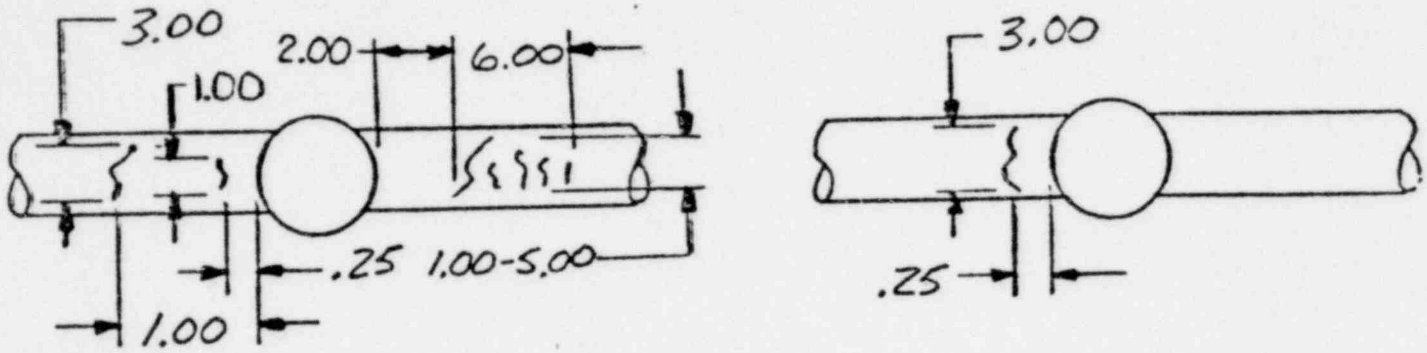
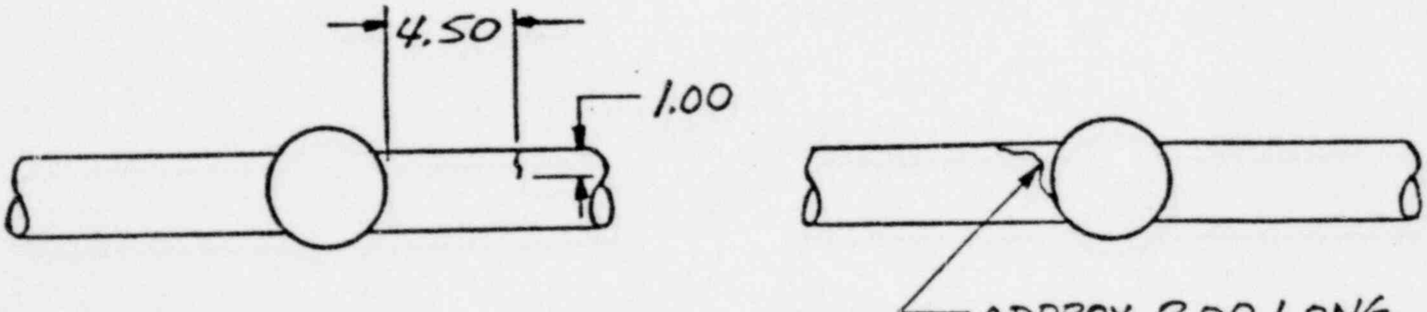
PILGRIM CORE SPRAY SPARGER
INDICATIONS



5°

175°

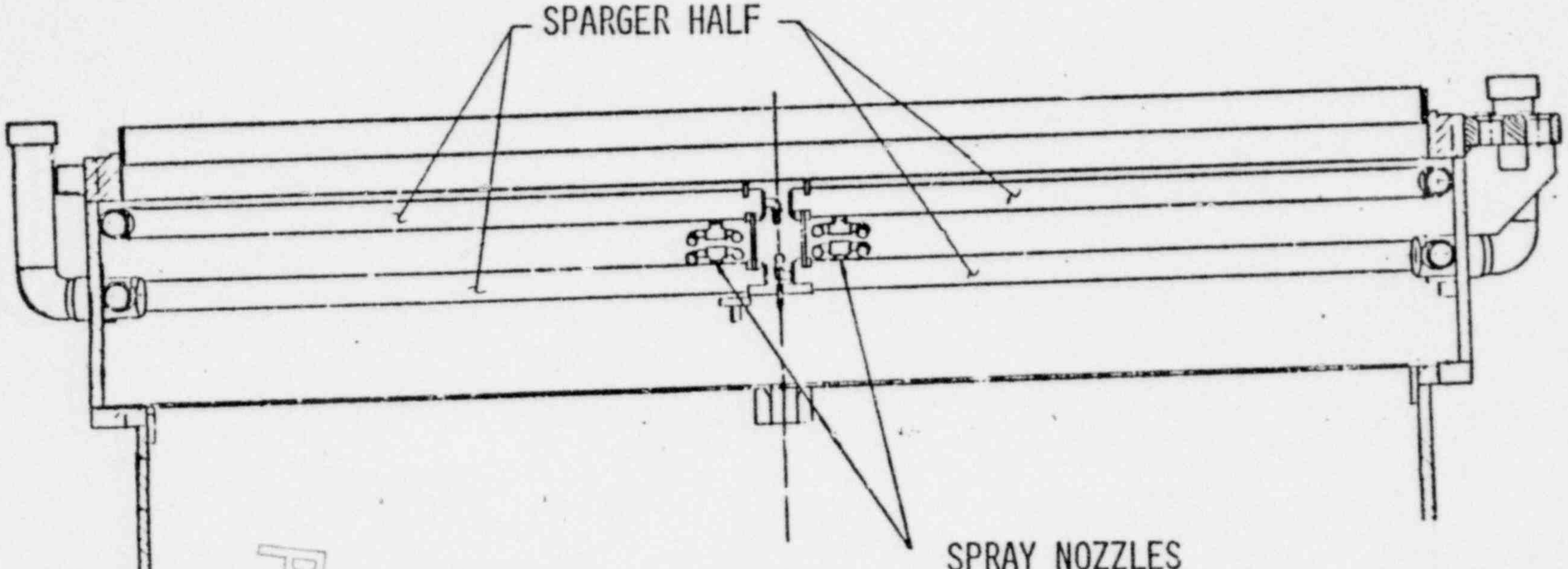
UPPER SPARGER



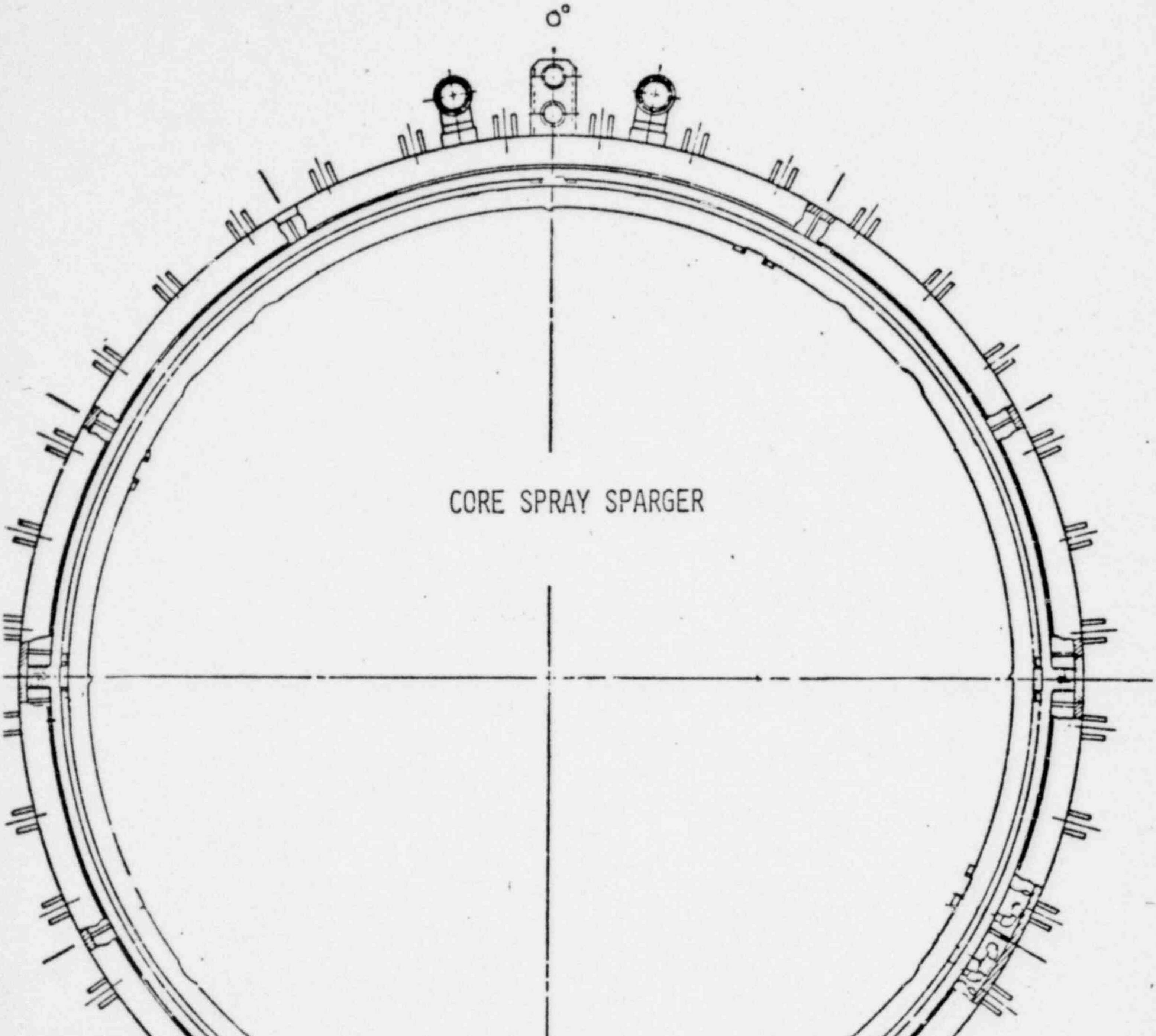
185°

355°

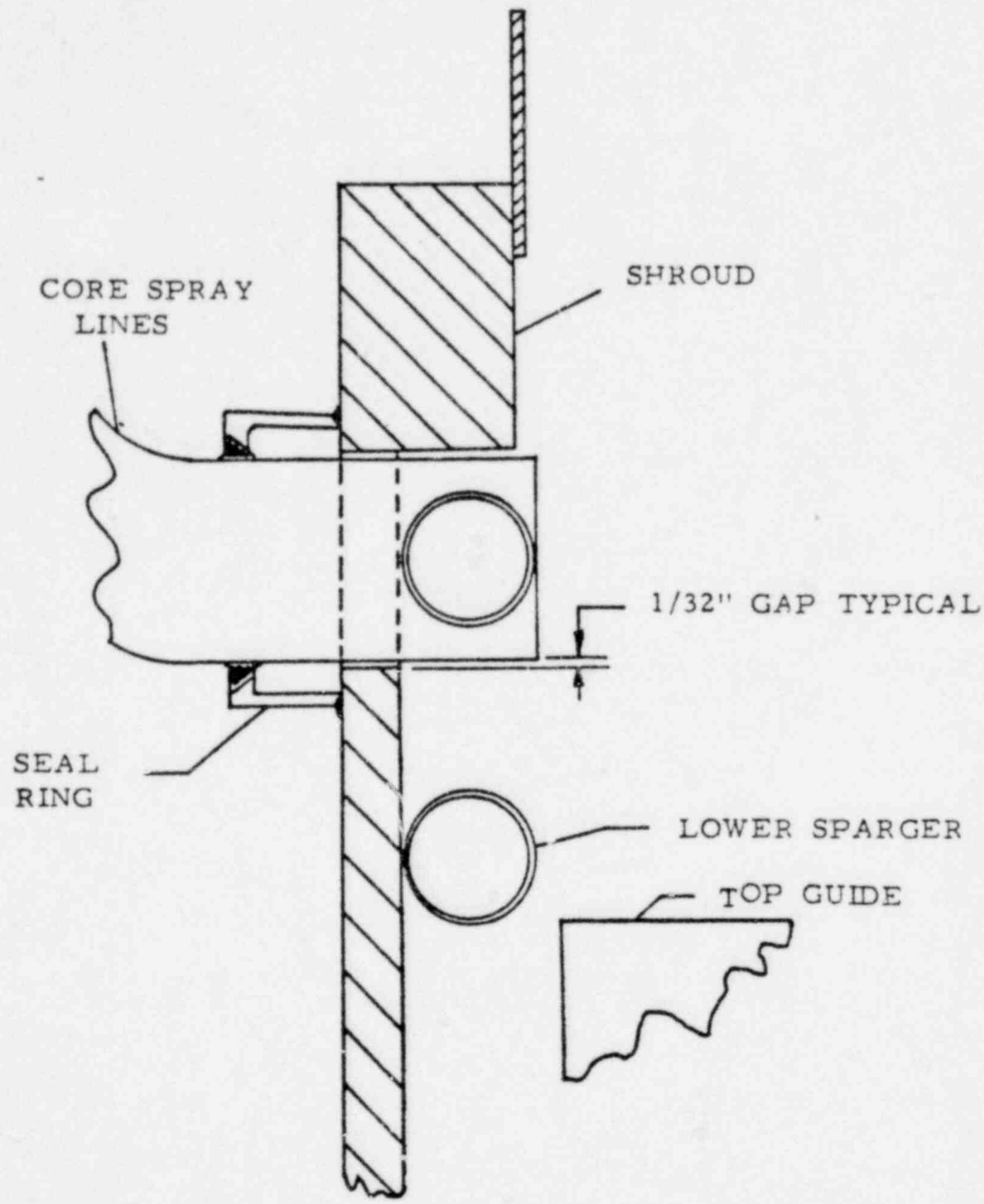
LOWER SPARGER



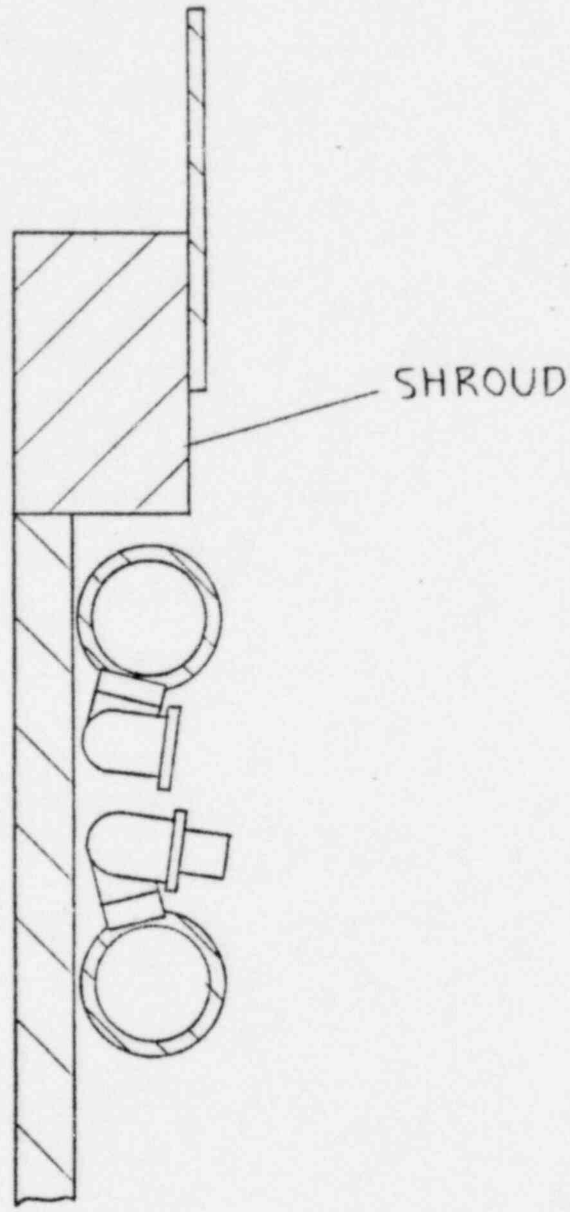
CORE SPRAY SPARGER



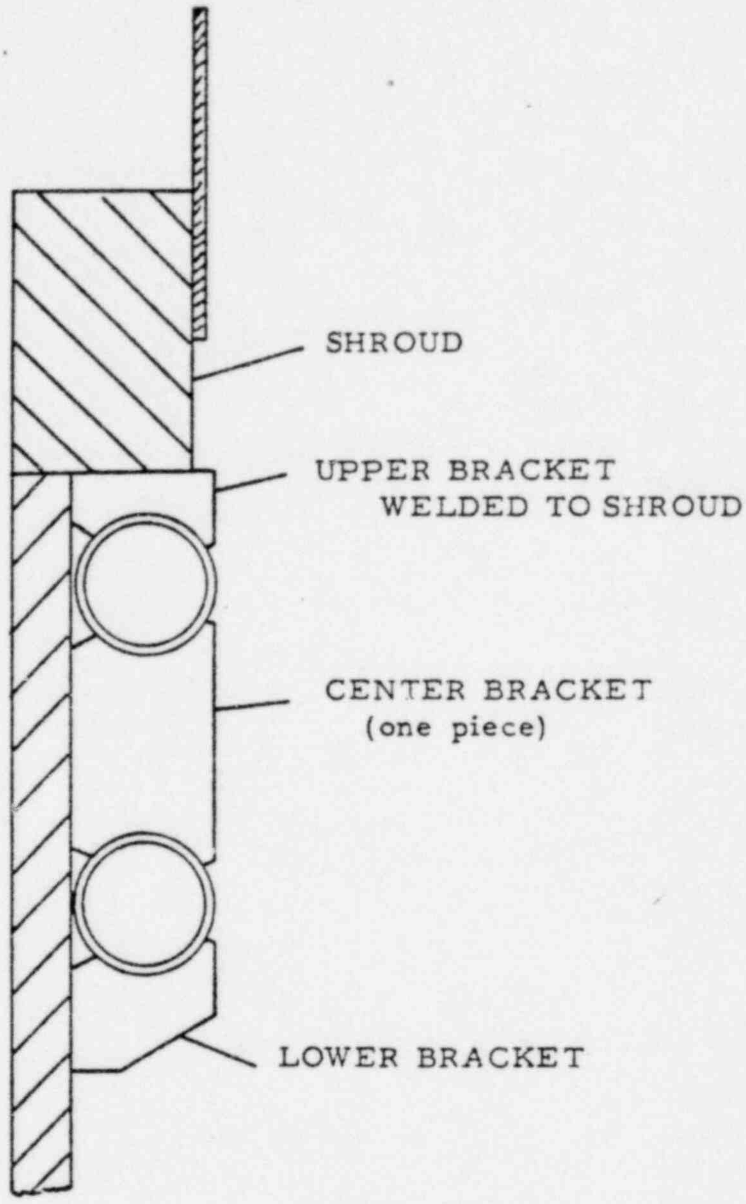
POOR ORIGINAL



SPARGER TO SHROUD
ATTACHMENT METHOD



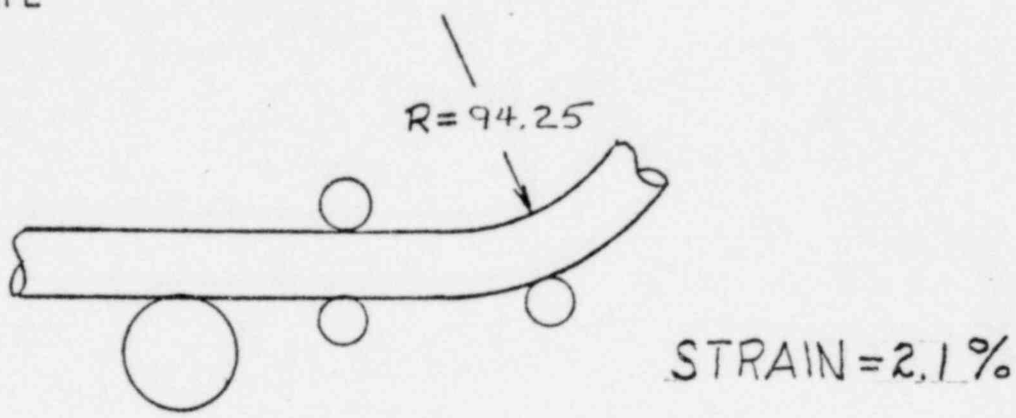
SPARGER NOZZLES



SPARGER SUPPORT METHOD

FABRICATION HISTORY

- BEND PIPE



- FIT UP IN SHROUD (CHECK FIT)
- WELD HEADERS TO T-BOX (SHOP OPERATION)
- DRILL NOZZLE HOLES
- WELD HALF COUPLINGS TO HEADERS
- INSTALL ELBOWS
- MOUNT SPARGER IN SHROUD (COLD SPRINGING ASSUMED)
- AIM AND TACK WELD ELBOWS AND NOZZLES

PERFORMANCE HISTORY

- FIRST CRITICAL - JUNE 1972
- NO INADVERTANT CORE SPRAY INJECTIONS
- CORE SPRAY MAINTENANCE FLOW DURING EACH REFUELING

  MAX. $\Delta T = 130^{\circ}$ F
- FOUND INDICATIONS ON INNER BEND RADIUS - FEB. 1980

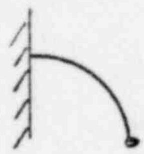
STRESSES - NORMAL OPERATION

- ALL IDENTIFIED STRESSES DURING NORMAL OPERATIONS FOUND TO BE NEGLIGIBLE
- CONSIDERED
    - IMPINGEMENT - FLOW PAST SPARGERS
    - SEISMIC - PROPERLY MOUNTED IS RIGID STRUCTURE
    - PRESSURE - $\Delta P = 0$
    - THERMAL MISMATCH - $\Delta T \simeq 0$
    - STAGNANT LINE
        - TOP TO BOTTOM $\Delta T < 8^{o}$ F
        - THRU WALL $\Delta T < 8^{o}$ F
    - WEIGHT - NEGLIGIBLE
        - PIPE 9.11 LB/FT
        - WATER 4.2 LB/FT
        - NOZZLES 3 LB/FT

STRESSES - NORMAL OPERATION - CONTINUED

FLOW INDUCED VIBRATION

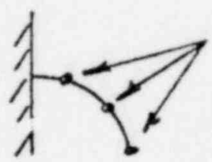
CASE 1



PINNED

$F_N \cong 21$ Hz

CASE 2

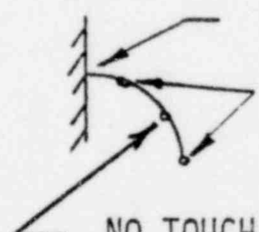


SUPPORTED

$F_N \cong$ ~~19~~ 74 Hz

Ch 1
JNA
3-13-80

CASE 3



RESTRAINT IGNORED

SUPPORTED

NO TOUCH

$F_N \cong 19$ Hz

VORTEX SHEDDING FREQUENCY $= \frac{.22V}{D}$

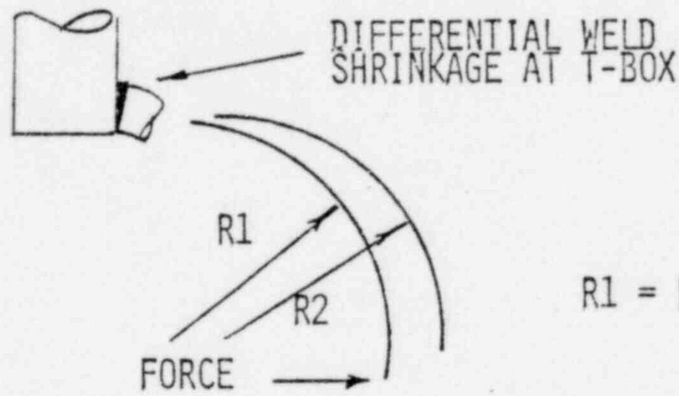
$F_V = 2.64$ Hz

<u>CONCLUSION</u> - UNLESS UNSUPPORTED THERE WILL BE NO CONCERN FOR FLOW INDUCED VIBRATION.

POSTULATED INSTALLATION STRESSES

INSTALLATION-RADIAL MISMATCH

CASE 1

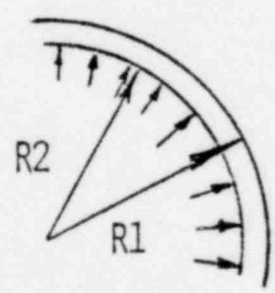


R1 = R2

FOR SHRINK = 1/8 INCH

σ AT T-BOX $\cong$ 24 KSI (ELASTIC)

CASE 2



R1 < R2

ASSUME R1 = 93.25

R2 = 94.25

UNIFORM FORMING

$\varepsilon \cong 1.1\%$

$\sigma \cong 38.3$ KSI (FROM σ-ε CURVE)

CONCLUSION - RADIAL MISMATCH

- RADIAL MISMATCH CAN RESULT IN TENSILE STRESSES AT INNER BEND RADIUS
- STRESSES WILL RELAX TO ELEVATED TEMPERATURE YIELD STRESS DURING OPERATION
- STRESSES ARE DEFLECTION LIMITED SECONDARY STRESSES

STRESSES DURING CORE SPRAY INJECTION

CONSIDERED

- IMPINGEMENT - FLOW PAST SPARGER = LESS THAN NORMAL OPERATION

- PRESSURE

  $\Delta P \cong$ 16 PSI, STRESS NEGLIGIBLE

  $\sigma \cong$ 160 PSI

- THERMAL

  HIGH CIRCUMFERENTIAL AND LONGITUDINAL STRESSES DUE TO THRU WALL GRADIENT. (SECONDARY STRESSES)

- SECONDARY BENDING DUE TO CHANGE IN BEND RADIUS

  $\sigma \cong$ 3KSI

- AXIAL STRESS DUE TO ΔP AND BRACKET FRICTION

  $\sigma <$ 300 PSI

- SEISMIC

  DUE TO THERMAL ΔR ALL SUPPORTS ACTING

  THEREFORE = RIDGID STRUCTURE

- TORSION DUE TO NOZZLE FLOW

  $\sigma <$ 200 PSI

- WEIGHT

  STRESS NEGLIGIBLE

<u>STRUCTURAL INTEGRITY OF A SPARGER WITH CRACKS</u>

CONSIDERED

- IMPINGEMENT

  BENDING - INCREASE PROPORTIONAL TO DECREASED SECTION MODULUS - STRESSES INSIGNIFICANT

- PRESSURE

  HOOP STRESS - NO CHANGE
  AXIAL STRESS - PROPORTIONAL TO CROSS SECTIONAL AREA

- THERMAL (THRU WALL)

  NO CHANGE IN MAX. STRESS

- CHANGE IN BEND RADIUS

  INCREASED STRESS PROPORTIONAL TO DECREASE IN SECTION MODULUS (DEFLECTION LIMITED)

NOTE:- THIS LOADING WILL CAUSE A THRU WALL CRACK TO OPEN UP. WORST CASE ESTIMATED TO INCREASE GAP BY .005 INCH.

STRUCTURAL INTEGRITY OF A SPARGER WITH CRACKS-CONTINUED

- AXIAL STRESS DUE TO ΔP AND BRACKET FRICTION

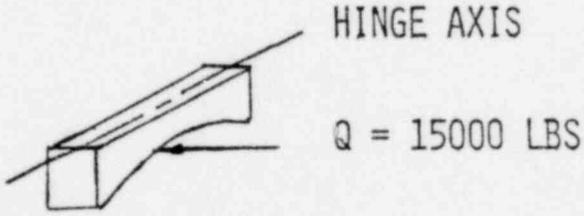
  WILL INCREASE PROPORTIONAL TO REDUCTION IN CROSS SECTIONAL AREA

  BOUNDING #1

  σ_A = 30 KSI FOR A THRU WALL CRACK OVER 90% OF THE CIRCUMFERENCE (PRESSURE AXIAL LOAD INCLUDED)

  BOUNDING #2

  ASSUME VESSEL WALL BRACKET HOLDS PIPE UNTIL BRACKET BENDS AS A PLASTIC HINGE



σ_A = 30 KSI FOR A THRU WALL CRACK OVER 80% OF THE CIRCUMFERENCE

CONCLUSIONS

- WITH THRU WALL CRACKS, SPARGER FLOW DISTRIBUTION MAY BE AFFECTED

BUT

- CORE SPRAY WATER WILL BE DELIVERED TO SHROUD INTERIOR

- SPARGER WILL RETAIN STRUCTURAL CONTINUITY

STRESS EVALUATION OF THE CORE SPRAY SPARGER

- OBJECTIVE IS TO EVALUATE DIFFERENT SOURCES OF STRESS IN THE SPARGER AND CONSIDER THEIR EFFECT ON THE OBSERVED CRACKING.

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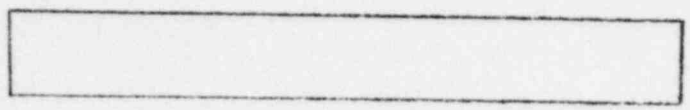
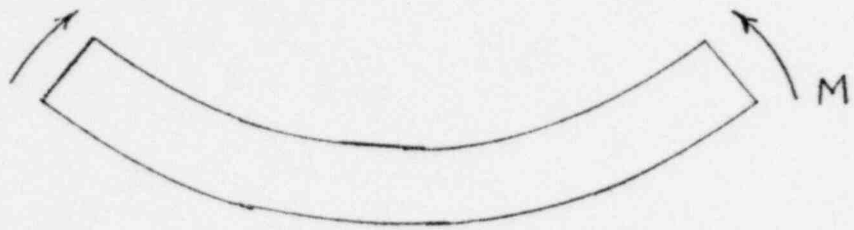
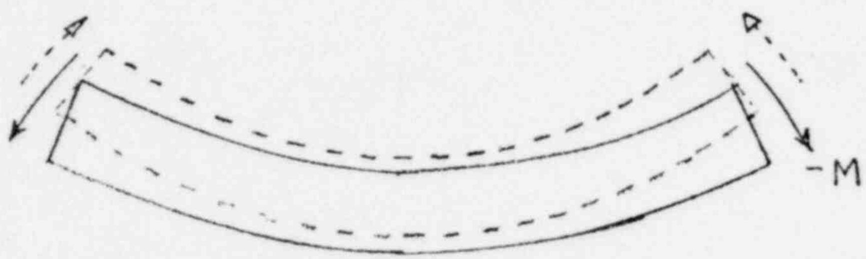


INITIAL CONFIGURATION



LOAD APPLICATION DURING FABRICATION



FINAL DEFORMED SHAPE AFTER LOAD REMOVAL

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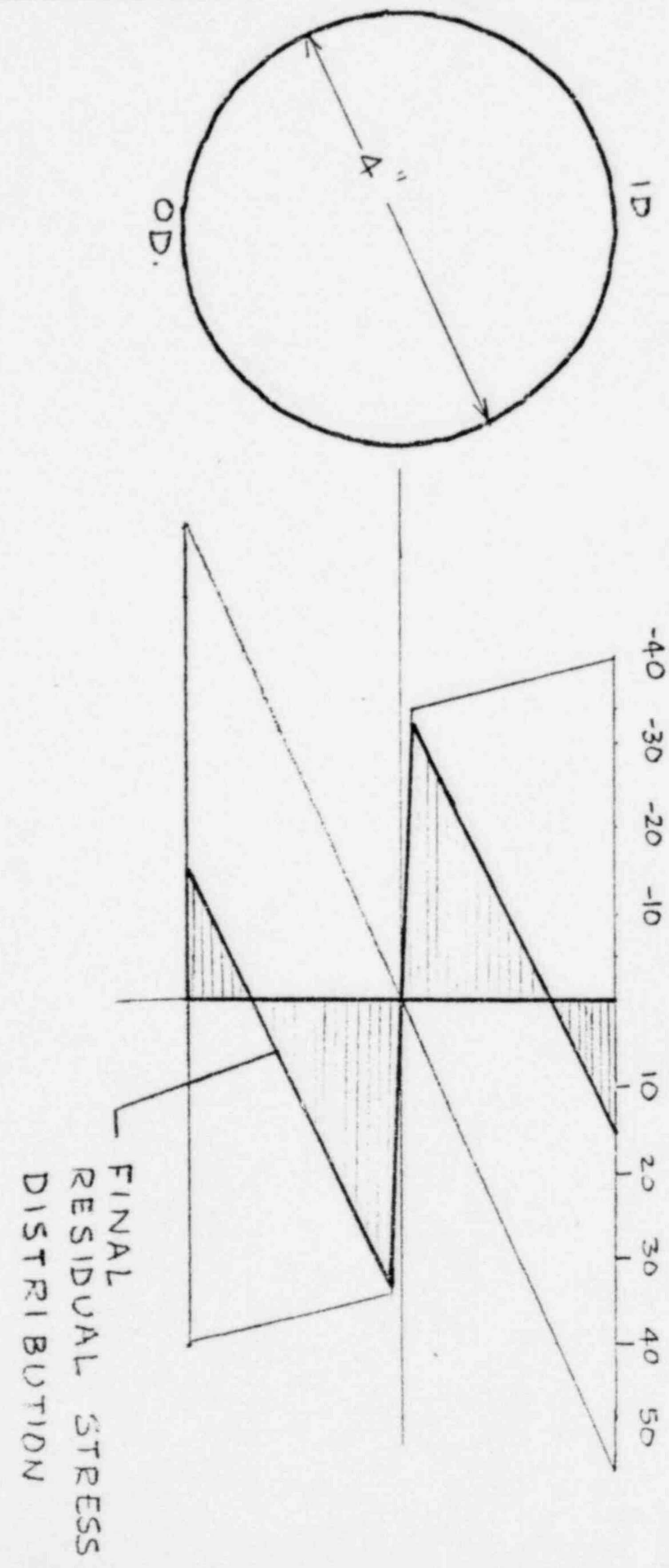
GENERAL ELECTRIC CO.

Nuclear Energy Division

ENGINEERING CALCULATION SHEET

NUMBER ______ DATE ______

SUBJECT ______ BY ______ SHEET ______ OF ______



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TRANSIENT STRESSES

- THERMAL AND PRESSURE STRESSES IN THE PIPE ARE SMALL
- FLOW INDUCED VIBRATION IS UNLIKELY
- FATIGUE USAGE DUE TO THE OPERATING TRANSIENTS IS THEREFORE NEGLIGIBLE

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STEADY STATE STRESSES

- STRESSES DUE TO FABRICATION COULD BE SIGNIFICANT AND WOULD EXIST THROUGHOUT PLANT OPERATION.

- STRESSES DUE TO INSTALLATION AND RESULTING BRACKET CONSTRAINT ARE IMPORTANT.

- THE RESTRAINT STRESSES WOULD BE FURTHER INTENSIFIED NEAR DISCONTINUITIES AND WELD REGIONS. THE WELD RESIDUAL STRESSES TOGETHER WITH THE CONSTRAINT STRESSES COULD BE SUFFICIENT TO CAUSE CRACK INITIATION.

- UNDER WORST CASE ASSUMPTIONS FOR STRESS CORROSION CRACKING, CRACK GROWTH COULD OCCUR WITH FLAWS OF 0.025 INCH DEPTH.

SR

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CRACK ARREST CONSIDERATIONS

- SINCE MOST OF THE APPLIED LOADING IS SECONDARY (DISPLACEMENT CONTROLLED), AS THE CRACKS GROW THE APPLIED STRESSES RELAX AND LEAD TO CRACK ARREST.

- THE RESIDUAL STRESSES DUE TO FABRICATION VARY FROM TENSION TO COMPRESSION. AS THE CRACKS PROPAGATE INTO REGIONS OF COMPRESSIVE STRESS THE APPLIED K VALUE DROPS AND CRACK ARREST IS LIKELY.

SP

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POTENTIAL LOOSE PIECES

I. SAFETY ANALYSIS

II. POTENTIAL CONCERNS

A. CHEMICAL OR CORROSION

B. FLOW BLOCKAGE

C. CONTROL ROD INTERFERENCE

III. LOOSE PIECES UNLIKELY

IV. REACTOR INTERNALS

A. SPARGER LOCATION

B. DIFFICULT PATH TO FUEL ORIFICE

C. DIFFICULT PATH TO CONTROL ROD

V. POTENTIAL SHAPES

A. PIPE

1. 2 THROUGH WALL 360^{0} CRACKS
2. WEIGH LESS THAN 100 LBS.
3. WILL SINK
4. CANNOT CAUSE FLOW BLOCKAGE
5. CANNOT INTERFERE WITH CONTROL ROD

B. NOZZLES

1. THROUGH WALL 360^{0} CRACK
2. WEIGH APPROXIMATELY 1 3/4 LBS.
3. WILL SINK
4. CANNOT CAUSE FLOW BLOCKAGE
5. CANNOT INTERFERE WITH CONTROL ROD

C. SMALL PIECES

1. LONGITUDINAL AND CIRCUMFERENTIAL CRACKS
2. WILL PROBABLY SINK
3. FLOW BLOCKAGE
   A. EXTREMELY UNLIKELY TO PASS THROUGH SEPARATOR
   B. DIFFICULT PATH TO FUEL ORIFICE
   C. SINGLE PIECE CANNOT CAUSE UNACCEPTABLE FLOW BLOCKAGE

4. CONTROL ROD INTERFERENCE

   A. DIFFICULT PATH TO CONTROL ROD

   B. REQUIRES PRECISELY SIZED PIECE

   C. MAY BE DETECTED

   D. IN WORST CASE, ROD WILL PROBABLY INSERT

   E. ONE FULLY STUCK OUT ROD IS ACCEPTABLE

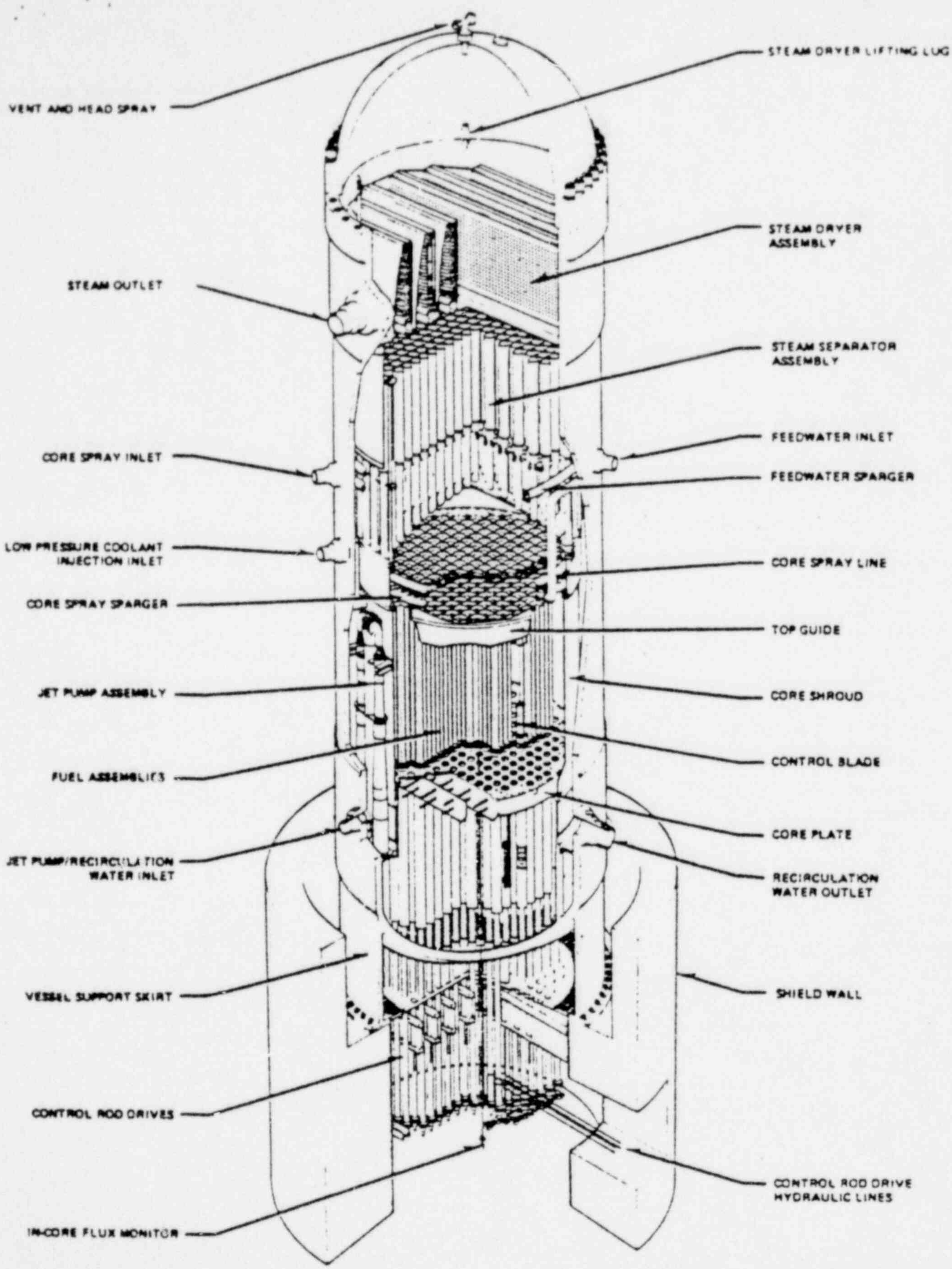
   F. UNACCEPTABLE INTERFERENCE REQUIRES MULTIPLE PRECISELY SIZED PIECES

VI. CONCLUSIONS

   A. NO POTENTIAL FOR UNACCEPTABLE CORROSION

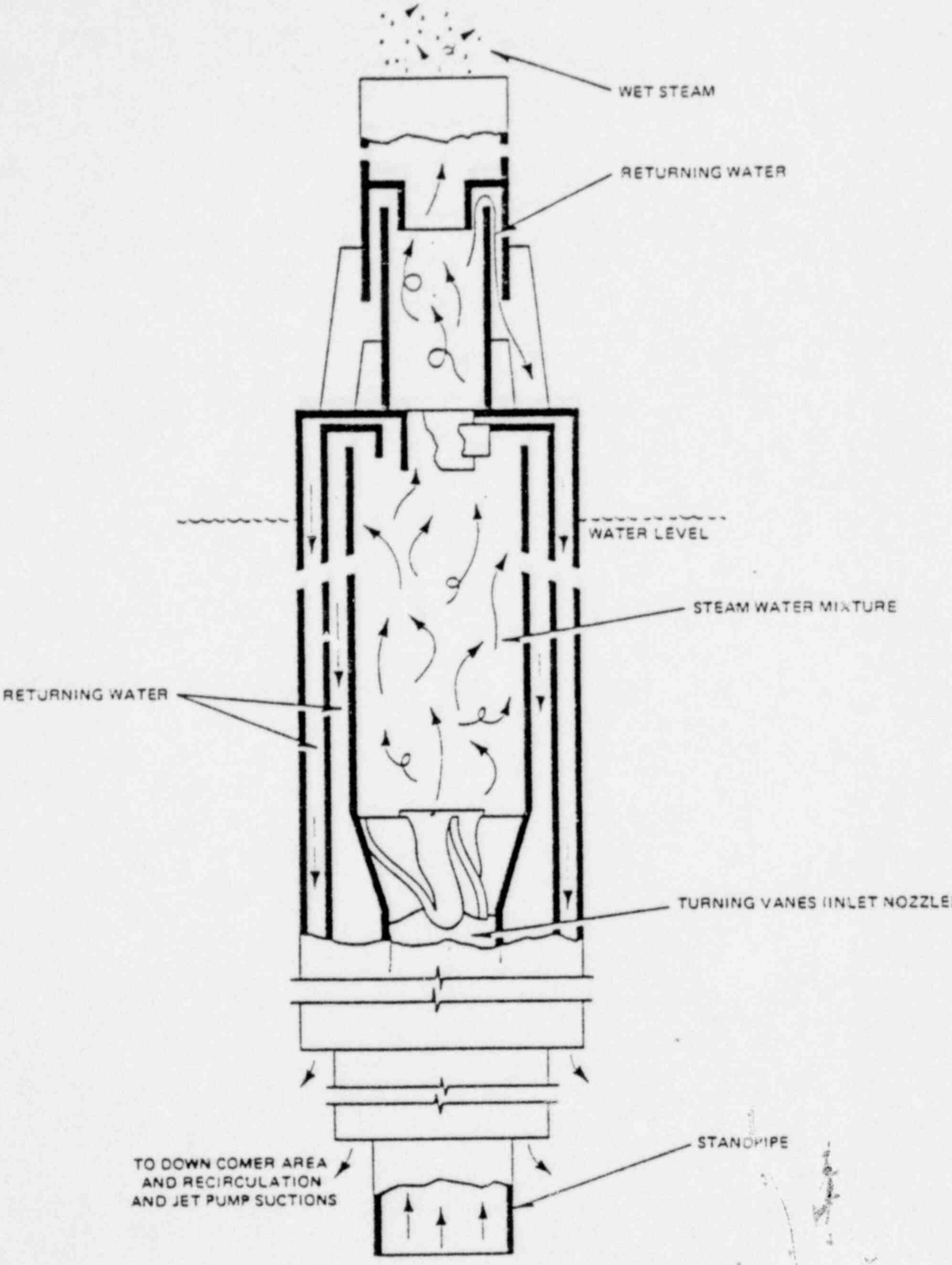
   B. POTENTIAL FOR UNACCEPTABLE FLOW BLOCKAGE IS ESSENTIALLY ZERO

   C. POTENTIAL FOR UNACCEPTABLE CONTROL ROD INTERFERENCE IS ESSENTIALLY ZERO



REV 0	Figure 1

TITLE: Reactor Vessel

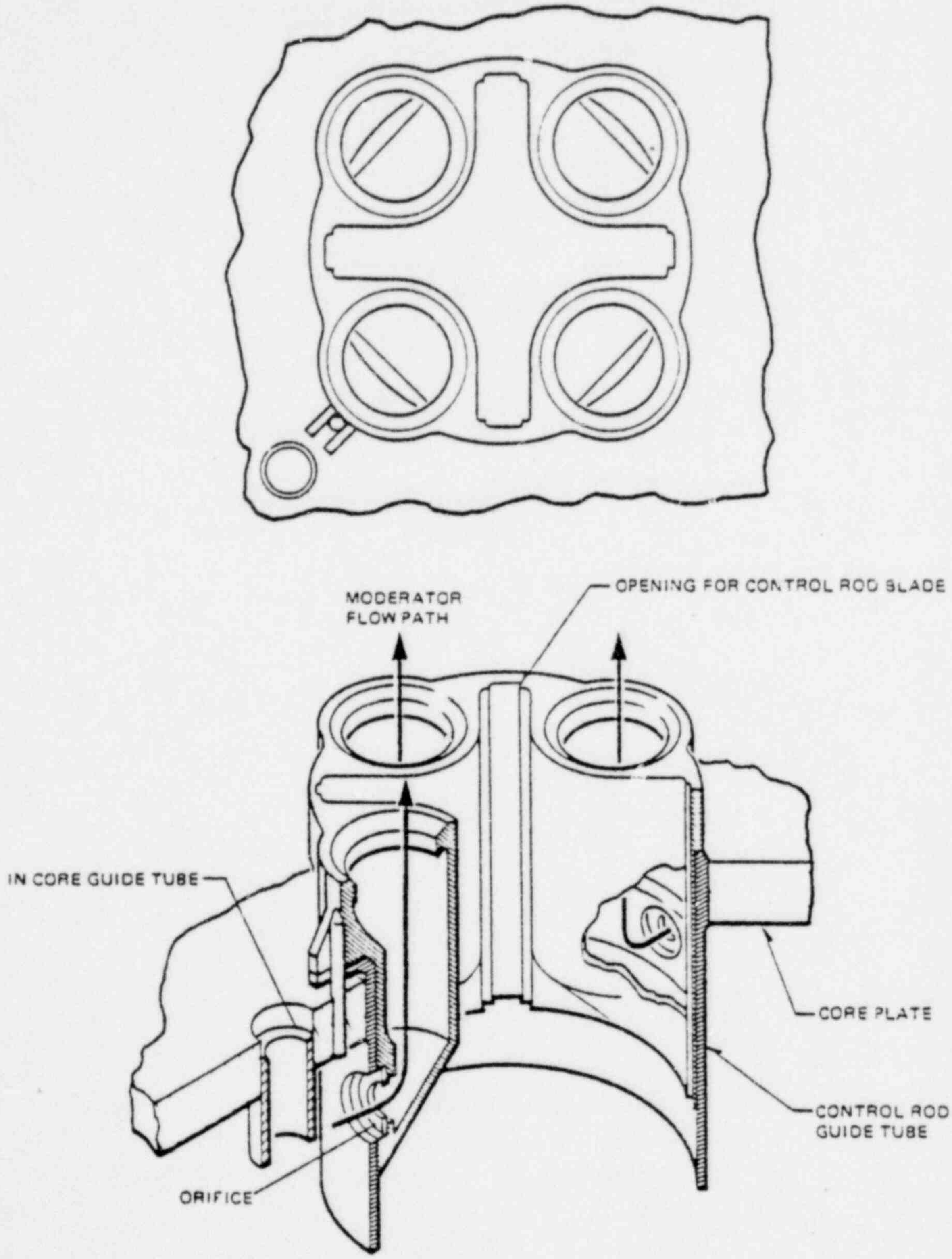


REV 0

Figure 26

TITLE:

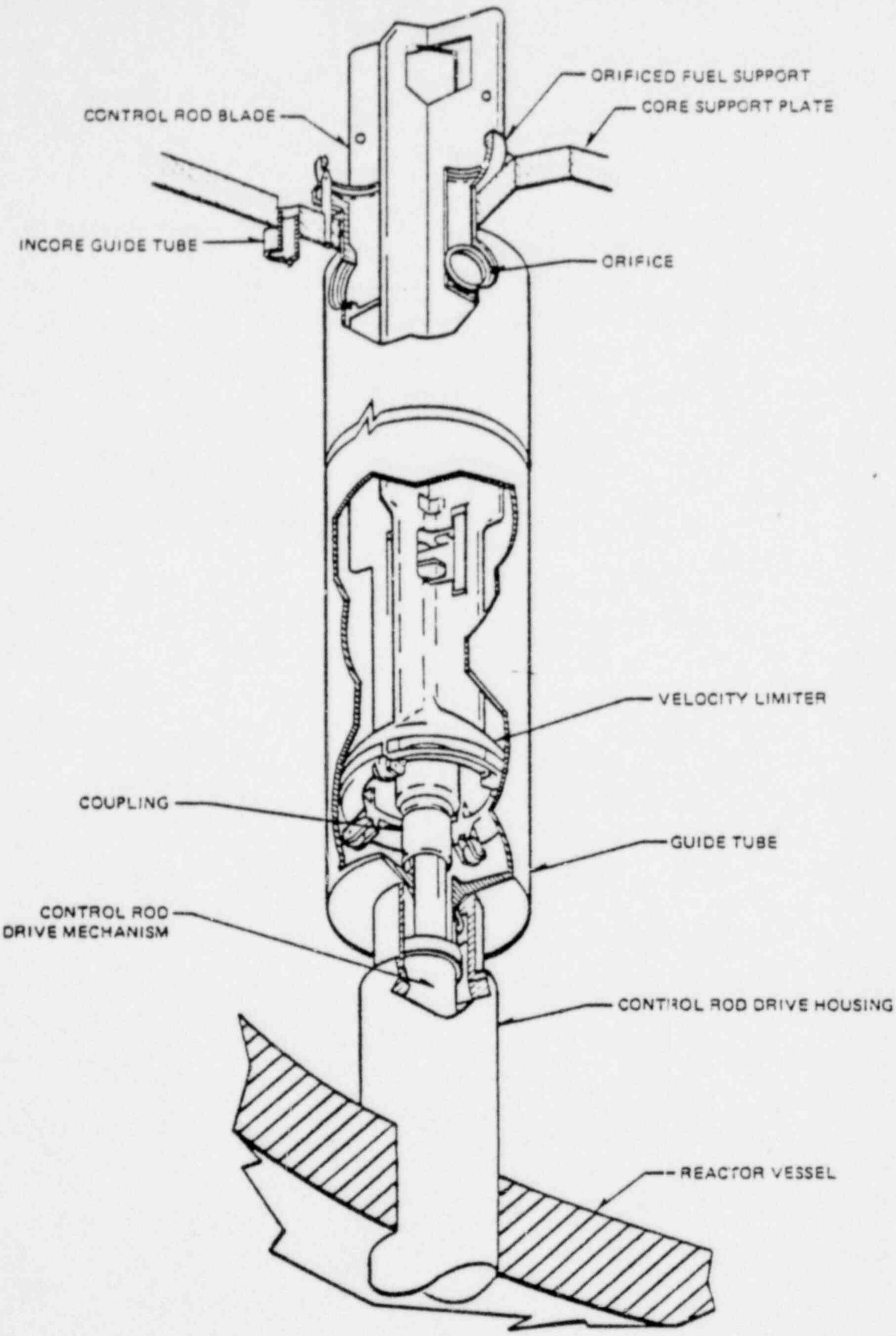
Steam Separator



REV 0	Figure 20

TITLE:

Orificed Fuel Support



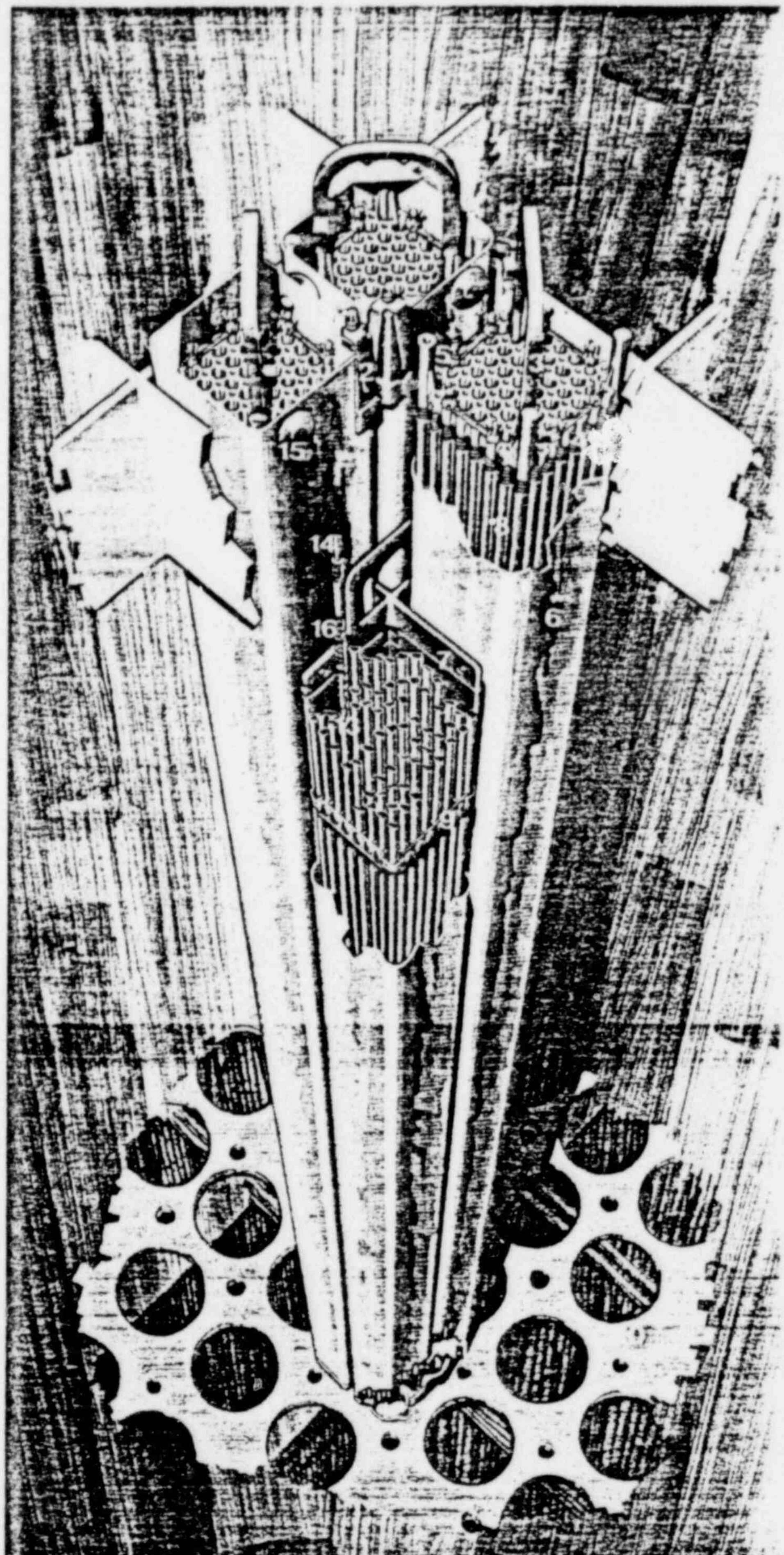
REV 0	Figure 19

TITLE:

Assembled Drive Line

FUEL ASSEMBLIES & CONTROL ROD MODULE

1.TOP FUEL GUIDE
2.CHANNEL FASTENER
3.UPPER TIE PLATE
4.EXPANSION SPRING
5.LOCKING TAB
6.CHANNEL
7.CONTROL ROD
8.FUEL ROD
9.SPACER
10.CORE PLATE ASSEMBLY
11.LOWER TIE PLATE
12.FUEL SUPPORT PIECE
13.FUEL PELLETS
14.END PLUG
15.CHANNEL SPACER
16.PLENUM SPRING



GENERAL ELECTRIC

GEZ-4383

POOR ORIGINAL

MATERIALS ASPECTS OF PILGRIM CORE SPRAY SPARGER CRACKING

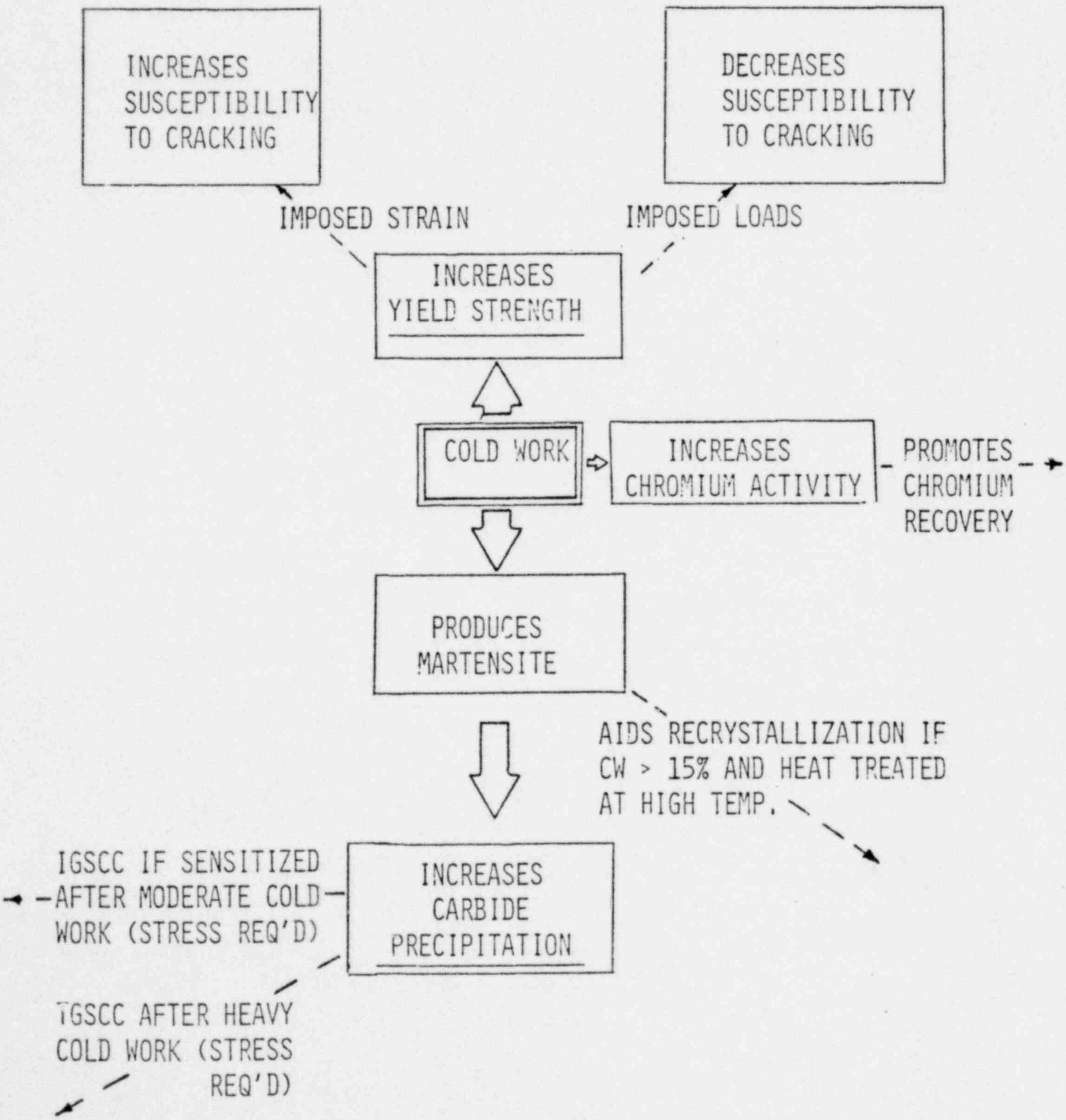
- LISTING OF POSSIBLE CAUSES OF CRACKING
- MATERIALS DISCUSSION OF COLD WORK AND IGSCC
- SUMMARY

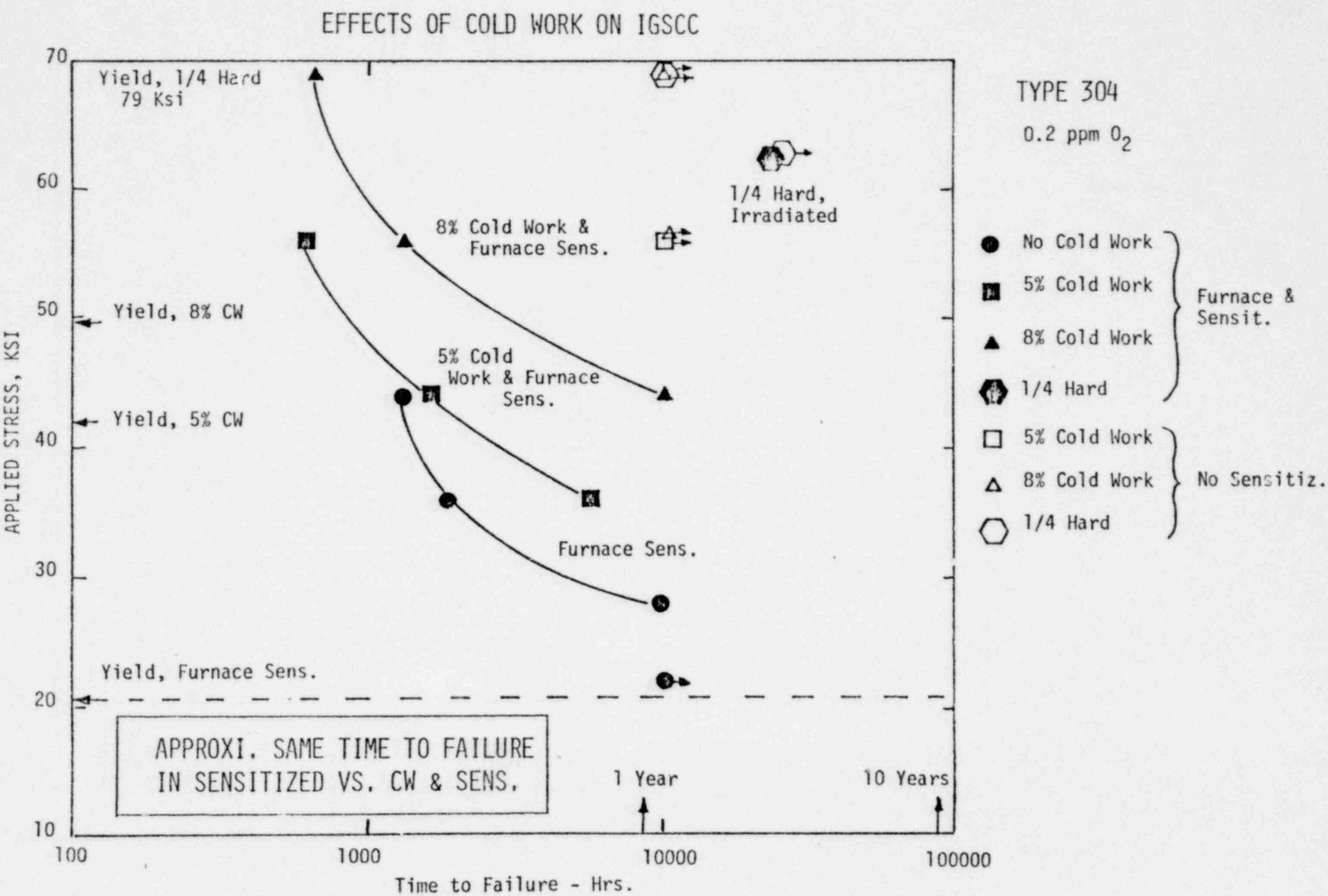
POSSIBLE CAUSES OF CRACKING

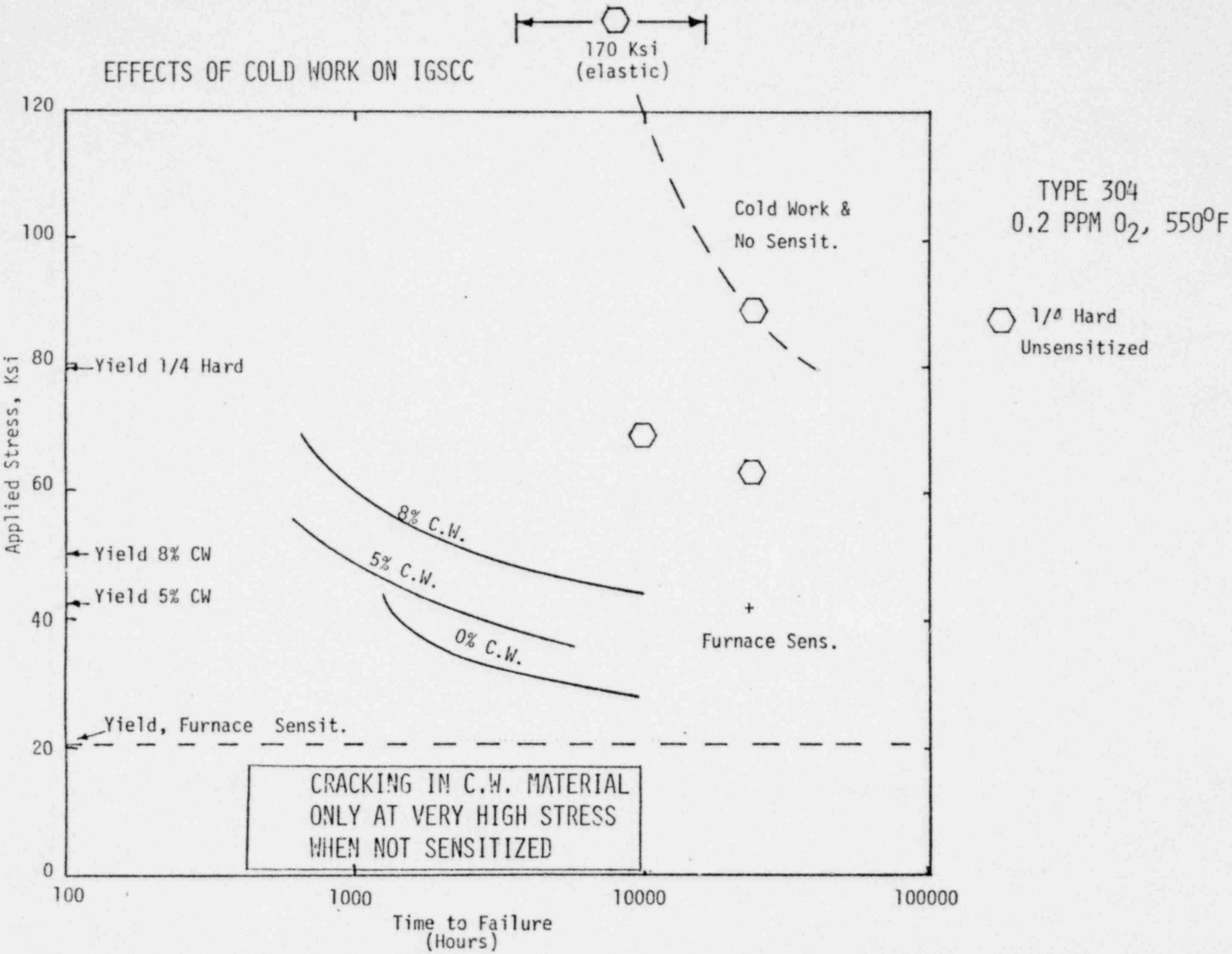
LOCATION	POSSIBLE CAUSE	EVIDENCE
1. SPARGER ARMS NEAR T-BOX		
	• SENSITIZATION BY WELDING	LOCATION OF CRACKS
	• COLD WORK FOLLOWED BY WELD SENSITIZATION	ESTIMATED 5% COLD WORK NEAR T-BOX
	• FATIGUE (THERMALLY INDUCED)	UNDER EVALUATION ΔT's ARE LOW
	• FATIGUE (FLOW-INDUCED VIBRATION)	UNDER EVALUATION AMPLITUDES ARE LIMITED
2. SPARGER ARMS AWAY FROM T-BOX	• SENSITIZATION FROM FABRICATION	NONE*
	• COLD WORK FOLLOWED BY SENSITIZATION	PIPE BEND FORMING;* NO EVIDENCE OF SENSITIZATION
	• LOCAL HEAVY COLD WORK	NONE*
	• FATIGUE	SAME AS ABOVE

* SENSITIZATION AND COLD WORK STATE OF SPARGERS NOT YET KNOWN

EFFECTS OF COLD WORK ON IGSCC
OF TYPE 304 STAINLESS STEEL

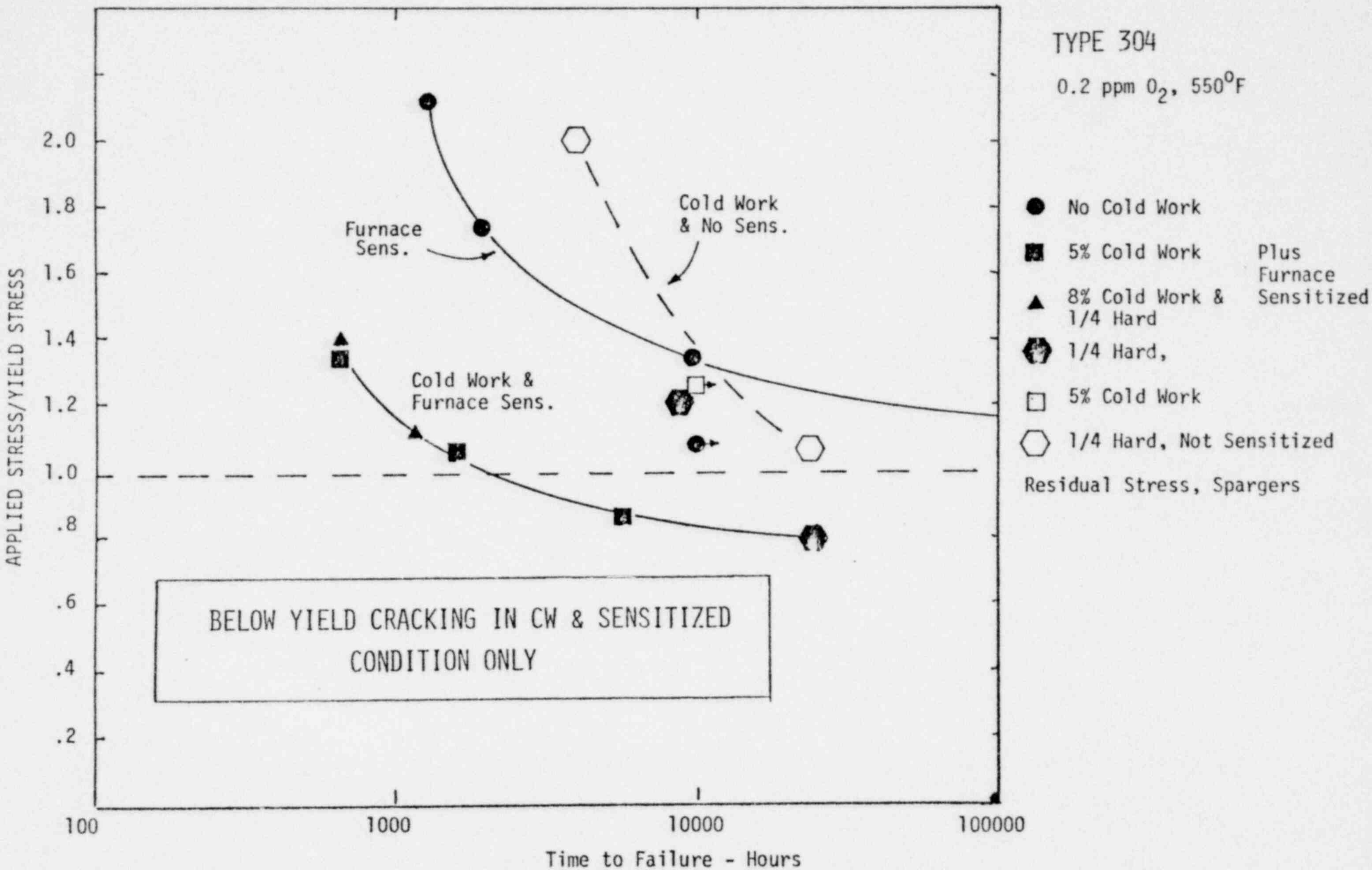


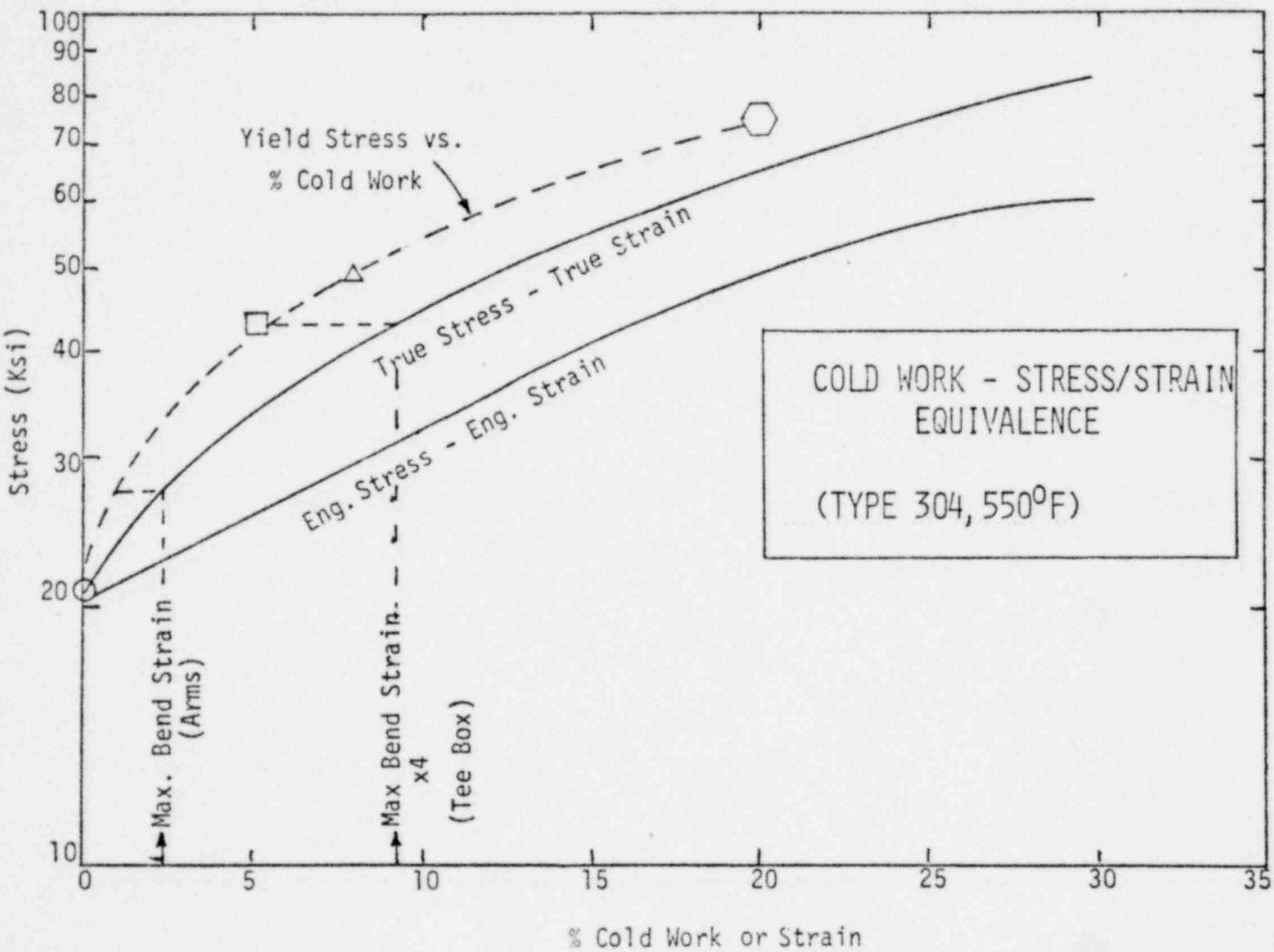

EFFECTS OF COLD WORK ON IGSCC
Yield, 1/4 Hard 79 Ksi
8% Cold Work & Furnace Sens.
1/4 Hard, Irradiated
Yield, 8% CW
5% Cold Work & Furnace Sens.
Yield, 5% CW
Furnace Sens.
Yield, Furnace Sens.
APPROXI. SAME TIME TO FAILURE IN SENSITIZED VS. CW & SENS.
1 Year
10 Years
APPLIED STRESS, KSI
70
60
50
40
30
20
10
100
1000
10000
100000
Time to Failure - Hrs.
TYPE 304
0.2 ppm O_2
No Cold Work
5% Cold Work
8% Cold Work
1/4 Hard
Furnace & Sensit.
5% Cold Work
8% Cold Work
1/4 Hard
No Sensitiz.



EFFECTS OF COLD WORK ON IGSCC
170 Ksi
(elastic)
TYPE 304
0.2 PPM O_2, 550°F
Cold Work &
No Sensit.
1/4 Hard
Unsensitized
Yield 1/4 Hard
Yield 8% CW
Yield 5% CW
8% C.W.
5% C.W.
0% C.W.
Furnace Sens.
Yield, Furnace Sensit.
CRACKING IN C.W. MATERIAL
ONLY AT VERY HIGH STRESS
WHEN NOT SENSITIZED
Applied Stress, Ksi
0
20
40
60
80
100
120
100
1000
10000
100000
Time to Failure
(Hours)

EFFECTS OF COLD WORK ON IGSCC





COLD WORK - STRESS/STRAIN EQUIVALENCE
(TYPE 304, 550°F)
Yield Stress vs. % Cold Work
True Stress - True Strain
Eng. Stress - Eng. Strain
Max. Bend Strain (Arms)
Max Bend Strain. x4 (Tee Box)
Stress (Ksi)
% Cold Work or Strain
100
90
80
70
60
50
40
30
20
10
0
5
10
15
20
25
30
35

COLD WORK AND IGSCC

- MECHANISM OF ENHANCED IGSCC SUSCEPTIBILITY IS COMPLEX; NUMEROUS FACTORS ARE INVOLVED.

- MODERATE AMOUNTS OF COLD WORK REDUCE STRESS THRESHOLD TO 0.8 COLD WORKED YIELD IF MATERIAL IS SENTITIZED AFTERWARDS.

- TGSCC HAS BEEN OBSERVED IN HIGHLY COLD WORKED MATERIAL BUT AT STRESSES ABOVE YIELD.

- LOCAL (SURFACE) COLD WORK, IF SEVERE, CAN INITIATE CRACKS WHICH MAY GROW BENEATH THE HARDENED REGION.
  - PIPE CRACKING EXPERIENCE

ROLE IN CORE SPRAY SPARGER MAY BE SIGNIFICANT

SCENARIO ON CAUSE OF CORE SPRAY SPARGER CRACKING

EVENT	VARIABLE FROM PLANT TO PLANT
1. SOME SENSITIZATION FROM PIPE VENDOR FABRICATION	✓
+	
2. COLD WORK DURING PIPE BENDING	✓
+	
3. WELD SENSITIZATION DURING T-BOX OR ELBOW WELDING	SOME PLANTS ARE 304L
+	
4. INSTALLATION & RESIDUAL STRESSES	✓
+	

COLD WORK/SENSITIZATION
(IGSCC)

- KEY CONTRIBUTORS TO CRACKING VARIABLE
- 21 PLANTS INSPECTED TO DATE
- 19 PLANTS REPORTED NO CRACKING

PILGRIM SPARGER CONCLUSIONS

- CONFIDENCE THAT CRACKING NEAR T-BOX CAN BE EXPLAINED BY DATA AND SPARGER CONDITION
- LESS CONFIDENT IN EXPLANATION OF CRACKING MECHANISM AWAY FROM T-BOX

PILGRIM
ECCS ANALYSIS

- REQUESTED BY BECO

- NO CREDIT FOR CORE SPRAY TRANSFER

- RUNS DONE WITH APPROVED MODELS CONSERVATIVE ASSUMPTIONS, NO MODEL IMPROVEMENTS CURRENTLY UNDER REVIEW

- PRELIMINARY RESULTS
  MAPLHGR REDUCED 5 - 10 %

- GE CONSIDERS BECO APPROACH EXCESSIVELY CONSERVATIVE

JAA -1
3/13/80

NO CORE HEAT TRANSFER CREDIT

- o LIMIT BREAK - 4.34 FT^2 SUCTION BREAK
- o EFFECT ON BLOWDOWN & REFILL CALCULATION
  - NO CCFL PREDICTED
  - NO REFLOOD DELAY
  - NO CHANGE IN DEPRESSURIZATION RATE, UNCOVERY TIME, OR REFLOOD TIME
- o EFFECT ON HEATUP CALCULATION
  - NO SPRAY TRANSFER ON FUEL RODS
  - NO CREDIT FOR CHANNEL WETTING
  - HIGHER PEAK CLADDING TEMPERATURES
- o FIVE FUEL TYPES CONSIDERED
  - 0 TO 30,000 MWD/ ST EXPOSURE RANGE

CONSERVATISM IN BECO APPROACH

- o BUNDLE HEAT TRANSFER DURING CORE SPRAY PERIOD
  - CORE SPRAY DISTRIBUTION
  - POOL OF WATER
  - CHANNEL COOLING
  - STEAM COOLING
- o REFLOOD TIME
  - CCFL CORRELATION
  - BYPASS LEAKAGE FLOW
  - CCFL BREAKDOWN
  - VAPORIZATION CORRELATION
- o OTHER MODEL CONSERVATISMS
  - DEPARTURE FROM NUCLEATE BOILING
  - FILM BOILING CORRELATION (BROMLEY)
  - DECAY HEAT (OLD ANS + 20%)

JAA - 3
3/13/80