Technical Evaluation of the Browns Ferry Nuclear Plant

Plant Unique Analysis Report

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September 1984

FIN A-3713

BNL-04243

ABSTRACT

This Technical Evaluation Report (TER) presents the results of the post-implementation audit of the Plant Unique Analysis Report (PUAR) for the Browns Ferry Nuclear Plant (Units 1, 2 and 3). 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 (Appendix A of NUREG-0661, Reference 1)
BNL	Brookhaven National Laboratory
BFN	Browns Ferry Nuclear Plant
BWR	Boiling Water Reactor
CO	Condensation Oscillation
DBA	Design Basis Accident
DL	Division of Licensing
DSI	Division of Systems Integration
FRC	Franklin Research Center
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
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 Browns Ferry Nuclear 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 Browns Ferry Nuclear Plant. The Browns Ferry 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, to the notes which follow in the text.

LOADS	NUREG-0661 AC SECTION	CRITERIA: MET	CRITERIA: NOT MET	NOT APPLICABLE	ALTERNATE APPROACH	NOTES
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: MET	CRITERIA: NOT MET	NOT APPLICABLE	ALTERNATE APPROACH	NOTES
<u>CONDENSATION OSCILLATION</u>						
TORUS SHELL LOADS	2.11.1				✓	2
LOADS ON SUBMERGED STRUCTURES	2.14.5				✓	2
VENT SYSTEM LOADS	2.11.3	✓				
DOWNCOMER DYNAMIC LOADS	2.11.2	✓				
<u>CHUGGING</u>						
TORUS SHELL LOADS	2.12.1				✓	3
LOADS ON SUBMERGED STRUCTURES	2.14.6				✓	4
VENT SYSTEM LOADS	2.12.3	✓				
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
<u>T-QUENCHER LOADS</u>						
DISCHARGE LINE CLEARING	2.13.2	✓				
TORUS SHELL PRESSURES	2.13.3				✓	5
JET LOADS ON SUBMERGED STRUCTURES	2.14.3	✓				
AIR BUBBLE DRAG	2.14.4	✓				
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		NOT APPLICABLE	ALTERNATE APPROACH	NOTES
		MET	NOT MET			
SUPRESSION POOL TEMPERATURE LIMIT	2.13.8	✓				6
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	✓				7
SRV LOAD ASSESSMENT BY IN-PLANT TEST	2.13.9	✓				

TABLE 1. (CONTINUED).

Table 1 Notes

1. The AC requires that a 21.5% safety margin be applied on the loads defined in the LDR for the torus net vertical upload and the torus shell pressure above the pool. BFN applied a margin of 6.5%. This method was found acceptable. See Section 3.1 for additional details.

2. For analyzing structures affected by CO loads, the LDR and NUREG-0661 prescribe absolute summation of the CO load harmonics at 1-Hz intervals from 1 to 50 Hz. BFN used an alternate approach where:

   (i) forcing frequencies above 31 Hz were neglected, and

   (ii) four particular load harmonics (the ones at 4-5, 5-6, 10-11, and 15-16 Hz) were added absolutely and added to the SRSS of the remaining 26.

   This method was found acceptable. See Section 3.2 for details.

3. While pre-chug loads were analyzed by BFN in accordance with the AC, the post-chug load definition differed from that of the AC. Instead of summing all the steady state responses from each of the prescribed forcing functions in the 1 to 50 Hz frequency range as stipulated in the AC, BFN neglected the forcing functions for frequencies above 30 Hz. The 30 included forcing functions were, however, summed in compliance with the AC. This method was found acceptable. See Sec. 3.3 for further details.

4. For post-chug drag loads on submerged structures, BFN used an approach different from the AC. All the prescribed forcing functions from 1-50 Hz were analyzed. However, instead of summing them absolutely, BFN combined the five largest forcing functions by absolute summation and added the

SRSS of the rest. This method was found acceptable, as discussed in Section 3.4 below.

5. BFN's multiple SRV load definition is an SRSS combination of the pressures due to the individual SRV's. This deviates from the AC, which prescribes an absolute summation. BFN's load methodology was found acceptable. See Section 3.5 for details.

6. The local suppression pool temperature limit was defined in the AC as 200F 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.

7. As a means to reduce shell pressures related to DBA pool swell, a positive pressure difference is maintained between the BFN drywell, including the vent system, and the torus air space. A nitrogen inerting system is used to pressurize the drywell, while the torus remains at ambient pressure. According to technical specifications, the plant is required to come to shutdown if the main Δp system fails.

3. EXCEPTIONS TO GENERIC ACCEPTANCE CRITERIA

The Browns Ferry Nuclear Plant was analyzed by the Tennessee Valley Authority, Division of Engineering Design, Civil Engineering Support Branch (Reference 5). The load application methodology differs from the generic acceptance criteria of NUREG-0661 in five major areas which are listed in Table 2.

In Sections 3.1-3.5, each of these five 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	Discussion	Status	
			Resolved	Open
1.	Margin applied to pool swell torus uploads	Sec. 3.1	X	
2.	Method of combining CO load harmonics	Sec. 3.2	X	
3.	Neglect of load harmonics above 30 Hz in post-chug torus load definition	Sec. 3.3	X	
4.	Method of combining load harmonics associated with post-chug drag loads on submerged structures	Sec. 3.4	X	
5.	SRV torus loads	Sec. 3.5	X	

3.1 Margin Applied to Pool Swell Torus Uploads

The AC stipulates that, in order to bound uncertainties in the empirical data base and its interpretation, the load specified in the LDR for the torus upload and airspace pressure during pool swell be increased by 21.5%. Part of this margin (6.5%) accounts for experimental scatter; and the rest (15%) for several uncertainties (see pp. 36-37 of Reference 1), one of which arose from the fact that the generic load definition was derived from tests done on a particular torus geometry.

BFN applied a margin of 6.5% to the LDR torus uploads. In other words, they imply that the added 15% margin is unnecessary in their case. There are several reasons for this (see Item 1 of Reference 7), among them the fact that the uncertainty in the generic load definition resulting from the use of a specific torus geometry was minimized because the torus geometry used was that of BFN. BFN also included several conservatisms in their load definition, for example, using absolute summation of the peak strain magnitudes due to the various loads to define a load combination. These reasons, plus the fact that the BFN torus tiedown design is not in any case controlled by a load combination involving pool swell, render the BFN methodology acceptable.

3.2 Method of Combining CO Load Harmonics

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 harmonics at 1 Hz intervals from 1 to 50 Hz, providing a rigid-wall pressure amplitude for each frequency interval. These load harmonics are to be used in conjunction with a flexible-wall coupled fluid-structure model. In the range from 4 to 16 Hz, three alternative sets of spectral amplitudes are provided and the alternative which maximized the response is to be used. The resulting responses 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 BFN torus proved to be too conservative and so an alternate approach based in part on a study performed in Reference 8 and subsequent related reports (References 9, 10) was used.

The BFN methodology for CO loads involved (i) neglecting those of the LDR load harmonics having frequencies greater than 30 Hz, and (ii) obtaining a load definition by adding the absolute magnitudes of four specific load harmonics (the ones at 4-5, 5-6, 10-11 and 15-16 Hz) to the SRSS of the remaining ones.

The neglect of the load harmonics with frequencies greater than 30 Hz is based on the structural response of the BFN plant. The responsive structural modes of the torus occur at frequencies below 30 Hz. This is in agreement with the analyses done by most other Mark I plants (see Reference 8). As for the submerged structure drag loads due to CO, these are small compared with the post-chug loads at frequencies over 30 Hz, and the latter were used in the critical load combinations.

The BFN method of combining load harmonics below 31 Hz is similar to one of those suggested in References 8-10, and found marginally acceptable in Reference 11 provided stresses are not within a few percent of allowables. The difference is that in Reference 8, the load definition calls for the absolute summation of those four load harmonics which produce the maximum structural response, whereas BFN used the four specific load harmonics quoted previously.

The BFN methodology was found acceptable. First, three of the four load harmonics which were absolute summed were in fact the ones producing the highest response in the torus. Secondly, BFN stated in a discussion with FRC on 13 September 1984 that the CO shell loads could be increased 2-1/2 times without exceeding allowable stresses for any required load combinations.

3.3 Neglect of Load Harmonics Above 30 Hz in Post-Chug Torus Load Definition

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.

BFN followed this procedure except that, consistent with the torus response referred to in the previous section, the forcing functions above 30 Hz were neglected. The absolute summation of all 30 remaining forcing functions is significantly more conservative than using the combination of the absolute sum of the four highest of them and the SRSS of the rest, as been found acceptable in Reference 11.

3.4 Combining of Load Harmonics Associated with Post-Chug Drag Loads on Submerged Structures

For submerged structure drag due to post-chug sources, a phased methodology, using the five maximum harmonic contributors plus the SRSS sum of the remaining 45, has been employed for BFN. Since post-chug loads for submerged structure drag loads can be expected to be even more desychronized than for shell loads and since absolute summing of the five maximum harmonics plus SRSS of the rest up to 50 Hz is one of the more conservative phasing approaches used in References 9 to 10, this method has been found acceptable.

3.5 SRV Torus Loads

In Section 4.2.2.1 of the PUAR, the applicant states that the torus shell pressures for multiple valve load cases are obtained by combining pressures from individual valve pressures by a square root of the sum of squares (SRSS) method. This represents an exception to the AC (Section 2.13.2.2) which requires linear superposition of the individual pressures. The applicant states this exception can be justified by comparing peak design loads with the measurements obtained during in-plant multiple valve tests. We concur with the applicant's position based on the following.

The multiple valve tests consisted of four near simultaneous actuations (20 msec. maximum interval) of three adjacent valves. It is our judgement that this represents a reasonable simulation of a "worst case" loading condition. The pressure data which was obtained exhibit very little variability. In particular, the peak overpressures (POP) in the four tests ranged from a low of 10.4 to a high of 12.0 psid with an average of 11.1 psid and a standard deviation of only 6%. The corresponding 95-95 nonexceedance pressure level, assuming a normal distribution of pressure loads, is 14.5 psid. This compares favorably with the design value of POP employed by the applicant (18.5 psid) since it implies an additional margin of almost 30%. This margin is sufficient to cover any increases needed to extrapolate the measured loads to design and to cover any other uncertainties relative to multiple valve load actuation cases.

4. CONCLUSIONS

A post-implementation pool dynamic load audit of the Browns Ferry 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 Browns Ferry 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 copies 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 copies 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.

(1) "Safety Evaluation Report, Mark I Long Term Program, Resolution of Generic Technical Activity A-7", NUREG-0661, July 1980.***

(2) "Mark I Containment Short-Term Program Safety Evaluation Report", NUREG-0408, December 1977.***

(3) General Electric Company, "Mark I Containment Program Load Definition Report", General Electric Topical Report NEDO-21888, Revision 2, November 1981.*

(4) Mark I Owners Group, "Mark I Containment Program Structural Acceptance Criteria Plant-Unique Analysis Applications Guide, Task Number 3.1.3", General Electric Topical Report NEDO-24583, Revision 1, July 1979.*

(5) "Browns Ferry Nuclear Plant, Torus Integrity Long Term Program, Plant Unique Analysis Report", Report No. CEB-83-34, Tennessee Velley Authority, Div. of Engineering Design, Civil Engineering Support Branch, December 21, 1983.*

(6) Letter from J. R. Lehner, BNL, to F. Eltawila, NRC, dated July 11, 1984. Subject: Request for Information Regarding Browns Ferry PUAR.*

(7) "BFN PUAR TVA Responses to NRC and Brookhaven National Laboratory Questions", Tennessee Valley Authority, Div. of Engineering Design, Civil Engineering Support Branch, 5 September 1984.*

(8) "Mark I Containment Program Evaluation of Harmonic Phasing for Mark I Torus Shell Condensation Oscillation Loads", NEDE-24840, prepared by Structural Mechanics Associates for General Electric Company, October 1980.*

(9) Kennedy, R. P., "Response Factors Appropriate for Use with CO Harmonic Response Combination Design Rules", SMA 12101.04-R002D, prepared by Structural Mechanics Associates for General Electric Company, March 1982.*

(10) Kennedy, R. P., "A Statistical Basis for Load Factors Appropriate for Use with CO Harmonic Response Combination Design Rules", SMA 12101.04-R003D, prepared by Structural Mechanics Associates for General Electric Company, March 1982.**

(11) Bienkowski, G., "Review of the Validity of Random Phasing Rules as Applied to CO Torus Loads", Internal BNL Memo, August 1983.

ENCLOSURE 2

SALP

prepared by the Containment Systems Branch

Evaluation Criteria	Category	BROWNS FERRY Narrative Description
1. Management Involvement	2	Management took positive steps to assume timely resolution of the issue.
2. Approach to Resolution of Technical Issues	2	Sound Technical Understanding of the issue. Worked closely with the staff and its consultant toward resolution of the issue.
3. Responsiveness	2	Met with the staff and its cons utant shortly after receiving the RAI.
4. Enforcement History		N/A
5. Reportable Events		N/A
6. Staffing		N/A
7. Training		N/A