VERMONT YANKEE
NUCLEAR POWER CORPORATION

RD 5, Box 169, Ferry Road, Brattleboro, VT 05301

BVY 89-31

REPLY TO
ENGINEERING OFFICE
580 MAIN STREET
BOLTON, MA 01740
(508) 779-6711

March 28, 1989

U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Attention: Document Control Desk

Reference: a) License No. DPR-28 (Docket No. 50-271)

Dear Sir:

Subject: Response to USNRC Request for Vermont Yankee Feedwater Check Valve V28B Flaws Evaluation

In accordance with the NRC staff's recent request, Vermont Yankee herewith provides, as Enclosure 1 to this letter, the subject evaluation. This evaluation addresses two flaws detected during the Cycle 13 outage in-service inspection of feedwater check valve V28B. These two flaws exceeded ASME Section XI acceptance criteria, as provided in IWB-3500, and accordingly this further evaluation was initiated.

As detailed in the enclosed evaluation, Vermont Yankee has concluded that the flaws are stable, static flaws in the stellite wear pads resulting from cracking coincident with casting defects. A detailed fracture mechanics evaluation was performed and compared against materials properties. Based on the results of our conservative analyses and comparisons with published industry data and related acceptance criteria, Vermont Yankee has determined that the reported worst case flaw is acceptable for service without repair during the next cycle of operation.

Although Vermont Yankee does not believe that rapid flaw growth is probable, at the request of the NRC staff, an evaluation of a 3" long through wall flaw was performed. The results show that the flaw is stable. Even conservatively assuming a gross failure of the feedwater check valve, the resulting break is bounded by the plant design basis accident analysis, thus no unreviewed safety question exists.

The enclosed evaluation demonstrates stable crack behavior in all cases up to and including a through wall flaw. However, as an added assurance of safe plant operation, Vermont Yankee will implement the enhanced leakage monitoring program specified in Appendix D of the enclosed evaluation. Further, Vermont Yankee will commit to repair or replace feedwater check valve V28B during the next scheduled refueling outage.

A047
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We trust this submittal is sufficient and fully responsive to your needs; however, should you have any questions or require further information concerning this matter, please do not hesitate to contact us.

Very truly yours,

VERMONT YANKEE NUCLEAR POWER CORPORATION

Warren P. Murphy
Vice President and
Manager of Operations

Enclosure - Evaluation (Figures and Appendices A-D)

/dm
cc: USNRC Regional Administrator, Region I
USNRC Resident Inspector, VYNPS
USNRC NRR Project Manager, VYNPS

50-271
Vermont Yankee
ACC. NBR. 8904120412
DOC DATE 3/28/90

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M. Fairtile
June 6, 1990

EVALUATION OF FEEDWATER CHECK VALVE V28B FLAWS

SUMMARY OF FINDINGS

Feedwater Check Valve V28B was opened for verification of free piston movement as part of the Vermont Yankee In-Service Test Program. While the valve was open, a visual examination of the inside surfaces of the valve was performed as required by ASME Section XI. Visual cracking was observed in the Stellite No. 6 wear pads in the piston guide portion of the valve (see Figure 1). The cracking was located within the approximately 1 inch wide Stellite No. 6 wear pads. The wear pads were created by machining a shallow groove in the bore of the piston housing and weld depositing Stellite No. 6 alloy. The bore was then machined to provide a cylindrical bore for the piston.

Ultrasonic inspections were performed on the valve. The thickness of the valve in the region of the flaws is approximately 2 inch to 2.1 inch. In valve V28B two flaws were identified, one with a maximum flaw depth of .65 inch and the other was a 0.40 inch deep flaw on the other side of the valve. The deeper flaw was radiographed, confirming the fact that the flaw was contained entirely within the width of the Stellite No. 6 pad. The ultrasonic examiners reported that casting inclusions made it difficult to discern the crack tip from the inclusions (i.e., the flaw could be shallower than reported). The casting inclusions were also seen in the radiograph. Since the reported flaw depths were in excess of Section XI acceptance criteria, detailed flaw evaluations were required.

Discussion of Flaws

All of the flaws were contained entirely within the width of the Stellite No. 6 wear pads (see Figure 1). Since the majority of the flaws are very shallow, this implies a very slow or nonexistent growth mechanism. Stellite No. 6 is a brittle material, and Stellite No. 6 cracking is not an uncommon occurrence. Inspection of the Stellite No. 6 showed visible evidence of "between bead" cracking and slag inclusions. (The Stellite No. 6 serves no pressure retaining function.)

Possible flaw initiation mechanisms have been evaluated. The thermal expansion coefficients of carbon steel and Stellite No. 6 are similar, so differential thermal expansion stresses and consequently thermal fatigue crack propagation will be low. It is highly likely that the majority of cracks remain in the Stellite No. 6 or extend slightly into the residual stress region resulting from the Stellite No. 6 weld deposit. (The Stellite No. 6 thickness is approximately 90 mils). Pressure cycling has been evaluated and shown to produce negligible flaw growth.

The two deeper flaws in Valve V2[illegible]B may be linked up to casting inclusions, or may even be simply in front of nonconnected casting inclusions.

Vermont Yankee concludes that all the flaws are stable, static flaws resulting from Stellite No. 6 cracking coincident with casting defects. The indications are in a region of the valve body that will see high pressure induced stresses, and it is possible that the flaws developed during the original valve hydrotest at 3,250 psig. In any event the flaws are evaluated considering the full reported flaw depth.

Flaw Evaluations

The region of the valve body containing the flaw is more complex than a simple cylinder, and the valve body material (ASTM A216 WCB cast carbon steel) is not a low alloy pressure vessel steel, so the "cookbook" flaw evaluation techniques of ASME Section XI cannot be utilized. Instead, a detailed fracture mechanics evaluation was performed utilizing a bench-marked, industry-accepted computer code (pc-CRACK, developed by Structural Integrity Associates).

In order to better represent the stress condition in the intersection region of the valve where the flaws are located, a two-dimensional finite element model was developed using ANSYS. The details and conservatisms associated with this model are discussed in Appendix A of this report.

Since the region of the valve containing the flaw is not a standard geometry, several fracture mechanics cases bounding the actual case were performed. The table below summarizes the cases evaluated and the K_I for a flaw 0.65 inch deep. Flaw evaluation reports are contained in Appendix B.

The flaws were evaluated for two conditions: using a design pressure for the piping system of 1,900 psig; and, using an operating pressure for the system of 1,100 psig. The design condition could only occur when the downstream manual isolation valve is shut, subjecting the piping to the combined shut off heads of the condensate and feedwater pumps. This is classified as a test condition.

The following table lists the conditions that were evaluated and the K_I values at 1,100 psig and 1,900 psig:

	K_I at a = 0.65 inches	
Flaw Evaluation Model	1,900 psig	1,100 psig
	(Units of ksi - √in)	
Elliptical Flaw in Cylinder (a/l = 0.2)	10.1	5.8
Elliptical Flaw in Cylinder (a/l = 0.5)	6.7	3.9
Fully Circumferential Flaw in Cylinder	13.9	8.0
Infinite Longitudinal Flaw in Cylinder	17.4	10.1
Elliptical Flaw in Flat Plate Subject to Bending and Tension	11.2	6.5
Limit	24.5	12.2

The above listed K_I values must be compared against the K_{Ic} values for the valve material. Since no impact testing was performed on the valve bodies at the time of manufacture, typical data from published reports have been used.

ASME Code Case N-463 provides a lower bound K_{Ic} value for ferritic steel piping, such as A106, Grade B. NRC Contractor Report NUREG/CR-3009 and NRC Report NUREG-0577 show that A216 WCB has superior toughness properties compared to A106, Grade B; therefore, it is conservative to use the lower bound value from Code Case N-463; the lower bound K_{Ic} is 36.7 ksi √in. Utilizing the appropriate factor of safety for the normal and test condition provides an acceptance criteria of K_{Ic} equals 24.5 ksi √in for the test condition and 12.2 ksi √in for the normal condition. As can be seen, both conditions satisfy their respective acceptance criteria by a significant margin.

As a worst case evaluation, we have considered the possibility that a flaw grows through wall. Figure 2 shows the hypothetical flaw sizes for the different evaluation models, as compared to the assumed initial flaw. The limiting mode of operation for this condition is RCIC injection. RCIC initially draws from the condensate storage tank. After the condensate storage tank is drawn down, suction is switched to the torus. For conservatism, we have assumed the RCIC injection water could be at 80°F, the minimum reported condensate storage tank temperature in winter. Figure 3 shows the calculated K_I values for the various flaw models compared to typical K_{Ic} data at 80°F extracted from NUREG/CR-3009. Significant margin exists. (Note that the center cracked plate flaw K_I is artificially high since the model does not allow a varying stress field. The peak stress had to be applied across the full thickness of the plate.)

CONCLUSION

Flaws were detected during in-service inspection in the feedwater check valve. The valve had two flaws exceeding ASME Section XI acceptance criteria. Fracture mechanics evaluations were performed and compared against conservative materials properties.

In all cases up to and including a through wall flaw, stable crack behavior is demonstrated and, therefore, gross failure will not occur. As added assurance of safe plant operation, an enhanced leakage monitoring program will be implemented. The specifics are discussed in Appendix D. In addition, repairs or replacement of V28B will be performed at the next scheduled refueling outage.

Finally, even if the feedwater check valve were to be conservatively assumed to experience a gross failure during operation, the resulting could be equivalent to a feedwater line break inside containment, which is within the plant accident analysis, so no unreviewed safety question exists.

FIGURES

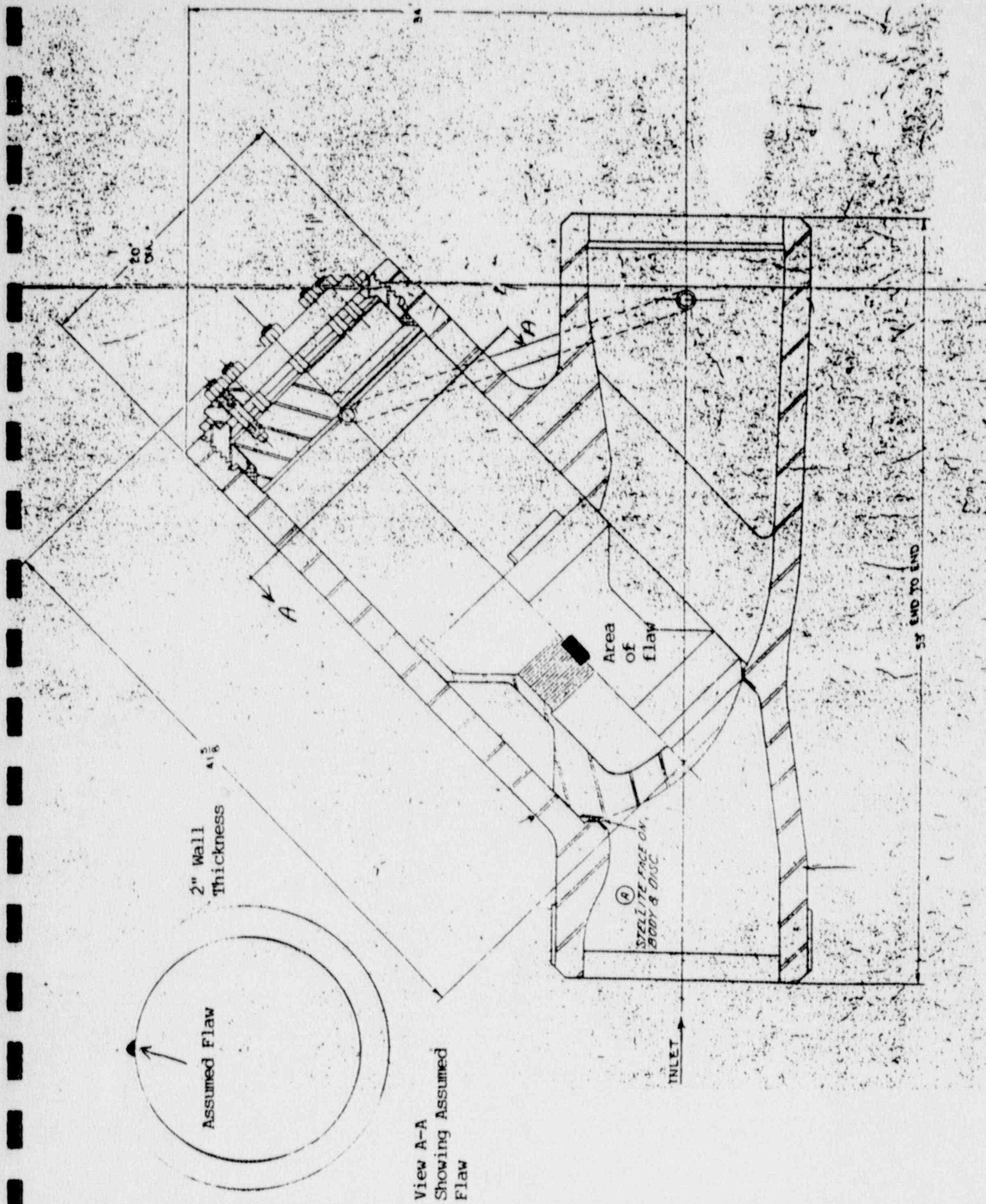

34
20" DIA
A
A
Area of flaw
41 5/8
2" Wall Thickness
Ⓐ STELLITE FACE ON BODY & DISC
INLET
53" END TO END
Assumed Flaw
View A-A Showing Assumed Flaw

FIGURE 1

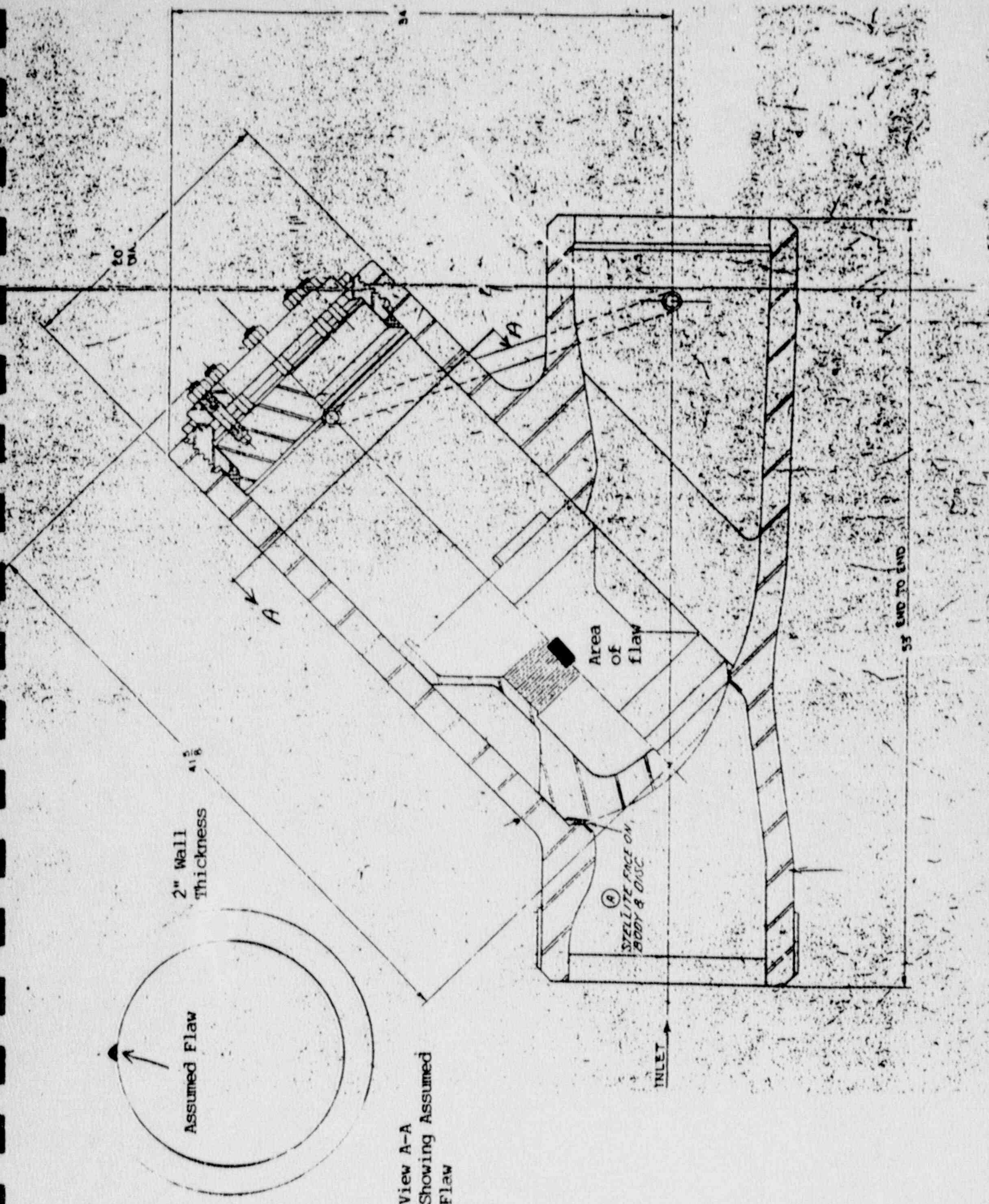
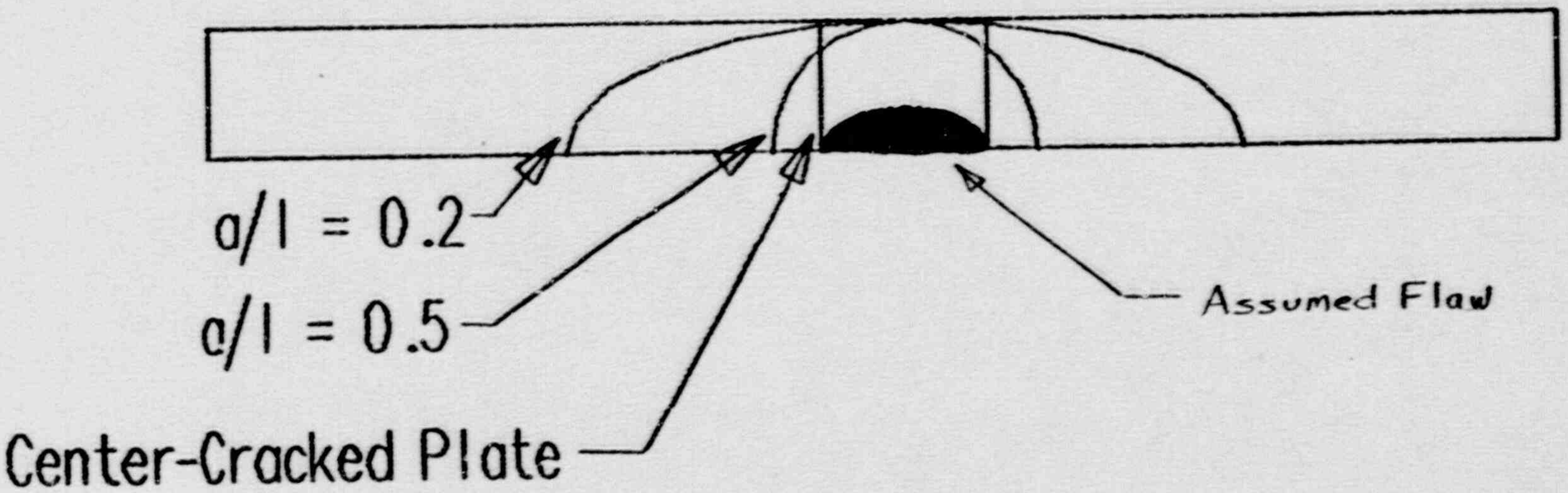

34
20" DIA.
A
A
Area of flaw
41 5/8
2" Wall Thickness
Ⓐ STELLITE FACE ON BODY & DISC
53" END TO END
INLET
Assumed Flaw
View A-A Showing Assumed Flaw

FIGURE 1

Comparison of Flaw Shapes
for
Fracture Mechanics Evaluation
of
Feedwater Check Valve V28B

Figure 2



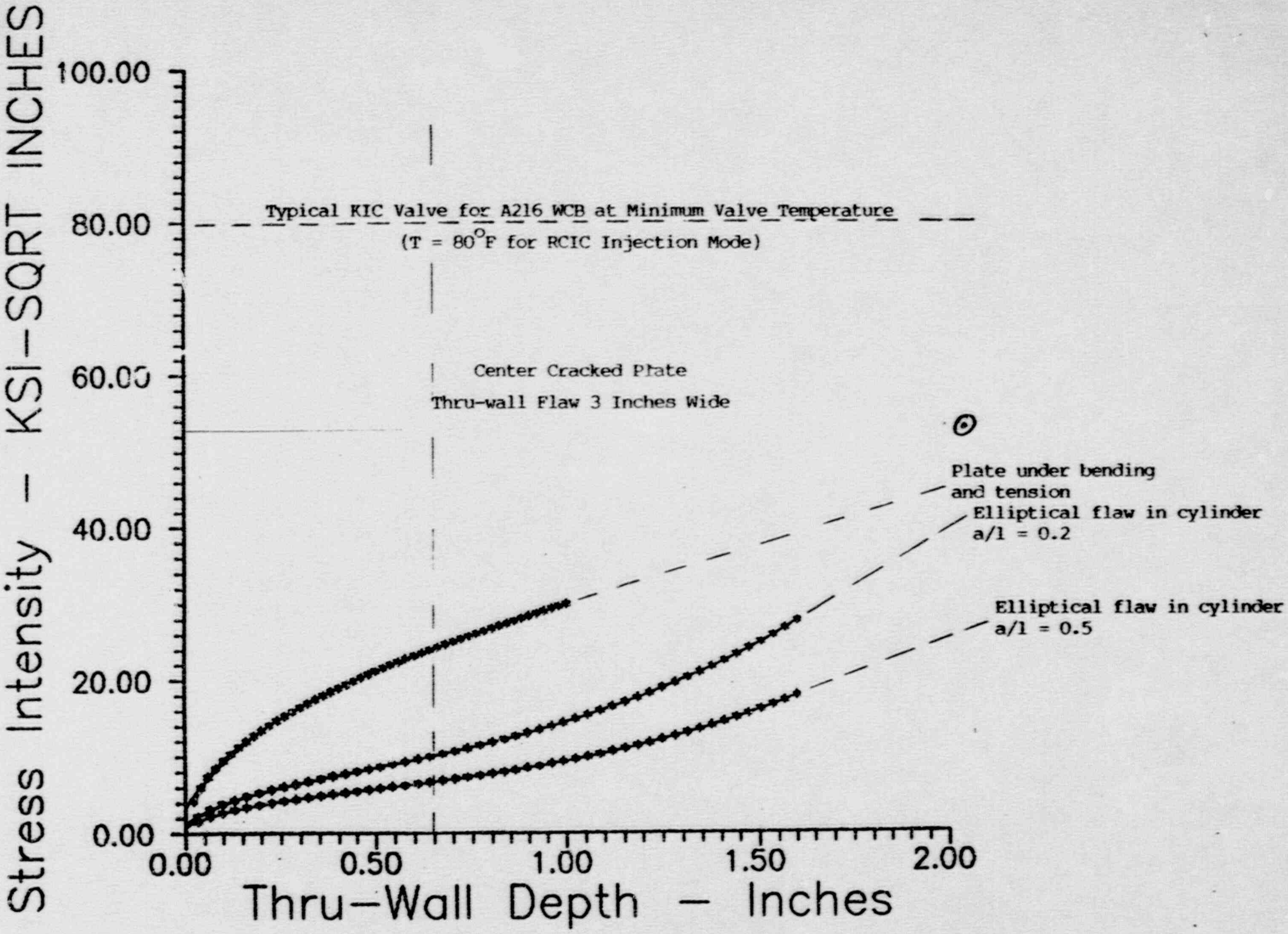

Stress Intensity - KSI-SQRT INCHES
Thru-Wall Depth - Inches
100.00
80.00
60.00
40.00
20.00
0.00
0.00
0.50
1.00
1.50
2.00
Typical KIC Valve for A216 WCB at Minimum Valve Temperature
(T = 80°F for RCIC Injection Mode)
Center Cracked Plate
Thru-wall Flaw 3 Inches Wide
Plate under bending
and tension
Elliptical flaw in cylinder
a/l = 0.2
Elliptical flaw in cylinder
a/l = 0.5

Figure 3

APPENDIX A
STRESS ANALYSIS OF FEEDWATER CHECK VALVE V28B

E. J. Betti
J. C. Fitzpatrick

APPENDIX A

Stress Analysis of Feedwater Check Valve V28B

A. APPLICABLE LOADINGS

1. Pressure

a. Design pressure 1,900 psig (G-191167). This valve is based on feedwater pump dynamic head plus condensate pump head (G-191139).

b. Operating pressure in this region is limited to reactor operating pressure plus the pressure drop across the feedwater spargers. During full feedwater flow, 1,250 psig is assumed, 200 psig over RPV operating pressure. During low feedwater (<10% of rated) 1,100 psig feedwater operating pressure is assumed.

2. Mechanical Loads

Mechanical loads are from the attached piping. The section of the check valve in question has a 20 inch OD with a 2 inch wall thickness. The attached piping is 16 inch SCH 120; t = 1.218 inch. The section modulus of the valve is as a minimum 2.4 times larger than the attached pipe in the region of the flaws. From combined dead weight, thermal, and seismic piping moments at the valve (VYC-634), valve stress was calculated to be less than 1,200 psi in the side region of the valve in the area of the detected flaws. In this region, the valve profile is flat. Therefore, localized through wall bending is not a concern.

3. Water Hammer and Valve Impact

Both water hammer or piston impact-induced stress were considered small. This system has not been subject to water hammer events. Also, with the exclusion of a double-ended pipe break upstream of the check valves, the Feedwater System is not subject to rapid pressure decreases which could result in rapid valve closure. Finally, the piston structure is much lighter than the valve body. Therefore, in the event of rapid valve closure, the piston, not the valve, would absorb the majority of impact energy.

4. Thermal Transient-Induced Stress

Full power and partial power transients do not result in severe temperature transients in the region of the 28B check valve. The largest potential thermal gradient that this valve could experience would be during a zero power hot standby condition when feedwater is in the low flow control mode (<10% of rated flow).

The B feedwater line is also used for RCIC, clean-up water return, and CRD return. The following is a summary of the system capacities:

- RCIC - 416 gpm capacity at 80°F
- CUW - 130 gpm at 430°F
- CRD - 60 gpm at 115°F
- FDW - 7,700 gpm at 375°F

The region of the valve in question is subject to membrane and through wall bending due to pressure. Hot-to-cold transients tend to decrease the through wall bending while cold-to-hot transients would add to pressure stress. Therefore, the following cold-to-hot transient was selected for investigation:

> Feedwater at 10% flow, 100°F with CUW water at 100% flow, 430°F. (Combined temperature of 152°F). Interruption of feedwater flow, continue 100% CUW flow at 430°F. The pressure is assumed to be at 1,100 psig.

B. STRESS MODEL FOR ANALYSIS

From field walk down of the feedwater check valve and in situ dimensions, it was apparent both membrane and local bending were important in the flaw region. The two dimensional constant strain model shown in Figure A1 was used for both stress and thermal analysis. The ANSYS finite element code was used to perform calculations and plots. This simplified, two dimensional model provides approximations of local membrane and bending stress in the flaw region.

C. STRESS PROFILE FOR FRACTURE MECHANICS ANALYSIS

The first case evaluated with the model was the effect of 1,900 psig internal pressure, the design pressure of the valve. This condition resulted in compressive forces on the inside face in the flaw region. A section stress profile for a 1,000 psig case is shown in Figure A2. The 1,900 psig stress profile was interpreted from these results.

From the finite element model results, an enveloping stress profile for fracture mechanics study was developed. The compressive stress profile on the inner face was changed to a constant 7,500 psi tensile stress to approximately mid-thickness. Toward the outside wall, a linearly increasing stress profile from the model was used. Changing the compressive portion of the stress profile to tensile provides a conservative "design" envelop for fracture mechanics evaluation.

To assure that the "design" stress profile is conservative, the maximum stress profile under thermal transient conditions was also studied (see Figure A3). The transient stress was combined with mechanical stress from piping and pressure stress and plotted on Figure A4 for comparison with the "design" stress profile. Figure A4 demonstrates that the "design" profile was an appropriate choice for fracture mechanics evaluation.

Figure A1

Feedwater Check Valve 2-D Model (Horizontal Plane)

EDC 3/27/89

Finite Element Model

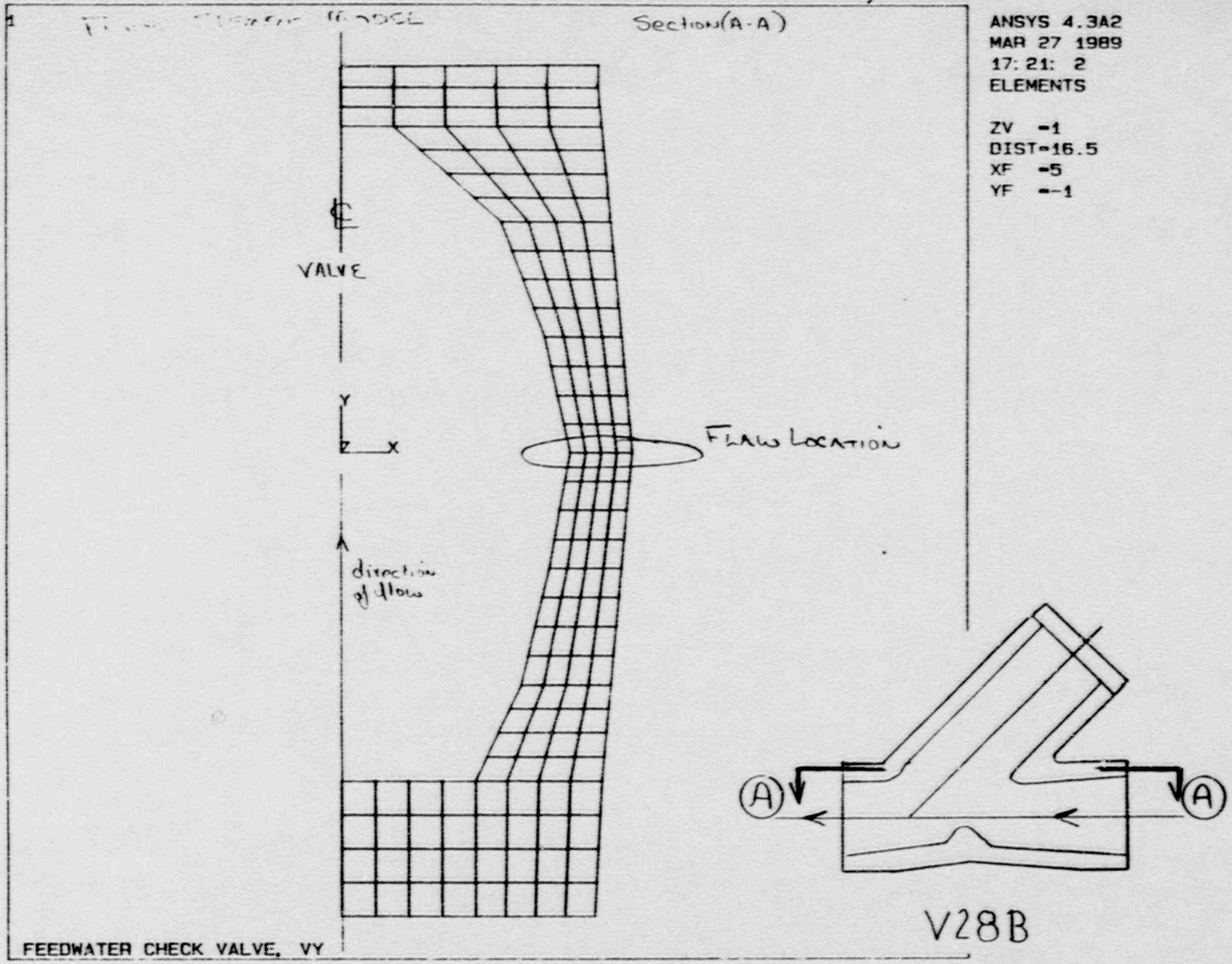
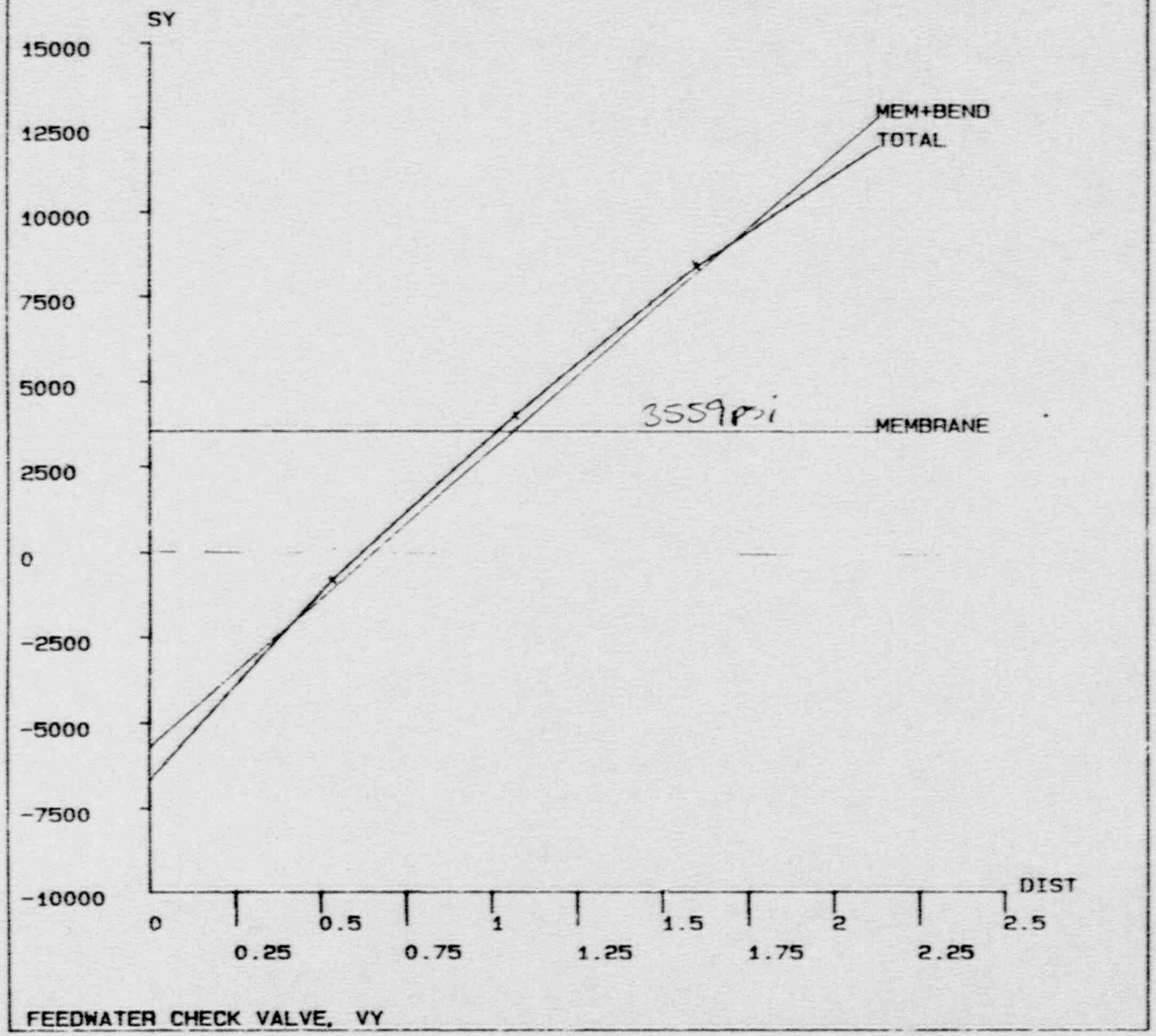


FIGURE 12

Axial Stress through Section @ FLAW

1000 psig INTERNAL PRESSURE



ANSYS 4.3A2
MAR 27 1989
17: 17: 56
POST1
STEP=1
ITER=1
TIME=30
SECTION PLOT
NOD1=35
NOD2=31
SY
STRESS GLOBAL

ZV =1
DIST=0.6666
XF =0.5
YF =0.5
ZF =0.5

FIGURE A3a: Temperature Profile Through Section @ FLAW, EVENT: INTERUPTION OF LOW FEEDWATER FLOW

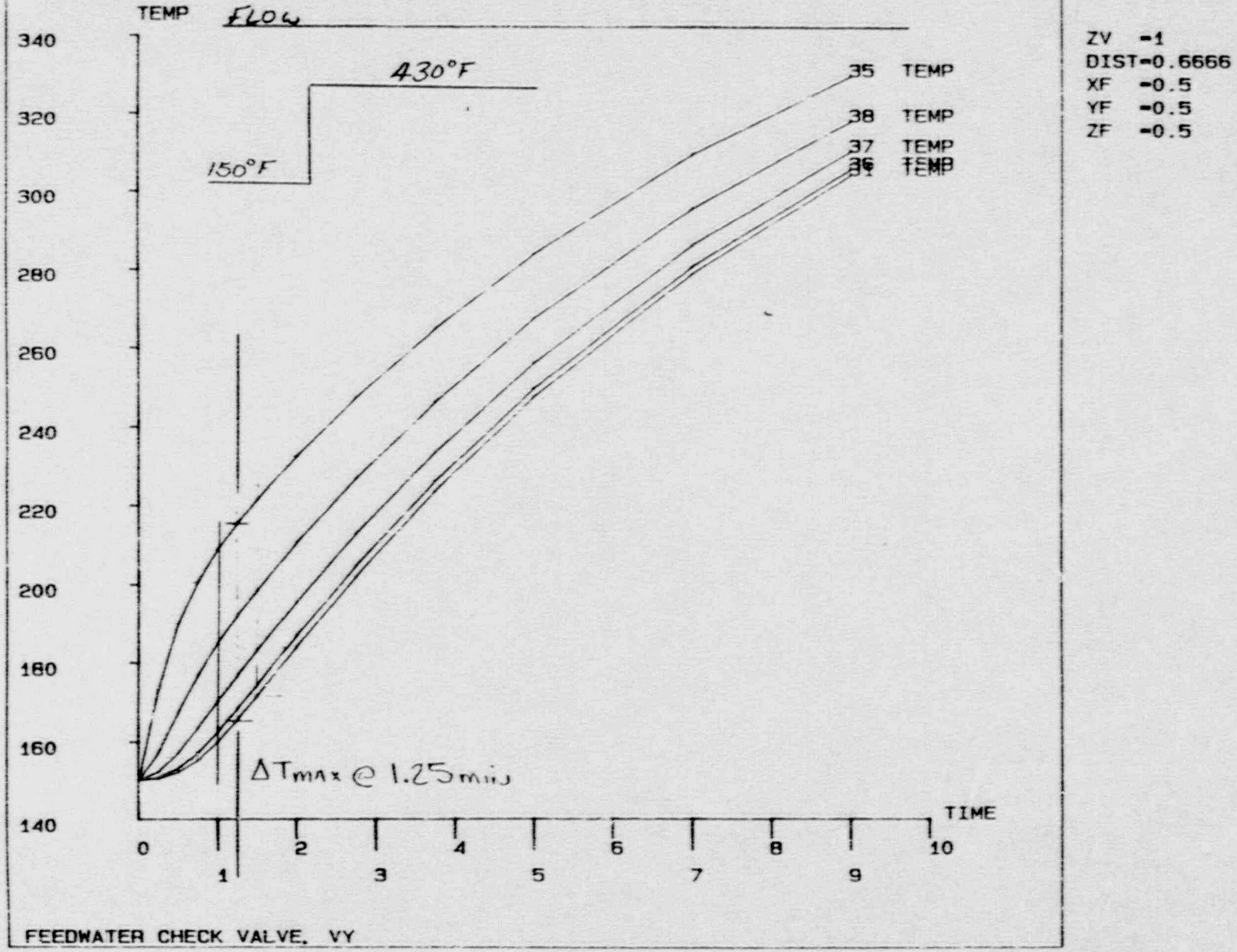
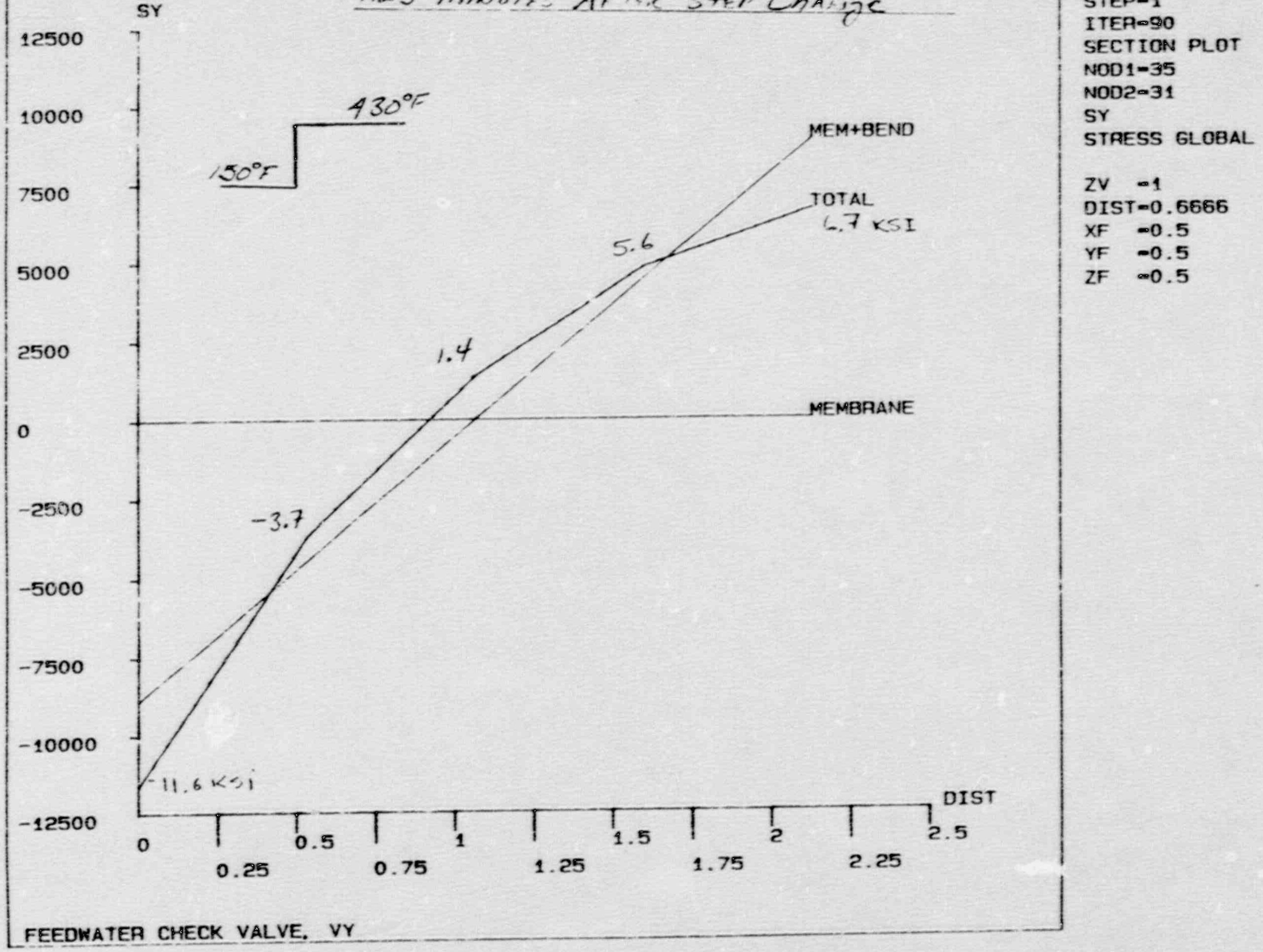


FIGURE A3b: Axial Stress Through Section @ FLAW

EVENT: INTERRUPTION OF LOW FEEDWATER FLOW

1.25 MINUTES AFTER STEP CHANGE



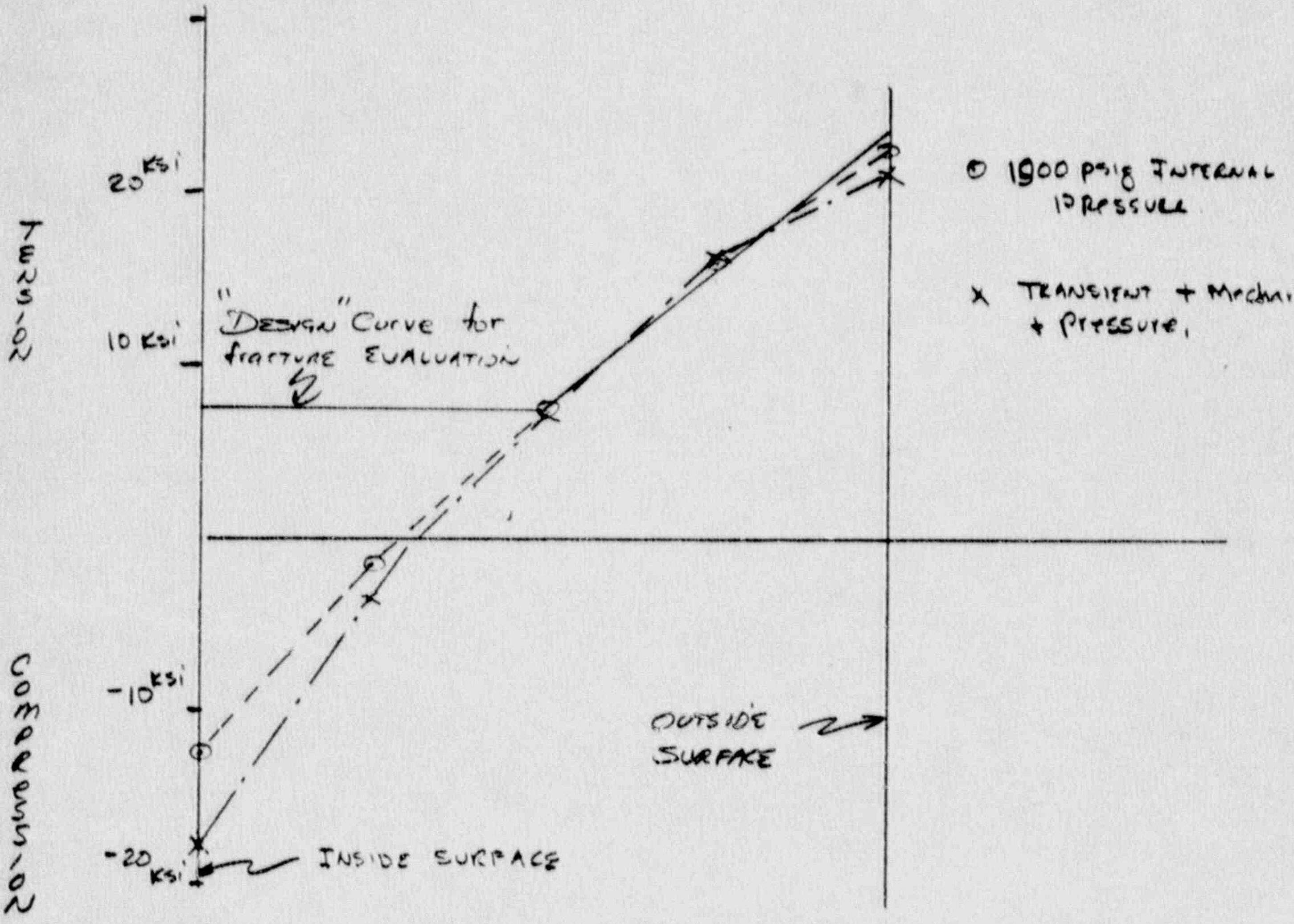
YANKEE ATOMIC ELECTRIC COMPANY

CALCULATION NO. ______ PAGE ______ OF ______

SUBJECT ______

PREPARED BY ______ DATE 3/28/89 REVIEWED BY ______ DATE ______ WORK ORDER NO. ______

FIGURE A4: Axial Through Wall Stress @ Flaw



	①	②	③	④	⑤
Pressure @ 1900 psig	-12650	-1406	7739	16184	22760
Mechanical	1200	1200	1200	1200	1200
TRANSIENT	-11600	-3700	1400	5600	6700
Pressure @ 1100 psig	-7324	-514	4480	9370	13178
TOTAL	-17724	-3314	7080	16170	21078

APPENDIX B
FLAW EVALUATION RESULTS

J. C. Fitzpatrick
J. R. Hoffman

7570R

A - Plot of Stress Profiles

B - Comparison of Flaw Profiles

C - Least Square Curve Fit Profile

D - Elliptical Flaw in Cylinder - $a/l = 0.2$

E - Elliptical Flaw in Cylinder - $a/l = 0.5$

F - Full Circumferential Flaw in Cylinder

G - Infinite Longitudinal Flaw in Cylinder

H - Elliptical Flaw in Flat Plate

I - Center Cracked Plate

J - Extrapolation of Elliptical Flaw to a Thru-Wall Flaw

K - Fatigue Crack Growth for Semi-Elliptical Flaw 1.5 Inches Deep at Three Times Applied Stress

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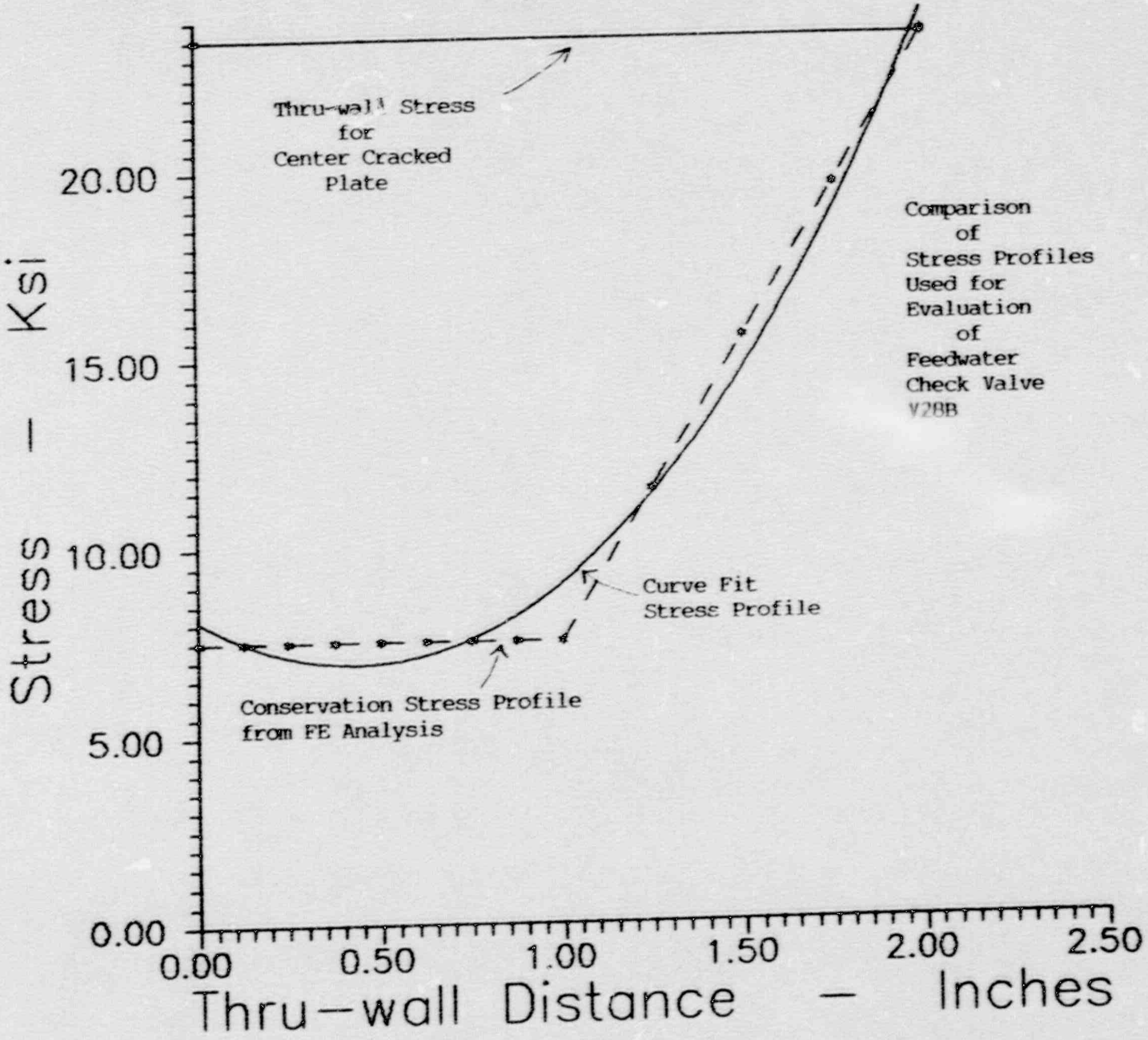
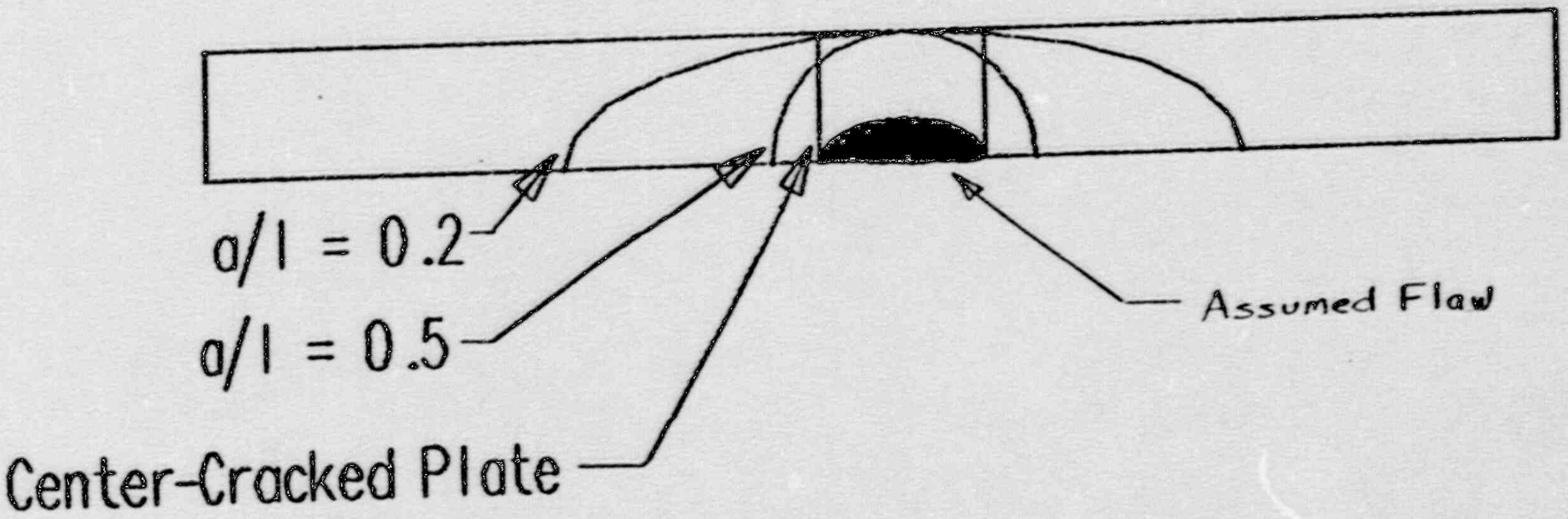


Comparison
of
Stress Profiles
Used for
Evaluation
of
Feedwater
Check Valve
V28B

Comparison of Flaw Shapes
for
Fracture Mechanics Evaluation
of
Feedwater Check Valve V28B



C

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                                     tm
                                pc-CRACK
                         (C) COPYRIGHT 1984, 1987
                    STRUCTURAL INTEGRITY ASSOCIATES, INC.
                        SAN JOSE, CA (408)978-8200
                               VERSION 1.2

                   LEAST SQUARE CURVE FIT OF STRESS PROFILE


ERMONT YANKEE FEEDWATER CHECK VALVE V28B

 TERM    COEFFICIENT
  C0      8.0867E+00
  C1     -5.335E+00
  C2      5.8800E+00
  C3      4.0177E-01


COEFFICIENT OF DETERMINATION R^2=     0.9845
CORRELATION COEFFICIENT=     0.9692


    X VALUE      Y VALUE      Y CALC        DIFF
  0.0000E+00  7.5000E+00  8.0867E+00  -5.867E-01
  1.2500E-01  7.5000E+00  7.5124E+00  -1.240E-02
  2.5000E-01  7.5000E+00  7.1266E+00  3.7340E-01
  3.7500E-01  7.5000E+00  6.9340E+00  5.6604E-01
  5.0000E-01  7.5000E+00  6.9392E+00  5.6080E-01
  6.2500E-01  7.5000E+00  7.1470E+00  3.5298E-01
  7.5000E-01  7.5000E+00  7.5621E+00  -6.213E-02
  8.7500E-01  7.5000E+00  8.1892E+00  -6.892E-01
  1.0000E+00  7.5000E+00  9.0331E+00  -1.533E+00
  1.2500E+00  1.1515E+01  1.1390E+01  1.2535E-01
  1.5000E+00  1.5530E+01  1.4670E+01  8.6043E-01
  1.7500E+00  1.9545E+01  1.8910E+01  6.3452E-01
  2.0000E+00  2.3560E+01  2.4150E+01  -5.900E-01


                              END OF pc-CRACK
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D

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                                    tm
                                pc-CRACK
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                       SAN JOSE, CA (408)978-8200
                               VERSION 1.2

              LINEAR ELASTIC FRACTURE MECHANICS EVALUATION


VERMONT YANKEE FEEDWATER CHECK VALVE V28B

CRACK MODEL:ELLIPTICAL LONGITUDINAL CRACK IN CYLINDER(T/R=0.1,A/L=0.2)

WALL THICKNESS=    2.0000

                              STRESS COEFFICIENTS
   CASE ID           C0           C1           C2           C3
  THRUWALL      23.5000       0.0000       0.0000       0.0000
     FWNRC       8.0867      -5.3350       5.8800       0.4018


    CRACK ---------------STRESS INTENSITY FACTOR----------------
    DEPTH          CASE         CASE
               THRUWALL        FWNRC

   0.0320         6.475        2.198
   0.0640         9.216        3.089
   0.0960        11.360        3.761
   0.1280        13.200        4.321
   0.1600        14.851        4.811
   0.1920        16.370        5.251
   0.2240        17.789        5.655
   0.2560        19.132        6.033
   0.2880        20.413        6.390
   0.3200        21.645        6.732
   0.3520        22.836        7.062
   0.3840        23.991        7.384
   0.4160        25.133        7.705
   0.4480        26.268        8.027
   0.4800        27.383        8.348
   0.5120        28.479        8.670
   0.5440        29.561        8.993
   0.5760        30.629        9.320
   0.6080        31.686        9.651
   0.6400        32.736        9.990
   0.6720        33.777       10.336
   0.7040        34.811       10.690
   0.7360        35.836       11.053
   0.7680        36.856       11.426
   0.8000        37.870       11.810
   0.8320        38.874       12.202
   0.8640        39.874       12.607
   0.8960        40.869       13.024
   0.9280        41.861       13.456
```

Ⓓ

```
     0.9600       42.849       13.901
     0.9920       43.835       14.362
     1.0240       44.866       14.857
     1.0560       45.913       15.375
     1.0880       46.960       15.912
     1.1200       48.008       16.470
     1.1520       49.056       17.048
     1.1840       50.104       17.649
     1.2160       51.151       18.269
     1.2480       52.195       18.911
     1.2800       53.240       19.576
     1.3120       54.286       20.266
     1.3440       55.333       20.982
     1.3760       56.382       21.724
     1.4080       57.434       22.494
     1.4400       58.493       23.297
     1.4720       59.554       24.130
     1.5040       60.618       24.992
     1.5360       61.683       25.885
     1.5680       62.750       26.810
     1.6000       63.820       27.768


                              END OF pc-CRACK
```

Ⓔ

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                                   tm
                               pc-CRACK
                      (C) COPYRIGHT 1984, 1987
                 STRUCTURAL INTEGRITY ASSOCIATES, INC.
                    SAN JOSE, CA (408)978-8200
                            VERSION 1.2

              LINEAR ELASTIC FRACTURE MECHANICS EVALUATION


VERMONT YANKEE FEEDWATER CHECK VALVE V28B

CRACK MODEL:ELLIPTICAL LONGITUDINAL CRACK IN CYLINDER(T/R=0.1,A/L=0.5)

WALL THICKNESS=    2.0000

                         STRESS COEFFICIENTS
   CASE ID         C0          C1          C2          C3
  THRUWALL    23.5000      0.0000      0.0000      0.0000
     FWNRC     8.0867     -5.3350      5.8800      0.4018


     CRACK ---------------STRESS INTENSITY FACTOR----------------
     DEPTH         CASE        CASE
                THRUWALL       FWNRC

    0.0320        4.726       1.602
    0.0640        6.695       2.238
    0.0960        8.214       2.710
    0.1280        9.501       3.095
    0.1600       10.641       3.427
    0.1920       11.678       3.720
    0.2240       12.634       3.985
    0.2560       13.528       4.229
    0.2880       14.371       4.457
    0.3200       15.173       4.672
    0.3520       15.939       4.879
    0.3840       16.674       5.078
    0.4160       17.385       5.273
    0.4480       18.075       5.466
    0.4800       18.744       5.657
    0.5120       19.395       5.848
    0.5440       20.030       6.041
    0.5760       20.649       6.235
    0.6080       21.253       6.433
    0.6400       21.843       6.632
    0.6720       22.420       6.837
    0.7040       22.987       7.047
    0.7360       23.544       7.263
    0.7680       24.091       7.486
    0.8000       24.629       7.717
    0.8320       25.164       7.958
    0.8640       25.691       8.208
    0.8960       26.211       8.468
    0.9280       26.724       8.738
```

```
     0.9600        27.232        9.019
     0.9920        27.733        9.311
     1.0240        28.232        9.616
     1.0560        28.726        9.935
     1.0880        29.216       10.268
     1.1200        29.701       10.614
     1.1520        30.182       10.976
     1.1840        30.658       11.352
     1.2160        31.133       11.744
     1.2480        31.606       12.152
     1.2800        32.076       12.577
     1.3120        32.542       13.018
     1.3440        33.005       13.478
     1.3760        33.466       13.955
     1.4080        33.922       14.452
     1.4400        34.371       14.968
     1.4720        34.818       15.504
     1.5040        35.263       16.060
     1.5360        35.704       16.638
     1.5680        36.144       17.236
     1.6000        36.581       17.857

                                   END OF pc-CRACK
```

Ⓕ pg'

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         LINEAR ELASTIC FRACTURE MECHANICS EVALUATION


ERMONT YANKEE FEEDWATER CHECK VALVE V28B

CRACK MODEL:CIRCUMFERENTIAL CRACK IN CYLINDER(T/R=0.2)

ALL THICKNESS=    2.0000

                     STRESS COEFFICIENTS
   CASE ID          C0          C1          C2          C3
     FWNRC      8.0867     -5.3354      5.8800      0.4018


    CRACK ---------------STRESS INTENSITY FACTOR---------------
    DEPTH          CASE
                  FWNRC

   0.0320         2.799
   0.0640         3.930
   0.0960         4.781
   0.1280         5.487
   0.1600         6.100
   0.1920         6.649
   0.2240         7.181
   0.2560         7.692
   0.2880         8.178
   0.3200         8.646
   0.3520         9.100
   0.3840         9.545
   0.4160        10.017
   0.4480        10.523
   0.4800        11.032
   0.5120        11.545
   0.5440        12.064
   0.5760        12.590
   0.6080        13.138
   0.6400        13.736   ←
   0.6720        14.349
   0.7040        14.978
   0.7360        15.624
   0.7680        16.288
   0.8000        16.972
   0.8320        17.705
   0.8640        18.460
   0.8960        19.239
   0.9280        20.042
   0.9600        20.871
```

```
     0.9920        21.727
     1.0240        22.686
     1.0560        23.704
     1.0880        24.758
     1.1200        25.850
     1.1520        26.981
     1.1840        28.153
     1.2160        29.406
     1.2480        30.747
     1.2800        32.137
     1.3120        33.578
     1.3440        35.073
     1.3760        36.623
     1.4080        38.251
     1.4400        40.002
     1.4720        41.816
     1.5040        43.695
     1.5360        45.642
     1.5680        47.659
     1.6000        49.747


                             END OF pc-CRACK
```

⑥ pg 1

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          LINEAR ELASTIC FRACTURE MECHANICS EVALUATION

VERMONT YANKEE FEEDWATER CHECK VALVE V28B

CRACK MODEL:LONGITUDINAL CRACK IN CYLINDER(T/R=0.2)

WALL THICKNESS=     2.0000

                        STRESS COEFFICIENTS
   CASE ID          C0          C1          C2          C3
     FWNRC      8.0867     -5.3354      5.8800      0.4018


    CRACK ---------------STRESS INTENSITY FACTOR---------------
    DEPTH        CASE
                 FWNRC

   0.0320        2.693
   0.0640        3.848
   0.0960        4.763
   0.1280        5.561
   0.1600        6.288
   0.1920        6.970
   0.2240        7.651
   0.2560        8.324
   0.2880        8.986
   0.3200        9.642
   0.3520       10.295
   0.3840       10.948
   0.4160       11.630
   0.4480       12.346
   0.4800       13.073
   0.5120       13.810
   0.5440       14.560
   0.5760       15.325
   0.6080       16.141
   0.6400       17.087  ←
   0.6720       18.060
   0.7040       19.058
   0.7360       20.085
   0.7680       21.141
   0.8000       22.227
   0.8320       23.523
   0.8640       24.860
   0.8960       26.239
   0.9280       27.662
   0.9600       29.131
```

```
      0.9920          30.647
      1.0240          32.401
      1.0560          34.278
      1.0880          36.217
      1.1200          38.223
      1.1520          40.295
      1.1840          42.438
      1.2160          44.778
      1.2480          47.329
      1.2800          49.971
      1.3120          52.708
      1.3440          55.543
      1.3760          58.480
      1.4080          61.637
      1.4400          65.258
      1.4720          69.006
      1.5040          72.884
      1.5360          76.896
      1.5680          81.048
      1.6000          85.343


                                END OF pc-CRACK
```

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                LINEAR ELASTIC FRACTURE MECHANICS EVALUATION


VERMONT YANKEE FEEDWATER CHECK VALVE V28B


CRACK MODEL:ELLIPTICAL SURFACE CRACK PLATE UNDER MEMBRANE & BENDING STRESSES

WALL THICKNESS=     2.0000
YIELD STRESS=    30.8000
CRACK ASPECT RATIO(A/L)=     0.2500


              STRESS COEFFICIENTS
    CASE ID           C0           C1
      FWNRC      8.0867       0.0000


      CRACK ---------------STRESS INTENSITY FACTOR----------------
      DEPTH         CASE
                    FWNRC

     0.0200         1.854
     0.0400         2.623
     0.0600         3.214
     0.0800         3.713
     0.1000         4.154
     0.1200         4.552
     0.1400         4.919
     0.1600         5.261
     0.1800         5.583
     0.2000         5.887
     0.2200         6.197
     0.2400         6.496
     0.2600         6.785
     0.280C         7.067
     0.3000         7.341
     0.3200         7.609
     0.3400         7.871
     0.3600         8.127
     0.3800         8.379
     0.4000         8.627
     0.4200         8.844
     0.4400         9.056
     0.4600         9.264
     0.4800         9.467
     0.5000         9.667
     0.5200         9.862
```

```
     0.5400       10.055
     0.5600       10.244
     0.5800       10.429
     0.6000       10.612
     0.6200       10.849
     0.6400       11.084
     0.6600       11.319
     0.6800       11.553
     0.7000       11.787
     0.7200       12.019
     0.7400       12.252
     0.7600       12.484
     0.7800       12.715
     0.8000       12.947
     0.8200       13.199
     0.8400       13.452
     0.8600       13.705
     0.8800       13.959
     0.9000       14.212
     0.9200       14.467
     0.9400       14.721
     0.9600       14.976
     0.9800       15.232
     1.0000       15.487


                           END OF pc-CRACK
```

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                  LINEAR ELASTIC FRACTURE MECHANICS EVALUATION

VERMONT YANKEE FEEDWATER CHECK VALVE V28B


CRACK MODEL:CENTER CRACK PLATE UNDER REMOTE TENSION STRESS

HALF PLATE WIDTH=    10.0000

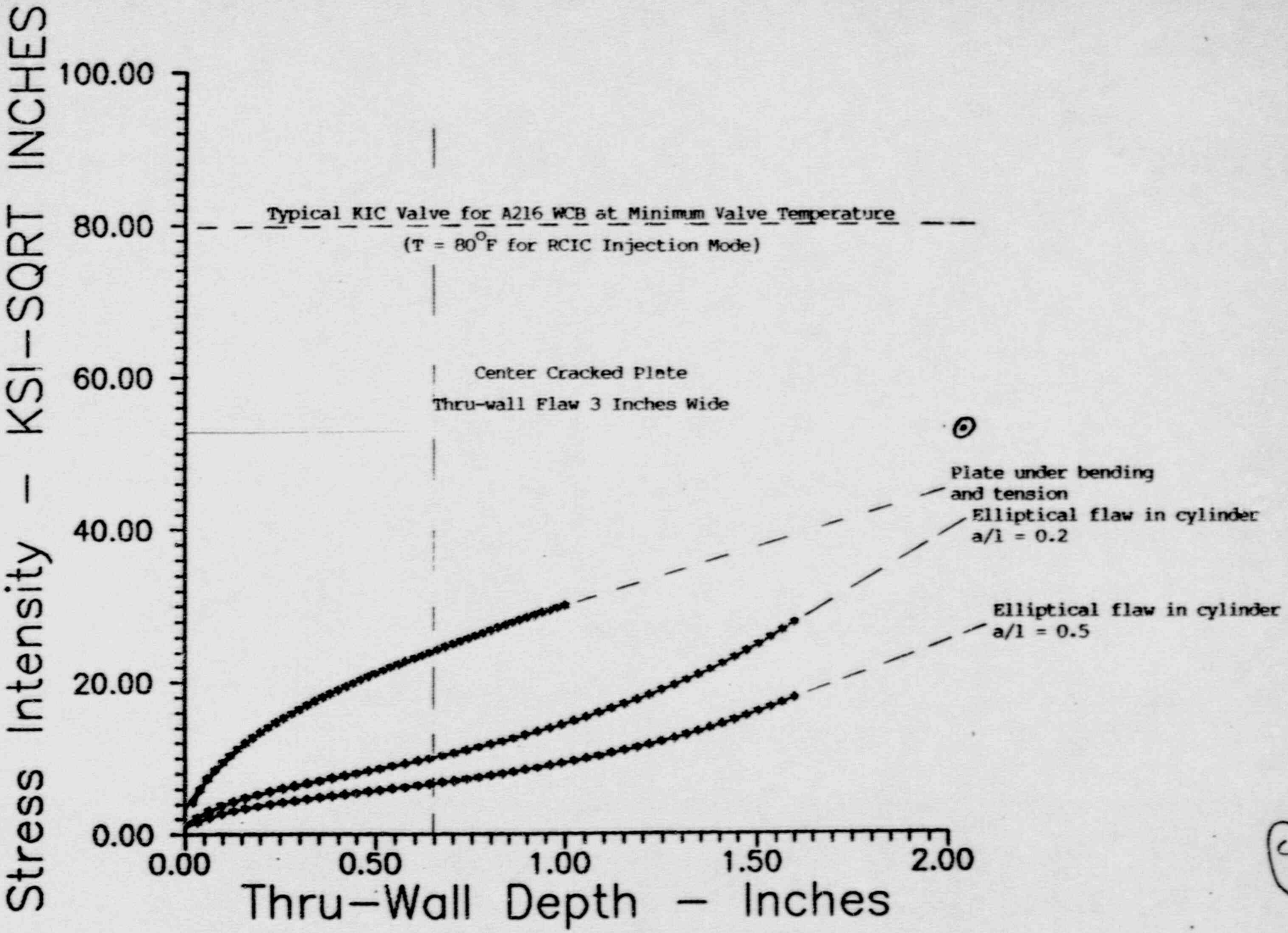

            STRESS COEFFICIENTS
    CASE ID          C0          C1
      FWNRC     8.0867
   THRUWALL    23.5000


     CRACK ---------------STRESS INTENSITY FACTOR----------------
     DEPTH          CASE      CASE
                   FWNRC  THRUWALL

    0.0400         2.867     8.331
    0.0800         4.054    11.782
    0.1200         4.966    14.430
    0.1600         5.734    16.664
    0.2000         6.412    18.632
    0.2400         7.024    20.413
    0.2800         7.588    22.051
    0.3200         8.113    23.577
    0.3600         8.607    25.011
    0.4000         9.074    26.368
    0.4400         9.519    27.661
    0.4800         9.944    28.897
    0.5200        10.352    30.084
    0.5600        10.746    31.228
    0.6000        11.126    32.333
    0.6400        11.495    33.403
    0.6800        11.852    34.442
    0.7200        12.200    35.452
    0.7600        12.538    36.437
    0.8000        12.869    37.397
    0.8400        13.192    38.336
    0.8800        13.508    39.254
    0.9200        13.817    40.153
    0.9600        14.121    41.035
    1.0000        14.419    41.901
    1.0400        14.712    42.752
    1.0800        14.999    43.588
```

```
      1.1200       15.283       44.412
      1.1600       15.562       45.223
      1.2000       15.837       46.022
      1.2400       16.108       46.810
      1.2800       16.376       47.588
      1.3200       16.640       48.356
      1.3600       16.901       49.115
      1.4000       17.159       49.865
      1.4400       17.415       50.607
      1.4800       17.667       51.342
      1.5200       17.918       52.069
      1.5600       18.165       52.789
      1.6000       18.411       53.502
      1.6400       18.654       54.210
      1.6800       18.896       54.911
      1.7200       19.135       55.607
      1.7600       19.373       56.298
      1.8000       19.609       56.984
      1.8400       19.843       57.665
      1.8800       20.076       58.342
      1.9200       20.308       59.014
      1.9600       20.538       59.683
      2.0000       20.767       60.348

                              END OF pc-CRACK
```


Stress Intensity - KSI-SQRT INCHES
100.00
80.00
60.00
40.00
20.00
0.00
0.00
0.50
1.00
1.50
2.00
Thru-Wall Depth - Inches
Typical KIC Valve for A216 WCB at Minimum Valve Temperature
(T = 80°F for RCIC Injection Mode)
Center Cracked Plate
Thru-wall Flaw 3 Inches Wide
Plate under bending
and tension
Elliptical flaw in cylinder
a/l = 0.2
Elliptical flaw in cylinder
a/l = 0.5

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Ⓚ pg 1

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                  FATIGUE CRACK GROWTH ANALYSIS

ERMONT YANKEE FEEDWATER CHECK VALVE V28B

INITIAL CRACK SIZE=  1.5000
ALL THICKNESS=  2.0000
AX CRACK SIZE FOR FCG=  1.6000

                    FATIGUE CRACK GROWTH LAW(S)
         ASME SECTION XI BILINEAR LAWS FOR WATER ENVIRONMENT

R = Kmin / Kmax
F R < 0.25 THEN R' = 0.25
F R > 0.65 THEN R' = 0.65
            ELSE R' = R
   QL = 26.9 * R' - 5.725
   QU = 3.75 * R' + 0.06
KTRAN = (D * QU / QL)^0.25
   dK = Kmax - Kmin

F dK < KTRAN  THEN
da/dN = CL * QL * dK^5.95

F dK > KTRAN  THEN
da/dN = CU * QU * dK^1.95

HERE:
   CL = 1.020000E-12
   CU = 1.010001E-07
    D = 9.902034E+04
RE FOR THE CURRENTLY ASSUMED UNITS OF:
   FORCE: kips   LENGTH: inches


                       STRESS COEFFICIENTS
   CASE ID         C0          C1          C2          C3
    FWNRC      8.0867     -5.3354      5.8800      0.4018


UMBER OF CYCLE BLOCKS=                    18
RINT INCREMENT OF CYCLE BLOCK=           1.0

                NUMBER OF    CALCULATION            PRINT       FCG
 SUBBLOCK          CYCLES      INCREMENT        INCREMENT      LAW ID
       1              1.0            1.0              1.0 SECT XI LAW
```

```
                       Kmax                               Kmin
SUBBLOCK      CASE ID   SCALE FACTOR       CASE ID   SCALE FACTOR
     1          FWNRC      3.0000             FWNRC      0.0000

CRACK MODEL:ELLIPTICAL LONGITUDINAL CRACK IN CYLINDER(T/R=0.1,A/L=0.5)

     CRACK ---------------STRESS INTENSITY FACTOR---------------
     DEPTH          CASE
                   FWNRC

    0.0320          1.602
    0.0640          2.238
    0.0960          2.710
    0.1280          3.095
    0.1600          3.427
    0.1920          3.720
    0.2240          3.985
    0.2560          4.229
    0.2880          4.457
    0.3200          4.672
    0.3520          4.878
    0.3840          5.078
    0.4160          5.273
    0.4480          5.466
    0.4800          5.657
    0.5120          5.848
    0.5440          6.041
    0.5760          6.235
    0.6080          6.432
    0.6400          6.632
    0.6720          6.837
    0.7040          7.047
    0.7360          7.263
    0.7680          7.486
    0.8000          7.717
    0.8320          7.958
    0.8640          8.208
    0.8960          8.468
    0.9280          8.738
    0.9600          9.018
    0.9920          9.310
    1.0240          9.616
    1.0560          9.935
    1.0880         10.267
    1.1200         10.614
    1.1520         10.975
    1.1840         11.352
    1.2160         11.744
    1.2480         12.151
    1.2800         12.576
    1.3120         13.018
    1.3440         13.477
    1.3760         13.955
    1.4080         14.451
```

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```
      1.4400       14.967
      1.4720       15.503
      1.5040       16.060
      1.5360       16.637
      1.5680       17.236
      1.6000       17.856



  TOTAL  SUPBLOCK
  CYCLE    CYCLE       KMAX       KMIN     DELTAK      R     DADN      DA          A   A/T

BLOCK  1
    1.0      1.0      47.97      0.00      47.97   0.00 1.9E-04 0.0002     1.5002 0.75

BLOCK  2
    2.0      1.0      47.98      0.00      47.98   0.00 1.9E-04 0.0002     1.5004 0.75

BLOCK  3
    3.0      1.0      47.99      0.00      47.99   0.00 1.9E-04 0.0002     1.5006 0.75

BLOCK  4
    4.0      1.0      48.00      0.00      48.00   0.00 1.9E-04 0.0002     1.5008 0.75

BLOCK  5
    5.0      1.0      48.01      0.00      48.01   0.00 1.9E-04 0.0002     1.5010 0.75

BLOCK  6
    6.0      1.0      48.02      0.00      48.02   0.00 1.9E-04 0.0002     1.5011 0.75

BLOCK  7
    7.0      1.0      48.03      0.00      48.03   0.00 1.9E-04 0.0002     1.5013 0.75

BLOCK  8
    8.0      1.0      48.04      0.00      48.04   0.00 1.9E-04 0.0002     1.5015 0.75

BLOCK  9
    9.0      1.0      48.05      0.00      48.05   0.00 1.9E-04 0.0002     1.5017 0.75

BLOCK  10
   10.0      1.0      48.06      0.00      48.06   0.00 1.9E-04 0.0002     1.5019 0.75
```

K

```
BLOCK  11
   11.0       1.0     48.07      0.00      48.07  0.00 1.9E-04 0.0002    1.5021 0.75

BLOCK  12
   12.0       1.0     48.08      0.00      48.08  0.00 1.9E-04 0.0002    1.5023 0.75

BLOCK  13
   13.0       1.0     48.09      0.00      48.09  0.00 1.9E-04 0.0002    1.5025 0.75

BLOCK  14
   14.0       1.0     48.10      0.00      48.10  0.00 1.9E-04 0.0002    1.5027 0.75

BLOCK  15
   15.0       1.0     48.11      0.00      48.11  0.00 1.9E-04 0.0002    1.5029 0.75

BLOCK  16
   16.0       1.0     48.12      0.00      48.12  0.00 1.9E-04 0.0002    1.5031 0.75

BLOCK  17
   17.0       1.0     48.13      0.00      48.13  0.00 1.9E-04 0.0002    1.5033 0.75

BLOCK  18
   18.0       1.0     48.14      0.00      48.14  0.00 1.9E-04 0.0002    1.5035 0.75

                           END OF pc-CRACK
```

APPENDIX C

FRACTURE TOUGHNESS DATA FOR A216 WCB CAST MATERIAL

NUREG/CR-3009
SAND78-2347

Fracture Toughness of PWR Components Supports

Prepared by G. A. Knorovski, R. D. Krieg, G. C. Allen, Jr.

Sandia National Laboratories

Prepared for
U.S. Nuclear Regulatory
Commission

Table 3.2

Classification of Wrought Grades into Groups

Plain carbon: A-7, A-53, A-106, A-201, A-212, A-283, A-284 A-285, A-306, A-307, A-501, A-515

Carbon-manganese: A-36, A-105, A-516, A-537

High-strength low-alloy: A-441, A-572, A-588, A-618

Low alloy (not quenched & tempered): A-302, A-322, A-353, A-387

Quenched & tempered: A-193, A-194, A-325, A-354, A-461, A-490, A-508, A-514, A-517, A-533, A-537, A-540, A-543, A-563, A-574.

Table 4.4
Computation of NDT Results

Material		$\overline{NDT}$	σ	$\overline{NDT} + 1.3\sigma$	$\overline{NDT} + 2\sigma$
Cast Steels					
A-27, A-216	1"	- 6°F	12°F	10°F	18°F
(heat treated	>1"	35	17	57	69
condition)					
A-352					max. -20
Wrought Steels					
all "mild" steels*		27	31	67	89
all "mild" steels except A-201		40	28	77	96
C-Mn* (as-hot rolled)		22	13	39	48
(normalized)		-28	18	- 5	8
HSLA* (as-hot rolled)		25**	12**	41**	49**
(normalized)		-50**	18**	-27**	-14**
low alloy non Q&T		8	28	45	64
A-302					max. -320
A-353					65**
A-387					
Quenched & Tempered					
A-508 C12					max. 40°F
A-514					max. -10°F
A-517					max. -20°F
A-533B C11					max. 20°F
A-537 C12					max. -60°F
A-543					max. -60°F

* See table 3.2 for ASTM specs included in this category
** See discussion in Appendix B

4.4.3 Fracture Toughness

Minimum values for fracture toughness of the material groups are indicated in Table 4.5. These are usually dynamic values or static values obtained at lower temperatures equivalenced via the Barsom temperature shift (see section 4.2). Data at the reference temperature, 75°F, was not always obtainable. If data was not obtainable,

APPENDIX B - MATERIAL DATA

B.1 Data Obtained

The sources of material data for the various groups are listed in Tables B.1 through B.7. Included in these tables are data sources which were not used in the body of the report. The actual data (NDT and K-type) have been plotted in Figs. B.1 through B.25. Tabulation of $\overline{\mathrm{NDT}}$ data and standard deviations (where possible) are indicated in Table 4.4.

NDT data for several grades of steel were not located. Assignment into susceptibility groups for these materials were based on the minimum requirements of the appropriate standards under which the materials were procured (see Appendix C), as compared to materials for which data were obtained.

B.2 Cast Steels

Four grades of cast steels were listed in the utility submittals (not counting a stainless steel casting for Yankee, considered not to have a problem with respect to fracture toughness or lamellar tearing). Two of the grades, A-27 Gr 70-40 and A-216 Gr WCB are carbon manganese-silicon types; one, A-148 (Gr 80-40 and Gr 80-50) is not chemically specified (which indicates it may be either C-Mn or low-alloy depending upon the heat treatment and/or section size) and the last, A-352 Gr LC3, is a high (3-4%) nickel content heat-treated alloy requiring CVN testing. (Note: all % are by weight)

The A-352 Gr LC3 grade in either the double normalized and tempered, or quenched and tempered condition is expected to show excellent fracture toughness with NDT's in the range of -100°F for

1" section size (Fig. B.1). Some utility data (Ref. B-1) indicated thick section NDT's in the -100 to -60°F range with a maximum value (one example) of -20°F.

A-27 Gr 70-40 and A-216 Gr WCB are both C-Mn-Si type alloys varying only slightly in chemical composition allowables, and primarily in minimum yield strength (40 vs 36 ksi, respectively). Of the two, the A-27 Gr 70-40 allows less carbon (.25% vs .30%) but more manganese (1.2% vs 1.0%). A-216 Gr WCC is virtually identical to A-27 Gr 70-40 in this respect. A histogram of NDT values for A-27 Gr 70-40 heats mainly in the normalized and tempered condition (five were normalized and four were quenched and tempered) plus five heats of A-216 Gr WCB is shown in Fig. B.2. This is taken from a compilation made by the Steel Founder's Society of America (Ref. B-2). The statistics of these data imply that 95% of all heats have NDT's below 20°F. However, these data are taken from 1" thick test castings, and a section size effect may be expected. A second source of data (Ref. B-3) for these materials indicated that NDT was 35°F with a standard deviation (σ) of 17°F for 12 specimens of varying thickness (from 2-1/2" to 5") poured from two heats in the normalized and tempered condition. This still indicates that 95% have their NDT below 70°F, but not with as much margin as the 1 in. thickness case. Finally, these two specifications allow the possibility of producing heats in the annealed condition, if the mechanical properties can be met. This would be expected to further degrade their fracture toughness properties since a coarser microstructure would result. This implies the only way to meet strength requirements would be by increasing carbon content.

Finally, A-148 Gr 80-40 and Gr 80-50 (40 and 50 ksi yield strength, respectively) are more difficult to evaluate, since chemical specifications and data are lacking. The added strength requirements over A27 Gr 70-40 could be met in a number of ways; via heat treatment, via additional carbon content, or via alloy content. Since additional carbon is usually the least expensive route, the implication is that these sub-grades of A-148 would have less desirable NDT values than the previously discussed A-27 and A-216. However, A-148 was specified by only one plant and was part of a wire rope system, which is probably not as critical a location as the other cast grades, which were typically in the sliding pedestal category of plants. In Fig. B.1 some NDT data (Ref. B-4) is available for normalized and tempered A-148 Gr 80-50 which indicate excellent NDT's around -10F; however, these heats contained approximately 2% Ni. Thus these data would be indicative of the best practices in meeting the mechanical property requirements.

K_{Ic} data were located for two heats of A-216 Gr WCC (Refs B-5, B-6). These are shown in Figs. B.3. Applying a temperature shift of about 150°F, equivalent K_{Id} values at 75°F are roughly 40 ksi $\sqrt{\text{in}}$. These specimens were taken from immense (20"x20"x48") castings, and probably represent the worst possible section size effect.

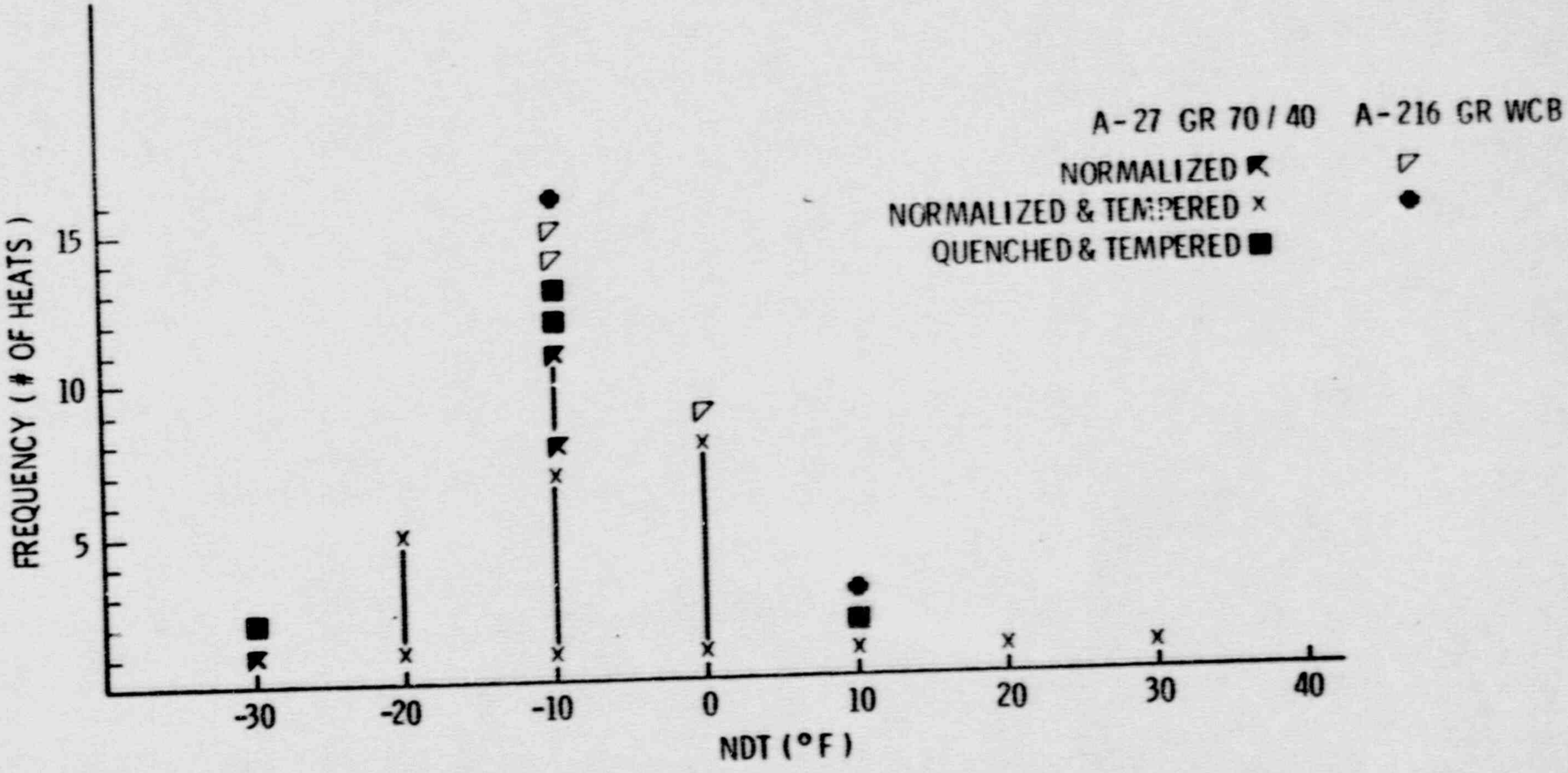
B.3 Weld Consumables

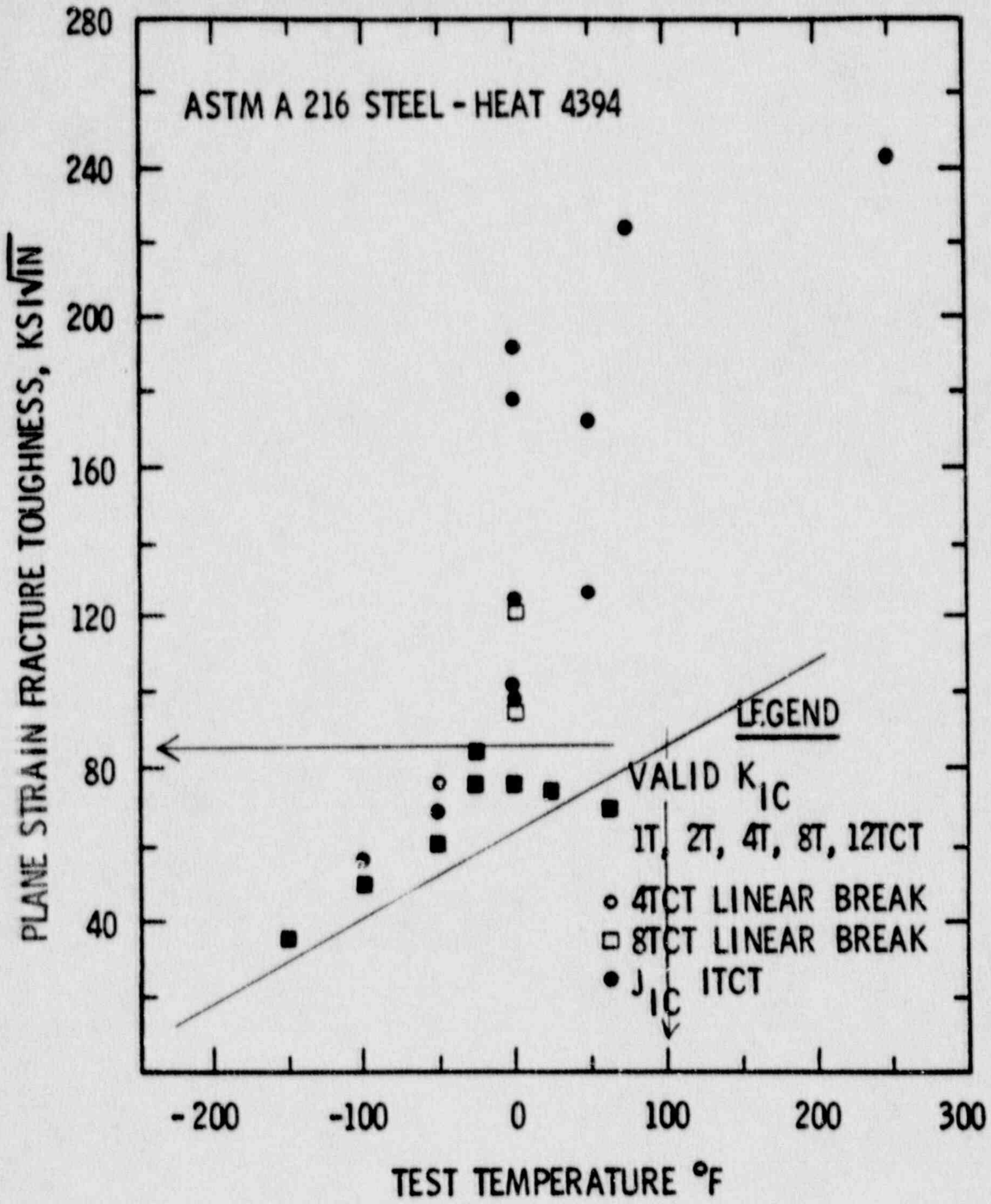
The weld metals are also in the cast steel category. It is difficult to evaluate weld metal properties separately from the base materials being joined, since dilution effects can occur which significantly change the chemical composition of the fused metal. Further-

FIG. B.2 NDT FOR CAST GRADES

$\langle NDT \rangle$ FOR A-27 IS -7°F

σ " 13 °F





- FRACTURE TOUGHNESS VERSUS TEST TEMPERATURE

FIGURE B.3(a) A-216 K_{IC} DATA

APPENDIX D
ENHANCED LEAKAGE MONITORING PROGRAM FOR FEEDWATER CHECK VALVE V28B

APPENDIX D

ENHANCED LEAKAGE MONITORING PROGRAM FOR FEEDWATER CHECK VALVE V28B

To augment Vermont Yankee's existing Primary Containment Leakage Monitoring System, a Local Leak Detection System has been installed on the FDW-28B valve. This additional system is a Techmark Leak Detection System to provide constant leakage monitoring during the next operating cycle. The system consists of three moisture sensitive tape (MST) transducers mounted on the mirror insulation below the valve (V28B). To install the transducers, a ½" hole was drilled through the insulation for the transducer sensor tube to be inserted. The sensor tube provides a path for moisture from under the insulation to contact the MST. The transducers have the ability to detect leakage as low as 0.1 gpm. The transducers provide a multiplex signal to an indicator/control unit (TUM 700) mounted in the Reactor Building. The control unit interrogates all sensors once per second and provides a digital display of sensor location(s) for alarm or trouble conditions. The unit also provides remote alarm indication in the main control room.

The Local Leak Detection System will be utilized by operations personnel to initiate further administrative actions/controls which have been developed as part of this enhanced plan. These administrative controls identify, in part, operator action upon receipt of an alarm on the MST unit, compensatory action if the unit experiences trouble as well as establishing additional leakage rate criteria below that contained in Technical Specifications.

As stated above, the Local Leak Detection System is intended to augment the existing systems and provide additional assurance that any leakage from the FDW-28B valve will not go undetected. This system will provide operators with an "early warning system" to initiate additional measures of this augmented program.