STRUCTURAL REEVALUATION OF MARK I CONTAINMENT FOR HYDRODYNAMIC LOADS

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SUMMARY

The first generations of General Electric boiling water reactor (BWR) nuclear steam supply systems are housed in containment vessels designated as Mark I containments. Twenty-five BWR facilities with Mark I containments have been, or are being, built in the United States. The original design of Mark I containments considered postulated accident loads previously associated with containment design. These loads included pressure and temperature loads associated with a loss-of-coolant accident (LOCA), seismic loads, dead loads, jet-impingement loads, hydrostatic loads due to water in the suppression chamber, overload pressure test loads, and construction loads. However, since the establishment of the original design criteria, additional suppression pool hydrodynamic loads have been identified in the course of large-scale testing of Mark III containments and during in-plant testing of Mark I containments. Consequently, in February and April 1975, the U.S. Nuclear Regulatory Commission (NRC) transmitted letters to all utilities owning BWR facilities with Mark I containments, requesting that the owners quantify the hydrodynamic loads and assess the effect of these loads on the containments. A detailed presentation of the problem and the program for resolution are included in the NRC's safety evaluation reports for the short-term program and the long-term program. The objective of this paper is to present certain important features of the structural reevaluations for hydrodynamic loading, and structural modifications which were required during the short-term and long-term programs for Mark I containments. In addition, the criteria developed at the Franklin Research Center for auditing the structural analyses presented in plant-unique analysis reports by Mark I owners are briefly explained. All utilities owning Mark I BWR facilities are required to submit plant-unique analysis reports in order to demonstrate that the originally intended safety margin is restored after all necessary structural modifications are made.

1. Introduction

The Mark I containment is designed to condense steam released during a postulated LOCA and to serve as a source of water for the emergency core cooling system. It consists of a drywell, a toroidal pressure suppression chamber, a vent system, containment isolation valves, containment cooling systems, and other service equipment. Figure 1 shows the major components of the Mark I containment. The suppression chamber in Brunswick Units 1 and 2 is a reinforced concrete torus with a steel liner. For all other Mark I plants, the suppression chamber is a toroidal steel pressure vessel. The Mark I vent system typically has 8 to 10 main vents and 48 to 120 downcomers. Table I lists the plants with Mark I containment that are licensed for operation or are being built in the United States. The original design criteria of these plants did not include the suppression pool loads due to hydrodynamic phenomena subsequently identified in the course of large-scale testing of Mark III containments and during in-plant testing of Mark I containments. Consequently, several concerns arose regarding the margin of safety existing in the original design; in 1975, the NRC initiated comprehensive programs for resolving these concerns. For a complete understanding of these concerns and their resolution the reader is referred to the safety evaluation reports [1, 2] issued by the NRC. Important features of the Mark I containment reevaluation are presented in this paper with emphasis on structural aspects of the program. This paper does not address details of the hydrodynamic load definition methodology, related concerns, and their resolution, since they have been discussed in the Load Definition Report presented by the General Electric Company [3] and in the NRC safety evaluation report [2].

2. Mark I Containment Hydrodynamic Loads

Hydrodynamic loads in Mark I containment can originate from a LOCA or safety relief valve (SRV) discharge phenomena [3]. The sequence of events after a postulated LOCA and the potential loading conditions associated with these events are shown in Figure 2. Hydrodynamic loads due to SRV actuation are mainly due to drag and jet impingement on submerged structures, air-clearing, and temperature ~~rise~~ increase. Table II shows the interaction of the hydrodynamic loads due to LOCA and SRV discharge on various structural components of Mark I containment. Most of the concerns regarding the safety margins existing in the design of United States BWR plants with Mark I containment have been resolved in the course of the short-term and long-term programs completed by the affected utilities; the NRC has issued safety evaluation reports pertaining to these programs [1, 2]. The following sections of this paper present an overview of the achievements of the short-term program and the long-term program for Mark I containment with regard to the structural reevaluation.

3. Mark I Containment Short-Term Program (STP)

The objectives of the STP were (1) to examine the containment of each BWR facility with Mark I containment design in order to verify that it would maintain its integrity and functional capability when subjected to the most probable loads induced by a postulated design basis LOCA and (2) to verify that the licensed Mark I facilities may continue to operate safely without undue risk to the health and safety of the public, while a methodical, comprehensive long-term program (LTP) ~~be~~ was conducted. It was determined that for the STP, "maintenance of the containment integrity and function" would be adequately assured if a safety margin of at least 2 was demonstrated to exist for the weakest structural or mechanical component in the Mark I containment.

Consistent with the objectives of the STP, review of the newly identified types of hydrodynamic loads focused on those loads judged to be most significant in terms of the structural response of the Mark I containment system. Such loads were designated as "primary loads." The remaining loads were considered to be of secondary importance and were not considered further in the STP. The primary loads for the STP were defined by considering all existing applicable test data, both domestic and foreign, related to the hydrodynamic phenomena postulated to occur in a Mark I suppression chamber. In addition, where sufficient test data did not exist for specific loading conditions, small-scale tests on a toroidal segment of a Mark I suppression chamber were performed to provide an estimate of the loading magnitudes. The hydrodynamic load combinations were then specified for a typical (i.e., reference plant) Mark I suppression chamber. Where structural analyses indicated a need, load variation functions were developed from test data and analytical models to define the loading conditions for specific suppression chamber configurations.

As the STP progressed, the structural evaluation of the critical elements separated into two parts: (1) an assessment of the integrity of the structures, equipment, and components located within the suppression chamber for all plants, and (2) an assessment of the integrity of the suppression chamber, chamber supports, and the piping systems externally attached to the suppression chamber for operating plants. Where necessary, material testing programs were conducted to support the analysis of specific critical elements, and the "as built" configuration of certain plant-specific critical elements was confirmed by field inspections conducted by the NRC's Office of Inspection and Enforcement. Table III indicates some of the plant modifications found necessary during the STP. The acceptance criteria for the structural evaluations established the methods of analysis, methods for load application, loading conditions, and stress limits.

Further details on the STP and the NRC's conclusions are described in Reference 1. It was concluded in Reference 1 that a sufficient margin of safety had been demonstrated to assure the functional performance of the Mark I containment, and hence the NRC granted the operating Mark I facilities exemptions relating to the structural factor of safety requirements of 10CFR50.55(a). These exemptions were granted for an interim period of approximately 2 years while the comprehensive LTP was being conducted.

4. Mark I Containment Long-Term Program (LTP)

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.

Most of the LTP tasks were directed toward the development of experimental and analytical information that could be used to develop generic suppression pool hydrodynamic load definition and assessment procedures. Other tasks provided information concerning potential structural modifications and hydrodynamic load mitigation techniques that could be used to implement the program in the plant-unique analyses.

During July and August 1976, the Mark I Owners Group made several presentations to the NRC staff regarding the proposed content and schedule for completion of the LTP. Much of this information was subsequently documented in the "Mark I Containment Program, Program Action Plan" submitted to the NRC [4].

As a result of NRC staff comments and questions on this document, the Mark I Owners Group revised several of the proposed LTP tasks and objectives. These revisions were discussed with the NRC staff in meetings held in February 1977 and are documented in Revision 1 to the "Mark I Containment Program, Program Action Plan" [5]. During the course of the LTP, additional revisions [6, 7] were made to the Program Action Plan to reflect task scope and schedule changes that evolved from the initial results of specific tasks.

The generic aspects of the LTP were completed with the submittal of the "Mark I Containment Program Load Definition Report" [3] and the "Mark I Containment Program Structural Acceptance Criteria Plant Unique Analysis Application Guide" (PUAAG) [8], as well as supporting reports on the LTP experimental and analytical tasks. The requirements resulting from the NRC's evaluation of the LTP presented in Reference 2 are being used by each BWR/Mark I licensee to perform plant-unique analyses. These analyses are intended to confirm that the originally intended safety margins have been restored after the necessary modifications. Reference 2 indicates that the structural acceptance criteria for the plant-unique analysis proposed in the PUAAG ~~Plant Unique Analysis Application Guide~~ [8] are acceptable to the NRC. These criteria are briefly examined in the following section.

5. Structural Acceptance Criteria for Plant-Unique Analyses

The purpose of the structural acceptance criteria for plant-unique analyses ~~are~~ as presented in the ~~Plant Unique Analysis Application Guide~~ (PUAAG) [8] ~~. The purpose of the PUAAG~~ is to allow consistent application of these ~~structural acceptance~~ criteria by those evaluating each of the specific containments. The following aspects are addressed in the PUAAG [8]:

a. Code classification based on the ASME Boiler and Pressure Vessel Code [9].

b. Load combinations and categorizations based on the Load Definition Report [3].

c. Reference to code and standard rules, procedures, and criteria to be followed for all structural elements.

d. Alternative structural acceptance criteria.

e. When required, descriptions of the minimum analytical models or procedures to be followed and other guides concerning the plant-unique analysis.

6. Post-Implementation Review

At present, a post-implementation review of the Mark I containment structure is being conducted by the NRC, aided by its consultants, Franklin Research Center (structural analysis) and Brookhaven National Laboratory (loads). As part of this program, Franklin Research Center is auditing plant-unique analysis (PUA) reports of Mark I facilities in order to determine their technical adequacy and compliance with the criteria [8]. The audit is based on a review of a set of key items in the PUA reports, as explained in the audit procedure developed by the Franklin Research Center [10]. After a preliminary review, an Interim Technical Evaluation Report is issued containing a request for additional information on any aspect of the report requiring clarification. Specifically, the licensee is requested to justify any deviation from the criteria unless the licensee's approach is determined to be more conservative than the criteria requirements. More emphasis is placed on the evaluation of the torus, the torus support system, the vent system, and essential piping systems in comparison to internal structures that have been adequately modified. The PUA reports reviewed so far indicate that licensees prefer to use the generic approaches proposed by the Mark I Owners Group for a bounding fatigue analysis of piping and for vacuum breaker valve analysis. ~~In general,~~ Modifications of critical structures such as torus and torus supports have ~~helped to~~ restored their originally intended margins of safety in conjunction with load mitigation devices such as the T-quencher and vent deflector ~~have also helped~~ to reduce the hydrodynamic loads.

7. Conclusion

The structural reevaluation of Mark I containment for newly identified hydrodynamic loads is nearing successful completion due to the joint efforts of the affected utilities, their consultants, and the NRC on solving the complex analytical, experimental, and engineering aspects of the problem. The preliminary findings of the Franklin Research Center post-implementation audit of the PUA reports of some of the affected plants indicate that the licensees have generally complied with the requirements of the criteria and ~~are committed to resolving all the concerns.~~

those exceptions taken to the criteria ~~thereto~~ have been technically evaluated and found acceptable.

REFERENCES

1. U.S. Nuclear Regulatory Commission, "Mark I Containment Short-Term Program Safety Evaluation Report," NUREG-0408, December 1977
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8. General Electric Company, "Mark I Containment Program Structural Acceptance Criteria Plant Unique Analysis Application Guide," NEDO-24583-1, October 1979
9. American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section III, Division 1, "Nuclear Power Plant Components," 1977 Edition and Addenda up to Summer 1977
10. Franklin Research Center, "Audit Procedure for Mark I Containment Long-Term Program--Structural Analysis," TER-C5506-308, June 1982

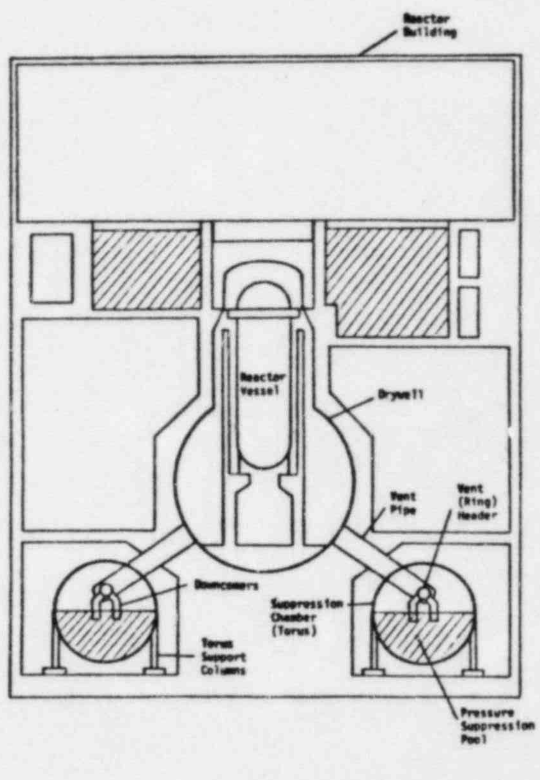

Figure 1. Composite Section Through Suppression Chamber

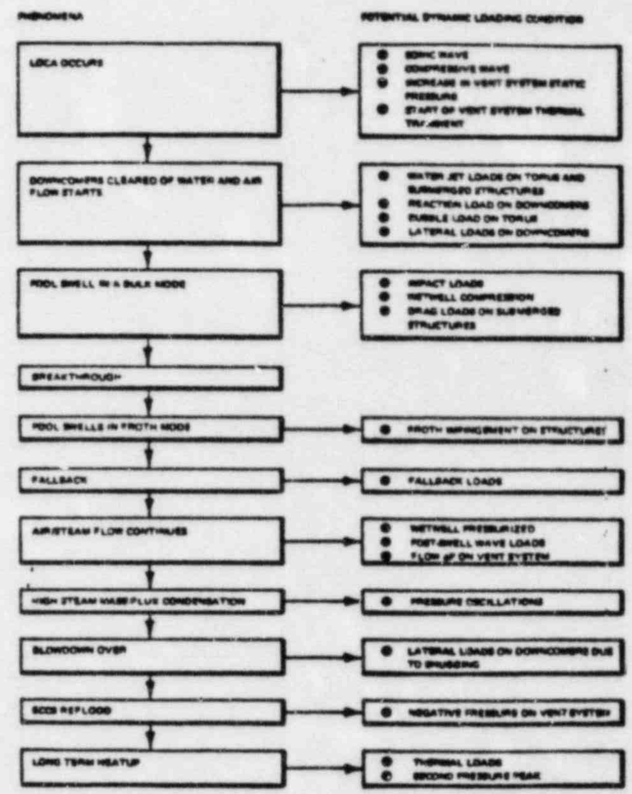

Figure 2. Sequence of Events and Potential Loading Conditions Following a Postulated LOCA

TABLE I

LISTING OF DOMESTIC BWR FACILITIES WITH THE MARK I CONTAINMENT SYSTEM

Plants Licensed for Power Operation	Licensee
Browns Ferry Units 1, 2, and 3	Tennessee Valley Authority
Brunswick Units 1 and 2	Carolina Power and Light
Cooper Station	Nebraska Public Power District
Dresden Units 2 and 3	Commonwealth Edison Company
Duane Arnold	Iowa Electric Light and Power
FitzPatrick	Power Authority, State of New York
Hatch Units 1 and 2	Georgia Power Company
Millstone Unit 1	Northeast Nuclear Energy Company
Monticello	Northern States Power Company
Nine Mile Point Unit 1	Niagara Mohawk Power Corporation
Oyster Creek	Jersey Central Power and Light
Peach Bottom Units 2 and 3	Philadelphia Electric Company
Pilgrim Unit 1	Boston Edison Company
Quad Cities Units 1 and 2	Commonwealth Edison Company
Vermont Yankee	Yankee Atomic Electric Company
Plants Under Construction	**Applicant**
Fermi Unit 2	Detroit Edison Company
Hope Creek Units 1 and 2	Public Service Electric and Gas

Table II. Structural Loads Matrix

Loads	Structures						Other Wetwell Interior Structures		
	Torus Shell	Torus Support System	Main Vents	Vent Header	Downcomers	SRV Piping	[illegible]	[illegible]	[illegible]
1. Containment Pressure and Temperature	X	X	X	X	X	X	X	X	X
2. Vent System Thrust Loads			X	X	X				
3. Pool Swell									
3.1 Torus Net Vertical Loads	X	X							
3.2 Torus Shell Pressure Histories	X	X							
3.3 Vent System Impact and Drag			X	X	X				
3.4 Impact and Drag on Other Structures			X			X	X		
3.5 Froth Impingement	X	X	X			X	X		
3.6 Pool Fallback						X	X	X	
3.7 LOCA Jet						X			X
3.8 LOCA Bubble Drag						X		X	X
4. Condensation Oscillation									
4.1 Torus Shell Loads	X	X							
4.2 Load on Submerged Structures						X		X	X
4.3 Lateral Loads on Downcomers				X	X				
4.4 Vent System Loads			X	X					
5. Chugging									
5.1 Torus Shell Loads	X	X							
5.2 Loads on Submerged Structures						X		X	X
5.3 Lateral Loads on Downcomers				X	X				
5.4 Vent System Loads			X	X					
6. T-Quencher Loads									
6.1 Discharge Line Clearing						X			
6.2 Torus Shell Pressures	X	X							
6.4 Jet Loads on Submerged Structures					X	X		X	X
6.5 Air Bubble Drag					X	X		X	X
6.6 Thrust Loads on T-Quencher Arms						X			
6.7 S/RVDL Environmental Temperature						X			
7. Ramshead Loads									
7.1 Discharge Line Clearing						X			
7.2 Torus Shell Pressures	X	X							
7.4 Jet Loads on Submerged Structures					X	X		X	X
7.5 Air Bubble Drag					X	X		X	X
7.6 S/RVDL Environmental Temperature						X			

X Loads required by NUREG-0661

Table III. LISTING OF STP MODIFICATIONS TO MARK I TORUS SUPPORT SYSTEM COMPONENTS [1]

PLANT	MODIFICATIONS
DUANE ARNOLD	1. Uplift anchor brackets were added
BROWNS FERRY UNITS 1, 2, AND 3	1. Single vent header columns changed to twin columns and SRV line restraints stengthened
COOPER	1. Web reinforcing plates added to each side of the torus support column at the column-torus shell weld
DRESDEN UNITS 2 AND 3	1. Jackets added to inner torus support column and bearing blocks installed in inside pin connections
FITZPATRICK	1. Checkered plate catwalks removed
HATCH UNIT 1	1. Strengthened the torus support column to torus shell welds and reinforced the torus support column connection to the torus by adding gusset plates
	2. Installed anchor bolts in the base plate of each torus support column
MILLSTONE UNIT 1	1. Two new anchor bolts added on both inner and outer torus support columns
	2. Jackets added to inner torus support column and bearing blocks installed in inside and outside pin connections
	3. Replacement of two pipe supports with spring hangers on atmospheric control line
MONTICELLO	1. Jackets added to inside and outside torus support columns, bearing blocks installed in inside and outside pin connections, additional anchor bolts installed
	2. Strengthened torus support column to torus shell welds and reinforced the upper torus support column connection to the torus
NINE MILE POINT UNIT 1	1. Checkered plate catwalks removed
PILGRIM UNIT 1	1. Gusset plates have been added to the ring girder web in the area of the outer torus column to shell attachment
QUAD CITIES UNITS 1 AND 2	1. Addition of weld materials to existing web and flange welds at the torus column to torus shell connection
VERMONT YANKEE	1. Modifications were made in March 1976 to provide tie-down to the torus support columns
PEACH BOTTOM UNITS 2 AND 3	1. Saddle supports added to Units 2 and 3
HATCH UNIT 2	1. Saddle supports added to the torus
	2. Vent header support column connections strengthened

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