From: Robert Tregoning PFG
To: bassbr@ornl.gov; Nilesh Chokshi; WILLIAMSpt@ornl.gov
Date: 10/24/02 12:29PM
Subject: Initial plan — rough draft

All:

This is a stream of consciousness document that I've put together this morning so please excuse it's crudeness and any gramatical errors. In light of urgency however, I want to send it to you now for some inital comment prior to polishing and forwarding up the chain.

I'll be leaving for a meeting for the rest of the afternoon, but will be in tomorrow morning to discuss. Please email any feedback that you may have in the meantime.

Rob

H-31

From: Robert Tregoning RES
To: Jeannette Torres
Date: 11/27/02 8:28AM
Subject: Fwd: Initial plan — rough draft

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Uncertainty Analysis for Davis Besse Failure

Background

Analysis of the Davis Besse cladding response within the cavity region was used to develop a pressure fragility curve (cumulative failure probability vs. pressure) has been generated for the current Davis Besse situation. The input variables utilized to create the fragility curve were either conservative assumed or best estimate values. The intent was to develop a fragility curve which represents a high confidence of low failure probability. In other words, an attempt was made to bound the uncertainty such that the median and low confidence fragility curves would predict failure at higher pressures than estimated.

Similarly cavity growth rate predictions have made to estimate a distribution of failure times as a function of assumed constant cavity erosion rates. Other than cavity growth shape assumptions, the failure prediction and modeling techniques are identical to the as found fragility predictions. Therefore, the intent was that these predictions would serve to represent a high confidence limit that the median and low confidence failure curves would all require longer time. Both of these analyses were completed by the end of September.

In the meantime, more relevant information has been uncovered which may erode the high confidence of the earlier analysis. First, cracking was found in the Davis Besse cladding at the center of the unrestrained portion of the cavity, which represents the highest stress region of the cladding. Second, it has been determined that the actual cladding material within the cavity region may consistent of three distinct material conditions. Six-wire SAW cladding was employed around the outer radius of the shell while the apex was coated using the SMAW process. Information on sketches indicate that the transition radius between the two processes is approximately 17". If true, this would imply that the cladding within the cavity likely consists of both SMAW and SAW material. It is also possible that the flaw may reside near the interface region between the two processes. This interface region may have a unique, and possibly brittle, set of material properties.

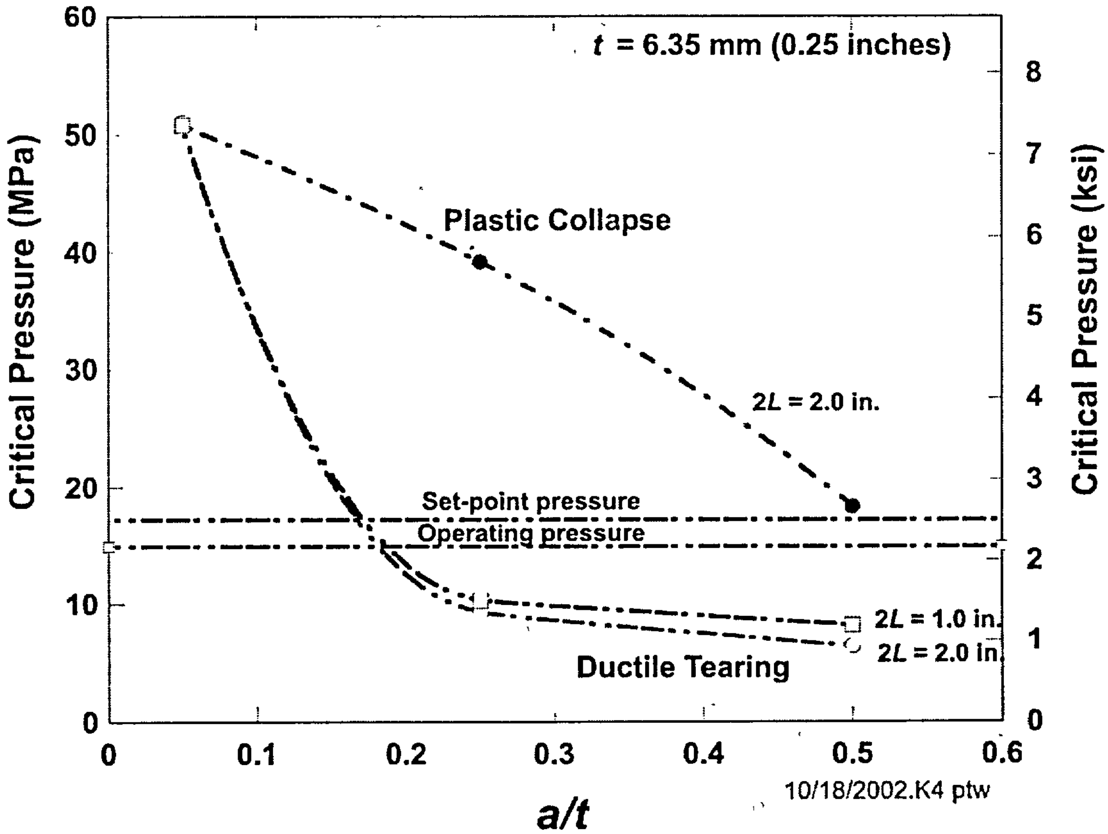
It is clear that a more rigorous uncertainty analysis is required in light of this additional information, and information that is planned from the failure analysis of the Davis Besse material, and from additional tests and analysis to be described herein.

Approach:

Short Term

In light of the flaws that have been found and other analysis uncertainties, the previously developed fragility curve, based on a plastic collapse failure model, may actually represent a representative upper limit prediction of the failure pressures of the as-found condition. A failure model that is based on ductile tearing initiation, with approximately conservative material properties, should represent a conservative lower limit failure prediction. The predicted failure pressures are a function of the model chosen (plastic collapse or ductile tearing initiation), the flaw size (depth relative to thickness), and material properties. A representative depiction of the influence of flaw size on the failure pressure curves for a given set of material properties is provided in the following figure. Given appropriately chosen material properties for the constitutive relationship and J_{Ic} material properties, these curves represent high confidence and low confidence failure pressures. The only missing information is knowledge of the exact flaw depth to determine which range of failure pressures are applicable. It is proposed that information on the cladding flaw size distribution developed from earlier PNNL work be combined with the pressure curves to develop high and low confidence fragility curves. To create these curves the likelihood of the existence of a flaw (flaw density per weld area) would be assumed as 1. Then cladding flaw size distributions from the earlier PNNL work would be multiplied by the pressure vs. flaw size curve (as below) to determine the fragility curves. This analysis presumes that the flaw discovered was preexisting from the fabrication process and has not grown substantially during service. It also implicitly assumes that the PNNL flaw distributions are transferable and constant between both six wire SAW and SMAW processes and any interface region between the two processes. It is planned that this analysis can be completed within the next two weeks.

A similar bounding-type approach would be utilized to determine the failure time for the as-found cavity assuming continued operation. The high and low confidence fragility curves would be respectively combined with low and high corrosion rate data to develop a high and low confidence failure time envelope. Earlier assumptions utilized to develop the fragility curve apply as do additional assumption that the corrosion rate and cavity growth shape are appropriately bounded. This assumption would need validation. The intent is also to conduct this analysis within the next two weeks.



Longer Term

The fragility and failure time curves generated during the short term analysis are expected to overestimate the true confidence bounds of the actual Davis Besse that would be developed using a more rigorous uncertainty analysis as well as additional information planned in ongoing testing and analysis that is being conducted at ORNL. The magnitude of overestimation could possibly be quite large. Additional work planned over the next six months is aimed at more rigorously quantifying uncertainties through additional analysis, experimental testing, and examination of the Davis Besse cavity and cladding material. These uncertainties associated with the Davis Besse analysis and a general approach for quantifying these uncertainties are as follows. There are three primary areas of uncertainty: structural modeling uncertainty, material uncertainty, and failure model uncertainty.

A. Structural Modeling Uncertainty (Geometric similitude).

The numerical modeling of the Davis Besse structure, cavity, cladding, etc. is obviously simplified for expediency. Some earlier work has been performed to demonstrate the model robustness as a function of several model variables. For instance, the effect of the cavity shape on the failure pressures has been shown to be relatively unimportant as long as the unbacked cladding area is accurate. There are other assumptions such as cladding thickness, model restraint, and cladding morphology where conservative assumptions have been used in the analysis to generate a high confidence curve. In order to quantify uncertainty, some measure of the actual conditions are required. Fortunately, the Davis Besse inner surface profile and cladding thickness variation have been measured. Both of these represent an excellent global measure of the true structural conditions. The idea is to compare the numerical model predictions with these actual measurements at operating pressure to gauge the accuracy of the numerical model. Differences between the surface profile and thickness as a function of pressure (different from operating pressure) would then be used to estimate, in a crude sense, the uncertainty in the structural modeling and response. The uncertainty associated with the model can be conducted within the next month.

Material Uncertainty

As mentioned previously, it is currently unknown specifically what material constitutes the cladding. Also, geometrical and phenomenological information about the principal cladding flaw is unknown. Ongoing failure analysis, being conducted by Framatome will hopefully provide critical information in these areas. Specifically, cladding microstructural and microhardness analysis should be able to determine the cladding processes involved, locate any fusion regions between the two processes, and gauge material homogeneity in either the SMAW and SAW materials and any potential interface region. Chemical composition and microstructural information within various regions could then be used to ascertain expected constitutive and J-R curve properties of the various regions. These properties would have uncertainty associated with property randomness and also additional uncertainty resulting from the fact that properties will be inferred from indirect measures. There will also be uncertainties associated with potential material aging affects resulting from service time and operating conditions. The intent is to characterize these uncertainties largely through published literature results.

Knowledge of the existing flaw size is crucial to determining which failure model (ductile tearing instability or plastic collapse) is appropriate for this material. Additionally information about the flaw history is important. If it can be shown that the flaw was preexisting and hadn't grown during service, the uncertainties associated with this scenario are well defined and can likely be evaluated from earlier PNNL flaw distribution studies. However, if it can be determined that the flaw formed or grew during service, or represents incipient failure of the cladding, then the failure models utilized may need to be greatly modified to accurately incorporate this knowledge. It is expected that this portion of the uncertainty analysis could be completed within one month after receipt of the results from the Framatome analysis, assuming that this analysis provides the knowledge outlined above.

Failure Model Uncertainties

The most difficult uncertainties to quantify stem from the actual failure model chosen to represent the failure condition and additional uncertainties associated with each particular model. Each potential failure model has a limited range of applicability. Therefore, the flaw size, the mechanism for its initiation, and the existence of any potential growth during service is crucial to limit the modeling uncertainty. Without this information, these uncertainties are unavoidably large and various competing mechanisms (as in figure) will need to be assumed. If this information is obtained, a best estimate failure model can be chosen. Then, the uncertainty associated solely with that particular model is required. Based on the ductile nature of the 308 cladding, if the discovered clad crack is shallow, the plastic collapse failure model is expected to be the most appropriate. If, on the other hand, the flaw is relatively deep, a ductile instability tearing model is more appropriate. Neither of these models however are appropriate if crack growth due to environmental and fatigue loading has occurred in service. Current plans only consider the evaluation of these two models, which is of course subject to change pending the Framatome failure analysis. Some assessment as to the likely applicability weight of each model will be made so that individual uncertainties can be appropriately combined later.

The collapse fracture model had been calibrated from existing test results and as such is complete. The short term bounding analysis using the ductile instability model will initially only incorporate that onset of tearing (lower bound curve in figure), and assume that this represents structural failure. Actual structural failure from this model is predicted when the crack growth resistance can no longer support additional loading. Additional analysis will first be conducted to actually predict the tearing instability failure curve as a function of crack depth. This will elevate the lower bound failure pressure curve and eliminate some of this model's uncertainty. This additional analysis will be completed within one month's time.

Additional uncertainties associated with each failure model will be determined using experimental testing. Both flawed and unflawed disk burst tests are being conducted on strip cladding material using biaxial loading, structural constraint, and exposed cladding areas which are representative of the Davis Besse as-found condition. Constitutive and fracture toughness properties on the surrogate material will be measured separately a priori. The objective is to evaluate both the collapse and ductile failure instability models utilized to predict Davis Besse failure. Uncertainties in each model's ability to predict these simplified tests will be utilized directly to assume their uncertainty with respect to Davis Besse predictions. Completion of this portion of the uncertainty analysis will require approximately six months for completion.

Uncertainty Treatment

Finally, all individual portions of the uncertainty analysis will be combined so that more representative high and low confidence fragility curves can be obtained. This may entail direct combination of the associated probability density function associated with each individual portion of the analysis, or it may entail a more rigorous Monte Carlo simulation. The scheme utilized to appropriately combine uncertainties will be developed in concert with DRA. It is estimated that this analysis will require seven months to complete, or approximately one month after completion of the failure model uncertainty determination.