From: Gary Demoss RD
To: Don Marksberry; Mark Kirk; Michael Cheok
Date: 9/3/02 8:25AM
Subject: first cut at slides for Ashok

For Don and Mike, I have attached Mark Kirk's slides, which contain the pictures and graphics necessary to really describe the event

Gary
415-6225

H-106

Probabilistic Analysis Issues Associated the Davis Besse CRDM Nozzle Cracking and RPV Head Wastage

Gary DeMoss, Don Marksberry, Mike Cheok
RES/DRAA/OERAB

PREDECISIONAL INFORMATION

OVERVIEW

PERFORMANCE DEFICIENCY

- Licensee failed to properly implement a boric acid wastage program
- Licensee failed to properly implement an inspection program for the detection of reactor coolant leakage

THREE POTENTIAL FAILURE MECHANISMS LEADING TO LOCA

- *As-Found Cavity Rupture* - Cladding exposed in as-found condition fails at normal or transient conditions, pressure below SRV setpoints
- *Enlarged Cavity Rupture* - Cavity grows larger and fails at operating pressure
- *CRDM Ejection* - Circumferential crack grows and causes CRDM nozzle to fail and rod ejection

AS-FOUND CAVITY RUPTURE - MLOCA

Predecisional Information

Initiating event analysis - based on the rupture probability distribution multiplied by the frequency of pressure transients between operating pressure (2165 psi) and SRV set point (2500 psi)

- expected values of rupture pressure are around 6000 psi.

* Probability of failure *1 x 10^{-3}

Conditional Core Damage Probability given initiating event - SPAR Model and licensee provided values are about 3 x 10^{-3} for MLOCA

ΔCDF - *3 x 10^{-6}

Issues/uncertainties - Operating on the lower tail of the rupture probability distribution; uncertainty in strength of cladding material

~~Predecisional Information~~

CRDM NOZZLE EJECTION- MLOCA

Initiating event - Have a probability of rupture vs. time curve from ANL. Assumed nozzle 3 wetted for 8 years. Then assumed nozzle 2 wetted for 4 years and nozzle 5 wetted for 2 years. They added 64% and 4% respectively. Probability of ejection is 2.7×10^{-2}.

Conditional Core Damage Probability given initiating event - SPAR Model and licensee provided values are about 3×10^{-3} for MLOCA

ΔCDF - *8×10^{-5}

Issues/uncertainties - Crack propagation rates of wetted nozzles.

~~Predecisional Information~~

ENLARGED CAVITY RUPTURE - LLOCA

- *Initiating event frequency* - calculated from the probability that DB operated longer, thus had more time for cavity growth

  Probability that DB was one of the five early B&W plants - 5/7=0.71

  Probability that DB had a better availability record - 2/7=0.2

  Probability that DB had 7 additional years - 5/7 *2/7 = 0.2

Probabilities based on B&W reactor availability factors:

  Probability that DB operated for additional 1.44 years before Oconee 3 cracking discovered - 0.57

  Probability that DB operated for additional 2.0 years before Oconee 3 cracking discovered - 0.14

Initiating event frequency range - 0.2 to 0.57 / yr.

Predecisional Information

ENLARGED CAVITY RUPTURE - LLOCA (Continued)

- *Conditional Core Damage Probability given initiating event* - SPAR Model estimate is 2×10^{-2}, licensee provided value is about 1×10^{-2} for LLOCA

  ΔCDF - 2×10^{-3} to 6.2×10^{-3}

Issues/Uncertainties

Bounding corrosion rates

2"/yr - 4.5 to 7.5 years until rupture
7"/yr. - 1 to 2 years until rupture

Likely ASP approach - At the time of discovery, the probability of LLOCA was not significantly greater than nominal.

Predecisional Information

CONDITIONAL CORE DAMAGE PROBABILITIES

Source	LOCA CCDPs		
	SLOCA	MLOCA	LLOCA
DB IPE	not provided	6.87×10^{-3}	1.08×10^{-2}
DB Recalculated for size of the exposed clad area	N/A	2.91×10^{-3}	N/A
SPAR 2QA	6.46×10^{-4}	Not Analyzed	
SPAR 3i (MLOCA range is 2" to 5")	3.47×10^{-4}	2.54×10^{-3}	2.11×10^{-2}

SUMMARY OF RESULTS - VERY PRELIMINARY

Predecisional Information

Rupture Type	***LOCA Size***	***Initiating Event Frequency***	***CCDP***	***ΔCDF***
as-found cavity	medium	$<1x10^{-3}$	$2.91x10^{-3}$	$<2.9x10^{-6}$
enlarged cavity	large	0.2 to 0.57	$1.08x10^{-2}$	$2.0x10^{-3}$ to $6.2x10^{-3}$
nozzle ejection	medium	$2.7x10^{-2}$	$2.91x10^{-3}$	$8x10^{-5}$

~~Predecisional Information~~

MEB Inputs to NRR Probabilistic Assessment of Davis Besse Head Degradation

Mark Kirk, Bill Cullen, Wally Norris, Jim Davis, Nilesh Chokshi

Office of Nuclear Regulatory Research, Division of Engineering Technology, Materials Engineering Branch, United States Nuclear Regulatory Commission

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Overview of Presentation

- **Photos / depictions of corrosion cavity at Nozzle #3**
- **Contents of NRR Phase 3 RSD**
- **Stress analysis**
  - **As-found condition**
  - **Potential future states**
    - ✓ **Corrosion rate**
- **CRDM circumferential cracking**

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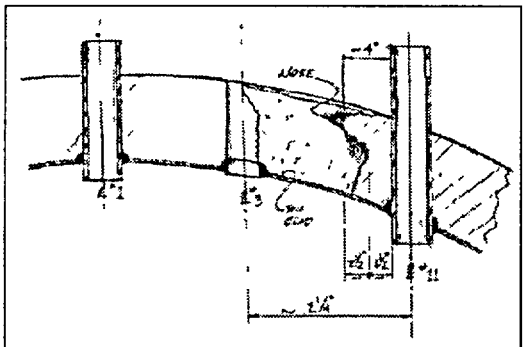
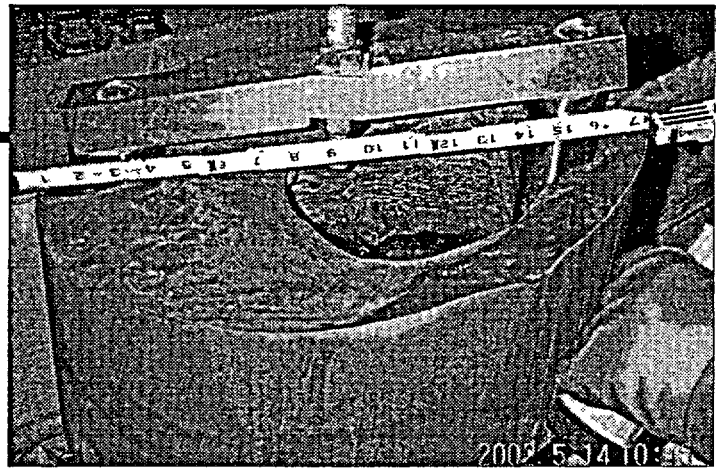
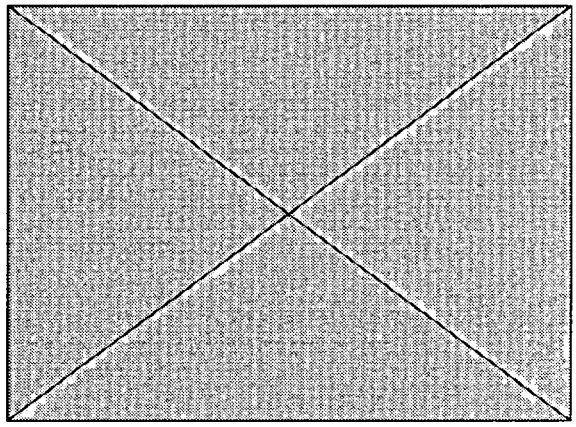
Nozzle #3
Corrosion Cavity



The above figure shows the Davis Besse reactor vessel head degradation between nozzle #3 and nozzle #1. This sketch was provided to the NRC by the Licensee





Contents of NRR Phase 3 RSD

- **The Phase 3 Risk Significance Determination that has been drafted by Steve Long analyzes three accident sequences that could contribute to risk**
  - **Vessel failure caused by rupture of the un-backed cladding**
    - ✓ **For the corrosion cavity as it existed when Davis Besse stopped operations in February 2002**
  - **Vessel failure caused by rupture of the un-backed cladding**
    - ✓ **For the corrosion cavity in a larger condition that might have existed .... ?????**
  - **Vessel failure caused by the development of a 360° circumferential crack, followed by ejection of the nozzle from the RPV head**

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Philosophy Driving MEB Stress Analysis of Cladding Rupture

- **Preliminary analyses (in 3/02 & 4/02) showed that the probability of cladding rupture caused by pressures up to the set-point pressure (2500 psi) is very low**
- **Most "uncertainties" in this analysis are knowable, at least in principal**
  - **Cavity geometry**
  - **Cladding tensile properties**
  - **Cladding thickness & geometry**

  Because of the low rupture probability, these "uncertainties" have been bounded in our calculations (pending availability of better information).

The one uncertainty that we have retained in our calculation is the uncertainty in how accurately our finite element model can predict cladding rupture

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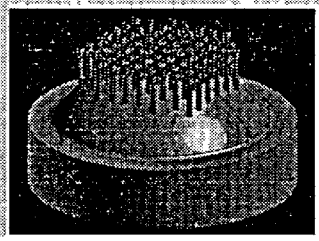
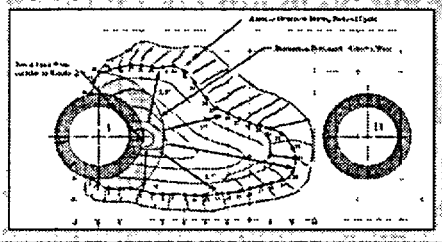
Basis of Finite Element Model

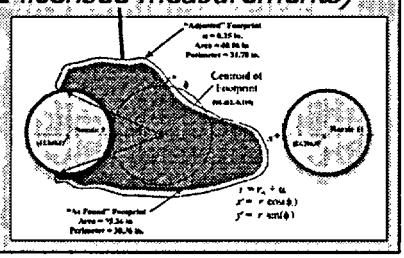
Design of the Head



Wastage Geometry

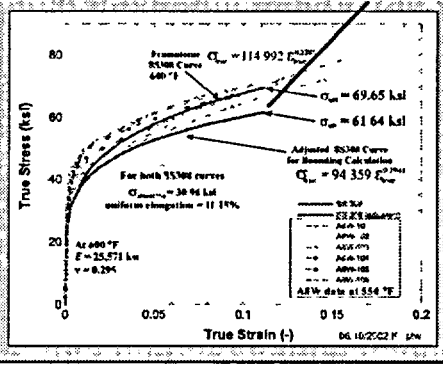
(upper-bounded from April '02 licensee measurements)





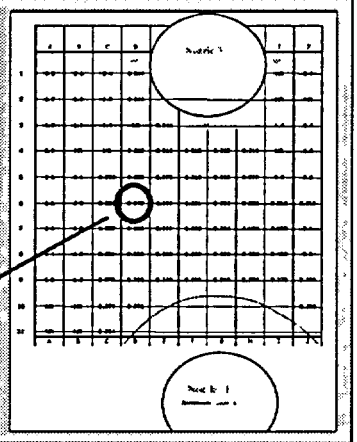
Cladding Tensile Properties

(lower-bounded from available data)

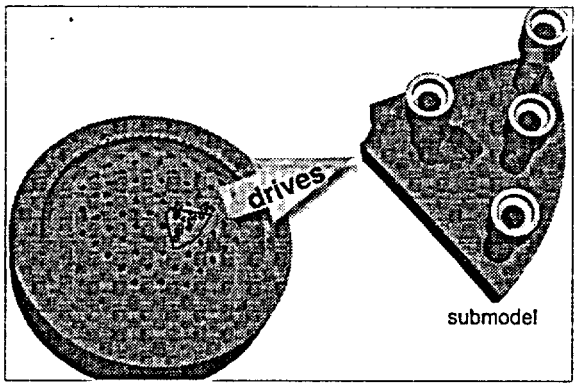


Cladding Thickness

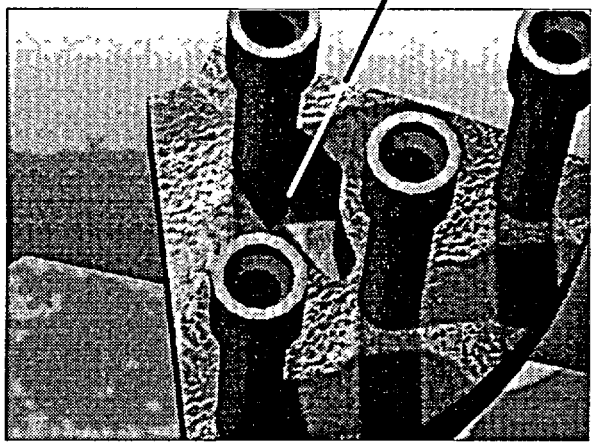
(minimum reported by licensee 0.24-in.)



Finite Element Model



Reinforcement provided by J-groove weld was *not* modeled.



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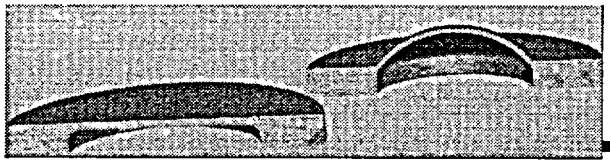
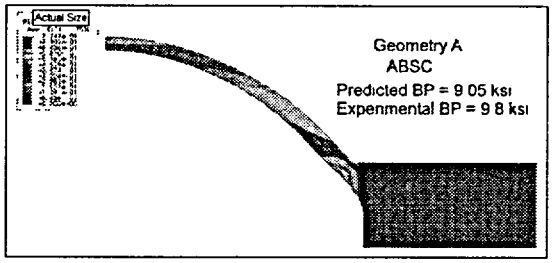
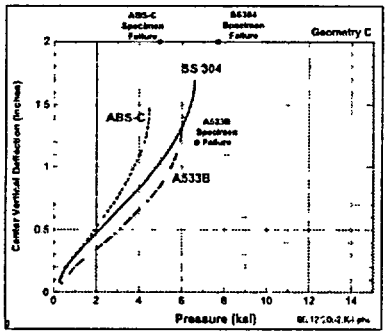
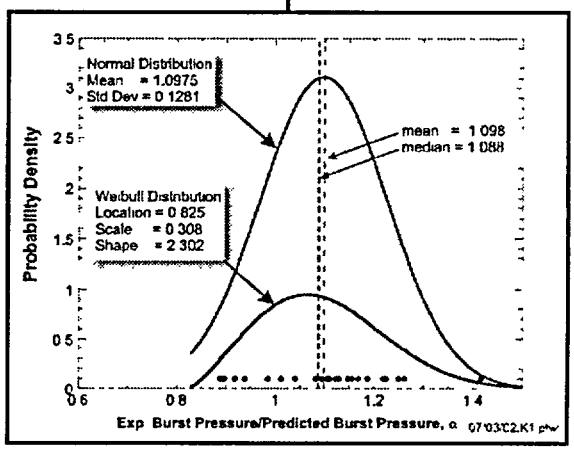


Uncertainty in Rupture Prediction

- → ♉♋●♓♌□♋♦♏♎ ♦□ disc burst tests reported by P. Riccardella [ASME '72 PVP]
  - → 6-in. diameter
  - → 1/8 and ¼-in. thick
- → Experiments used to quantify uncertainty and bias in using FE analyses to predict rupture of an unsupported membrane subjected to pressure loading
- → This statistical distribution is then used along with 3D FE model of Davis Besse cavity to assess probability of cladding rupture in the "as found" condition







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Results for "As Found" Condition

Clad Thickness [in.]		Pressure at Numerical Instability [psi]	Estimated Median Failure Pressure [psi]
Minimum Measured	0.24	6650	7355
Spec. Nominal	0.1825	5180	5732

Distribution	Failure Probabilities	
	at Operating Pressure (2165 psi)	at Set Point Pressure (2500 psi)
Log-Laplace	4.14E-07	2.15E-06
Beta	0	0
Gamma	8.17E-19	1.50E-15
Normal	8.44E-10	8.90E-09
Random Walk	0	0
Inverse Gaussian	4.01E-29	1.79E-22
Averages	6.91E-08	3.60E-07

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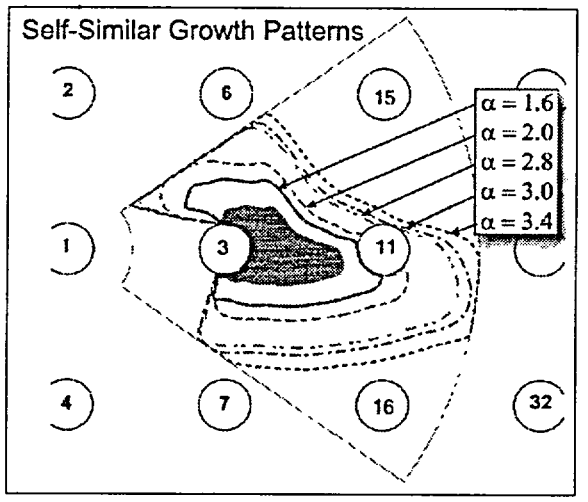
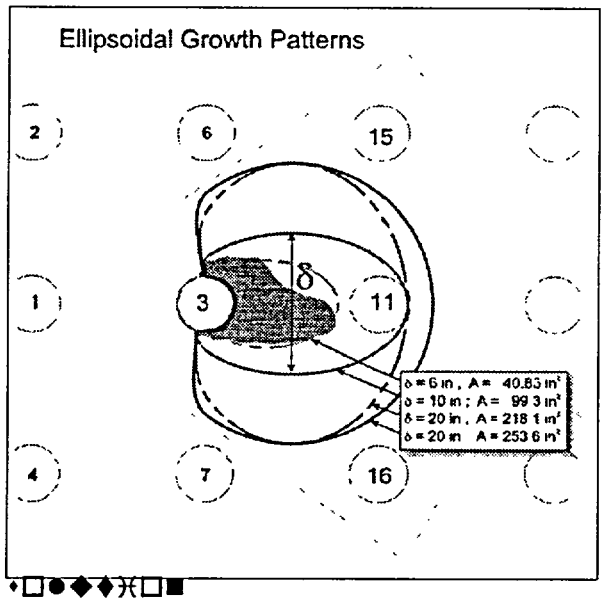
Analysis of Larger Cavities





Circular Growth Patterns

→ Chakrabarty & Alexander, 1970

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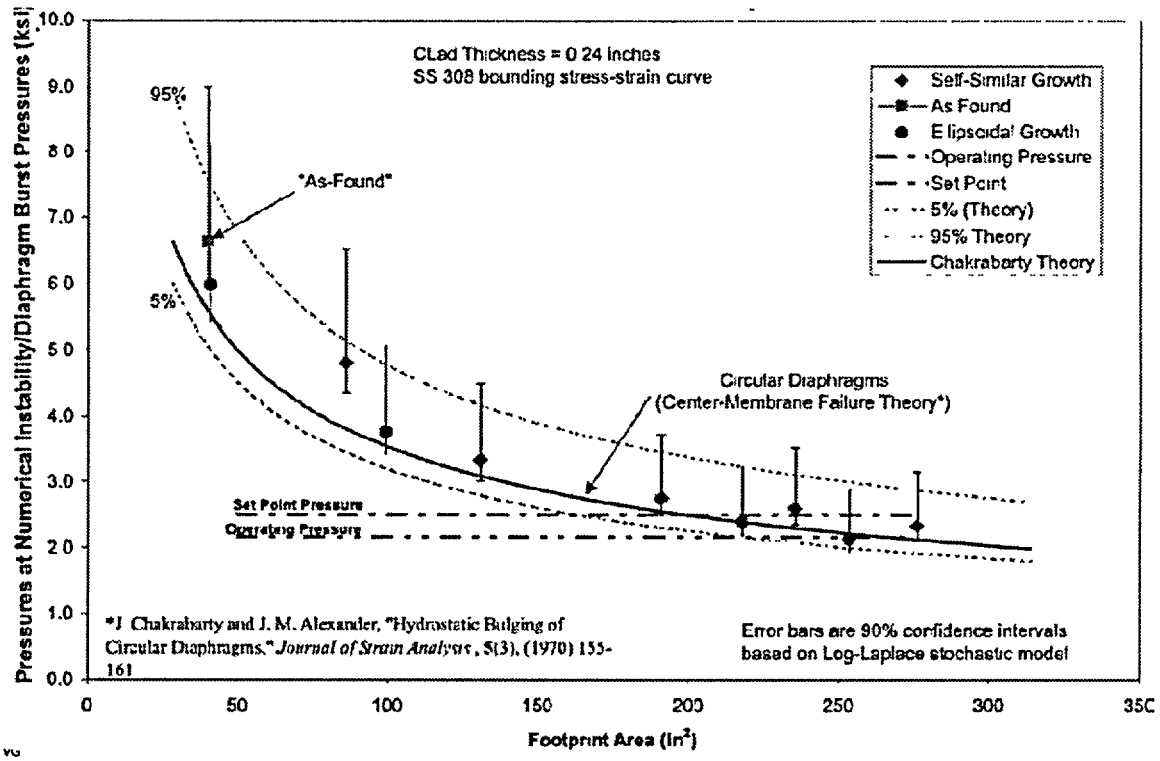
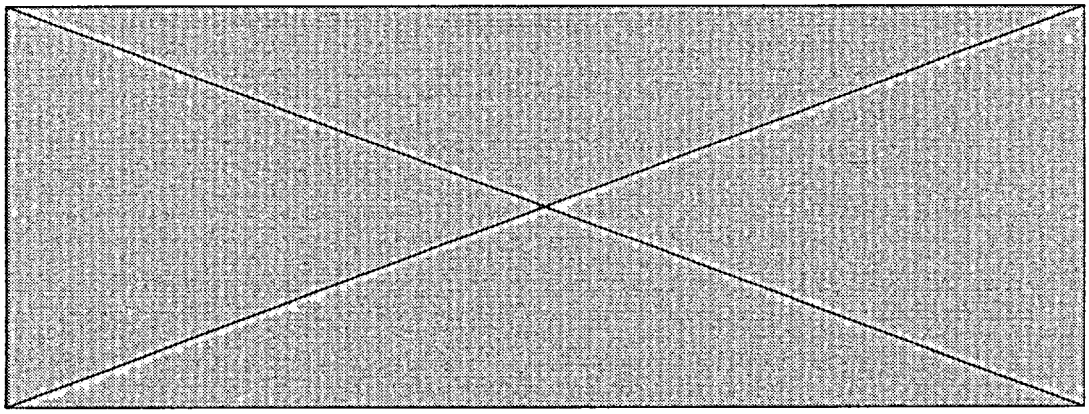
Results for Larger Cavities



Observations from Analyses of Larger Cavities

- **Cavity shape has only a minor effect on the predicted burst pressure, especially at pressures near the set-point and operating pressures**



At a corrosion growth rate of 2-4 in/year would have taken
- **11-26 months to rupture at the set-point pressure**
- **15-33 months to rupture at the operating-point pressure**

Completing this Work

- **Reporting**
  - **2 ORNL letter reports**
    - ✓ **1 is done**
    - ✓ **1 is in review**
  - **Provide comments to NRR on DRAFT RSD dated 8-28-02**
- **<u>May</u> wish to**
  - **Compare exposed cladding geometry modeled to that measured from dental mold**
  - **Compare tensile properties used in analysis to those measured from Davis Besse cladding**

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