UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

November 16, 1987

MEMORANDUM FOR: Jack W. Roe, Division of Licensee Performance and Quality Evaluation, NRR

Lawrence Shao, Director
Division of Engineering and Systems Technology, NRR

FROM: Steven A. Varga, Director
Division of Reactor Projects - I/II, NRR

SUBJECT: FOLLOW-UP ACTIONS - COMMISSION BRIEFING ON NORTH ANNA - UNIT 1 STEAM GENERATOR TUBE RUPTURE EVENT

The need for follow-up of a number of items were identified as a result of the staff's November 9, 1987 briefing to the Commission on the subject event. Although a Commission final request will be following, action on the following items should be started as soon as possible. The Lead Manager is identified for each item and schedules where appropriate.

Specifically:

1. The adequacy of shift staffing on a generic basis to properly man communications system with NRC without interfering with plant operations during emergency situations. (Roe)

2. Recent audits of plant Procedure Generator Packages and Emergency Operating Procedures at several facilities have indicated deficiencies. These deficiencies indicate that additional audits be scheduled and conducted at more facilities. (Shao)

3. Complete the arranging of meetings with the licensees of those facilities identified as most susceptible to steam generator tube fatigue - type failures. All meetings are to be conducted and completed by November 25, 1987. (Varga)

4. Review adequacy of steam generator leak rate detection systems (i.e., sensitivity, criteria and administration controls for Westinghouse designed facilities. (Shao)

5. Develop a program and implement generic resolution of fatigue - related steam generator tube failure issue, including activation of Westinghouse Regulatory Response Group. Integrate resolution in USI A-3, A-4 and A-5. (Shao)

4988

D/56

6. Maintain cognizance of above activities and prepare report to the Commission on activities and lessons learned for the event. (Varga - scheduled to be developed).

Please provide to Leon Engle, the Lead Project Manager, your contact and proposed milestones for completing the above items. This information should be provided no later than November 23, 1987.

Steven A. Varga, Director
Division of Reactor Projects - I/II, NRR

cc: T. E. Murley
J. H. Sniezek
F. J. Miraglia
R. W. Starostecki

Circa 1988

STEAM GENERATOR EVALUATION

WESTINGHOUSE PRESENTER : KEN HUFFMAN

TOPICS:

- FAILURE MECHANISM
- NO. ANNA 1 - S.G. 'C' R9C51 TUBE CONDITIONS
- NO. ANNA CORRECTIVE ACTIONS
- GENERIC CONSIDERATIONS

D/57

FAILURE MECHANISM

HIGH CYCLE FATIGUE

- TUBE SHOWED TYPICAL PHYSICAL AND METALLURGICAL PROPERTIES
- NO EVIDENCE OF CORROSION CONTRIBUTION

STRESS CONTRIBUTORS

- DENTING INDUCED MEAN STRESS
- VIBRATION INDUCED ALTERNATING STRESS

VIBRATION

- FLOW INDUCED
- LOW AMPLITUDE FLUIDELASTIC

NO. ANNA 1 - S.G. 'C' R9C51 TUBE CONDITIONS

TOP TUBE SUPPORT PLATE DENTING

- TUBE AT YIELD STRESS
- TUBE - TUBE SUPPORT VIBRATION DAMPING MINIMIZED

ANTIVIBRATION BAR (AVB) SUPPORT

- ROW 11 MINIMUM REQUIREMENT
- ESSENTIALLY ALL AVB'S EXCEED MINIMUM, ROWS - 10, 9, 8
- R9C51, NO AVB SUPPORT

HIGH FLOW CONDITIONS

- HIGH FLOW PLANT CONDITIONS
- LOCAL AVB GEOMETRY INDUCED HIGH FLOW

NO. ANNA S.G. MODIFICATIONS

ACCEPTANCE CRITERIA

- REDUCE FUTURE FATIGUE USAGE
- ALTERNATING STRESS REDUCTION
- REDUCTION IN STABILITY RATIO OF 10%

R9C51 TUBE STABILIZATION

- HOT LEG CABLE STABILIZER
- COLD LEG SPEAR STABILIZER/SLEEVE CONNECTION

DOWNCOMER FLOW RESISTANCE PLATE (DFRP)

- REDUCE BUNDLE FLOW TO LOWER TUBE LOADS
- LOADING IMPROVEMENT, 8 - 15%

PREVENTIVE PLUGGING

- TUBES EXCEEDING LOADING CRITERIA AND HAVING NO AVB SUPPORT
- ADDITIONAL TUBES SELECTED TO IMPROVE MARGIN
- SENTINEL PLUGS UTILIZED TO PROVIDE FOR A FUTURE DATA BASE

GENERIC CONSIDERATIONS

(W) S.G. (PLANT) CHARACTERIZATION

- TOP TUBE SUPPORT PLATE DENTING
- S.G. THERMAL HYDRAULIC LOADING CONDITIONS
- SCREENING CRITERIA DEVELOPED BASED ON NO. ANNA EXPERIENCE

RESULTS

- TYPE I AND TYPE II PLANTS
- HANDFUL OF TYPE I (POTENTIALLY SUSCEPTIBLE) PLANTS DEFINED
- NRC INFORMED OF (W) ACTIVITIES

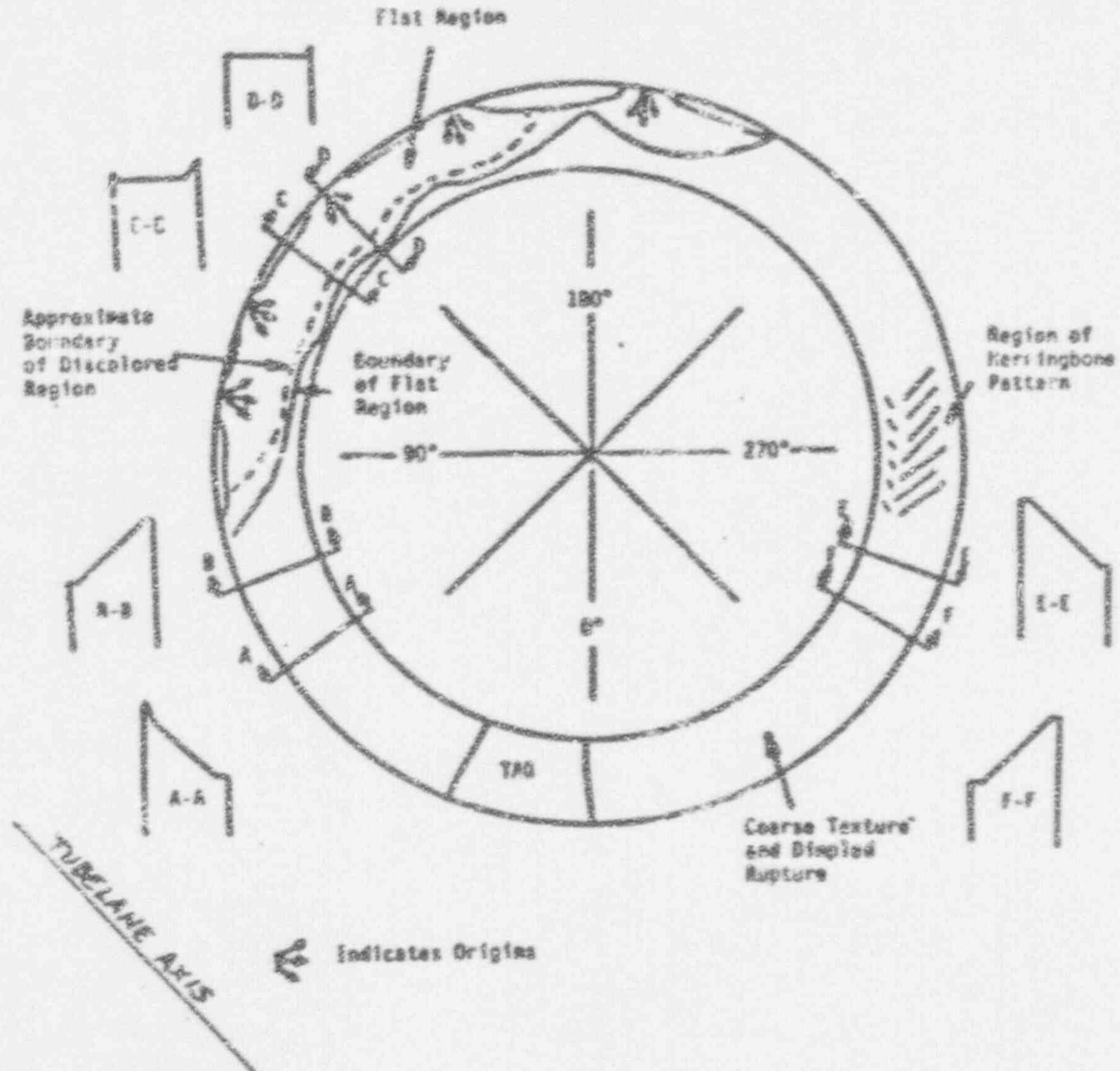
RECOMMENDATIONS TO ALL UTILITIES

- CONFIRM DENTING STATUS
- QUALIFY AVB POSITIONS
- REVIEW LEAK RATE MONITORING
- TECHNICAL MEETING

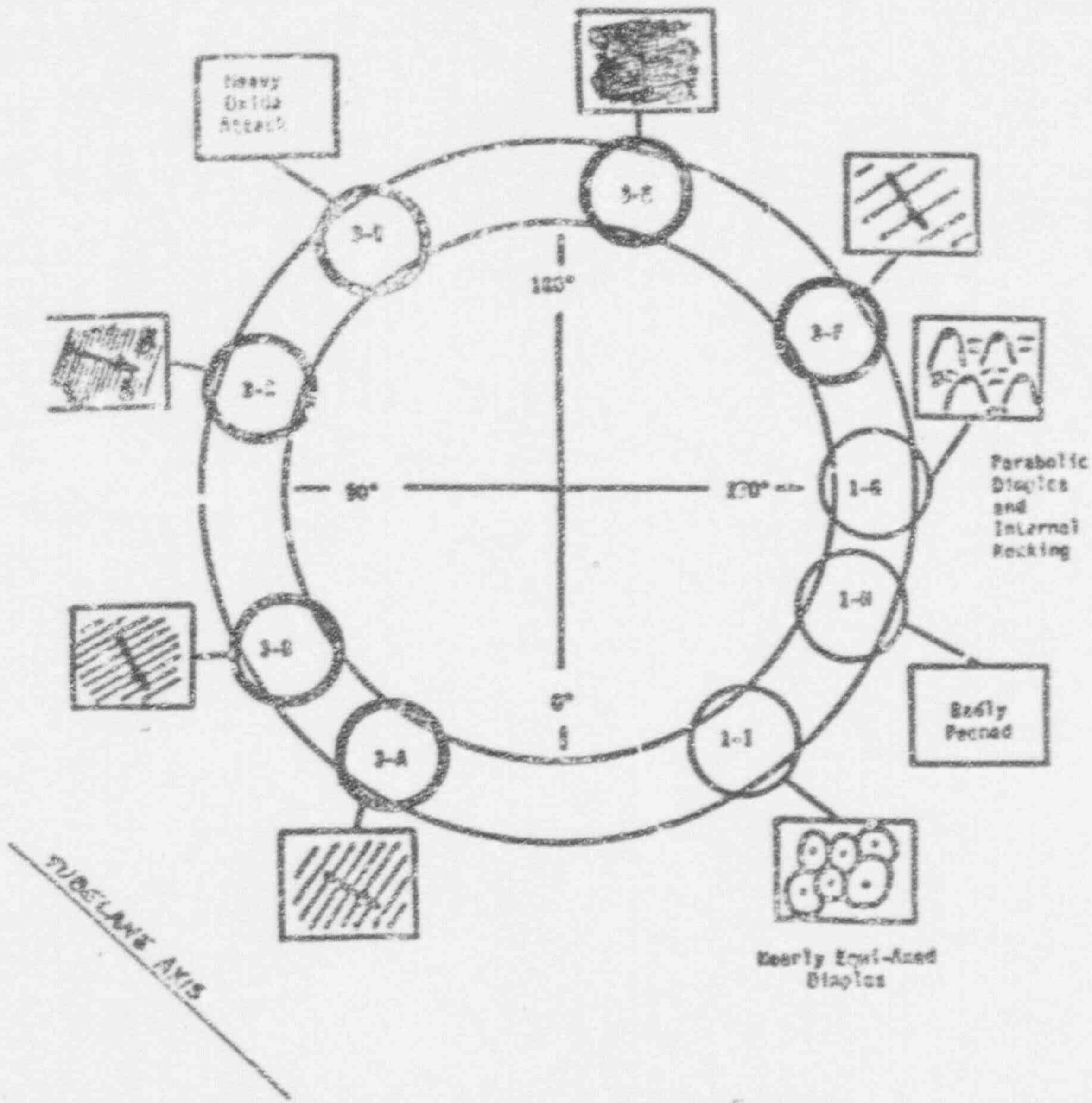
ON-GOING GENERIC ACTIVITIES

- TECHNICAL DEVELOPMENTS
- ADDITIONAL INFORMATION DEMONSTRATES THE CONSERVATISMS OF THE NO. ANNA CRITERIA AND MODIFICATIONS

TEM FRACTOGRAPHIC EXAMINATION OF SURFACE



R9C51 FRACTURE SURFACE MAPPING



Note: Arrows Indicate Direction of Fracture Propagation

TUBE EXAM CONCLUSIONS

- TUBING HAS EXPECTED PHYSICAL AND METALLURGICAL PROPERTIES

- FATIGUE INITIATION APPROXIMATELY 90 DEGREES FROM U-BEND PLANE

- CIRCUMFERENTIAL FATIGUE CRACK PROPAGATION

- LEAKAGE BELIEVED TO HAVE INITIATED IN A LOCALIZED REGION IN THE AREA OF FATIGUE INITIATION

Stress Amplitude for Crack Initiation is Based on Measurements Taken from the Examination of the Pulled Tube

Striation Spacings (S)

→ Correlation Equation

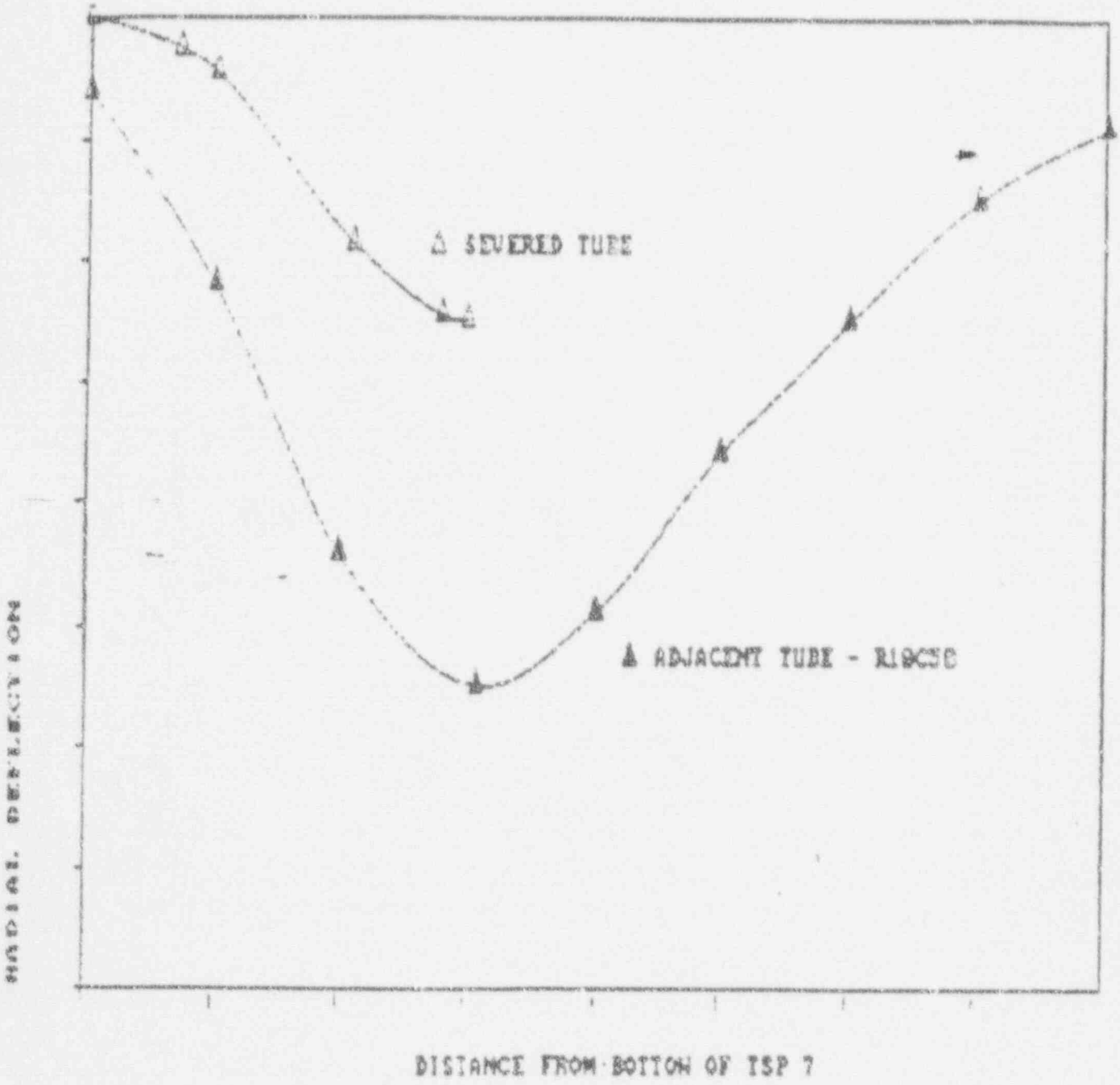
→ Range of Stress Intensity Factors (ΔK)

→ Stress Analysis

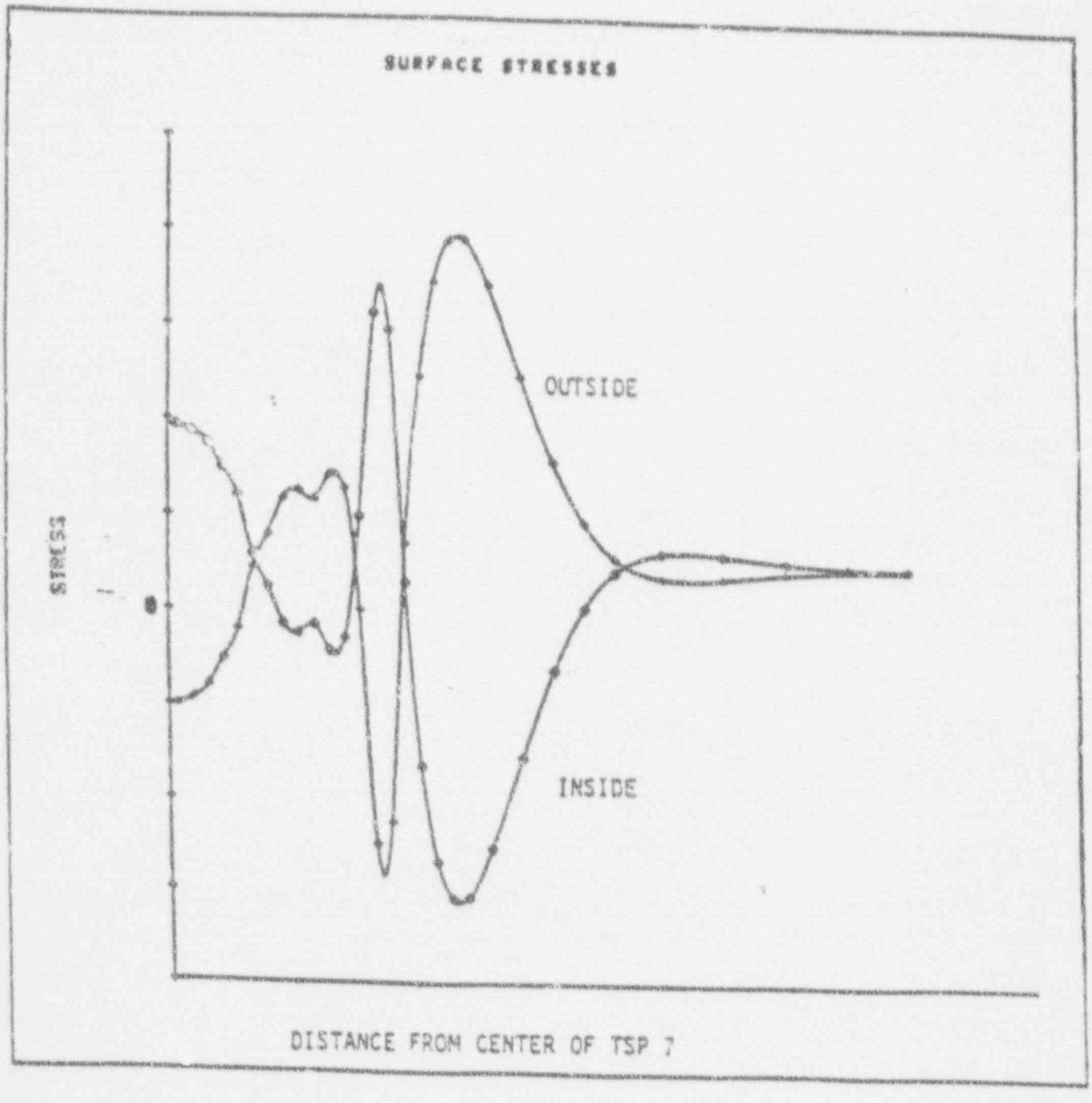
→ Stress Amplitude at Crack Origin

Result: 4 KSI $< \sigma_A <$ 10 KSI

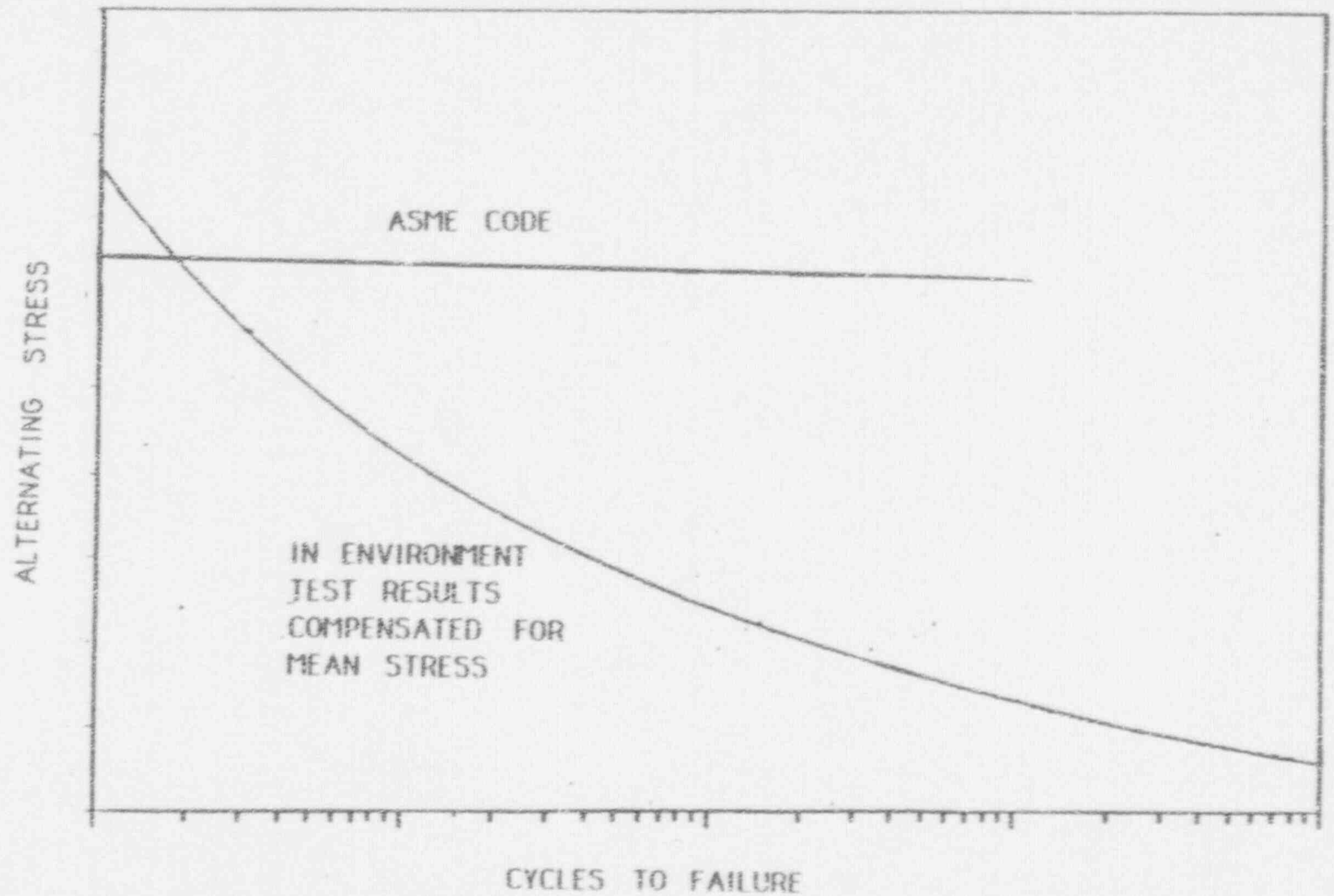
DENTED TUBE PROFILES



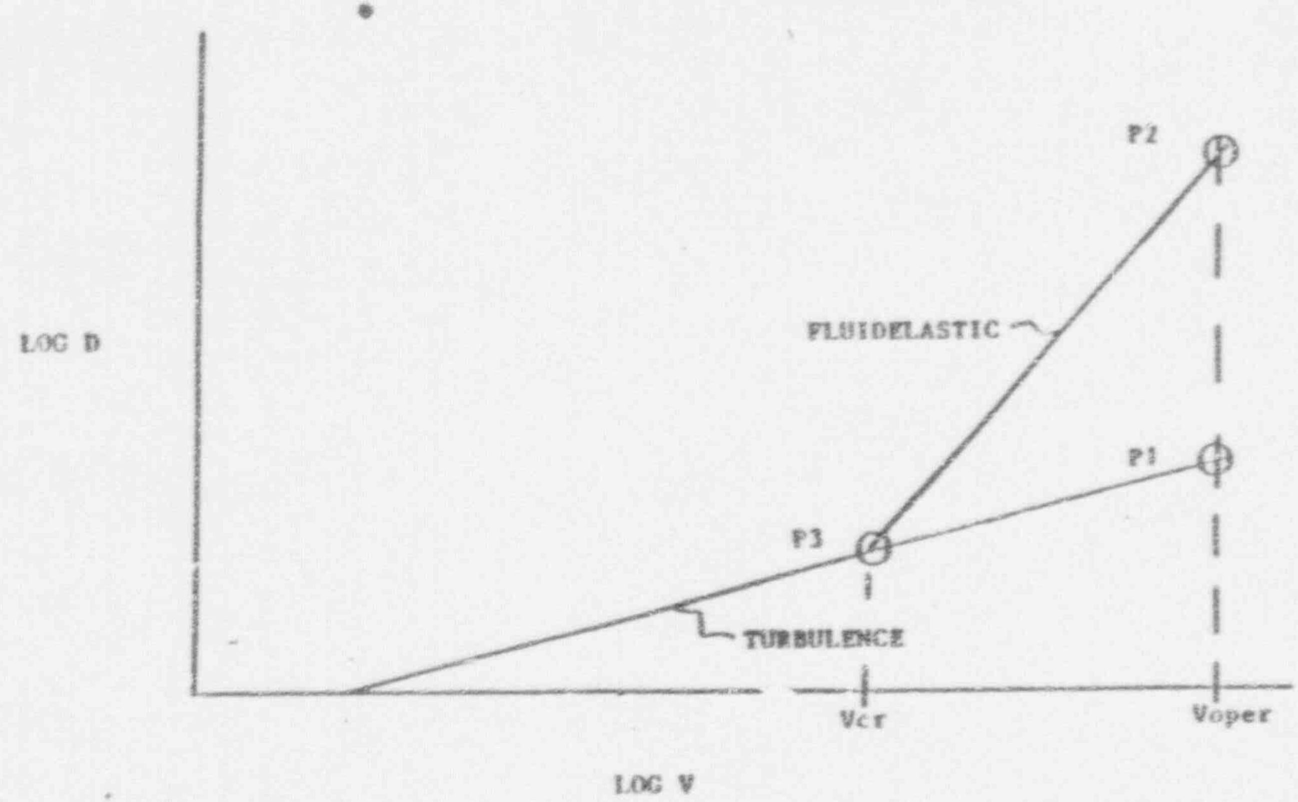
DENTED TUBE SURFACE AXIAL STRESSES



INCONEL 600 FATIGUE CURVES



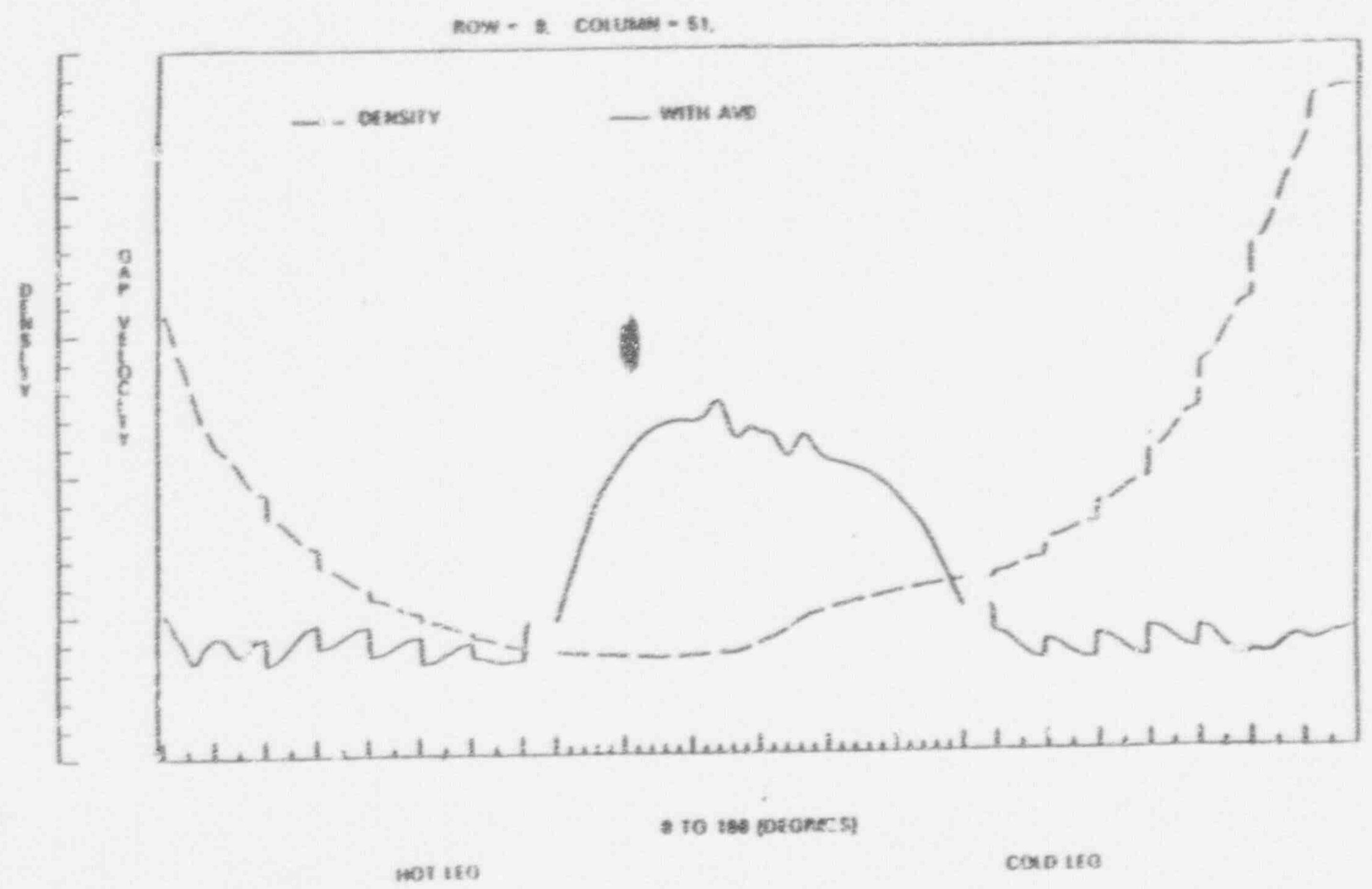
VIBRATION DISPLACEMENT - VELOCITY RELATIONSHIP



R9C51 STABILITY RATIO EVALUATION

CONDITION	EVALUATED STABILITY RATIO
NOMINAL	LESS THAN 1.0
NOMINAL, PLUS CORRELATION VARIATIONS	LESS THAN 1.0
LOCAL VELOCITY EFFECTS PLUS DAMPING REDUCTION	GREATER THAN 1.0

U-BEND THERMAL-HYDRAULIC DISTRIBUTIONS

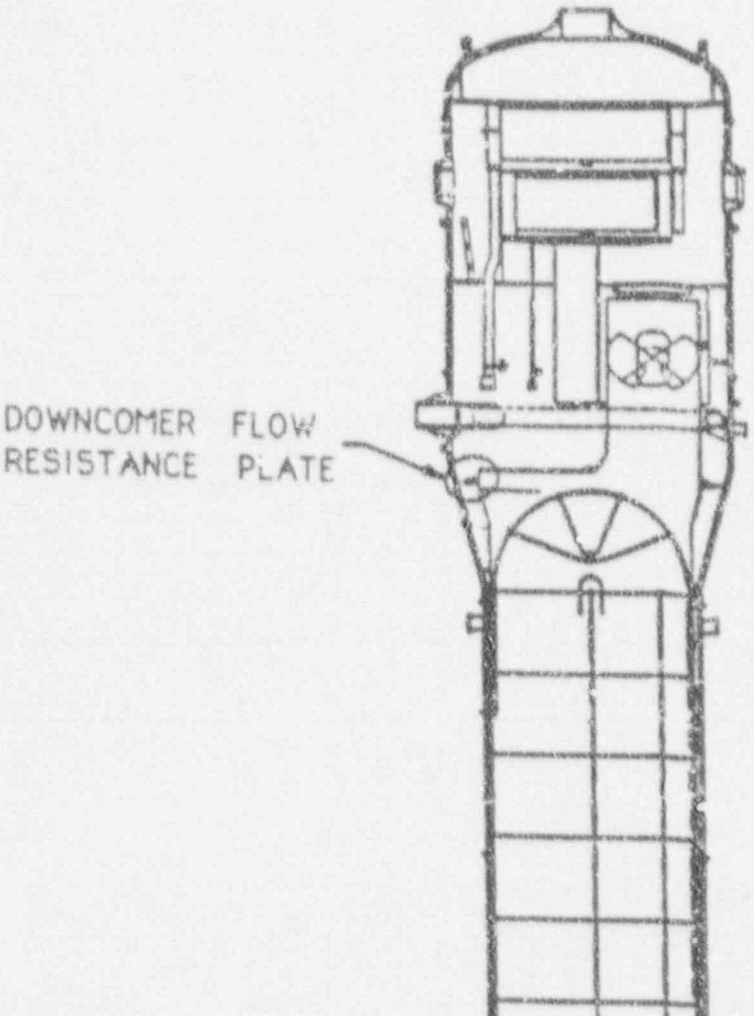


DAMPING REDUCTION DUE TO DENTING

TUBE DAMPING VS SUPPORT CONDITION

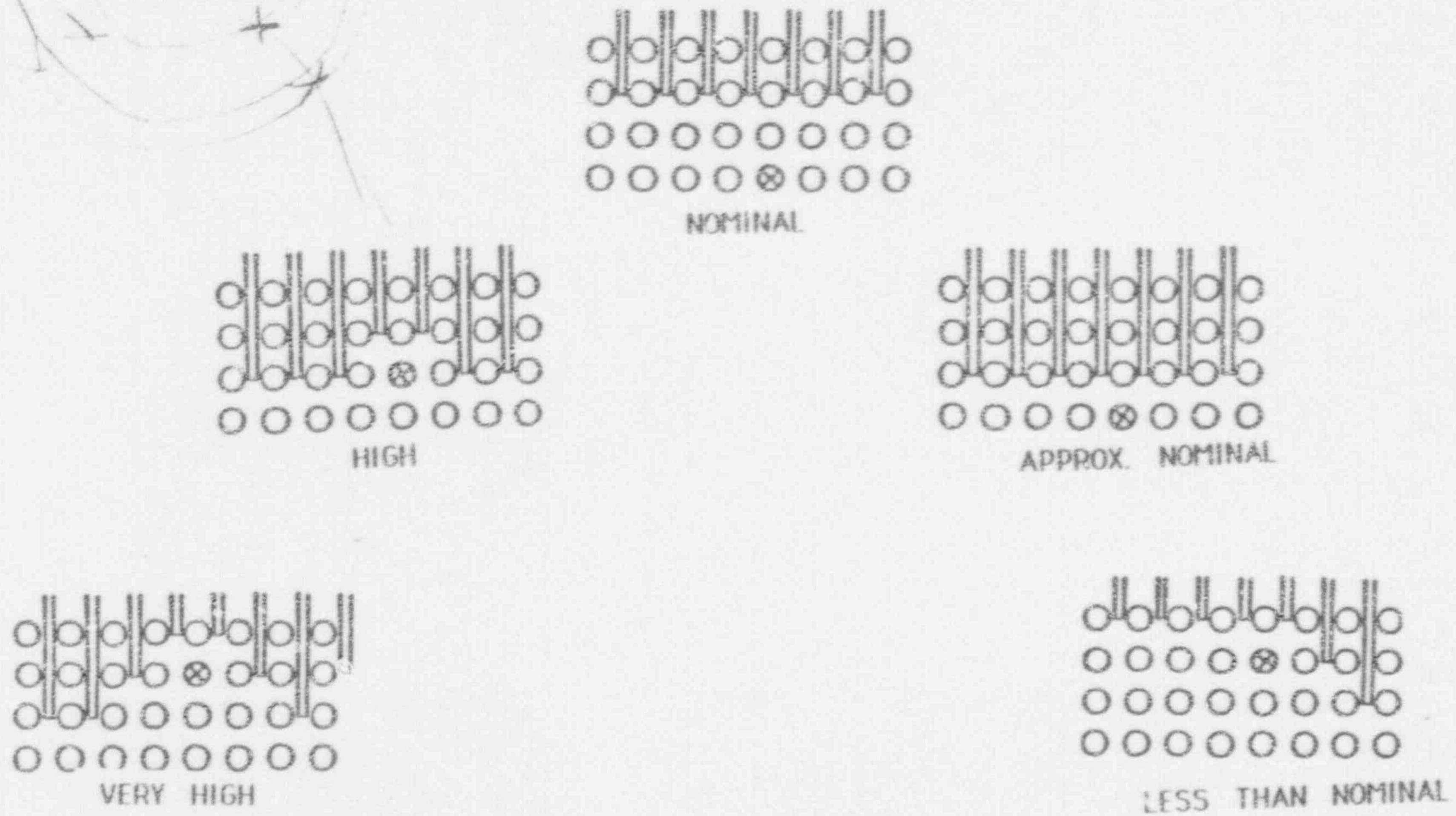
SUPPORT CONDITION	TUBE DAMPING REDUCTION
PINNED, (ROTATION ALLOWED)	0%, (NOMINAL CONDITION)
CLAMPED, (NO ROTATION)	-65%
CLAMPED, (NO ROTATION, NO FLUID DAMPING IN U-BEND)	-90%

DOWNCOMER FLOW RESISTANCE PLATE LOCATION

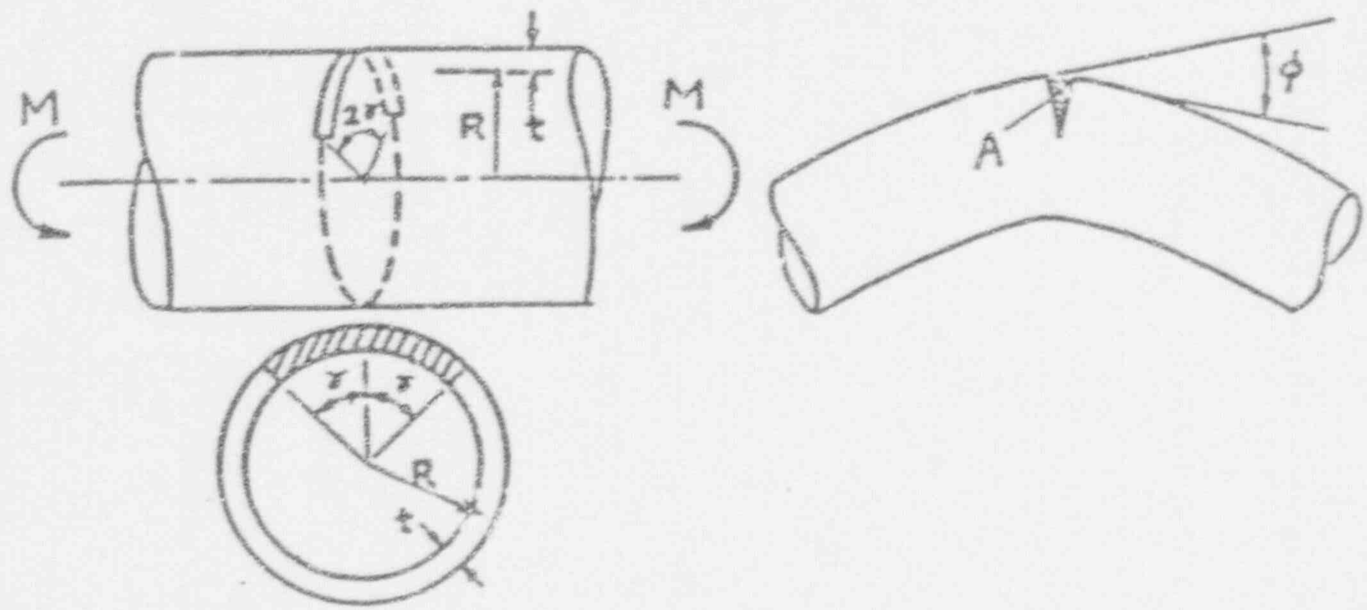


FLOW PEAKING VIBRATION TEST RESULTS

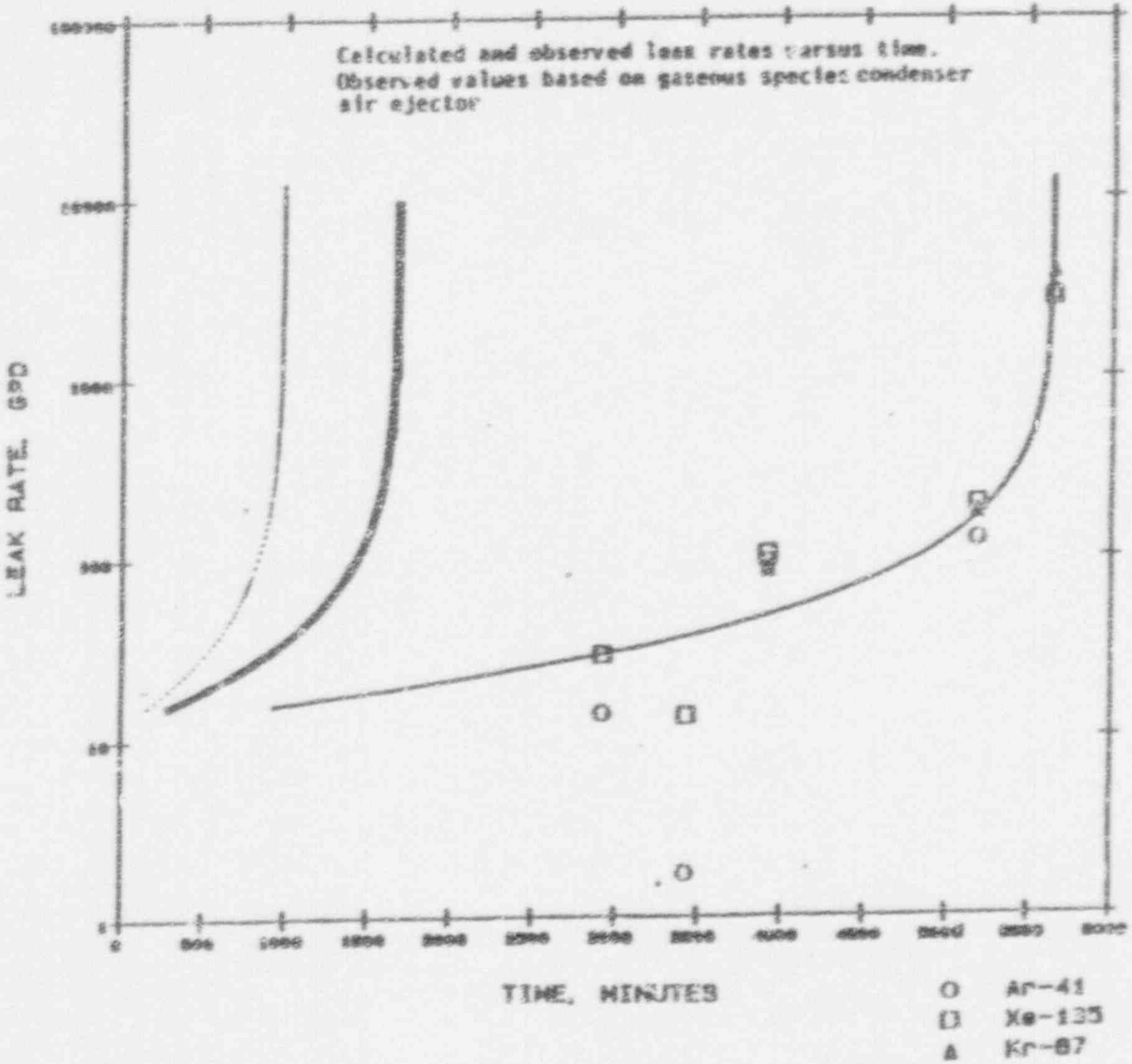
GEOMETRY PEAKING FACTOR RELATIONSHIPS



CRACK GROWTH MODEL SCHEMATIC



MODEL RESULTS COMPARED TO LEAKAGE DATA



MULTIPLE TUBE RUPTURE CONSIDERATIONS

FATIGUE PROCESS - SIGNIFICANT INITIATION PERIOD

1. Stage I

   A. Localized Plastic Straining
      Occurs very early in the cyclic life

   B. Formation of "persistent slip bands"

   C. Formation of "extrusions & intrusions" at the surface

2. Stage II

   A. Formation of a "micro-crack"

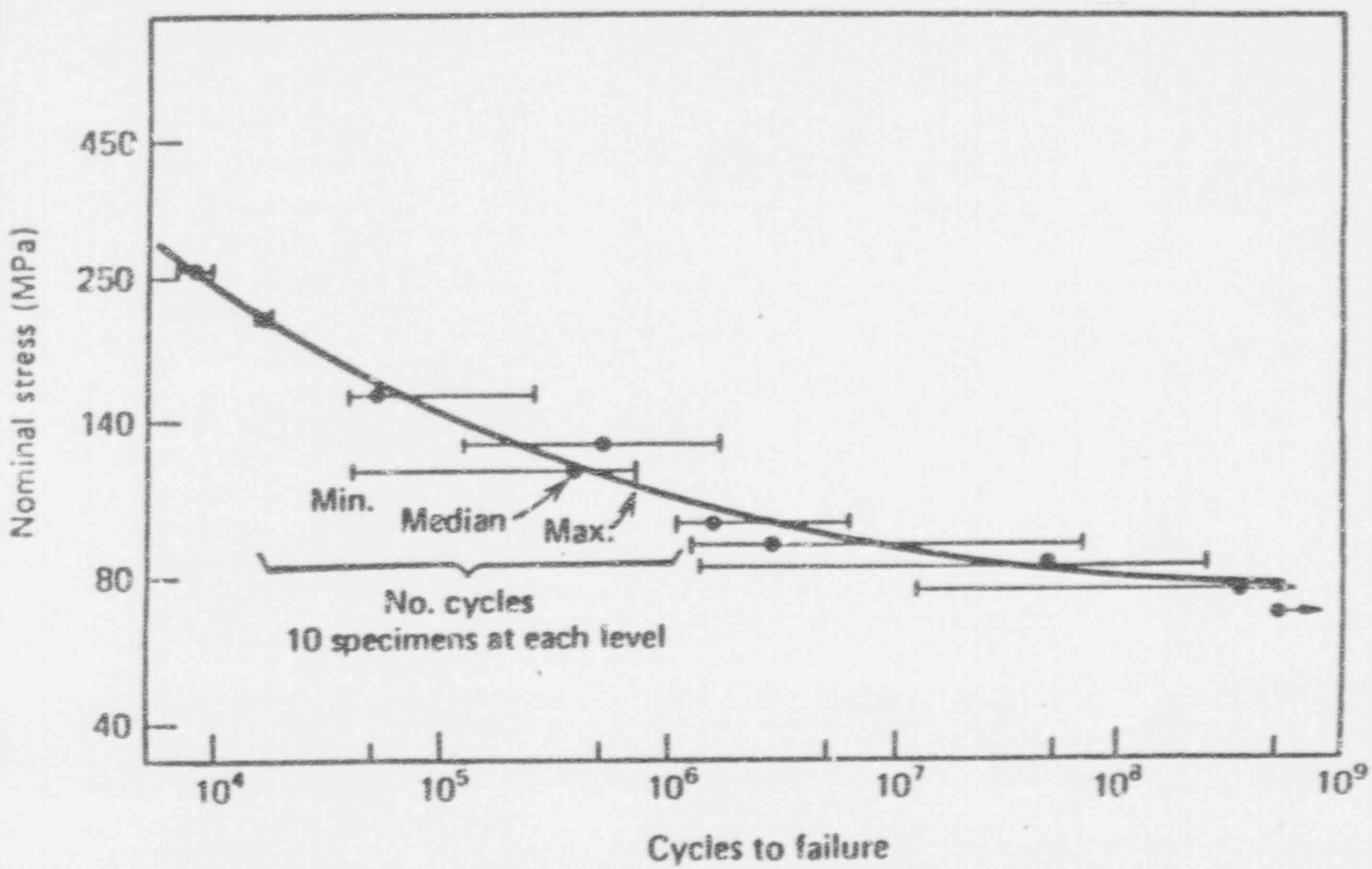
      1) Within plastically hardened slip zone

   B. Growth into a "macro-crack"

      1) Rules of LEFM apply

MULTIPLE TUBE RUPTURE CONSIDERATIONS

FATIGUE PROCESS - VARIABLE BEHAVIOR



MULTIPLE TUBE RUPTURE CONSIDERATIONS
FATIGUE PROCESS - MULTIPLE PARAMETERS

1. METALLURGICAL
   - A. FATIGUE, YIELD, & ULTIMATE TENSILE STRENGTH
   - B. STRAIN HARDENING CHARACTERISTICS
   - C. SURFACE FEATURES
   - D. LOCAL MATERIAL STRUCTURE
     - 1) GRAIN SIZE
     - 2) GRAIN ORIENTATION
   - E. FABRICATION HISTORY
     - 1) RESIDUAL STRESSES
     - 2) WORK HARDENING
     - 3) PRIOR FATIGUE DAMAGE

2. GEOMETRY
   - A. TUBE
     - 1) MOMENT OF INERTIA
       - A) DIAMETER
       - B) THICKNESS
       - C) LOCAL THICKNESS VARIATIONS
     - 2) STRUCTURAL DAMPING
     - 3) U-BEND RADIUS
     - 4) LOCAL SURFACE IMPERFECTIONS
   - B. ENVIRONMENT
     - 1) LEVEL OF DENTING
     - 2) ORIENTATION OF DENTING
     - 3) PROXIMITY OF AVB'S
     - 4) PROXIMITY OF NEIGHBOR TUBES
       - A) TSP HOLE LOCATIONS

3. LOADING
   - A. LOCAL FLOW FIELD VARIATIONS
     - 1) RESPONSE OF NEIGHBORING TUBES
     - 2) POSITION IN THE TUBE BUNDLE
   - B. SG LOADING HISTORY
     - 1) SG TO SG FLOW VARIATIONS

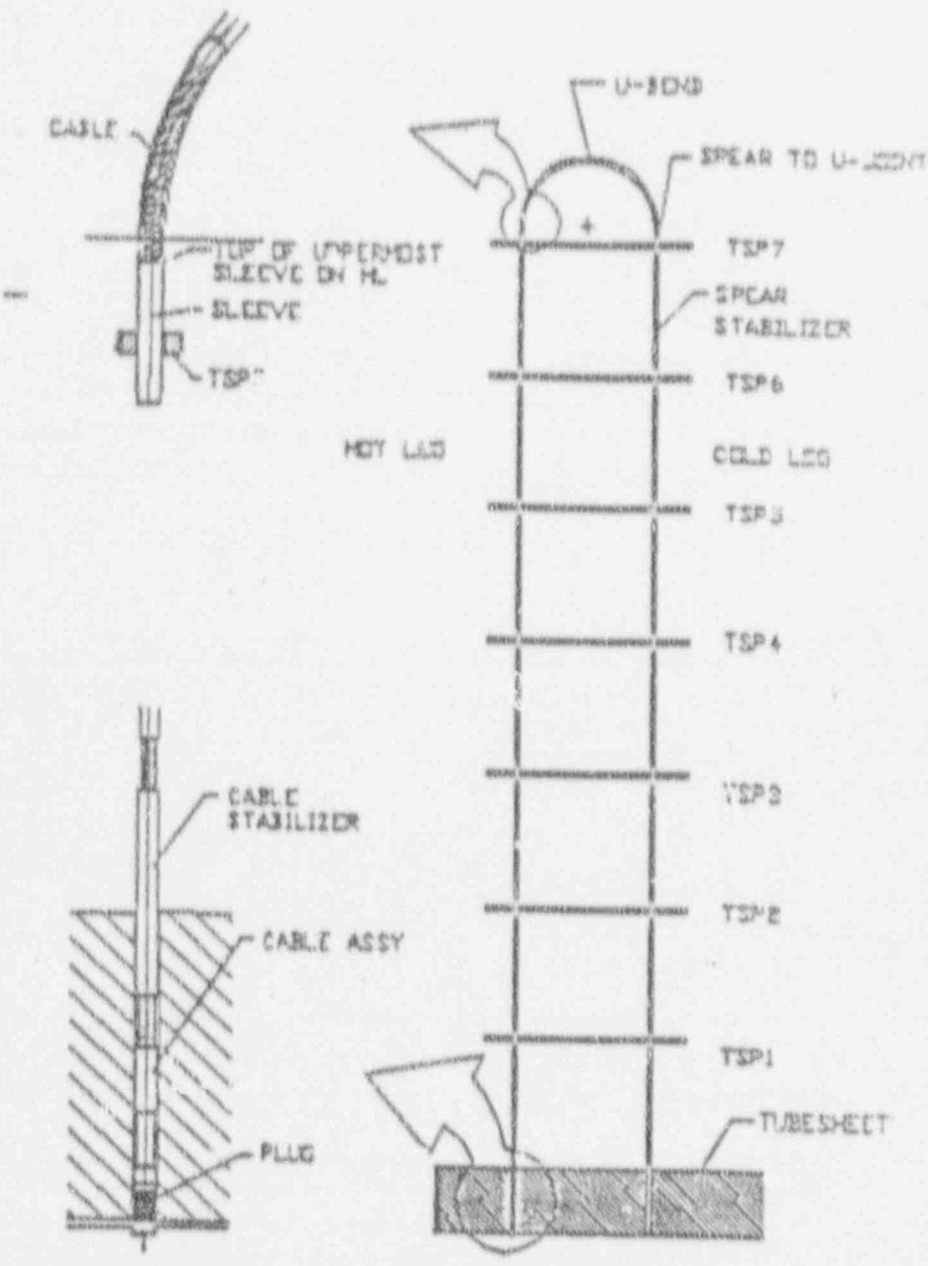
ACCEPTANCE CRITERIA BOUNDING ANALYSIS

RANGE OF INITIATING STRESS AMPLITUDES CAN BE BOUNDED BY --

- TOTAL TIME OF OPERATION WHICH GIVES A LOWER BOUND ALTERNATING STRESS AMPLITUDE, 5.6 KSI.

- MAXIMUM STRESS DERIVED FROM FRACTURE ANALYSIS AND SHORTER EFFECTIVE INTERVAL WHICH GIVES A UPPER BOUND ALTERNATING STRESS AMPLITUDE, 9.5 KSI.

R9C51 HOT LEG CABLE STABILIZER



Acceptance Criteria

Assessment of Future Fatigue Usage

- Minimum stress case with a 5% reduction in stability ratio,

  $\sigma_2 = 3.95$ KSI

  $U \approx 0.0207$ per year

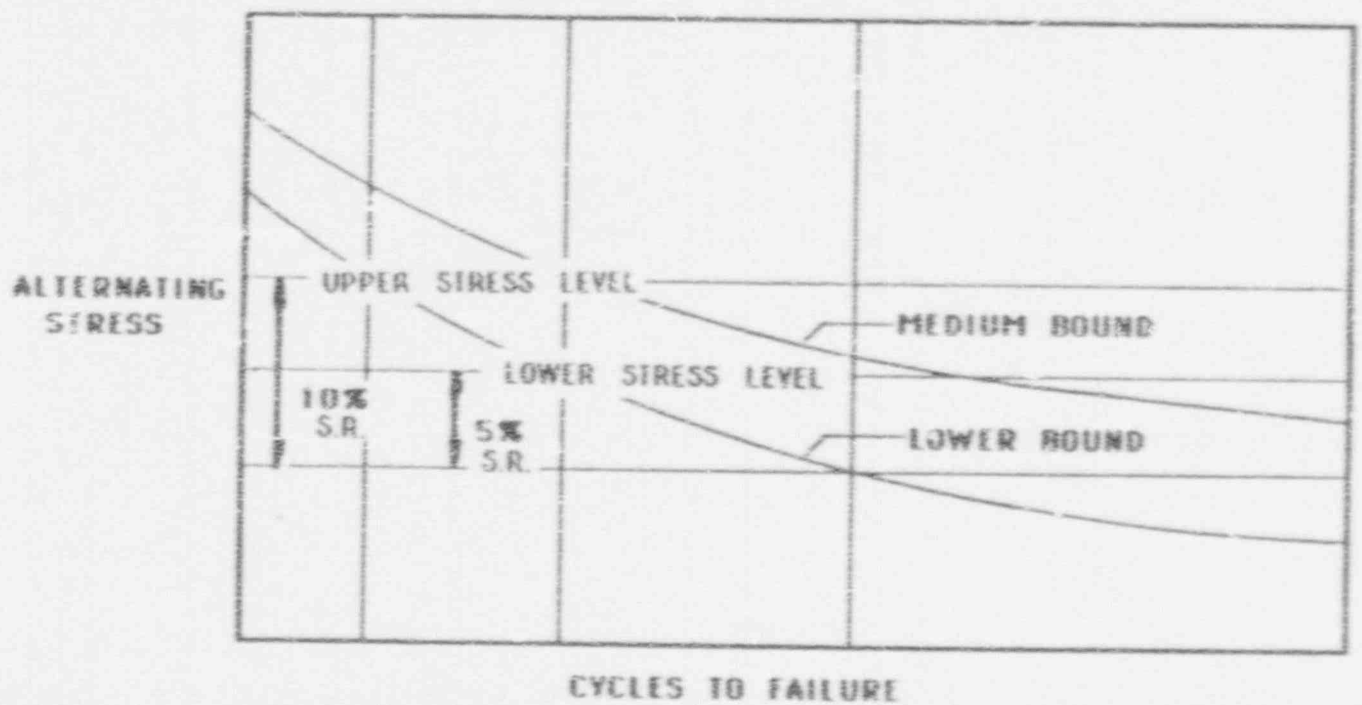
- Maximum stress case with a 10% reduction in stability ratio,

  $\sigma_2 = 3.96$ KSI

  $U = 0.0209$ per year

STABILITY RATIO REDUCTION RESULTS

STABILITY RATIO - ALTERNATING STRESS REDUCTION



NO. ANNA S.G. MODIFICATIONS

R9C51 TUBE STABILIZATION

- RESTORE INTEGRITY TO R9C51 U-BEND

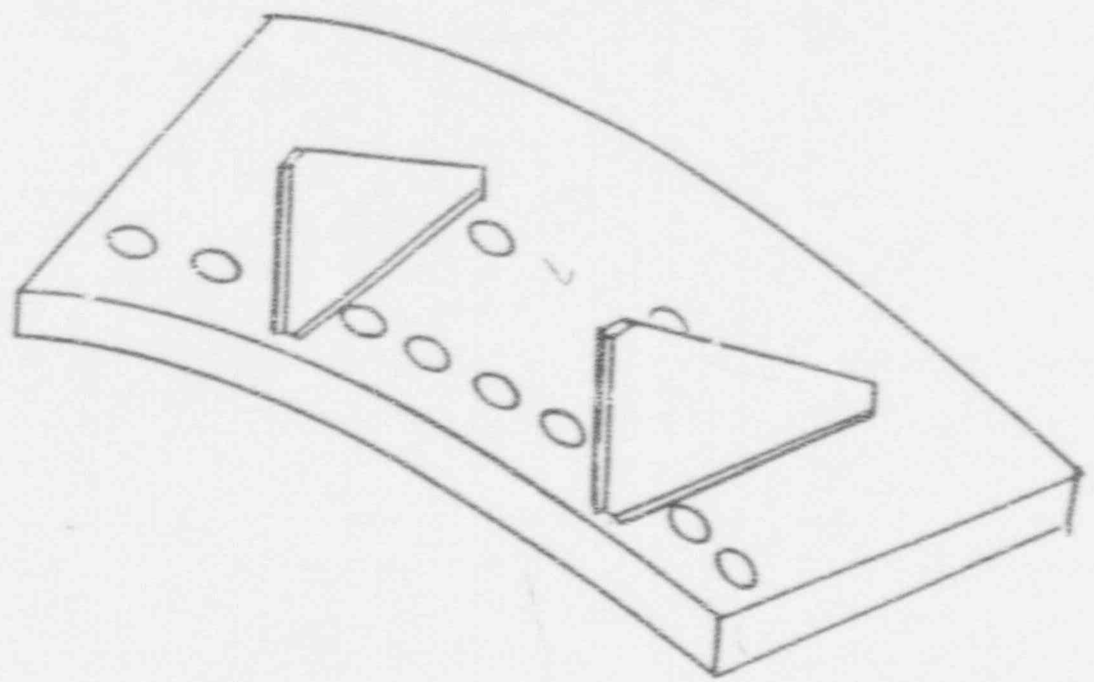
DOWNCOMER FLOW RESISTANCE PLATE

- REDUCE VIBRATION LOADS

PREVENTIVE PLUGGING

- INCORPORATE ADDITIONAL MARGIN

DOWNCOMER FLOW RESISTANCE PLATE SCHEMATIC



DOWNCOMER FLOW RESISTANCE PLATE EXPERIENCE

INTRODUCED IN EARLY S.G. FOR CIRCULATION CONTROL

- THERMAL HYDRAULIC STABILITY
- MOISTURE SEPARATOR LOADING
- MIX OF CONFIGURATIONS OPERATING

PRIOR EXPERIENCE

- CIRCULATION RATIO (CR) RANGES FROM LOW 2'S TO OVER 5
- IN-BUNDLE INSTRUMENTATION EXPERIENCE THROUGHOUT THE CR RANGE

NO. ANNA DESIGN SELECTION

- MAXIMIZE REDUCTION IN VIBRATION LOADS
- STAY WITHIN PRIOR EXPERIENCE BASE

DOWNCOMER FLOW RESISTANCE PLATE
STABILITY RATIO IMPROVEMENT
SENSITIVITY STUDY

ASSUMPTION(S)	STABILITY RATIO REDUCTION
NO TWO-PHASE DAMPING EFFECTS	22%
REDUCED TWO-PHASE DAMPING EFFECTS	13 - 15%
NOMINAL TWO-PHASE DAMPING EFFECTS	8%

PREVENTIVE TUBE PLUGGING

NO. ANNA UNIT 1 PLUGGING TOTALS

	S.G. 'A'	S.G. 'B'	S.G. 'C'
NO AVB SUPPORT IN ROWS ≥9	12	3	9
ADDITIONAL BASED ON CONSERVATIVE ASSUMPTIONS	68	9	61

SENTINEL TUBE PLUG

- STANDARD TUBE PLUG WITH ORIFICE OPENING
- ORIFICE SIZE SELECTED FOR DESIRED FLOWRATE
- PROVIDES FOR ON-GOING INTEGRITY MONITOR

GENERIC CONSIDERATIONS

- INFORM OWNERS OF (W) PLANTS
- CRITICAL INFORMATION RECOMMENDATIONS
- PLANT CHARACTERIZATION STUDY
- MEET PLANT SPECIFIC NEEDS

RELATIVE FLUIDELASTIC STABILITY RATIOS

Compare relative susceptibility to fluidelastic instability

- Relative to stability ratio (SR) for North Anna 1 (VRA)
- SR = Fluidelastic stability ratio

$$SR = \frac{U_{effective}}{U_{critical\ at\ onset\ of\ instability}}$$

$$\left(\frac{SR_{plant}}{SR_{VRA}}\right) = \left(\frac{(\rho v^2)^{1/2}\ plant}{(\rho v^2)^{1/2}\ VRA}\right) \cdot \left(\frac{(m_{VRA})^{1/2}}{(m_{plant})^{1/2}}\right) \cdot \left(\frac{f_n\ VRA}{f_n\ plant}\right) \cdot \left(\frac{(\zeta_{VRA})^{1/2}}{(\zeta_{plant})^{1/2}}\right)$$

- Where:

ρ, v = Average U-bend density and radial gap velocity

= F (tube bundle geometry, Ps, Ws, circ ratio)

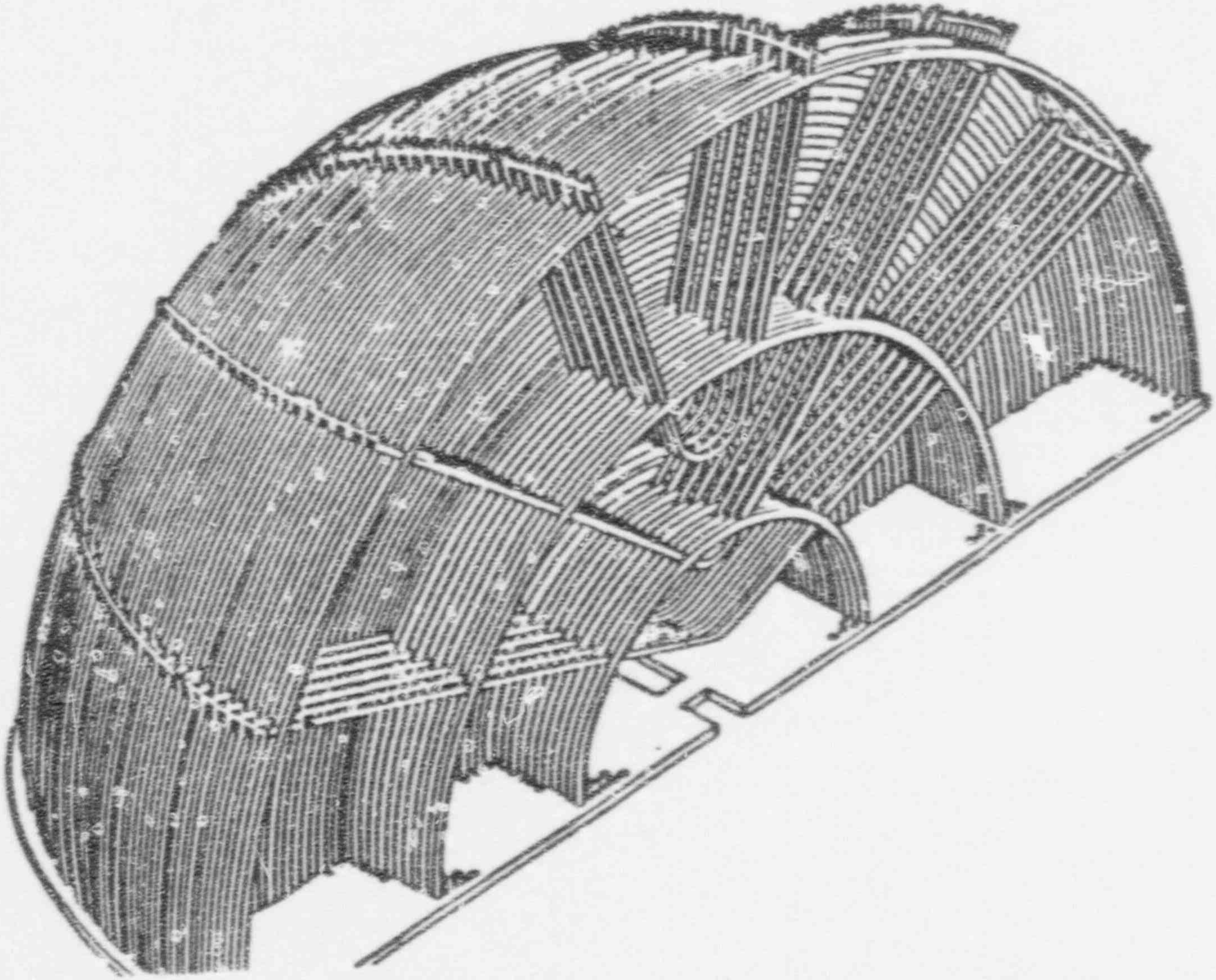
m = Tube incremental mass

= $(M_{tube} + M_{primary} + M_{secondary})$/length in a unit cell

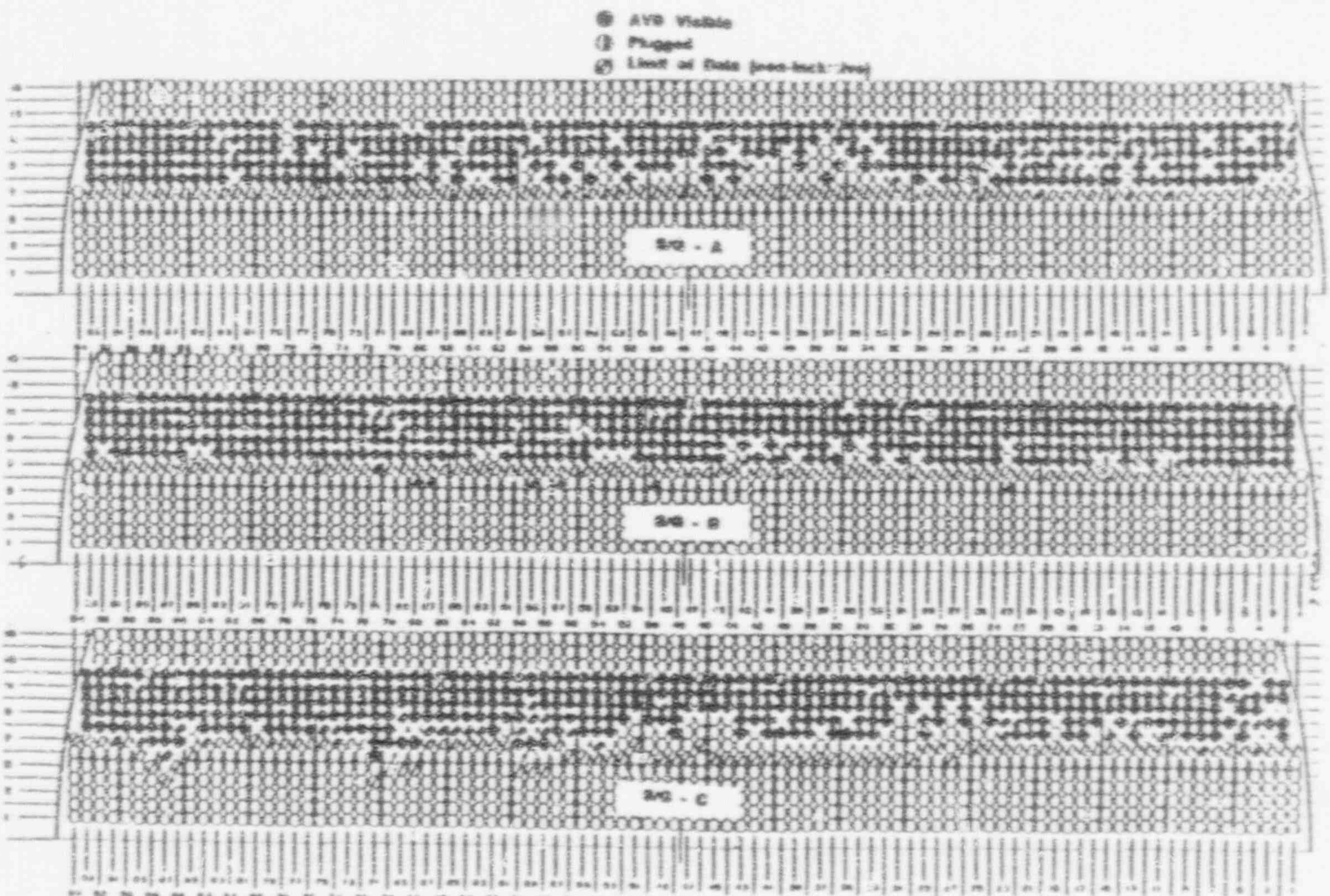
f_n = Tube natural frequency calculated for clamped condition

ζ = Damping, % of critical

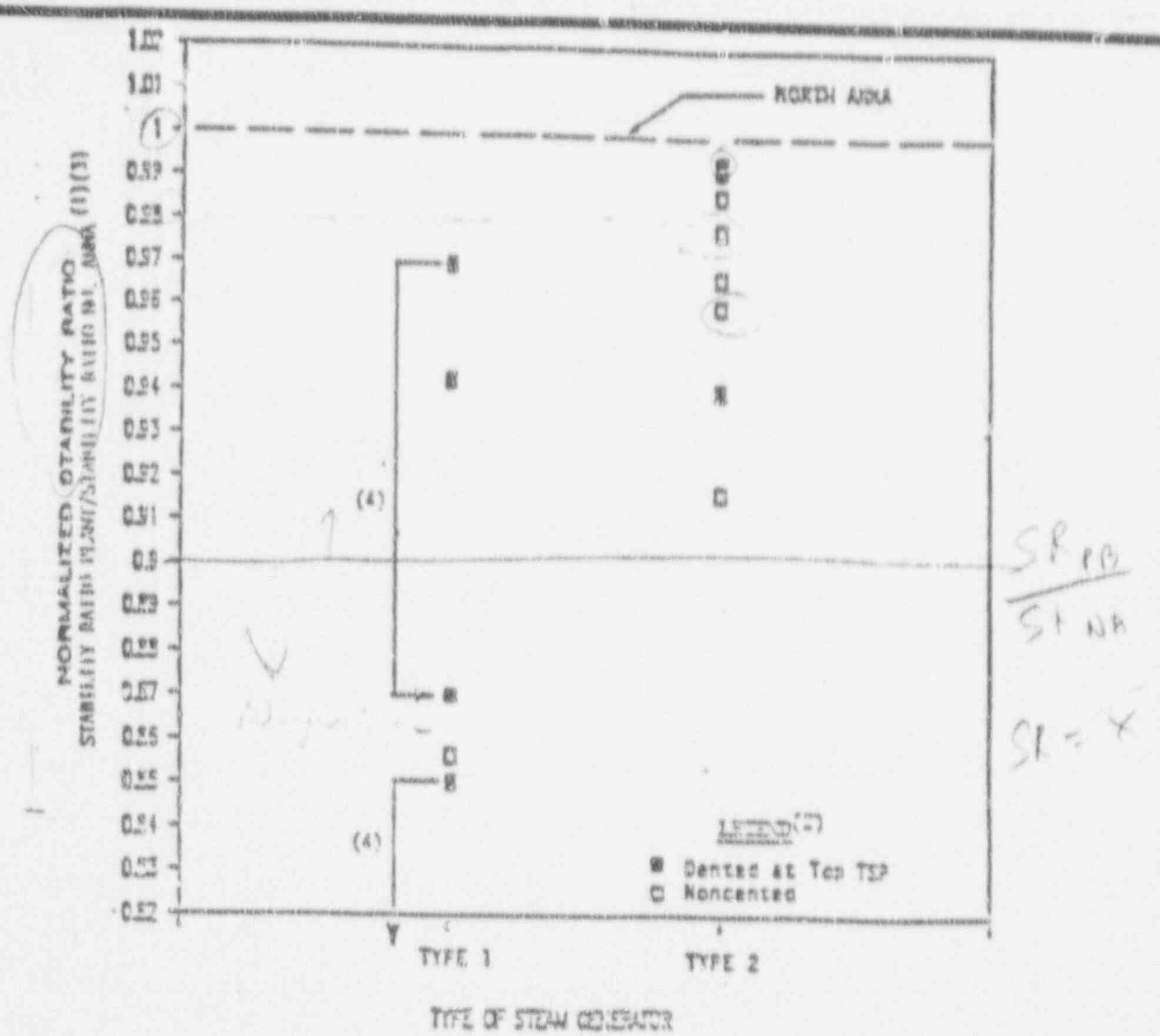
ANTI-VIBRATION BAR ARRANGEMENT



AVB POSITIONS



LOADING EVALUATION - NORMALIZED STABILITY RATIO



1. Evaluation based upon nominal power capability parameters and plant data where available.

2. Denting status based upon Westinghouse information of known conditions.

3. Configuration based upon Westinghouse records and plant data where available.

4. Revision from initial evaluation based on refined evaluation.

5. All type 3 S.G.'s have normalized stability ratios less than 0.7.

WESTINGHOUSE PLANT OWNER COMMUNICATIONS

(W) NOTIFICATION LETTER

- SEPTEMBER 1987
- PLANT CHARACTERIZATION IDENTIFIED
- STRESSED QUANTIFICATION OF S.G. CONDITIONS
  - TOP TUBE SUPPORT PLATE DENTING
  - AVB POSITIONS
  - REVIEW LEAKAGE MONITORING

(W) TECHNICAL MEETING

- OCTOBER 1987
- ALL (W) PLANT OWNERS INVITED
- DETAILED TECHNICAL SEMINAR
- VA. POWER PARTICIPATED IN PRESENTATION
- STRESSED UNDERSTANDING OF PHENOMENA
  - RESULTS OF DENTING
  - VIBRATION CONSIDERATIONS
  - INSPECTION PARAMETERS

ON-GOING TECHNICAL ACTIVITIES

ALTERNATING STRESS LEVEL FOR R9C51 TUBE

THRESHOLD STRESS FOR CRACK GROWTH

DAMPING TESTS, DENTED SUPPORT REQUIREMENTS

VIBRATION TESTS, FLOW PEAKING FACTORS

Cumulative Fatigue Usage for Row 9 Column 51

Fuel Cycle	Stability Ratio	Normalized Alternating Stress	Days	Cycles at 60 Hz
a. 6u, 7u	1.0	1.0	170	8.813×10^8
b. 2,3,4	0.995	0.970	898	4.655×10^9
c. 6, 6u (95)	0.961	0.788	204	1.058×10^9
d. 2(95), 3(95),4(95)	0.949	0.728	25	1.296×10^8
e. 5,6(95), 6u(90), 7u(90)	0.937	0.678	349	1.809×10^9
Total cycles				8.533×10^9

A cumulative fatigue usage of 1.0 is obtained for a most recent stress amplitude of 6660 psi and the most cumulative usage occurred during the second to the fourth fuel cycles.

Fuel Cycle	Alternating Stress	N	n/N
a.	6660	5.489×10^9	0.161
b.	6460	6.392×10^9	0.728
c.	5250	1.773×10^{10}	0.060
d.	4850	2.600×10^{10}	0.005
e.	4520	3.641×10^{10}	0.050
Total Usage			1.004

THRESHOLD STRESS AMPLITUDE FOR CONTINUED CRACK GROWTH

STRESS - STABILITY RATIO REDUCTION SELECTION

- BASED ON PROVIDING VERY LOW FUTURE USAGE
- R9C51 RECENT ALTERNATING STRESS ASSESSMENT SUGGESTS 10% REDUCTION EXCEEDS MINIMUM REQUIRED

EVALUATION OF CRACK GROWTH POTENTIAL

- STRESS LEVEL ASSOCIATED WITH ACCEPTANCE CRITERIA
- CRACK SIZE NEAR THAT ASSOCIATED WITH CONVENTIONAL INSPECTION METHOD DETECTION THRESHOLD
- STRESS LEVEL LOW ENOUGH TO PRECLUDE CRACK PROPOGATION

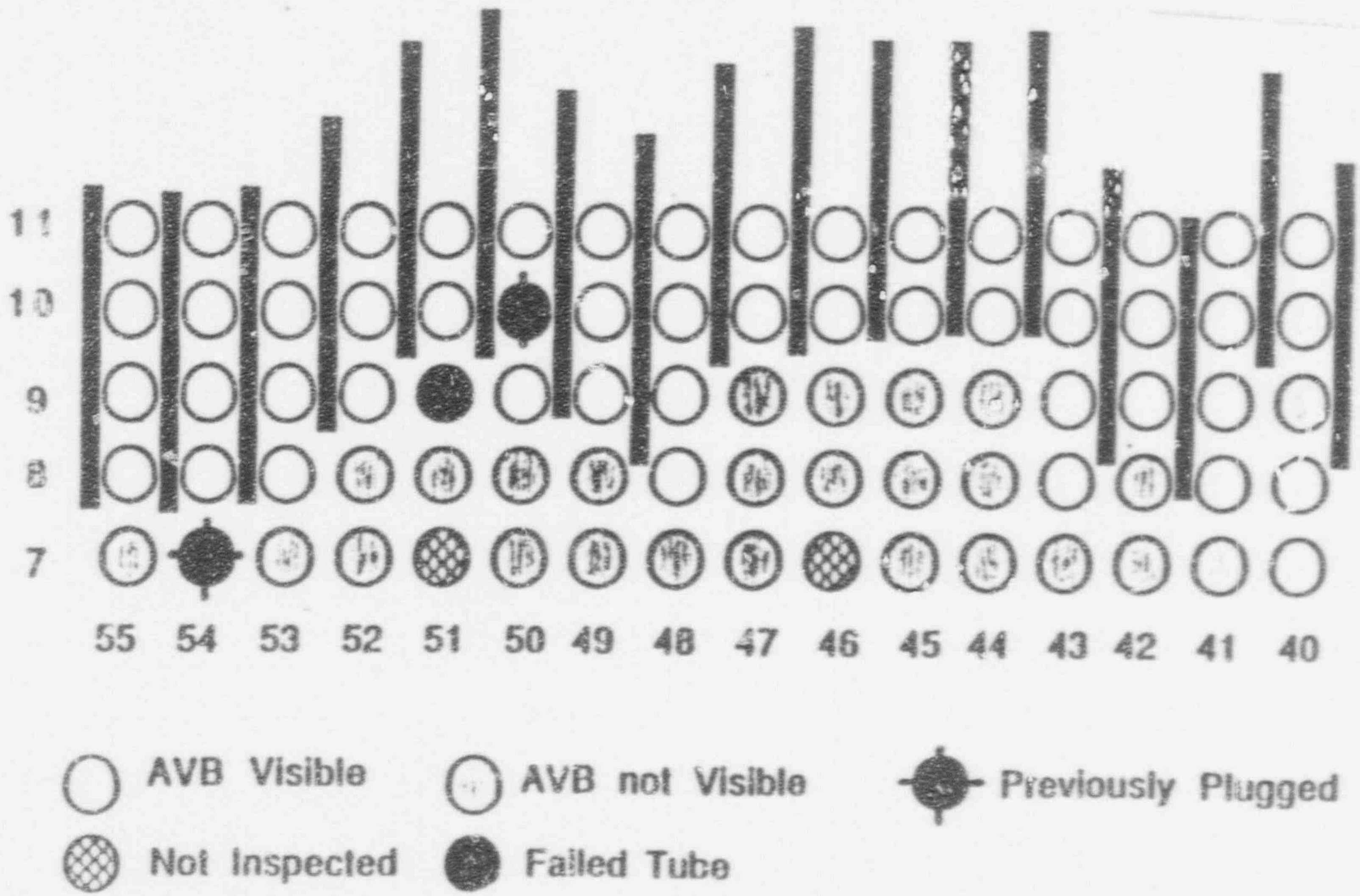
DAMPING TESTS, DENTED SUPPORT REQUIREMENTS

EVALUATION OF TUBE RESPONSE WITH ALTERNATIVE SUPPORT CONDITIONS --

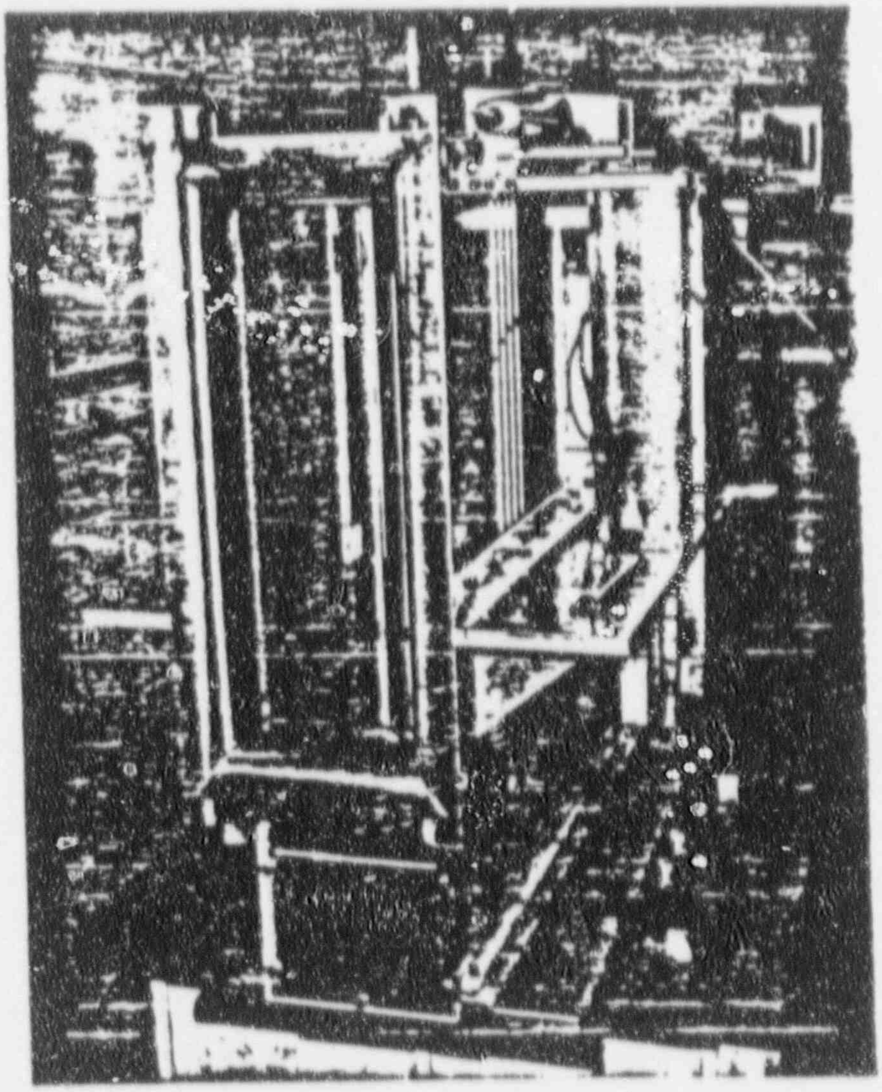
- CONFIGURATIONS
  - SMALL GAP
  - VARIABLE CLAMPING

- RESULTS
  - PRELIMINARY
  - PRONOUNCED TREND
  - RIGID CLAMPED CONDITION SHOWS SIGNIFICANT DAMPING REDUCTION COMPARED TO OTHERS

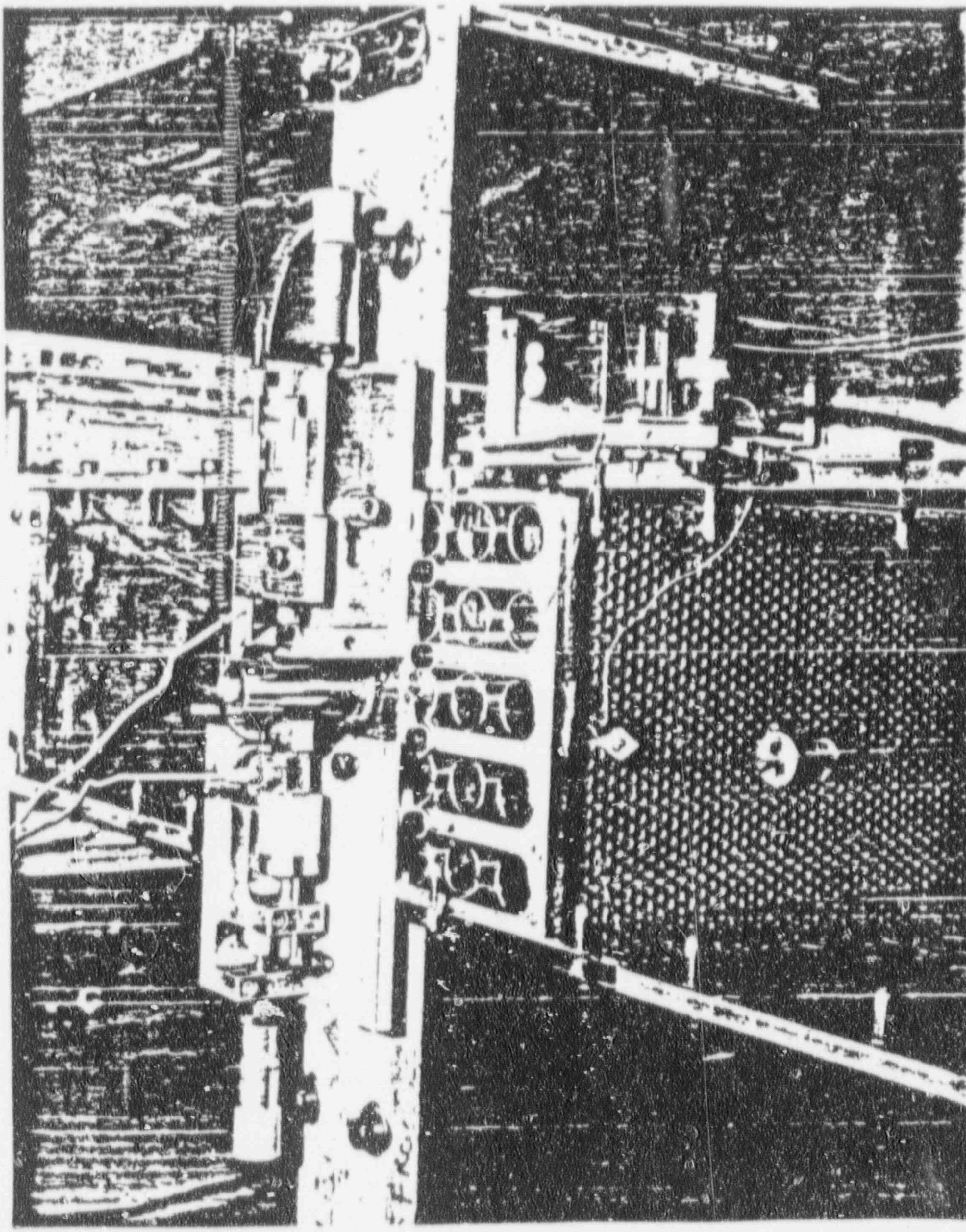
N. Anna : S/G - C
Tube Support Conditions



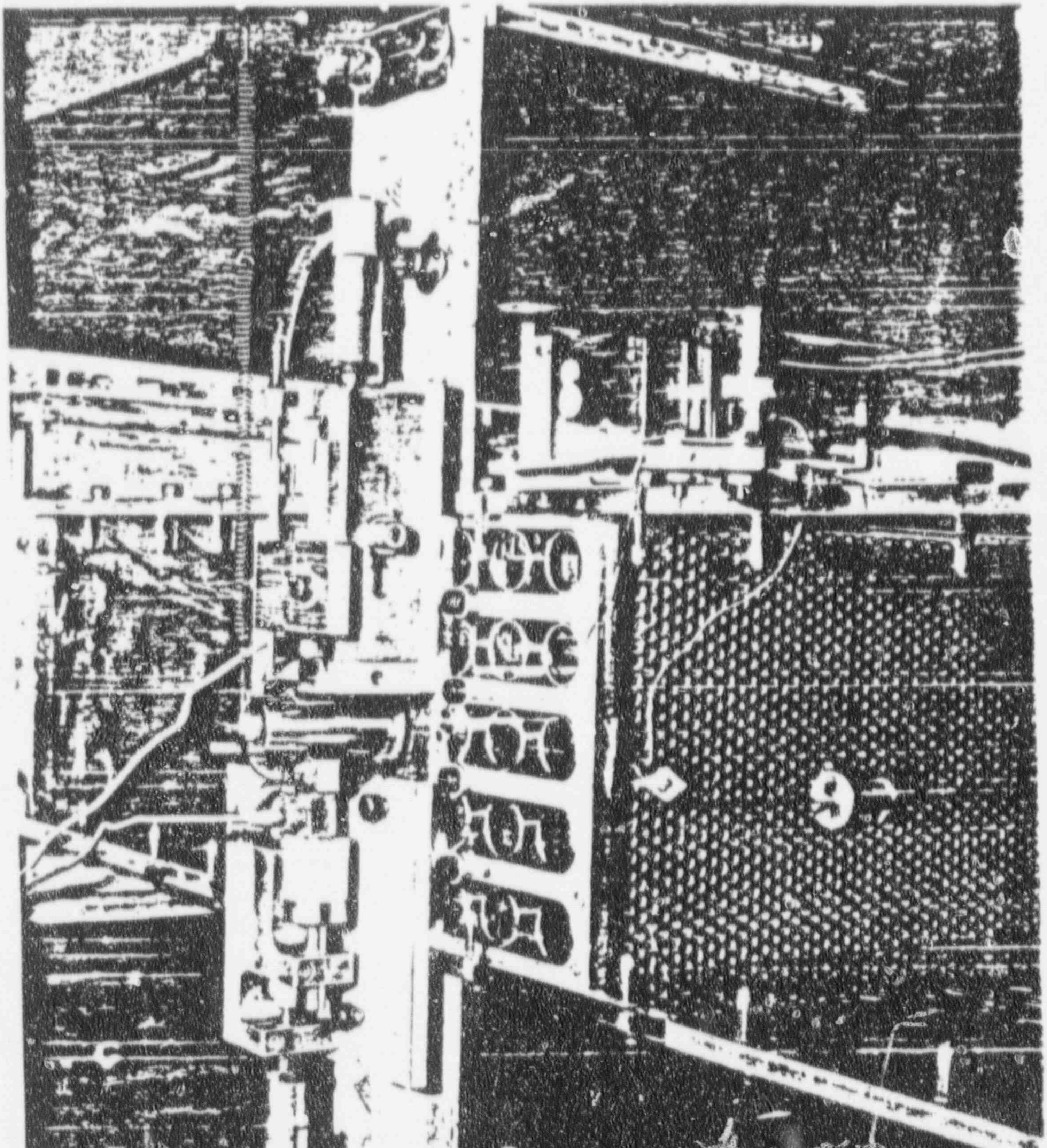
Obtain from Comm.

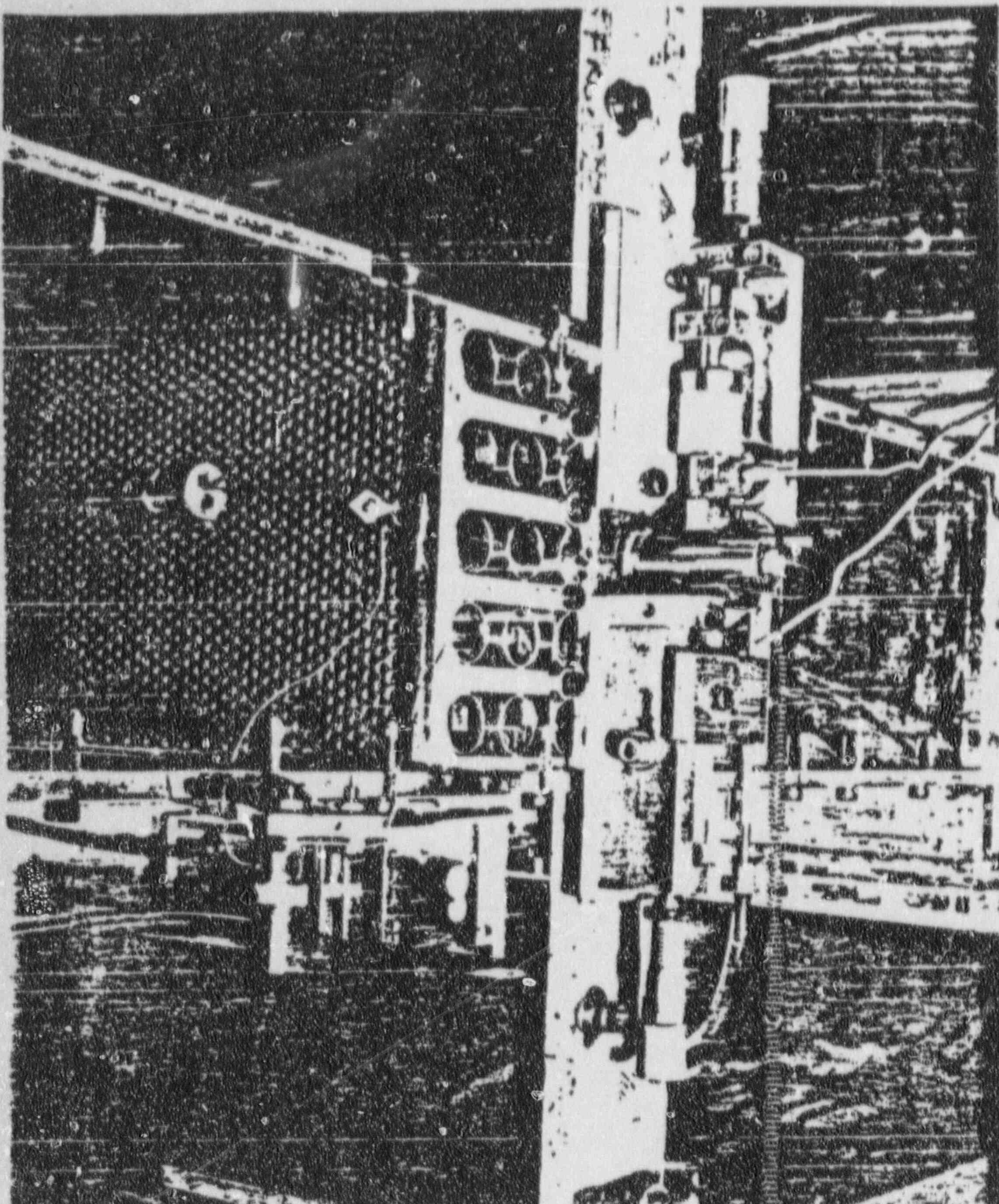


Obtain
from



Obtain from





FLOW PEAKING VIBRATION TEST RESULTS

RESULTS:

- The tube vibration below the threshold velocity is small, typical of turbulence-induced vibration,and increases very rapidly when the threshold velocity for the initiation of fluidelastic vibration is exceeded.

- Configuration R9C51 has the lowest threshold velocity of all the configurations tested.

- The instability of R9C51 is very repeatable and the configuration was periodically rerun to sucessfully verify the consistency of the tests apparatus

SUMMARY

HIGH CYCLE FATIGUE FAILURE

DENTED, UNSUPPORTED TUBES

LOCAL FLOW EFFECTS IMPORTANT

FEW TUBES POTENTIALLY INVOLVED