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.

5.0 REFERENCES

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Date: June 28, 2002