SMiRT-16 Workshop

Structural and Leakage Evaluations for CRDM Cracking

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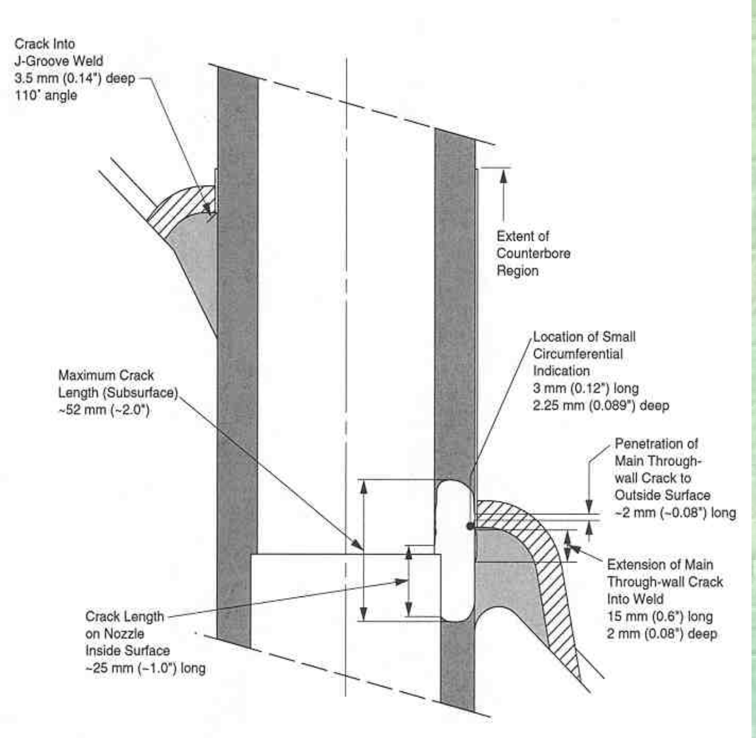
CRDM Cracking

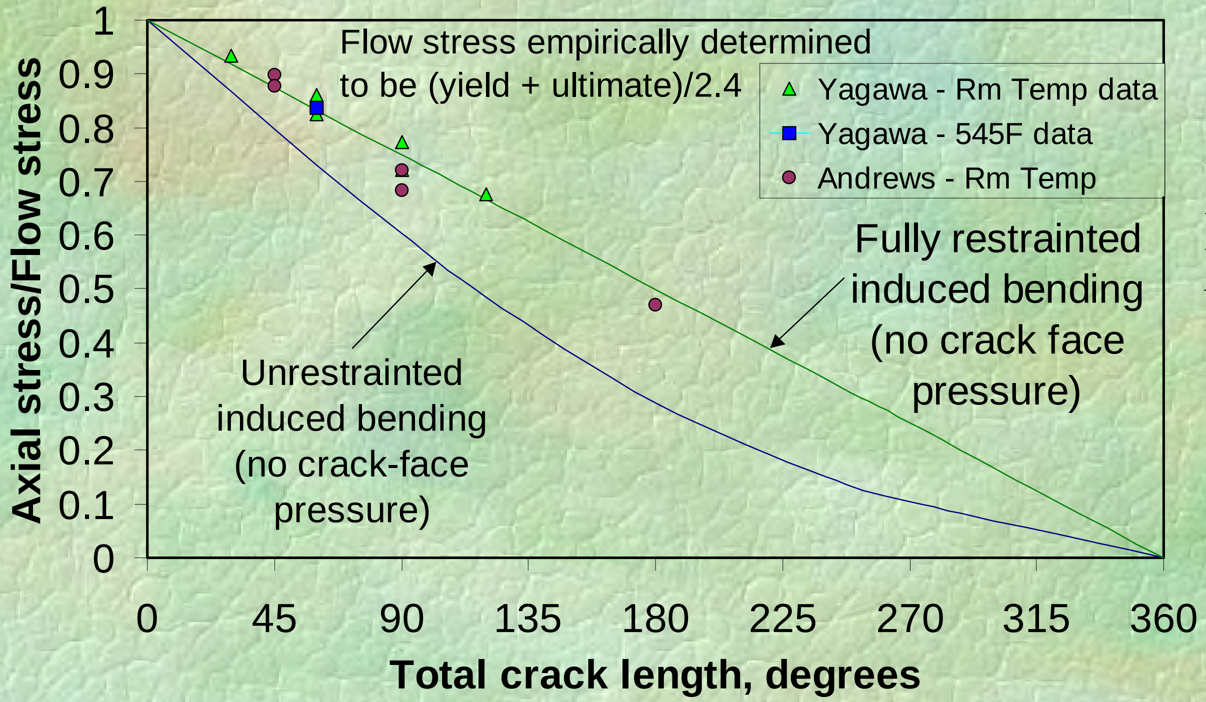
- Conducted review of several documents relative to CRDM cracking and performed analyses to assess concerns with circumferential cracking

- Issues investigated include
  - Critical flaw size
  - Leakage
  - Subcritical crack growth



Critical Flaw Size Evaluations

- Geometrical constraints restrain bending of cylinder caused by eccentricity of the crack.
- Load-carrying capacity is dependent on amount of bending restraint.



Crack face pressure could be assumed to be full pressure for limit load since large flaw will not allow pressure drop across the crack

Limit Load Screening

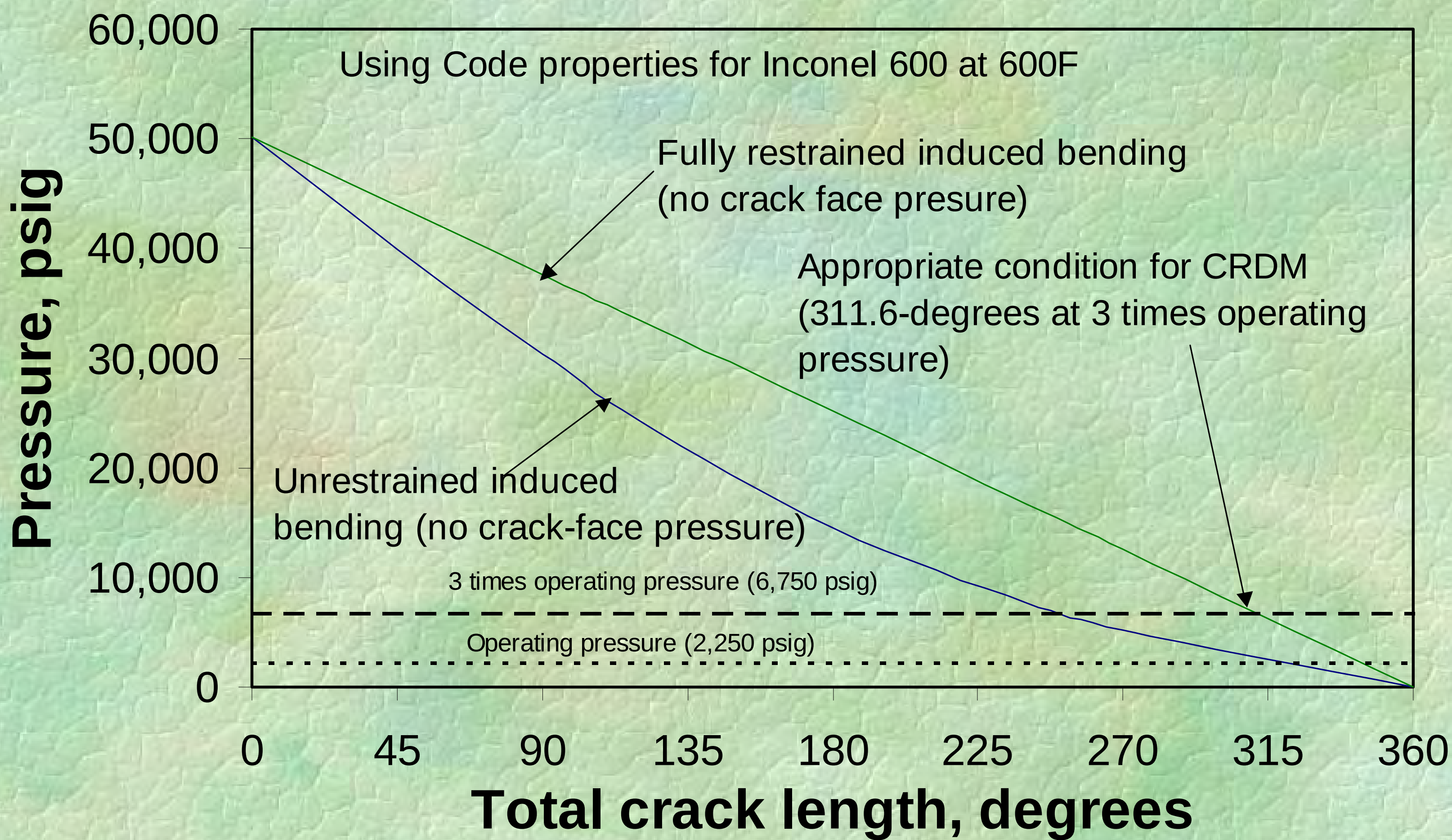
- A screening criterion is needed to assure limit load conditions.

- Based on size of plastic zone (Irwin) relative to uncracked ligament

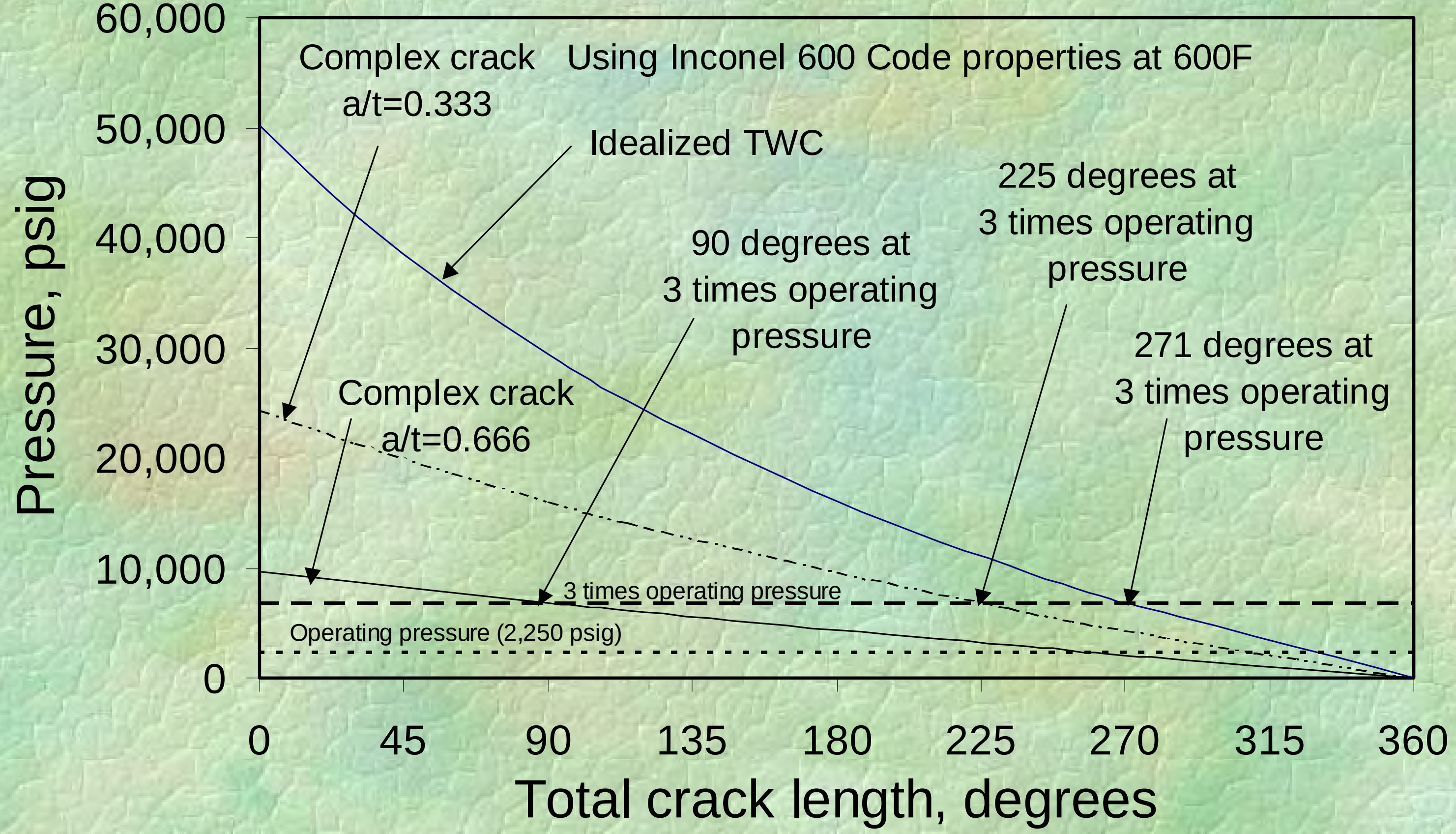
$$EJ_{Ic}/(\pi^2\sigma_f^{\,2}D) > 1.0$$

- For CRDM tubes (OD=4 inch, wt=0.625 inch, Inconel 600 at 550F, ligament = 2π), limit load conditions prevail.

Limit Load with Inconel 600 Code Properties at 600F



Effects of Complex Crack on Limit Load



Includes crack face pressure

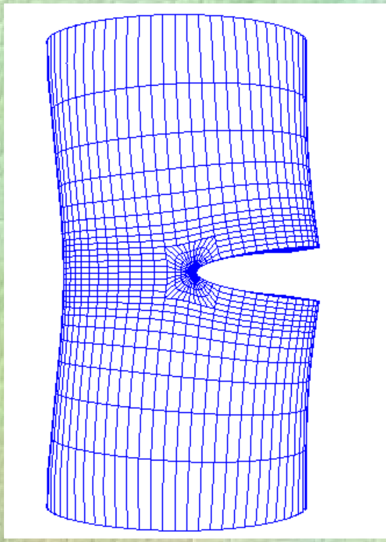
Limit Load - Notes

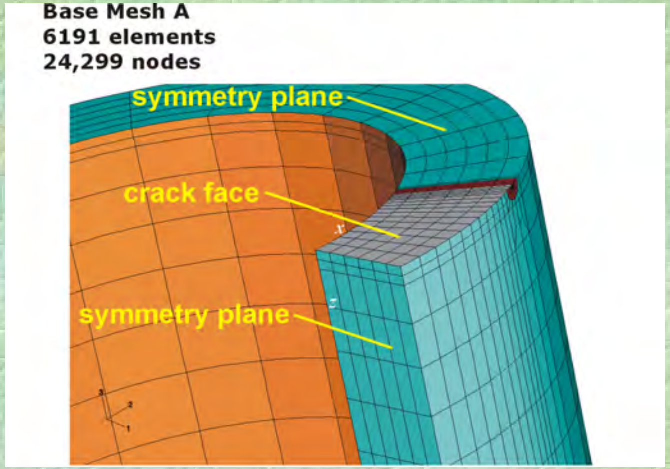
- Analyses shows a linear relationship between limit-load pressure and crack length when no crack-face pressure is assumed.
- That relationship becomes non-linear when full crack-face pressure is added
- The introduction of a complex crack severely reduces the critical through-wall crack length
- For an idealized through-wall crack, the critical crack length at 3 times operating pressure is 271 degrees around the circumference.

Leakage Calculations

- Considerations:
  - COD with restrained bending – leakage and pressure drop across crack for TWC
  - Effects of temperature, hoop stress, axial force on fit between tube and hole
  - Leakage through annular gap

Finite Element Analyses





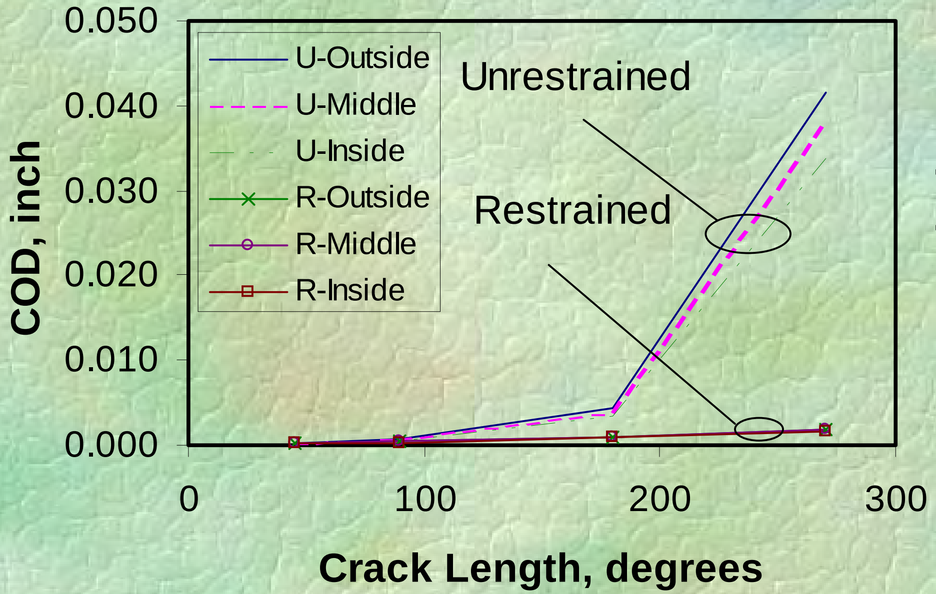
Emc² analyses

- Restrained and unrestrained ends
- Elastic
- No crack-face pressure

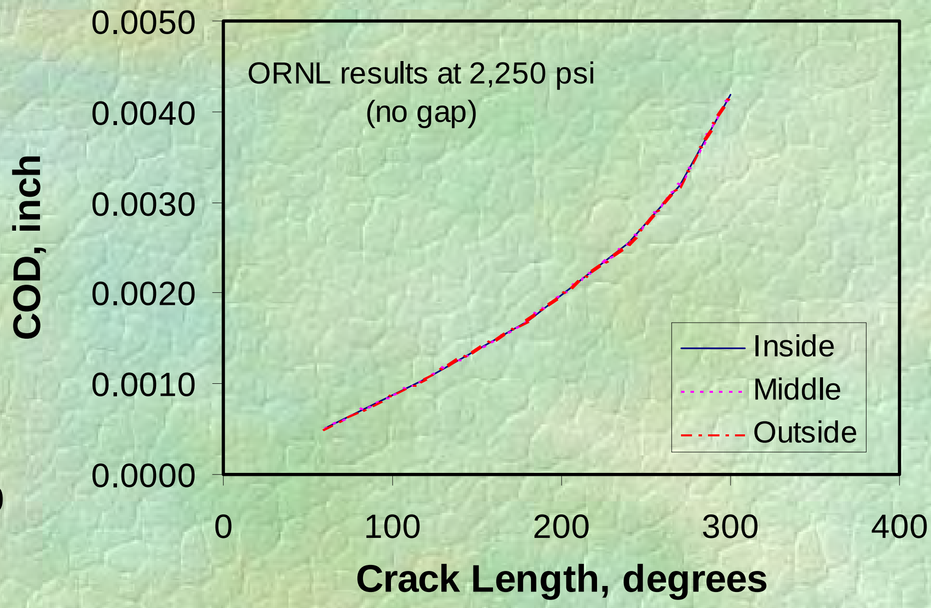
ORNL analyses

- Fully restrained
- Elastic plastic
- Full crack-face pressure

Crack-Opening Displacement Predictions

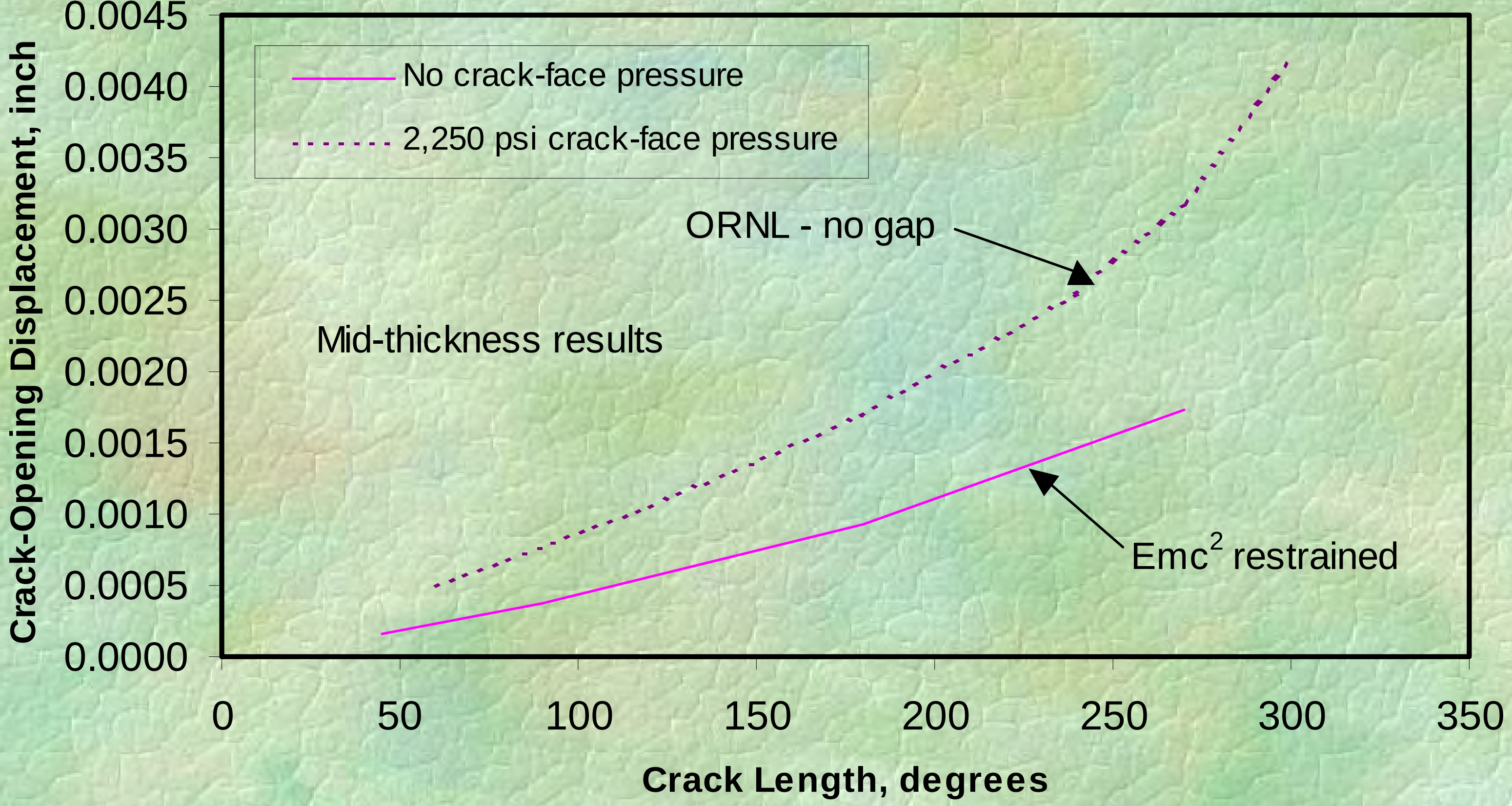


Emc²



ORNL

Comparison of Results

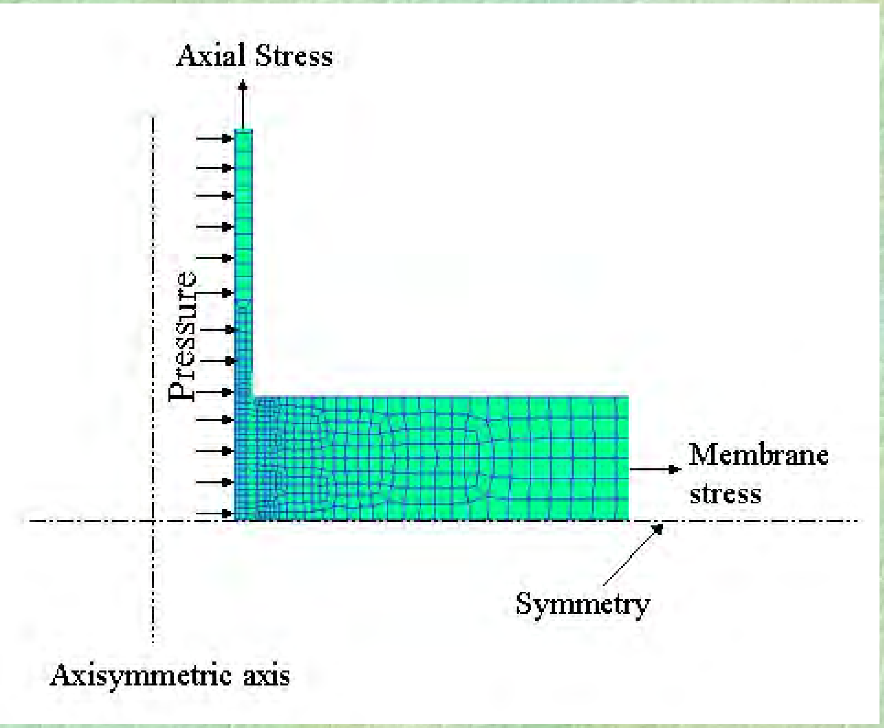


ORNL solution indicated conditions are elastic

Leak-Rate Calculations

- Assumptions:
  - Material properties – ASME Section II code
  - Head (flat plate) contained only one central hole
  - 0.005 inch initial diametrical clearance
  - Tube cooled to –140F before insertion into head
  - IGSCC crack morphology (elliptical shape)

Annular Gap Estimation

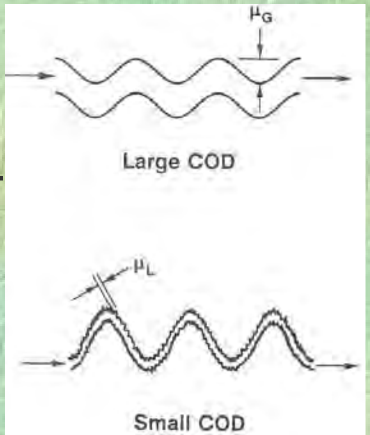


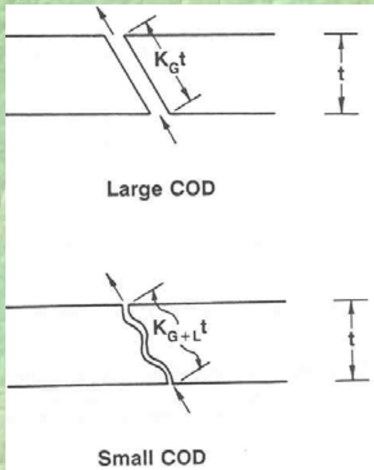
- Axisymmetric analysis
- 4-inch dia x 0.625”wt cylinder
- 9-inch thick head
- -140F initial temperature
- 2,250 psi and 650 F operating conditions

Loading	**Total Diametrical Clearance, in**
Initial	0.005
Heat tube to 70F	-0.00004
Operating conditions	0.0012

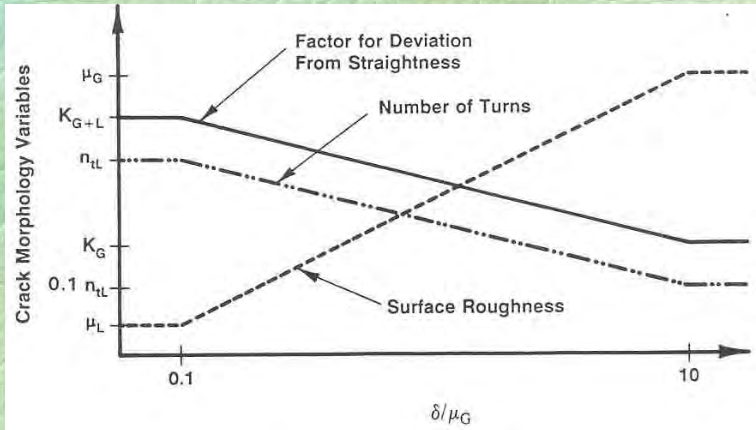
Leakage through CRDM Tube

- Statistical roughness parameters used for IGSCC – NUREG/CR-6004



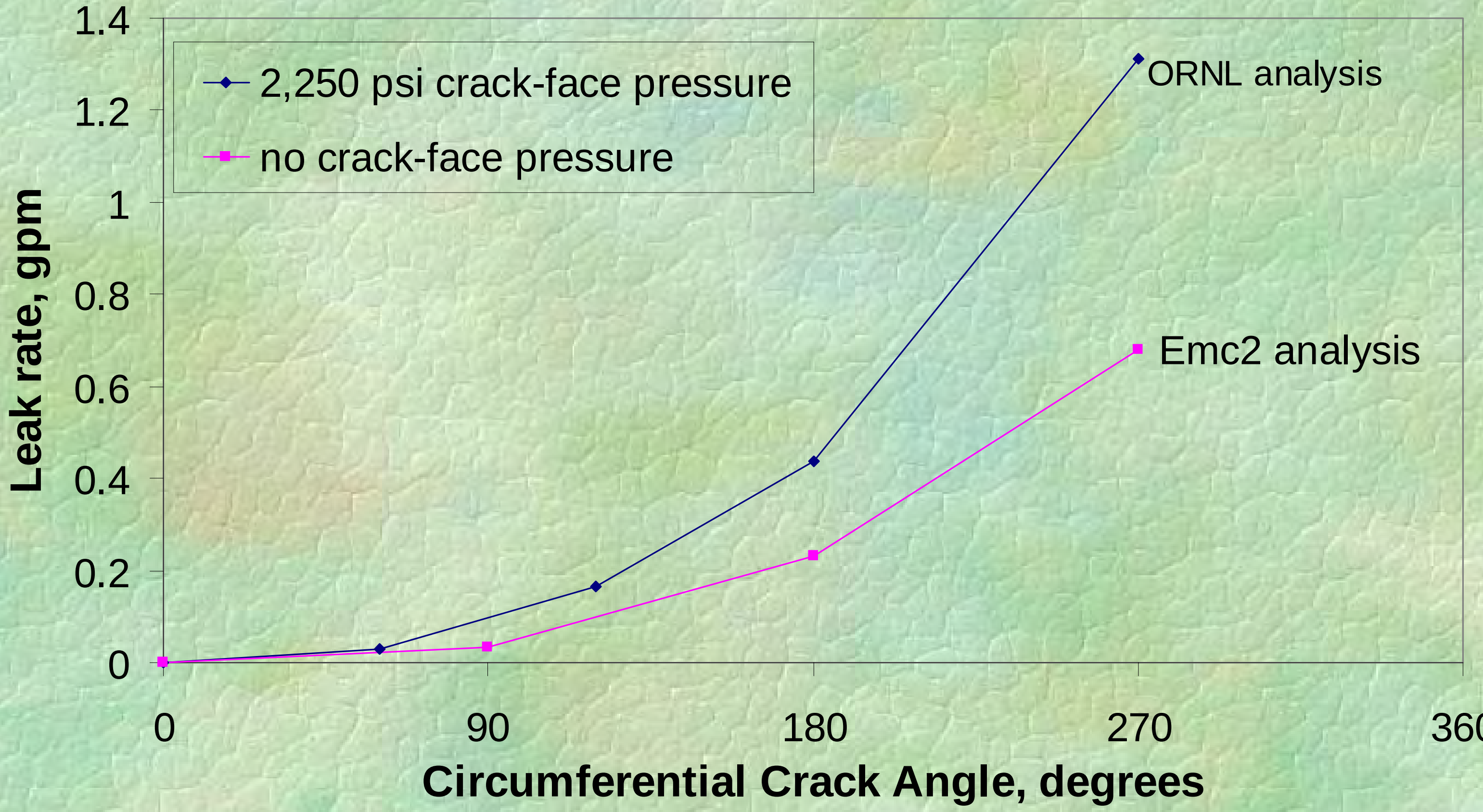


Crack Morphology variable	IGSCC cracks	
	mean	standard deviation
μ_L, µm	4.699	3.937
μ_G, µm	80.01	39.01
n_{tL}, mm^{-1}	28.2	18.9
K_G	1.07	0.10
K_{G+L}	1.33	0.17



Both PICEP rev. 4 and SQUIRT ver. 2.4a were used in this analysis

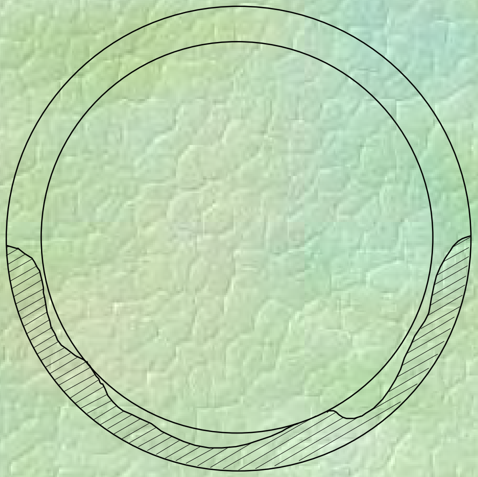
Leakage through CRDM Tube



Exit conditions at 180 degree flaw
were 127.8 psig and 346 F

Leak Rate through Tube - Notes

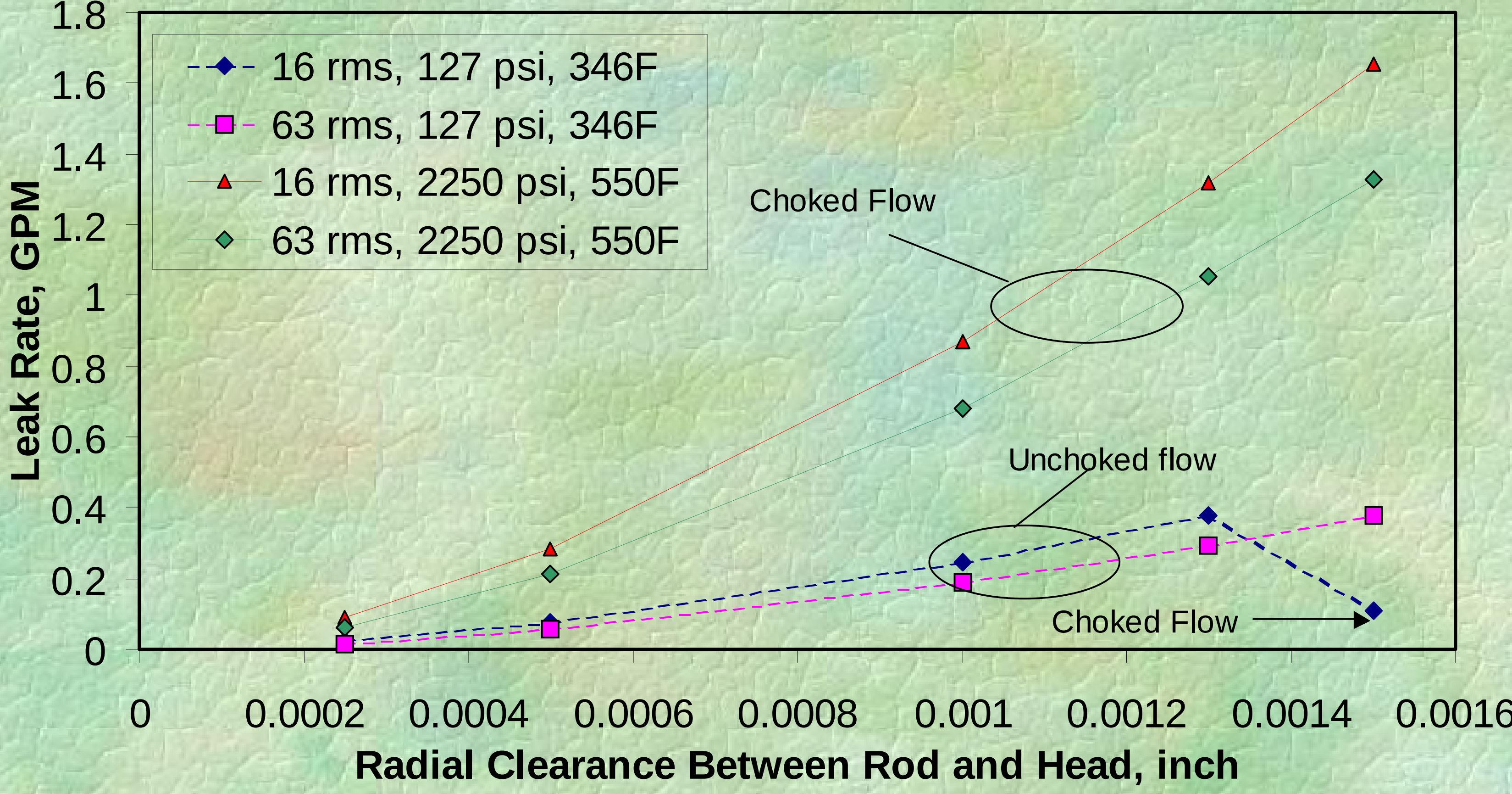
- Weld residual stresses not addressed
- Thermal expansion effects on crack face
- Most flaws are not idealized TWC



Leakage through Gap

- At operating conditions a gap may exist between tube and head
- Surface roughness of hole in head affects leak rate. Assumed +0.002-0.000" tolerance with 63 rms (drilling) and ±0.0005" tolerance with 16 rms (reaming)
- Conditions at start are represented by exit conditions of crack – assumed 127 psig and 346 F
- Studies on annular gap give values ranging from 1.2 mils to 2.9 mils

Leakage though Gap

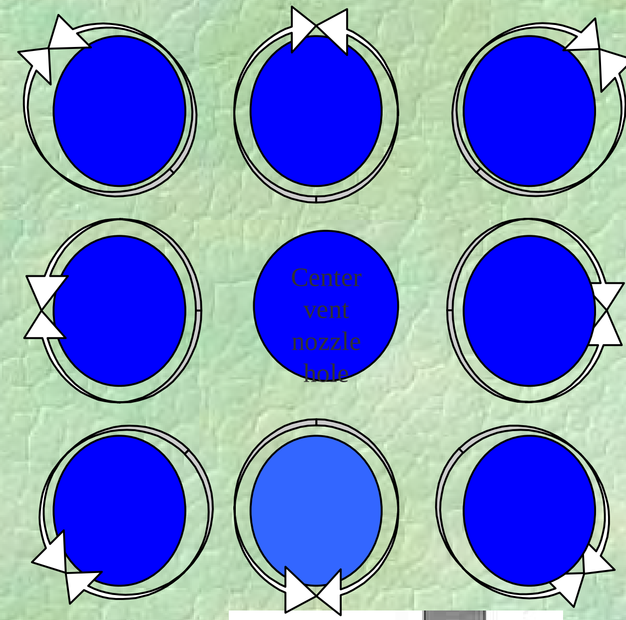


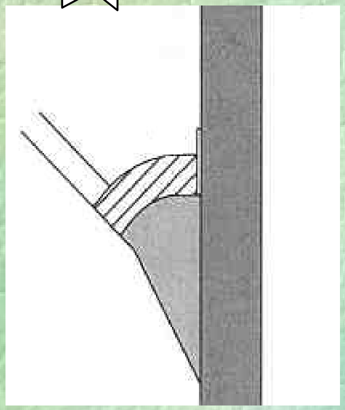
Leakage Notes

- Neither code (PICEP,SQUIRT) could predict water conditions at exit plane of gap
- From boric crystals found at the exit plane, leakage was estimated at 1 gal/yr, 24,000 times smaller than calculated leakage of idealized through-wall flaw
- If water is <100% quality, boric acid would stay in solution – water would cause the crystals to dissolve
- Plugging due to corrosion products may happen – but no data is available to confirm this

Subcritical Crack Growth

- Factors that may affect crack growth
  - Weld residual stress
    - Reports from industry were reviewed
    - Weld sequencing may affect residual stresses
    - Correct sequence needs to be modeled
  - Discontinuity at root of J-weld
    - Combination of counterbore, thermal expansion differences and residual stresses affect driving force.
    - These contributions were not analyzed in this study





Conclusions

- Initial investigation in CRDM cracking and leakage suggests
  - Limit-load conditions apply for cylinder size analyzed
  - True through-wall crack length must be known to calculated failure loads
  - Thermal expansion differences between tube and head affects leakage though crack and annular gap and stress intensity at counterbore
  - Crack morphology and hole surface roughness must be fully defined to calculate leak rate
  - Weld residual stresses and counterbore will affect crack driving force
  - Additional analyses is needed to fully define this problem