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FRC TASK 326

AUDIT FOR MARK I CONTAINMENT LONG-TERM PROGRAM -
STRUCTURAL ANALYSIS FOR OPERATING REACTORS

NORTHERN STATES POWER COMPANY
MONTICELLO NUCLEAR GENERATING PLANT

TER-C5506-326

Prepared for

Nuclear Regulatory Commission
Washington, D.C. 20555

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FOREWORD

This Technical Evaluation Report was prepared by Franklin Research Center under a contract with the U.S. Nuclear Regulatory Commission (Office of Nuclear Reactor Regulation, Division of Operating Reactors) for technical assistance in support of NRC operating reactor licensing actions. The technical evaluation was conducted in accordance with criteria established by the NRC.

1. INTRODUCTION

The capability of the boiling water reactor (BWR) Mark I containment suppression chamber to withstand hydrodynamic loads was not considered in the original design of the structures. The resolution of this issue was divided into a short-term program and a long-term program.

Based on the results of the short-term program, which verified that each Mark I containment would maintain its integrity and functional capability when subjected to the loads induced by a design-basis loss-of-coolant accident (LOCA), the NRC staff granted an exemption relating to the structural factor of safety requirements of 10CFR50, 55(a).

The objective of the long-term program was to restore the margins of safety in the Mark I containment structures to the originally intended margins. The results of the long-term program are contained in NUREG-0661 [1], which describes the generic hydrodynamic load definition and structural acceptance criteria consistent with the requirements of the applicable codes and standards.

The objective of this report is to present the results of an audit of the Monticello Nuclear Generating Plant plant-unique analysis (PUA) report with regard to structural analysis. The audit was performed using a moderately detailed audit procedure developed earlier [2] and attached to this report as Appendix A. The key items of the audit procedure are obtained from "Mark I Containment Program Structural Acceptance Criteria Plant Unique Analysis Application Guide" [3], which meets the criteria of Reference 1.

2. AUDIT FINDINGS

A detailed presentation of the audit for Monticello Nuclear Generating Plant is provided in Appendix A, which contains information with regard to several key items outlined in the audit procedure [2]. Based on this detailed audit, it was concluded earlier that certain items in the Monticello PUA report [4] indicated noncompliance with the requirements of the criteria [3] and that several aspects of the analysis required further information. The required information was determined to be similar to that of the Duane Arnold plant. Therefore, the responses obtained from the Duane Arnold plant were used as a basis for the evaluation of the Monticello plant.

During the course of reviewing the analytical techniques for stress calculations of the torus attached piping systems, Franklin Research Center (FRC) staff raised concerns regarding the verification of the computer program CMDOF (Coupling of Multiple Degrees of Freedom), which was used by the NUTECH technical staff to qualify the Mark I torus attached piping systems in a number of nuclear power plants. Meetings were held with NUTECH technical staff and representatives of affected utilities to discuss and resolve concerns associated with this program. In accordance with an FRC request for additional study to verify the program, the Monticello plant used some in-plant safety relief valve tests performed in 1980 for verification purposes, and the results of this study were found acceptable. Appendix B of this report provides the background and assessments relating to this program The Licensee has responded [8] to all the items contained in the request for additional information; a brief review of each response is provided below.

Item 1 Provide calculations demonstrating conformance to the 10% rule of Section 3.1.1 of the plant-unique analysis (PUA) report [4] for small bore piping systems in the Monticello plant that were exempted from analysis because of the 10% rule.

Response 1

In response to this item, the Licensee provided a summary of the method for applying the 10% rule that exempted some small bore pipes from analysis; the method is listed below:

- o At the small bore piping attachment point, the stresses in the large bore piping due to combined Mark I loads were calculated.
- o The large bore piping stress combinations for Levels B, C, and D were compared against 10% of the respective allowables. Stress intensification factor values were also included where applicable.
- o Any small bore piping connected to large bore piping that met the 10% rule at the attachment point was then exempted from further Mark I evaluation.

The Licensee also provided a table showing the distance from the torus along each large bore line to the point at which the 10% rule comes into effect. The Licensee's response indicates that sufficient calculations have been made to ensure compliance with the 10% rule of Section 6.2d of the criteria [3].

Item 2 With reference to Table 5.2-2 of the PUA report [4], provide and justify the reasons for not considering load cases which include loads such as pool swell and safe shutdown earthquake.

Response 2

The Licensee indicated that load combinations involving pool swell and safe shutdown earthquake (SSE) are primarily service level C load combinations, for which allowable stresses are significantly higher than for service level B. The Licensee also stated that comparison of pool swell and SSE loads against condensation oscillation (CO), chugging, and safety relief valve (SRV) loads showed that the service level B load combinations involving CO, chugging, and SRV completely bound the service level C load combinations involving pool swell and SSE. The Licensee's response is technically adequate.

Item 3: With respect to Section 5.2.1 of the PUA report [4], provide and justify the reasons for considering the reduction factor of 1.87 to be the representative value for SRV discharge loads for all TAP lines when this reduction factor was determined using test results [9] for the Monticello RCIC line only.

Response 3

In this response, the Licensee asserted that the reduction factor was only used for selected systems and components. For piping, the reduction factor for SRV discharge loads was selectively used only for the RCIC turbine exhaust system of the torus attached piping for which the test results are available. For penetration, the 1.87 reduction factor was used for both the RCIC and HPCI turbine exhaust penetrations because of the geometric similarities of their internal piping and structures. The Licensee's response is satisfactory.

Item 4: Tables 3.5-1, 3.5-2, and 5.5-4 of the PUA report [4] indicate that the calculated values of certain stresses are equal to the respective allowables. Indicate conservatisms in the analysis to show that these calculated values would not be exceeded if the concerns expressed in Items 2 and 3 really have a significant effect on the results or if a different analytical approach were to be used.

Response 4

In this response, the Licensee asserted that the small margins to code allowables do not require additional justification as there is conservatism in the calculated stress results. The following sources of conservatism were given: the code allowable limits provide adequate factors of safety; loads are conservatively defined based on test results; and conservative load combinations are used, in which peak response are assumed to occur simultaneously. The Licensee's response is satisfactory.

Item 5: The computer code CMODF has been used in the torus attached piping analysis for all plants that used NUTECH as their contractor. With regard to the code provide the following information:

a. Theoretical background of CMODF computer program
b. Program verification
c. Applicability of the computer program to the torus attached piping analysis.

Response 5

The Licensee's response has resolved these concerns. (A technical report addressing these concerns is provided in Appendix B of this TER.)

3. CONCLUSIONS

Based on the audit of the Monticello plant-unique analysis report, it was concluded earlier that certain aspects required additional information. Based on the Licensee's responses to the request for additional information for the Duane Arnold plant, which is applicable to the Monticello plant [6, 7], and the Licensee's response to the request for additional information for the Monticello plant [8], it is concluded that the Licensee's structural analyses with regard to major plant modifications and the torus-attached piping conform to the criteria requirements. With reference to the verification of the computer program CMDOF used to qualify the torus attached piping systems, the results of a verification study for the Monticello in-plant safety relief valve tests performed by NUTECH technical staff were found acceptable as documented in Appendix B of this report. The Licensee's approach to the evaluation of piping fatigue conforms to the approach recommended by the Mark I Owner's Group, which has been accepted by the NRC. The evaluation criteria of the containment vacuum breaker modifications are not addressed in Reference 3 and are therefore outside the scope of this TER; however, this issue will still be examined as part of the Mark I Long-Term Program.

4. REFERENCES

1. NUREG-0661
"Safety Evaluation Report, Mark I Containment Long-Term Program Resolution of Generic Technical Activity A-7"
Office of Nuclear Reactor Regulation
USNRC
July 1980

2. Technical Evaluation Report
Audit Procedure for Mark I Containment Long-Term Program - Structural Analysis
Franklin Research Center, Philadelphia, PA
June 1982, TER-C5506-308

3. NEDO-24583-1
"Mark I Containment Program Structural Acceptance Criteria Plant Unique Analysis Application Guide"
General Electric Co., San Jose, CA
October 1979

4. Monticello Nuclear Generating Plant
Plant Unique Analysis Report
Volumes 1, 2, 3, 4, 5, 6
Northern States Power Company
November 1982

5. P. M. Kasik
"Mark I Piping Fatigue," Presentation at the NRC Meeting, Bethesda, MD
September 10, 1982

6. R. W. McGauphy (Iowa Electric Light and Power Company)
Letter with Attachments to H. Denton (NRC)
Subject: Response to NRC Request for Additional Information on the Mark I Containment Long-Term Program
June 20, 1983

7. R. W. McGauphy (Iowa Electric Light and Power Company)
Letter to H. Denton (NRC)
Subject: Clarifications Regarding the Duane Arnold Energy Center PUAR
September 17, 1984

8. D. Musolf (Northern States Power Company)
Letter with Attachments to NRC
Subject: Submittal of Responses to Questions on the Monticello Mark I Containment Long-Term Program Plant Unique Analysis Report
September 4, 1984

9. NUTECH
Monticello Submerged Structure Test Results
NSP-49-010, Revision 1
September 1981

APPENDIX A

AUDIT DETAILS

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1. INTRODUCTION

The key items used to evaluate the Licensee's general compliance with the requirements of NUREG-0661 [1] and specific compliance with the requirements of "Mark I Containment Program Structural Acceptance Criteria Plant Unique Analysis Application Guide" [2] are contained in Table 2-1. This audit procedure is applicable to all Mark I containments, except the Brunswick containments, which have a concrete torus.

For each requirement listed in Table 2-1, several options are possible. Ideally, the requirement is met by the Licensee, but if the requirement is not met, an alternative approach could have been used. This alternative approach will be reviewed and compared with the audit requirement. An explanation of why the approach was found conservative or unconservative will be provided. A column indicating "Additional Information Required" will be used when the information provided by the Licensee is inadequate to make an assessment.

A few remarks concerning Tables 2-1 and 2-2 will facilitate their future use:

- o A summary of the audit as detailed in Table 2-1 is provided in Table 2-2, highlighting major concerns. When deviations are identified, reference to appropriate notes are listed in Table 2-1.
- o Notes will be used extensively in both tables under the various columns when the actual audits are conducted, to provide a reference that explains the reasons behind the decision. Where the criterion is satisfied, a check mark will be used to indicate compliance.
- o When a particular requirement is not met, the specific reasons for noncompliance will be given.

Table 2-1. Audit Procedure for Structural Acceptance Criteria of Mark I Containment Long-Term Program

Section No. [2]	Key Items Considered in the Audit	Criteria Met	Criteria Not Met	Addtl. Info. Reqd.	Licensee Uses Alternate Approach: Conservative	Licensee Uses Alternate Approach: Unconservative	NA	Remarks
1.2	All structural elements of the vent system and suppression chamber must be considered in the review. The following pressure retaining elements (and their supports) must be considered in the review:							
	o Torus shell with associated penetrations, reinforcing rings, and support attachments	✓						
	o Torus shell supports to the containment structure	✓						
	o Vents between the drywell and the vent ring header (including penetrations therein)	✓						
	o Region of drywell local to vent penetrations	✓						
	o Bellows between vents and torus shell (internal or external to torus)	✓						
	o Vent ring header and the downcomers attached to it	✓						
	o Vent ring header supports to the torus	✓						
	o Vacuum breaker valves attached to vent penetrations within the torus (where applicable)			SEE NOTE 1				THIS CONCERN HAS BEEN RESOLVED [8] VACUUM BREAKER VALVE MODIFICATIONS ARE OUTSIDE THE SCOPE OF THIS TER
	o Vacuum breaker piping systems, including vacuum breaker valves attached to torus shell penetra-			SEE NOTE 1				

Table 2-1. Audit Procedure for Structural Acceptance Criteria of Mark I Containment Long-Term Program

Section No. [2]	Key Items Considered in the Audit	Criteria Met	Criteria Not Met	Addtl. Info. Reqd.	Licensee Uses Alternate Approach: Conservative	Licensee Uses Alternate Approach: Unconservative	NA	Remarks
1.2	(Cont.)							
	tions and to vent penetrations external to the torus (where applicable)							
	o Piping systems, including pumps and valves internal to the torus, attached to the torus shell and/or vent penetrations			SEE NOTE 2				THIS CONCERN HAS BEEN RESOLVED [8]
	o All main steam system safety relief valve (SRV) piping	✓						
	o Applicable portions of the following piping systems:			SEE NOTE 3				— do —
	- Active containment system piping systems (e.g., emergency core cooling system (ECCS) and other piping required to maintain core cooling after loss-of-coolant accident (LOCA))							
	- Piping systems which provide a drywell-to-wetwell pressure differential (to alleviate pool swell effects)							
	- Other piping systems, including vent drains							
	o Supports of piping systems mentioned in previous item			SEE NOTES 1, 2, 3				THESE CONCERNS HAVE BEEN RESOLVED [8]
	o Vent header deflectors including associated hardware	✓						

Table 2-1. Audit Procedure for Structural Acceptance Criteria of Mark I Containment Long-Term Program

Section No. [2]	Key Items Considered in the Audit	Criteria Met	Criteria Not Met	Addtl. Info. Reqd.	Licensee Uses Alternate Approach: Conservative	Licensee Uses Alternate Approach: Unconservative	NA	Remarks
1.2	(Cont.)							
	o Internal structural elements (e.g., monorails, catwalks, their supports) whose failure might impair the containment function	✓						
1.3	a. The structural acceptance criteria for existing Mark I containment systems are contained in the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code, Section III, Division 1 (1977 Edition), with addenda through the Summer 1977 Addenda [3] to be referred herein as the Code. The alternatives to this criteria provided in Reference 2 are also acceptable.	✓						
	b. When complete application of the criteria (item 1.3a) results in hardships or unusual difficulties without a compensating increase in level of quality and safety, other structural acceptance criteria may be used after approval by the Nuclear Regulatory Commission.						✓	

Table 2-1. Audit Procedure for Structural Acceptance Criteria of Mark I Containment Long-Term Program

Section No. [2]	Key Items Considered in the Audit	Criteria Met	Criteria Not Met	Addtl. Info. Reqd.	Licensee Uses Alternate Approach: Conservative	Licensee Uses Alternate Approach: Unconservative	NA	Remarks
2.1	a. Identify the code or other classification of the structural element	✓						
	b. Prepare specific dimensional boundary definition for the specific Mark I containment systems (Note: Welds connecting piping to a nozzle are piping welds, not Class MC welds)	✓						
2.2	Guidelines for classification of structural elements and boundary definition are as follows:							
	(Refer to Table 2-3 and Table 2-4 for non-piping and piping structural elements, respectively, and to item 5 in this table for row designations used for defining limits of boundaries)							
	a. Torus shell (Row 1) - The torus membrane in combination with reinforcing rings, penetration elements within the NE-3334 [3] limit of reinforcement normal to the torus shell, and attachment welds to the inner or outer surface of the above members but not to nozzles, is a Class MC [3] vessel.	✓						

Table 2-1. Audit Procedure for Structural Acceptance Criteria of Mark I Containment Long-Term Program

Section No. [2]	Key Items Considered in the Audit	Criteria Met	Criteria Not Met	Addtl. Info. Reqd.	Licensee Uses Alternate Approach: Conservative	Licensee Uses Alternate Approach: Unconservative	NA	Remarks
2.2	(Cont.)							
	b. Torus shell supports (Row 1) - Subsection NF [3] support structures between the torus shell and the building structure, exclusive of the attachment welds to the torus shell; welded or mechanical attachments to the building structures (excluding embedments); and seismic constraints between the torus shell and the building structure are Class MC [3] supports.	✓						
	c. External vents and vent-to-torus bellows (Row 1) - The external vents (between the attachment weld to the drywell and the attachment weld to the bellows) including: vent penetrations within the NE-3334 [3] limit of reinforcement normal to the vent, internal or external attachment welds to the external vent but not to nozzles, and the vent-to-torus bellows (including attachment welds to the torus shell and to the external vents) are Class MC [3] vessels.	✓						

Table 2-1. Audit Procedure for Structural Acceptance Criteria of Mark I Containment Long-Term Program

Section No. [2]	Key Items Considered in the Audit	Criteria Met	Criteria Not Met	Addtl. Info. Reqd.	Licensee Uses Alternate Approach: Conservative	Licensee Uses Alternate Approach: Unconservative	NA	Remarks
2.2	(Cont.)							
	d. Drywell-vent connection region (Row 1) - Vent welded connections to the drywell (the drywell and the drywell region of interest for this program is up to the NE-3334 [3] limit of reinforcement on the drywell shell) are Class MC [3] vessels.	✓						
	e. Internal vents (Rows 2 and 3) - Are the continuation of the vents internal to the torus shell from the vent-bellows welds and include: the cylindrical shell, the closure head, penetrations in the cylindrical shell or closure head within the NE-3334 [3] limit of reinforcement normal to the vent, and attachment welds to inner or outer surface of the vent but not to nozzles.	✓						
	f. Vent ring header (Rows 4 and 5) and downcomers (Row 6) - Vent ring header including the downcomers and internal or external attachment welds to the ring header and the attachment welds to the downcomers are Class MC [3] vessels.	✓						

Table 2-1. Audit Procedure for Structural Acceptance Criteria of Mark I Containment Long-Term Program

Section No. [2]	Key Items Considered in the Audit	Criteria Met	Criteria Not Met	Addtl. Info. Reqd.	Licensee Uses Alternate Approach: Conservative	Licensee Uses Alternate Approach: Unconservative	NA	Remarks
2.2	(Cont.)							
	- The portion of the downcomer within the NE-3334 [3] limit of reinforcement normal to the vent ring header and portion of the vent ring header within NE-3334 limit of reinforcement arc considered under Row 5.	✓						
	g. Vent ring header supports (Row 7) - Subsection NF [3] supports, exclusive of the attachment welds to the vent ring header and to the torus shell, are Class MC [3] supports.	✓						
	h. Essential (Rows 10 and 11) and non-essential (Rows 12 and 13) piping systems - A piping system or a portion of it is essential if the system is necessary to assure the integrity of the reactor coolant pressure boundary, the capability to shut down the reactor and maintain it in a shutdown condition, or the capability to prevent or mitigate the consequences of			SEE NOTE 4				THIS CONCERN HAS BEEN RESOLVED [8]

Table 2-1. Audit Procedure for Structural Acceptance Criteria of Mark I Containment Long-Term Program

Section No. [2]	Key Items Considered in the Audit	Criteria Met	Criteria Not Met	Addtl. Info. Reqd.	Licensee Uses Alternate Approach: Conservative	Licensee Uses Alternate Approach: Unconservative	NA	Remarks
2.2	(Cont.) accidents which could result in potential off site exposures comparable to the guideline exposure of 10CFR100 [4]. Piping should be considered essential if it performs a safety-related role at a later time during the event combination being considered or during any subsequent event combination.							
	i. Active and inactive component (Rows 10-13) - Active component is a pump or valve in an essential piping system which is required to perform a mechanical motion during the course of accomplishing a system safety function.			SEE NOTE 4				THIS CONCERN HAS BEEN RESOLVED [B]
	j. Containment vacuum breakers (Row 2) - Vacuum breakers valves mounted on the vent internal to the torus or on piping associated with the torus are Class 2 [3] components.			SEE NOTE 1				—do—

Table 2-1. Audit Procedure for Structural Acceptance Criteria of Mark I Containment Long-Term Program

Section No. [2]	Key Items Considered in the Audit	Criteria Met	Criteria Not Met	Addtl. Info. Reqd.	Licensee Uses Alternate Approach: Conservative	Licensee Uses Alternate Approach: Unconservative	NA	Remarks
2.2	(Cont.)							
	k. External piping and supports (Rows 10-13): - No Class 1 piping - Piping external to and penetrating the torus or the external vents, including the attachment weld to the torus or vent nozzle is Class 2 [3] piping. The other terminal end of such external piping should be determined based on its function and isolation capability. - Subsection NF [3] support for such external piping including welded or mechanical attachment to structure; excluding any attachment welds to the piping or other pressure retaining component are Class 2 [3] supports.			SEE NOTE 2				THIS CONCERN HAS BEEN RESOLVED [8]
	l. Internal piping and supports (Rows 10-13) - Are Class 2 or Class 3 piping and Class 2 or Class 3 component supports.	✓						
	m. Internal structures (Row 8) - Non-safety-related elements which are not pressure retaining, exclusive of attachment welds to any pressure retaining	✓						

Table 2-1. Audit Procedure for Structural Acceptance Criteria of Mark I Containment Long-Term Program

Section No. [2]	Key Items Considered in the Audit	Criteria Met	Criteria Not Met	Addtl. Info. Reqd.	Licensee Uses Alternate Approach Conservative	Licensee Uses Alternate Approach Unconservative	NA	Remarks
2.2	(Cont.) member (e.g., monorails, ladders, catwalks, and their supports).							
	n. Vent deflectors (Row 9) - Vent header flow deflectors and associated hardware (not including attachment welds to Class MC vessels) are internal structures.	✓						
3.2	Load terminology used should be based on Final Safety Analysis Report (FSAR) for the unit or the Load Definition Report (LDR) [5]. In case of conflict, the LDR loads shall be used.	✓						
3.3	Consideration of all load combinations defined in Section 3 of the LDR [5] shall be provided.	✓						
4.3	a. No reevaluation for limits set for design pressure and design temperature values is needed for present structural elements.						✓	
	b. Design limit requirements used for initial construction following normal practice with respect to load definition and allowable stress shall be used for systems or	✓						

Table 2-1. Audit Procedure for Structural Acceptance Criteria of Mark I Containment Long-Term Program

Section No. [2]	Key Items Considered in the Audit	Criteria Met	Criteria Not Met	Addtl. Info. Reqd.	Licensee Uses Alternate Approach: Conservative	Licensee Uses Alternate Approach: Unconservative	NA	Remarks
4.3	(Cont.) portions of systems that are replaced and for new systems.							
4.4	Service Limits and Design Procedures shall be based on the B&PV Code, Section III, Division 1 including addenda up to Summer 1977 Addenda [3], specifically:							See definition for Service Limits in Section 4 of Reference 2.
	a. Class MC containment vessels: Article NE-3000 [3]	✓						
	b. Linear-type component (Class 2 and 3) support - with three modifications to the Code: - For bolted connections, the requirements of Service Limits A and B shall be applied to Service Limits C and D without increase in the allowables above those applicable to Service Levels A and B; - NF-3231.1 (a) [3] is for primary plus secondary stress range;			SEE NOTE 10				THIS CONCERN HAS BEEN RESOLVED [8]

Table 2-1. Audit Procedure for Structural Acceptance Criteria of Mark I Containment Long-Term Program

Section No. [2]	Key Items Considered in the Audit	Criteria Met	Criteria Not Met	Addtl. Info. Reqd.	Licensee Uses Alternate Approach: Conservative	Licensee Uses Alternate Approach: Unconservative	NA	Remarks
	- All increases in allowable stress permitted by Subsection NF [3] are limited by Appendix XVII-2110(b) [3] when buckling is a consideration.							
	c. Class 2 and 3 piping, pumps, valves, and internal structures (also Class MC)			SEE NOTE 2				THIS CONCERN HAS BEEN RESOLVED [8]
5.3	The components, component loadings, and service level assignments for Class MC [3] components and internal structures shall be as defined in Table 5-1 of Reference 2.	✓						
5.4	The components, component loadings, and service level assignments for Class 2 and Class 3 piping systems shall be defined in Table 5-2 of Reference 2.	✓						
5.5	The definition of operability is the ability to perform required mechanical motion and functionality is the ability to pass rated flow.							
	a. Active components shall be proven operable. Active components shall be considered operable if Service Limits A or B or more conservative limits (if the original design criteria required it) are met.			SEE NOTE 4				— do —

Table 2-1. Audit Procedure for Structural Acceptance Criteria of Mark I Containment Long-Term Program

Section No. [2]	Key Items Considered in the Audit	Criteria Met	Criteria Not Met	Addtl. Info. Reqd.	Licensee Uses Alternate Approach: Conservative	Licensee Uses Alternate Approach: Unconservative	NA	Remarks
5.5	(Cont.)							
	b. Piping components shall be proven functional in a manner consistent with the original design criteria.			SEE NOTE 4				THIS CONCERN HAS BEEN RESOLVED [8]
6.1	Analysis guidelines provided herein shall apply to all structural elements identified in item 1.2 of this table.							
	a. All loadings defined in subsection 3.2 of Reference 2 shall be considered.	✓						See Section 3.3 of this table.
	b. A summary technical report on the analysis shall be submitted to the NRC.			SEE NOTES 1,2, 5,9				THESE CONCERNS HAVE BEEN RESOLVED [8]
6.2	The following general guidelines shall be applied to all structural elements analyzed:							
	a. Perform analysis according to guideline defined herein for all loads defined in LDR [5]. (For loads considered in original design, but not redefined by LDR, previous analyses or new analyses may be used.)	✓						
	b. Only limiting load combination events need be considered.	✓						

Table 3-1. Audit Procedure for Structural Acceptance Criteria of Mark I Containment Long-Term Program

Section No. [2]	Key Items Considered in the Audit	Criteria Met	Criteria Not Met	Addtl. Info. Reqd.	Licensee Uses Alternate Approach: Conservative	Licensee Uses Alternate Approach: Unconservative	NA	Remarks
6.2	(Cont.)							
	c. Fatigue effects of all operational cycles shall be considered.			SEE NOTE 5				THIS CONCERN HAS BEEN RESOLVED [8]
	d. No further evaluation of structural elements for which combined effect of loads defined in LDR [5] produces stresses less than 10% of allowable is required. Calculations demonstrating conformance with the 10% rule shall be provided.							
	e. Damping values used in dynamic analyses shall be in accordance with NRC Regulatory Guide 1.61 [6].	✓						
6.3	Structural responses for loads resulting from the combination of two dynamic phenomena shall be obtained in the following manner:							
	a. Absolute sum of stress components, or	✓						
	b. Cumulative distribution function method if absolute sum of stress components does not satisfy the acceptance criteria.	✓						
6.4	Torus analysis shall consist of:							

Table 2-1. Audit Procedure for Structural Acceptance Criteria of Mark I Containment Long-Term Program

Section No. [2]	Key Items Considered in the Audit	Criteria Met	Criteria Not Met	Addtl. Info. Reqd.	Licensee Uses Alternate Approach: Conservative	Licensee Uses Alternate Approach: Unconservative	NA	Remarks
6.4	(Cont.)							
	a. Finite element analysis for hydrodynamic loads (time history analysis) and normal and other loads (static analysis) making up the load combinations shall be performed for the most highly loaded segment of the torus, including the shell, ring, girders, and support.			SEE NOTES 6, 7, 8, 9				THESE CONCERNS HAVE BEEN RESOLVED [8]
	b. Evaluation of overall effects of seismic and other nonsymmetric loads shall be provided using beam models (of at least 180° of the torus including columns and seismic restraints) by use of either dynamic load factors or time history analysis.	✓						
	c. Provide a non-linear time history analysis, using a spring mass model of torus and support if net tensile forces are produced in columns due to upward phase of loading.	✓						
	d. Bijlaard formulas shall be used in analyzing each torus nozzle for effect of reactions produced by attached piping. If Bijlaard formulas are not			SEE NOTE 2				-do-

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NRC Contract No. NRC-03-81-130
FRC Project No. C5506
FRC Assignment No. 12
FRC Task No. 326
Plant Name MONTICELLO

Table 2-1. Audit Procedure for Structural Acceptance Criteria of Mark I Containment Long-Term Program

Section No. [2]	Key items Considered in the Audit	Criteria Met	Criteria Not Met	Addtl. Info. Reqd.	Licensee Uses Alternate Approach: Conservative	Licensee Uses Alternate Approach: Unconservative	NA	Remarks
6.4	(Cont.) applicable for any nozzle, finite element analysis shall be performed.							
6.5	In analysis of the vent system (including vent penetration in drywell, vent pipes, ring header, downcomers and their intersections, vent column supports, vent-torus bellows, vacuum breaker penetration, and the vent deflectors), the following guidelines shall be followed:							
	a. Finite element model shall represent the most highly loaded portion of ring header shell in the "non-vent" bay with the downcomers attached.			SEE NOTE 6				THIS CONCERN HAS BEEN RESOLVED [E]
	b. Finite element analysis shall be performed to evaluate local effects in the ring header shell and downcomer intersections. Use time history analysis for pool swell transient and equivalent static analysis for downcomer lateral loads.	✓						

Table 2-1. Audit Procedure for Structural Acceptance Criteria of Mark I Containment Long-Term Program

Section No. [2]	Key Items Considered in the Audit	Criteria Met	Criteria Not Met	Addtl. Info. Reqd.	Licensee Uses Alternate Approach: Conservative	Licensee Uses Alternate Approach: Unconservative	NA	Remarks
6.5	(Cont.)							
	c. Evaluation of overall effects of seismic and other nonsymmetrical loads shall be provided using beam models (of at least 180° of the vent system including vent pipes, ring header and column supports) by the use of either dynamic load factors or time history analysis.	✓						
	d. Use beam models in analysis of vent deflectors.						✓	VENT DEFLECTOR IS INCLUDED IN THE OVERALL MODEL
	e. Consider appropriate superposition of reactions from the vent deflectors and ring headers in evaluating the vent support columns for pool swell.						✓	
6.6	a. Analysis of torus internals shall include the catwalks with supports, monorails, and miscellaneous internal piping.	✓						
	b. It shall be based on hand calculations or simple beam models and dynamic load factors and equivalent static analysis.	✓						

Table 2-1. Audit Procedure for Structural Acceptance Criteria of Mark I Containment Long-Term Program

Section No. [2]	Key Items Considered in the Audit	Criteria Met	Criteria Not Met	Addtl. Info. Reqd.	Licensee Uses Alternate Approach: Conservative	Licensee Uses Alternate Approach: Unconservative	NA	Remarks
6.6	(Cont.)							
	c. It shall consider Service Level D or E when specified by the structural acceptance criteria using a simplified nonlinear analysis technique (e.g., Bigg's Method).			SEE NOTE 11				THIS CONCERN HAS BEEN RESOLVED DUE TO THE CONSERVATIVE ESTIMATES OF THE LOADS AND LOAD COMBINATIONS
6.7	Analysis of the torus attached piping shall be performed as follows:							
	a. Designate in the summary technical report submitted all piping systems as essential or non-essential for each load combination.			SEE NOTE 4				THIS CONCERN HAS BEEN RESOLVED [8]
	b. Analytical model shall represent piping and supports from torus to first rigid anchor (or where effect of torus motion is insignificant).			SEE NOTE 2				— do —
	c. Use response spectrum or time history analysis for dynamic effect of torus motion at the attachment point, except for piping systems less than 6" in diameter, for which equivalent static analysis (using appropriate amplification factor) may be performed.			SEE NOTE 2				— do —

Table 2-1. Audit Procedure for Structural Acceptance Criteria of Mark I Containment Long-Term Program

Section No. [2]	Key Items Considered in the Audit	Criteria Met	Criteria Not Met	Addtl. Info. Reqd.	Licensee Uses Alternate Approach: Conservative	Licensee Uses Alternate Approach: Unconservative	NA	Remarks
6.7	(Cont.)							
	d. Effect of anchor displacement due to torus motion may be neglected from Equation 9 of NC or ND-3652.2 [3] if considered in Equations 10 and 11 of NC or ND-3652.3 [3].			SEE NOTE 2				THIS CONCERN HAS BEEN RESOLVED [8]
6.8	Safety relief valve discharge piping shall be analyzed as follows:							
	a. Analyze each discharge line.	✓						
	b. Model shall represent piping and supports, from nozzle at main steam line to discharge in suppression pool, and include discharge device and its supports.	✓						
	c. For discharge thrust loads, use time history analysis.	✓						
	d. Use spectrum analysis or dynamic load factors for other dynamic loads.	✓						

Table 2-2. Audit Summary for Structural Acceptance Criteria of Mark I Containment Long-Term Program

Structural Element	General Requirements			Analysis Requirements					Remarks
	Code Classification	Loads	Service Limits	Method of Analysis	All Limiting Loads Considered	Fatigue Effects	Method of Combining Response	Results	
a. Torus shell with associated penetrations, reinforcing rings, and support attachments	✓	✓	✓	✓	✓	✓	✓	✓	
b. Torus shell supports to the building structure	✓	✓	✓	✓	✓	✓	✓	✓	
c. Vents between the drywell and the vent ring header (including penetrations therein)	✓	✓	✓	✓	✓	✓	✓	✓	
d. Region of drywell local to vent penetrations	✓	✓	✓	✓	✓	✓	✓	✓	
e. Bellows between vents and torus shell (internal or external to torus)	✓	✓	✓	✓	✓	✓	✓	✓	
f. Vent ring header and the downcomers attached to it	✓	✓	✓	✓	✓	✓	✓	✓	
g. Vent ring header supports to the torus shell	✓	✓	✓	✓	✓	✓	✓	✓	
h. Vacuum breaker valves attached to vent penetrations within the torus (where applicable)	✓	✓	✓	✓	✓	✓	✓	✓	
i. Vacuum breaker piping systems, including vacuum breaker valves attached to torus shell penetrations and to vent penetrations external to the torus (where applicable)	✓	✓	✓	✓	✓	✓	✓	✓	VACUUM BREAKER VALVE MODIFICATIONS ARE OUTSIDE THE SCOPE OF THIS TER
j. Piping systems, including pumps and valves internal to the torus, attached to the torus shell and/or vent penetrations	✓	✓	✓	✓	✓	✓	✓	✓	

Table 2-2. Audit Summary for Structural Acceptance Criteria of Mark I Containment Long-Term Program

Structural Element	General Requirements			Analysis Requirements					Remarks
	Code Classification	Loads	Service Limits	Method of Analysis	All Limiting Loads Considered	Fatigue Effects	Method of Combining Response	Results	
k. All main steam system safety relief valve (SRV) piping	✓	✓	✓	✓	✓	✓	✓	✓	
l. Applicable portions of the following piping systems:	✓	✓	✓	✓	✓	✓	✓	✓	
(1) Active containment system piping systems (e.g., emergency core cooling system (ECCS) suction piping and other piping required to maintain core cooling after loss-of-coolant accident (LOCA))									
(2) Piping systems which provide a drywell-to-wetwell pressure differential (to alleviate pool swell effects)									
(3) Other piping systems, including vent drains									
m. Supports of piping systems mentioned in previous item	✓	✓	✓	✓	✓	✓	✓	✓	
n. Vent header deflectors including associated hardware	✓	✓	✓	✓	✓	✓	✓	✓	
o. Internal structural elements (e.g., monorails, catwalks, their supports) whose failure might impair the containment function	✓	✓	✓	✓	✓	✓	✓	✓	

Table 2-3. Non-Piping Structural Elements

STRUCTURAL ELEMENT	ROW
External Class MC	
Torus, Bellows, External Vent Pipe, Drywell (at Vent), Attachment Welds, Torus Supports, Seismic Restraints	1
Internals Vent Pipe	
General and Attachment Welds	2
At Penetration (e.g., Header)	3
Vent Ring Header	
General and Attachment Welds	4
At Penetrations (e.g., Downcomers)	5
Downcomers	
General and Attachment Welds	6
Internals Supports	7
Internals Structures	
General	8
Vent Deflector	9

Table 2-4. Piping Structural Elements

STRUCTURAL ELEMENT	ROW
Essential Piping Systems	
With IBA/DBA	10
With SBA	11
Nonessential Piping Systems	
With IBA/DBA	12
With SBA	13

NOTES RELATED TO TABLES 2-1 AND 2-2

Note 1: The Licensee has not provided information on the analysis of the vacuum breaker piping systems and the vacuum breaker valves attached to vent penetrations within the torus, and has not indicated that these are Class 2 components.

Note 2: The Licensee has not provided information on the analysis of torus attached piping systems.

Note 3: The Licensee has not provided information on the analysis of active containment system piping systems, piping systems which provide a drywell-to-wetwell pressure differential, and other internal piping systems.

Note 4: The Licensee has not provided information indicating whether the piping and its supports have been classified as Class 2 or Class 3 piping, or essential or non-essential piping systems, and whether a pump or valve associated with the piping is an active or inactive component, and is considered operable.

Note 5: For the case of piping fatigue analysis, the NRC staff has requested the conclusions of a study presented at the NRC meeting [7] to be documented and submitted for NRC approval. If these conclusions are acceptable to the NRC, each PUA report would be required to indicate that the fatigue usage factors for the SRV piping systems and the torus attached piping are sufficiently small that a plant-unique fatigue analysis of these piping systems is not warranted.

Note 6: Tables 2-2.4-1 and 3-2.4-1 [8] indicate that the natural frequency of the suppression chamber and that of the vent system are very close to each other for the first mode. The Licensee should provide more details of the calculation for the spring stiffness $[K]_{SC}$ in Figure 3-2.4-1 and should show that the coupling effects between the vent system and the suppression chamber have been properly accounted for in the analysis.

Note 7: Tables 2-2.5-6 and 2-2.5-7 of Reference 8 indicate that the calculated values of certain stresses are very close to or equal to the respective allowables. The Licensee should indicate the conservatisms in the analysis to show that these calculated values would not be exceeded if a different analytical approach were to be used.

Note 8: With reference to Figures 2-2.4-1 and 2-2.4-2 of Reference 8, the Licensee has not provided justifications and/or reasons for modeling the torus reinforcing ring as beam elements connected to the torus shell by offset rigid links. Also, the Licensee should discuss the conservatisms, if any, used in the above-mentioned approach in comparison to the modeling of the reinforcing ring as plate elements.

Note 9: The Licensee has not provided information on the results of the analysis of the reinforcing ring which has been analyzed separately for submerged structure loads.

Note 10: The Licensee has not indicated whether all linear type component supports meet the criteria requirements as specified in Section 4.4 of Reference 2.

Note 11: With reference to Section 4.2.5 of the PUAAG [2], Level E Service Limits permit subsequent qualification of the component, despite the postulated failure, if it can be shown by a consequence analysis that no impairment of any Mark I safety function will result. It appears that a possible violation of the intent of the Level E Service Limits may be indicated in Table 4-2.5-1 [8]. Here, a Level E Service stress limit which exceeds the Level D Service stress limit and equals the ultimate strength of the materials is shown for the monorail.

3. REFERENCES FOR APPENDIX A

1. NUREG-0661
   "Safety Evaluation Report, Mark I Containment Long-Term Program Resolution of Generic Technical Activity A-7"
   Office of Nuclear Reactor Regulation
   USNRC
   July 1980

2. NEDO-24583-1
   "Mark I Containment Program Structural Acceptance Criteria Plant Unique Analysis Application Guide"
   General Electric Co., San Jose, CA
   October 1979

3. American Society of Mechanical Engineers
   Boiler and Pressure Vessel Code, Section III, Division 1
   "Nuclear Power Plant Components"
   New York: 1977 Edition and Addenda up to Summer 1977

4. Title 10 of the Code of Federal Regulations

5. NEDO-21888 Revision 2
   "Mark I Containment Program Load Definition Report"
   General Electric Co., San Jose, CA
   November 1981

6. NRC
   "Damping Values for Seismic Design of Nuclear Power Plants"
   Regulatory Guide 1.61
   October 1973

7. P. M. Kasik
   "Mark I Piping Fatigue," Presentation at the NRC meeting, Bethesda, MD
   September 10, 1982

8. Northern States Power Company
   Monticello Nuclear Generating Plant
   Plant Unique Analysis Report
   Volumes 1, 2, 3, 4, and 5
   NPS-74-103, Revision 1
   November 1982

APPENDIX B

TECHNICAL REPORT ON THE USE OF THE CMDOF PROGRAM IN THE MARK I TORUS ATTACHED PIPING ANALYSIS

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TECHNICAL REPORT
ON THE USE OF THE CMDOF PROGRAM
IN THE MARK I TORUS ATTACHED PIPING ANALYSIS

BY

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A. A. Okaily

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April 1985

1. Background Information

The purpose of this report is to provide assessments and to document activities associated with the computer program CMDOF (Coupling of Multiple Degrees of Freedom) which was used by the NUTECH technical staff to qualify the Mark I torus attached piping systems in a number of nuclear power plants. This program was originally developed by Dr. R. P. Kennedy [1] of Structural Mechanics Associates and modified by NUTECH technical staff to establish the stress level of the torus attached piping under various hydrodynamic loading conditions associated with the Mark I structural evaluation program. In the course of reviewing the analytical procedures for stress calculations of the torus attached piping systems, Franklin Research Center (FRC) staff raised concerns associated with the verification of this program, which will be summarized in the next section of this report. A meeting was held with the NUTECH technical staff and a number of affected utilities on August 9 and 10, 1984 to discuss a number of technical issues related to this program. As a result of this meeting, a number of action items were requested from the affected utilities, to which the NUTECH technical staff responded [2]. The reviews of NUTECH responses indicated that the main concern, which is the validation of the program, remained unresolved. A report was then prepared and submitted to the NRC by FRC [3] to provide the review status of this program and highlight areas of concern associated with the use of this program.

A subsequent meeting was held on January 4, 1985 with the NUTECH technical staff, Dr. R. P. Kennedy of Structural Mechanics Associates, and representatives of the Mark I owner group and a number of utility companies. In this meeting, Dr. Kennedy provided an overview of the technical background of this program. It was also learned that the Bechtel Power Corporation attempted to verify the program by comparing the results obtained by the program with those obtained from a combined torus/piping model. However, due to numerical instabilities of the combined torus/piping model, this attempt was not successful. At the end of this meeting, it was obvious that FRC's concerns were not resolved and the affected licensees expressed their opposition to perform further investigations regarding the program verification. However, it was learned later that the Monticello plant selected some in-plant test data (SRV in-plant test data) to verify the program. The results of this study were submitted for review [4]. FRC review of this latest document is given in Section 4 of this report.

2. Technical Background of the CMDOF Program

The standard practice for performing dynamic analysis of the torus and attached piping systems is to perform independent uncoupled dynamic analysis of the torus and of the attached piping. First, the torus model is developed and a dynamic analysis of the torus subjected to the postulated hydrodynamic load is performed using this uncoupled model. The response time history at the penetration point of the attached piping is obtained. Then this response time history is used in conjunction with the uncoupled dynamic model of the attached piping to calculate piping responses. This approach is known as an uncoupled analysis because the dynamic model of the torus and the attached piping are never directly coupled. It has been recognized that this approach results in a conservative estimate of the piping responses.

The other acceptable approach is to carry out a coupled analysis in which the torus and associated piping are combined in a single coupled model. The model is fairly complicated and also results in high computational cost, especially when a significant number of loading time histories have to be considered. Therefore, this coupled analysis does not represent an attractive alternative. In fact, none of the Mark I facility resorts to this approach.

The CMDOF program was developed to take into account the coupling effects without carrying out the coupled analysis described above. Essentially, this program is used to modify the response time history obtained from the uncoupled torus model at the penetration point of the attached piping and this modified time history is then used to obtain the piping response of the uncoupled piping model. In order to use this program, the modal response characteristics of the torus and attached piping have to be established first by applying an unit force at the attachment location. These modal response characteristics along with the uncoupled response time history of the torus at the penetration point will be input into the CMDOF program, which will produce a modified response time history to be used in obtaining the piping response. This program, in principle, is supposed to remove the conservatism associated with the uncoupled analysis.

3. Concerns Associated with the CMDOF Program

Based on the review of pipe stresses obtained via this program and other information relating to this program, FRC staff raised a number of questions in connection with the validation of this program [3]. A program of this nature requires a substantial validation effort in order to use it in a production mode. Also, this program is relatively new and the originator of the program cautioned:

> "It has been carefully programmed and checked against a number of test cases by comparing its results for coupled response with those obtained from coupled structure and equipment analyses. However, it has not been used to date (April, 1980) by other than the authors. It is not a production program which can be used as a "black box". Users should independently verify their own use of the program and understand its basis and applicability before using it in a production mode." [1]

FRC's concerns are briefly summarized below:

- The verification problems provided were extremely simple compared with the problem of the torus and attached piping. Basically, the verification problem consists of a spring-mass system with a few degrees of freedom.

- The parameters (mass and stiffness) given in the verification problems did not resemble a wide range of values (mass and stiffness) encountered in the actual problem.

- Based on some study by NUTECH [4], it was observed that the CMDOF could reduce the input loading to the attached piping by as much as 3 or 4 times when compared with a standard uncoupled analysis.

- Calculated stresses of the affected piping systems in a number of plants in some cases were closed or equal to the stress allowables.

4. Review of CMDOF Verification

In-plant SRV tests performed at the Monticello plant in 1980 were used as a basis for verification of the CMDOF program. Test data from five tests were selected for comparison. Specifically, data from strain gauges located on the

RCIC turbine exhaust line (RS3-8 in-HE) approximately 1 foot and 20 feet from the torus penetration, as shown in Figure 1, were used for comparison. The tests were conducted by actuating one safety relief valve under cold pipe and normal water leg conditions with a reactor power level of 80%. Plots of strain time histories were recorded during each test and were compared directly with the predicted values obtained by the CMODF program.

With regard to load development, two programs (GE computer codes RVFOR04 and QBUBSO3) were used to develop the SRV torus shell pressure time histories corresponding to the test case conditions (i.e., cold pipe, normal water leg, reactor at 80% rated power). With respect to the torus and piping structural models, the Licensee indicated that these models were developed to reflect the as-tested condition.

The CMDOF program was used in conjunction with the modal characteristics of the torus and attached piping to obtain the modified responses at the attachment location to the test SRV loadings. Displacement, velocity, and acceleration responses were developed at all piping degrees of freedom coupled to the torus. From these responses, a modal superposition was employed in conjunction with transfer junction methodology to obtain stress time histories at the strain gauge locations of interest for comparison with the test results.

The Monticello SRV test strain gauge data (converted to stress) were compared with the predicted stresses obtained by the CMDOF program. The responses on the time domain and frequency domain (by Fourier transformation) at strain gauge locations were compared with those obtained by the analysis. In addition, the maximum stress values were used in the comparison. The results indicated that a factor of conservatism is excess of 3 was observed in the analysis.

Based on FRC's review of various stress time histories and the maximum stress level of the test data and analysis, it is observed that there is conservatism associated with the analytical procedures. This conservatism could be attributed to the following sources: methodology by which loads were generated, low damping values used in the analysis, possible nonlinearity resulting from pipe supports. The comparison between the test and predicted

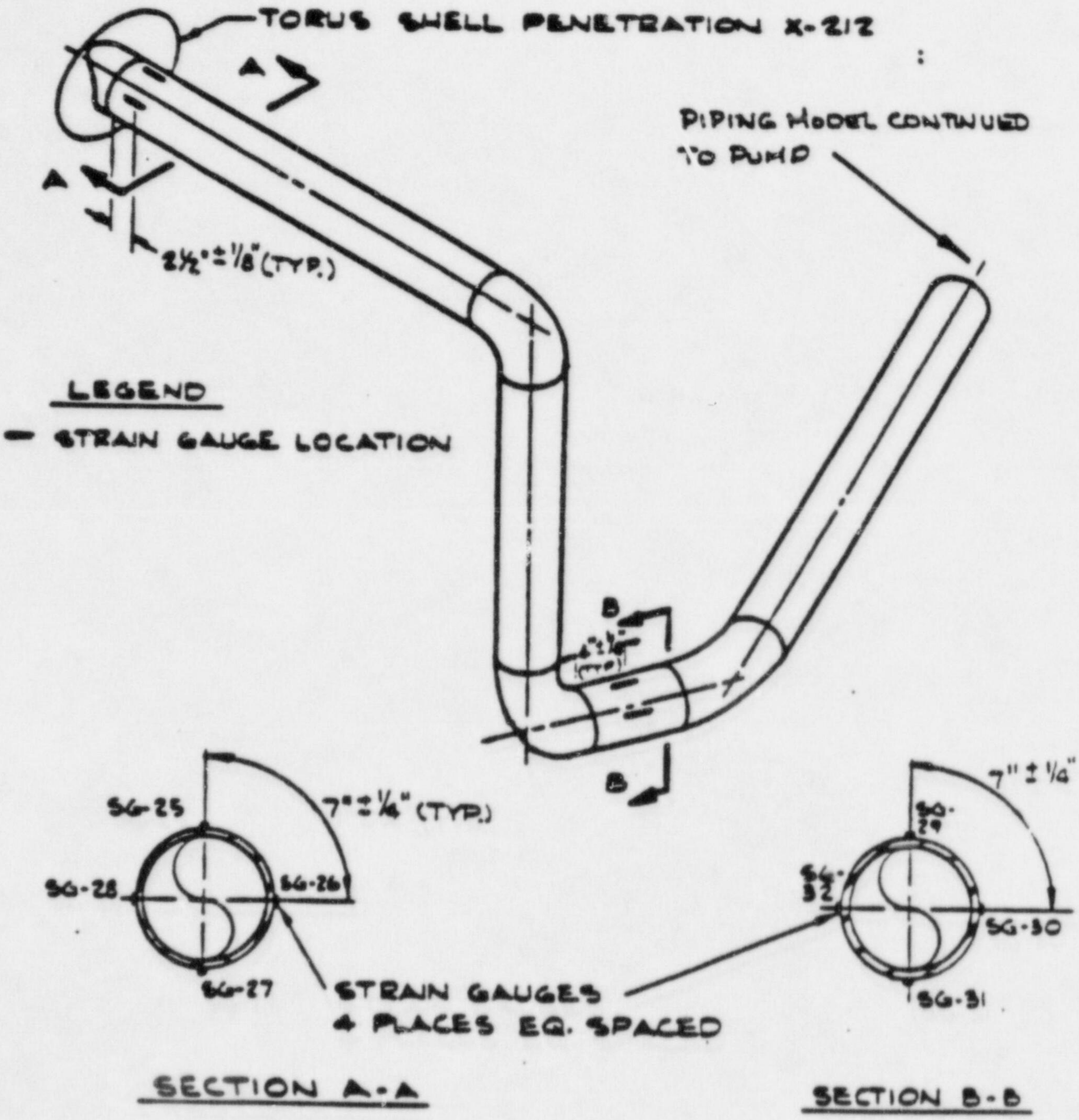

Figure 1. Strain Gauge Locations on RCIC Turbine Exhaust Line

values indicated that there is conservatism associated with the analytical procedures, which provides a basis for alleviating the concerns related to some calculated stress values presented in the Licensee's original submittals.

REFERENCES

1. Kennedy, R. P. and Kincaid, R. H., "CMDOF - A Computer Program to Couple the Response of Structures and Supported Equipment for Multiple Degrees of Coupling Using the Results from Uncoupled Structure and Equipment Analysis," SMA 12101.03, Structural Mechanics Associates, Inc., Newport Beach, California, November 1980

2. R. W. McGaughy (Iowa Electric Light and Power Company)
Letter with Attachments to H. Denton (NRC)
Subject: Clarifications Regarding the Duane Arnold Energy Center Plant Unique Analysis Report, Mark I Containment Program, NG-84-3937
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3. Con, V. N., "Review of the Computer Code CMDOF (Coupling of Multiple Degrees of Freedom," Franklin Research Center, October 1984

4. D. Musolf (Northern States Power Company)
Letter with Attachments to H. Denton (NRC)
Subject: Additional Information Related to Computer Program CMDOF
February 25, 1985