Table 2-1. Instrument List

Symbol	Instrument	Range	Accuracy	Comment
DP1	Differential Pressure Transmitter	0-650 inches of water	+/-1 inch of water	Strainer head loss.
DP3	Differential Pressure Transmitter	0-250 inches of water	+/-0.4 inches of water	Used with venturi (+/- 300 GPM accuracy)
A/D	Data Acquisition	0.5 volts	+/-0.025%	Record pressure and flow data.
T1	Thermometer	25-120 degrees F	+/-3 degrees F	Water temperature commercial grade.
B1	Balance	0-100 pounds	+/-0.5 pounds	Weight debris commercial grade.

Strainer

A photograph of the GE stacked disk strainer is shown in Figure 2-3.

Debris Materials

The test materials used in the program were supplied by the manufacturer or were supplied by utilities participating in the program. See the tables and plots in Appendix A for the materials used in the tests.

Summary of Test Procedures

The test procedures duplicated the test procedures used in the BWROG strainer tests. The procedures are summarized below.

The main test procedure defines the steps necessary to perform one complete test for measuring strainer head loss. The main steps in this procedure include system start up, material addition, data acquisition, flow rate control, and test termination. Data acquisition is started before the pumps are turned on and material is added to the vessel after the flow rate has been established. The time of material introduction is recorded. The amount of material added is determined by the test matrix.

During a test the flow rate is maintained at a nearly constant value determined by the test matrix, unless the strainer maximum pressure drop is reached or the maximum pump flow is achieved. After the strainer head loss has reached approximately steady state, the flow rate can be adjusted down and up (a flow sweep) to obtain head loss at different flow rates. A nun is terminated when the strainer head loss reaches approximately steady state or a determined value of head loss has been achieved (after conducting any required flow sweeps). After test termination, a backup copy of the digitally recorded data is made and the ending water temperature is taken.

Daily procedures are followed to check the differential pressure transducers and data acquisition system. Differential pressure cell zeros and known water height readings are taken and compared to the transducer output. The output of the data acquisition system is also checked to insure it is operating correctly and that the instruments are correctly connected. Periodic confidence checks on the scales and thermometer are also conducted as required.

Also associated with each main test procedure is a material preparation procedure which defines how much material is to be added to the vessel. This procedure defines the methods to identify and quantify the materials to be used for each test. All material used in the program is identified by a unique number.

Data is stored on disk as voltages from the differential pressure transducers. Using the calibration curves for each instrument, the voltages are converted to engineering units (either inches of water or gallons per minute). The clean head loss as a function of flow rate is subtracted from each head loss data point to obtain the head loss across the debris bed. The data is plotted in Appendix A as a function of time along with tabulated approximate steady state values.

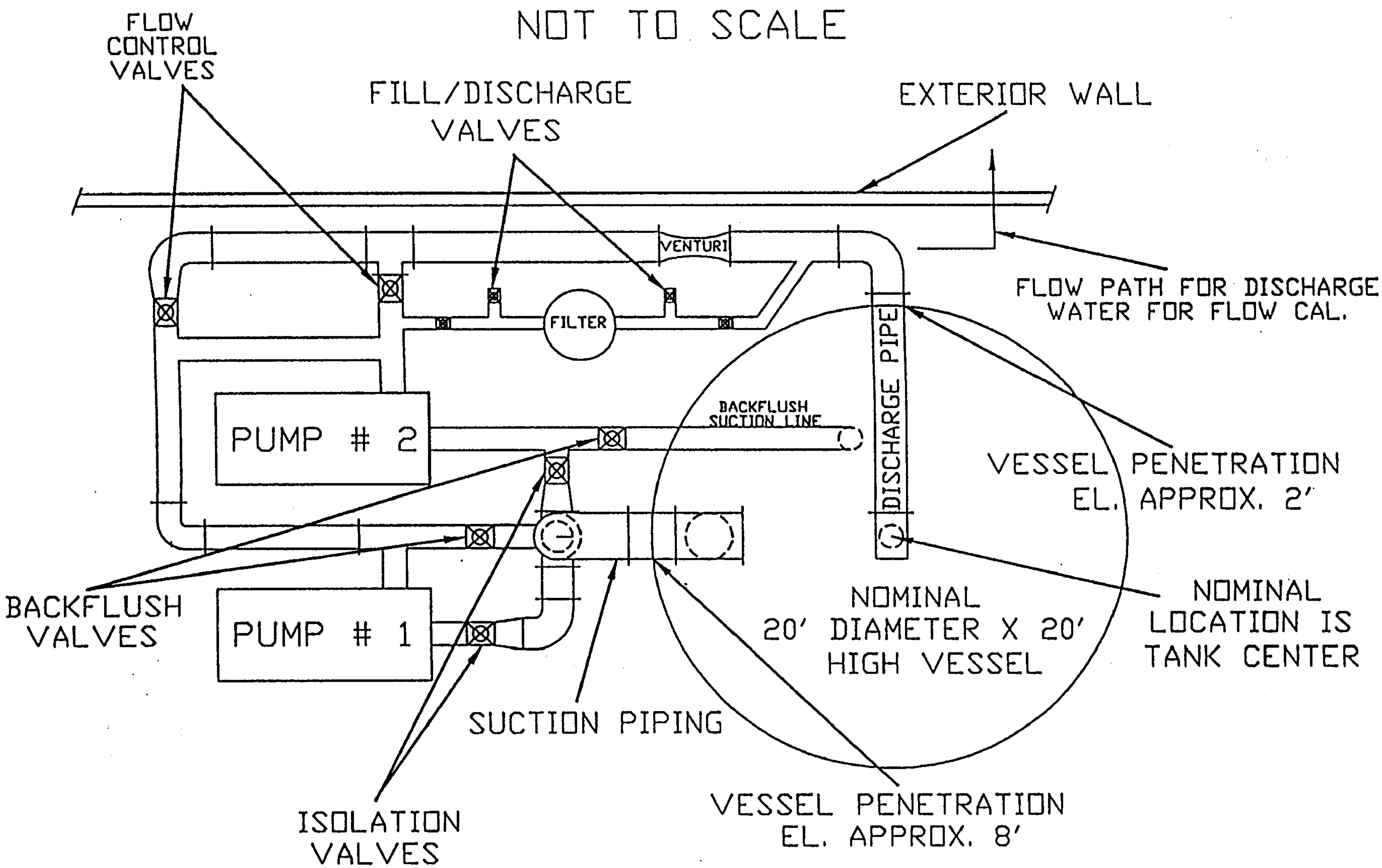

Figure 2-1. Schematic of test facility

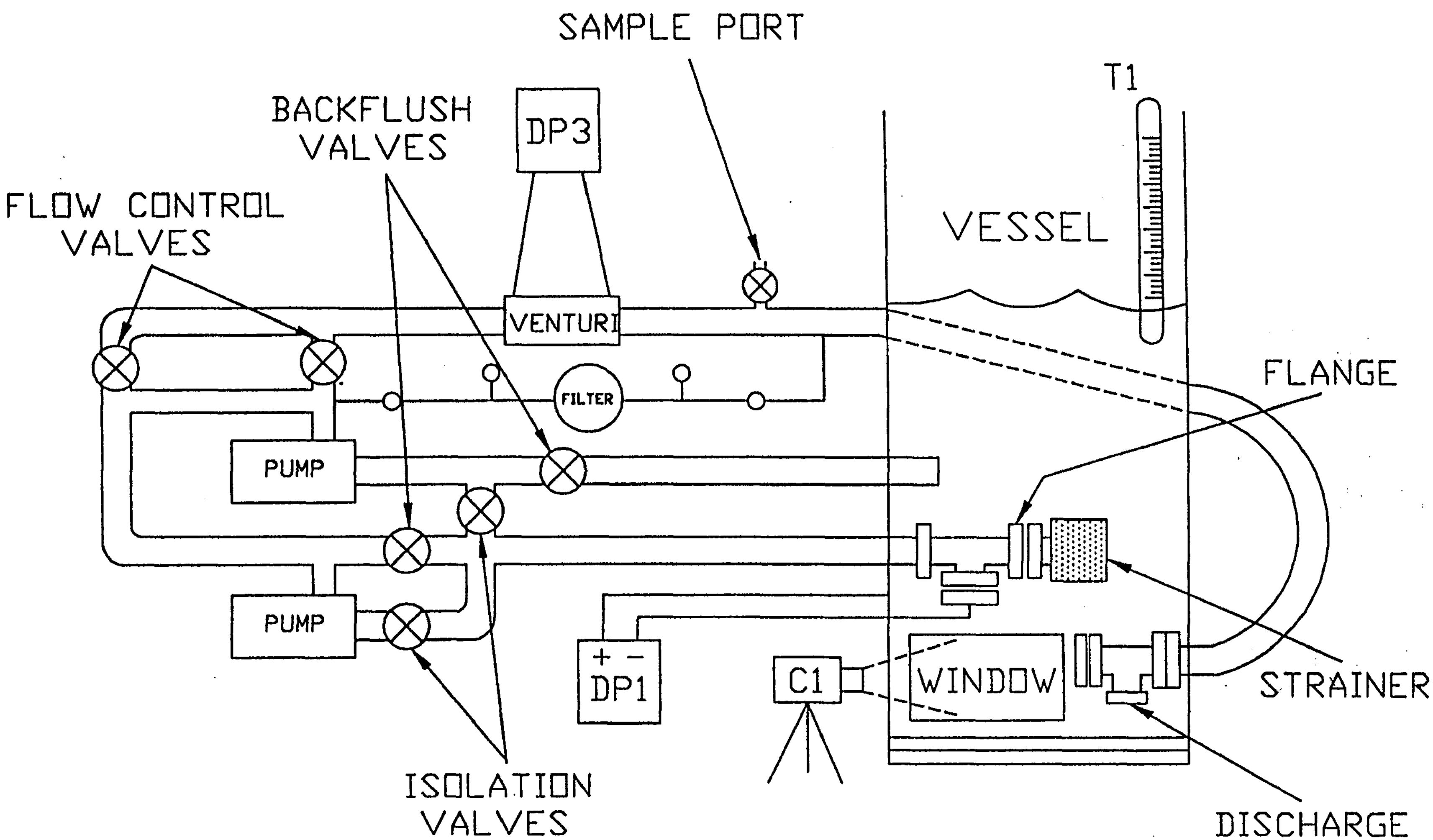

Figure 2-2. Schematic of instrument locations.

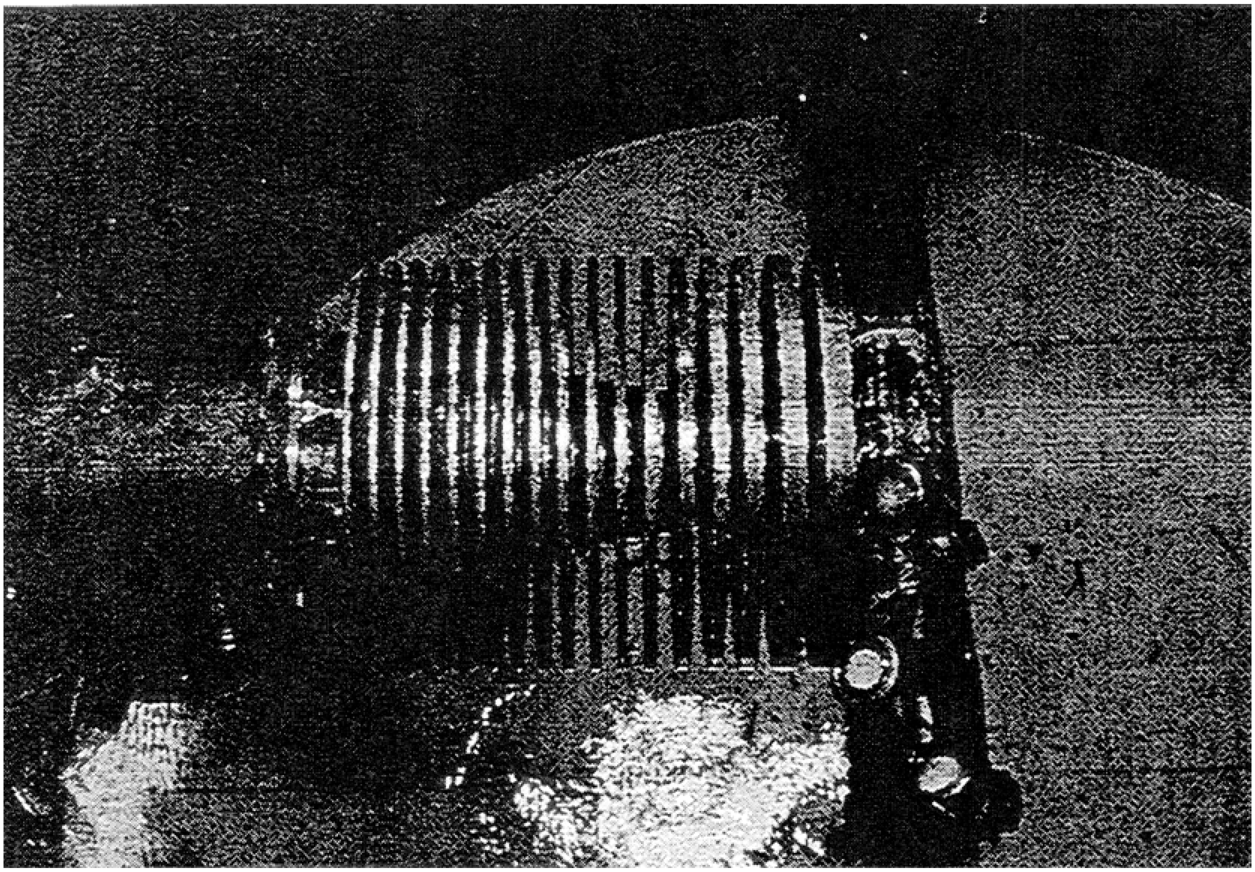

Figure 2-3. Photograph of stacked disk strainer.

3. TEST DATA

Tabular data collected from the test program is included in Appendix A. The tables contain specific information about each test including run number, run date, flow rates tested, mass/amount of materials, the average water temperature and the steady state differential pressure across the strainer (head loss) for that condition. All of the tabulated head loss values represent the head loss across the debris bed. The head loss of the clean strainer has been subtracted (except for the baseline, clean strainer case).

Plots for each of the runs are also included in Appendix A. The plots show the strainer differential pressure and the corresponding flow rate as a function of time. Material addition times and other run specific notes are indicated on the plots. The strainer differential pressure represents the head loss across the debris bed only, "dean" head loss has been subtracted out.

The data contained in the tables and the plots in the Appendix have been verified according to C.D.I. Quality Assurance procedures. Notes for each run are also provided.

4. QUALITY ASSURANCE

All quality related test activities were performed in accordance with the Continuum Dynamics, Inc. Quality Assurance Manual, Revision 12 (Ref. 4). Quality related activities are those which are directly related to the planning, execution and objectives of the tests. Supporting activities such as test apparatus design, fabrication and assembly are not controlled by the C.D.I. Quality Assurance Manual. C.D.L's Quality Assurance Program provides for compliance with the reporting requirements of 10 CFR Part 21. All instrument certification and calibration, test procedures, data reduction procedures and test results will be contained in a Design Record File which (upon completion) will be kept on file at C.D.I. offices.

5. REFERENCES

1. Continuum Dynamics, Inc., Plan for Testing GE Strainer, Revision 1, 31 October 1996.

2. Continuum Dynamics, Inc., DRF-G-118, "Full Scale Strainer Head Loss Testing with Fibrous Insulation and Corrosion Products + Other Debris," July 1996.

3. Continuum Dynamics, Inc., DRF-R-124, "Strainer Testing with Fibrous Insulation & Corrosion Products," December 1996.

4. Continuum Dynamics, Inc., Quality Assurance Manual, Revision 12, October 1996.

A. TEST RESULTS AND DATA PLOTS

The test results and plots of head loss across the debris bed and flow rate are shown for the respective tests. For all runs, except GE1, the clean head loss is subtracted from the total measured head loss to provide the head loss across the debris bed. Head loss is measured in inches of water and flow rate is measured in gallons per minute (GPM).

The following test data is included in this report:

Run GE1

Run GE2

Run GE3

Run GE4

Run GE6

Run GE7

Run GE8

Run GE9

Run GE10.

Appendix B

"Fast Panel Analysis of Strainer Designs"
(CDI Technical Memo No. 97-03, January 1997)

C.D.I. TECHNICAL MEMORANDUM NO. 97-03

FAST PANEL ANALYSIS OF STRAINER DESIGNS

Rev. 0

Prepared by

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February 1997

SUMMARY

A fast panel analysis is used to: (1) predict the hydrodynamic mass coefficients of three GE optimal stacked disk strainer designs placed in an inviscid flow field, and (2) compare these predicted values with predicted mass coefficients for solid cylinders of the same corresponding dimensions.

THEORY

A boundary element analysis developed for nonlifting potential flow is employed to calculate the virtual mass of a closed body. The panel analysis proceeds by first discretizing the surface of the closed body into a collection of constant-strength boundary elements (panels), and then adjusting the individual strengths of the panels so that the superposition of the ambient flow and the flow induced by the panels has zero normal component at every panel centroid. The velocity induced by a panel with constant source strength σ_i is given by:

$$u_i(R) = \sigma_i \int_{A_i} \frac{R - \rho}{r^3}\, dA, \quad r = \left| R - \rho \right| \qquad (1)$$

where A; is the panel area, R is the evaluation point and p is a point on the panel surface. For sufficiently distant observation points, the integral in Eq (1) can be approximated by:

$$u_i(R) = \sigma_i \; A_i \frac{R - \rho_c}{r_c^3} \qquad (2)$$

where ρ_c; is the panel centroid. The non-penetration condition is imposed by requiring for all panels, i=1 to N, that:

$$2\pi\sigma_i + \hat{n}_i \cdot \left(u_\infty + \sum_{j \neq i} u_j\,(R_i) \right) = 0 \qquad (3)$$

The set of equations represented in Eq (3) comprises an N-body problem where each panel interacts with all other panels. The characteristic $O(N^2)$ computational complexity associated with such problems is reduced to O(NlogN) by invoking multipole-based fast summation procedures applied to Eq (2). This fast velocity calculation is embedded within a GMRES iteration sequence to invert Eq (3) for σ_i. Complete details of the fast panel scheme are given in Ref. 1.

Once the panel strengths are known, the panel-induced potential is determined using:

$$\phi(R) = -\sum_{i=1}^{N} \sigma_i \int_{A_i} \frac{1}{r}\, dA \qquad (4)$$

The negative sign reflects preference for the convention:

$$U(R) = +\nabla_R \phi(R) \tag{5}$$

The pressure is given by:

$$P = -\rho \frac{\partial \phi}{\partial t} \tag{6}$$

and the time-varying potential by:

$$\phi(R,t) = \beta(t)\, \phi_0(R) \tag{7}$$

where ϕ_0 is the potential associated with a steady-state flow with unit magnitude ambient velocity (note that from Eqs (3) and (4) the panel strengths and hence potential scale linearly with velocity magnitude). Consequently, to compute the virtual mass it suffices to know the surface potential under steady state conditions. Specifically, Eq (4) is evaluated at every panel centroid. Once again, fast summation methods are employed to reduced computation time. Virtual mass coefficients are obtained by summing:

$$m = -\int_s P\hat{n}\, dA = +\rho\beta\,(t)\int_s \phi_0(R)\hat{n}\, dA \cong +\rho\beta(t)\sum_{i=1}^{N} \phi_0(R_i)\hat{n}(R_i)\hat{n}_i\, A_i \tag{8}$$

Equation (8) accounts only for the panel-induced potential. The contribution from the free stream potential $\phi_0 = u_\infty \cdot R$ is:

$$m_\infty = +\rho\beta(t)\cdot\int_s \hat{n}(R\cdot u_\infty)\, dA = +\rho\beta(t)\; Vu_\infty \tag{9}$$

where V is the volume of the immersed body.

DISCUSSION

Important design values for the GE optimal stacked disk strainer are its hydrodynamic mass coefficients for coaxial flow impinging on the strainer, and for flow normal to the axis of revolution of the strainer. As illustrated in Figure 1 by the velocities $U_1(t)$ and $U_2(t)$, respectively, these flow components create an apparent mass to the strainer, and therefore augment its actual mass in any loads analysis. By definition, the hydrodynamic mass coefficient C_h multiplies the strainer mass defined by the mass enclosed in a solid cylinder of radius R and length L to give the strainer hydrodynamic mass, while the virtual mass coefficient Cm multiplies the strainer volume defined by the volume enclosed in a solid cylinder of radius R and length L to give the strainer acceleration drag volume.

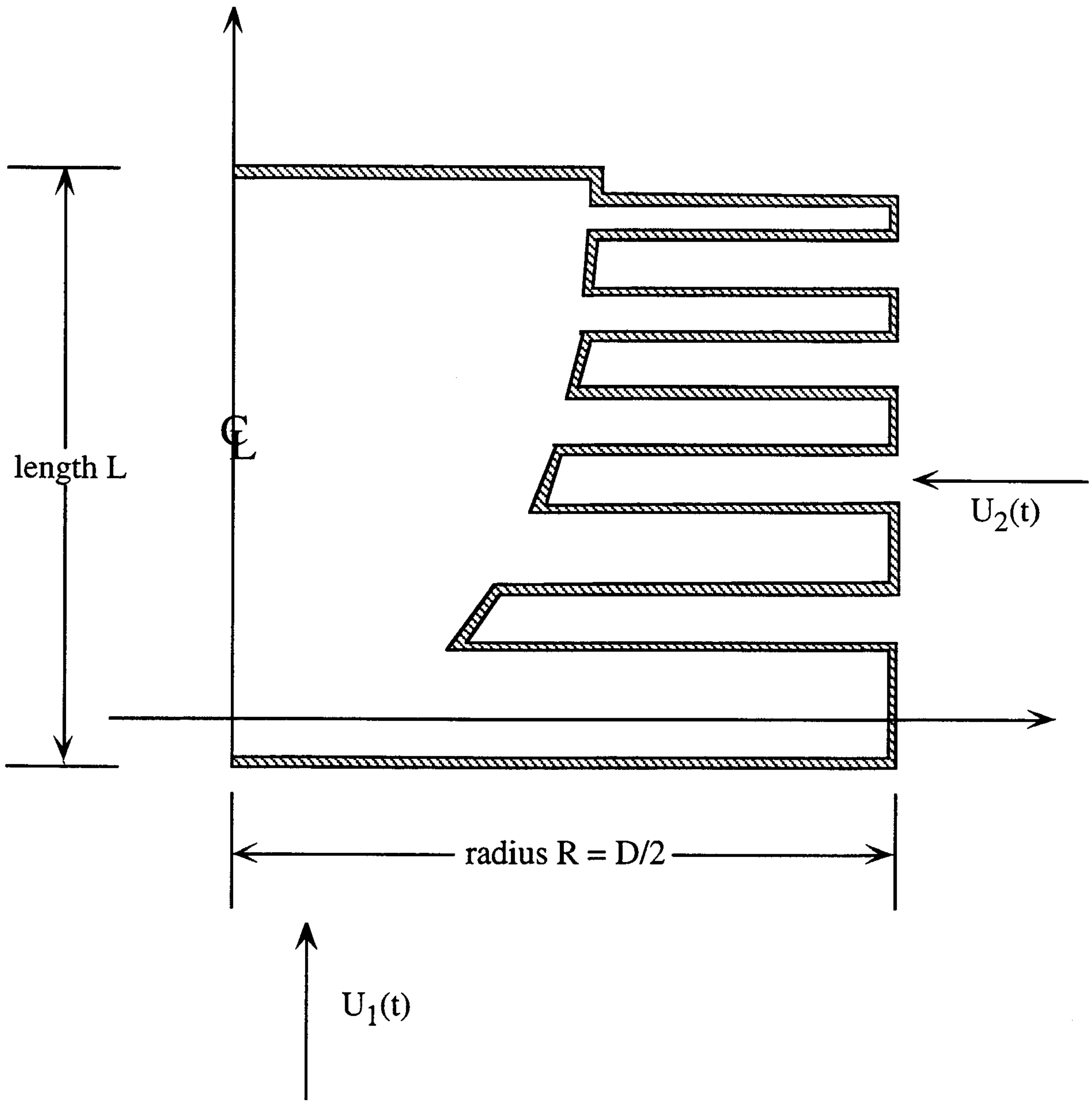

Figure 1. Optimal stacked disk strainer geometry. The strainer has a diameter of D and length of L, with an assumed longitudinal velocity of $U_1(t)$ and crossflow velocity of $U_2(t)$.

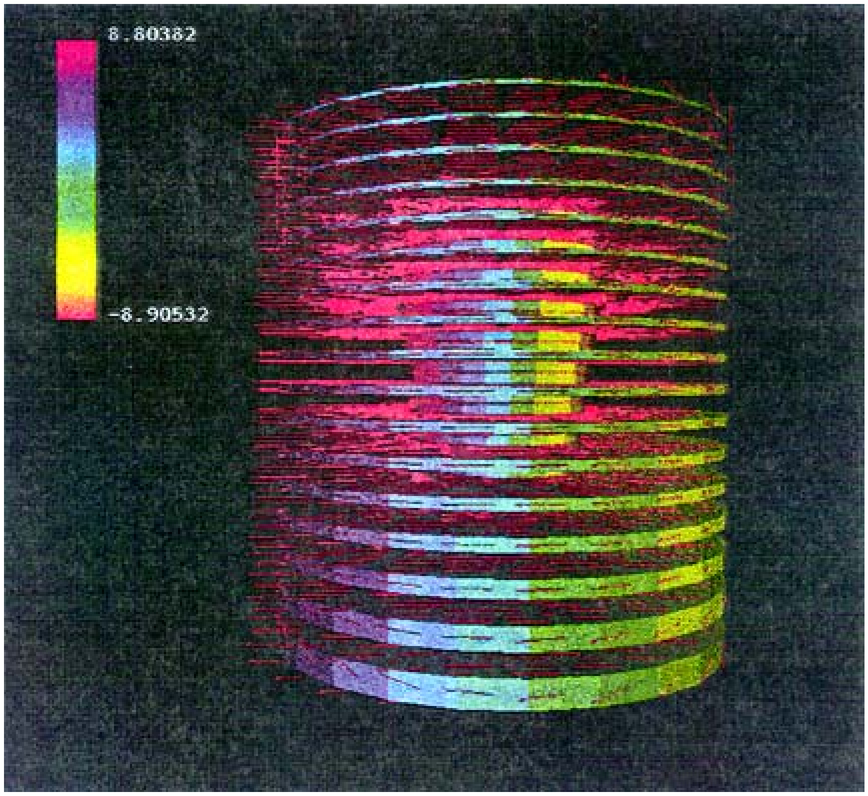

Figure 2. Typical flow field around a stacked strainer for an assumed crossflow velocity of $U_2(t)$. Normalized velocity vectors are shown by red arrows; normalized pressure levels on the surface of the strainer are given by the color scale in the upper left hand corner of the figure.

Table 1. Assumed geometry for the fast-panel inviscid analysis of several stacked disk strainer designs.

D/L	0.6	0.89	1.2
Radius (in)	17.9	21.4	31.4
Length (in)	60.0	48.0	52.6
Number of Plates	20	17	19
Volume (ft^3)	17.52	17.50	33.21
Cylindrical Fraction	0.501	0.438	0.352

REFERENCES

1. Boschitsch, A. H., T. B. Curbishley, T. R. Quackenbush and M. E. Teske. 1996. A Fast Panel Method for Potential Flows about Complex Geometries. Paper No. A96-0024. 34th AIAA Aerospace Sciences Meeting and Exhibit: Reno, NV.

2. Boschitsch, A. H. and T. R. Quackenbush. 1996. Fast Panel Analysis (FPA) (Mod 0.0) User Manual. Technical Memorandum No. 96-20. Continuum Dynamics, Inc: Princeton, NJ.

3. Moody, F. J. 1997. Hydrodynamic Loads on CDI Strainer Design. General Electric Company: San Jose, CA.

4. Lamb, H. 1879. Hydrodynamics: Treatise on the Mathematical Theory of the Motion of Fluids. Dover Publications: New York, NY.

5. 1981. Mark I Containment Program Load Definition Report. NEDO-21888. General Electric Company: San Jose, CA. Table 4.3.4-1 (Revision 2).

Appendix C

Example Output of Strainer Size Calculation

Inputs for ECCS Suction Strainer Design

Plant: Design/Load Case: Calculation Date:	**Example** **Example LTR Calcs.** **3/19/97**
System	**RHR**
# of Pumps	
Rated Pump Flow (gpm)	
# of Strainers	
# of Strainers (CS Sizing)	
# of Strainers (RHR Sizing)	
Strainer Flowrate (gpm)	9349
Load Factor	1
Blockage Area (ft^2)	0
Total Headloss Limit (ft.)	5.26
Strainer Inside Radius (in.)	11.625
Strainer	**RHR**
Strainer Outside Radius (in.)	22
Nominal Flange Size	20
# of Flange Bolt Holes	20
# of Ribs	10
# of “Half” Ribs	0
“Half” Rib Length	0
Rib Width (in)	2
Rib Thickness (in)	0.38
Pool Temperature (F)	130
Volume of Fiber, Vf (ft^3)	10.04
Fiber Type	Nukon
Fiber Diameter (ft)	2.33E-05
Fiber Spacing (ft)	1.56E-04
Fiber Density, rho	2.4
Crud Mass (lb)	145.5
Misc. debris Loads (lb)	
Paint	133.3
Rust	13.2
Sand	0
Dirt/Dust	39.7
Zinc	0
Ca. Si	1.09
RMI Type	2.5 mil SS
Area of RMI Foil (ft^2)	0
US for RMI type	0.39
Kt for RMI Type	0.014
Kp for RMI Type	4.9

Example		RHR			Example LTR Calcs.						
			ECCS Suction Strainer Sizing Calculation								
				(Hydraulic Resistance Formulation – Stack by Stack Method)							
	R =	22	inch		External Radius of the strainer (in.)						
	r(L) =	11.625	inch		Inside radius of ECCS suction strainer flange (in)						
	t(L) =	0.4	inch		Maximum inside disk thickness (in)						
	l,gap =	1.75	inch		Length of gap between disks (in)						
	t,w =	0.12	inch		Thickness of Perforated Plate (11 gauge) (in)						
	t,f =	0.2	inch		Allowance for flow blockage at corner of spacers/disk (in.)						
	b =	5.25	inch		length blocking the circumference of the inner radius of the						
	wb =	10.5	sq. inch		area blocking the central flow						
	ro =	2.7518	inch								
	U/Uc =	0.0068									
	Ud/Uc <	1									
	U/Ud >	0.0068									
	-0.00995										
Stack No.	**f**	**r (in)**	**t (in)**	**A (in^2)**	**L (in.)**	**U/Ud**	**Ud/Uc**	**Uc/Uc**	**Qi/Qt, 1**	**Ai/At**	**Qi/Qt,2**
1	-0.00011	3.137	1.400	3006	3.390	0.007	1.000	0.143	0.049	0.049	0.049
2	-0.00027	4.038	0.992	2986	6.372	0.007	1.000	0.184	0.049	0.049	0.049
3	-0.00056	4.763	0.798	2952	9.160	0.007	1.000	0.217	0.048	0.048	0.048
4	-0.00068	5.385	0.680	2917	11.830	0.007	1.000	0.245	0.048	0.048	0.048
5	-0.00073	5.936	0.598	2883	14.418	0.007	1.000	0.270	0.047	0.047	0.047
6	-0.00074	6.434	0.537	2848	16.945	0.007	1.000	0.292	0.047	0.047	0.047
7	-0.00073	6.890	0.490	2813	19.425	0.007	1.000	0.313	0.046	0.046	0.046
8	-0.00071	7.313	0.452	2779	21.867	0.007	1.000	0.332	0.046	0.046	0.046
9	-0.00067	7.709	0.420	2745	24.276	0.007	1.000	0.350	0.045	0.045	0.045
10	-0.00063	8.080	0.400	2711	26.666	0.007	0.982	0.361	0.044	0.044	0.044
11	-0.00059	8.431	0.400	2677	29.056	0.007	0.924	0.354	0.044	0.044	0.044
12	-0.00055	8.763	0.400	2644	31.446	0.008	0.873	0.348	0.043	0.043	0.043
13	-0.0005	9.080	0.400	2611	33.836	0.008	0.827	0.341	0.043	0.043	0.043
14	-0.00046	9.382	0.400	2578	36.226	0.009	0.787	0.336	0.042	0.042	0.042
15	-0.00041	9.671	0.400	2546	38.616	0.009	0.751	0.330	0.042	0.042	0.042
16	-0.00036	9.948	0.400	2514	41.006	0.009	0.718	0.325	0.041	0.041	0.041
17	-0.00031	10.214	0.400	2482	43.396	0.0010	0.688	0.319	0.041	0.041	0.041
18	-0.00027	10.470	0.400	2451	45.78	0.010	0.660	0.314	0.040	0.040	0.040
19	-0.00022	10.717	0.400	2420	48.176	0.011	0.635	0.309	0.040	0.040	0.040
20	-0.00018	10.956	0.400	2389	50.566	0.011	0.611	0.304	0.039	0.039	0.039
21	-0.00013	11.186	0.400	2359	52.956	0.012	0.589	0.299	0.039	0.039	0.039
22	-8.6E-05	11.409	0.400	2329	55.346	0.012	0.568	0.295	0.038	0.038	0.038
23	-4.3E-05	11.625	0.400	2299	55.986	0.012	0.549	0.290	0.038	0.038	0.038

Example	RHR			Example LTR Calcs		3/19/97
	Head Loss Calculation					
Debris Load:				RMI Summary:		
Mf =	24.10	lb		RMI Type	2.5 mil SS	
	Mx/Mf			Us for RMI Type	0.39	
Crud (Mc/Mf)	6.04			Kt for RMI Type	0.01	
Paint Chip	5.53			Kp for RMI Type	4.90	
Rust	0.55			tmax	0.87	
Sand	0.00			ta, use if >tp	0.00	
Dirt/C. Dust	1.65			tp	0.87	
Zinc	0.00			Dh	0.66	ft
Ca. Silicate	0.05					
Q	9349					
D	44					
L	55.00					
Ac	52.80	ft^2		Surface Area of Cylinder w/Strainer L&D		
Ac, corr	52.80	ft^2				
U	0.39	ft/sec		Flow Velocity for pi*DL (ft/sec)		
U1	0.29	ft/sec		Flow Velocity for pi*Dl + front and back surface (ft/sec)		
nu	5.43E-06	ft^2/sec				
Re,d	11.332					
t	0.19			Fiber thickness of cylindrical strainer (ft) = Vf *LF/Ac		
t/D	0.0519	ft				
Fq	1.000					
Ft	0.500					
Re,df	1.262					
Kh	1.037					
Dh	0.54					
Kbu	2.14					
				Clean Head Loss		
Dh,t	1.15 ft			Q(cu.ft/sec)	20.83	cuft/s
Clean Headloss +	1.83 ft			Flange head (ft)	1649	20” Diameter of suction line
Total Headloss =	2.99 ft	←		Str. Head(ft)	0.775	24” Inner diameter of strainer
RMI Headloss	0.66 ft	←		Str. Loss	1.736	ft
Headloss Limit	5.26 ft	←	+	Flange Loss	0.096	ft
Margin	2.27 ft			Total Clean =	1.832	ft

Example	RHR					Example LTR Calcs.			
Outputs Based on Hydraulic Sizing Methodology – Fiber Loading									
Step	Characteristic					Variable		Value	Units
1	Outside Diameter					D	=	44.00	in
2	Strainer Active Length					L	=	55.00	in
3	Circumscribed Area					Ac	=	52.80	sq. ft.
4	Strainer Blockage					B	=	0.00	sq. ft.
5	Corrected Area					Ac,cor	=	52.80	sq. ft.
6	Flowrate					Q	=	9349	gpm
7	Load FActor					LF	=	1.00	
8	Total NSPH Limit					NPSH,D	=	5.26	ft.
9	Pool Temperature					T	=	130	F
10	Kinematic Viscosity					nu	=	0.00	lb-s-ft/slugs
11	total Volume of Fiber					Vf,t	=	10.04	cu.ft.
12	Volume of Fiber/Strainer					Vf	=	10.04	cu.ft.
13	Density of Fiber					rho,f	=	2.40	lbm/cu.ft.
14	Interfiber Spacing					d	=	0.00	ft.
15	Mass of Fiber/Strainer					Mf	=	24.10	lbm.
16	Total Mass of Corrosion Sludge					Ms,t	=	145.50	lbm.
17	Total Mass of Dirt/Dust					Md,t	=	39.70	lbm.
18	Total Mass of Corrosion Products					Mc,t	=	185.20	lbm.
19	Total Mc,t per Strainer					Mc,t	=	185.20	lbm.
20	Ratio of Corr. Prod/Fiber					Mc/Mf	=	6.04	
21	Strainer Approach Velocity					U	=	0.39	ft./sec.
22	Reynolds Number					Re	=	11.33	
23	Fiber Thickness					t	=	0.19	ft.
24	Ratio of Fiber Thickness/Dia.					t/D	=	0.05	
25	Nondim. Headloss, Kh					Kh	=	1.04	
26	GE Strainer Headloss					Dh	=	0.54	ft.
27	Bump Up Factor					Kbu	=	2.14	ft.
27		Paint Chips	Mx/Mf	=	5.53	Mx	=	133.30	lbm
		Rust	Mx/Mf	=	0.55	Mx	=	13.20	lbm.
		Sand	Mx/Mf	=	0.00	Mx	=	0.00	lbm.
		Dirt/Dust	Mx/Mf	=	1.65	Mx	=	39.70	lbm.
		Zinc	Mx/Mf	=	0.00	Mx	=	0.00	lbm.
		Ca.Si.	Mx/Mf	=	0.05	Mx	=	1.09	lbm.
28	Corrected Head Loss					Dh,cor	=	1.15	ft.
29	Clean Head Loss					Dh,cln	=	1.83	ft.
30	Total Head Loss					Dh,t	=	2.99	ft.
31	NPSH Margin Left					M	=	2.27	ft.

Example	RHR	Example LTR Calcs. 3/19/97

Parts List

Flange Size	20
# of Flange Bolt Holes	20
# of Ribs	10
Disk Sets	23

	Parts	Number of Unique Parts	Number of Parts	Part Number	
				First	Last
1	Bolt	1	20		1
2	Flange	1	1		2
3	Flange Lug	1	2		3
4	Top Support	1	1		4
5	Lifting Pipe	1	1		5
5	Compression Plate	1	10		6
6	Rib	1	10		7
7	Perforated Disk	46	46	8	53
8	Outer Disk Support Ring	23	23	54	76
9	Spacer (Inner Ring)	23	23	77	99
10	Internal Finger	23	230	100	122
	TOTALS	122	367		

Example	RHR	Example LTR Calcs. 3/19/97

PERFORATED DISK

Material: 304L or 304 SST
Thickness: 0.1198 in.
Hole/Spacing Dia. 0.12 x 0.19 spacing

Item No.	Disk No.	Location	Qty.	Outer Dia	Tol	Inner Dia	Tolerance	
							Minus	Plus
8	1	Top	1	43.75	+/- 0.02	6.25	0.01	0.02
9	1	Bot	1	43.785	+/- 0.02	6.03	0.01	0.02
10	2	Top	1	43.75	+/- 0.02	6.27	0.01	0.02
11	2	Bot	1	43.75	+/- 0.02	7.84	0.01	0.02
12	3	Top	1	43.75	+/- 0.02	8.08	0.01	0.02
13	3	Bot	1	43.75	+/- 0.02	9.29	0.01	0.02
14	4	Top	1	43.75	+/- 0.02	9.53	0.01	0.02
15	4	Bot	1	43.75	+/- 0.02	10.53	0.01	0.02
16	5	Top	1	43.75	+/- 0.02	10.77	0.01	0.02
17	5	Bot	1	43.75	+/- 0.02	11.63	0.01	0.02
18	6	Top	1	43.75	+/- 0.02	11.87	0.01	0.02
19	6	Bot	1	43.75	+/- 0.02	12.63	0.01	0.02
20	7	Top	1	43.75	+/- 0.02	12.87	0.01	0.02
21	7	Bot	1	43.75	+/- 0.02	13.54	0.01	0.02
22	8	Top	1	43.75	+/- 0.02	13.78	0.01	0.02
23	8	Bot	1	43.75	+/- 0.02	14.39	0.01	0.02
24	9	Top	1	43.75	+/- 0.02	14.63	0.01	0.02
25	9	Bot	1	43.75	+/- 0.02	15.18	0.01	0.02
26	10	Top	1	43.75	+/- 0.02	15.42	0.01	0.02
27	10	Bot	1	43.75	+/- 0.02	15.92	0.01	0.02
28	11	Top	1	43.75	+/- 0.02	16.16	0.01	0.02
29	11	Bot	1	43.75	+/- 0.02	16.62	0.01	0.02
30	12	Top	1	43.75	+/- 0.02	16.86	0.01	0.02
31	12	Bot	1	43.75	+/- 0.02	17.29	0.01	0.02
32	13	Top	1	43.75	+/- 0.02	17.53	0.01	0.02
33	13	Bot	1	43.75	+/- 0.02	17.92	0.01	0.02
34	14	Top	1	43.75	+/- 0.02	18.16	0.01	0.02
35	14	Bot	1	43.75	+/- 0.02	18.52	0.01	0.02
36	15	Top	1	43.75	+/- 0.02	18.76	0.01	0.02
37	15	Bot	1	43.75	+/- 0.02	19.10	0.01	0.02
38	16	Top	1	43.75	+/- 0.02	19.34	0.01	0.02
39	16	Bot	1	43.75	+/- 0.02	19.66	0.01	0.02
40	17	Top	1	43.75	+/- 0.02	1990	0.01	0.02
41	17	Bot	1	43.75	+/- 0.02	20.19	0.01	0.02
42	18	Top	1	43.75	+/- 0.02	20.43	0.01	0.02
43	18	Bot	1	43.75	+/- 0.02	20.70	0.01	0.02
44	19	Top	1	43.75	+/- 0.02	20.94	0.01	0.02
45	19	Bot	1	43.75	+/- 0.02	21.19	0.01	0.02
46	20	Top	1	43.75	+/- 0.02	21.43	0.01	0.02
47	20	Bot	1	43.75	+/- 0.02	21.67	0.01	0.02
48	21	Top	1	43.75	+/- 0.02	21.91	0.01	0.02

49	21	Top	1	43.75	+/- 0.02	22.13	0.01	0.02
50	22	Bot	1	43.75	+/- 0.02	22.37	0.01	0.02
51	22	Top	1	43.75	+/- 0.02	22.58	0.01	0.02
52	23	Bot	1	43.75	+/- 0.02	22.82	0.01	0.02
53	23	Top	1	43.75	+/- 0.02	23.01	0.01	0.02

Example	RHR	Example LTR Calcs. 3/19/97

DISK SUPPORT RING

Material: 304L or 304 SST
Thickness: 0.25 inch (stock)

Item No.	Disk No.	Qty	Outer Dia	Tolerance		Depth	Tol	Thickness
				Minus	Plus			
54	1	1	44.00	0.06	0.00	1.38	+/- 0.02	0.25 STK
55	2	1	44.00	0.06	0.00	0.97	+/- 0.02	0.25 STK
56	3	1	44.00	0.06	0.00	0.78	+/- 0.02	0.25 STK
57	4	1	44.00	0.06	0.00	0.66	+/- 0.02	0.25 STK
58	5	1	44.00	0.06	0.00	0.58	+/- 0.02	0.25 STK
59	6	1	44.00	0.06	0.00	0.52	+/- 0.02	0.25 STK
60	7	1	44.00	0.06	0.00	0.47	+/- 0.02	0.25 STK
61	8	1	44.00	0.06	0.00	0.43	+/- 0.02	0.25 STK
62	9	1	44.00	0.06	0.00	0.40	+/- 0.02	0.25 STK
63	10	1	44.00	0.06	0.00	0.38	+/- 0.02	0.25 STK
64	11	1	44.00	0.06	0.00	0.38	+/- 0.02	0.25 STK
65	12	1	44.00	0.06	0.00	0.38	+/- 0.02	0.25 STK
66	13	1	44.00	0.06	0.00	0.38	+/- 0.02	0.25 STK
67	14	1	44.00	0.06	0.00	0.38	+/- 0.02	0.25 STK
68	15	1	44.00	0.06	0.00	0.38	+/- 0.02	0.25 STK
69	16	1	44.00	0.06	0.00	0.38	+/- 0.02	0.25 STK
70	17	1	44.00	0.06	0.00	0.38	+/- 0.02	0.25 STK
71	18	1	44.00	0.06	0.00	0.38	+/- 0.02	0.25 STK
72	19	1	44.00	0.06	0.00	0.38	+/- 0.02	0.25 STK
73	20	1	44.00	0.06	0.00	0.38	+/- 0.02	0.25 STK
74	21	1	44.00	0.06	0.00	0.38	+/- 0.02	0.25 STK
75	22	1	44.00	0.06	0.00	0.38	+/- 0.02	0.25 STK
76	23	1	44.00	0.06	0.00	0.38	+/- 0.02	0.25 STK

Example	RHR	Example LTR Calcs. 3/19/97

SPACER (PERFORATED METAL)

Material: 304 SST
Thickness: 0.1198 in.
Hole/Spacing Dia. 0.12 x 0.19 spacing

Item No.	Disk No.	Qty	Inner Dia	Tolerance	Depth	Tol
77	1	1	6.27	+/- 0.02	1.75	+/-0.02
78	2	1	8.08	+/- 0.02	1.75	+/-0.02
79	3	1	9.53	+/- 0.02	1.75	+/-0.02
80	4	1	10.77	+/- 0.02	1.75	+/-0.02
81	5	1	11.87	+/- 0.02	1.75	+/-0.02
82	6	1	12.87	+/- 0.02	1.75	+/-0.02
83	7	1	13.78	+/- 0.02	1.75	+/-0.02
84	8	1	14.63	+/- 0.02	1.75	+/-0.02
85	9	1	15.42	+/- 0.02	1.75	+/-0.02
86	10	1	16.16	+/- 0.02	1.75	+/-0.02
87	11	1	16.86	+/- 0.02	1.75	+/-0.02
88	12	1	17.53	+/- 0.02	1.75	+/-0.02
89	13	1	18.16	+/- 0.02	1.75	+/-0.02
90	14	1	18.76	+/- 0.02	1.75	+/-0.02
91	15	1	19.34	+/- 0.02	1.75	+/-0.02
92	16	1	19.90	+/- 0.02	1.75	+/-0.02
93	17	1	20.43	+/- 0.02	1.75	+/-0.02
94	18	1	20.94	+/- 0.02	1.75	+/-0.02
95	19	1	21.43	+/- 0.02	1.75	+/-0.02
96	20	1	21.91	+/- 0.02	1.75	+/-0.02
97	21	1	22.37	+/- 0.02	1.75	+/-0.02
98	22	1	22.82	+/- 0.02	1.75	+/-0.02
99	23	1	23.25	+/- 0.02	3.06	+/-0.02

Example	RHR	Example LTR Calcs. 3/19/97

INTERNAL FINGER

Material: 304 SST
Thickness: 0.25 inch (stock)

Item No.	Disk No.	Qty	Length	Tol	Depth	Tol	Thickness
100	1	10	20.11	+/- 0.10	1.40	+/- 0.02	0.25 STK
101	2	10	19.21	+/- 0.10	0.99	+/- 0.02	0.25 STK
102	3	10	18.49	+/- 0.10	0.80	+/- 0.02	0.25 STK
103	4	10	17.87	+/- 0.10	0.60	+/- 0.02	0.25 STK
104	5	10	17.31	+/- 0.10	0.54	+/- 0.02	0.25 STK
105	6	10	1682	+/- 0.10	0.49	+/- 0.02	0.25 STK
106	7	10	16.36	+/- 0.10	0.45	+/- 0.02	0.25 STK
107	8	10	15.94	+/- 0.10	0.42	+/- 0.02	0.25 STK
108	9	10	15.54	+/- 0.10	0.40	+/- 0.02	0.25 STK
109	10	10	15.17	+/- 0.10	0.40	+/- 0.02	0.25 STK
110	11	10	14.82	+/- 0.10	0.40	+/- 0.02	0.25 STK
111	12	10	14.49	+/- 0.10	0.40	+/- 0.02	0.25 STK
112	13	10	14.17	+/- 0.10	0.40	+/- 0.02	0.25 STK
113	14	10	13.87	+/- 0.10	0.40	+/- 0.02	0.25 STK
114	15	10	13.58	+/- 0.10	0.40	+/- 0.02	0.25 STK
115	16	10	13.30	+/- 0.10	0.40	+/- 0.02	0.25 STK
116	17	10	13.04	+/- 0.10	0.40	+/- 0.02	0.25 STK
117	18	10	12.78	+/- 0.10	0.40	+/- 0.02	0.25 STK
118	19	10	12.53	+/- 0.10	0.40	+/- 0.02	0.25 STK
119	20	10	12.29	+/- 0.10	0.40	+/- 0.02	0.25 STK
120	21	10	12.06	+/- 0.10	0.40	+/- 0.02	0.25 STK
121	22	10	11.84	+/- 0.10	0.40	+/- 0.02	0.25 STK
122	23	10	11.63	+/- 0.10	0.40	+/- 0.02	0.25 STK

Example	RHR	Example LTR Calcs. 3/19/97

RIB

Material: XM-19 SST
Thickness: 0.38 (stock)
L-offset (base): 3.50 in.

Item No.	Length	Tol	Depth	Tol
1	61.24	+/- 0.15	10.49	+/- 0.15
2	57.85	+/- 0.15	8.49	+/- 0.15
3	54.86	+/- 0.15	7.59	+/- 0.15
4	52.08	+/- 0.15	6.86	+/- 0.15
5	49.41	+/- 0.15	6.24	+/- 0.15
6	46.82	+/- 0.15	5.69	+/- 0.15
7	44.29	+/- 0.15	5.19	+/- 0.15
8	41.81	+/- 0.15	4.73	+/- 0.15
9	39.37	+/- 0.15	4.31	+/- 0.15
10	36.96	+/- 0.15	3.92	+/- 0.15
11	34.57	+/- 0.15	3.55	+/- 0.15
12	32.18	+/- 0.15	3.19	+/- 0.15
13	29.79	+/- 0.15	2.86	+/- 0.15
14	27.40	+/- 0.15	2.55	+/- 0.15
15	25.01	+/- 0.15	2.24	+/- 0.15
16	22.62	+/- 0.15	1.95	+/- 0.15
17	20.23	+/- 0.15	1.68	+/- 0.15
18	17.84	+/- 0.15	1.41	+/- 0.15
19	15.45	+/- 0.15	1.15	+/- 0.15
20	13.06	+/- 0.15	0.91	+/- 0.15
21	10.67	+/- 0.15	0.67	+/- 0.15
22	8.28	+/- 0.15	0.44	+/- 0.15
23	5.89	+/- 0.15	0.22	+/-0-.15