TECHNICAL AUDIT OF VERMONT YANKEE STEAM DRYER ANALYSIS IN SUPPORT OF EXTENDED POWER UPRATE REQUEST

Docket No.	50-271
License No.	DPR-28
Licensee:	Entergy Nuclear Vermont Yankee, LLC.
Facility:	Vermont Yankee Nuclear Power Station
Audit Location:	General Electric Nuclear Energy in San Jose, CA
Dates:	August 24-26, 2004
Participants:	Thomas G. Scarbrough, NRC/NRR/DE/EMEB
	Cheng-Ih (John) Wu, NRC/NRR/DE/EMEB
	Shah N.M. Malik, NRC/RES/DET/MEB
	Dr. Vikram N. Shah, Argonne National Laboratory (ANL)
	Dr. Thomas M. Mulcahy, ANL consultant
	Dr. Shoei-Sheng Chen, ANL consultant
	Eugene Imbro, NRC/NRR/DE/EMEB (August 25-26)

I. BACKGROUND

On August 24 through 26, 2004, the NRC staff conducted a technical audit of the analysis submitted by Entergy Nuclear Northeast (licensee) of the steam dryer at the Vermont Yankee nuclear power plant in support of its request to operate the plant at extended power uprate (EPU) conditions. Staff members from the NRC Office of Nuclear Reactor Regulation and Office of Nuclear Regulatory Research, and staff contractors from the Argonne National Laboratory (ANL) conducted the audit of the licensee's methodology and supporting calculations for the steam dryer analysis at the GE Nuclear Energy office in San Jose, CA. The NRC staff members and contract personnel participating in the audit (collectively referred to as the staff in this report) are listed in Appendix A to this report.

II. AUDIT OBJECTIVE

The objective of the audit was to obtain sufficient information to enable the NRC to reach a decision regarding the adequacy of the current analysis of the Vermont Yankee steam dryer in support of the licensee's EPU request by (1) understanding the details of the steam dryer analysis and its supporting calculations; (2) obtaining responses to specific staff questions related to the steam dryer analysis; and (3) learning about any further support for the capability of the steam dryer that might be provided by the licensee in the near future. The audit provided an opportunity for the staff to obtain sufficient information to reach a decision on the adequacy of the current analysis of the Vermont Yankee steam dryer in support of the licensee's EPU request.

III. PERFORMANCE OF AUDIT

At the entrance meeting, the staff discussed the objective of the audit and its plans for conducting the audit. The staff emphasized that the audit would be used to gather information on the Vermont Yankee steam dryer analysis, and that a decision regarding the adequacy of the Vermont Yankee steam dryer analysis would not be made during the audit. The staff indicated that the NRC would make a decision regarding the Vermont Yankee steam dryer analysis following review of the audit results and discussions with NRC staff and management. A list of individuals from Entergy Nuclear Northeast, GE Nuclear Energy, and other industry organizations contacted as part of this audit (collectively referred to as the licensee in this report) is provided in Appendix B to this report.

At the outset of the technical discussions, the licensee presented an overview of the evolution of the analysis of the steam dryer at Vermont Yankee. The licensee described the Equivalent Static Method and Dynamic Response Spectrum Method used in analyzing the Vermont Yankee steam dryer. The licensee also described the recent modifications to the Vermont Yankee steam dryer that significantly improve its structural capability. Appendix C to this report includes the overview slides presented by the licensee.

Following the overview, the staff specified the principal areas of concern with the Vermont Yankee steam dryer analysis based on review of the licensee's submittals and discussions during public meetings on July 21 and 22, 2004. For example, the licensee included a scaling factor of 0.03446 (1/29) in the Vermont Yankee steam dryer analysis to reduce the predicted stress to the fatigue failure criterion. Further, the correlation between data collected at three other nuclear power plants and the load on the steam dryer at

Vermont Yankee under EPU conditions was not clear. In addition, the basis for using scale model test data to correlate data collected at different in-plant measurement locations was not apparent.

During the audit, the staff discussed the information provided in the licensee's response dated July 2, 2004, to the staff's request for additional information (RAI) dated May 28, 2004. A supplemental handout provided by the licensee during these discussions is included in Appendix D to this report. The staff reviewed the basis for the Vermont Yankee steam dryer analysis presented in proprietary GE documents. A list of the documents reviewed during the audit is provided in Appendix E to this report. The staff also observed the performance of the ANSYS computer model in identifying the mode shapes for the Vermont Yankee steam dryer.

As part of the audit, the staff visited the small scale test facility used to model steam dryer performance at the GE Nuclear Energy office. The staff studied the steam dryer model and discussed the mock-up with test personnel. The staff also discussed the computer analysis of the collected data with the test personnel. The staff observed a test run of the facility that was set-up to model the steam dryer at the Quad Cities Unit 1 nuclear power plant and its steam lines.

In its discussions, the licensee acknowledged the uncertainties in its analysis of the Vermont Yankee steam dryer for EPU conditions. While the licensee considers the current analysis sufficient in light of the modifications to strengthen the Vermont Yankee steam dryer, the licensee presented the status of its ongoing development of a new acoustic circuit analysis of the Vermont Yankee steam dryer, preparation of a new computational fluid dynamics (CFD) model of its modified steam dryer, and collection of plant data to focus its analysis of the Vermont Yankee steam dryer. The slides from the licensee's presentation of ongoing steam dryer analysis activities are provided in Appendix F to this report. The licensee plans to present some of the results of its additional analysis of the steam dryer at Vermont Yankee to the NRC staff in late September 2004. [During the audit, industry personnel from Exelon Generation Company provided the staff with a brief summary of the ongoing activities at Quad Cities and Dresden to resolve the steam dryer issues at those nuclear power plants.]

At the conclusion of the audit, the staff noted several follow-up items where the licensee was unable to provide specific information during the audit. The audit follow-up items are listed in Appendix G to this report. The licensee agreed to provide information to address the audit follow-up items as soon as possible. The additional information is not expected to significantly affect the results of the audit as described in this report. A supplement to this report will be prepared following receipt of the additional information, if necessary.

IV. EVALUATION

A. Overview

The steam dryer at Vermont Yankee is designed to remove moisture from the steam produced in the reactor core before the steam is directed through piping to the turbine generator. At the outset of the audit, the NRC staff and licensee personnel discussed the intent of the licensee's analysis of the steam dryer at Vermont Yankee. As indicated in those discussions, the licensee assumes that the Vermont Yankee steam dryer will maintain its structural integrity under EPU conditions. The licensee did not assert that it is acceptable for the Vermont Yankee steam dryer to fail to maintain its structural integrity, and cause loose parts in the reactor coolant, steam, or feedwater systems, or result in a significant increase in moisture carryover in the steam directed to the turbine generator. Therefore, the staff's evaluation of the Vermont Yankee steam dryer analysis during the audit focused on the capability of the steam dryer to maintain its structural integrity under EPU conditions.

B. Steam Dryer Analysis Methodology

In support of its EPU request, the licensee modified the steam dryer at Vermont Yankee to improve its structural capability based on an analysis referred to as the Equivalent Static Method performed by GE Nuclear Energy. In the steam dryer modifications, the licensee also incorporated lessons learned from the evaluation of cracks found in the steam dryer at Quad Cities Unit 2 during its refueling outage in the spring of 2004. The licensee evaluated the capability of the Vermont Yankee steam dryer to maintain its structural capability under EPU conditions using a more recent analysis referred to as the Dynamic Response Spectrum Method. The staff discussed the Equivalent Static Method with the licensee during the audit to obtain an understanding of the evolution of the analyses used in assessing the Vermont Yankee steam dryer. However, the staff focused its evaluation of the adequacy of the Vermont Yankee steam dryer analysis on the Dynamic Response Spectrum Method.

In analyzing the capability of the Vermont Yankee steam dryer using the Dynamic Response Spectrum Method, GE Nuclear Energy obtained pressure data from instruments installed in three BWR plants (one in the United States and two in other countries) and used that data to develop loading to be applied to the Vermont Yankee steam dryer. The Dynamic Response Spectrum Method can be summarized in a simplified manner as follows:

1. a pressure time history is obtained from each instrument installed in three reference plants operating at different power levels;

2. each pressure time history is transformed to a pressure spectrum of pressure versus frequency at the dryer with the use of location multipliers determined from scale model testing;

3. each pressure spectrum is then extrapolated to EPU conditions based on the ratio of the average steam line velocities at Vermont Yankee to the specific instrumented plant;

4. each pressure spectrum on the dryer is used to generate a synthetic pressure time history with the new amplitude but with the original phases;

5. each synthetic pressure time history is used to generate an acceleration response spectrum with its peaks then broadened to account for uncertainties;

6. a single response spectrum enveloping the response spectra developed above is prepared;

7. the enveloping response spectrum is further broadened in an effort to include pressure peaks in certain frequency ranges that might occur at Vermont Yankee;

8. using the ANSYS computer code, a structural evaluation of the steam dryer is performed based on the enveloping response spectrum;

9. peak stress for each steam dryer component is multiplied by stress concentration factors to account for undersized welds and weld quality factors; and

10. the highest stress predicted at the outer cover plate weld is scaled down to meet the fatigue failure criterion of 27,200 pounds per square inch (psi), with the stress at other steam dryer locations scaled down using the same factor.

The licensee considers the modifications to the Vermont Yankee steam dryer together with its analysis of steam dryer capability using the Dynamic Response Spectrum Method to be sufficient to justify the structural integrity of the steam dryer under EPU conditions. Nevertheless, the licensee plans to supplement the current analysis of record for the Vermont Yankee steam dryer using an acoustic circuit analysis, an updated CFD model, and plant-specific data.

C. Specific Areas of Review

1. Background

The assessment of flow-induced vibration (FIV) for a nuclear reactor system component can be fairly simple or very complex depending on the structural geometry and flow field. The steam dryer is located inside the upper portion of the reactor pressure vessel and is subject to complex, steam flows both internally and externally. Although there are no moving parts, the dryer is composed of many structural elements. It is expected that various FIV phenomena exist and dynamic fluid/structure interactions can be rather complex. Since the steam dryer does not have a safety function, potential detrimental effects of FIV, including fatigue resulting from FIV, were not considered explicitly or in detail in the original design evaluation. Also, the characteristics of steam dryer flow have not been as well studied as other components that possess safety functions. During the audit, the staff evaluated specific aspects of the licensee's analysis of the Vermont Yankee steam dryer as discussed in the following paragraphs.

2. FIV Excitation Mechanisms

In its report prepared after the failure of the Quad Cities Unit 2 steam dryer in the summer of 2003, GENE-0000-0018-3359-P (Revision 1), GE Nuclear Energy stated:

> The cause of the dryer failure is <u>postulated</u> to be high cycle fatigue resulting from low frequency pressure loading on the outer hoods during normal operation. The pressure loading is <u>thought</u> to be amplified by the geometric configuration of the main steamlines. The cracks in the hoods and braces are <u>most likely</u> to have been initiated during steady-state EPU power operation. The cracks continued to grow until the transient pressure loads from the stuck open relief valve and subsequent manual valve openings opened the cracks through-wall, leading to the increased steam moisture content. The previous cover plate failure in 2002 subjected the dryer structure on the 90° side to significant additional loading. [emphasis added]

The staff's review of the information submitted in support of the EPU request for Vermont Yankee and further presented by the licensee during this audit revealed that the uncertainties noted in the above paragraph have not been resolved.

Identification of the excitation mechanism and formulation of a load definition is difficult, because no direct measurements of the pressure loading on the Vermont Yankee steam dryer are available. Instead of focusing on identification of FIV excitation sources, the licensee's major effort involved defining the dryer loading using best engineering judgement and available information. In-plant pressure time histories from three other BWR nuclear power plants from instrumentation installed in flow regions below and above the dryer hoods were used to generate a generic load definition for all steam dryers.

The licensee had performed prior scale-model testing in an effort to determine if the coincident alignment of the vortex shedding frequency, acoustic load frequency, and natural frequency of the steam dryer was the FIV excitation mechanism responsible for the 2002 Quad Cities Unit 2 steam dryer failure. In essence, the licensee postulated that vortex shedding was the excitation source amplified by an acoustic resonance that caused forced vibration of the dryer at one of its natural frequencies. Also, pressure time histories were obtained in previous scale model testing, which could have been used to define the dryer loading. However, based on discussions during the audit, it was apparent that the excitation source could not be confirmed and that the direct application of the time histories was not appropriate, because the main steam line piping was not adequately simulated. Also, the Reynolds number is distorted by a factor of 500, and simulation of boundary layer phenomena, such as separation and flow-regime development, is not assured.

Several recently initiated activities might shed light on the FIV excitation mechanism. For example, scale model testing is intended to simulate the effects of the piping system on the dryer. The improved modeling might aid in the identification of the excitation source and provide confirmation of assumptions made in determining the load definition. In addition, the licensee is collecting data at Vermont Yankee for use in an acoustic circuit analysis of the steam dryer. This effort is intended to confirm the generic load definition, but it may also reveal inadequacies in the load definition and provide new insights into the excitation mechanism. The licensee is also performing CFD analysis (using the Fluent code) of the flow over the dryer to assess the creation of turbulent flow and vortex shedding from the dryer hood and resulting fluid excitations. Vortex shedding may act as a trigger, or excitation source, that is amplified by acoustic resonances in the main steam lines or dryer plenum. This analysis might provide useful information on the flow phenomena that occur over the dryer hood as well as provide a source for validation of scale-model testing.

3. Load Definition

The definition of the load on the Vermont Yankee steam dryer is made difficult by the lack of complete understanding of the FIV excitation mechanisms and direct measurement of the pressures on the steam dryer. Without direct information, the licensee used engineering judgement to generate a load definition for the Vermont Yankee steam dryer under EPU conditions. The licensee then applied the load definition in conducting a structural analysis of the dynamic response of the steam dryer to flow excitations.

Based on review of the information submitted by the licensee and provided during the audit, the character of the resulting load definition is questionable in that it does not reflect the complexity of the fluid pressures on the steam dryer. The basic assumption in the licensee's analysis regarding the nature of the pressure loading on the steam dryer is that the pressure is uniform and in phase over the outer hood components facing the exit nozzles. The loading over the rest of the dryer (inner hoods) is assumed to be the same, except the magnitude is one-half that on the faces of the outer hood. In reality, significant variations in the magnitude and phasing of the pressure distribution are expected to occur over the dryer external surfaces. For example, large variations in the acoustic wavelengths are possible because of the varied geometry in the dryer plenum, and large variations in the flow velocity distribution over the face of the hood will occur as the flow converges to exit the reactor vessel. Also, based on CFD calculations and scale-model testing results reviewed during the audit, swirling and bi-stable flow can occur near the steam line exit nozzles. In addition, nonuniform pressures can be expected on and near the surfaces where the flow jets from the steam dryer exits.

The ability of the load definition presented by the licensee to predict reasonable bounds on flow-induced dryer response is questionable for the following reasons:

The licensee's analysis did not adequately assess the potential contribution to failure of the steam dryer from vibration in higher modes. The assumption of uniform, in-phase, fluctuating pressures over the entire dryer structure favors excitation of lower vibration modes with longer wavelengths (e.g., the fundamental mode of the vertical hood plate). Nonuniform and out-of-phase fluctuating pressure loads are more likely to excite higher modes, which would generate different stresses and maximum stress locations. As part of the audit, the staff reviewed natural vibration modes and natural frequencies for the Vermont Yankee steam dryer in its unmodified and modified configurations from the licensee's ANSYS computer models. In its unmodified configuration, the Vermont Yankee steam dryer had many modes that could have been excited based on the frequency content of the load definition. However, contributions due to vibrations in the higher modes were not fully evaluated, because nonuniform loading is not modeled in the load definition. With respect to the modified configuration, the contributions of nonuniform loading to the dynamic response of the Vermont Yankee steam dryer might be more important. In particular, the modification of the Vermont Yankee steam dryer made the portion of the hood facing the exit nozzles very robust and stiff as a result of doubling the thicknesses of the vertical face plate and cover plates of the hood, and welding three gussets to the vertical and lower horizontal plates. The licensee's modal analysis now indicates that the lowest frequency occurs around 70 Hz with the higher modes at frequencies above 120 Hz, where the load definition again suggests significant energy content. For the hood, the spatial variations of the mode shapes have become more complex. The maximum modal accelerations now occur on the hood's side plates, which were not stiffened, and the antinodes on the front and sides of the dryer are often out of phase.

The lack of inclusiveness of the frequency content and the magnitude of the licensee's load definition question its ability to bound dynamic dryer response. Four separate time histories from in-plant transducers in three other BWR plants were used to calculate four separate acceleration response spectra at licensed power levels and EPU conditions. However, direct in-plant measurements of loading were not made on the critical surfaces of the dryer (e.g., vertical and cover plates). The in-plant measurements were made in the stagnant flow area in the annular region between the dryer skirt and the reactor pressure vessel, at flow rates at and below licensed power levels. The magnitudes of the in-plant pressure spectra were scaled to

Vermont Yankee current licensed thermal power (CLTP) levels and EPU conditions, based on average main steam line velocity. Also, scalar location multipliers were used to define the critical surface loading from the in-plant measurements.

The licensee has not justified the scaling of the in-plant pressure spectra based on average main steam line flow velocity. For example, a comparison of the CFD results for Vermont Yankee and Quad Cities at original licensed power levels indicates that the average main steam line flow velocities are significantly larger at Quad Cities than at Vermont Yankee. However, the flow velocities over the top of the dryer hoods in both plants are similar with the magnitude of the velocities diverging as the flow approaches the exit nozzles. Therefore, the geometric scaling factor used to size the reactor internals and the main steam lines can be different.

During the audit, the licensee was unable to provide a CFD model of the modified steam dryer at Vermont Yankee. As noted in Appendix G to this report, the licensee agreed to provide an updated CFD model of the Vermont Yankee steam dryer with Reynolds numbers specified at significant locations as a follow-up item to this audit.

The use of scalar location multipliers to determine the load definition presumes that the pressures at the in-plant locations and on the critical surfaces are strongly correlated, or fully coherent in the frequency domain, for all excitation sources. Thus, the frequency of an FIV source and its energy not prominent in the in-plant measurements will not be included in the load definition. For instance, because of the location of the in-plant transducers, frequency content due to vortex shedding or flow turbulence close to the steam exit nozzles will not be prominently represented in the in-plant measurements or the load definition. As noted in Appendix G to this report, the licensee agreed to provide the scale model pressure spectra used in determining the location multipliers as a follow-up item to this audit.

In addition to not using pressure time histories from the scale model tests, the licensee has not evaluated the correlation between pressure measurements at different locations. Correlations or coherence analysis could have identified the relation between the frequency content and phasing of the critical-surface loading and the measurements at the in-plant locations. Instead, the licensee compared pressure spectra from the in-plant measurements and judged them to have similar frequency content, with some exceptions. Where obvious frequency content was missing, the licensee broadened the acceleration spectra calculated using the load definition in an attempt to account for the effects of the missing excitation energy.

Even if the use of location multipliers is accepted for determination of the load definition, their ability to provide upper bounds on the pressure loads is questionable, because their determination was not based on a validated scale model. The scale model pressures at the in-plant locations and on the faces of the dryer do not include all main steam line acoustic effects, because simulation of the main steam line in the scale model was incomplete. The distortion of the Reynolds number in the scale model distortion might also affect the multipliers, because the boundary layer flow regimes that control vortex shedding and turbulence might not be correctly simulated at the very small scale.

During the audit, the staff learned that the licensee's structural evaluation did not include dynamic effects of acoustic loads in the stress calculation for the steam dryer at the normal and upset operating conditions as well as the faulted condition due to the main steam line break. As noted as a follow-up action in Appendix G to this report, the licensee plans to assess the acoustic load under faulted conditions for Vermont Yankee EPU request, and to consider any applicable generic issues. Also as noted in Appendix G, the licensee plans to assess the fluctuating load for normal and upset plant conditions provided in the response to staff question EMEB-B-1 in its submittal dated July 2, 2004.

4. Extrapolation of the Load Definition to EPU Conditions

In collecting data to establish a load definition, in-plant pressures at the three reference BWR plants were not measured on the dryer faces or in the dryer plenum. Also, the absolute pressure time histories obtained in scale-model testing were not used to benchmark the pressure extrapolations. As a result, the pressures on the faces of the steam dryer extrapolated from CLTP to EPU conditions for Vermont Yankee have not been validated.

Implicit in the extrapolation method employed by the licensee to define the loads at EPU conditions is the assumption that the flow regime does not change and no new FIV excitation sources will occur above 100% CLTP. The licensee attempted to determine the rates at which the magnitudes of the peaks in the spectra of the in-plant pressure measurements increased with average main steam line flow velocity over the range of 80% to 100% CLTP. These rates were used to extrapolate pressures to EPU conditions. In light of the large variations, the licensee determined the rates by averaging over broad frequency ranges (~50 to 100 Hz). Rates significantly higher than expected were found in the higher frequency range (above 120 Hz), where most of the modified dryer natural frequencies occur. These higher rates can be an indicator of the transition to different flow regimes or the occurrence of new FIV excitation mechanisms.

The licensee had not evaluated potential fluid-elastic instabilities based on the assumption that displacements in the steam dryer structure will be small. However, fluid-elastic instabilities will be more likely to occur at EPU conditions. The licensee's extrapolation method does not resolve this uncertainty in the predicted results.

The licensee assumes that the acoustic peaks in the measured data are stable and that no new peaks will form and overtake the existing peaks when scaling the measured data to EPU conditions. The staff's review of the spectra revealed that most of the peak frequencies were similar to those used in the load definition and some were not in the definition. For example, data from one of the three reference plants above 100 Hz were not used, because the licensee did not have confidence in the higher frequency response of the transducer. In other spectra, peaks appeared at intermediate flow rates (above 50% CLTP conditions) and higher frequencies (above 100 Hz), but it is not apparent that all would disappear as flow rates were further increased.

The geometric scale factor used to size reactor internals and the main steam lines might be different for reactors with different CLTP levels. It is likely that the flow velocities over the top of the steam dryers in the different plants at CLTP will be similar, but might be different as the flow approaches the nozzle exits. This was revealed for Vermont Yankee and Quad Cities, but is not discussed for other reactors. The flow velocity gradients along the vertical face of the hood are significantly larger in the Quad Cities steam dryer. The licensee's analysis does not justify that extrapolation of the in-plant data should be based on average main steam line velocity instead the maximum velocity or velocities at specific dryer locations.

In summary, without experimental data or analytical/numerical results of fluid excitation forces at EPU conditions, extrapolation of fluid excitation forces from other plants to Vermont Yankee makes the prediction of stresses due to FIV speculative. For example, the licensee's assumption that the rate of increase of fluid excitation sources does not change at the EPU conditions is not confirmed by the available data on fluid pressure. Further, the licensee's assumption that the flow field and its effects on the dryer response to fluid excitation are in the same flow domain as those under CLTP conditions does not address the consideration that, in some cases, dynamic fluid/structure interactions can change drastically.

5. Dynamic Response Spectrum Methodology

The licensee's Dynamic Response Spectrum Methodology considers four different pressure time histories: three measured on the skirt and one measured on the cover plate of the steam dryers at three different BWR plants (two foreign and one domestic). In the methodology, each of the time histories is transformed to a pressure spectrum, which is then scaled to Vermont Yankee operating conditions and Vermont Yankee steam dryer locations. Subsequently, a synthetic time history is generated from the scaled pressure spectrum that has the new amplitudes but retains the original frequencies and phases. The scaling of the pressure spectrum is based on the Vermont Yankee main steam line velocity and the multipliers derived from scale-model testing.

Using the synthetic pressure time history and assuming [ ] for all vibration modes, the licensee generates a response spectrum for acceleration. (The response spectrum does not contain the phasing information that is present in the synthetic pressure time history.) The licensee then [ ] to account for the few frequencies that may be present at Vermont Yankee but were absent at the other three reference plants. The licensee follows this process for each of the four measured pressure time histories and develops the corresponding broadened response spectra. Then, the licensee envelops these response spectra and further broadens the enveloping spectrum.

Finally, the licensee uses the broadened, enveloped response spectrum and the ANSYS computer program to model the Vermont Yankee steam dryer and calculate the stresses in the steam dryer structural elements. The licensee applies the square-root-sum-of-the-square (SRSS) approach to combine the stress responses from each mode. The maximum calculated oscillating stress for the unmodified dryer at CLTP conditions is determined to be [ ] per square inch (ksi) at the weld on the outer hood cover plate. The licensee assumes that, because the Vermont Yankee steam dryer has not experienced any high-cycle fatigue cracking, the maximum oscillating stress should be less than 27.2 ksi. Therefore, the licensee divides the maximum stress by 27.2 ksi and obtains a scaling factor of 29. The licensee applies this same scaling factor to the calculated oscillating stresses at all locations for both the unmodified and modified Vermont Yankee steam dryer at both CLTP and EPU conditions.

The staff considers the calculated oscillating stresses to be unrealistically high, even for a method intended to bound the structural response of the Vermont Yankee steam dryer. In addition, the details of the scale model testing, scaling of the in-plant measurements, and the assumptions of modal damping are lost due to the broadening of the response spectrum. Further, the licensee broadened the response spectrum twice to account for the uncertainties in the fluid pressure and structural model. Nevertheless, certain response frequencies might be present at Vermont Yankee but not revealed at the plants where data were collected. The broadening of the response spectrum indirectly excited many additional vibration modes of the Vermont Yankee steam dryer and resulted in the unrealistically high stresses. Also, the broadening of the response spectrum and the use of a scaling factor of 29 are likely to mask deficiencies in defining the pressure loading on the Vermont Yankee steam dryer. In addition, many modes of the steam dryer are closely spaced and, therefore, the use of an SRSS methodology to account for the phasing of these mode shapes is questionable. As a result, the staff considers the Dynamic Response Spectrum Methodology used for fatigue evaluation of the Vermont Yankee steam dryer to not be realistic.

6. Conservatism of the Response Calculation Methodology

The licensee's use of a scaling factor of 29 at the maximum stress location for the Vermont Yankee steam dryer in its unmodified configuration subject to CLTP conditions might be technically justified based on the absence of high-cycle fatigue cracking at that location. However, the use of the same scaling factor for all other locations on the unmodified and modified Vermont Yankee steam dryer under both CLTP and EPU conditions has not been justified. Scaling factors for locations other than the maximum stress location could be smaller in light of the absence of fatigue cracking at those locations. Therefore, the Dynamic Response Spectrum Methodology used for the fatigue evaluation of the Vermont Yankee steam dryer might not be conservative.

The stress results for the modified dryer subject to CLTP conditions indicate that the oscillating stress at the outer hood cover plate location (maximum stress location in the unmodified dryer) has decreased because the thickness of the cover plate was increased from 0.25 inches to 0.625 inches. However, the oscillating stresses have increased at some other locations in the modified dryer where the original plate thickness was not changed. In the modified dryer, the outer hood vertical plates and cover plates are fully or partially replaced with thicker plates, but the thickness of the inner hood and side hood plates are not changed. It is possible that the use of smaller scaling factors would have raised these stresses above the high-cycle fatigue failure criteria of 13.6 ksi. Therefore, the modified dryer design might have moved the susceptible fatigue failure location from the outer hood to the inner hood of the Vermont Yankee steam dryer and possibly the side plates.

During the audit, the staff identified errors in the stresses reported in the licensee's submittal dated July 2, 2004, on the analysis of its steam dryer. The licensee will provide a corrected submittal as a follow-up action from this audit.

7. Inspection of Underwater Welds

The staff discussed the quality of the underwater welds performed on the modified steam dryer. For welding at a depth of less than 10 meters, the licensee reported that the welds have the same quality (i.e., porosity) as those made in the shop. Since the underwater welding for the modified Vermont Yankee steam dryer was performed at a depth less than 10 meters, the quality of these welds is likely to be acceptable. The staff suggested that the licensee consider volumetric inspection of a sample of the underwater welds to verify that large porosity is not present. Further, the use of ASME Section XI visual inspection (VT-1) might be inadequate for detecting intergranular stress corrosion cracking (IGSCC) or fatigue cracks in the steam dryer. The staff also suggested that the licensee consider enhanced visual inspection (EVT-1) for the steam dryer similar to the BWR Owners' Group recommendation for the safety-related BWR vessel internals.

D. Findings

Based on the above evaluation, the NRC staff has reached the following principal findings regarding the adequacy of the licensee's analysis, as currently presented, in supporting the structural integrity of the Vermont Yankee steam dryer under EPU conditions:

1. The excitation source for flow-induced vibration effects and, thus, the actual applied forcing function on the Vermont Yankee steam dryer has not been adequately determined; thereby, leaving unanswered the question of whether the Vermont Yankee steam dryer is susceptible to the same FIV mechanisms responsible for the recent steam dryer failures at other BWR plants operating at EPU conditions.

2. The load definition on the Vermont Yankee steam dryer is incomplete. For example, the licensee's analysis does not resolve the uncertainties in the load definition that attempts to bound the complex nature of the fluid excitation forces acting on the dryer at EPU conditions. Also, the ability to construct a dynamic response spectrum to bound the dryer response is questionable because its frequency content and magnitude are extrapolated from the response using in-plant pressure measurements from other reactors in stagnant regions of flow located significantly away from the critical dryer hood surfaces. Also, the extrapolation relies, in part, on the small-scale model testing, where the effects of significant Reynolds number distortion are unknown.

3. The Dynamic Response Spectrum Methodology used for fatigue evaluation of unmodified and modified Vermont Yankee steam dryers has not been demonstrated to be realistic. The maximum calculated stress (789 ksi) for the unmodified steam dryer at CLTP conditions is unrealistically high and reflects the uncertainty in simplifying the complex nature of loads experienced at EPU conditions.

4. The Dynamic Response Spectrum Methodology might not be conservative. For example, the same scaling factor determined at the maximum stress location for the unmodified dryer at CLTP is used to scale (reduce) the stress at other locations for both the modified and unmodified dryer at CLTP and EPU conditions. This approach to predict stresses at various locations has not been justified. Further, in the modified dryer, the outer hood vertical plates and cover plates are fully or partially replaced with thicker plates, but the thickness of the inner hood and side hood plates are not changed. The analysis results show that the stresses at the outer hood locations in the modified dryer will be reduced, but the stresses at some inner hood locations will increase. It is possible that the use of smaller scaling factors would have raised these stresses above the high-cycle fatigue failure criterion of 13.6 ksi. Therefore, the modified dryer design might have moved the susceptible fatigue failure location from the outer hood to the inner hood of the Vermont Yankee steam dryer and possibly the side plates.

5. Some of the in-plant measured pressure data from three other BWR plants used as input to the structural analysis for the Vermont Yankee steam dryer was collected at dryer skirt locations. The pressure fluctuations at the dryer skirt are modified using location multipliers based on the scale model test data in an attempt to generate data

that can be applied to the upper dryer components. The scale model tests did not account for the complete steam line geometry and Reynolds number. For example, the scale model did not account for the high pressure coolant injection (HPCI) steam line, the reactor core isolation cooling (RCIC) steam line, main steam isolation valves (MSIVs), turbine stop valves, and electrohydraulic controls (EHC), which are considered potential acoustic loading sources. Also, there was no attempt to show that the dryer skirt and hood pressures were correlated. Therefore, the validity of the scale model test data in establishing the location multipliers has not been justified.

6. The pressure on the faces of the dryer extrapolated from CLTP to EPU has not been validated. No information on pressures above CLTP is available. To define the loads at EPU, the assumption is made that the flow regime does not change and that no new FIV excitation sources will occur above 100% CLTP.

7. The formulation used to define the Vermont Yankee plant-specific load is assumed to be dependent on the average steam line velocity. However, the formulation has not been benchmarked against test data.

8. The Vermont Yankee steam dryer analysis used the SRSS method to combine structural responses determined for various modes of each dryer component. However, the SRSS method used to calculate resultant stresses might be non-conservative because the dryer model contains many closely-spaced modes.

9. The licensee's structural evaluation did not include dynamic effects of acoustic loads in the stress calculation for the steam dryer at the normal and upset operating conditions as well as the faulted condition due to the main steam line break.

10. The inspection plan for the modified steam dryer does not include inspections to verify the quality of the underwater welds, which could contain large porosity. Further, the use of ASME Code, Section XI visual inspection method (VT-1) might be inadequate for detecting any IGSCC or fatigue cracks in the steam dryer.

V. CONCLUSION

Based on review of the information provided by the licensee in its submittals, during public meetings, and as part of the audit at GE Nuclear Energy, the NRC staff concludes that the licensee's analysis of record does not demonstrate that the steam dryer at the Vermont Yankee nuclear power plant will remain capable of maintaining its structural integrity under EPU conditions. For example, the licensee's analysis of the Vermont Yankee steam dryer as currently submitted in support of its EPU request (1) has not adequately identified and verified the excitation sources for flow-induced vibration mechanisms that resulted in significant degradation of similar steam dryers at other BWR nuclear power plants operating at EPU conditions; (2) has not provided a complete load definition for the Vermont Yankee steam dryer for EPU conditions in light of several assumptions that have not been adequately justified; (3) has not justified the applied methodology as realistic in light of assumptions to account for uncertainties that resulted in apparent significant overestimation of predicted steam dryer stresses; (4) might be non-conservative based on assumptions for reducing the stress experienced by steam dryer parts and the creation of new potential fatigue failure locations as a result of modifications to the Vermont Yankee steam dryer; and (5) has not validated the extrapolation of pressure peaks from original power levels to EPU conditions for the steam dryer at Vermont Yankee. The licensee may submit a revised analysis of the steam dryer in support of its request to operate Vermont Yankee at EPU conditions.

APPENDIX A

AUDIT PARTICIPANTS

Thomas G. Scarbrough, Audit Lead
Senior Mechanical Engineer
NRC/NRR/DE/EMEB

Cheng-Ih (John) Wu
Mechanical Engineer
NRC/NRR/DE/EMEB

Shah N.M. Malik
Senior Materials Engineer
NRC/RES/DET/MEB

Dr. Vikram N. Shah
Mechanical Engineer
Argonne National Laboratory (ANL)

Dr. Thomas M. Mulcahy
Senior Mechanical Engineer
ANL consultant

Dr. Shoei-Sheng Chen
Senior Mechanical Engineer
ANL consultant

Eugene Imbro
Branch Chief
NRC/NRR/DE/EMEB
(August 25-26)

APPENDIX B

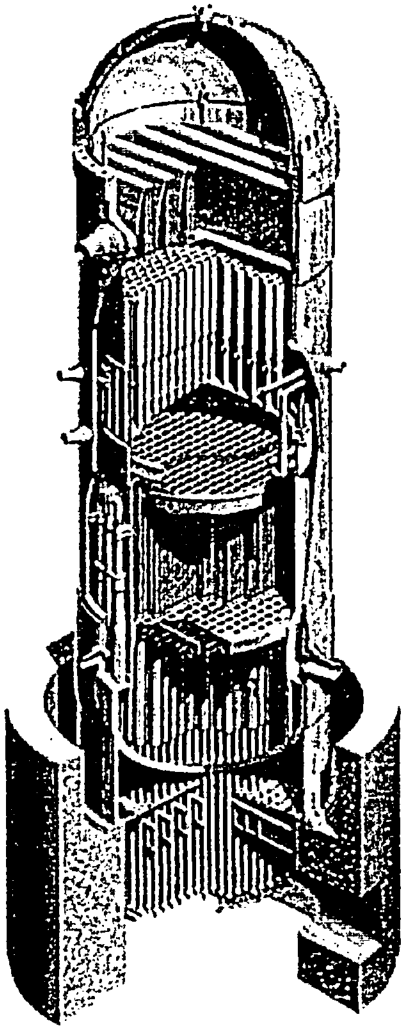
INDUSTRY PERSONNEL

NAME	TITLE	ORGANIZATION
Jim Callaghan	Design Engineering Manager	Entergy - Vermont Yankee
Tom Cizauskas	EPU Engineer	Entergy - Vermont Yankee
John Dreyfuss	Director, Engineering	Entergy - Vermont Yankee
Scott Goodwin	Engineering Supervisor	Entergy - Vermont Yankee
Brian Hobbs	EPU Supervisor	Entergy - Vermont Yankee
Donald Johnson	EPU Engineer	Entergy - Vermont Yankee
Craig J. Nichols	EPU Project Manager	Entergy - Vermont Yankee
Pedro Perez	Senior Engineer	Entergy - Vermont Yankee
Michael J. Dick	VY EPU Project Manager	GE Nuclear
Tom Green	BWROG Project Manager	GE Nuclear
Henry Hwang	Principal Engineer	GE Nuclear
Jim Klapproth	Manager, Engineering and Technology	GE Nuclear
Dave Lunger	NSM	GE Nuclear
Har Mehta	Engineering Fellow	GE Nuclear
Dan Pappone	Engineering Fellow	GE Nuclear
George Paptzun	AES Delivery Manager and Process Leader	GE Nuclear
Alex Pinkser	Principal Engineer	GE Nuclear
Elijio Prado	Mechanical Engineer	GE Nuclear
Louis Quintana	Manager, Licensing	GE Nuclear
Dave Sandusky	Materials Application Fellow	GE Nuclear
Dan Sommerville	Engineer	GE Nuclear
George Stramback	Manager, Regulatory Services	GE Nuclear
P.T. Tran	Project Manager	GE Nuclear
Richard Wu	Principal Engineer	GE Nuclear
Guy DeBoo	Senior Staff Engineer	Exelon Nuclear
Marcos Herrera	Senior Consultant	Structural Integrity Associates

APPENDIX C

STEAM DRYER FLOW INDUCED VIBRATION STRUCTURAL ANALYSIS TECHNIQUES

Steam Dryer
Flow Induced Vibration
Structural Analysis Techniques



Richard Wu
August 24, 2004

[[

(3)]]

"Equivalent Static Method of Structural Analysis"

(November 2003)

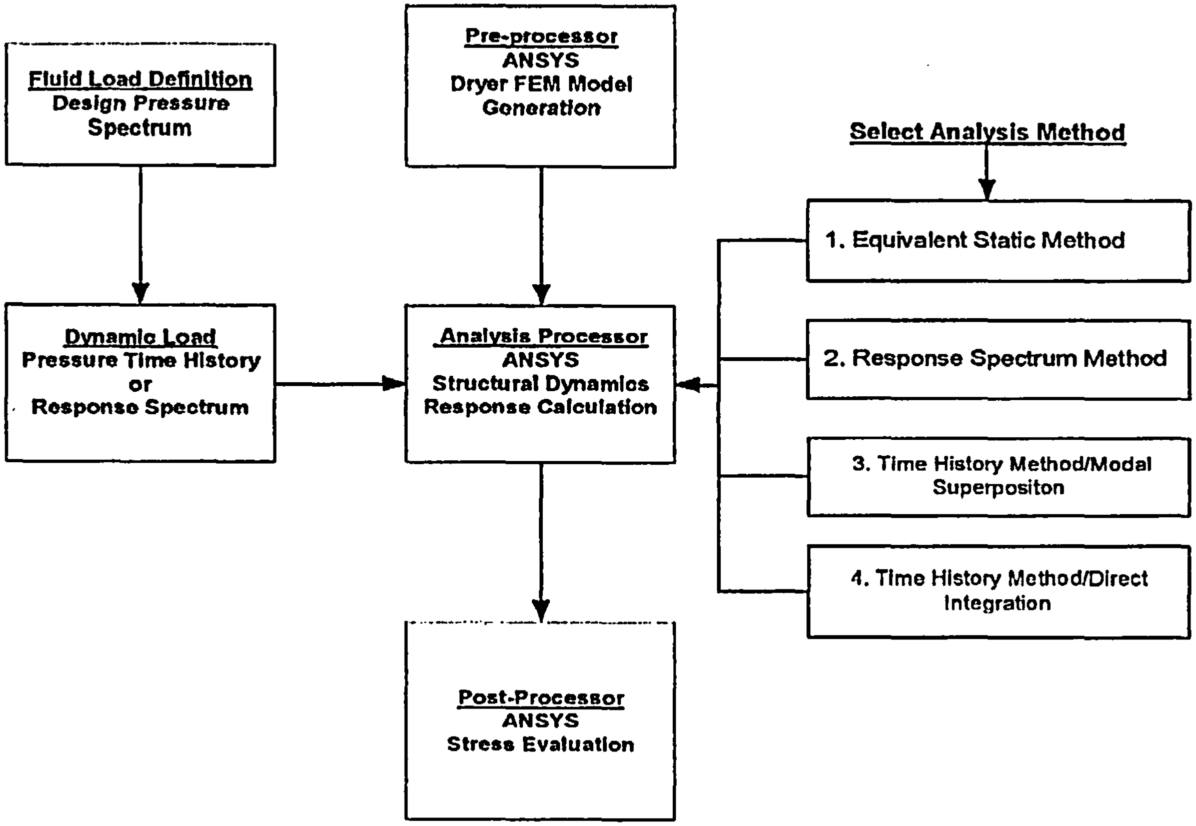
[[

[3]]]

“Response Spectrum Method of Structural Analysis”

(February 2004)

Steam Dryer Structural Dynamic Analysis Procedure



Fluid Load Definition
Design Pressure
Spectrum

Pre-processor
ANSYS
Dryer FEM Model
Generation

Select Analysis Method

1. Equivalent Static Method
2. Response Spectrum Method
3. Time History Method/Modal Superpositon
4. Time History Method/Direct Integration

Dynamic Load
Pressure Time History
or
Response Spectrum

Analysis Processor
ANSYS
Structural Dynamics
Response Calculation

Post-Processor
ANSYS
Stress Evaluation

[[

(3)]]

Equivalent Static Method

1. Start with the FEA model of the Original Dryer.

2. Compute dryer component (a) natural frequencies and (b) stresses from a reference 1-psi (unit) static pressure loading.

3. The Dynamic Stresses (DS) on the steam dryer components are computed as:

   DS = (Pm+Pb) x (FIV Load rms) x (P) x (SF) x (C) x (Q)

   where:

   DS = Intensified Dynamic Stress (psi)

   Pm+Pb = Surface stress (unintensified).

   FIV Load rms = pre-EPU Pressure load as a function of component frequency (root-mean-squared, rms, magnitude).

   P = Conversion factor from rms magnitude to Peak magnitude of the fluctuating pressure load.

Equivalent Static Method (continued)

C = Weld Stress Concentration Factor.

Q = Weld Quality Factor

SF = Scaling Factor (to account for the dynamics amplification and the load scaling)

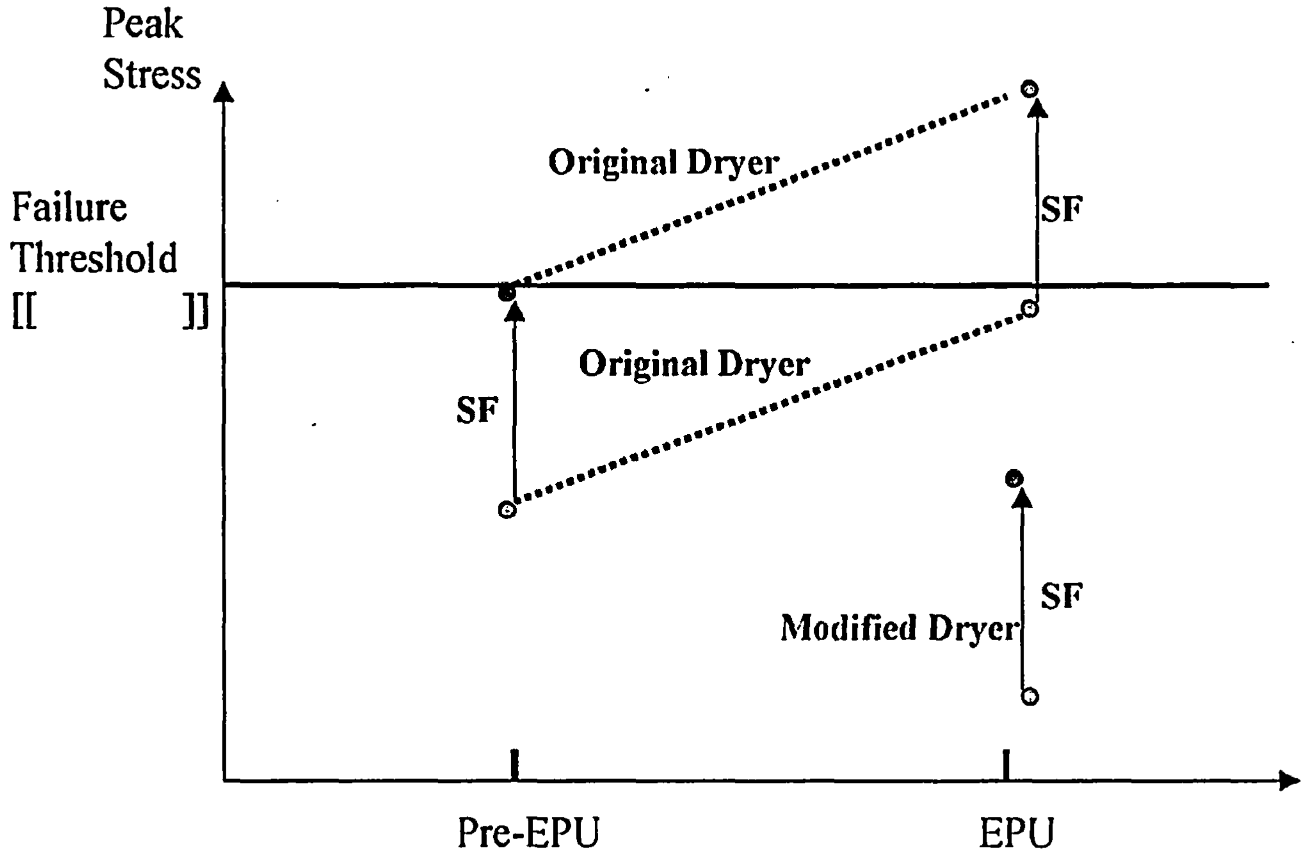
$$SF = \frac{[[\qquad]]}{(Pm + Pb)(FIVLoadrms)(P)(C)(Q)}$$

(No component of the Original dryer has failed at pre-EPU condition)

4. Repeat Step 1 to 3 with the Modified Dryer and EPU condition using the same SF as computed from Step 3.

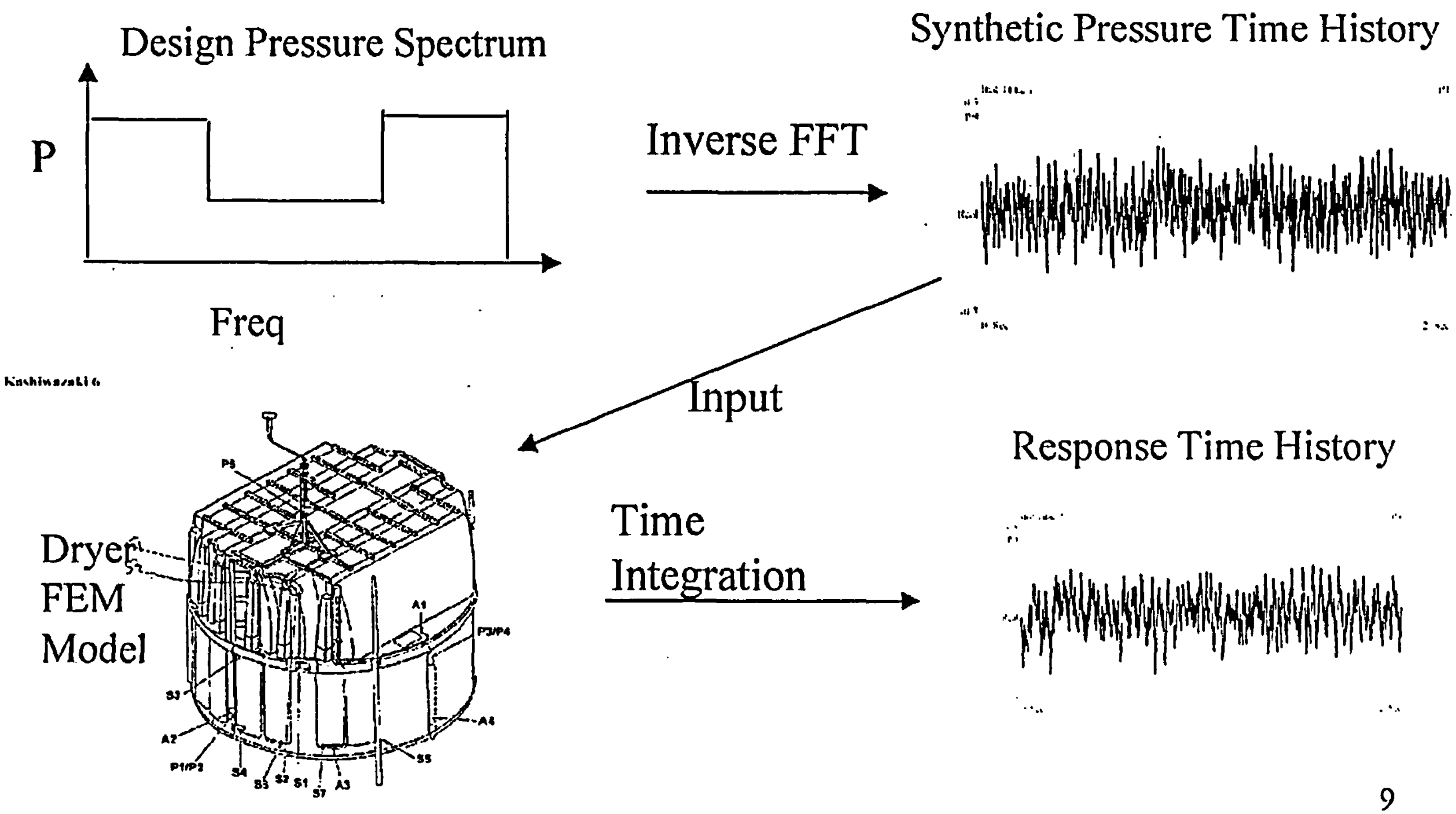
Scaling Factor

(Equivalent Static Method)



Dryer Structural Dynamic Response Calculation

Time History Method



Design Pressure Spectrum

P

Freq

Inverse FFT

Synthetic Pressure Time History

Input

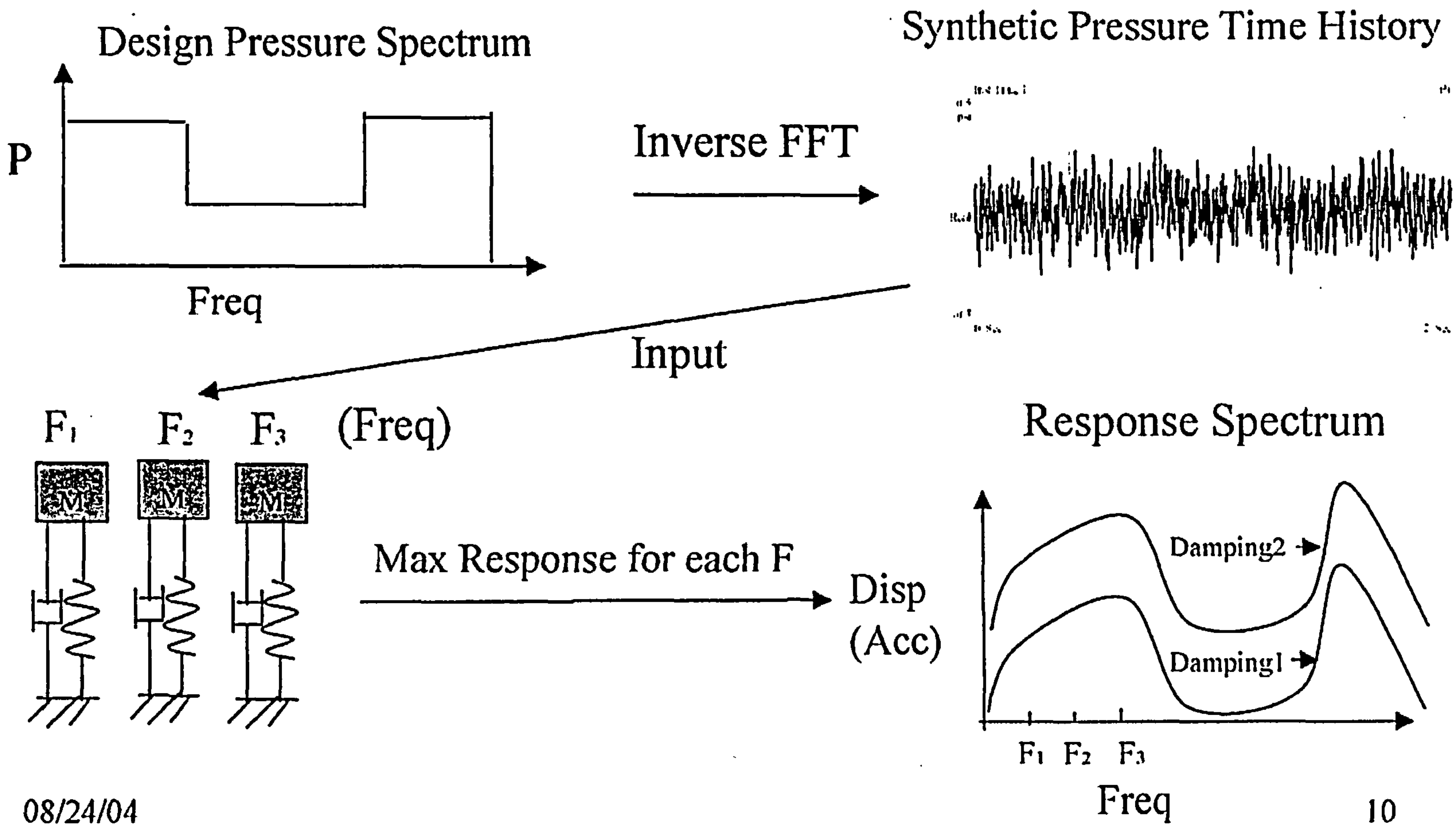
Dryer FEM Model

Time Integration

Response Time History

Dryer Structural Dynamic Response Calculation

Response Spectrum Method



Design Pressure Spectrum

Inverse FFT

Synthetic Pressure Time History

Input

Max Response for each F

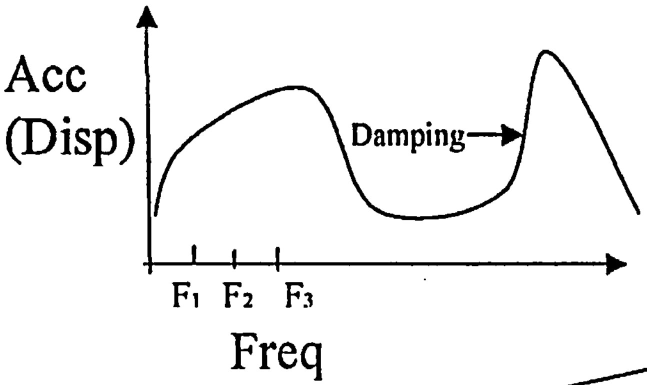
Disp (Acc)

Response Spectrum

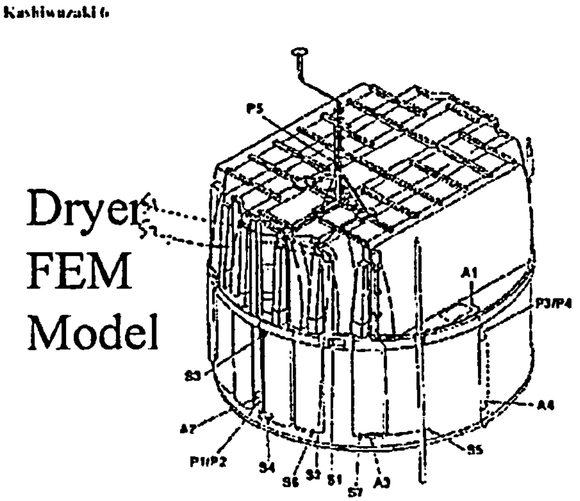
Dryer Structural Dynamic Response Calculation

Response Spectrum Method (Concluded)

Response Spectrum



Input →



Dryer
FEM
Model

$F_1, F_2, F_3, F_4,$ ---- F_n

Maximum Response for Each Dryer Vibration Mode:

Stress)mode 1

Stress)mode 2

--

--

Stress)mode n

SRSS or
ABS →

Final Maximum
(peak) Stress

SPECA05V (GENE Level 2 Code)
Acceleration Response Spectrum Generation

Single Degree of Freedom System

Seismic Excitation

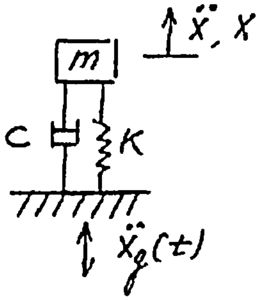
$$m\ddot{x} + c\dot{x} + kx = -m\ddot{x}_g(t)$$

$$\ddot{x} + \frac{c}{m}\dot{x} + \frac{k}{m}x = -\ddot{x}_g(t)$$

$$\boxed{\ddot{x} + 2\xi\omega\dot{x} + \omega^2 x = -\ddot{x}_g(t)}$$

$\ddot{x}_g$ – Ground Motion Time History

$\left\{ \begin{array}{ll} \ddot{x}_g & \text{– Input} \\ \ddot{x} & \text{– output} \end{array} \right.$



Forcing Excitation

$$m\ddot{x} + c\dot{x} + Kx = F(t) = A\,p(t)$$

$$\ddot{x} + \frac{c}{m}\dot{x} + \frac{K}{m}x = \frac{A}{m}\,p(t)$$

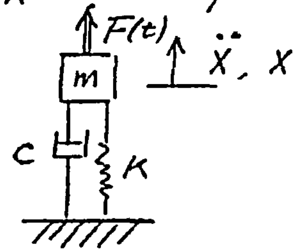
$$\boxed{\ddot{x} + 2\xi\omega\dot{x} + \omega^2 x = \frac{A}{m}\,p(t)}$$

A – unit Area

m – unit Mass

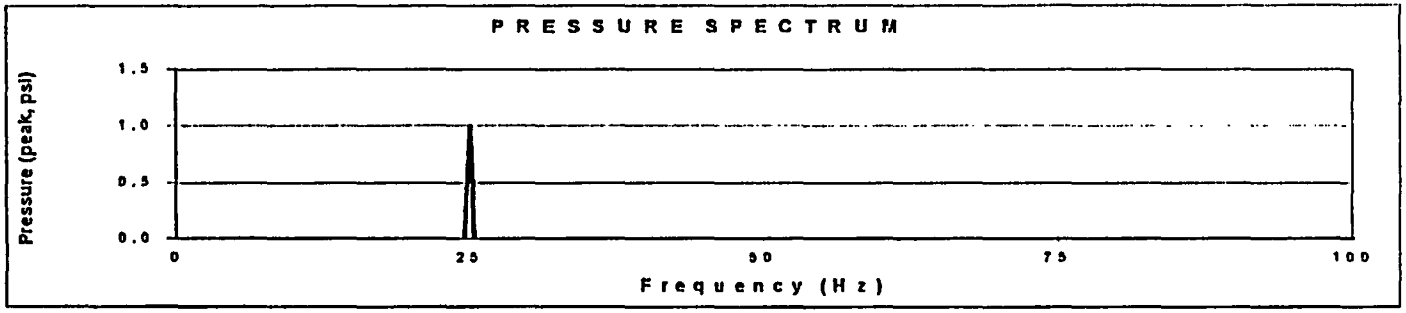
p(t) – pressure time history

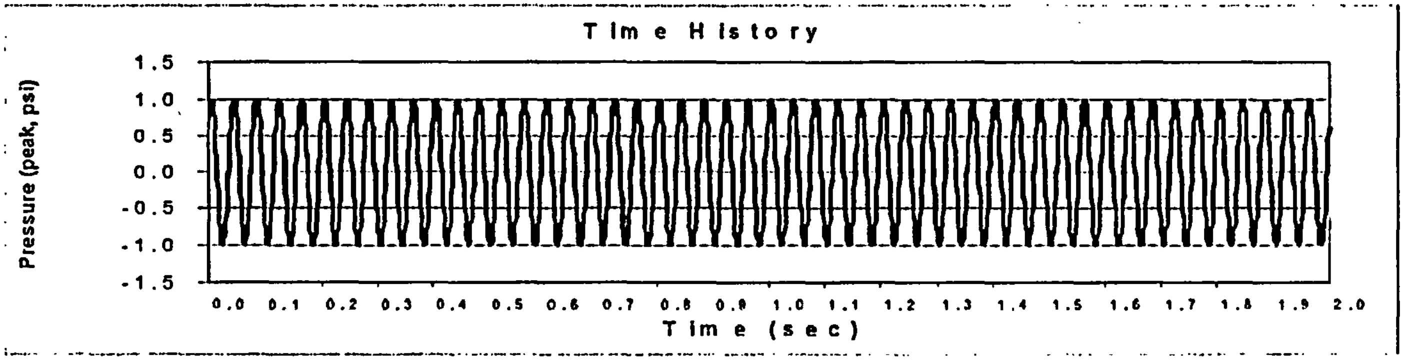
$\left\{ \begin{array}{ll} p(t) & \text{– Input} \\ \ddot{x} & \text{– output} \end{array} \right.$

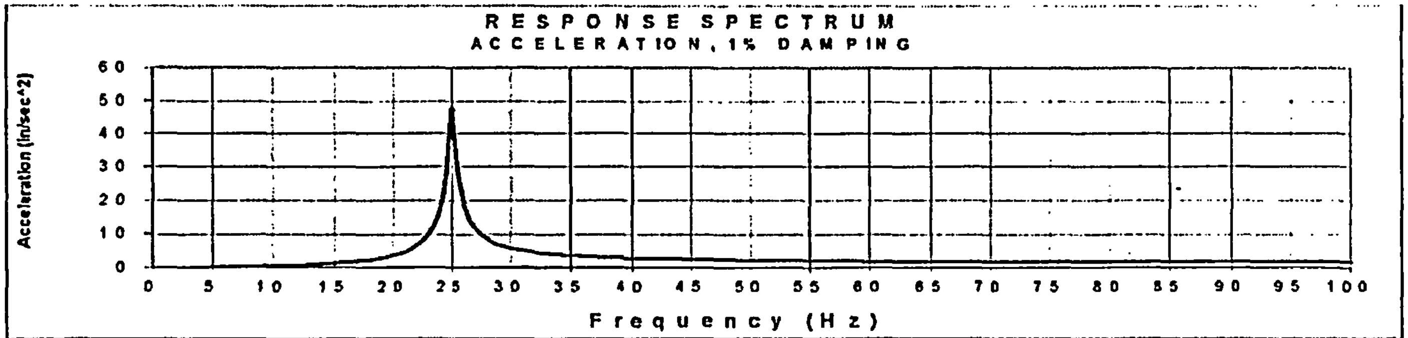


Single Sine Wave Pressure Input

(1 psi 0-peak, 25Hz)

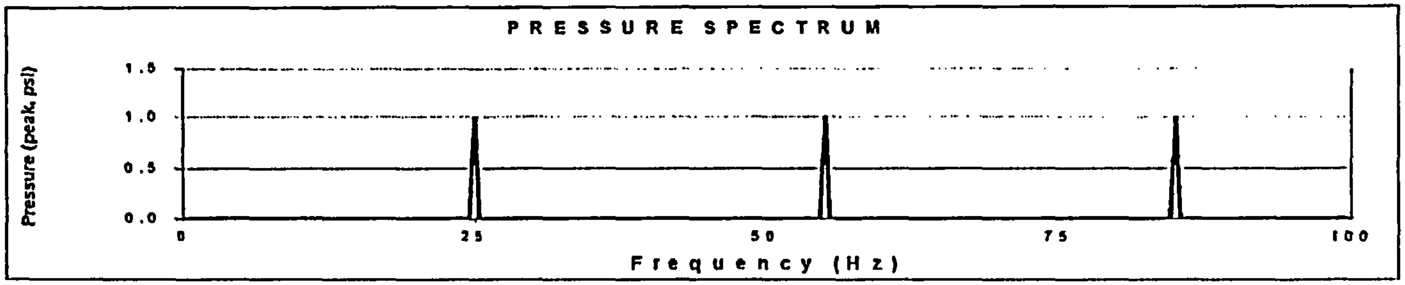


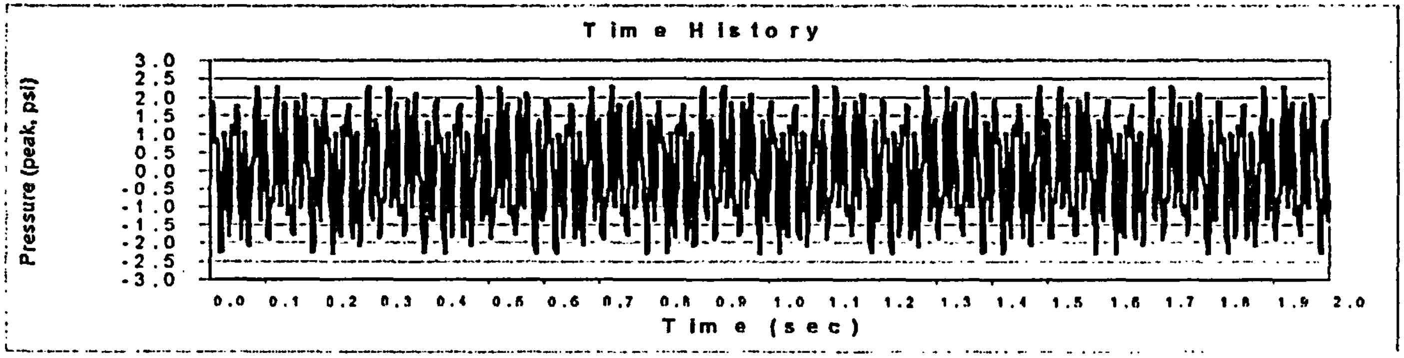


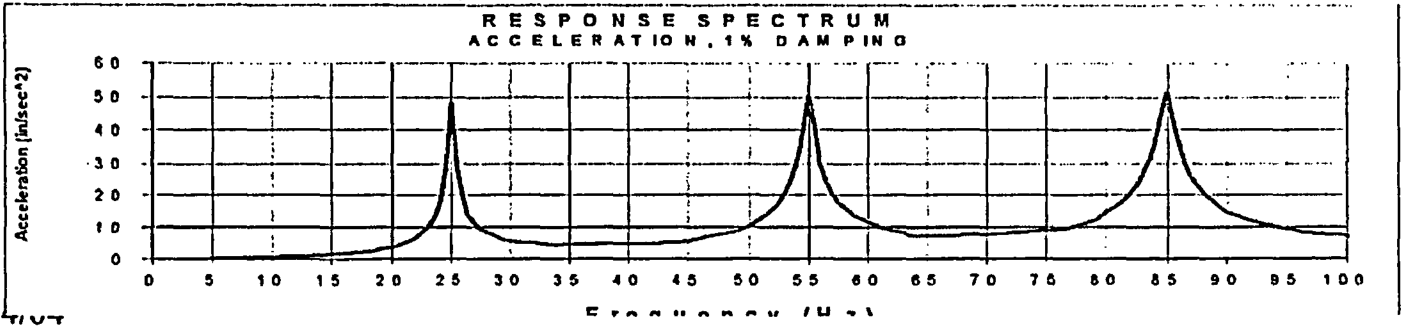


Three Sine Waves Pressure Input

(1 psi 0-peak, 25Hz, 55Hz, 85Hz)

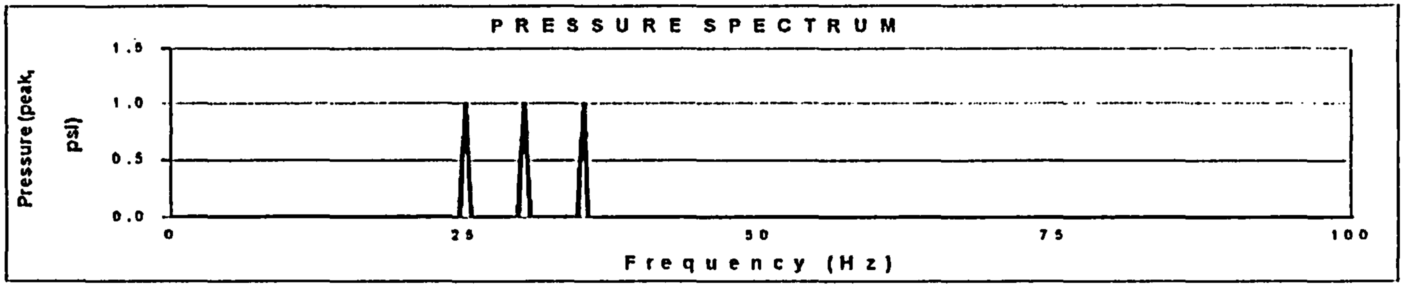


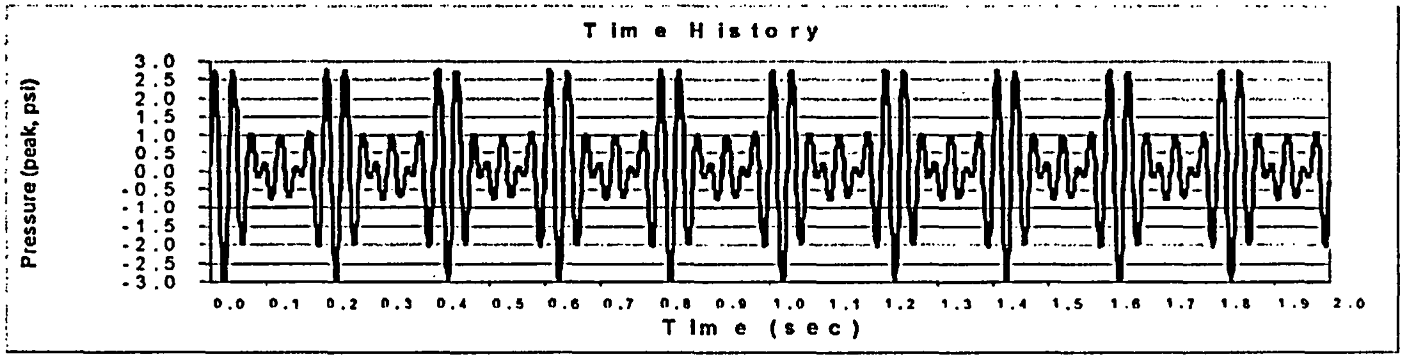


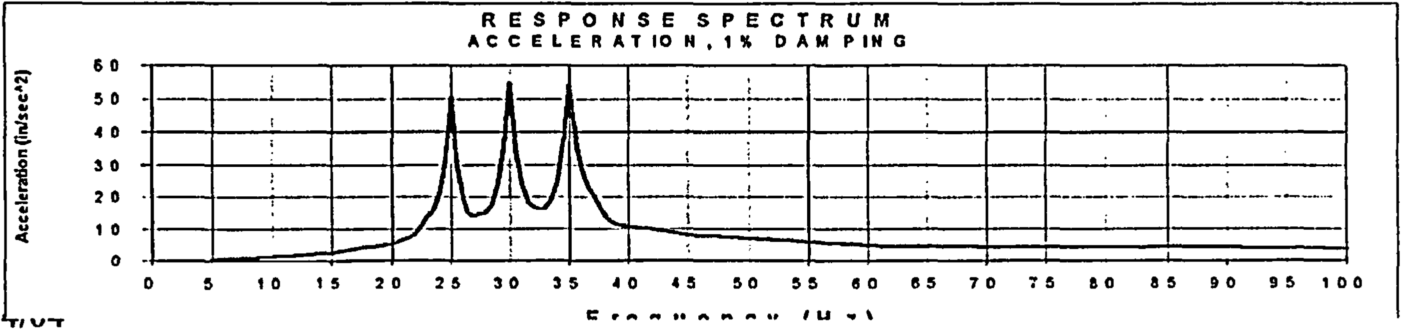


Three Sine Waves Pressure Input

(1 psi 0-peak, 25Hz, 30Hz, 35Hz)

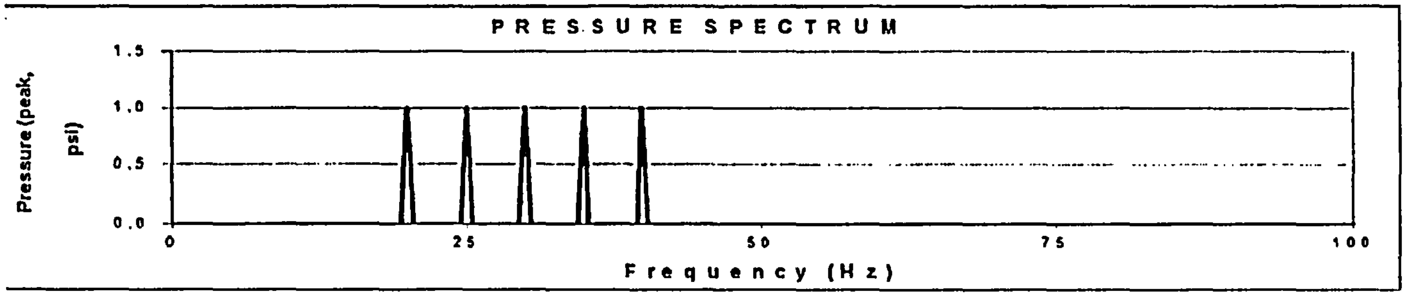


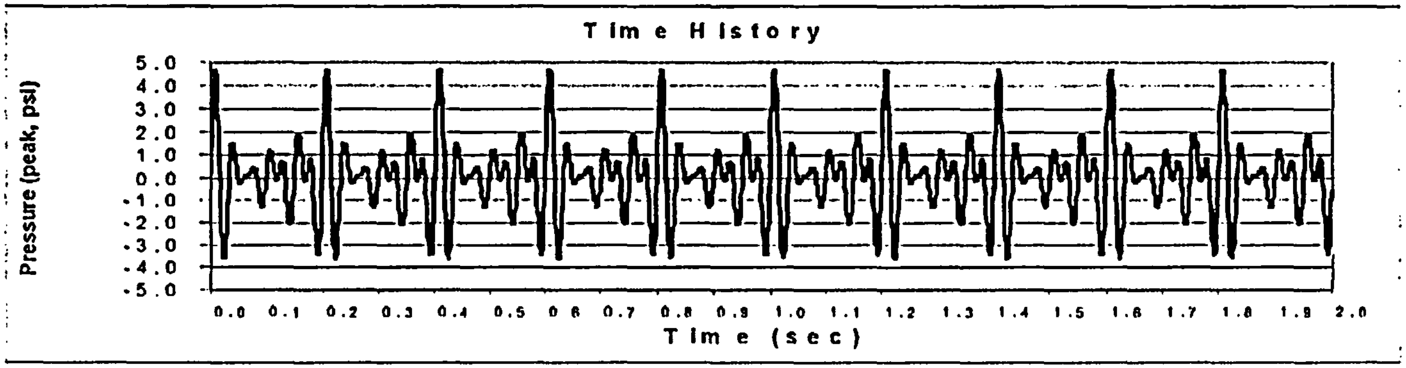


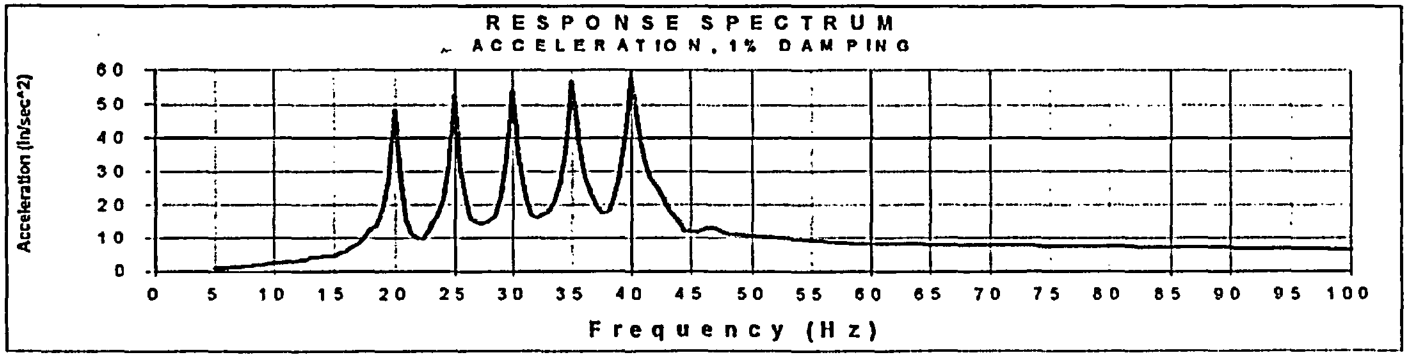


Five Sine Waves Pressure Input

(1 psi 0-peak, 20Hz, 25Hz, 30Hz, 35Hz, 40Hz)







Dynamic Response Calculation
Response Spectrum Method

Multi-Degree of Freedom System

Forcing Excitation

$$[M]\{\ddot{x}\} + [C]\{\dot{x}\} + [K]\{x\} = \{F(t)\} = \{A\,P(t)\}$$

$$\omega_i \, , \; \{\phi\}_i , \; q_i \quad , \; i = 1, \cdots N$$

$$\{x\} = \sum_{i=1}^{N} \{\phi\}_i \, q_i$$

$$\ddot{q}_i + 2\zeta_i \cdot \omega_i \cdot \dot{q}_i + \omega_i^2 \cdot q_i = \frac{\{\phi\}_i^T \cdot \{A\}\,P(t)}{\{\phi\}_i^T [M] \{\phi\}_i}$$

$$\{\phi\}_i^T [M] \{\phi\}_i = 1$$

$$q_i^{max} = \frac{\Gamma_i \cdot S_i}{\omega_i^2} \quad \text{and} \quad x_i^{max} = \{\phi\}_i \cdot q_i^{max}$$

where $\Gamma_i = \{\phi\}_i^T \{A\}$ modal participation Factor

S_i = Acceleration Response Spectral Value

$$X^{max} = SRSS\,(X_1^{max},\; X_2^{max} \cdots X_N^{max})$$

ANSYS Input Procedure

Note that the material dependent damping contribution is computed in the modal expansion phase, so that this damping contribution must be included there.

Participation Factors and Mode Coefficients

The participation factors for the given excitation direction are defined as:

$$\gamma_i = \{\phi\}_i^T[M]\{D\} \quad \text{for the base excitation option} \qquad (17.7\text{–}2)$$

$$\gamma_i = \{\phi\}_i^T\{F\} \quad \text{for the force excitation option} \qquad (17.7\text{–}3)$$

where:

γ_i = participation factor for the i^{th} mode

$\{\phi\}_i$ = eigenvector normalized using equation (17.3–6) (*Nrmkey* on the **MODOPT** command has no effect)

$\{D\}$ = vector describing the excitation direction (see equation (17.7–4))

$\{F\}$ = input force vector

ANSYS Input Procedure

$$\{r\}_i = \omega_i^m A_i \{\phi\}_i \qquad (17.7\text{–}12)$$

where: $m = \begin{cases} 0 & \text{if label} = \text{DISP} \\ 1 & \text{if label} = \text{VELO} \\ 2 & \text{if label} = \text{ACEL} \end{cases}$

label = third field on the mode combination commands (**SRSS**, **CQC**, **GRP**, **DSUM**, **NRLSUM**)

A_i = mode coefficient (see below)

The mode coefficient is computed in five different ways, depending on the type of excitation (**SVTYP** command).

2. For **SVTYP**, 1 (force excitation)

$$A_i = \frac{S_{fi}\,\gamma_i}{\omega_i^2} \qquad (17.7\text{–}14)$$

where: S_{fi} = spectral force for the i^{th} mode (obtained from the input amplitude multiplier table at frequency f_i and effective damping ratio ξ_i').

3. For **SVTYP**, 2 (acceleration excitation of base)

$$A_i = \frac{S_{ai}\,\gamma_i}{\omega_i^2} \qquad (17.7\text{–}15)$$

where: S_{ai} = spectral acceleration for the i^{th} mode (obtained from the input acceleration response spectrum at frequency f_i and effective damping ratio ξ_i').

[[

[3]]]

Vermont Yankee, CLTP Dryer Load 1

[[

{3}]]

[[

(3)]]

Vermont Yankee, CLTP Dryer Load 2

[[

{3}]]

Input Response Spectrum

1. Start with a (Single) Plant Measured Pressure Time History
2. Transform to Pressure Spectrum (Frequency, Amplitude, and Phase)
3. Scale the Pressure Spectrum Amplitude According to Plant Specific Operating Condition
4. Generate a new Pressure Time History with the new Amplitude and the Original Phase
5. Calculate a Response Spectrum based on the new Pressure Time History
6. Repeat Steps 1 through 5 with a Different Plant and/or a Different Gage Measured Pressure Time History
7. Envelope and Broaden the Response Spectra from Step 5
8. Input to ANSYS for Steam Dryer Dynamic Response Evaluation

[[

[3]]]

[[

(3)]]

[[

(3)]]

[[

(3)]]

[[

(3)]]

[[

[3]]]

[[

{3}]]

[[

(3)]]

[[

(3)]]

[[

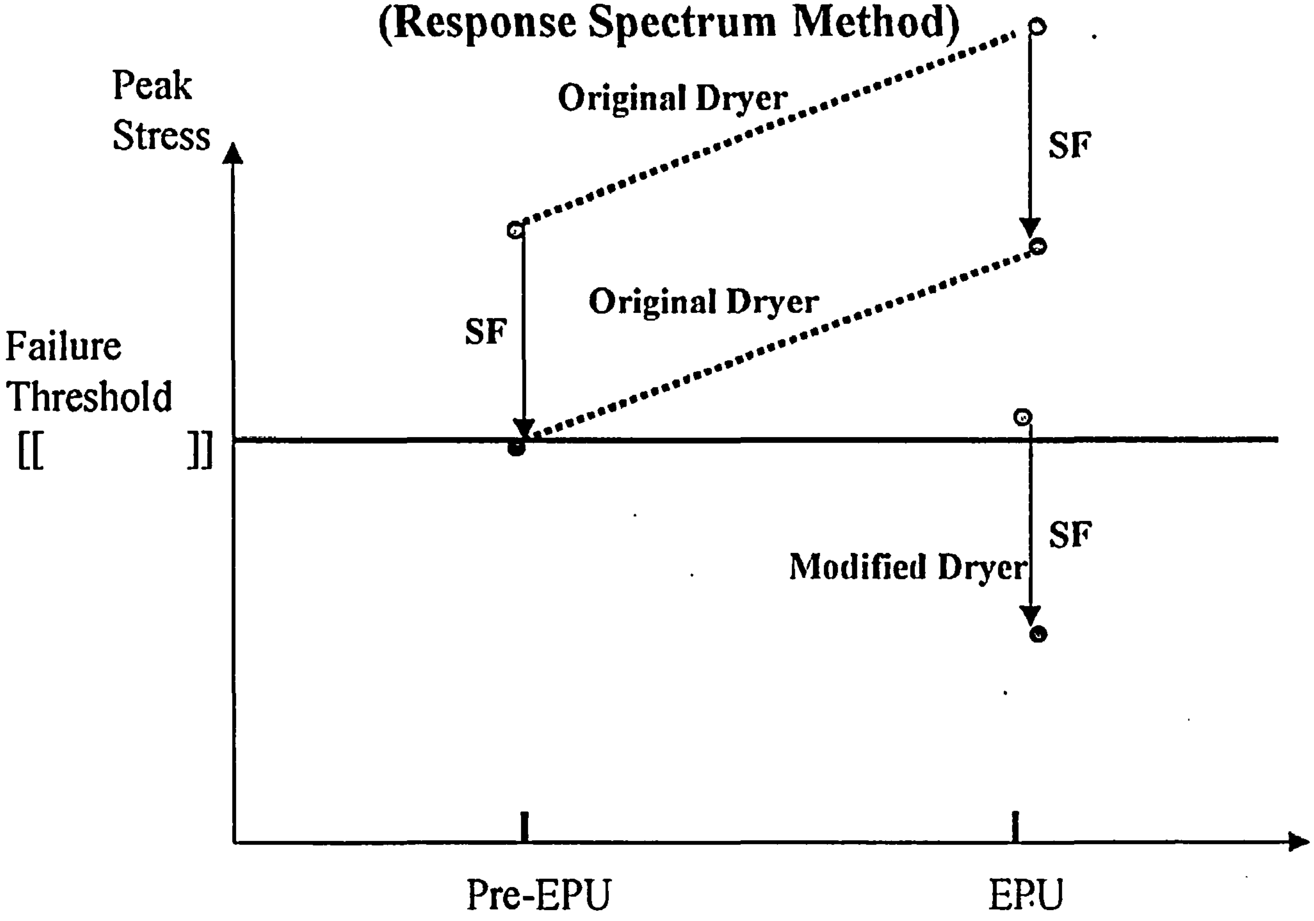
(3)]]

[[

(3)]]

Scaling Factor

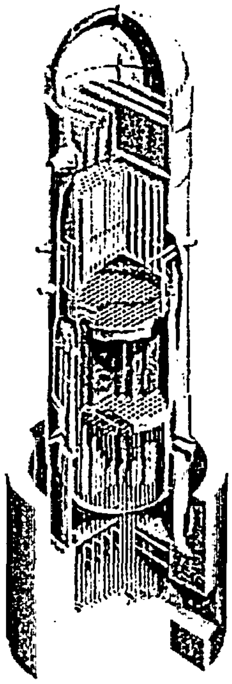
(Response Spectrum Method)



APPENDIX D

VERMONT YANKEE PLANT-SPECIFIC ANALYSIS

VY Plant Specific Analysis

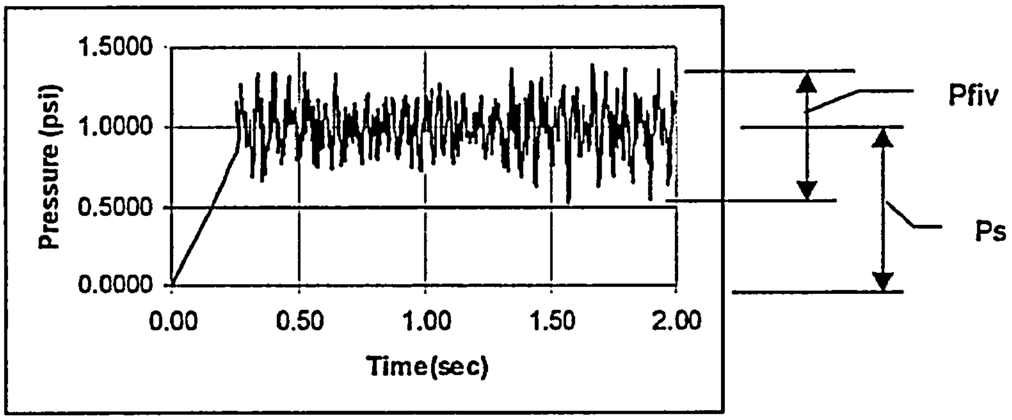


By : Henry Hwang

July 21, 2004

1.0 Dryer pressure loads

Example of dryer pressure time history is shown below:



The pressure time history can be divided to two parts, Ps and Pfiv,

Ps Static pressure on the dryer
Pfiv Fluctuation component causes **Flow Induced Vibration (FIV).**

From this morning meeting,

(1) QC steam dryer cracking was caused by high cycle fatigue.

(2) The fractures initiated at the weld toes.

(3) No dryer failures prior to QC power uprate.
VY MS LPU flow velocity is less than QC CLTP

Therefore, Pfiv is the major concern

2.0 FIV Alternating Stress by **Response spectrum analysis, peak broadened, enveloped and scaled**

The purpose of this section is to explain:

Stress distribution from response spectrum analyses (sec 2.1)
    Example plots cover plate and front hood

Conversion of maximum shell stress to S_{alt} in the welds (sec 2.2)
    Example Cover plate and front hood
        Original dryer and modified dryer

Explain Normalized factor 29 (sec 2.3)

Explain the reasons: (sec 2.4)
    Modified dryer cover plate stress reduction 17 times
    Modified dryer front hood top weld stress reduction 3 times

Toe of Fillet weld stress from 2D-isoparametric solid detail model (sec 2.5)

Stress distribution from response spectrum analyses
Example plots cover plate and front hood

(2.1.1) Example stress distribution plots forVY original dryer lower cover plate, CLTP

[[

]]

(2.1-2) VY original dryer response spectrum analysis front hood stress distribution, CLTP

[[

]]

(2.1-3) Stress distribution plots forVY modifier dryer cover plate, CLTP

[[

]]

(2.1-4) VY Modified dryer response spectrum analysis, outer hood, CLTP-

[[

]]

(2.1-5) Stress distribution plots forVY modifier dryer cover plate, LPU

[[

]]

(2.1-6) VY Modified dryer response spectrum analysis, outer hood, LPU-

[[

]]

Conversion of maximum shell stress to S_{alt} in the welds
Example Cover plate and front hood
Original dryer and modified dryer

(2.2-1) Dryer plate thicknesses
Original Dryer

	plate thickness	Weld size	Under size factor	Weld factor	Total stresss factor
Original dryer Lower Cover plate	0.25	0.187	[[		
Original dryer, front hood	0.5	0.5			]]

Modifier Dryer

	Plate Thickness	Weld size at top plate	Under size factor	Weld factor	Total stresss factor
Modified dryer, lower cover plate, tip	0.625	0.625	[[		
Modified dryer, front hood top weld	1.0	0.625			]]

(2.2-2) S_{alt} Stress calculation

[[

]]

Original dryer, CLTP (Current Licensed Thermal Power)

	Max Surface Stress (psi)	Weld Factor	plate thick	weld size	under size factor (16)	CLTP Peak Stress (1)x(5)x(6)
	(1)	(5)			(6)	(9)
Outer cover plate 1/4", 3/16" weld	[[		0.250	0.188	[[	
Outer front hood		]]	0.50	0.500		]]

Modified dryer, CLTP and LPU (Licensed Power Uprate)

	CLTP Max Surface Stress (psi)	LPU Max Surface Stress (psi)	Weld Factor	plate thick	weld size	under size factor (16)	CLTP Peak Stress (1)x(5)x(6)	Repaired LPU Peak
	(1)	(2)	(5)			(6)	(9)	(10)
Outer cover plate tips	[[			0.625	0.625	[[		
Outer hood, top weld			]]	1.00	0.625			]]

(2.3) Explain Normalized factor [[ ]]

Because the dryer has not failed at the maximum stress location for years of operation, the peak stress value is normalized to the fatigue failure criterion [[ ]] for CLTP.

Stress limit ASME Appendix I, Figure I.9.2.2 Curve C

Allowable number of cycle = 10^{11}

Salt = 13,600 psi,

The maximum effect mean stress is included in Curve C.

The normalized factor, NF is back-calculated:

[[

]]

(2.4) Explain the reasons:

Modified dryer cover plate stress reduction 17 times
Modified dryer front hood top weld stress reduction 3 times

Alternating Stresses for the Original Versus the Modified Dryer at CLTP.

Item	Unmodified dryer	Modified dryer	Ratio	Remark
Cover plate weld	27,200	1,544	17.6	
Front Vertical hood weld	11,656	3,843	3.0	

2.5 Toe of Fillet weld stress from 2D-isoparametric solid model, plane strain

[[

]]

From analysis results of shell model for 1 psi static case.
The average forces at 3.5" away from the fillet weld front hood surface are as follows.

[[

]]

Cover plate thickness = 0.375"

The Fy acting on the fillet weld creates a moment of [[ ]] on the fillet weld

[[

]]

Factor used in the report:

[[

]]

Therefore, the factors are reasonable

3.0 Equivalent Static (Confirmation check)

The purpose of this section is to explain earlier edition of the VY dryer analysis report, which uses equivalent static analysis.

[[

]]

Item	**Unmodified dryer**	**Modified dryer**	**Ratio**
Cover plate weld	[[		
Front Vertical hood weld			]]

4.0 ASME loads and load Combinations

ASME Primary load stress limits:

Pm	General membrane stress
Pm+Pb	Primary membrane plus bending stress

	P_m	P_m+P_b
Service Levels A/B	$1.0\ S_m$ = [[ ]]	$1.5S_m$ = [[ ]]
Service Level D	$2.4S_m$= [[ ]]	$3.6S_m$ = [[ ]]

ASME Code Section III Load Combinations

Service Level	Load Combination
Level A	normal pressure + dead weight
Level B 1	upset pressure + dead weight + OBE
Level B 2	upset pressure + dead weight - OBE
Level B 3	normal pressure + dead weight + TSV + OBE
Level B 4	normal pressure + dead weight + TSV - OBE
Level B 5	normal pressure + dead weight + TSVflow-induced + OBE
Level B 6	normal pressure + dead weight + TSVflow-induced + OBE
Level D 1	faulted pressure + dead weight + SSE
Level D 2	faulted pressure + dead weight - SSE

The most limiting stress is Service Level B

Positive and negative seismic load are combined (equivalent to absolute sum)

For Modifier dryer the maximum stress occurs at long gusset listed below. All other locations are listed in stress report.

Long Gussets Welds ASME Primary and Secondary Stresses

Item	Service Level	Load Case	(A) Local membrane stress (psi)	(B) Surface maximum stress (psi)	Plate thickness (inch)	Fillet weld size (inch)	(C) Undersized Weld stress factor	P_m+P_b (A) x (C) at weld (psi)	Local membrane Allowable stress (psi)	(D) Primary stress ratio	$P_m + P_b + Q$ stress, (B)x(C) (psi)	Alternating stress, Salt (psi)
1	1 psi		[[		0.500	2x0.375	[[					
2	Level A	1			0.500	2x0.375						
3	Level B	1			0.500	2x0.375						
4	Level B	2			0.500	2x0.375						
5	Level B	3			0.500	2x0.375						
6	Level B	4			0.500	2x0.375						
7	Level B	5			0.500	2x0.375						
8	Level B	6			0.500	2x0.375						
9	Level D	1			0.500	2x0.375						
10	Level D	2		]]	0.500	2x0.375						]]

ASME Primary Stresses Evaluation, maximum stresses

Unmodified dryer, Pm+Pb Level B-4 = [[ ]] <1.5Sm
(This is at lower cover plate)

Modified dryer, Pm+Pb Level B-3 = [[ ]] < 1.5 Sm
(stress ratio= 0.676, This is at long gusset)

Fatigue usage factor due to ASME load cycles < 0.050
[[ ]]

APPENDIX E

DOCUMENTS REVIEWED

GE-NE-0000-0024-7944-1 (Revision 1, March 2004)
"Entergy Nuclear Operations Incorporated Vermont Yankee Nuclear Power Station Steam Dryer Modification"
[Proprietary]

GE-NE-0000-0024-7944-2 (Revision 0, April 2004)
"Entergy Nuclear Operations Incorporated Vermont Yankee Nuclear Power Station Steam Dryer Modification Supplement 1"
[Proprietary]

GE-NE-0000-0024-7944-3 (Revision 0, June 2004)
"Entergy Nuclear Power Operations Incorporated Vermont Yankee Nuclear Power Station Steam Dryer Dynamic Response Spectrum Analysis"
[Proprietary]

GE-NE-0000-0016-9523-01 (Revision 0, July 2003)
"Entergy Nuclear Operations Incorporated Vermont Yankee Nuclear Power Station Extended Power Uprate Task T0303: RPV Internals Structural Integrity Evaluation"
[Proprietary]

GE-NE-0000-0016-4161-01 (Revision 0, January 2004)
"Entergy Nuclear Operations Incorporated Vermont Yankee Nuclear Power Station Extended Power Uprate Task T0305: RPV Flow Induced Vibration"
[Proprietary]

GE-NE-189-11-0292 (March 1992)
"Steam Dryer Vibration Measurement Program Fukushima Daiichi Unit 1"
[Proprietary]

GE-F4100056-02 (February 1997)
"Kashiwazaki-6 Steam Dryer Hammer Test Final Report"
[Proprietary]

NEDC-32791P (February 1999)
"Vermont Yankee Nuclear Power Station Increased Flow Analysis"
[Proprietary]

NEDC-33090P Table 1-1 "Computer Codes Used for CPPU"
[Proprietary]

DRF 0000-0016-1512 (April 21, 2003)
Quad Cities Steam Dryer Report

DRF 0000-0019-1512 (July 28, 2003)
Vermont Yankee Steam Dryer CFD Report

DRF 0000-0020-4661
Section 0000-0022-4955 (August 24, 2004)
"Reference Fluctuating Pressure Load Definition"
[Proprietary]

DRF 0000-0028-9723
Section 0000-0028-9735 (May 15, 2004)
"Vermont Yankee Fluctuating Pressure Load Definition - 'Refined' Approach"
[Proprietary]

PL234C6402 (Revision 1, April 2, 2004)
"Steam Dryer Modification"
Parts List
Installation Specification
[Proprietary]

MDE #199-0985 (October 1985)
"Susquehanna-1 Steam Dryer Vibration Steady State and Transient Response"
[Proprietary]

Methods of Radiographic Test and Classification of Radiographs for Stainless Steel Welds, JIS Z 3106 (Japan Industrial Standards), 1971

APPENDIX F

ENTERGY VERMONT YANKEE POWER UPRATE PROJECT NRR GE NUCLEAR ENERGY DRYER AUDIT PRESENTATION

Entergy

Entergy VY
Power Uprate Project

NRR GENE Dryer Audit Presentation

August 26, 2004

John Dreyfuss, Craig Nichols, Brian Hobbs,
Tom Cizauskas, Don Johnson, Pedro Perez (via phone)

Entergy

VY Presentation Overview

- Review of key NRR Audit Team issues
- VY plant-specific load definition
  - Confirm applicability of GE load definition by:
    - Data collection
    - Acoustic circuit model development
    - ACM analysis
    - Results application
- VY vortex shedding evaluation
  - CFD model development
  - Results application
- Schedule for meeting with NRR on results

Key NRR Audit Team Issues

- Applicability of generic load definition:
  - Frequency & amplitude spectrum
  - Addressed by CDI acoustic circuit model
- Vortex shedding:
  - Contribution to dryer loads
  - Addressed by Fluent CFD model
- Identification of acoustic sources:
  - Branch lines, TCV's, turbine control system
  - Addressed by CDI acoustic circuit model

VY Plant-Specific Load Definition

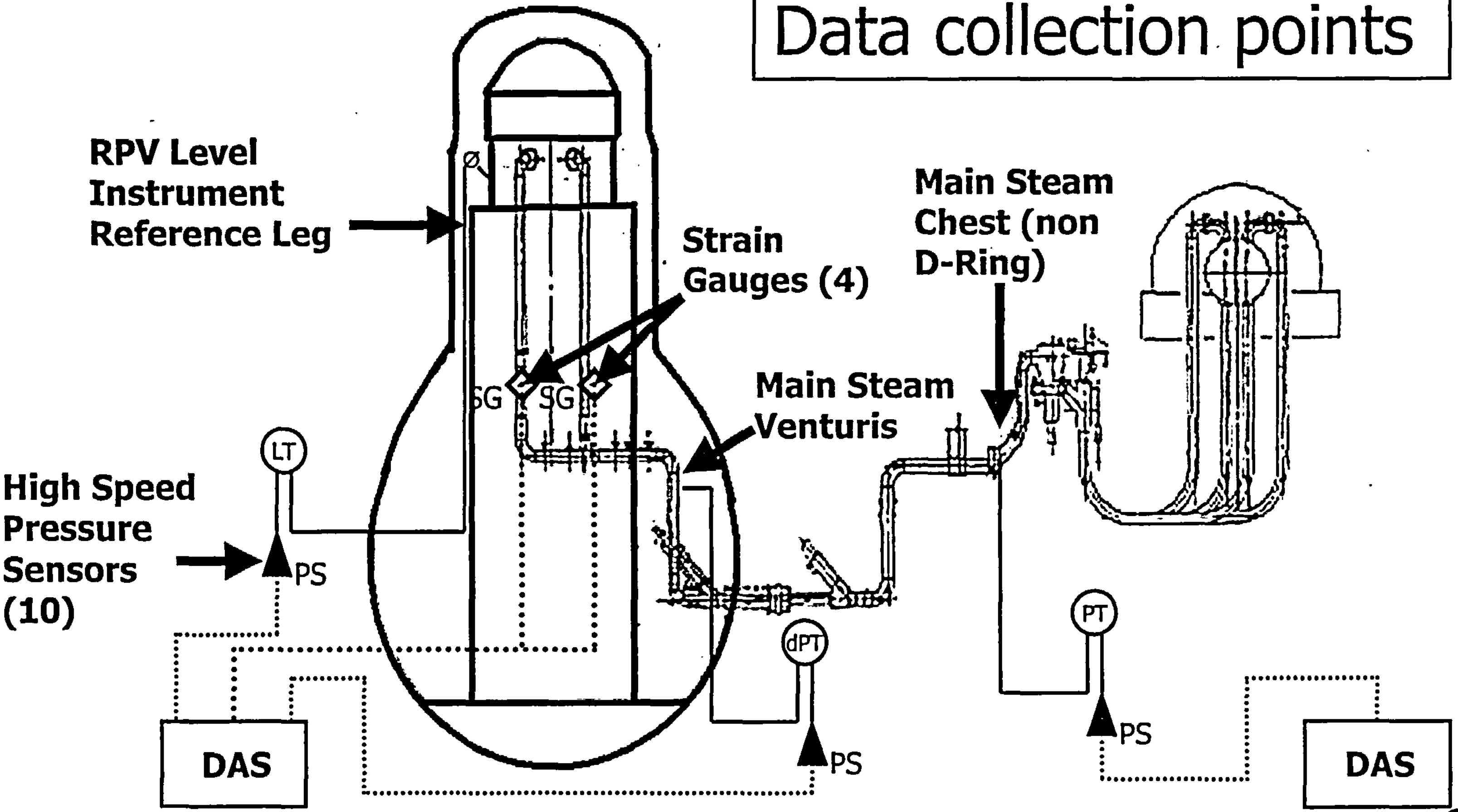
- Collection of plant-specific data
- Development of VY Acoustic Circuit Model
- Acoustic circuit analysis
- Application of results
- Piping vibration plant data

VY Plant-Specific Load Definition (cont.)

- Plant-specific data collection
  - VY pressure data taken at:
    - MSL venturis (one on each steamline)
    - Vessel instrument reference legs (2)
    - Main steam header (one on each steamline)
  - VY strain gauge data taken at:
    - MSL, vertical run close to RPV (one on each steamline)
  - Sampling rate i 1024 samples/sec
  - Data taken at 80%, 85%, 90%, 92%, 95%, 96% and 100% power

VY Plant-Specific Load Definition (cont.)

Data collection points



RPV Level Instrument Reference Leg

Strain Gauges (4)

Main Steam Chest (non D-Ring)

Main Steam Venturis

High Speed Pressure Sensors (10)

Entergy

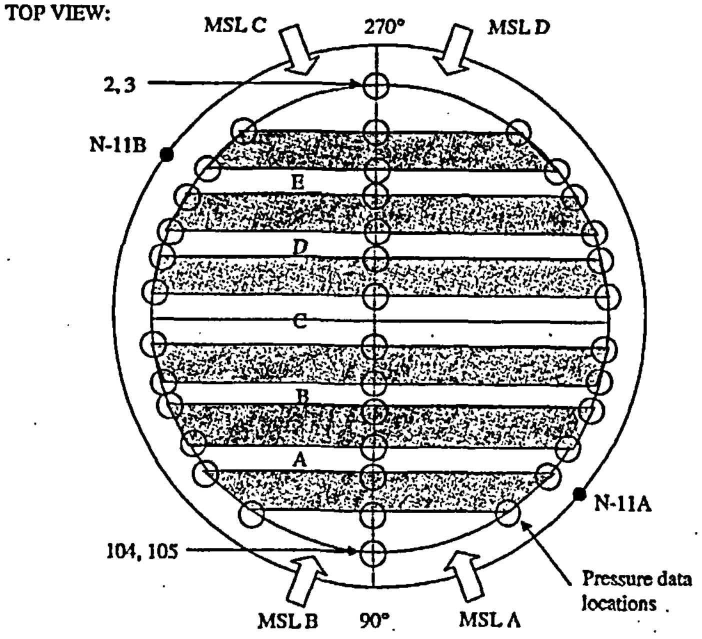
VY Plant-Specific Load Definition (cont.)

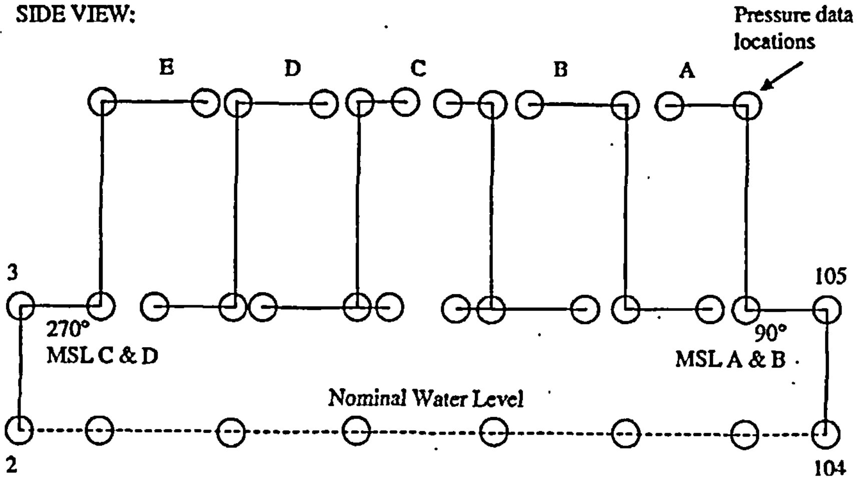
- Acoustic circuit model developed using:
  - VY (modified) dryer dimensions
  - Main steam system dimensions, including branch lines
- Model will be independently audited

Entergy

VY Plant-Specific Load Definition (cont.)

- Acoustic circuit dryer diagram:

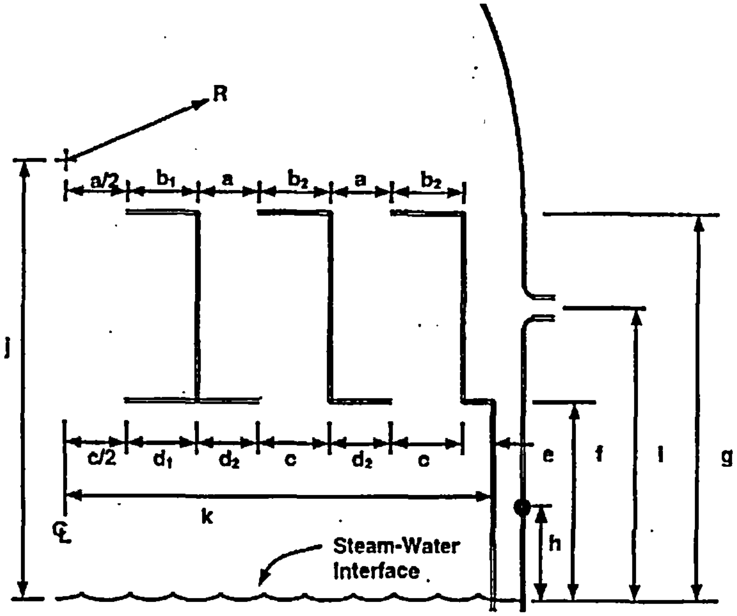




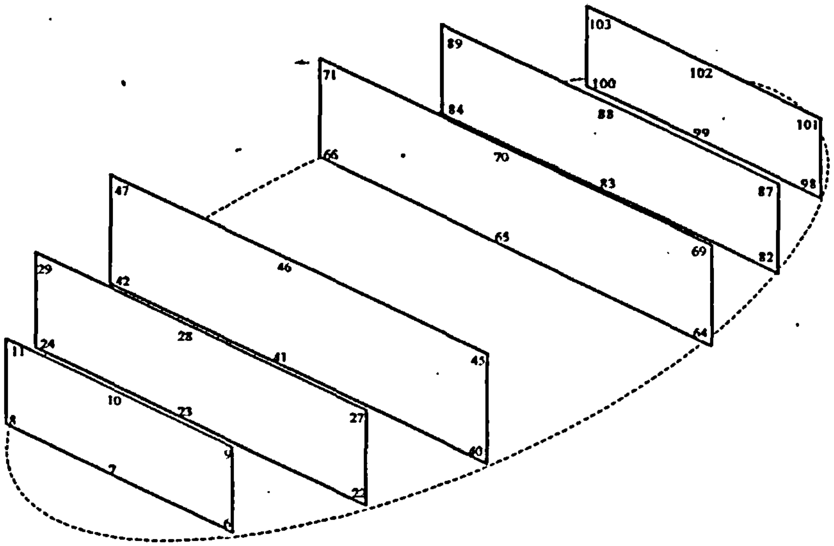
Schematic of pressure node locations on the steam dryer at Vermont Yankee.

VY Plant-Specific Load Definition (cont.)

- Acoustic circuit dryer diagram (cont.):



Cross-sectional description of the steam dome and dryer at Vermont Yankee, with the validated dimensions of $a = 6.0$ in, $b_1 = 13.75$ in, $b_2 = 27.5$ in, $c = 18.0$ in, $d_1 = 7.75$ in, $d_2 = 15.5$ in, $e = 16.75$ in, $f = 75.5$ in, $g = 137.0$ in, $h = 35.5$ in (reference legs), $i = 88.5$ in, $j = 148.5$ in, $k = 100.5$ in, and $R = 102.5$ in.



Entergy

VY Plant-Specific Load Definition (cont.)

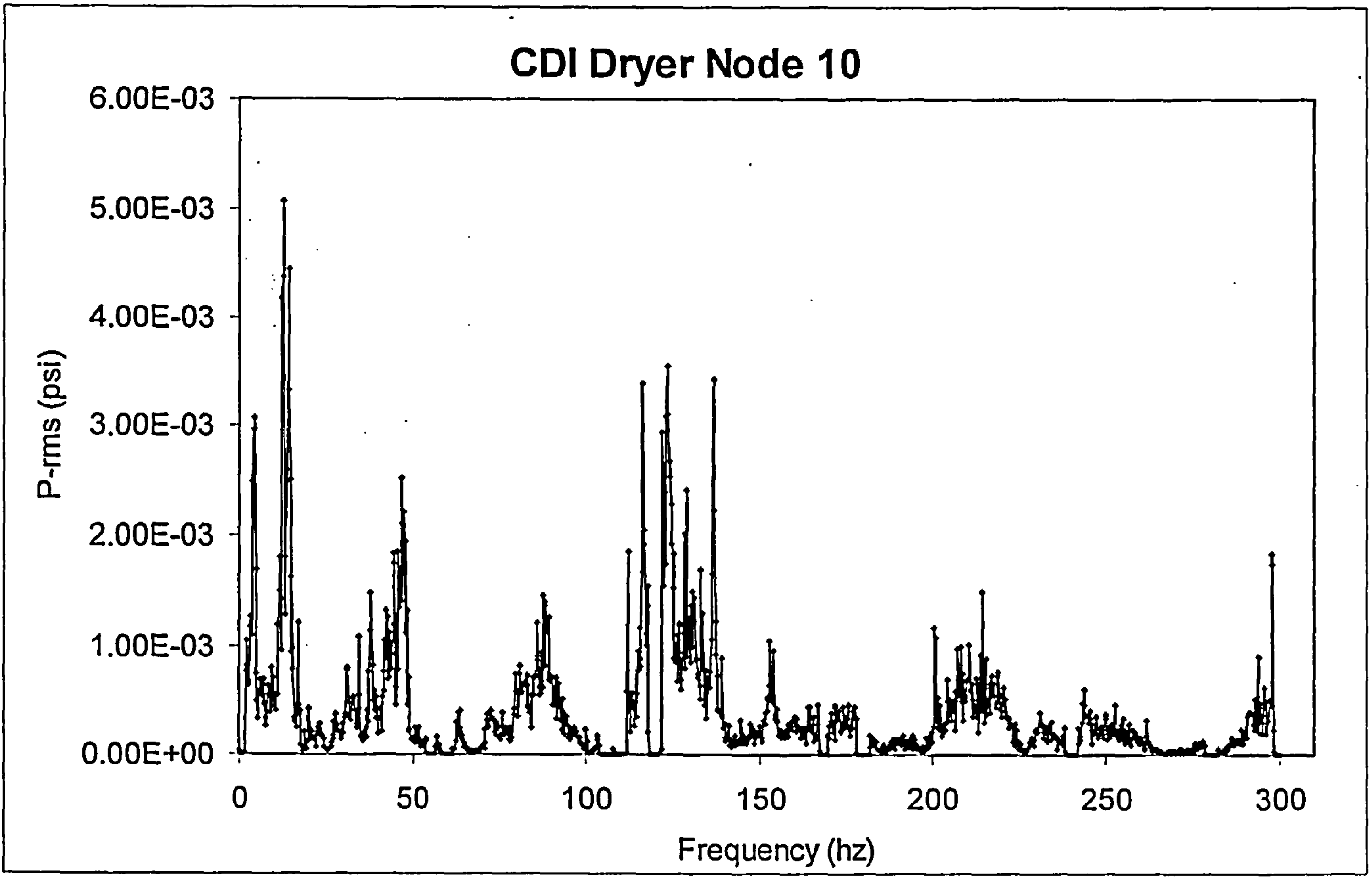
- Application of acoustic circuit results
  - Comparison to GE load definition
  - Comparison to other plants' acoustic loads
  - Extrapolation to EPU conditions
    - Confirm during Power Ascension Testing

VY Plant-Specific Load Definition (cont.)

- Preliminary results (in review):
  - Acoustic loads similar to Brunswick
  - Acoustic loads < Quad Cities

Entergy

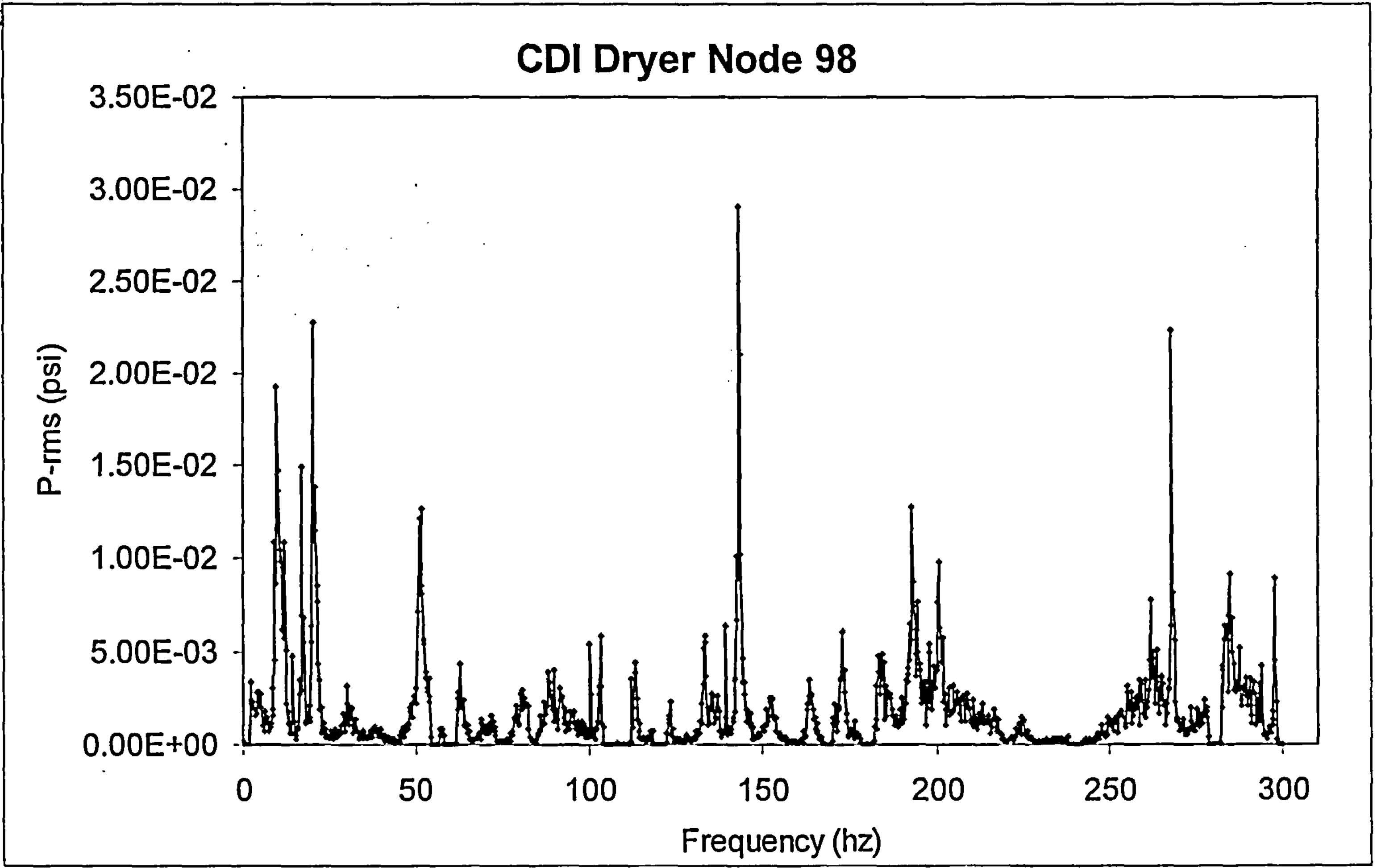
VY Plant-Specific Load Definition (cont.)



PRELIMINARY UNVERIFIED

Entergy

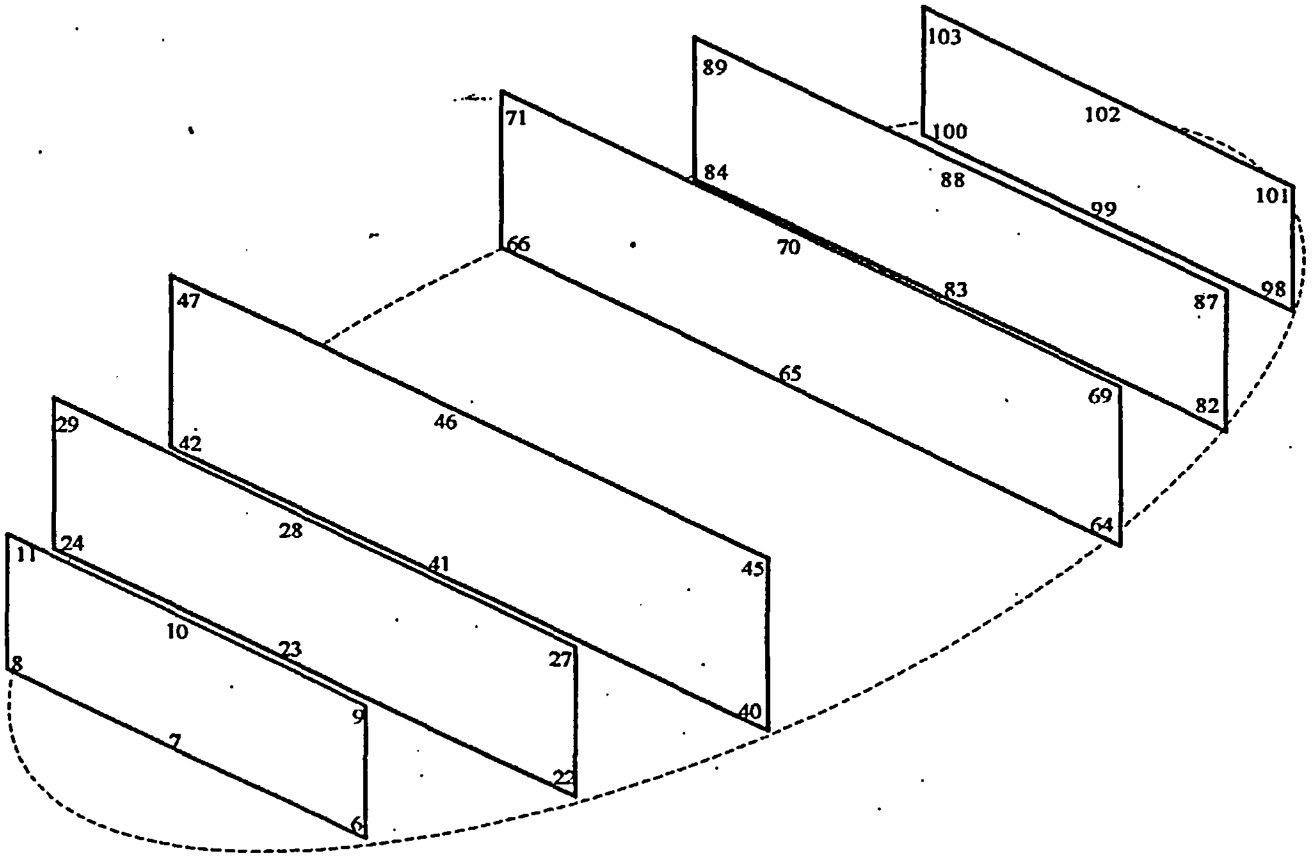
VY Plant-Specific Load Definition (cont.)



PRELIMINARY UNVERIFIED

Entergy

VY Plant-Specific Load Definition (cont.)



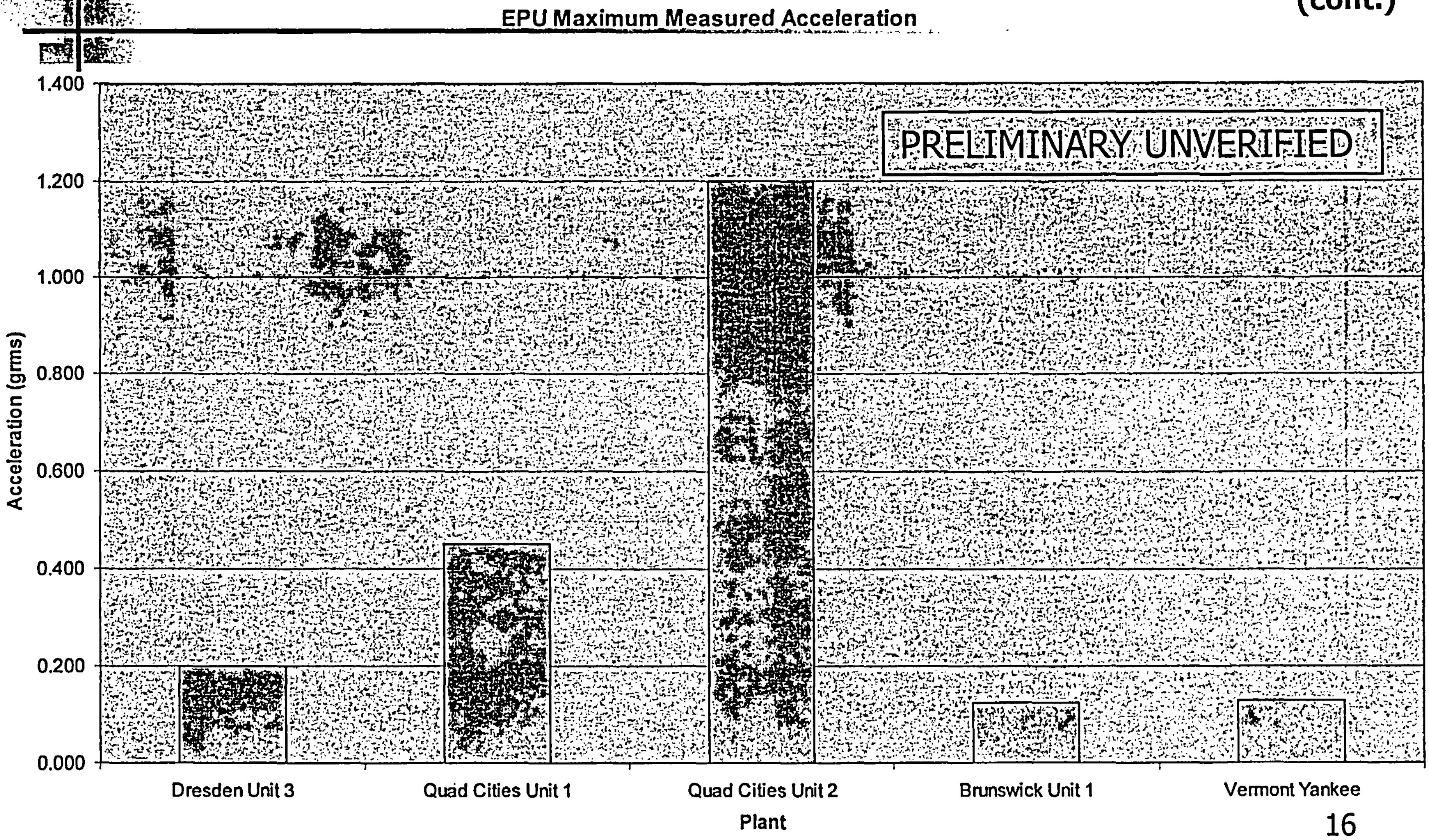
PRELIMINARY UNVERIFIED

VY Plant-Specific Load Definition (cont.)

- Piping vibration plant data
  - Indicator of acoustic load frequency and amplitude
  - Plant EPU vibration comparisons (see chart):
    - Piping vibration similar to Brunswick
    - Piping vibration < Quad Cities

Entergy

VY Plant-Specific Load Definition
(cont.)



VY Vortex Shedding Evaluation

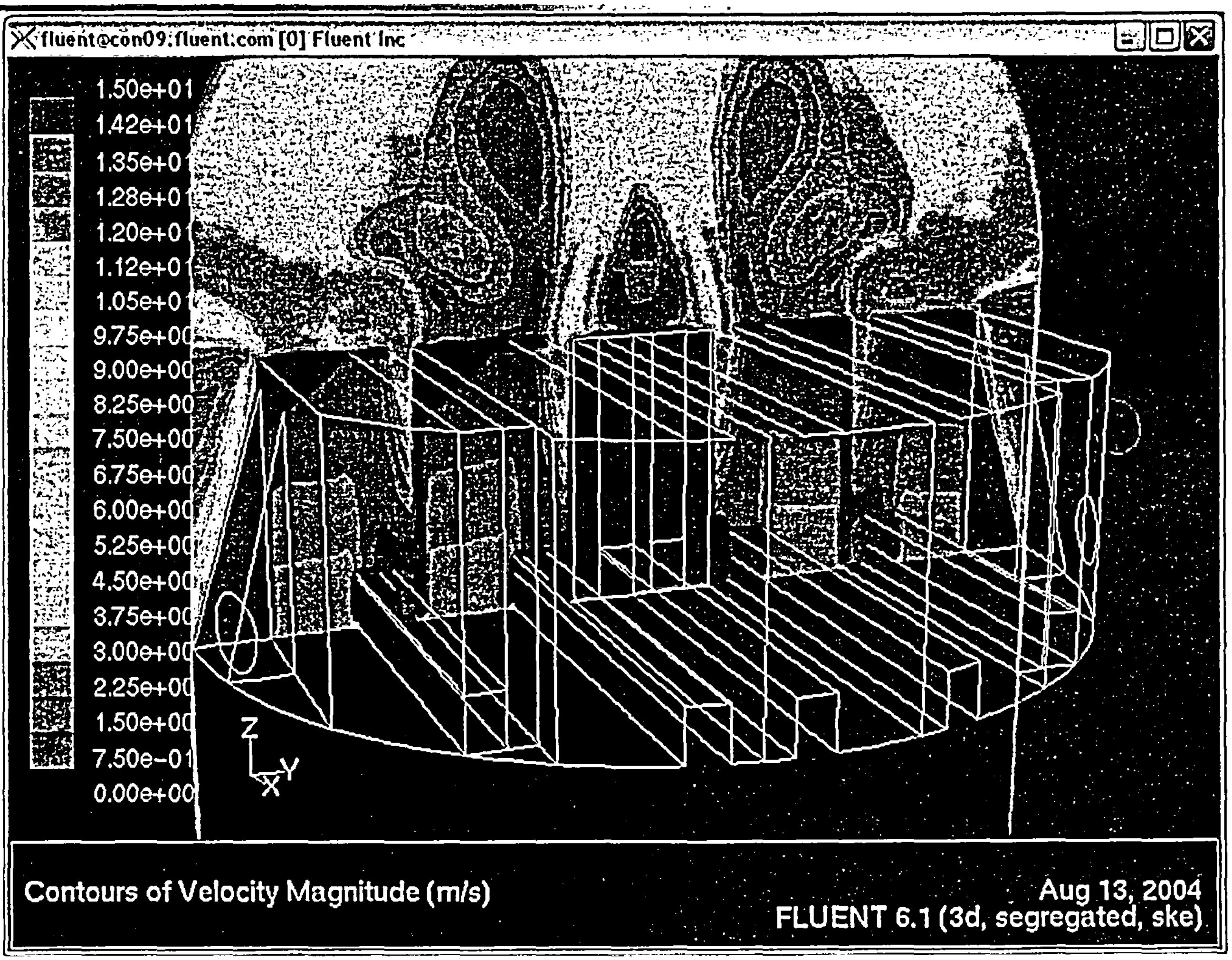
- CFD model development
- Results application

VY Vortex Shedding Evaluation (cont.)

- CFD model development:
  - Methodology - Fluent
  - Boundaries, geometry & mesh
    - RPV Dome, RPV annular region, Dryer internals and Skirt
  - RANS unsteady solution provides LES boundary conditions
  - LES solution capable of modeling local vortices at cover plate

RANS Model

- Preliminary results
- Example
    - Contours of velocity magnitude

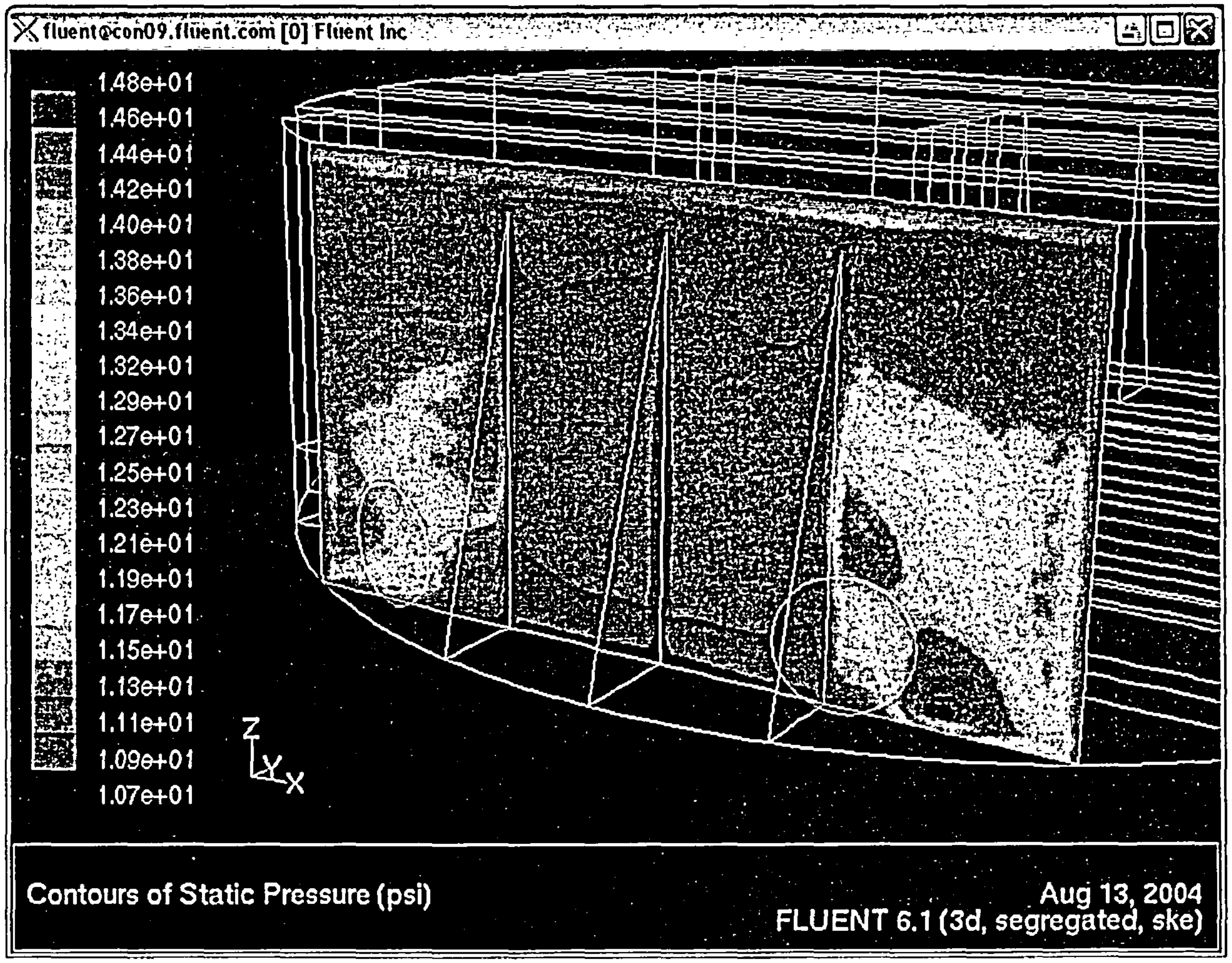


Contours of Velocity Magnitude (m/s)

Aug 13, 2004
FLUENT 6.1 (3d, segregated, ske)

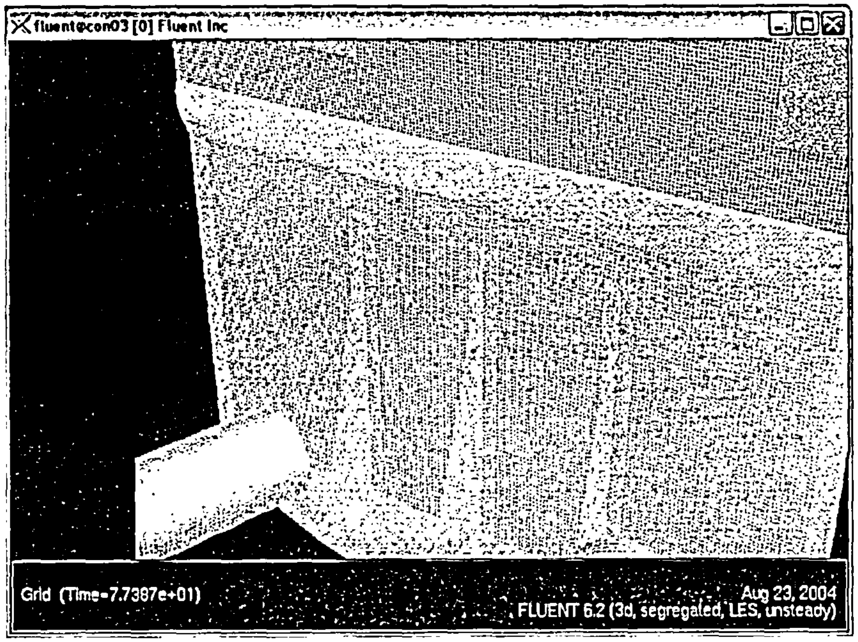
RANS Solution

- Preliminary results
- Example
    - Contours of pressure



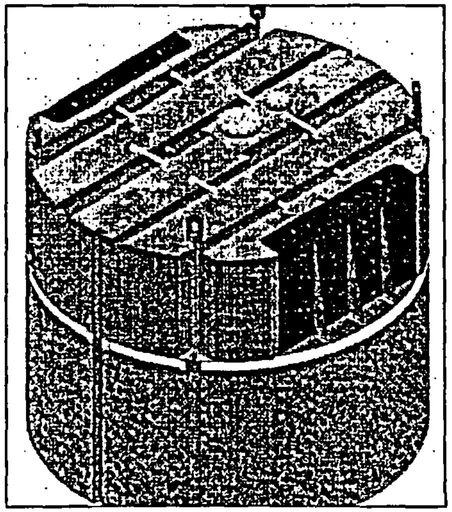
LES Mesh

- Hybrid mesh
- Significant volume decomposition for maximum use of hex cells.
- ~2M cells
- Profile of u,v,w,k,e from RANS solution imposed at velocity inlet



Grid (Time=7.7387e+01)

Aug 23, 2004
FLUENT 6.2 (3d, segregated, LES, unsteady)



VY Vortex Shedding Evaluation (cont.)

- CFD results application:
  - Address turbulence driven and vortex shedding load contribution

Entergy

Schedule for Meeting with NRR

- Complete VY-specific load definition -- early September
- GE compare VY-specific and GE load definitions – mid-September
- Entergy meet with NRR – late September

APPENDIX G

AUDIT FOLLOW-UP ITEMS

1. Vermont Yankee CFD analysis for modified dryer with Reynolds numbers specified at significant locations

2. Assessment of acoustic load under faulted conditions for Vermont Yankee EPU request and any generic issue

3. Scale model pressure spectra used in determining location multipliers

4. Correction of Table EMEB-B-1-3 in Entergy submittal dated July 2, 2004, with explanation of changes

5. Assessment of fluctuating load for normal and upset plant conditions for RAI response EMEB-B-1 in Entergy submittal dated July 2, 2004