TELEDYNE
ENGINEERING SERVICES

TECHNICAL REPORT

TR-7353-1
REVISION 1

NINE MILE POINT UNIT 1
REDUCTION IN MARK I TORUS PROGRAM CONDENSATION
OSCILLATION LOAD DEFINITION
AND RESULTING EFFECT ON MINIMUM SHELL THICKNESS REQUIREMENTS

APRIL 22, 1991

NIAGARA MOHAWK POWER CORPORATION
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SYRACUSE, NEW YORK 13212

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APRIL 22, 1991

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RECORD OF REVISIONS

REVISION	PAGE	DESCRIPTION
1	Cover	Changed Revision 0 to Revision 1 and date from December 18, 1990 to April 22, 1991
	Title	Changed Revision 0 to Revision 1 and date from December 18, 1990 to April 22, 1991
	-ii-	Add Record of Revisions
	-iii-	Add -iii- to Table of Contents Page and "Revision 1" at top of page
	1 thru 15	Add "Revision 1" at top of page
	-13-	Based on present predictions, for the original analysis, the year the corrosion allowance will be consumed is 1994. Changed 1992 to 1994, 2005 to 2007, 2027 to 2029 and fifteen years to sixteen years.
	-15-	Changed Reference 12 from Revision 0 to Revision 1 and date from November 16, 1990 to April 22, 1991
	Appendix 1 Cover Page	Added "Revision 1" at top of page

TABLE OF CONTENTS

1.0 INTRODUCTION

Teledyne Engineering Services (TES) has been retained by Niagara Mohawk Power Corporation (NMPC) to explore the possibility of a short term fix which will increase the present margin on the minimum required torus shell thickness at Nine Mile Point Unit 1 (NMP-1).

The purpose of the Mark I Torus Program was to evaluate the effects of hydrodynamic loads resulting from a loss of coolant accident (LOCA) and/or an SRV discharge on the torus structure. Teledyne Engineering Services Technical Report TR-5320-1, Revision 1, "Mark I Containment Program, Plant-Unique Analysis Report of the Torus Suppression Chamber for Nine Mile Point Unit 1 Nuclear Generating Station," dated September 21, 1984, summarizes the results of extensive analysis on the Nine Mile Point Unit 1 torus structure and reports safety margins against established criteria. The content of that report deals with the torus shell, external support system, vent header system and internal structures.

The loads on which the Teledyne structural analysis is based are presented primarily in G.E. Report NEDO-21888, Rev. 2, "Mark I Containment Program Load Definition Report," dated November, 1981.

The criteria used to evaluate the torus structure is the 1977 ASME Boiler and Pressure Vessel Code, Section III, Division 1, with addenda through Summer 1978 and Code Case N-197.

During the Mark I Program, TES identified a Design Basis Accident (DBA) case with the Condensation Oscillation (CO) loading condition, as the limiting event combination for the torus shell primary membrane stress intensity at mid-bay bottom dead center. Upon program completion, an independent review of the methodology and results was performed by the NRC, and its consultants, to assure conformance with NUREG-0661 Safety Evaluation Report.

In 1979, Continuum Dynamics, Inc. was asked by the Mark I owners group, through G.E., to assess the conservatism in the Condensation Oscillation torus loads measured during the FSTF blowdown tests. This effort confirmed generally accepted conservatism in the tests with regard to test initial condition thermodynamics, and identified a significant conservatism which was not identified during test design. This conservatism was introduced by the very geometry of the test facility, one-sixteenth sector which is equivalently a 22-1/2° segment of the Mark I Pressure Suppression Pool Torus. The test facility, although full-scale in cross section, attempted to simulate at full-scale the condensation phenomenon in one bay only. End caps were required to contain the pool water and the airspace above the pool in the bay. The analysis, which analyzes the hydrodynamic consequences of these end caps, was presented to the Mark I owners in 1980. To expedite completion of this issue, the Mark I owners decided not to pursue reducing this conservatism at that time. This work is revisited for this effort and developed specifically for Nine Mile Point Unit 1.

The joint Teledyne and Continuum Dynamics effort presented herein consists of an analytical reduction in the Mark I Torus Program Condensation Oscillation Load Definition. The analysis shows that the eight downcomer bays have bay averaged CO loads which are conservative by at least 19% at frequencies other than 5-6 Hz and for four downcomer bays, the bay averaged CO loads are conservative by at least 38% at frequencies other than 5-6 Hz. The load conservatisms in the 5-6 Hz frequency band are 6% and 28% for the eight and four downcomer bays, respectively.

Removal of these conservatisms results in a smaller minimum shell thickness requirement.

The methods of structural analysis and the structural models used are identical to those used in the original Mark I Torus Program.

2.0 BACKGROUND

The Mark I Program (GE) determined the magnitude of the Condensation Oscillation (CO) loading(3) based on the test results from the Full Scale Test Facility (FSTF). As a result of the FSTF geometric boundary condition configuration, the facility was one bay with end caps to contain the fluid, a conservative prediction of the CO shell pressure loading was obtained. Conservatism in the CO load definition on the order of 15 to 30 percent was recognized during the Program but the Mark I Owners' Group determined at that time that it would not be cost effective to fund the analysis and documentation effort necessary to achieve further reduction in the CO load definition. Most of the Mark I plants had adequate margin on Code(6) stress allowables for the CO frequency domain event combination loading and therefore, did not require any further refinement to the load definition.

However, the NMP-1 torus has a thin shell (0.46 in.) compared with most of Mark I plants, and as a result, the postulated event combination which includes DBA pressure and CO (event combination 20) controls the margin on torus shell thickness. TES and NMPC recognized this problem as being critical early in the Mark I program, and we jointly took the necessary steps to mitigate loads from this event combination. First, TES refined the Torus Analysis for DBA pressure and CO including modeling techniques and the post processing of results. Then, TES and NMPC initiated a series of thin shell meetings at GE for NMP-1 and Oyster Creek. These meetings identified areas of conservatism in the load definition to be further explored by GE.

The reduction in NMP-1 DBA pressure resulting from these meetings was essential to the successful compliance of NMP-1 to the Mark I Program Structural Acceptance Criteria(11) for the CO event combination. The DBA pressure, rather than the CO loading conservatisms, were addressed based on cost and time considerations.

This report deals with the refinement of the CO load definition specifically for Nine Mile Point Unit 1.

3.0 SUMMARY OF CONDENSATION OSCILLATION WORK PERFORMED FOR THIS EFFORT

Pressures measured in the FSTF facility are measured as if all other bays are exactly in phase or are coherent with the bay modeled by FSTF. In addition, the rigid end caps in the FSTF facility imply that adjoining bays also have the same number of downcomers. In Nine Mile Point, adjoining bays only have one half of the number of downcomers. These differences have been exploited in the condensation oscillation load reduction effort performed herein.

Continuum Dynamics, Inc. (CDI), under contract to TES, has performed the hydrodynamic loading portion of the following described work. CDI was a consultant to the Mark I Owners' Group in the area of hydrodynamic loading phenomenon.

An approximate acoustic model of the Nine Mile Point containment, as if configured for testing by the FSTF facility, has been developed. This acoustic model computes the torus bottom center pressure anticipated in Nine Mile Point with the vent sources configured in an 8-4-8-4 downcomer per bay configuration and utilizes the information that there is a lack of coherence among the condensation pressures at the downcomer exits for most of the frequency range. This analysis has assumed, for practical reasons, that the torus can be unwound for analysis and has provided a table of bottom pressure load reduction factors as a function of frequency.

An analysis has also been performed, and is presented in the Continuum Dynamics Report, that addresses the influence that actual Torus curvature has on the analytically assumed "unwrapped" configuration. It was determined that the additional load reduction from a curvature correction would be small and no credit has been taken for this conservatism.

In addition, although it is shown that the load reduction factors are larger for smaller water acoustic speeds, no attempt has been made to take credit for this conservatism either.

The analysis has been done for both the bays containing eight (8) downcomers and the vent bays containing four (4) downcomers.

TES has determined the differential pressure transmissibility between the Load Definition Report, Reference 3, and newly derived CO definitions from Reference 9. We have adjusted the component stresses at the critical torus shell location by hand. The critical location is that which had been determined to control the margin on minimum required torus shell thickness in the Reference 10 report. Implicit in the adjustment of stresses by hand is the fact that the existing 1/40th torus finite element model fundamental physical results have been used for both the vent bay reduced loading and the non-vent bay reduced loading, separately.

4.0 COMPUTER MODEL

Analysis of the torus suppression chamber was accomplished using the STARDYNE computer model shown in Figures 1 through 4. The shell model shown was used to calculate the effects of all loads on shell stress.

The detailed finite element model simulates one-half of the non-vent bay. It is bounded by the ring girder on one end and the mid-bay point on the other. This model was constructed with the assumption that the small offset that exists between the ring girder and mitre joint will not affect results; accordingly, the offset is not included in the model.

Modeling of the water mass was accomplished using a 3-D virtual mass simulation as an integral part of the structural analysis.

This model includes 525 structural nodes, 615 plate elements, 2193 static degrees of freedom and 364 dynamic degrees of freedom. Symmetric boundary conditions were used at both ends of the model.

This is the same model that was used in the original Torus Analysis and reviewed and accepted by the NRC.

Figure 1

Detailed 1/40th Shell Model

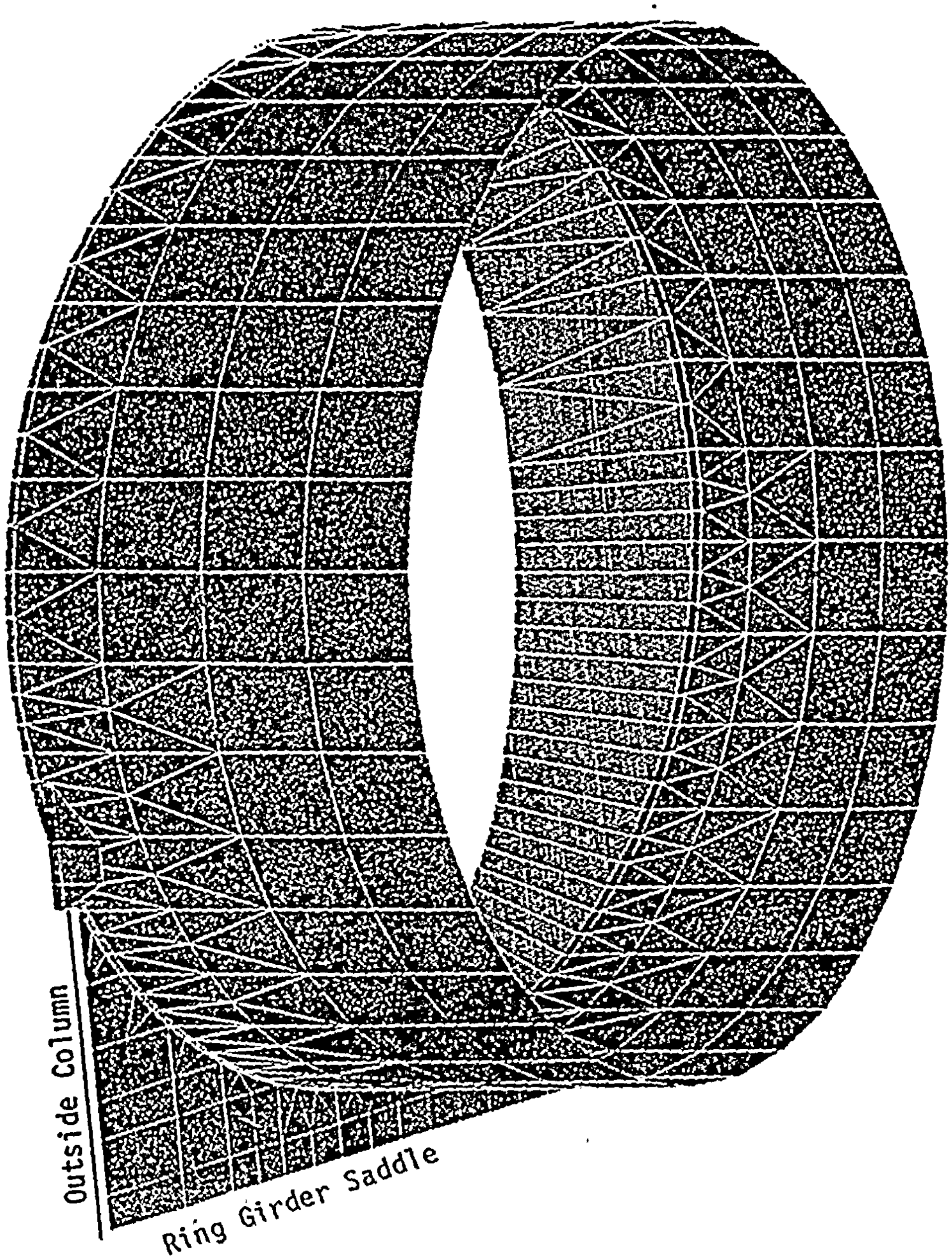


Figure 2

Torus 1/40th Shell Model

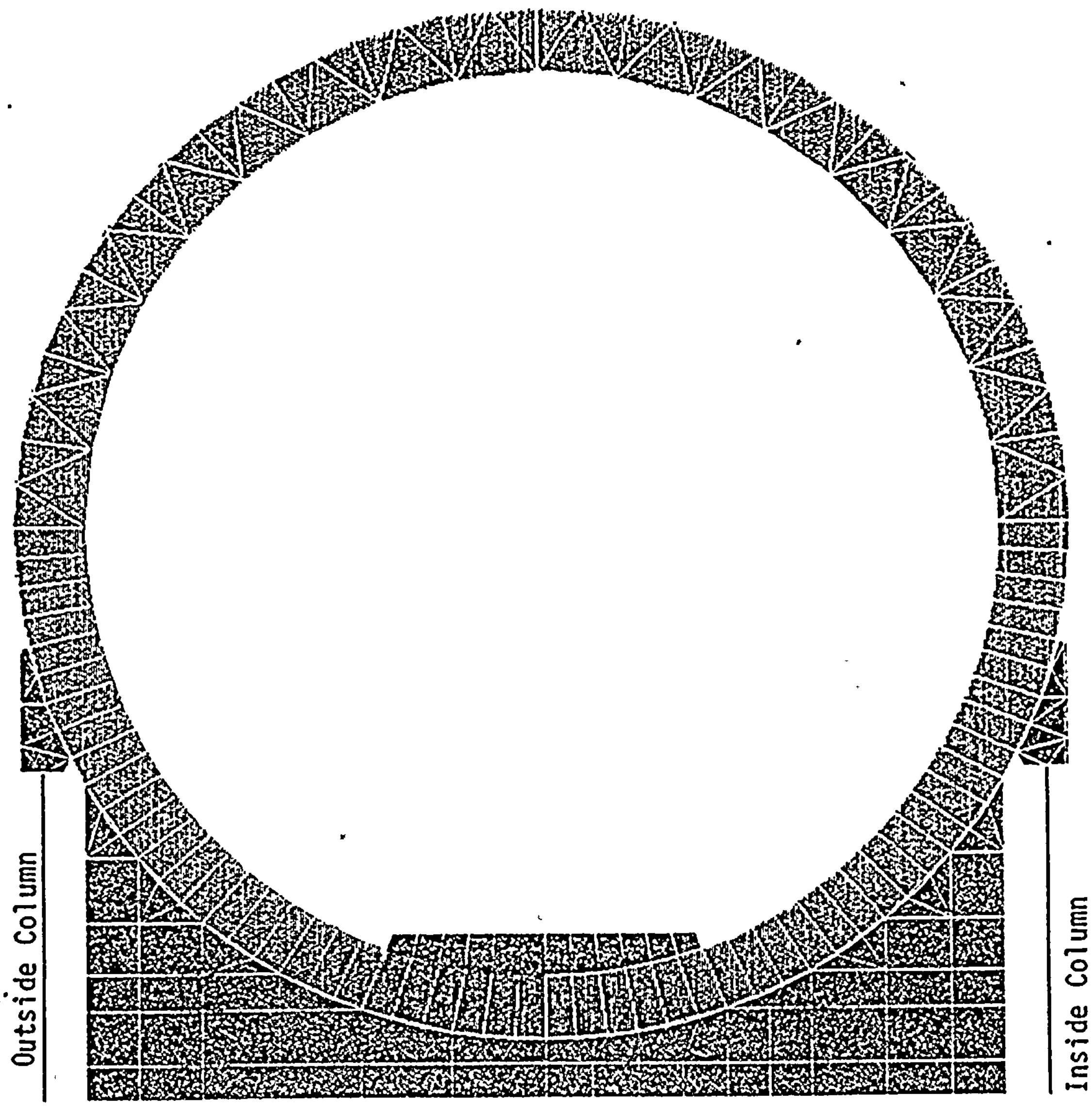
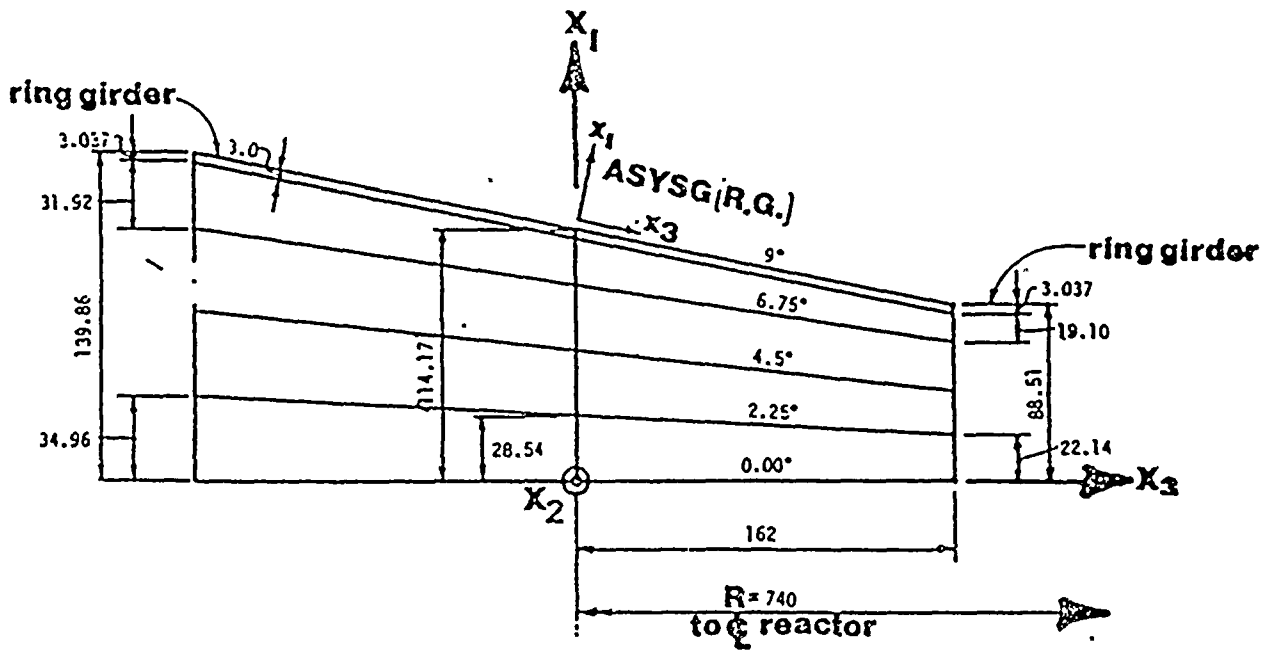


Figure 3

Detailed Shell Model

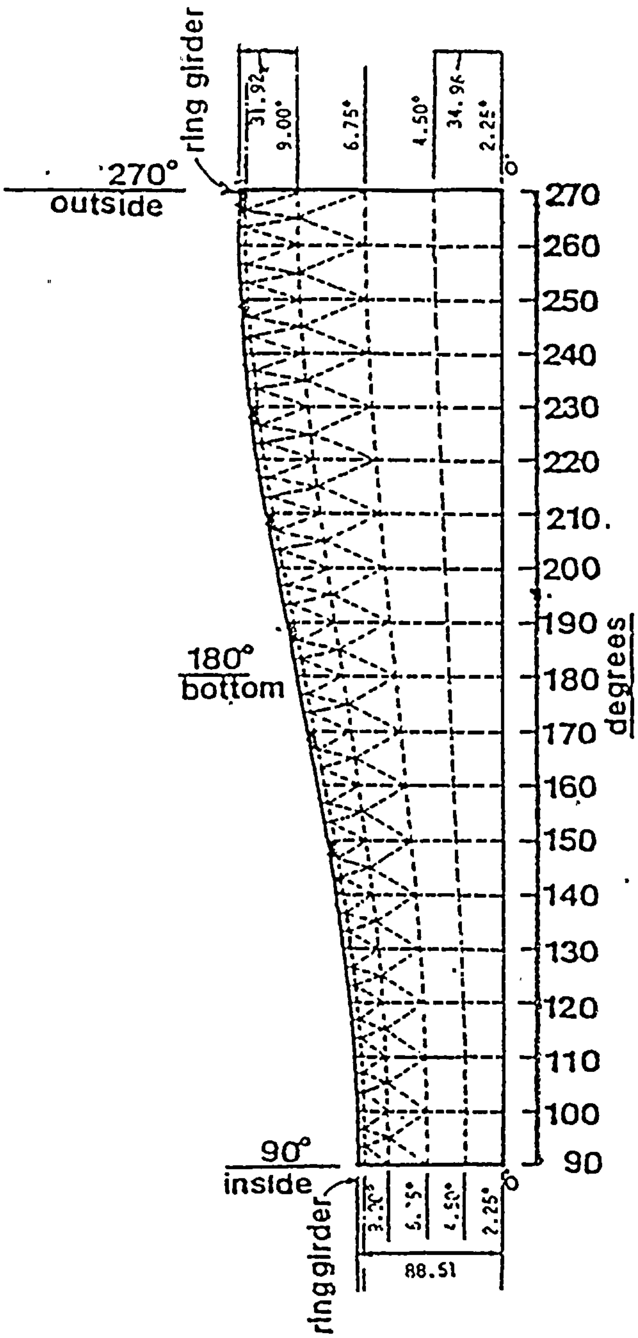
1/40th
TORUS MODEL



NINE MILE NUCLEAR PLANT UNIT 1

Figure 4

Torus 1/40th Shell Model Lower Half



5.0 LOAD ANALYSIS

5.1 Deadweight and Pressure

Deadweight and internal pressure analyses were done using the computer model shown in Figure 1. The water weight considered was that which corresponds to a downcomer submergence of 4.25'. The DBA pressure used was 26 psig.

5.2 Seismic

Seismic analysis for shell stress was done by applying static G loads to the model in Figure 1.

5.3 Condensation Oscillation

The condensation oscillation shell load is specified as a spectrum of pressures in 1 Hz bands (Reference 3). The analysis for this load was performed by considering the effects of unit loads at each load frequency (harmonic analysis) and then scaling and combining the individual frequency effects to determine total stress at the critical element. The three variations in the CO spectrum (Reference 3) were evaluated by rescaling the results of the unit load analysis. 100% of water mass was used for all CO analysis. The reduction factors presented in Table 1 of Reference 9 were applied to the individual harmonic pressures.

The combination of individual harmonic stresses into total element stress was done by considering frequency contributions at 31 Hz and below. The actual combination was done by adding the absolute value of the four highest harmonic contributors to the SRSS combination of the others for shell stress. This combination method and use of the 31 Hz cutoff are the result of extensive numerical evaluation of full scale test data, which is reported and discussed in References 4 and 7.

6.0 RESULTS

The controlling Mark I Containment Program event combination for shell stress was Event Combination 20 which involves Condensation Oscillation (CO) loading as a major contributor to the primary membrane stress intensity and resulted in a free shell total membrane stress of 16,025 psi which provides for a corrosion allowance of (1-(16025/16500)) .46=.013 inches. This membrane stress occurs at the bottom of the mid-bay of the Torus, which is element 19 of the finite element model, and represents the largest, and therefore, controlling membrane stress.

Element 19 has been re-evaluated by hand using the same procedures for condensation oscillation as well as deadweight, seismic and internal pressure, as were used in the original torus analysis. The only difference is the incorporation of the CO load reduction factors for the bays containing eight (8) downcomers and the bays containing four (4) downcomers. This re-evaluation is contained in TES Calculation Package 7353-1, Revision 0, Reference 12.

These CO load reduction factors are given in Reference 9, Table 1 entitled "Condensation Oscillation Rigid Wall Pressure Amplitude Reduction Factors for Nine Mile Point." The average values from these tables have been used since bay averaging was used to process FSTF data and this averaging introduces no additional approximation then what has already been utilized.

Three evaluations of element 19 have been done for this effort (Reference 12). The first evaluation reproduced the original analysis. The second evaluation provided the stresses for the bays containing eight downcomers and the third evaluation provided the stresses for the bays containing four downcomers. Condensation Oscillation stresses were evaluated at the component level for each frequency and component stresses at each frequency were then combined with the other frequencies. The resulting component stresses were then combined with deadweight, seismic and pressure stresses and then the maximum principal stress was evaluated. This eliminated conservatism which would be introduced by combining principal stresses.

CONTROLLING SHELL STRESSES - NINE MILE POINT UNIT 1

Condition	Type of Stress	Location	Actual Stress, psi	Allowable Stress, psi
Original Analysis	Membrane	Free Shell Element 19	16,025	16,500
Original Analysis	Membrane & Bending	Free Shell Element 19	16,618	24,750
Reduced C.O. 8 D.C. Bay	Membrane	Free Shell Element 19	15,452	16,500
Reduced C.O. 8 D.C. Bay	Membrane & Bending	Free Shell Element 19	16,044	24,750
Reduced C.O. 4 D.C. Bay	Membrane	Free Shell Element 19	14,460	16,500
Reduced C.O. 4 D.C. Bay	Membrane & Bending	Free Shell Element 19	15,040	24,750

CORROSION ALLOWANCE

Condition	Corrosion Allowance, In.	Year Corrosion Allowance Will Be Consumed*
Original Analysis	.0132	1994
Reduced C.O. 8 D.C. Bay	.0292	$\frac{.0292-.0132}{.00126} + 1994 = 2007$
Reduced C.O. 4 D.C. Bay	.0569	$\frac{.0569-.0132}{.00126} + 1994 = 2029$

* At a corrosion rate of .00126" per year

Based on the foregoing, and an anticipated operating life to the year 2024, it appears that half the bays, i.e., those with four downcomers, will not need any attention; and that the eight downcomer bays will need attention within the next sixteen years.

7.0 REFERENCES

1. PR-7461, Revision 1, "Reduction in Mark I Torus Program Condensation Oscillation Load Definition," dated February 13, 1990.

2. TES Report TR-5320-1, Rev. 1, "Mark I Containment Program, Plant-Unique Analysis Report of the Torus Suppression Chamber for Nine Mile Point Unit 1 Nuclear Generating Station," dated September 21, 1984.

3. G.E. Report NEDO-21888, Rev. 2, "Mark I Containment Program Load Definition Report," dated November 1981.

4. G.E. Report NEDE-24840, "Mark I Containment Program - Evaluation of Harmonic Phasing for Mark I Torus Shell Condensation Oscillation Loads," dated October 1980.

5. G.E. Report NEDO-24574, Rev. 1, "Mark I Containment Program - Plant-Unique Load Definition - Nine Mile Point 1 Nuclear Generating Plant," dated July 1981.

6. ASME B&PV Code, Section III, Division 1 through Summer 1977.

7. Structural Mechanics Association Report SMA-12101.04-R002D, "Response Factors Appropriate for Use with CO Harmonic Response Combination Design Rules," dated March 1982.

8. G.E. Supplementary Support Effort (SSE) Response Number 310, dated February 8, 1982.

7.0 REFERENCES (Continued)

9. Continuum Dynamics Technical Note No. 90-11, "Reduction of Torus Shell Condensation Oscillation Hydrodynamic Loads for Nine Mile Point Unit 1," dated November 1990.

10. TES Technical Report TR-6801-2, "Mark I Torus Shell and Vent System Thickness Requirements," Nine Mile Point Unit 1 Nuclear Station, January 29, 1988, Rev. 1.

11. Mark I Containment Program, Structural Acceptance Criteria, Plant Unique Analysis Application Guide, NEDO-24583-1, October 1978.

12. TES Calculation Package 7353-1, Revision 1, "Nine Mile Point Unit 1, Reduction in Mark I Torus Program Condensation Oscillation Load Definition and Resulting Effect on Minimum Shell Thickness Requirements," dated April 22, 1991.

8.0 APPENDIX 1

C.D.I. TECHNICAL NOTE NO. 90-11

REDUCTION OF TORUS SHELL CONDENSATION OSCILLATION HYDRODYNAMIC LOADS FOR NINE MILE POINT UNIT 1

Revision 0

TELEDYNE ENGINEERING SERVICES
CONTROLLED
DOCUMENT
TES PROJ. NO. 7353
DATE 11-20-90

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

An analysis is reported which investigates the conservatism of the hydrodynamic torus condensation oscillation load definition derived from data taken in the Mark I Full-Scale Test Facility (FSTF). It is shown that during condensation oscillation (CO), the condensation events at the downcomer exits are, as a function of frequency, random in phase for most harmonic components. As a consequence of this observation, and the geometrical constraints built into the FSTF, measured CO loads applied to Nine Mile Point are conservative for two reasons.

- o Alternate downcomer bays in Nine Mile Point have four-eight-four-eight, etc., downcomers per bay. The FSTF facility, by construct, assumes that all bays have eight downcomers per bay.

- o The FSTF modeled a 22 1/2° sector of a prototypical Mark I suppression pool. The water was contained in the sector by two very rigid end caps which would not exist in a full suppression pool. These end caps hydrodynamically act as mirrors. This results in a measured load, as if all bays in a full torus had condensation phenomenon identical in phase and amplitude, to the instrumented bay.

The analysis contained herein shows that for Nine Mile Point:

- o Eight downcomer bays have bay averaged CO loads which are conservative by at least 19% at frequencies other than 5-6 Hz.

- o Four downcomer bays have bay averaged CO loads which are conservative by at least 38% at frequencies other than 5-6 Hz.

INTRODUCTION

In 1979, Continuum Dynamics, Inc. was asked by the Mark I owners group, through G.E., to assess the conservatism in the Condensation Oscillation torus loads measured during the FSTF blowdown tests. This effort confirmed generally accepted conservatism in the tests with regard to test initial condition thermodynamics, and identified a significant conservatism which was not identified during test design. This conservatism was introduced by the very geometry of the test facility, a one-sixteenth sector which is equivalently a 22 1/2° segment of the Mark I Pressure Suppression Pool Torus. The sector or segment is referred to as a bay in subsequent discussion. The test facility, although full-scale in cross section, attempted to simulate at full-scale the condensation phenomenon in one bay only. End caps were required (which do not exist in actual suppression pool tori) to contain the pool water and the airspace above the pool in the bay. The analysis, which analyzes the hydrodynamic consequences of these end caps, was presented to the Mark I owners in 1980 and is documented as Reference 1. Since the documentation may not have received wide distribution, key portions of the analysis which are needed to support the current work are repeated here. An attempt is made here to assemble one document which supports reduction of the condensation oscillation load definition (Ref. 2) for Nine Mile Point.

CONDENSATION OSCILLATION DOWNCOMER PRESSURE

The FSTF facility contained one bay with eight downcomers which were fed steam from a prototypical main vent. The details of the facility and the instrumentation utilized is documented in Reference 3. During condensation oscillation, steam exiting the downcomers established a pulsating steam-water interface at the downcomer exit. This pulsation, resulting from unsteady steam condensation, produces pressure pulses which are transmitted through the pool water to the torus walls. Curiously, the loads which would be transmitted to the torus walls of a prototypical suppression pool torus depend on the correlation of the unsteady condensation at the exit of each downcomer.

Fortunately, in FSTF, the correlation between unsteady condensation at each downcomer exit is easy to assess as a consequence of pressure transducers located three feet above each of the eight downcomers. During condensation oscillation the steam-water interface is positioned as schematically illustrated in Figure 1 relative to the downcomer exit transducers. The unsteady pressure signals measured by these transducers is then, for the most part, a measure of the unsteadiness in condensation at the steam-water interface near which the transducer is mounted.

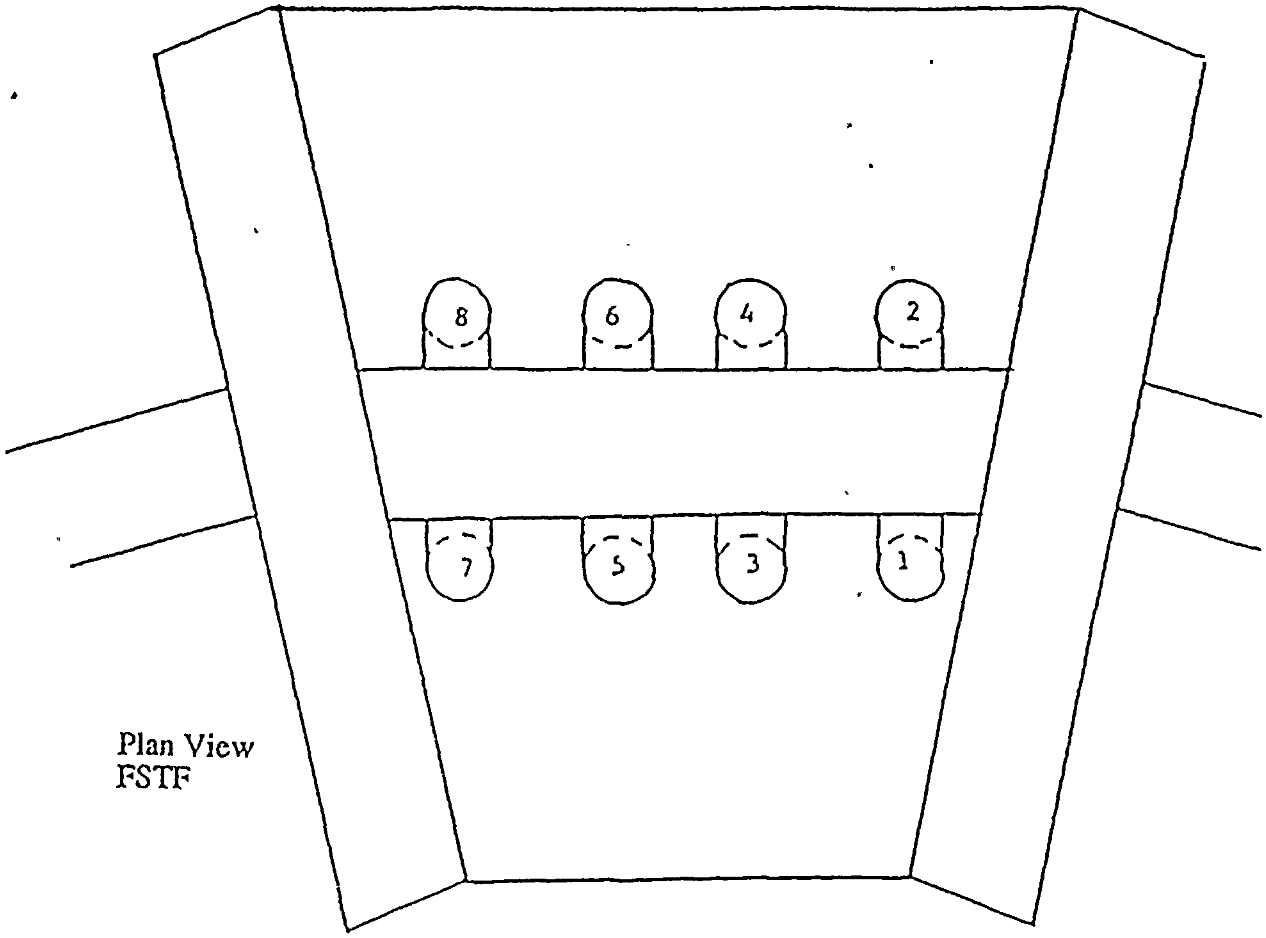
The mean square pressure between transducers in two downcomers with pressures $p_i(t)$ and $p_j(t)$ is given by

$$\overline{(p_i + p_j)^2}^{\,*} = \overline{p_i^2}^{\,*} + \overline{p_j^2}^{\,*} + 2\,\overline{p_i p_j}^{\,*} \tag{1}$$

where the overbar star notation denotes time average. The signals p_i and p_j are random and coherent if $\overline{p_i p_j}^{\,*} = 0$ when $i \neq j$. The correlation coefficient

$$\rho_{ij} = \frac{\overline{p_i p_j}^{\,*}}{\sqrt{p_i^2}\,\sqrt{p_j^2}} = 0 \tag{2}$$

then is necessarily equal to zero.



VENT	TRANSDUCER
1	P5123
2	P5243
3	P5323
4	P5443
5	P5523
6	P5643
7	P5723
8	P5843

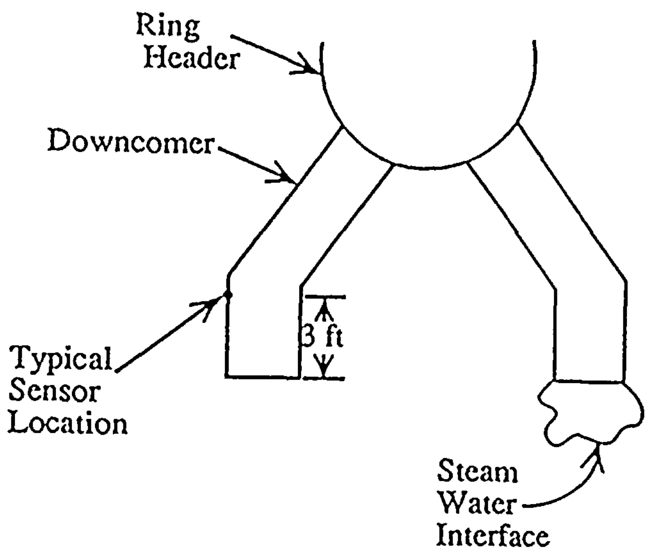


Figure 1. Downcomer exit pressure transducers in FSTF.

During Run M8 in the FSTF test series, upon which the load definition is based, strong condensation oscillation loads were observed on the torus shell for the time period 20-35 seconds after test initiation. The data from vent exit pressure transducers 3-5 was Fourier decomposed and then used to construct the mean square pressure signal $\overline{(p_i + p_j)^2}^{\,*}$ and components $\overline{p_i^2}^{\,*} + \overline{p_j^2}^{\,*}$ and $2\,\overline{p_i\,p_j}^{\,*}$ for 15 of the downcomer pair combinations. These components were calculated as a function of bandwidth with the band starting at zero frequency. Typical results are shown in Figure 2 between downcomers 5 and 6 in the bandwidth range 0-50 Hz. The result is that the pressure signals measured at the downcomer exits are correlated only between 5 and 6 Hz. Note that vents 5 and 6 are very close physically to each other and little if any cross talk (cross correlation) is observed at other than at 5-6 Hz. Analysis of other downcomer pair combinations during condensation oscillation also show correlation only at the 5-6 Hz. frequency. In fact, the correlation coefficient in the frequency range 5-6 Hz. is approximately 0.5 .

The following analysis allows the conclusion to be drawn, that it is reasonable to expect, that during condensation oscillation in a full torus, condensation phenomenon at downcomer exits are for the most part (except 5-6 Hz.) random and incoherent. Therefore, tests run in the FSTF facility must necessarily measure higher loads, because of the reflection built into the end caps required by the facility. These end caps do not permit incoherent pressures from adjoining bays to sum up to a lower load. This result is now quantified with regard to measured loads in FSTF and evaluated for Nine Mile Point.

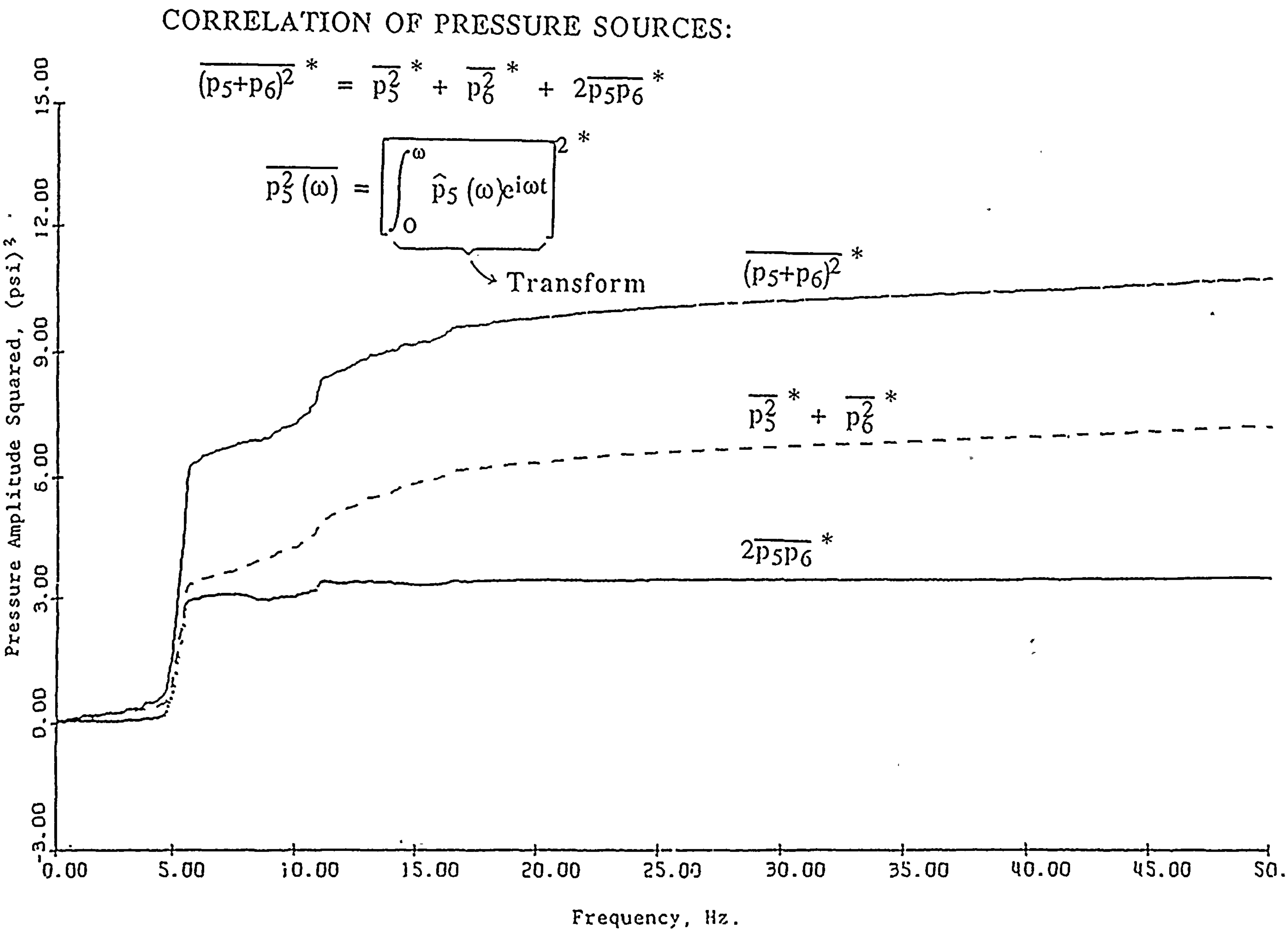


Figure 2. Mean Square pressure signals between downcomers 5 and 6, FSTF Run M8, 20 - 35 seconds during condensation oscillation as a function of frequency (measured from zero frequency.).

NINE MILE POINT DOWNCOMER GEOMETRY

On Figure 3 is shown the plan view of the Nine Mile Point suppression pool torus with bays alternating between four and eight downcomers, respectively. It is clear from this geometry that the bottom dead center pressure loads in a four downcomer bay will differ considerably from that in an eight downcomer bay. In the analysis to follow, analytic models are developed to account for the alternating distribution of downcomers in bays as well as the toroidal geometry. It will be seen that significant load reductions are shown to exist in the current bottom center load definition resulting from incoherence between sources and alternating number of downcomers between bays. Little or no relief can be identified with torus curvature which in the Appendix is shown to modify the distribution of pressure along the bottom of the torus only slightly.

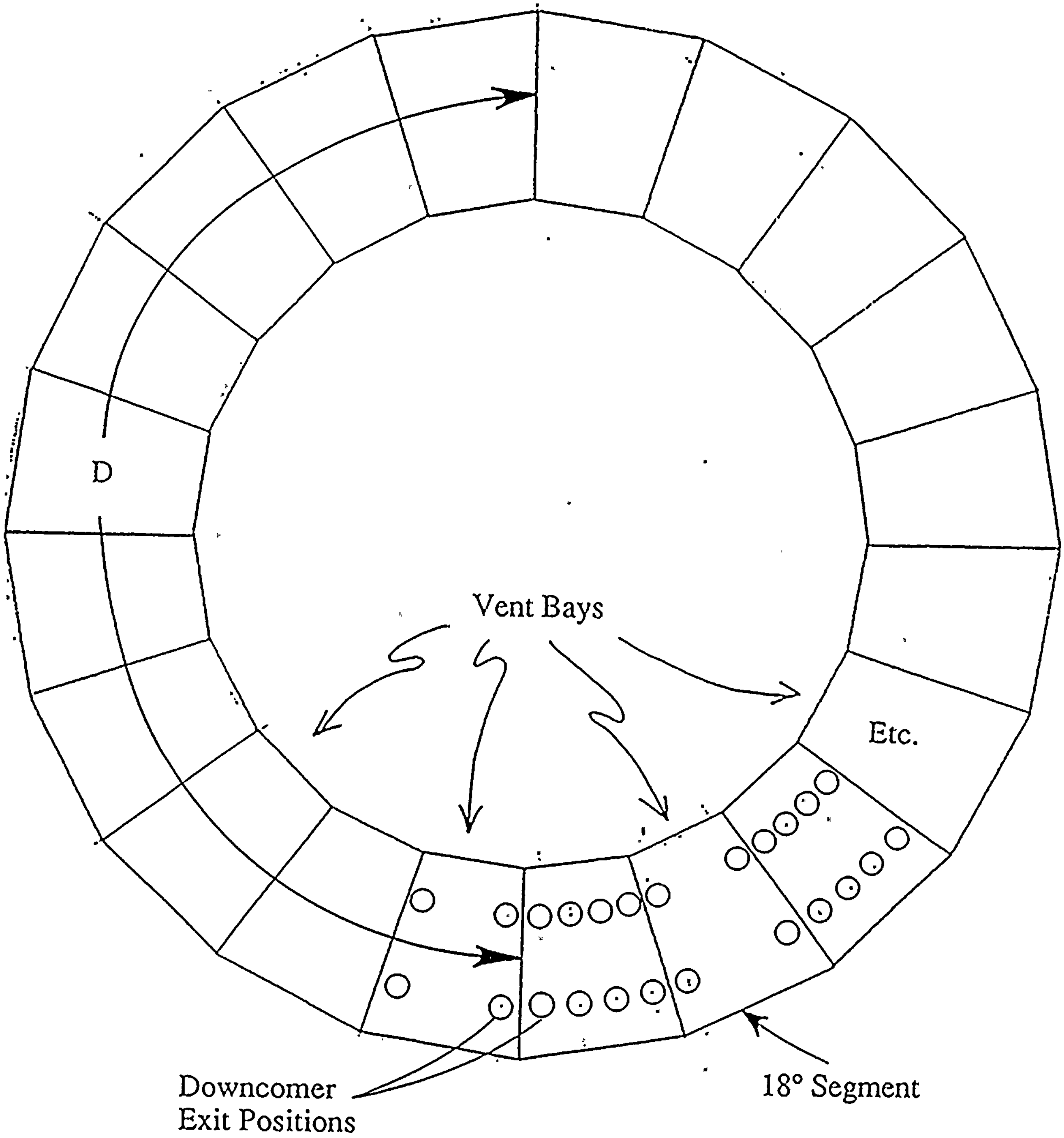


Figure 3. Plan view of Nine Mile Point suppression pool showing 8-4-8-4 downcomer/bay geometry. (Not to Scale)

ANALYSIS

The analysis of a full torus proceeds by unwinding the torus as shown in Figure 4. The torus has radius a and a source is located at $r = r_V$, $\theta = \theta_V$, and $z = 0$. At $z = D$ (half circumference) the pressure must satisfy a reflection boundary condition to account for waves traveling to the right and left of the torus. The pressure p satisfies the wave equation

$$\frac{\partial^2 p}{\partial r^2} + \frac{1}{r}\frac{\partial p}{\partial r} + \frac{1}{r^2}\frac{\partial^2 p}{\partial \theta^2} + \frac{\partial^2 p}{\partial z^2} - \frac{1}{c^2}\frac{\partial^2 p}{\partial t^2} = 0 \tag{3}$$

where c is the acoustic speed in the pool. The solution to the wave equation must satisfy the following boundary conditions

$$p(r, 0, z, t) = p(r, \pi, z, t) = 0 \qquad 0 \le r \le a, 0 \le z \le D$$

$$\frac{\partial p}{\partial r}(a, \theta, z, t) = 0 \qquad 0 \le \theta \le \pi, 0 \le z \le D$$

$$\frac{\partial p}{\partial z}(r, \theta, D, t) = 0 \qquad 0 \le r \le a, 0 \le \theta \le \pi \tag{4}$$

For harmonic time dependence of the form $e^{i\omega t}$ it has been shown (Ref.1) that the root mean square pressure $\overline{p}$ on the torus wall satisfies (note overbar denotes r.m.s.)

$$\overline{p}(a, \theta, z) = \frac{2\rho\omega\overline{Q}}{\pi a^2} \sum_{n=1}^{\infty} \sum_{j=1}^{\infty} \hat{c}_{nj} \sin n\theta \cosh\left[\alpha_{nj}(D-z)\right] \tag{5}$$

where

$$\hat{c}_{nj} = \frac{\sin n\theta_V}{\alpha_{nj} \sinh\left[\alpha_{nj} D\right]} \frac{J_n\left(m_n^j \frac{r_V}{a}\right)}{J_n\left(m_n^j\right)} \left[\frac{\left(m_n^j\right)^2}{\left(m_n^j\right)^2 - n^2}\right]$$

$$\alpha_{nj} = \frac{1}{a}\sqrt{\left(m_n^j\right)^2 - \left(\frac{\omega a}{c}\right)^2}$$

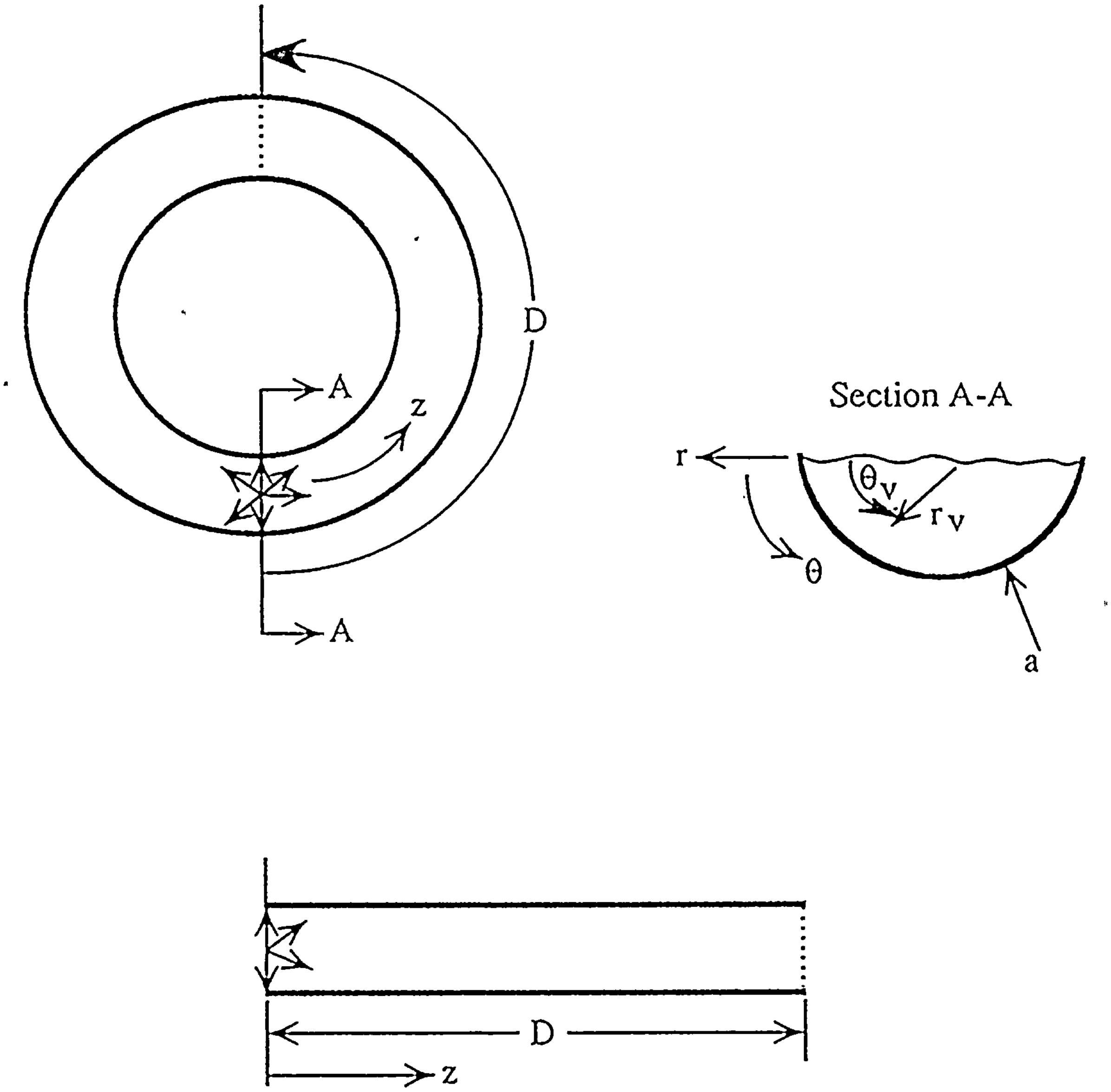


Figure 4. Coordinate system for analysis of Mark I Torus. A source is located at $r = r_v$, $\theta = \theta_v$, $z = 0$.

$$m_n^j = j^{th} \text{ stationary value of the Bessel function } J_n \tag{6}$$

The analysis to this point is exactly that which was given in Reference 1. Since we are interested in computing the variation of the load by going from eight vent to four vent bays the area averaged vertical component of the rms pressure is not computed as before but is averaged over θ only by

$$\bar{p}_{av} = \frac{1}{2a}\int_0^{\pi} \bar{p} \sin\theta \; a d\theta \tag{7}$$

yielding the important result (as before) that only the n= 1 term in the pressure will result in a net vertical load on the torus shell. Therefore,

$$\bar{p}_{av}(z) = \frac{\rho\omega\bar{Q}}{2a^2}\sum_{j=1}^{\infty} \hat{c}_{1j} \cosh\left[\alpha_{1j}(D-z)\right], \quad 0 \le z \le D \tag{8}$$

Now in the FSTF facility, if the sources are assumed correlated it has been shown (Ref. 1) that the source strength is related to the experimentally measured pressure by

$$\bar{Q}_c = \frac{\bar{p}_{av}\, \ell_v\, a^2}{2\rho\omega}\left[\sum_{j=1}^{\infty} K_{j1} \cosh\left[\alpha_{1j}\frac{\ell_v}{4}\right]\right]^{-1} \tag{9}$$

where

$$K_{j1} = \frac{\sin\theta_v}{\alpha_1^2} \; \frac{\sinh\left[\alpha_{1j}\frac{\ell_v}{4}\right]}{\sinh\left[\alpha_{1j}\frac{\ell_v}{2}\right]} \; \frac{J_1\left(m_1^j \frac{r_v}{a}\right)}{J_1\left(m_1^j\right)}\left[\frac{\left(m_1^j\right)^2}{\left(m_1^j\right)^2 - 1}\right] \tag{10}$$

The subscript c denotes the source strength for the correlated case and ℓ_v is the distance between downcomers in FSTF.

However, when the vents are uncorrelated the sources have been shown (Ref. 1) to be related to the correlated source strength by

$$\overline{Q}_u = \sqrt{8}\ \overline{Q}_c \tag{11}$$

The above pressure solution summed over the appropriate downcomer locations permit the direct computation of condensation oscillation load reduction factors. As a check the non-correlated load reduction factors for FSTF are reproduced here by

1. Determining $\overline{Q}_c$ for $\overline{p}_{av} = 1$ and $\ell_v = 4.88$ ft.
2. Determining $\overline{Q}_u = \sqrt{8}\ \overline{Q}_c$
3. Summing $\overline{p}_{av}$ over 8 downcomers/FSTF bay over 16 bays as the square root of the sum of the squares.
4. Plotting the result as Figure 5 (since the average pressure for the correlated case was taken to be unity this summation is the load reduction factor).

The results are shown in Figure 5 (Ref.1). This is the reduction of harmonic amplitude which would be measured in FSTF had the facility included all 16 segments (except at 5-6 Hz.). It is seen from the plotted result that the harmonic load reduction factors are both a function of frequency and pool water acoustic speed. By assuming a high acoustic speed (5000 ft./sec.) conservative load reduction factors are anticipated. These results when squared can be compared to Figure 9 of Reference 1 and, since derived by an independent summation method, provide a check on the current analysis.

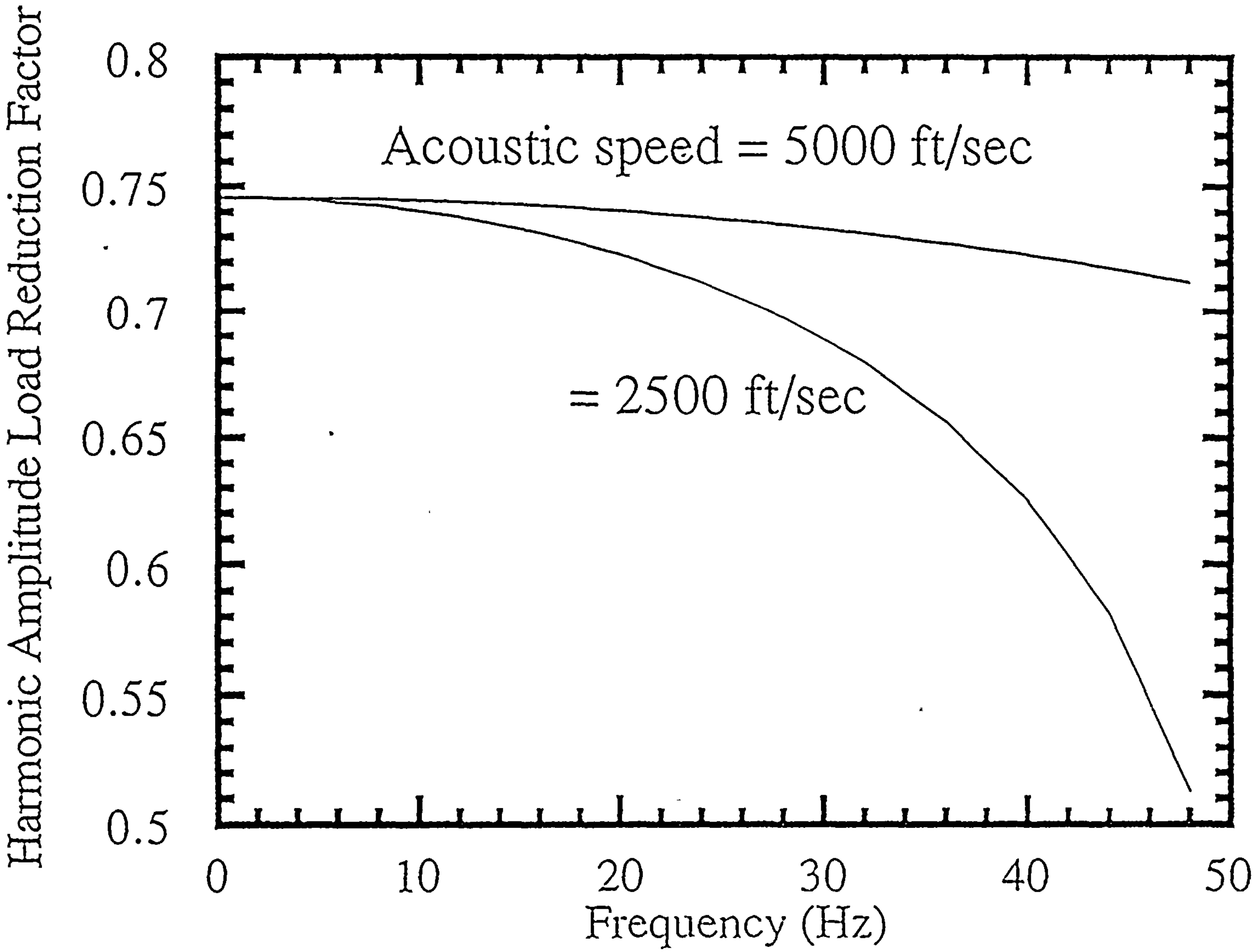


Figure 5. Harmonic amplitude load reduction factor (uncorrelated sources) for FSTF..

RESULTS - NINE MILE POINT

Referring to Figure 3, load reduction factors for Nine Mile Point are computed by:

For Correlated Sources

1. Evaluating the source strength $\overline{Q}_c$ for $\overline{p}_{av} = 1$ for FSTF, physical dimensions.

2. Summing the pressure for each frequency and location of each downcomer in Nine Mile Point according to:

$$\text{Load Reduction Factor} = \sum_{d=0}^{120} \overline{p}_{av}(z,\omega)$$

(Note that downcomer spacing and torus dimensions are as per Nine Mile Point)

For Uncorrelated Sources

1. Evaluating the uncorrelated source strength $\overline{Q}_u = \sqrt{8}\ \overline{Q}_c$ for $\overline{p}_{av} = 1$ in FSTF.

2. Summing the pressure for each frequency and location of each downcomer in Nine Mile Point according to

$$\text{Load Reduction Factor} = \left(\sum_{d=0}^{120} \overline{p}_{av}^{2}(z,\omega) \right)^{1/2}$$

The results of the above calculations are plotted in Figure 6 for an acoustic speed of 5000 ft./sec. at frequencies of 5-6 Hz. and 30-31 Hz. for illustration. Note that the local reduction factor is now a function of position along the bay and is a minimum in the center of the four downcomer bay as was expected. Also, note the anticipated result that there exists significant load reduction in the bay averaged eight downcomer bays and four downcomer bays, even when the sources are correlated.

The results above may be utilized in a conservative manner by specifying load reduction factors which are a maximum in the eight downcomer and four downcomer bays, respectively. Referring to Figure 6, the eight downcomer bay conservative load reduction factor is evaluated at station four and the four downcomer conservative load reduction factor is always evaluated at station eight, which is very conservative.

Conservative load reduction factors for Nine Mile Point are given in Table 1 entitled: "Condensation Oscillation Rigid Wall Pressure Amplitude Reduction Factors for Nine Mile Point." Note that only in the 5-6 Hz. frequency range is the reduction factor given for correlated sources as discussed above. Recall that no credit (load reduction) is taken for reduced acoustic speed which is surely the case during condensation oscillation. These load reduction factors are to be applied directly to the Condensation Oscillation Baseline Rigid Wall Pressure Amplitudes in Torus Shell Bottom Dead Center as given in Table 4.4.1-2 in the Mark 1 Load Definition Report NEDO-21888. After these tables are reduced by the load reduction factor the structural analysis should be undertaken as per the Load Definition Report except that the factor used to adjust the Nine Mile Point Downcomer/Pool area from FSTF is not to be used since this adjustment is included in the plant unique analysis. Also note that columns entitled "Reduction Factor, Average Value" (columns three and five) have been tabulated and may be used in place of the "Maximum" values (columns two and four) since bay averaging was used to process FSTF data and this averaging introduces no additional approximations.

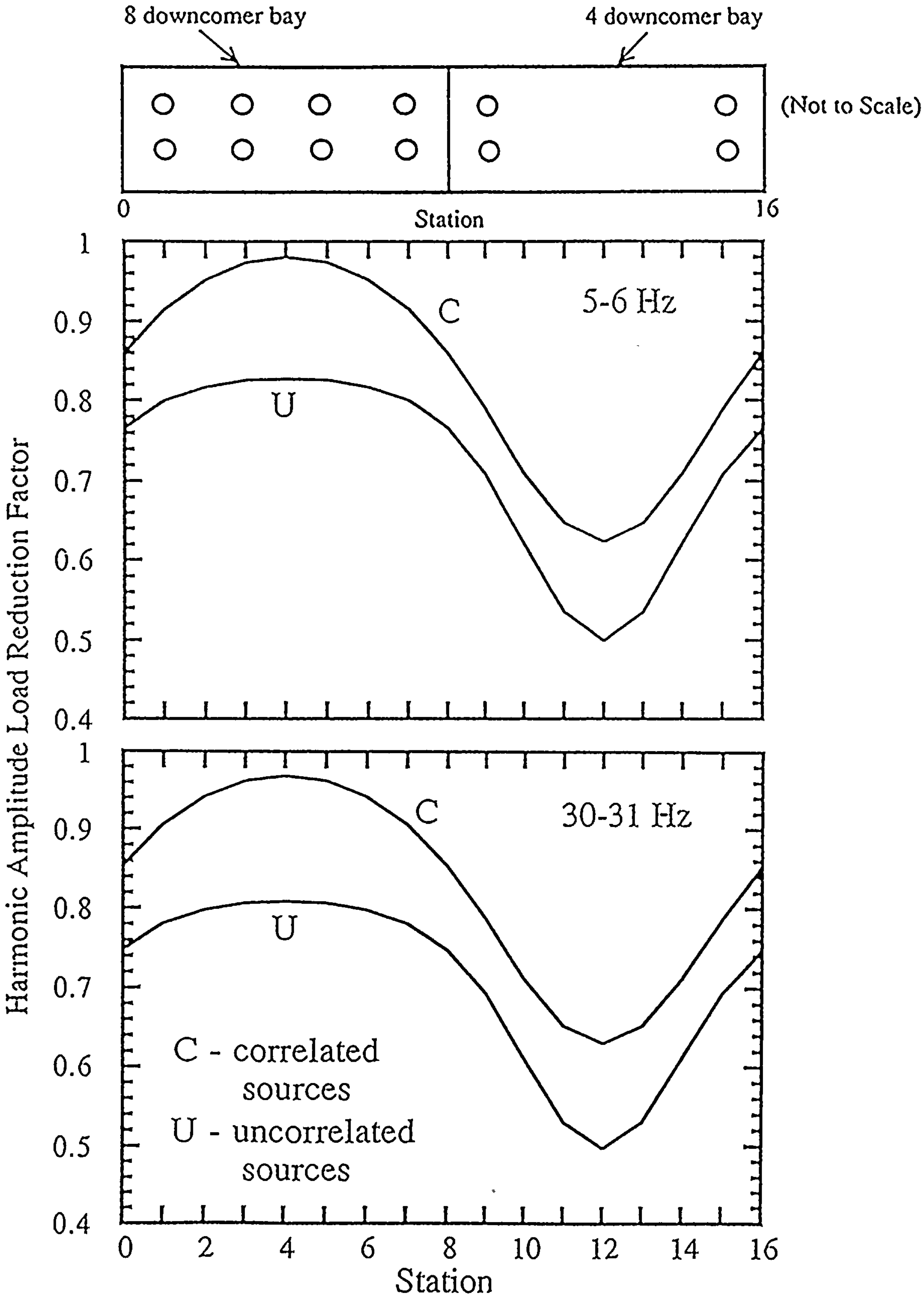


Figure 6. Harmonic amplitude load reduction factor as a function or frequency. Acoustic speed = 5000 ft/sec for Nine Mile Point.

TABLE 1
CONDENSATION OSCILLATION RIGID WALL PRESSURE
AMPLITUDE REDUCTION FACTORS FOR
NINE MILE POINT

Frequency Range (Hz.)	Reduction Factor - 8 Downcomers Bays		Reduction Factor - 4 Downcomer Bays	
	Max. Value	Average Value	Max. Value	Average Value
0-1	0.83	0.81	0.77	0.62
1-2	0.83	0.81	0.77	0.62
2-3	0.83	0.81	0.77	0.62
3-4	0.83	0.81	0.77	0.62
4-5	0.83	0.81	0.77	0.62
5-6	0.98	0.94	0.86	0.72
6-7	0.83	0.81	0.77	0.62
7-8	0.83	0.81	0.77	0.62
8-9	0.83	0.81	0.76	0.62
9-10	0.83	0.81	0.76	0.62
10-11	0.83	0.81	0.76	0.62
11-12	0.82	0.81	0.76	0.62
12-13	0.82	0.81	0.76	0.62
13-14	0.82	0.81	0.76	0.62
14-15	0.82	0.81	0.76	0.62
15-16	0.82	0.81	0.76	0.62
16-17	0.82	0.80	0.76	0.62
17-18	0.82	0.80	0.76	0.62
18-19	0.82	0.80	0.76	0.62
19-20	0.82	0.80	0.76	0.62
20-21	0.82	0.80	0.76	0.62
21-22	0.82	0.80	0.76	0.62
22-23	0.82	0.80	0.76	0.62
23-24	0.82	0.80	0.76	0.62
24-25	0.82	0.80	0.75	0.62
25-26	0.81	0.80	0.75	0.62
26-27	0.81	0.80	0.75	0.62
27-28	0.81	0.79	0.75	0.62
28-29	0.81	0.79	0.75	0.62
29-30	0.81	0.79	0.75	0.61
30-31	0.81	0.79	0.75	0.61
31-32	0.81	0.79	0.75	0.61
32-33	0.81	0.79	0.75	0.61
33-34	0.80	0.79	0.74	0.61
34-35	0.80	0.79	0.74	0.61
35-36	0.80	0.78	0.74	0.61
36-37	0.80	0.78	0.74	0.61
37-38	0.80	0.78	0.74	0.61
38-39	0.80	0.78	0.74	0.61
39-40	0.79	0.78	0.73	0.61
40-41	0.79	0.77	0.73	0.61
41-42	0.79	0.77	0.73	0.60

TABLE 1 (Continued)
CONDENSATION OSCILLATION RIGID WALL PRESSURE
AMPLITUDE REDUCTION FACTORS FOR
NINE MILE POINT

Frequency Range (Hz.)	Reduction Factor - 8 Downcomers Bays		Reduction Factor - 4 Downcomer Bays	
	Max. Value	Average Value	Max. Value	Average Value
42-43	0.79	0.77	0.73	0.60
43-44	0.79	0.77	0.73	0.60
44-45	0.78	0.77	0.72	0.60
45-46	0.78	0.76	0.72	0.60
46-47	0.78	0.76	0.72	0.60
47-48	0.78	0.76	0.72	0.60
48-49	0.78	0.76	0.72	0.60
49-50	0.77	0.76	0.71	0.59

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APPENDIX A

ANALYSIS OF TORUS CURVATURE EFFECTS

The analysis presented in the main body of this report approximates the toroidal containment vessel by its equivalent unwrapped configuration. This appendix shows how curvature effects can be included in the framework of a more elaborate solution using a perturbation method. It is shown that the primary curvature effects are of order a/R, where a is the cross-sectional radius of the torus and R is the radius of the torus itself, measured to the cross-sectional center. Furthermore, curvature produces only a small change in the net download and its distribution. The following development presents the problem formulation from which these important conclusions can be drawn.

The wave equation is solved in a locally curved cylindrical coordinate system the properties of which are given in Reference 4. In these coordinates the wave equation takes the form:

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial p}{\partial r}\right) + \frac{\cos\theta}{R + r\cos\theta}\frac{\partial p}{\partial r} + \frac{1}{r^2}\frac{\partial^2 p}{\partial \theta^2} - \frac{\sin\theta}{r\,(R + r\cos\theta)}\frac{\partial p}{\partial \theta}$$
$$+ \frac{R^2}{(R + r\cos\theta)^2}\frac{\partial^2 p}{\partial z^2} - \frac{1}{c^2}\frac{\partial^2 p}{\partial t^2} = 0 \qquad \text{(A1)}$$

The corresponding velocities are found by solving the momentum equation

$$-\rho_0\frac{\partial \vec{V}}{\partial t} = \vec{\nabla} p = \frac{\partial p}{\partial r}\vec{i}_r + \frac{1}{r}\frac{\partial p}{\partial \theta}\vec{i}_\theta + \frac{R}{R + r\cos\theta}\frac{\partial p}{\partial z}\vec{i}_z \qquad \text{(A2)}$$

Defining dimensionless coordinates $\bar{r} = r/a$, $\bar{z} = z/a$ and $\bar{t} = \omega t$, and defining $\varepsilon = a/R$, then gives the governing equation in dimensionless variables:

$$\frac{1}{\bar{r}}\frac{\partial}{\partial \bar{r}}\left(\bar{r}\frac{\partial p}{\partial \bar{r}}\right) + \frac{\varepsilon\cos\theta}{1+\varepsilon\bar{r}\cos\theta}\frac{\partial p}{\partial \bar{r}} + \frac{1}{\bar{r}^2}\frac{\partial^2 p}{\partial\theta^2} - \frac{\varepsilon\sin\theta}{\bar{r}(1+\varepsilon\bar{r}\cos\theta)}\frac{\partial p}{\partial\theta}$$

$$+ \frac{1}{(1+\varepsilon\bar{r}\cos\theta)^2}\frac{\partial^2 p}{\partial \bar{z}^2} - \left(\frac{\omega a}{c}\right)^2\frac{\partial^2 p}{\partial \bar{t}^2} = 0 \qquad \text{(A3)}$$

Note that in this Appendix, an overbar denotes a nondimensional variable.

The momentum equation expressed with dimensionless space and time variables is

$$-\rho_o c\left(\frac{\omega a}{c}\right)\frac{\partial\vec{V}}{\partial \bar{t}} = \bar{\bar{\nabla}}p = \frac{\partial p}{\partial \bar{r}}\vec{i}_r + \frac{1}{\bar{r}}\frac{\partial p}{\partial\theta}\vec{i}_\theta + \frac{1}{1+\bar{r}\cos\theta}\frac{\partial p}{\partial \bar{z}}\vec{i}_z \qquad \text{(A4)}$$

The pressure is sought in terms of a power series solution in the curvature parameter ε.

$$p(r, \theta, z, t) = \left[p_0(\bar{r}, \theta, \bar{z}) + \varepsilon p_1(\bar{r}, \theta, \bar{z}) + \varepsilon^2 p_2(\bar{r}, \theta, \bar{z}) + \ldots\right] e^{i\bar{t}} \qquad \text{(A5)}$$

with a similar power series for the velocity vector.

$$\vec{V}(r, \theta, z, t) = \left[\vec{V}_0(\bar{r}, \theta, \bar{z}) + \varepsilon\vec{V}_1(\bar{r}, \theta, \bar{z}) + \varepsilon^2\vec{V}_2(\bar{r}, \theta, \bar{z}) + ..\right] e^{i\bar{t}} \qquad \text{(A6)}$$

Substituting these series expansions into the nondimensional wave equation and the momentum equation, and equating like powers of ε yields equations for p_0, p_1, etc.

To lowest order, the wave equation becomes

$$O[1]: \qquad \frac{1}{\bar{r}}\frac{\partial}{\partial \bar{r}}\left(\bar{r}\frac{\partial p_0}{\partial \bar{r}}\right) + \frac{1}{\bar{r}^2}\frac{\partial^2 p_0}{\partial\theta^2} + \frac{\partial^2 p_0}{\partial \bar{z}^2} + \left(\frac{\omega a}{c}\right)^2 p_0 = 0 \qquad \text{(A7)}$$

and the corresponding momentum equation is to lowest order

$$-\rho_o c\left(\frac{\omega a}{c}\right)\vec{V}_0 = \bar{\bar{\nabla}}p_0 = \frac{\partial p_0}{\partial \bar{r}}\vec{i}_r + \frac{1}{\bar{r}}\frac{\partial p_0}{\partial\theta}\vec{i}_\theta + \frac{\partial p_0}{\partial \bar{z}}\vec{i}_z \qquad \text{(A8)}$$

Note that the equation (A-7) governing p_0 corresponds to the problem of the equivalent unwrapped torus, since this equation corresponds to the case $\varepsilon \to 0$. The solution of this equation and boundary conditions was described in Reference 1, and in the main body of this report. The general solution is constructed as the sum of pressure mode solutions of the form

$$p_{0nj} = c_{nj} J_n (m_n^j \bar{r}) \sin(n\theta) \frac{\cosh[\alpha_{nj}(D - z)]}{\cosh[\alpha_{nj} D]} \tag{A9}$$

To order ε the wave equation is

$$O[\varepsilon]: \quad \frac{1}{\bar{r}}\frac{\partial}{\partial \bar{r}}\left(\bar{r}\frac{\partial p_1}{\partial \bar{r}}\right) + \frac{1}{\bar{r}^2}\frac{\partial^2 p_1}{\partial \theta^2} + \frac{\partial^2 p_1}{\partial \bar{z}^2} + \left(\frac{\omega a}{c}\right)^2 p_1$$
$$= -\cos\theta \frac{\partial p_0}{\partial \bar{r}} + \sin\theta \frac{1}{\bar{r}}\frac{\partial p_0}{\partial \theta} + 2\bar{r}\cos\theta \frac{\partial^2 p_0}{\partial \bar{z}^2} \tag{A10}$$

and the corresponding order ε momentum equation is

$$-\rho_0 c\left(\frac{\omega a}{c}\right)\vec{V}_1 = \bar{\nabla} p_1 = \frac{\partial p_1}{\partial \bar{r}}\vec{i}_r + \frac{1}{\bar{r}}\frac{\partial p_1}{\partial \theta}\vec{i}_\theta + \left[\frac{\partial p_1}{\partial \bar{z}} - \bar{r}\cos\theta \frac{\partial p_0}{\partial \bar{z}}\right]\vec{i}_z \tag{A11}$$

Equation (A10) governing p_1 must be solved along with appropriate boundary conditions to determine the effect of curvature. It can be shown that the general solution for p_1 is constructed as the sum of pressure modes of the form:

$$p_{1nj} = \frac{c_{nj}}{2} P_{1nj}^{+}(\bar{r}) \sin([n+1]\theta) \frac{\cosh[\alpha_{nj}(D - z)]}{\cosh[\alpha_{nj} D]}$$
$$+ \frac{c_{nj}}{2} P_{1nj}^{-}(\bar{r}) \sin([n-1]\theta) \frac{\cosh[\alpha_{nj}(D - z)]}{\cosh[\alpha_{nj} D]} \tag{A12}$$

which are chosen to satisfy equation (A9), plus the sum of modes of the form

$$p_{0mk} = d_{mk} J_m(m_m^k \bar{r}) \sin(m\theta) \frac{\cosh[\alpha_{mk}(D - z)]}{\cosh[\alpha_{mk} D]} \tag{A13}$$

which satisfy the homogeneous form of equation (A10). The primary problem is to find the functions $P_{1nj}^{+}(\bar{r})$ and $P_{1nj}^{-}(\bar{r})$ in equation (A12) that satisfy equation (A10) and the boundary condition of no flow through the rigid torus wall. Note that the functional forms of both equations (A12) and (A13) have been chosen to satisfy the reflection condition halfway around the torus $(z = D)$ and the condition that the perturbation pressure vanish at the free surface $(\theta = 0$ and $\theta = \pi)$. The functional form of equation (A13), which is similar to that of equation (A9), already satisfies the condition of a rigid torus wall.

Substituting equation (A12) into equation (A10) and equating like dependences of $\sin([n+1]\theta)$ and $\sin([n-1]\theta)$ gives separate nonhomogeneous Bessel equations for $P_{1nj}^{+}(\bar{r})$ and $P_{1nj}^{-}(\bar{r})$:

$$\begin{aligned} &\frac{1}{\bar{r}}\frac{\partial}{\partial \bar{r}}\left(\bar{r}\frac{\partial}{\partial \bar{r}} P_{1nj}^{+}(\bar{r})\right) - \frac{(n+1)^2}{\bar{r}^2} P_{1nj}^{+}(\bar{r}) + (m_n^j)^2 P_{1nj}^{+}(\bar{r}) \\ &= -\frac{\partial}{\partial \bar{r}} J_n(m_n^j \bar{r}) + \frac{n}{\bar{r}} J_n(m_n^j \bar{r}) + 2\bar{r}\,\alpha_{nj}^2 a^2 J_n(m_n^j \bar{r}) \equiv G_{nj}^{+}(\bar{r}) \end{aligned} \tag{A14}$$

and

$$\begin{aligned} &\frac{1}{\bar{r}}\frac{\partial}{\partial \bar{r}}\left(\bar{r}\frac{\partial}{\partial \bar{r}} P_{1nj}^{-}(\bar{r})\right) - \frac{(n-1)^2}{\bar{r}^2} P_{1nj}^{-}(\bar{r}) + (m_n^j)^2 P_{1nj}^{-}(\bar{r}) \\ &= -\frac{\partial}{\partial \bar{r}} J_n(m_n^j \bar{r}) - \frac{n}{\bar{r}} J_n(m_n^j \bar{r}) + 2\bar{r}\,\alpha_{nj}^2 a^2 J_n(m_n^j \bar{r}) \equiv G_{nj}^{-}(\bar{r}) \end{aligned} \tag{A15}$$

These Bessel equations have homogeneous solutions of the form

$$P_{1nj}^{+}(\bar{r})_H = A_{nj}^{+} J_{n+1}(m_n^j \bar{r}) + B_{nj}^{+} Y_{n+1}(m_n^j \bar{r}) \tag{A16}$$

and

$$P_{1nj}^{-}(\bar{r})_H = A_{nj}^{-} J_{n-1}(m_n^j \bar{r}) + B_{nj}^{-} Y_{n-1}(m_n^j \bar{r}) \tag{A17}$$

The coefficients $B^+_{nj} = B^-_{nj} = 0$ since the Bessel function Y_{n+1} and Y_{n-1} are singular at the origin. Once the homogeneous solutions are known for a second order linear ordinary differential equation, the particular solution can be constructed by the method of variation of parameters, see Reference 5. A very lengthy calculation gives the result

$$P^+_{1nj}(\bar{r}) = \frac{2}{\pi m^j_n}\left(U_{Y^+_{nj}}(1) - \frac{Y'_{n+1}(m^j_n)}{J'_{n+1}(m^j_n)} U_{J^+_{nj}}(1)\right) J_{n+1}(m^j_n \bar{r}) - \frac{2}{\pi m^j_n}\left[U_{Y^+_{nj}}(\bar{r}) J_{n+1}(m^j_n \bar{r}) + U_{J^+_{nj}}(\bar{r}) Y_{n+1}(m^j_n \bar{r})\right] \tag{A18}$$

where

$$U_{Y^+_{nj}}(\bar{r}) = \int_0^{\bar{r}} \bar{r}\, Y_{n+1}(m^j_n \bar{\xi})\, G^+_{nj}(\bar{\xi})\, d\bar{\xi} \tag{A19}$$

and

$$U_{J^+_{nj}}(\bar{r}) = \int_0^{\bar{r}} \bar{r}\, J_{n+1}(m^j_n \bar{\xi})\, G^+_{nj}(\bar{\xi})\, d\bar{\xi} \tag{A20}$$

Likewise,

$$P^-_{1nj}(\bar{r}) = \frac{2}{\pi m^j_n}\left(U_{Y^-_{nj}}(1) - \frac{Y'_{n-1}(m^j_n)}{J'_{n-1}(m^j_n)} U_{J^-_{nj}}(1)\right) J_{n-1}(m^j_n \bar{r}) - \frac{2}{\pi m^j_n}\left[U_{Y^-_{nj}}(\bar{r}) J_{n-1}(m^j_n \bar{r}) + U_{J^-_{nj}}(\bar{r}) Y_{n-1}(m^j_n \bar{r})\right] \tag{A21}$$

where

$$U_{J^-_{nj}}(\bar{r}) = \int_0^{\bar{r}} \bar{r}\, J_{n-1}(m^j_n \bar{\xi})\, G^-_{nj}(\bar{\xi})\, d\bar{\xi} \tag{A22}$$

and

$$U_{Y^-_{nj}}(\bar{r}) = \int_0^{\bar{r}} \bar{r}\, Y_{n-1}(m^j_n \bar{\xi})\, G^-_{nj}(\bar{\xi})\, d\bar{\xi} \tag{A23}$$

In the above solutions, equations (A19) and (A21), portions of the homogeneous solution, equations (A16) and (A17), have been added to satisfy the boundary condition that the normal velocity vanish on the rigid torus walls.

The general solution for the pressure field, which includes terms of $O\,[1]$ and $O\,[\varepsilon]$, can now be assembled by summing equations (A9), (A12), and (A13) over all indices, and substituting these summations into equation (A5).

$$
\begin{aligned}
p(r, \theta, z, t) = \sum_{j=1}^{\infty}\sum_{n=1}^{\infty} c_{nj} \Big[& J_n(m_n^j \bar{r}) \sin(n\theta) + \frac{\varepsilon}{2} P_{1nj}^{+}(\bar{r}) \sin([n+1]\theta) \\
& + \frac{\varepsilon}{2} P_{1nj}^{-}(\bar{r}) \sin([n-1]\theta)\Big] \frac{\cosh[\alpha_{nj}(D - z)]}{\cosh[\alpha_{nj} D]} e^{i\bar{t}} \\
& + \sum_{k=1}^{\infty}\sum_{m=1}^{\infty} \varepsilon\, d_{mk}\, J_m(m_m^k \bar{r}) \sin(m\theta) \frac{\cosh[\alpha_{mk}(D - z)]}{\cosh[\alpha_{mk} D]} e^{i\bar{t}}
\end{aligned} \tag{A24}
$$

All the terms in equation (A24) satisfy the rigid wall boundary condition on the torus sides, the free surface condition, and the end reflection condition halfway around the torus. The remaining constants c_{nj} and d_{mk} are used to satisfy the vent source velocity boundary condition in the plane $z = 0$. This is most easily done by choosing d_{mk} such that the $O\,[\varepsilon]$ velocity component normal to this plane vanishes at $z = 0$. From the momentum equation, this condition is equivalent to requiring the z-derivative of the $O\,[\varepsilon]$ terms in equation (A24) to vanish at $z = 0$. Then the constants d_{mk} are re-expressed in terms of the constants c_{nj}. The advantage of this approach is that the remaining constants c_{nj} then take on exactly the same values as given previously, since the $O\,[\varepsilon]$ terms no longer contribute directly to the source boundary condition. A very lengthy calculation, utilizing the orthogonality relations for sine functions and for Bessel functions, then gives:

$$
\begin{aligned}
d_{mk} = \frac{-2\,[\alpha_{mk}\tanh(\alpha_{mk} D)]^{-1}}{\left[1 - \left(\frac{m}{m_m^k}\right)^{-1}\right] J_m^2(m_m^k)} \sum_{j=1}^{\infty} \Big\{ & c_{m-1,j} \int_0^1 P_{1m-1,j}^{+}(\bar{r})\, J_m(m_m^k \bar{r})\, \bar{r}\, d\bar{r} \\
& + c_{m+1,j} \int_0^1 P_{1m+1,j}^{-}(\bar{r})\, J_m(m_m^k \bar{r})\, \bar{r}\, d\bar{r} \Big\}
\end{aligned} \tag{A25}
$$

Finally the vent velocity boundary condition must be applied. Because of the way the solution has been structured, with $O[\varepsilon]$ terms vanishing at $z = 0$, only the $O[1]$ terms participate, making the process identical to that described in Reference 1. Following similar notation, let

$$c_{nj} = \hat{c}_{mk} \frac{2i\rho\omega Q \cosh(\alpha_{nj} D)}{\pi a^2 J_n(m_n^j)} \tag{A26}$$

where $\hat{c}_{mk}$ is still given by equation (8) in the main body of the report.

The above permits an estimate to be made as to the magnitude of load reduction to be anticipated from a curvature correction. First note that, as in the main body of the report, the net vertical load is associated with $\sin\theta$ dependence in the modes, hence in equation (A24), $n = 2$ and $m = 1$ provide the only contribution from the order ε terms. Second, note that the downcomers are constructed in pairs and that for each downcomer pair the portion of the order ε solution which leads to a net vertical load seems to cancel. Physically interpreted, one source in the pair raises the load while the other reduces the load by an equal amount, to this order correction. Therefore, to this order, there is no change in total load and it seems that the change in total load occurs at order $\varepsilon^2 = a^2/R^2$. This ratio evaluated for Nine Mile Point is order of 0.04 and is judged too small in light of other uncertainties to pursue further.

ATTACHMENT 2

Mark I Program Summary

In 1975 the NRC requested that owners of Mark I BWR's analyze plant containment structures for newly identified dynamic loads associated with safety relief valve (SRV's) discharges and loss-of-coolant accidents (LOCA). The Mark I Owners Group (of which NMPC was a member) was formed later that same year to focus on development of a technically sound approach to identification and quantification of the aforementioned loads.

Mark I Short-Term Program

The Mark I Owners Group generated a two-phase program to address the NRC concerns. The first phase, a short-term program, consisted of evaluation of generic reference plants to confirm the adequacy of containment to maintain integrity under the most probable loss of coolant accident. In addition, under the short-term program, plant unique analysis was performed by each utility on external structures and attached piping of the suppression chamber.

In response to the short-term program requirements, a plant unique analysis report was prepared by Teledyne Materials Research for NMPC in July, 1976, which analyzed LOCA pool swell effects on the torus support system and external attached piping. The result of this short-term program coupled with direction incorporated in NUREG 0408 (December, 1977) resulted in the establishment of a 1 psi differential pressure requirement between the wetwell and drywell and the establishment of minimum torus water level. Niagara Mohawk Power Corporation submitted technical specification changes on these issues in January, 1979.

Mark I Long-Term Program

The Mark I Owners Group second phase of the Mark I containment program consisted of a long-term program which had as its objectives the establishment of design basis loads that were appropriate for the anticipated life of each Mark I BWR facility. A long-term program (LTP) action plan was accepted by the NRC in February, 1977, and further revised during the LTP Program.

Individual load definitions were established through both analytical and experimental methods including the development and utilization of a full scale test facility (FSTF) which was a full scale, 22.5° sector of a typical Mark I torus. This facility was utilized to define condensation oscillation loading which consists of both condensation oscillation and chugging.

The results of the LTP were summarized in the "Mark I Containment Program Load Definition Report" developed by General Electric and submitted to the NRC in December, 1978, and "Mark I Containment Program Structural Acceptance Criteria Plant-Unique Analysis Applications Guide, Task Number 3.1.3" developed by the Mark I Owners Group and published in December, 1978.

As a result of submittal of the aforementioned Owners Group documents, the NRC developed a safety evaluation report (NUREG 0661) on the Mark I containment long-term program which was issued in July, 1980. The SER concluded that the load definition techniques established in the GE and Mark I Owners Group documents would provide conservative estimates of the dynamic loading conditions with the exception of downcomer oscillation loads. This issue was resolved through further testing at the FSTF which resulted in a submittal in April, 1981, of revised load definition by General Electric Company entitled "Mark I Containment Program Letter Report: Supplemental Full-Scale Condensation Test Results and Load Confirmation". This report was reviewed and accepted by the NRC in August, 1982, in Supplement No. 1 to the NRC's SER (NUREG 0661) on the Mark I Containment Long-Term Program.

Installed Torus Modifications

During the course of and following the LTP, Niagara Mohawk implemented a number of modifications to the torus to address areas of concern identified during the program. The list of modifications and their completion dates are as follows:

	Modification	Completion Date
1.	Install Downcomer Ties	1979
2.	Install Vent Header Deflector	1979
3.	Install Monorail	1979
4.	Remove Catwalk	1979
5.	Install Supports in Vent Pipe & Intersection	1979
6.	Install Mitred Joint Saddles	1980
7.	Install Vent Header Downcomer Stiffeners	1981
8.	Install Drywell to Wetwell Vacuum Breaker Discs	1981
9.	Install Additional SRV Vacuum Breakers on SRV Lines	1981
10.	Reroute & Rehang N_2 Purge and Fill Lines	1981

Modification		Completion Date
11.	Replace Torus Spray Header	1981
12.	Install Four-Inch Torus Penetration & Four-Inch Water Quality Line	1981
13.	Remove and Replace CAD Return Line	1981
14.	Modify Manhole Cover for SRV Test	1981
15.	Modify Torus Drain Line	1981
16.	Install Torus Saddle Anchor Bolts	1981
17.	Install Temperature Monitoring System	1983
18.	Install Y-Quenchers and Supports	1983
19.	Reinforce SRV Line Penetration (At Vent Pipe)	1983
20.	Install Additional Torus Column Anchor Bolts	1983

The above modifications are described in Teledyne Engineering Services (TES) Technical Report TR-5320-1 Rev. 1, entitled "Mark I Containment Plant Unique Analysis Report of the Torus Suppression Chamber for Nine Mile Point Unit #1 Nuclear Generating Station" dated September 21, 1984. This report summarized the results of NMP1 plant unique analysis on the torus structure based on generic load definitions established during the LTP and further refined in the "Plant Unique Load Definition; Nine Mile Point Unit #1 Nuclear Generating Plant" issued by General Electric in July, 1981.

The TES Report 5320-1 was submitted to the NRC on November 10, 1983. This submittal resulted in an NRC SER of the NMPC pool dynamic load (Docket No. 50-220) which accepted the results of the TES report.

NMP1 Torus Shell Thickness

The torus shell was originally fabricated from carbon steel plate certified to a thickness of at least 0.46". No corrosion inhibitors or coatings were applied to the interior shell surfaces. Red lead primer was applied to the vent spheres and downcomers during the original installation. The original analysis for the torus shell, performed by CBI, took credit for a 0.40" shell thickness. The torus shell was certified as having at least a 0.46" thickness, leaving a 1/16" corrosion allowance.

The plant unique load analysis was further reviewed in January, 1988, to analyze the torus shell and vent system thickness requirements to establish required minimum wall thickness associated with the Mark I hydrodynamic load. This resulted in a worst case minimum wall thickness of 0.447" at bottom mid-bay dead center. The results of this analysis is documented in Teledyne Report TR-6801-2.

Niagara Mohawk has monitored torus wall thickness since 1975 because of its criticality to primary containment. The trend of these early UT measurements indicate a corrosion rate at or below the original design basis.

NMP1 Restart Action Plan (RAP)

During an inspection conducted in March and April, 1988, (combined Inspection Report No. 50-220/88-09 and 50-410/88-09) the NRC performed independent measurements of the torus wall thickness. The NRC's measurements were close to minimum wall as required by Niagara Mohawk's original stress calculations and Mark I containment program calculations. The NRC inspectors concluded that it was necessary for Niagara Mohawk to take action before the next anticipated outage (1990) and requested Niagara Mohawk to provide justification for operation until 1990. On April 26, 1988, NMPC presented its position to Region I of the NRC. This included commitments to develop a program that would provide for consistency on how UT measurements would be taken and their location. In addition, NMPC identified a number of areas that were being explored to eliminate and/or mitigate the effects of corrosion, among which were coatings, structural modifications and/or analysis of additional margin which may be available due to a reduction for condensation oscillation (CO) loads. An action item from that presentation was subsequently documented as Restart Action Plan (RAP) Issue #7. RAP Issue #7 contained corrective actions and commitments, including presentation of torus wall thinning to the NRC and establishment of baseline torus wall thickness.

The NRC conducted an inspection in December, 1988, concluding that no violations were observed and that there had been no discernible change in torus wall thickness.

Torus Corrosion Rate

As a result of further internal review of this issue, Niagara Mohawk undertook a new corrosion monitoring program in August, 1989. Under this program 1' x 3' grids on all 40 mid bay bottom plates were UT inspected. MPR Associates Inc. Report MPR-1152 (Ref. 9) delineates the results of this inspection. These measurements did not show any significant loss due to corrosion or pitting even at the normal water level region; and there were no wall thickness measurements that would require application of the methods described in Teledyne Report TR-6801-2. MPR quantified the shell thickness loss, over 20 years, by comparing the measured shell thickness values to the calculated original plate thickness. Thirty-four shell plates, traceable to the original mil certifications, were used in this comparison. Original plate thicknesses were calculated using

plate dimensions, weight and density of the steel. These thicknesses were compared to the UT thicknesses obtained in August, 1989, on the same 34 plates. The results indicated an average corrosion loss of 0.8 mils per year. This rate translates to a total loss of 32 mils or about 1/32" over the original projected 40-year plant life; and compares closely to the rate predicted by Radiological & Chemical Technology Inc. (RCT), based on analysis of sludge samples in 1979. Due to variations in the original plate dimensions and weights, and UT measurements, one standard deviation was added to the 0.8 mils per year. This resulted in a conservative prediction of 1.26 mils per year corrosion rate.

Additionally, Niagara Mohawk Power Corporation committed to perform UT measurements on a six-month basis and provide the NRC with the results (Ref. November 22, 1989, letter C. Terry to NRC). Since baseline establishment of the new corrosion program of 1989, four six-month measurements have been conducted, the most recent of which were taken in March, 1991. Further analysis and trending of these measurements indicate that a conservative corrosion rate of 1 mil/yr. including one standard deviation is a more realistic corrosion rate than the baseline estimate of 1.26 mils/year. The most probable prediction of corrosion rate is still 0.8 mils/yr., but the later results have reduced the standard deviation to ± 0.2 mils/yr.

<u>Alternative Torus Wall Modifications</u>

An in-house analysis of torus modification alternatives has also been performed. Cathodic protection was evaluated and rejected as a viable fix due to low torus water conductivity which would preclude the use of sacrificial anodes; concerns over impact of LOCA loads on submerged cathodic protection equipment eliminated use of an impressed current cathodic protection system from further consideration.

Coating systems were considered and rejected due to ALARA impacts, relatively short service life, outage critical path impact, and need for extensive long-term maintenance.

Stiffening rings were analyzed and considered the most viable modification option for mitigation of torus corrosion. This decision was based on minimizing total short and long-term costs and reduced outage critical path requirements for installation. This modification would reestablish an adequate corrosion allowance for the projected remaining plant life plus a 20-year extension.

In parallel, Teledyne Engineering Services, in conjunction with Continuum Dynamics Inc. analyzed condensation oscillation loadings on the NMP1 torus. It was concluded that conservatisms in condensation oscillation loads result in reduced minimum wall thickness, providing additional corrosion allowance such that no modifications would be required to the torus until 2007 even at a most conservative corrosion rate of 1.26 mils/yr.

ATTACHMENT 3

Information Requested at
April 24, 1991 Meeting

A. Torus Coating Study References are as follows:

1. Philadelphia Electric Co. - Torus Recoating Effort Mark I Containment - Utility Survey, February 26, 1990.

2. Torus Coating Evaluation for Dresden (Commonwealth Edison) by Impell Corp., January 1985.

3. Torus Corrosion - Survey of Operators of BWR/MKI Containment Plants, November 14, 1989 by Structural Integrity Associates, Inc. for EPRI.

B. Torus Leakage/Surveillance Program

1. Leakage

The NMP1 design includes both redundant torus water level monitoring and torus room water level monitoring. Both monitoring systems include continuous indication and alarm in the control room. If a gross leak were to develop in the torus, the water level would begin to drop in the torus. The decreasing water level would be detected and monitored by the torus water level instrumentation. The leak would spill onto the floor of the torus room (normally closed or sealed with bulkhead doors) where the torus room level detection equipment would begin to monitor the leakage.

2. Surveillance

a. Surveillance or inspection of the torus interior is done each refuelling outage (not to exceed two years $\pm$ 25%). This is a visual inspection covering interior components such as vent pipes, bellows, downcomers and the torus shell.

b. Shell thickness measurements are performed approximately every six (6) months. The current program includes six (6) 1' x 3' grid locations representing the thinnest areas from the one-time UT inspection of all 20 torus bays in 1989.

c. Water chemistry surveillance of torus water constituents is performed at approximate one week intervals. Constituents monitored include the following:

PH
chloride
fluoride
conductivity
silica
dissolved O_2
suspended solids
isotopic analysis
microbiological (MIC)

Other constituents are monitored at less frequent intervals such as:

- sulfate
- boron
- iron
- copper
- chromium
- zinc
- magnesium
- ammonia
- calcium

The limits established for the above constituents are far below those recommended in EPRI NP-4946-SP, BWR Normal Water Chemistry Guidelines (Appendix A).

d. An integrated leak rate test (ILRT) is performed each refueling outage. During this test the containment is pressurized to 17.9 psig and a walkdown performed to identify any potentially leaking penetrations. The containment is further pressurized to 22 + 3, -0 psig and the total leakage rate calculated.

C. <u>Torus UT Measurements</u>

The latest six (6) month UT torus shell measurements are attached. The calibration sheets are also included. These calibration sheets indicate step wedge thicknesses of 0.402" and 0.502" are used to check instrument calibration. The step wedge measurements are recorded, along with the clock time, after each row of measurements on a grid; and form the basis for calibration correction, if any, to be applied to the measurements.

CALC NO. S22.4-WW198-STAT Ø1 REV. 3

NIAGARA MOHAWK — ULTRASONIC EXAMINATION REPORT

Plant/Unit: Nine Mile Point Unit 1
ISO/Dwg.: F-45001-C SHT. 2 REV. 0
System/Loop: TORUS

NDE Report: 1-6.05-91-0003
Work Document: N1-MPM-201-SA001 REV. 00
Page 1 of 3
Exam Item: TORUS
Procedure/Rev.: NDEP-UT- 6.05 / 4
Title: ULTRASONIC THICKNESS MEASUREMENT

INSTRUMENT SETTINGS			
Serial #	QA-NDE-UT-018		
MFG./Model #	KB - USL 37		
Sweep Length	5.86		
Sweep Delay	6.60		
Pulse Length/Damp.	FIXED		
Freq.	2.5	Range	.5
DEC/Gate	ON	Reject	MIN
Jacks	R		
Mode Select	SFD		
Coarse Gain	*	Fine	*
Scan Sens.	* Maint. 80%BR		

INSTRUMENT LINEARITY					
1	100	50	6	50	25
2	90	45	7	40	20
3	80	40	8	30	15
4	70	35	9	20	10
5	60	30			

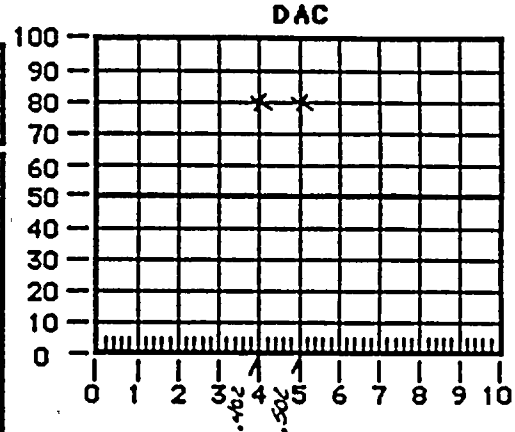
AMPLITUDE LINEARITY	
80 - 6= 40	80 - 12= 20
40 + 6= 80	20 + 12= 80

QUARTERLY LINEARITY
Due: 05/13/91

Orientation	0 DEGREE
Scan Area	THICKNESS

DAC			
	Reflector	%FSH	Position
1	.402 STEP	80	4.0
2	.502 STEP	80	5.0
3	N/A		
4	N/A		
5	N/A		
6	N/A		

DAC



SEARCH UNIT	
Serial #	028236
Brand	KB-AEROTECH
Frequency	2.25 MHz
Size/Shape	1.0 /ROUND
Style/Type	GAMMA
Fixture	N/A
Scan Angle	0
Measured Angle	N/A
Mode	LONGITUDINAL
Cable	BNC-BNC 1x6'

Couplant Batch	8868
Couplant Brand	ULTRAGEL II

Calibration Checks	:Time
Initial Calib.	1034
Intermediate	N/A
Intermediate	N/A
Intermediate	N/A
Final Calib.	1135

Thermometer	QA-NDE-T-013
Block Temperature	72 °F
Comp. Temperature	66 °F

CALIBRATION BLOCK	
NMP-1SW-1020-CS	
Block Thickness	.100-1.0 "
Comp. Thickness	** "
Surface	OD

CRT Calibrated In Inches of Depth
Each Major Screen Div. = .10"

Comments/Remarks

AREAS 10-I; 10-O; AND 6-O

*CALIBRATION AND ALL READINGS WERE TAKEN AT 80% FSH BR.
** COMPONENT THICKNESSES ARE AS NOTED ON ATTACHMENTS.
GATE WAS ON AND DISPLAYED - ALL READINGS WERE TAKEN FROM DIGITAL DISPLAY.

NOTE: 1" - 2.25 MHZ X-DUCER WAS USED PER MEMO FROM L.M. IVGER TO J. SHEPHERD DATED 8-7-89. JJ Clinto 3-14-91

Reason(s) for Incomplete Exam

N/A

Exam Item ACCEPTABLE

Examiner 1: Timothy G. Beck Level: II Company: NMPC Date: 3/13/91

Examiner 2: Larry W. Taylor Level: II Company: NMPC Date: 3/13/91

Reviewer 1: JJ Clinto Level: III Date: 3-14-91

ANII: N/A Date: N/A

Computer Review: No Entry Errors

Previous Outage Data Reviewed? Yes ☒ No ☒
Reviewer: [signature]

CALC. NO. 522.4-WW198-STAT Ø1 REV. 3

PG 177

NIAGARA MOHAWK — ULTRASONIC EXAMINATION REPORT

NDE Report: 1-6.05-91-0004

Plant/Unit: Nine Mile Point Unit 1

Work Document: N1-MPM-201-SA001 REV. 00

ISO/Dwg.: F-45001-C SHT. 2 REV. 0

Page 1 of 1

System/Loop: TORUS

Exam Item: TORUS

Procedure/Rev.: NDEP-UT- 6.05 / 4

Title: ULTRASONIC THICKNESS MEASUREMENT

INSTRUMENT SETTINGS			
Serial #	QA-NDE-UT-018		
MFG./Model #	KB - USL 37		
Sweep Length	0.84		
Sweep Delay	6.34		
Pulse Length/Damp.	FIXED		
Freq.	2.5	Range	.5
DEC/Gate	ON	Reject	MIN
Jacks	R		
Mode Select	SFD		
Coarse Gain	*	Fine	*
Scan Sens.	* Maint. 80%BR		

INSTRUMENT LINEARITY					
1	100	50	6	50	25
2	90	45	7	40	20
3	80	40	8	30	15
4	70	35	9	20	10
5	60	30			

AMPLITUDE LINEARITY	
80 - 6= 40	80 - 12= 20
40 + 6= 80	20 + 12= 80

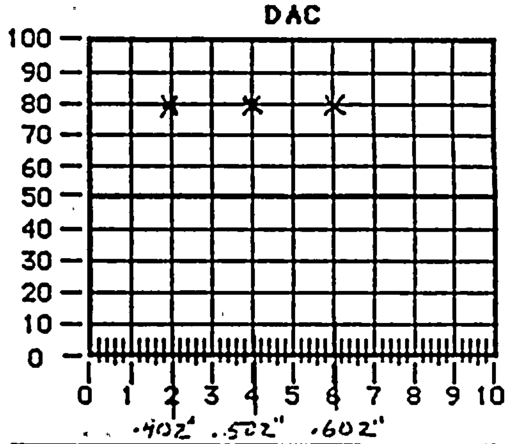
QUARTERLY LINEARITY

Due: 05/13/91

Orientation	0 DEGREE
Scan Area	THICKNESS

DAC			
	Reflector	%FSH	Position
1	.402 STEP	80	2.0
2	.502 STEP	80	4.0
3	.602 STEP	80	6.0
4	N/A		
5	N/A		
6	N/A		

DAC



SEARCH UNIT	
Serial #	028236
Brand	KB-AEROTECH
Frequency	2.25 MHz
Size/Shape	1.0 /ROUND
Style/Type	GAMMA
Fixture	N/A
Scan Angle	0
Measured Angle	N/A
Mode	LONGITUDINAL
Cable	BNC-BNC 1x6'

CRT Calibrated in Inches of Metal Path

Each Major Screen Div. = .05"

Couplant Batch	8868
Couplant Brand	ULTRAGEL II

Calibration Checks	:Time
Initial Calib.	2020
Intermediate	2110
Intermediate	2115
Intermediate	N/A
Final Calib.	2130

Thermometer	QA-NDE-T-013
Block Temperature	75°F
Comp. Temperature	69°F

CALIBRATION BLOCK	
NMP-1SW-1020-CS	
Block Thickness	.100-1.0"
Comp. Thickness	**"
Surface	OD

Comments/Remarks

AREA 17-O

*CALIBRATION AND ALL READINGS WERE TAKEN AT 80% FSH USING A GATED AREA AND DIGITAL DISPLAY.

READINGS TAKEN AT ENGINEERINGS REQUEST FOR VERIFICATION OF THICKNESS READINGS (BAY 17 OUTSIDE, LOCATIONS E-7 AND E-8) TAKEN PER NDE REPORT # 1-6.01-91-0002.

** COMPONENT THICKNESSES ARE AS FOLLOWS:

BAY 17 OUTSIDE, LOCATION E-7: .448"
BAY 17 OUTSIDE, LOCATION E-8: .452"

Reason(s) for Incomplete Exam

N/A

Exam Item ACCEPTABLE

Examiner 1: [signature] Scott D. Reed Level: III Company: NMPC Date: 3/18/91

Examiner 2: N/A Level: N/A Company: N/A Date: 3/18/91

Reviewer 1: N/A [signature] Level: II Date: 3-19-91

ANII: N/A Date:

Computer Review: No Entry Errors

Previous Outage Data Reviewed? Yes ☒ No N/A

Reviewer: [signature]

CALC NO. S22-4-WW198-STAT Ø1 REV. 3

NIAGARA MOHAWK — ULTRASONIC EXAMINATION REPORT

Plant/Unit: Nine Mile Point Unit	1
ISO/Dwg.:	F-45001-C SHT. 2 REV. 0
System/Loop:	TORUS
NDE Report:	1-6.05-91-0002
Work Document:	N1-MPM-201-SA001 REV. 00
Page	1 of 3
Exam Item:	TORUS
Procedure/Rev.:	NDEP-UT- 6.05 / 4
Title:	ULTRASONIC THICKNESS MEASUREMENT

INSTRUMENT SETTINGS

Serial #	QA-NDE-UT-018
MFG./Model #	KB - USL 37
Sweep Length	5.86
Sweep Delay	6.60
Pulse Length/Damp.	FIXED
Freq.	2.5
Range	.5
DEC/Gate	ON
Reject	MIN
Jacks	R
Mode Select	SFD
Coarse Gain	*
Fine	*
Scan Sens.	* Maint. 80%BR

INSTRUMENT LINEARITY

1	100	50	6	50	25
2	90	45	7	40	20
3	80	40	8	30	15
4	70	35	9	20	10
5	60	30			

AMPLITUDE LINEARITY

80 − 6= 40	80 − 12= 20
40 + 6= 80	20 + 12= 80

QUARTERLY LINEARITY

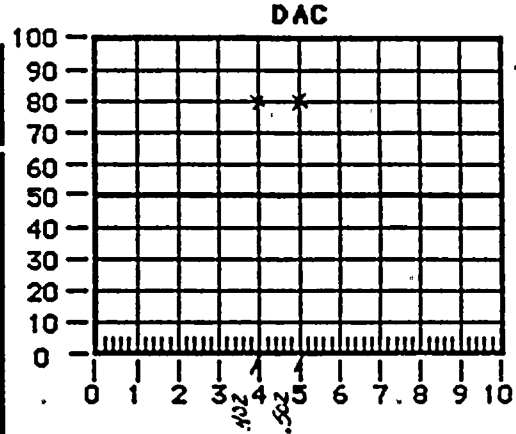
Due: 05/13/91

Orientation	0 DEGREE
Scan Area	THICKNESS

DAC

	Reflector	%FSH	Position
1	.402 STEP	80	4.0
2	.502 STEP	80	5.0
3	N/A		
4	N/A		
5	N/A		
6	N/A		

DAC



SEARCH UNIT

Serial #	G28236
Brand	KB-AEROTECH
Frequency	2.25 MHz
Size/Shape	1.0 /ROUND
Style/Type	GAMMA
Fixture	N/A
Scan Angle	0
Measured Angle	N/A
Mode	LONGITUDINAL
Cable	BNC-BNC 1x6'

Couplant Batch	8868
Couplant Brand	ULTRAGEL II

Calibration Checks	:Time
Initial Calib.	0905
Intermediate	N/A
Intermediate	N/A
Intermediate	N/A
Final Calib.	1032

Thermometer	QA-NDE-T-013
Block Temperature	72 °F
Comp. Temperature	66 °F

CALIBRATION BLOCK

NMP-1SW-1020-CS

Block Thickness	.100-1.0 "
Comp. Thickness	** "
Surface	OD

CRT Calibrated In Inches of

Depth

Each Major Screen Div. = .10"

Comments/Remarks

AREAS 17-I; 17-O; AND 20-O

*CALIBRATION AND ALL READINGS WERE TAKEN AT 80% FSH BR.

** COMPONENT THICKNESSES ARE AS NOTED ON ATTACHMENTS.

GATE WAS ON AND DISPLAYED - ALL READINGS WERE TAKEN FROM DIGITAL DISPLAY.

NOTE: 1"X 2.25 MHZ X-DUCER WAS USED PER MEMO FROM L. MCVEIL TO J. SHEPHERD DATED 8-7-87 JJ Cilento 3-14-91

Reason(s) for Incomplete Exam

N/A

Exam Item ACCEPTABLE

Examiner 1: JJ Cilento (Joseph J. Cilento)	Level: III	Company: NMPC	Date: 3/13/91
Examiner 2: Ted Sievers (Ted Siever)	Level: II	Company: NMPC	Date: 3/13/91
Reviewer 1: Larry M. Naylor	Level: II		Date: 3/14/91
ANII: N/A			Date: N/A

Computer Review: No Entry Errors

Previous Outage Data Reviewed? Yes ☒ No ☒

Reviewer: [illegible]

CALC. NO. S22.4-WW198-STAT Ø1 REV. 3

NIAGARA MOHAWK — TORUS THICKNESS EXAMINATION REPORT

Plant/Unit: Nine Mile Point Unit One
ISO/Dwg.: F-45001-C Sht. 2 Rev. 0
System/Loop: Torus

NDE Report: 1-6.05-91-0003
Work Document: N1-MPM-201-SA001 Rev. 00

Exam Item: Torus Grid 6-0
Procedure/Rev.: NDEP-UT-6.05 / Rev. 4
Title: Ultrasonic Thickness Measurement

3" × 3" grid

INSIDE (I)				A		WELD SEAM	OUTSIDE (O)				A	
N/A	N/A	N/A	N/A	N/A	1		.459	.457	.457	.460	.459	1
N/A	N/A	N/A	N/A	N/A			.457	.458	.457	.459	.460	
N/A	N/A	N/A	N/A	N/A			.458	.458	.458	.460	.459	
N/A	N/A	N/A	N/A	N/A			.454	.454	.458	.458	.462	
N/A	N/A	N/A	N/A	N/A			.452	.457	.458	.459	.460	
N/A	N/A	N/A	N/A	N/A			.455	.458	.458	.459	.458	
N/A	N/A	N/A	N/A	N/A			.454	.458	.457	.458	.459	
N/A	N/A	N/A	N/A	N/A			.457	.458	.453	.460	.457	
N/A	N/A	N/A	N/A	N/A			.455	.453	.457	.459	.459	
N/A	N/A	N/A	N/A	N/A			.457	.455	.458	.459	.459	
N/A	N/A	N/A	N/A	N/A			.452	.453	.455	.458	.457	
N/A	N/A	N/A	N/A	N/A			.453	.458	.454	.457	.458	
N/A	N/A	N/A	N/A	N/A			.457	.458	.459	.453	.455	

	START TIME	CALIB. CHECK TIME	READINGS MIN.	READINGS MAX.
INSIDE				
Row A :	1034	1038	.402	.502
Row B :	1038	1041	.402	.502
Row C :	1041	1044	.402	.502
Row D :	1044	1048	.402	.504
Row E :	1048	1052	.404	.505
OUTSIDE				
Row A :	N/A			
Row B :	N/A			
Row C :	N/A			
Row D :	N/A			
Row E :	N/A			

Examiner 1: [signature] Level : II Company: NMPC Date: 3-13-91
Examiner 2: Larry W Naylor Level : II Company: NMPC Date: 3-13-91
Reviewer 1: [signature] Level : III Date: 3-14-91

CALC. NO. S22.4-WW198-STAT Ø1 REV. 3

NIAGARA MOHAWK — **TORUS THICKNESS EXAMINATION REPORT**

Plant/Unit: Nine Mile Point Unit One
ISO/Dwg.: F-45001-C Sht. 2 Rev. 0
System/Loop: Torus

NDE Report: 1-6.05-91-0003
Work Document: N1-MPM-201-SA001 Rev. 00

Exam Item: Torus Grids 10-I and 10-0
Procedure/Rev.: NDEP-UT-6.05 / Rev. 4
Title: Ultrasonic Thickness Measurement

3" × 3" grid

INSIDE (I)

				A	
.464	.465	.468	.463	.465	1
.463	.464	.464	.468	.464	
.462	.464	.465	.465	.464	
.462	.463	.462	.465	.464	
.464	.464	.464	.463	.461	
.463	.462	.461	.460	.464	
.463	.462	.458	.460	.463	
.465	.464	.460	.462	.463	
.463	.464	.461	.459	.463	
.465	.465	.462	.462	.461	
.463	.464	.463	.463	.462	
.464	.463	.461	.460	.459	
.464	.465	.462	.463	.463	

WELD SEAM

OUTSIDE (O)

				A	
.459	.464	.465	.458	.463	1
.463	.462	.463	.462	.461	
.462	.464	.468	.463	.463	
.452	.460	.465	.464	.463	
.462	.458	.465	.463	.465	
.460	.463	.465	.463	.463	
.464	.462	.464	.463	.459	
.458	.457	.464	.463	.462	
.461	.462	.464	.464	.464	
.460	.460	.464	.464	.464	
.458	.460	.468	.464	.461	
.458	.460	.462	.465	.463	
.461	.461	.460	.463	.463	

	START TIME	CALIB. CHECK TIME	READINGS MIN.	READINGS MAX.
INSIDE				
Row A:	1057	1104	.402	.502
Row B:	1104	1107	.402	.503
Row C:	1107	1109	.401	.504
Row D:	1109	1111	.403	.505
Row E:	1111	1113	.401	.504
OUTSIDE				
Row A:	1114	1118	.402	.506
Row B:	1118	1121	.401	.504
Row C:	1121	1126	.402	.503
Row D:	1126	1130	.403	.502
Row E:	1131	1135	.401	.504

Examiner 1: [signature] Level: II Company: NMPC Date: 3-13-91
Examiner 2: [signature] Level: II Company: NMPC Date: 3-13-91
Reviewer 1: [signature] Level: III Date: 3-19-91

NIAGARA MOHAWK — TORUS THICKNESS EXAMINATION REPORT

Plant/Unit: Nine Mile Point Unit One
ISO/Dwg.: F-45001-C Sht. 2 Rev. 0
System/Loop: Torus

NDE Report: 1-6.05-91-0002
Work Document: N1-MPM-201-SA001 Rev. 00

Exam Item: Torus Grids 17-I and 17-0
Procedure/Rev.: NDEP-UT-6.05 / Rev. 4
Title: Ultrasonic Thickness Measurement

3" × 3" grid

INSIDE (I)

				A
.458	.454	.455	.455	.455
.458	.458	.454	.455	.457
.458	.458	.458	.455	.455
.455	.455	.458	.458	.455
.458	.458	.454	.455	.457
.459	.457	.458	.457	.457
.459	.458	.455	.458	.455
.458	.457	.458	.455	.457
.460	.457	.458	.458	.457
.458	.459	.457	.458	.455
.458	.458	.458	.455	.454
.458	.458	.455	.458	.457
.460	.457	.458	.453	.458

1

WELD SEAM

OUTSIDE (O)

				A
.453	.454	.451	.452	.453
.453	.455	.451	.455	.453
.454	.453	.453	.454	.452
.452	.454	.454	.458	.455
.454	.453	.455	.453	.454
.454	.453	.458	.458	.455
* ~~.446~~ SAR .448	.451	.453	.457	.455
* ~~.449~~ SAR .452	.452	.454	.458	.454
.452	.453	.455	.454	.457
.455	.453	.454	.454	.455
.453	.458	.453	.453	.458
.454	.455	.455	.458	.457
.454	.454	.457	.455	.458

1

* SEE PAGE 177

	START TIME	CALIB. CHECK TIME	READINGS MIN.	READINGS MAX.
INSIDE				
Row A:	1005	1009	.402	.503
Row B:	1010	1015	.402	.501
Row C:	1016	1020	.402	.502
Row D:	1021	1026	.402	.501
Row E:	1027	1032	.400	.501
OUTSIDE				
Row A:	0942	0945	.401	.502
Row B:	0946	0950	.401	.502
Row C:	0951	0955	.402	.503
Row D:	0956	1000	.402	.503
Row E:	1001	1004	.402	.503

Examiner 1: J J Cilento Level : III Company: NMPC Date: 3-13-91
Examiner 2: Ted Stever Level : II Company: NMPC Date: 3-13-91
Reviewer 1: Jerry M Taylor Level : II Date: 3/14/91

CALC NO. S22-4-WW198-STAT Ø1 REV. 3

NIAGARA MOHAWK — TORUS THICKNESS EXAMINATION REPORT

Plant/Unit: Nine Mile Point Unit One
ISO/Dwg.: F-45001-C Sht. 2 Rev. 0
System/Loop: Torus

NDE Report: 1-6.05-91-0002
Work Document: N1-MPM-201-SA001 Rev. 00
Page 3 of 3
Exam Item: Torus Grid 20-0
Procedure/Rev.: NDEP-UT-6.05 / Rev. 4
Title: Ultrasonic Thickness Measurement

3" 3"

INSIDE (I) — WELD SEAM — OUTSIDE (O)

				A						A	
N/A	N/A	N/A	N/A	N/A	1	.459	.457	.454	.453	.460	1
N/A	N/A	N/A	N/A	N/A		.460	.457	.454	.454	.456	
N/A	N/A	N/A	N/A	N/A		.459	.458	.457	.454	.462	
N/A	N/A	N/A	N/A	N/A		.456	.457	.456	.456	.457	
N/A	N/A	N/A	N/A	N/A		.453	.458	.455	.456	.457	
N/A	N/A	N/A	N/A	N/A		.460	.454	.454	.459	.458	
N/A	N/A	N/A	N/A	N/A		.456	.454	.454	.454	.458	
N/A	N/A	N/A	N/A	N/A		.454	.455	.455	.453	.461	
N/A	N/A	N/A	N/A	N/A		.455	.454	.455	.461	.456	
N/A	N/A	N/A	N/A	N/A		.455	.455	.456	.458	.458	
N/A	N/A	N/A	N/A	N/A		.456	.455	.453	.459	.455	
N/A	N/A	N/A	N/A	N/A		.456	.454	.456	.460	.453	
N/A	N/A	N/A	N/A	N/A		.454	.455	.455	.456	.455	

	START TIME	CALIB. CHECK TIME	READINGS MIN.	READINGS MAX.
INSIDE				
Row A:	0915	0918	.402	.502
Row B:	0920	0925	.402	.501
Row C:	0926	0930	.402	.502
Row D:	0933	0936	.402	.503
Row E:	0937	0941	.402	.503

OUTSIDE
Row A: N/A
Row B: N/A
Row C: N/A
Row D: N/A
Row E: N/A

Examiner 1: J J Clintr Level : III Company: NMPC Date: 3-13-91

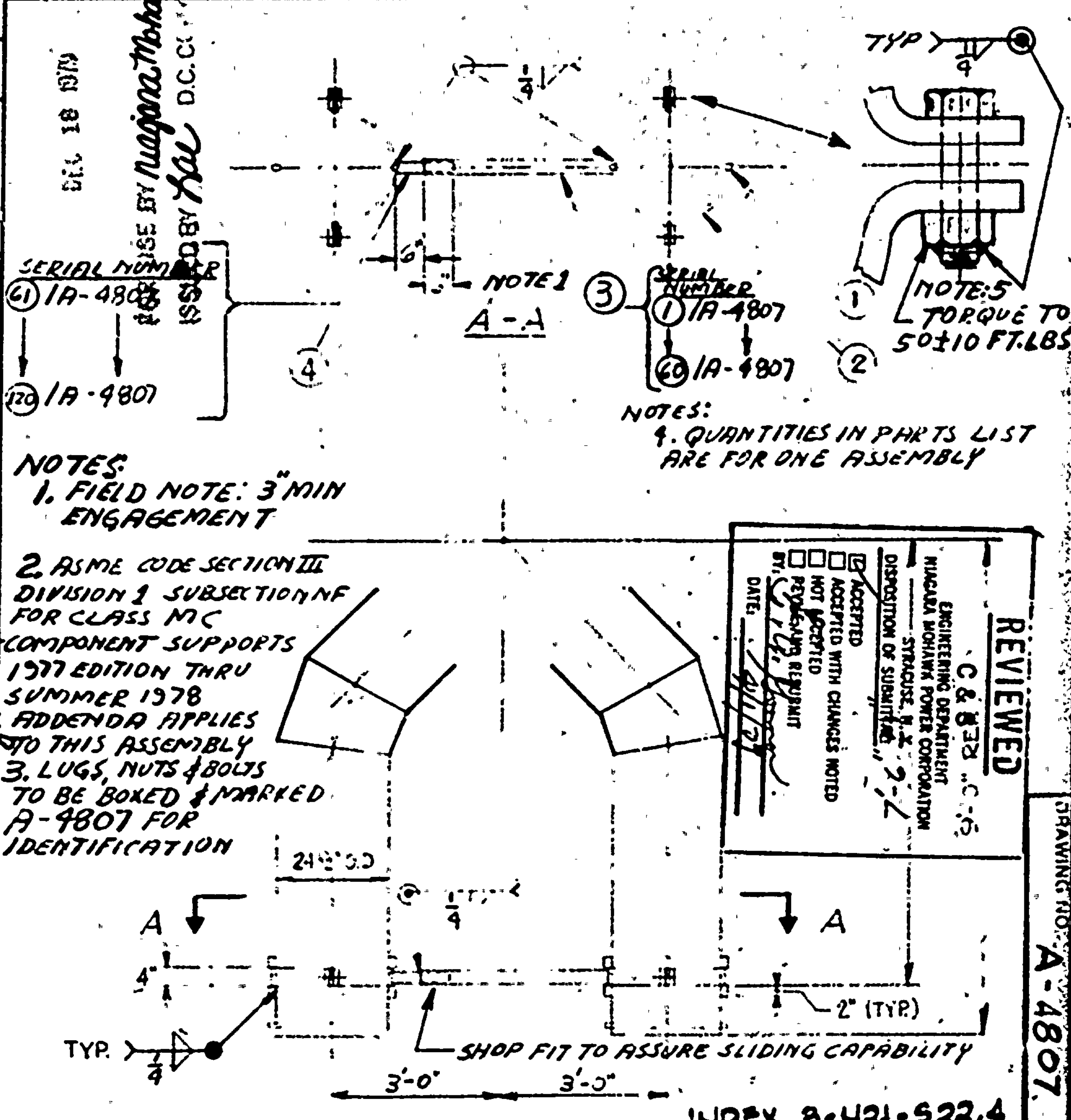
Examiner 2: Ted Steller Level : II Company: NMPC Date: 3-13-91

Reviewer 1: Larry W Taylor Level : II Date: 3-14-91

D. Drawings

Dwg. No.	By	Information
A-4807	Teledyne	Downcomer Stiffeners
430	CBI	Downcomer Stiffeners
211	CBI	Torus Saddle Support
212	CBI	Torus Saddle Support
224	CBI	Torus Saddle Support
313	CBI	Bellows (Header Vent Sys.)
Q-2892	Pathway Bellows	Bellows Assembly
C-15176-C	NMPC	Drywell Refueling Seal Bellows
C-15423-C	NMPC	Drywell Refueling Seal
Sh. 1 & 2		Bellows Details (Sh. 2) Aluminum Cover ("Silver Dollars")
C-34135-C	NMPC	Closures & Cover Support Frames ("Silver Dollars")

ITEM	DESCRIPTION/MATERIAL	QTY
1	1" x 1" x 2" LUG MAT: SA 516 GR. 70	8
2	SPECIAL PIPE CLAMP - TELEDYNE DWG. NO. C-4505	2
3	2 1/2" PIPE SCH. 40 x 40" LONG - MAT SA 106 GR. B	1
4	2" PIPE SCH. 80 x 12" LONG - MAT SA 106 GR. B	1



NOTES:
4. QUANTITIES IN PARTS LIST ARE FOR ONE ASSEMBLY

NOTES:
1. FIELD NOTE: 3" MIN ENGAGEMENT
2. ASME CODE SECTION III DIVISION 1 SUBSECTION NF FOR CLASS MC COMPONENT SUPPORTS 1977 EDITION THRU SUMMER 1978 ADDENDA APPLIES TO THIS ASSEMBLY
3. LUGS, NUTS & BOLTS TO BE BOXED & MARKED A-4807 FOR IDENTIFICATION

INDEX 3-N21-S22.4

DRAWING NO. A-4807

REV	DCO	DESCRIPTION	DWN	CKD	APP	DWG CON	DATE	DCO
1	1913	ADDED ITEMS WELD SYMBOL FOR LUGS ADDED NOTE 9 ADDED SHOP FIT NOTE	Leone	LJD	SAR			
2	1958	REVISED WELD FOR 1 1/4 BOLT	Leone	LJD	SAR			

SYSTEM —	DESIGNED LJD	DATE 1-9-79	TELEDYNE ENGINEERING SERVICES WALTHAM, MASS	
REF DWG —	DRAWN VARELA	1/9/79	INFORMATION ONLY 5/1/91	
APPLICABLE CODE SEE NOTE 2	CHECKED Leone	1/9/79	TITLE 3-N21-S22.4 DOWNCOMER TIE STRAPS 9 MILE POINT	
SEISMIC CLASS	ANALYZED LJD	1-9-79		
NO REQD 60 ASSEMBLIES	ENGR APPR MSC	1/16/79		
MARK NO A-4807	DWG CON GHC	1-16-79	PROJECT NO 3134	DRAWING NO A-4807 SHEET 1 of 1 REV 2