TECHNICAL EVALUATION OF THE DUANE ARNOLD ENERGY CENTER PLANT-UNIQUE ANALYSIS REPORT

John D. Ranlet

George Bienkowski

Reactor Safety Licensing Assistance Division
Department of Nuclear Energy
Brookhaven National Laboratory
Upton, New York 11973

March 1984

FIN A-3713

BNL-04243

ABSTRACT

The objective of this report is to document the post-implementation audit which compared the Duane Arnold plant-unique analysis reports against the hydrodynamic load acceptance criteria presented in NUREG-0661. A summary of the audit findings, as well as an overview of the various issues or exceptions to the acceptance criteria identified during the audit, is included. In addition, a table highlighting each issue is provided, along with an indication of the type and status of each issue.

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 Ms. Beverly Barnhart of the Technical Assistance Program Management Group of the Division of Licensing. Mr. Byron Siegel of Operating Reactors Branch No. 2 (DL) was Lead Project Manager for the project.

List of Acronyms

AC	Acceptance Criteria
BNL	Brookhaven National Laboratory
BWR	Boiling Water Reactor
CO	Condensation Oscillation
DAEC	Duane Arnold Energy Center
DLF	Dynamic Load Factor
FSI	Fluid Structure Interaction
FSTF	Full Scale Test Facility
LDR	Load Definition Report
LOCA	Loss-of-Coolant Accident
LTP	Long Term Program
NRC	Nuclear Regulatory Commission
PUA	Plant-Unique Analysis
PUAAG	Plant-Unique Analysis - Applications Guide
PUAR	Plant-Unique Analysis Report
PULD	Plant-Unique Load Definition Report
QSTF	Quarter Scale Test Facility
RFI	Request For Information
SER	Safety Evaluation Report
S/RV	Safety/Relief Valve
S/RVDL	Safety/Relief Valve Discharge Line
STP	Short Term Program

Table of Contents

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 is to perform a post-implementation audit of the Duane Arnold plant-unique analysis (Reference 5) against the hydrodynamic load criteria in NUREG-0661.

2. SUMMARY OF POST-IMPLEMENTATION AUDIT

The purpose of the post-implementation audit is to evaluate the hydrodynamic loading methodologies used for the major modification and torus attached piping portions of the Duane Arnold plant-unique analysis with regard to the NUREG-0661 acceptance criteria. The audit procedure consists primarily of a moderately detailed review of the plant-unique analysis report to verify both its completeness and its compliance with the AC. To facilitate this task, a checklist (see Table 1) of the various load categories specified in the AC is used. Table 1 also provides an overview of the audit and presents plant-unique information such as any AC approved alternate methods used in the PUAR. The notes in the right-hand margin which accomplish this task are explained at the end of Table 1.

In general, various exceptions to the AC or areas where additional information is required are identified during the audit of a PUAR. Since Table 1 contains all the load categories considered during an audit, along with their current status, it is not possible to determine from Table 1 the specific issues considered and resolved during the audit. Consequently, a complete list of all items considered is provided in Section 3 of the report, along with a brief description of each exception to the AC found during the audit.

LOADS	NUREG-0661 AC SECTION	CRITERIA		NOT APPLICABLE	ALTERNATE APPROACH	NOTES
		MET	NOT MET			
CONTAINMENT PRESSURE & TEMPERATURE	2.1	X				
VENT SYSTEM THRUST LOADS	2.2	X				
POOL SWELL						
TORUS NET VERTICAL LOADS	2.3	X				
TORUS SHELL PRESSURE HISTORIES	2.4	X				
VENT SYSTEM IMPACT AND DRAG	2.6	X				
IMPACT AND DRAG ON OTHER STRUCTURES	2.7	X				
FROTH IMPINGEMENT	2.8	X				1
POOL FALLBACK	2.9	X				
LOCA JET	2.14.1				X	2
LOCA BUBBLE DRAG	2.14.2				X	2
VENT HEADER DEFLECTOR LOADS	2.10	X				

TABLE 1. LOAD CHECKLIST FOR POST-IMPLEMENTATION AUDIT

LOADS	NUREG-0661 AC SECTION	CRITERIA		NOT APPLICABLE	ALTERNATE APPROACH	NOTES
		MET	NOT MET			
CONDENSATION OSCILLATION						
TORUS SHELL LOADS	2.11.1				X	3
LOADS ON SUBMERGED STRUCTURES	2.14.5				X	2,3
VENT SYSTEM LOADS	2.11.3	X				
DOWNCOMER DYNAMIC LOADS	2.11.2	X				
CHUGGING						
TORUS SHELL LOADS	2.12.1				X	3
LOADS ON SUBMERGED STRUCTURES	2.14.6				X	2,3
VENT SYSTEM LOADS	2.12.3	X				
LATERAL LOADS ON DOWNCOMERS	2.12.2	X				

TABLE 1. (CONTINUED)

LOADS	NUREG-0661 AC SECTION	CRITERIA		NOT APPLICABLE	ALTERNATE APPROACH	NOTES
		MET	NOT MET			
<u>T-QUENCHER LOADS</u>						
DISCHARGE LINE CLEARING	2.13.2	X				
TORUS SHELL PRESSURES	2.13.3	X				
JET LOADS ON SUBMERGED STRUCTURES	2.14.3				X	2,4
AIR BUBBLE DRAG	2.14.4				X	2,4
THRUST LOADS ON T/Q ARMS	2.13.5	X				
S/RVDL ENVIRONMENTAL TEMPERATURES	2.13.6	X				

TABLE 1. (CONTINUED)

	DESCRIPTION	NUREG-0661 AC SECTION	CRITERIA		NOT APPLICABLE	ALTERNATE APPROACH	NOTES
			MET	NOT MET			
1	SUPRESSION POOL TEMPERATURE LIMIT	2.13.8				X	5
2	SUPRESSION POOL TEMPERATURE MONITORING SYSTEM	2.13.9	X				
3	DIFFERENTIAL PRESSURE CONTROL SYSTEM FOR THOSE PLANTS USING A DRYWELL-TO-WETWELL PRESSURE DIFFERENCE AS A POOL SWELL MITIGATOR	2.16			X		
4	SRV LOAD ASSESSMENT BY IN-PLANT TEST	2.13.9				X	4

TABLE 1. (CONTINUED)

Notes to Table 1

NUMBER

1 An alternate procedure was used to define the Region I froth loads using the high-speed QSTF movies as allowed by Section 2.8 of the AC.

2 Published acceleration drag volumes were used to determine the drag loads on sharp cornered submerged structures instead of the equivalent cylinder procedure specified in the acceptance criteria. See the discussion in Section 3.2 for additional information. This procedure was found to be acceptable for DAEC.

3 In the analyses of structures for CO and post-chug loads, the 50 individual load harmonics were combined using a random phasing technique instead of using absolute summation as specified in the AC. See the discussion in Section 3.3 for additional detail. The alternate approach for combining the load harmonics was found to be acceptable for DAEC.

4 Calibration factors were developed from the in-plant tests conducted at DAEC for use in the determination of the drag loads on SRV lines, elbow support beams, T-quenchers and their supports, and vent header support columns. See the discussion in Section 3.1 for additional detail. The use of these factors was found to be acceptable for the DAEC application.

Notes to Table 1 (Cont'd.)

NUMBER

5 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 that was only recently presented to the staff. It has been concluded that the overall methodology provides a conservative way of computing pool temperature transients for purposes of demonstrating compliance with the provisions of NUREG-0783. Additional information can be found in Section 3.5.

3. SYNOPSIS OF THE DUANE ARNOLD REQUEST FOR INFORMATION

During the post-implementation audit of the Duane Arnold plant-unique analysis reports, various issues were identified as either exceptions to the acceptance criteria or as areas where additional information was required. In order to resolve these issues, a request for information (RFI) was sent to the licensee to obtain supplemental information to the PUAR. An overview of the Duane Arnold request for information (Reference 6) is presented in Table 2, along with an indication of the type and status of each item. As can be seen from this table, five exceptions to the AC were identified in the Duane Arnold plant-unique analyses.

The DAEC response to the RFI questions is contained in Reference 7. As a result of our review of the DAEC responses, all issues have been resolved. For completeness, a brief description of each exception to the AC and its justification is provided in the following sections. The numbering system of the various items discussed is consistent with the table.

TABLE 2. ISSUES IDENTIFIED DURING POST-IMPLEMENTATION AUDIT

		TYPE OF ISSUE		STATUS OF ISSUE	
ITEM	DESCRIPTION	EXCEPTION TO NUREG-0661 AC	REQUESTS FOR ADDITIONAL INFORMATION	RESOLVED	OPEN
1	DESCRIBE THE METHOD USED TO DETERMINE FROTH LOAD DIRECTION AND DURATION FOR MONORAIL ANALYSIS		X	X	
2	SPECIFY THE MAXIMUM VALUE OF DOWNCOMER SUBMERGENCE		X	X	
3	PROVIDE ADDITIONAL INFORMATION CONCERNING THE SUPPRESSION POOL TEMPERATURE MONITORING SYSTEM DESIGN		X	X	
4A&4B	PROVIDE ADDITIONAL INFORMATION CONCERNING THE METHODOLOGY USED TO DEFINE S/RV DISCHARGE LOADS		X	X	

TABLE 2 (CONTINUED)

		TYPE OF ISSUE		STATUS OF ISSUE	
ITEM	DESCRIPTION	EXCEPTION TO NUREG-0661 AC	REQUESTS FOR ADDITIONAL INFORMATION	RESOLVED	OPEN
4C	DESCRIBE IN DETAIL HOW THE CALIBRATION FACTORS WERE DEVELOPED FROM IN-PLANT TESTS FOR USE IN DEFINING SUBMERGED STRUCTURE DRAG LOADS	X		X	
5	DESCRIBE THE LOAD CASES CONSIDERED FOR THE CO AND CHUGGING EVALUATIONS		X	X	
6	JUSTIFY THE USE OF PROTOTYPICAL FSTF MARK I CO AND CHUGGING DATA FOR DAEC LOAD EVALUATIONS		X	X	
7	JUSTIFY THE USE OF PUBLISHED ACCELERATION DRAG VOLUMES TO DETERMINE DRAG ON SHARP CORNERED STRUCTURES	X		X	

TABLE 2 (Continued)

		TYPE OF ISSUE		STATUS OF ISSUE	
ITEM	DESCRIPTION	EXCEPTION TO NUREG-0661 AC	REQUESTS FOR ADDITIONAL INFORMATION	RESOLVED	OPEN
8	Provide more detailed documentation on the random phasing of the loading harmonics used for CO and chugging	X		X	
9	Describe the FSI methodology used for CO and chugging submerged structure loads	X		X	
10	Describe the method used to calculate the local-to-bulk temperature difference for the various S/RV load transients considered	X		X	

3.1 Discussion of Item 4C

The staff requested clarification of the detailed procedures used to derive the calibration factors from in-plant tests for SR/V submerged-structure loads. On the basis of the response, the staff considers the procedures as an acceptable modification of the acceptance criteria.

For the SR/V lines, elbow support beams and vent header support columns, the calibration factor is based on a comparison of the measured to calculated strain at test conditions. The resulting factor for each structure is then applied to the calculated stresses at design conditions.

The T-Quencher and support beam loads are computed on the basis of asymmetric bubble dynamics as per section 2.14.4 (1.b) of NUREG-0661, except that the bubble pressure is calibrated using test data rather than the factor 2.5 of NEDE-21878-P. A factor of 1.75 is derived based on Monticello data and shown to bound the DAEC in-plant tests.

The staff finds these procedures to be a reasonable application of the in-plant test results, and considers any potential uncertainties associated with the limited data base to be bounded by other conservatisms associated with the design load calculation procedures.

3.2 Discussion of Item 7

The Acceptance Criteria 2.14.2 section 2b in NUREG-0661 states that drag forces on structures with sharp corners (e.g. rectangles and "I" beams) must be computed by considering forces on an equivalent cylinder of diameter $D_{eq}=2^{\frac{1}{2}}L_{max}$ where L_{max} is the maximum transverse dimension. The intent of this criterion is to provide a conservative bound (based on very limited data) that includes non-potential flow effects such as vortex shedding on both the acceleration drag due to hydrodynamic mass and the "standard" drag proportional to velocity squared. Since the dominant load for the Ring Beam is acceleration drag, the issue concerns only the hydrodynamic mass or acceleration volume and not the drag coefficient in the DAEC plant-specific case.

The PUAR states that "published" acceleration drag volumes listed in Table 1-4.1-1 are used for sharp edged structures rather than the equivalent cylinder specified in the acceptance criteria. The detailed response to item 7 (Appendix A) explains that modelling of the actual structures is necessary, and in particular, forces on the web of the ring beam are obtained by modelling the beam by a circumscribed rectangle. In order to evaluate the implications of this modelling, detailed calculations were performed on the ring-beam web forces for the post-chug loading condition.

A direct application of the PUAR methodology but without inclusion of DLF's to account for the structural dynamics leads to a pressure differential on the web of approximately 5.9 psi. A computation of the force using the hydrodynamic mass of the equivalent cylinder of the Acceptance Criteria but the real volume for the "effective" buoyancy force results in an approximately 30% higher load.

The PUAR accounts for the dynamics of the structure, however, by using an equivalent static load and DLF's based on a single degree of freedom model with 2% damping and a natural frequency of near 45 Hz. This procedure overemphasizes the effect of the conservatively specified 40-50 Hz content of the source term to the extent that this frequency range contributes 86% of the final effective peak pressure differential of 46.9 psi. Evidence from other plant-unique analyses indicates that a reduction of as much as 40% can be obtained from a more realistic multi-degree of freedom model providing additional conservatism to balance any uncertainty in the modelling of the acceleration volume. Since the high-frequency portion of the Post-Chug load comes largely from the sharp "spikes" within post-chug pressure time histories, there is substantial conservatism in applying those loads in the frequency domain rather than as an initial value problem for each chug. Indeed, the maximum DLF for an initial value problem that one might expect for the "spike" portion of the chug is only about 2, instead of 25 at resonance of a 2% damped single degree of freedom system subject to harmonic loading.

On the basis of these comparisons we conclude that while the direct use of "published" acceleration volumes for sharp edge structures may not in general lead to conservative loads, the PUAR methodology for the application of these loads to the relevant structures, has sufficient conservatism to bound any hydrodynamically produced stresses that could arise in these structures.

3.3 Discussion of Item 8

The DBA condensation oscillation and the post-chug load definitions on the torus shell and on submerged structures, accepted in the NUREG-0661, were based on data from a series of blowdowns in the FSTF facility (NEDE-24539), subject to additional confirmatory tests reported in the General Electric Letter Report M1-LR-81-01 of April 1981.

The condensation oscillation load definition as described in NEDO-21888 is based on taking the absolute sum of 1 Hertz components of a spectrum from 0 to 50 Hz. Three alternative spectra are to be calculated with the one producing maximum response used for load definition. The procedure was found acceptable in the supplement to the SER (NUREG-0661), because the demonstrated high degree of conservatism associated with the direct summation of the Fourier components of the spectrum was sufficient to compensate for any uncertainties concomitant with the data available. The post-chug load definition is based on bounding FSTF chugging data but otherwise follows similar procedures to those used in the CO load definition.

The Fermi PUAR uses a factor of .65 to multiply the CO and post-chug loads computed on the basis of the absolute sum of the harmonic components. The justification is based on comparisons of measured and predicted stresses in the FSTF facility using different phasing models (NEDE-24840). The factor .65 is chosen to give 84% non-exceedance probability with a confidence level of 90%. The PUAR does use an additional spectrum, Alternate 4, for the CO loading, based on test M12 from the supplementary tests reported in the letter report M1-LR-81-01. The information supplied in Appendix A and Table 1-4.1-4 provide additional justification to show that the computed loads (using the .65 factor and Alternates 1 through 3) bound the measured stresses at critical points in the FSTF facility by 11% for axial shell stress to 69% for column force. The use of Alternate 4 in the DAEC plant provides an additional conservatism of about 20% to the shell response.

We have examined this information and conclude that the use of the "phasing factor" of .65 coupled with the inclusion of Alternate 4 for CO loading, provides a sufficiently conservative representation of the CO and post-chug loads to account for possible uncertainties associated with the data base.

3.4 Discussion of Item 9

A detailed discussion of the method used to account for FSI effects on condensation oscillation and chugging submerged structure loads is provided in Reference 8. The methodology described in this note is used to compute acceleration fields across a submerged structure anywhere in the torus resulting from FSI, based on knowing the torus boundary acceleration. The method is presented as an alternative to the NRC Acceptance Criteria suggestion of adding the boundary accelerations directly to the local fluid acceleration to account for FSI effects since the latter is deemed too conservative.

The review of the method outlined in Reference 8 has shown it to be reasonable and acceptable. The equations derived for fluid accelerations and pressure fields are plausible approximations for the conditions prevailing in the suppression pool. Assumed boundary conditions including the driving one at the torus wall are suitable. Overall trends as well as the acceleration fields depicted in the selected results appear reasonable. Therefore, the alternate procedure used to account for FSI effects on submerged structures is considered acceptable in this application.

3.5 Discussion of Item 10

The licensee has provided the results of certain plant-unique analyses used to obtain pool temperature responses to transients involving safety relief valve actuations as required by the AC. Results from these analyses indicate that the plant would be able to operate within the temperature limits specified in NUREG-0783. The licensee's analyses were developed by using a comprehensive computational methodology developed by the General Electric Company. A key element of this overall methodology is a computer code known as TPOOL which computes local pool temperatures as a function of NSSS, SRV and RHR performance. A description of TPOOL and the procedures used in its development and qualification have only recently been presented to the staff in a series of meetings, the last of which was on August 25, 1983. Based on the information presented at these meetings, the staff and its consultants have concluded that the total methodology which includes TPOOL, provides a conservative way of computing pool temperature transients for purposes of demonstrating compliance with the provisions of NUREG-0783. The staff will issue a report describing TPOOL and the bases for finding the total computational procedure acceptable for use in performing analyses of pool temperature transients involving operation of the S/RV in the second quarter of 1984. Based on our evaluation of the licensee's analyses, we conclude that the assumptions used are reasonably conservative and in agreement with the staff's recommendations set forth in NUREG-0783 and, therefore, are acceptable.

4. CONCLUSIONS

The purpose of the post-implementation pool dynamic load audit of the Duane Arnold plant-unique analysis reports was to verify compliance with the acceptance criteria of NUREG-0661. As a result of the audit, several aspects of the Duane Arnold plant-unique analysis required additional information. The licensee's response (Reference 7) to the request for information indicates that the pool dynamic load methodologies utilized in the PUAR are in general conformance with the acceptance criteria requirements.

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.

(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) "Duane Arnold Energy Center, Plant Unique Analysis Report", Volumes 1-6, Revision 1, Iowa Electric Light and Power Company (prepared by Nutech Engineers, Inc.), June 1983.*

(6) Attachment to Letter from J. D. Ranlet, BNL, to F. Eltawila, NRC, Subject: Duane Arnold Energy Center Request For Information, January 13, 1984.*

(7) Attachment to letter of March 2, 1984 from R. W. McGaughy of Iowa Electric Light and Power to H. Denton of NRC. Subject: Response to NRC Request for Additional Information Regarding Mark I Containment Plant Unique Analysis Report. Attachment NG-84-0864.

(8) A. J. Bilanin, "Mark I Methodology for FSI Induced Submerged Structure Fluid Acceleration Drag Loads", Continuum Dynamics Tech Note No. 82-15, June 1982.*