# Technical Evaluation of the Pilgrim I Plant Unique Analysis Report

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## ABSTRACT

This Technical Evaluation Report (TER) presents the results of the post-implementation audit of the Plant Unique Analysis Report (PUAR) for the Pilgrim I Nuclear Power Plant. The contents of the PUAR were compared against the hydrodynamic load Acceptance Criteria (AC) contained in NUREG-0661. The TER summarizes the audit findings (Table 1), and discusses the nature and status of the exceptions to the AC identified during the audit (Table 2).

ACKNOWLEDGEMENTS

The cognizant NRC Technical Monitor for this program was Dr. Farouk Eltawila of the Containment Systems Branch (DSI) and the NRC Project Manager was Mr. Jack N. Donohew of the Technical Assistance Program Management Group of the Division of Licensing. Mr. Byron Siegel of the Operating Reactors Branch Number 2 (DL) acted as Head Project Manager.

# List of Acronyms

| | |
|---|---|
| AC | Acceptance Criteria |
| BNL | Brookhaven National Laboratory |
| BWR | Boiling Water Reactor |
| CO | Condensation Oscillation |
| DBA | Design Basis Accident |
| DL | Division of Licensing |
| DSI | Division of Systems Integration |
| FSTF | Full Scale Test Facility |
| LDR | Load Definition Report |
| LOCA | Loss-of-Coolant Accident |
| LTP | Long Term Program |
| NRC | Nuclear Regulatory Commission |
| PUAR | Plant-Unique Analysis Report |
| RFI | Request For Information |
| SMA | Structural Mechanics Associates |
| SRSS | Square Root Sum of the Squares |
| SRV | Safety Relief Valve |
| STP | Short Term Program |
| TER | Technical Evaluation Report |
| TES | Teledyne Engineering Services |
| T/Q | T-Quencher |

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## 1. INTRODUCTION

The suppression pool hydrodynamic loads associated with a postulated loss-of-coolant accident (LOCA) were first identified during large-scale testing of an advanced design pressure-suppression containment (Mark III). These additional loads, which had not explicitly been included in the original Mark I containment design, result from the dynamic effects of drywell air and steam being rapidly forced into the suppression pool (torus). Because these hydrodynamic loads had not been considered in the original design of the Mark I containment, a detailed reevaluation of the Mark I containment system was required.

A historical development of the bases for the original Mark I design, as well as a summary of the two-part overall program (i.e., Short Term and Long Term Programs) used to resolve these issues can be found in Section 1 of Reference 1. Reference 2 describes the staff's evaluation of the Short Term Program (STP) used to verify that licensed Mark I facilities could continue to operate safely while the Long Term Program (LTP) was being conducted.

The objectives of the LTP were to establish design-basis (conservative) loads that are appropriate for the anticipated life of each Mark I BWR facility (40 years), and to restore the originally intended design-safety margins for each Mark I containment system. The principal thrust of the LTP has been the development of generic methods for the definition of suppression pool hydrodynamic loadings and the associated structural assessment techniques for the Mark I configuration. The generic aspects of the Mark I Owners Group LTP were completed with the submittal of the "Mark I Containment Program Load Definition Report" (Ref. 3) and the "Mark I Containment Program Structural Acceptance Guide" (Ref. 4), as well as supporting reports on the LTP experimental and analytical tasks. The Mark I containment LTP Safety Evaluation Report (NUREG-0661) presented the NRC staff's review of the generic suppression pool hydrodynamic load definition and structural assessment techniques proposed in the reports cited above. It was concluded that the load definition procedures utilized by the Mark I Owners Group, as modified by NRC requirements, provide conservative estimates of these loading conditions and that the structural acceptance criteria are consistent with the requirements of the applicable codes and standards.

The generic analysis techniques are intended to be used to perform a plant-unique analysis (PUA) for each Mark I facility to verify compliance with the acceptance criteria (AC) of Appendix A to NUREG-0661. The objective of this study was to perform a post-implementation audit of the plant-unique analysis for the Pilgrim I Nuclear Power Plant (Reference 5) against the hydrodynamic load criteria in NUREG-0661.

## 2. POST-IMPLEMENTATION AUDIT SUMMARY

The purpose of the post-implementation audit was to evaluate the hydrodynamic loading methodologies which were used as the basis for modifying the pressure suppression system of the Pilgrim I Nuclear Power Plant. The Pilgrim I PUAR methodologies (Reference 5) were compared with those of the LDR (Reference 3) as approved in the AC of NUREG-0661 (Reference 1). The audit procedure consisted of a moderately detailed review of the plant unique analysis report (PUAR) to verify both its completeness and its compliance with the acceptance criteria. A list of requests for further information was submitted (Reference 6), and answers were obtained at a meeting with the licensee (Reference 7).

Table 1 summarizes the audit results. It lists the various load categories specified in the AC, and indicates plant-unique information through the references, in the right-hand column, tc the notes which follow in the text.

This audit did not include the Torus Attached Piping Report.

| LOADS | NUREG-0661 AC SECTION | CRITERIA | | NOT APPLICABLE | ALTERNATE APPROACH | NOTES |
|---|---|---|---|---|---|---|
| | | MET | NOT MET | | | |
| CONTAINMENT PRESSURE & TEMPERATURE | 2.1 | ✓ | | | | |
| VENT SYSTEM THRUST LOADS | 2.2 | ✓ | | | | |
| POOL SWELL | | | | | | |
| TORUS NET VERTICAL LOADS | 2.3 | ✓ | | | | |
| TORUS SHELL PRESSURE HISTORIES | 2.4 | ✓ | | | | |
| VENT SYSTEM IMPACT AND DRAG | 2.6 | ✓ | | | | |
| IMPACT AND DRAG ON OTHER STRUCTURES | 2.7 | ✓ | | | | |
| FROTH IMPINGEMENT | 2.8 | ✓ | | | | |
| POOL FALLBACK | 2.9 | ✓ | | | | |
| LOCA JET | 2.14.1 | ✓ | | | | |
| LOCA BUBBLE DRAG | 2.14.2 | ✓ | | | | |
| VENT HEADER DEFLECTOR LOADS | 2.10 | ✓ | | | | |

TABLE 1. LOAD CHECKLIST FOR POST-IMPLEMENTATION AUDIT

| LOADS | NUREG-0661 AC SECTION | CRITERIA | | NOT APPLICABLE | ALTERNATE APPROACH | NOTES |
|---|---|---|---|---|---|---|
| | | MET | NOT MET | | | |
| <u>CONDENSATION OSCILLATION</u> | | | | | | |
| TORUS SHELL LOADS | 2.11.1 | | | | ✓ | 1 |
| LOADS ON SUBMERGED STRUCTURES | 2.14.5 | | | | ✓ | 2 |
| VENT SYSTEM LOADS | 2.11.3 | ✓ | | | | 3 |
| DOWNCOMER DYNAMIC LOADS | 2.11.2 | ✓ | | | | 4 |
| <u>CHUGGING</u> | | | | | | |
| TORUS SHELL LOADS | 2.12.1 | | | | ✓ | 5 |
| LOADS ON SUBMERGED STRUCTURES | 2.14.6 | | | | ✓ | 6 |
| VENT SYSTEM LOADS | 2.12.3 | ✓ | | | | 7 |
| LATERAL LOADS ON DOWNCOMERS | 2.12.2 | ✓ | | | | |

TABLE 1. (CONTINUED)

| LOADS | NUREG-0661 AC SECTION | CRITERIA MET | CRITERIA NOT MET | NOT APPLICABLE | ALTERNATE APPROACH | NOTES |
|---|---|---|---|---|---|---|
| T-QUENCHER LOADS | | | | | | |
| DISCHARGE LINE CLEARING | 2.13.2 | ✓ | | | | |
| TORUS SHELL PRESSURES | 2.13.3 | ✓ | | | | 8 |
| JET LOADS ON SUBMERGED STRUCTURES | 2.14.3 | | | | ✓ | 9 |
| AIR BUBBLE DRAG | 2.14.4 | | | | ✓ | 9 |
| THRUST LOADS ON T/Q ARMS | 2.13.5 | ✓ | | | | |
| S/RVDL ENVIRONMENTAL TEMPERATURES | 2.13.6 | ✓ | | | | |

Table 1. (Continued)

| DESCRIPTION | NUREG-0661 AC SECTION | CRITERIA MET | CRITERIA NOT MET | NOT APPLICABLE | ALTERNATE APPROACH | NOTES |
|---|---|---|---|---|---|---|
| SUPRESSION POOL TEMPERATURE LIMIT | 2.13.8 | | | | ✓ | 10 |
| SUPRESSION POOL TEMPERATURE MONITORING SYSTEM | 2.13.9 | ✓ | | | | |
| DIFFERENTIAL PRESSURE CONTROL SYSTEM FOR THOSE PLANTS USING A DRYWELL-TO-WETWELL PRESSURE DIFFERENCE AS A POOL SWELL MITIGATOR | 2.16 | ✓ | | | | 11 |
| SRV LOAD ASSESSMENT BY IN-PLANT TEST | 2.13.9 | ✓ | | | | 8 |

TABLE 1. (CONTINUED)

Table 1 Notes

1. The AC requires absolute summation of the CO load harmonics (from 1 to 50 Hz) for the analysis of structures affected by CO loads. Pilgrim I used a random phasing methodology instead, where the absolute sum of the four highest component responses is added algebraically to the SRSS of the remaining component responses to get a total shell response. Loads on support and anchor systems were determined by adding the absolute value of the three highest harmonic contributors to the SRSS of the others. Combination of individual harmonic stresses into total element stress was done by considering frequency contributions at 31 Hz and below. This methodology was found acceptable. See Section 3.1 for additional details.
2. For condensation oscillation loads on submerged structures, the AC requires that loads be computed on the basis of both the average of all sources and maximum nearest source as derived from FSTF data. FSI effects must be included. For Pilgrim I, phased CO sources were used for CO and CO-FSI drag. Final loads were determined by adding the four maximum frequency contributors to the SRSS sum of the others. See Section 3.1 for additional details.
3. Instead of using a sinusoidal load superimposed on a static load for a CO vent system load, both loads were applied in a static manner to calculate pressures for Pilgrim I. The low frequency of the applied pressure was cited as justification. This analysis was found acceptable.
4. The licensee states that an evaluation was performed which showed that the combined effects (i.e., horizontal and vertical components) of the CO downcomer load was comfortably bounded by the chugging lateral loads. Therefore, the licensee used chugging lateral load results for all load cases in place of CO downcomer loads. This analysis was found acceptable (See also Reference 7).

5. The AC requires that total response to post-chug loads is obtained by summing steady state response from each frequency from 1 to 50 Hz. The Pilgrim I post-chug response was bounded by using pre-chug stresses in the torus shell. This was justified on the basis of comparisons done on another TES plant and the low level of loads involved. This methodology was found acceptable. See Section 3.2 for further discussion.
6. For chugging loads on submerged structures, the approach used for Pilgrim I differs from that approved in the AC. As for CO, source strength for post-chug loads is based on a phasing methodology. However, for post-chug loads five maximum frequency contributors are added to the SRSS sum of the others. This method was found acceptable. See Section 3.2 for further discussion.
7. For internal vent system loads due to chugging, the licensee states that an evaluation was performed which showed that internal vent system pressures were substantially less than internal vent pressures resulting from pool swell. The licensee used the pool swell pressure values in all combined load cases involving chugging pressures. This analysis was found acceptable.
8. Torus shell pressures due to T-quencher loads were based on data collected during in-plant SRV tests. While this is in accordance with the AC, the way in which the design loads were developed represents an exception to the AC requirement of conservative interpretation of the test data. The methodology was found acceptable in part because of existing margins in the structure capacity. See Section 3.5 for additional information regarding this issue.

9. SRV drag loads on submerged structures in Pilgrim I were not computed according to AC approved methods. Instead, drag loads were based on data collected during in-plant SRV tests. Test data was scaled to correct for appropriate SRV conditions and then applied to the structural model to determine stress. This methodology represents an exception to the AC and was discussed with the licensee. It was found acceptable largely because of existing margins in the loads. See Section 3.4 for additional information regarding this issue.

10. The local suppression pool temperature limit was defined in NUREG-0661 as 200°F for the generic Mark I T-quencher as described in Appendix A, Section 2.13.8. Subsequently, NUREG-0783 provided procedures whereby the limit could be increased if certain restrictions could be met. Conformance with the above criteria was indicated in the PUAR. However, the applicant utilized a local pool temperature model whose overall methodology provides a conservative way of computing pool temperature transients for purposes of demonstrating compliance with the provisions of NUREG-0783.

11. As a means to reduce shell pressures related to DBA pool swell, a minimum positive pressure difference of 1.17 psi is maintained between the Pilgrim I drywell, including the vent system, and the torus air space. A nitrogen inerting system is used to pressurize the drywell to 1.17 psi, while the torus remains at ambient pressure. According to technical specifications, the plant is required to come to shutdown if the main $\Delta p$ system fails.

## 3. EXCEPTIONS TO GENERIC ACCEPTANCE CRITERIA

Pilgrim I is one of several plants analyzed by Teledyne Engineering Services based on an essentially common hydrodynamic loading methodology (Vermont Yankee, Millstone, J. A. Fitzpatrick and Nine Mile Point are other plants in this group). The methodology differs from the generic acceptance criteria of NUREG-0661 in five major areas which are listed in Table 2.

In what follows, each of these areas is discussed in detail, and the bases for the resolutions of the differences indicated.

Table 2: Issues Identified During Audit as Exceptions to the Generic Acceptance Criteria

| Issue No. | Description | Status: Resolved | Status: Open |
|---|---|---|---|
| 1. | Phasing of load harmonics used to analyze structures affected by CO loads | X | |
| 2. | Phasing of load harmonics used to analyze structures affected by post-chug loads | X | |
| 3. | CO/chug drag loads on the ring girder | X | |
| 4. | Submerged drag loads due to SRV water jet and air clearing | X | |
| 5. | SRV torus shell loads* | X | |

*While use of in-plant SRV test data to develop SRV torus shell pressure loads is permitted by the AC, the use of the data by Pilgrim I represents an exception to the AC requirement of conservative interpretation of the in-plant test data.

3.1 Harmonic Phasing for CO Response

The CO torus shell load is an oscillating load caused by periodic pressure oscillations superimposed upon the prevailing local static pressure. The LDR defines the load in terms of a rigid wall pressure amplitude versus frequency spectra from 0 to 50 Hz which is to be used in conjunction with a flexible wall coupled fluid structure model. In addition, three alternative sets of spectral amplitudes are provided in the range from 4 to 16 Hz and the alternative which maximized the response is to be used. The resulting reponses from applying the amplitude at each frequency given in the total spectra to be analyzed are to be summed. The above procedure was found acceptable in the AC because the high degree of conservatism associated with the direct summation of the Fourier components of the spectrum was more than sufficient to compensate for any uncertainties associated with the FSTF data from which the load specification was developed. Direct application of the above methodology to the Pilgrim I torus proved to be too conservative and so an alternate approach based on a study performed in Reference 8 was used. The alternative approach obtains the total response for CO by taking the absolute sum of the four highest harmonic component responses and adding algebraically the SRSS of the remaining component responses for shell stresses. Loads on the support and anchor systems are determined by adding the three highest harmonics to the SRSS of the others. For CO drag loads on submerged structures the four maximum harmonic contributors added to the SRSS sum of the others are used for source strength. In all these cases only harmonics of 31 Hz or below are considered, while the AC requires harmonics to 50 Hz.

The Pilgrim I procedure is one of several variations for implementing phasing in the CO load definition discussed in Reference 8 and subsequent SMA Reports (References 9, 10) which account for data obtained after Reference 8 was published. Reference 11 reviews the various design rules and their justification as given in References 8, 9 and 10 and discusses why they are acceptable alternatives to the LDR procedure. The method used for Pilgrim I shell stresses and torus loads was one which was found to be marginally acceptable in Reference 11 provided stresses are not within a few percent of allowables. Since critical stresses in the Pilgrim I shell and its support system are well below allowables for the controlling load combinations which include CO, the alternative approach for obtaining shell and support system CO response has been found acceptable. Using phased CO sources for submerged structure drag loads has been found acceptable since one can expect the CO pressure signals to be considerably more desynchronized for this loading than for the shell pressure loads.

3.2 Harmonic Phasing for Post-Chug Response

Post-chugging is defined as a spectral load across a wide band of frequencies, similar to CO, but lower in amplitude. The AC requires that total response to post-chug loads is obtained by summing steady state response from each frequency from 1 to 50 Hz. The response of the torus shell and associated support system was obtained for one TES plant by combining the 4 maximum harmonic responses with the SRSS of the others for frequencies below 32 Hz. The licensee states in the PUAR that post-chug stresses were small and loads due to post-chug were always bounded by pre-chug values. Therefore, the licensee used pre-chug stress values for all analysis involving post-chugging. In order to account for the 32-50 Hz harmonics in the post-chug spectrum, the PUAR further states that these pre-chug stresses may be increased by 53% and still meet allowables. Based on these statements by the licensee and the fact that chugging is generally acknowledged to be an asynchronous load, the use of pre-chug stresses for all load combinations involving post-chugging to evaluate shell and support system stresses has been found acceptable.

For submerged structure drag due to post-chug sources, a phased methodology, using the five maximum harmonic contributors plus the SRSS sum of the others, has been employed for Pilgrim I. Since post-chug loads for submerged structure drag loads can be expected to be even more desynchronized than for shell loads and since absolute summing of the five maximum harmonics is a fairly conservative phasing approach, this method has also been found acceptable.

3.3 CO/Chugging Ring Girder Drag Loads

The theoretical hydrodynamic mass coefficient used for the Ring Girder CO and chugging drag analysis of Pilgrim I is not the limiting one required by the AC, i.e., a circumscribed cylinder of diameter equal to $\sqrt{2}\,L_{max}$ in the maximum transverse dimension. Instead, a circumscribed cylinder of diameter $L_{max}$ is used, justified by the relatively low ratio of fluid motion to structural dimension. The staff finds this modelling conservative because of the overprediction of the "effective buoyancy" term for an I-beam like structure, and the great overprediction of the flange force. The reduction of the interference factor for web forces may not be totally justified by the argument in Appendix 3. The even greater reduction that could be used for flange forces, coupled to the remaining conservatism in the acceleration volume, provides adequate conservatism in the PUAR calculation of ring girder loads.

3.4 In-Plant SRV Data for Submerged Structure Drag

The AC and LDR require T-quencher bubble-induced drag loads on submerged structures to be calculated on the basis of an analytical model whose major assuptions are summarized in Section 5.2.5.1 of the LDR (Ref. 3). For Pilgrim I a completely different approach was used: During in-plant SRV tests in Pilgrim I and three other plants, strains were measured on two or three submerged structures in each plant. From these data (a total of 10 points) an equivalent static load was computed for each structure. This was done by calculating the static pressure load which would produce the same bending stresses as those measured, when applied uniformly to the structure. From these calculations a curve was developed showing static pressure values versus horizontal distance from the quencher. The curve is supposed to represent the equivalent static drag pressures, including quencher jet loads. To account for other SRV load cases besides those tested, the curve is scaled by the ratio of the calculated shell pressures for the various cases to the test case.

The staff had several concerns with this methodology, particularly since it did not account for bubble frequency content or structure reponse characteristics in a direct manner.

However, the stresses computed for Pilgrim I with this methodology were well below the allowable limits. The ratio by which the SRV-induced drag could be increased before the allowable load was reached ranged from 2 in the case of the downcomers to 40 in the case of vent header support pins, and was greater than 3.5 for all submerged structures other than the downcomers (7). For the downcomers, Teledyne has presented results calculated by a separate agent for another plant owned by a different utility which used a test calibrated version of the LDR methodology for its SRV drag loads. For a similar downcomer at a similar distance from the quencher, the loads calculated for this plant were comparable to those obtained by the Teledyne/Pilgrim I methodology, giving the staff confidence that a factor of 2 load margin was quite adequate for the downcomer in Pilgrim I.

Based on the large margins, therefore, and on the favorable comparison of loads on a similar downcomer computed using a method accepted by the NRC, the Pilgrim I submerged structure drag loads were found to be satisfactorily computed.

3.5 SRV Torus Loads

The design value used by Pilgrim I for SRV shell pressure loads was derived by extrapolation of the peak pressure (7.8 psid) observed during a series of four SRV actuations performed in the Pilgrim I plant. If the overall structural capability of the containment is not considered, this is an inadequate procedure in that it does not represent a "conservative interpretation of the in-plant test data" as required by the acceptance criteria (2.13.9.2.3).

Whenever the available data base is limited, and particularly when the data exhibit large variability, a bounding approach is not appropriate. Conventional engineering practice dictates the application of statistical methods for data interpretation to provide sufficient confidence that the loads used for design will not be exceeded.

For the Pilgrim I tests, the average of the four positive pressures that were recorded was 6.0 psid with a standard deviation of about 11%. The corresponding (95-95) nonexceedance value of positive pressure is 10.6 psid, a value substantially greater than the peak observed value. Extrapolation of this pressure to design conditions implies a design pressure of about 17 psid. This exceeds the value used by the applicant (12.6 psid), but is well below the value that can be accommodated by the structure according to the information supplied to us in Reference 7. On this basis we find the proposed design acceptable.

4. CONCLUSIONS

A post-implementation pool dynamic load audit of the Pilgrim I PUAR has been completed to verify compliance with the generic acceptance criteria of

NUREG-0661. Five major differences were identified between the PUAR and the generic acceptance criteria. Based on additional information supplied by the applicant as detailed in the previous section all of these issues were resolved. The review of the Pilgrim I PUAR Torus suppression chamber has been completed with no issues or concerns outstanding.

## 5. REFERENCES

References cited in this report are available as follows:

Those items marked with one asterisk (*) are available in the NRC Public Document Room for inspection; they may be copied for a fee.

Material marked with two asterisks (**) is not publicly available because it contains proprietary information; however, a nonproprietary version is available in the NRC Public Document Room for inspection and may be copied for a fee.

Those reference items marked with three asterisks (***) are available for purchase from the NRC/GPO Sales Program, U. S. Nuclear Regulatory Commission, Washington, D. C. 20555, and/or the National Technical Information Service, Springfield, Virginia 22161.

All other material referenced is in the open literature and is available through public technical libraries.

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