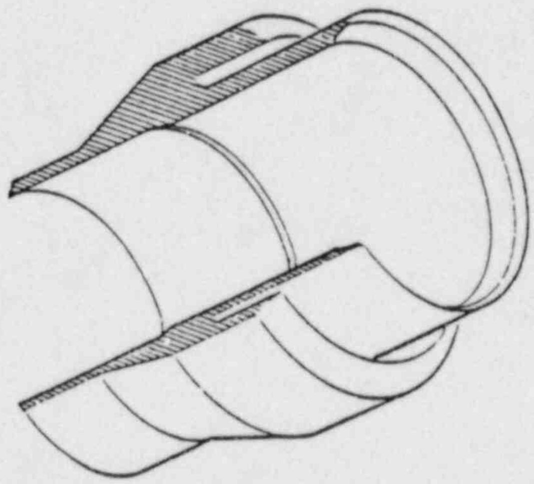
February 1988

Vermont Yankee Nuclear Power Station

Justification for Long Term Operation

for

Vermont Yankee Core Spray Nozzle Weld Overlays



Vermont Yankee Nuclear Power Corporation

JOHN R. HOFFMAN, P.E.

YANKEE ATOMIC ELECTRIC COMPANY

1671 Worcester Road
Framingham, Massachusetts 01701

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Justification for Long Term Operation

for

Vermont Yankee Core Spray Nozzle Weld Overlays

1. Summary

In May 1986 Vermont Yankee applied weld overlays to the safe end to nozzle welds on the two core spray nozzles on the reactor pressure vessel.[1,2] In January 1987 Vermont Yankee submitted an engineering report to the USNRC demonstrating that at least two cycles of operation with the overlays was justified.[3] The USNRC approved operation with the overlays through Cycle 13 (scheduled to end in February 1989) providing satisfactory results were obtained from ultrasonic examinations conducted during the Cycle 12 refueling outage.[4,13]

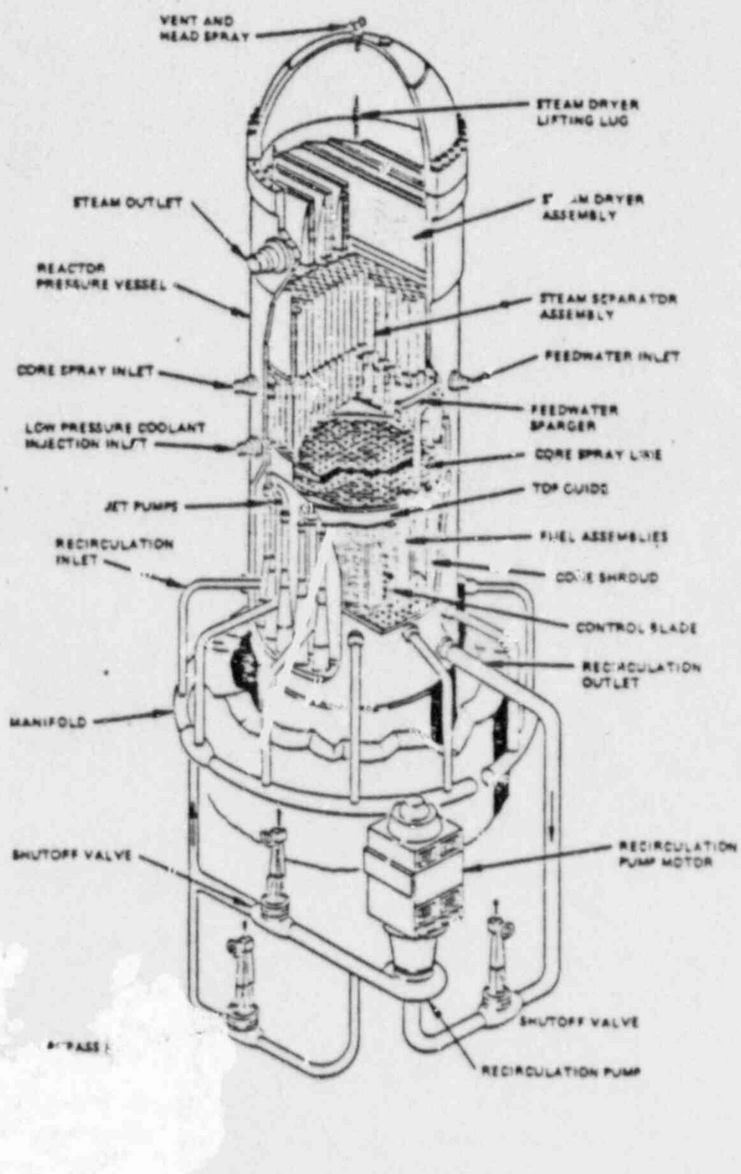
This report discusses the factors related to long term operation of the weld overlays and demonstrates that long term operation in accordance with the guidelines of NUREG-0313 Rev. 2 is justified.[5]

Flaw growth evaluations were performed using the guidelines provided in NUREG-0313 Rev 2. A flaw just below the threshold of detectability was assumed and no credit was taken for any residual stress benefit from the weld overlay. Even using this very conservative approach an unlimited service life was predicted.

The recent low alloy steel nozzle cracking incidents have been evaluated with respect to their impact on the use of weld overlays. For the geometry and applied stress conditions of the Vermont Yankee core spray nozzles the possibility of low alloy steel stress corrosion cracking provides no additional structural integrity concerns.

2. Background

The two core spray nozzles (called the N5 nozzles) are located on the shell portion of the reactor vessel, 180 degrees apart, as shown in Figure 2-1. The nozzles and safe ends are sized for a 10 inch connection, with a reducer being used to mate with the 8 inch core spray piping, as shown in Figure 2-2.



Fi[illegible] Reactor Pressure Vessel

The nozzle is fabricated from SA508 CL2 low alloy steel; the safe end is fabricated from SB166 Alloy 600 (Inconel 600). Both components are forgings. The nozzle is clad with Inconel 182 weld metal to allow for welding the safe end to the nozzle without having to perform a subsequent post weld heat treatment. The safe end is welded to the nozzle with Inconel 82 weld metal. The details of the weld joint are shown in Figure 2-3.

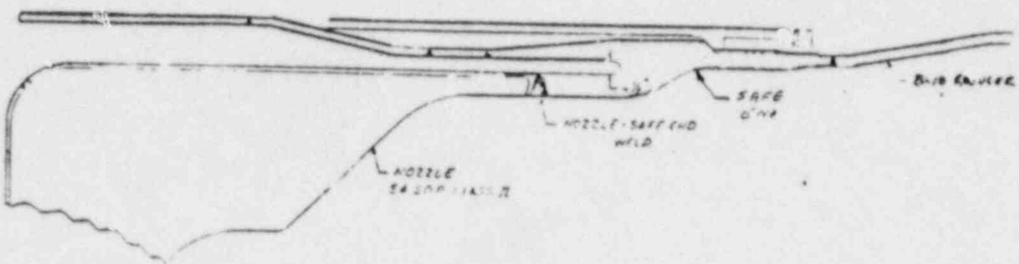


Fig. 2-2: Core Spray Safe End and Nozzle

During ultrasonic examination in April 1986 indications typical of intergranular stress corrosion cracking (IGSCC) were detected in the Inconel 182 weld metal on the face of the nozzle. Since Inconel 182 has been shown to be susceptible to IGSCC the joints were considered flawed and a weld overlay was applied.

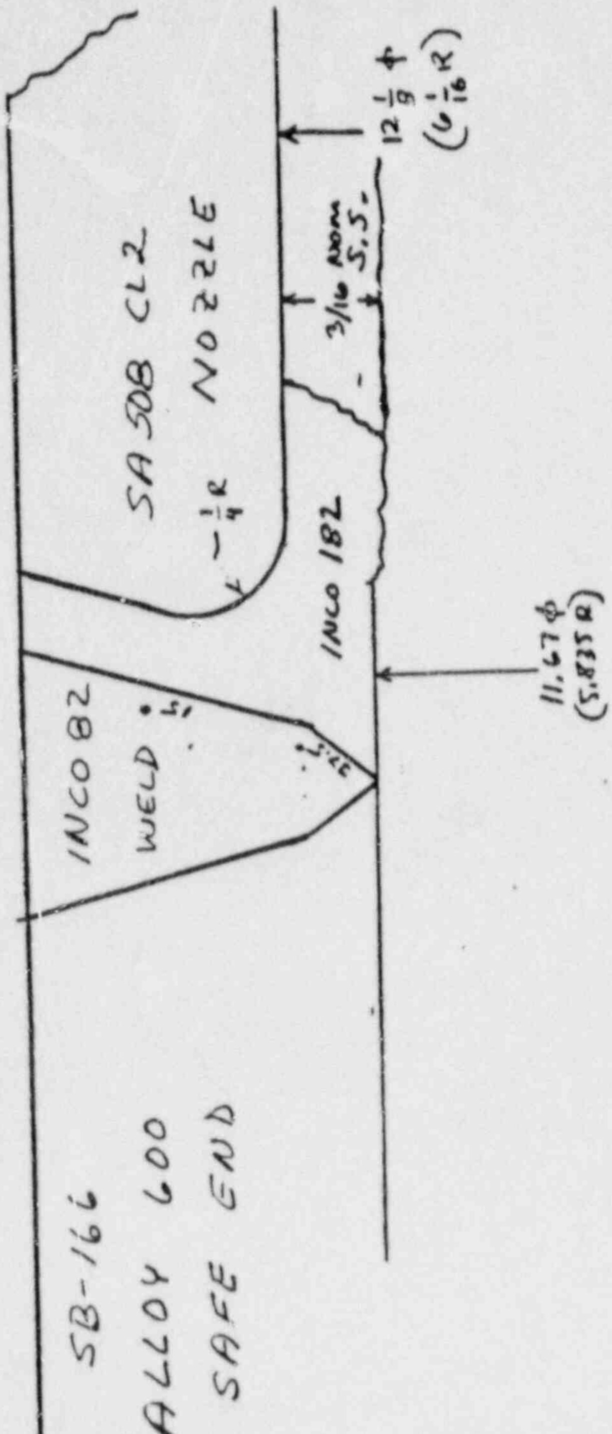


Fig. 2-3: Safe End Weld Detail

3. Weld Overlay Design

The weld overlay was designed in accordance with the requirements of the ASME Code, Section XI. The design stress information was taken from the original stress report for the reactor pressure vessel.[6]

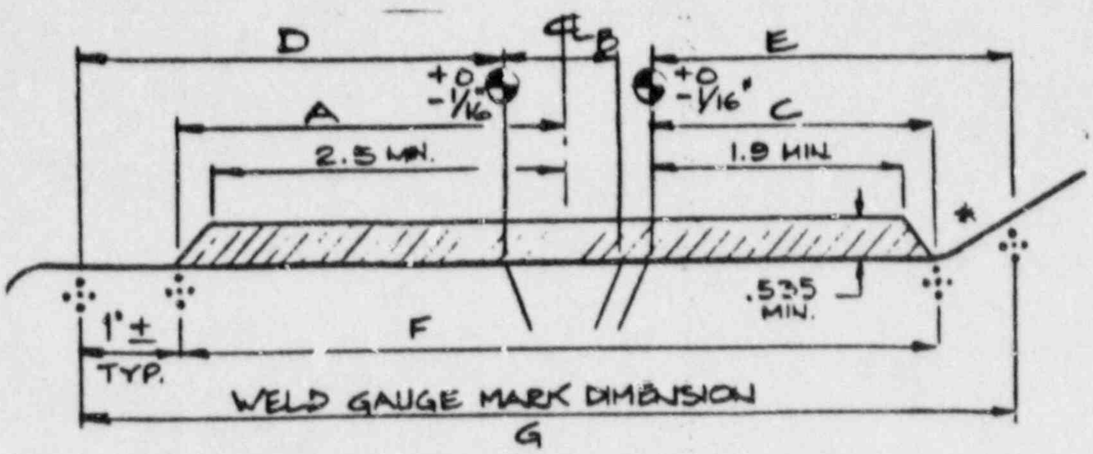
Because the SA508 CL2 nozzle material is a hardenable alloy specialized welding procedures were developed to allow welding without a subsequent post weld heat treatment. The procedures were based on the concepts discussed in References 7 and 8. Mockup testing was performed to develop site specific welding procedures.

Qualification testing was performed to demonstrate that the desired material toughness recovery was achieved.

The approach was to apply a three layer Inconel weld overlay as a butter-temper process to achieve the desired post weld heat treatment effect as well as to provide a minimum 0.125 inch thick weld deposit so that subsequent welding could be performed without any special controls relative to material embrittlement.[9]

Based on the design stress conditions a weld overlay thickness of 0.41 inches was required; allowing for the 0.125 butter-temper layers, a total overlay thickness of 0.535 inches was required. The finished weld overlay is shown in Figure 3-1.

A full discussion on the development and application of the weld overlays is contained in Appendix F.



G	WELD GAUGE DATA		
Location	Initial	Post Weld	Δ
0	8.462	8.447	-.015
90	8.350	8.347	-.003
180	8.323	8.302	-.021
270	8.313	8.315	+.002

DIMENSIONAL DATA						
Location	A	B	C	D	E	F
0	3.120	.781	2.513	3.750	3.531	6.475
90	3.120	.781	2.505	3.749	3.516	6.366
180	3.108	.781	2.512	3.739	3.533	6.310
270	3.180	.781	2.500	3.745	3.480	6.352

Fig. 3-1: Completed Weld Overlay

4. Long Term Operation with Weld Overlays

ALARA and economic considerations make it desirable to qualify the core spray nozzle weld overlays for long term operation.

In order to demonstrate that long term operation is justified in accordance with USNRC guidelines, the weld overlays have been re-evaluated using as-built data and updated design information.

4.1. As-built Data

The actual weld overlay thickness was measured following installation. Measurements were taken at four locations 90 degrees apart on the nozzle side and the safe end side of each overlay. The average overlay thickness was 0.571 inches. The lowest reading (at only one location) was 0.540 inches. For conservatism, 0.540 inches was selected as the installed overlay thickness.

4.2. Design Stress Data

As part of the process of designing replacement safe ends a new stress analysis was performed for the core spray nozzle and safe end.[10] Since this analysis represents current design methodology and analytical approaches the stresses from this analysis were used in re-evaluating the as-installed weld overlays.

Using the revised stress information a minimum overlay thickness of 0.314 inches was determined to be required.[11,14]

4.3. Flaw Growth Studies

Flaw growth studies[15] were performed to determine the time period available before the original flaw would grow deep enough to penetrate into the minimum required 0.314 inch overlay. The original flaw size was judged to be in the range of 30 to 35 percent of wall thickness; for conservatism, a flaw 75 percent of the original safe end wall thickness was assumed. This selection was based on the fact that the ultrasonic examination technique used on the overlays is demonstrated capable of detecting a flaw in the upper 25 percent of the original safe end.

The first evaluation was performed using the criteria from NUREG-0313.[5] No credit was taken for any residual stress benefit from the weld overlay. A residual stress pattern from NUREG-0313 was combined with the applied primary membrane, primary bending and secondary thermal stresses from the stress report[10] to create the applied stress field. The applied stresses were adjusted for the combined thickness of the safe end and overlay, as permitted by NUREG-0313 Rev 2 and discussed in Reference 16.

Figure 4-1 shows the net stress profile through the safe end in the axial direction. Figure 4-2 shows the net stress intensity profile resulting from that stress field. As can be seen due to the negative stress intensity region at the flaw tip no flaw growth beyond 75 percent deep is predicted. A flaw shallower than 75 percent could propagate, but it would arrest.

The second evaluation considered the effect of the local weld shrinkage caused by the weld overlay. A two-dimensional axisymmetric model of the reactor pressure vessel and core spray nozzle was developed.

The axial shrinkage obtained from the as-built data was applied to the model by adjusting the nodal temperatures. A discussion of the methods of analysis and the benchmarking of the computer program is contained in Appendices C and D, respectively.

As can be seen from Figure 4-3, approximately 90 percent of the original safe end and nozzle under the weld overlay is in compression. This result is consistent with other studies on weld overlay induced stresses[12]. The analysis considered the normal reactor pressure and applied loads, so the indicated stress profile is the net stress profile.

Since the stress profile is compressive, no flaw growth would be predicted; this conclusion is consistent with laboratory and field observations on flawed pipe overlays.

In summary, using the USNRC evaluation criteria provided in NUREG-0313 Rev 2, taking no credit for the weld overlay induced stresses, it has been demonstrated that no flaw growth is predicted beyond 75 percent of the original wall thickness.

In addition, using actual data from the weld overlay application, it has been shown that a significant compressive stress field is developed under the weld overlay. Thus, even if the NUREG-0313 Rev 2 residual stress field is neglected there is still no predicted flaw growth beyond 75 percent of original wall thickness.

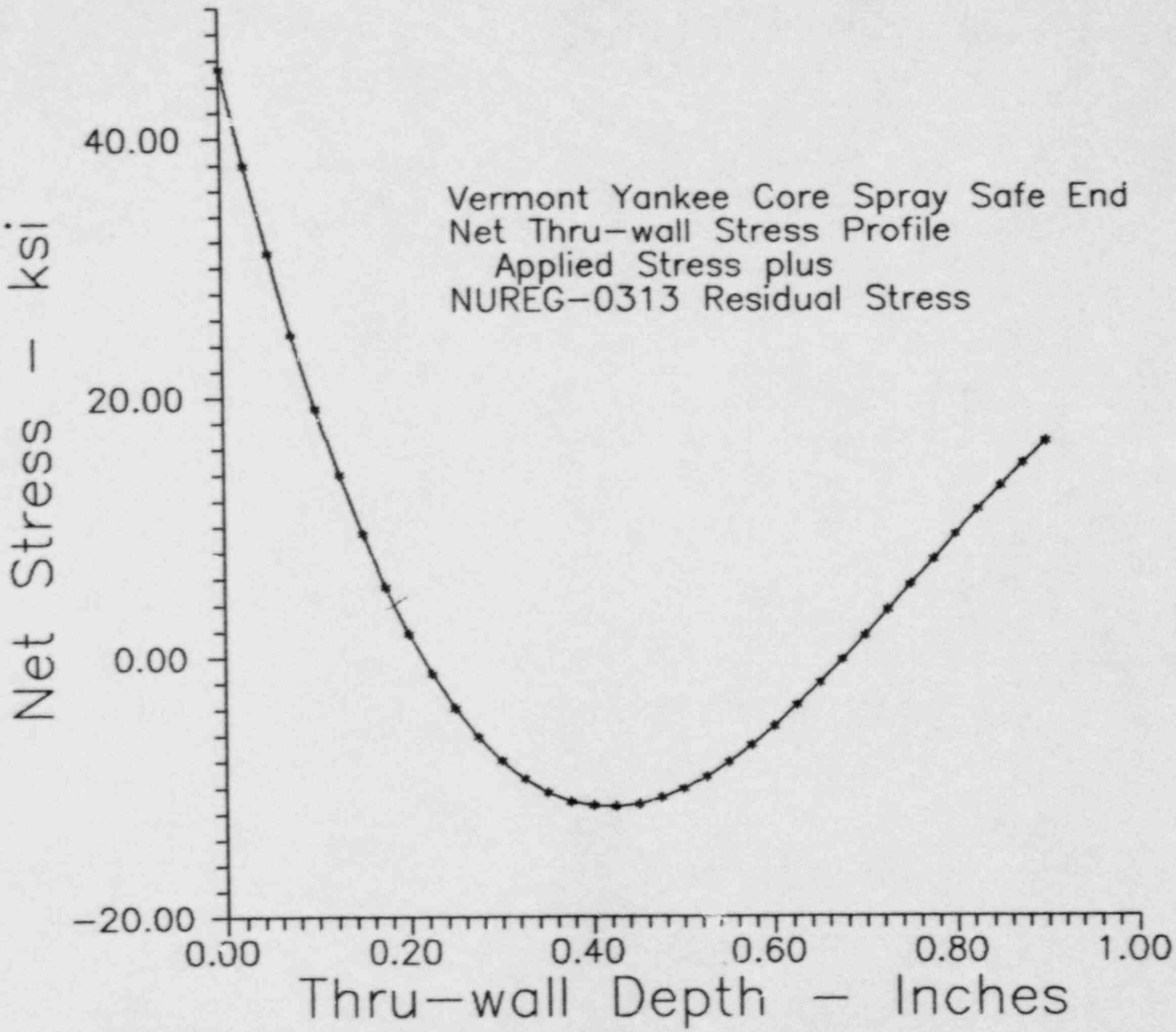


Fig. 4-1: Core Spray Safe End Axial Stress Profile

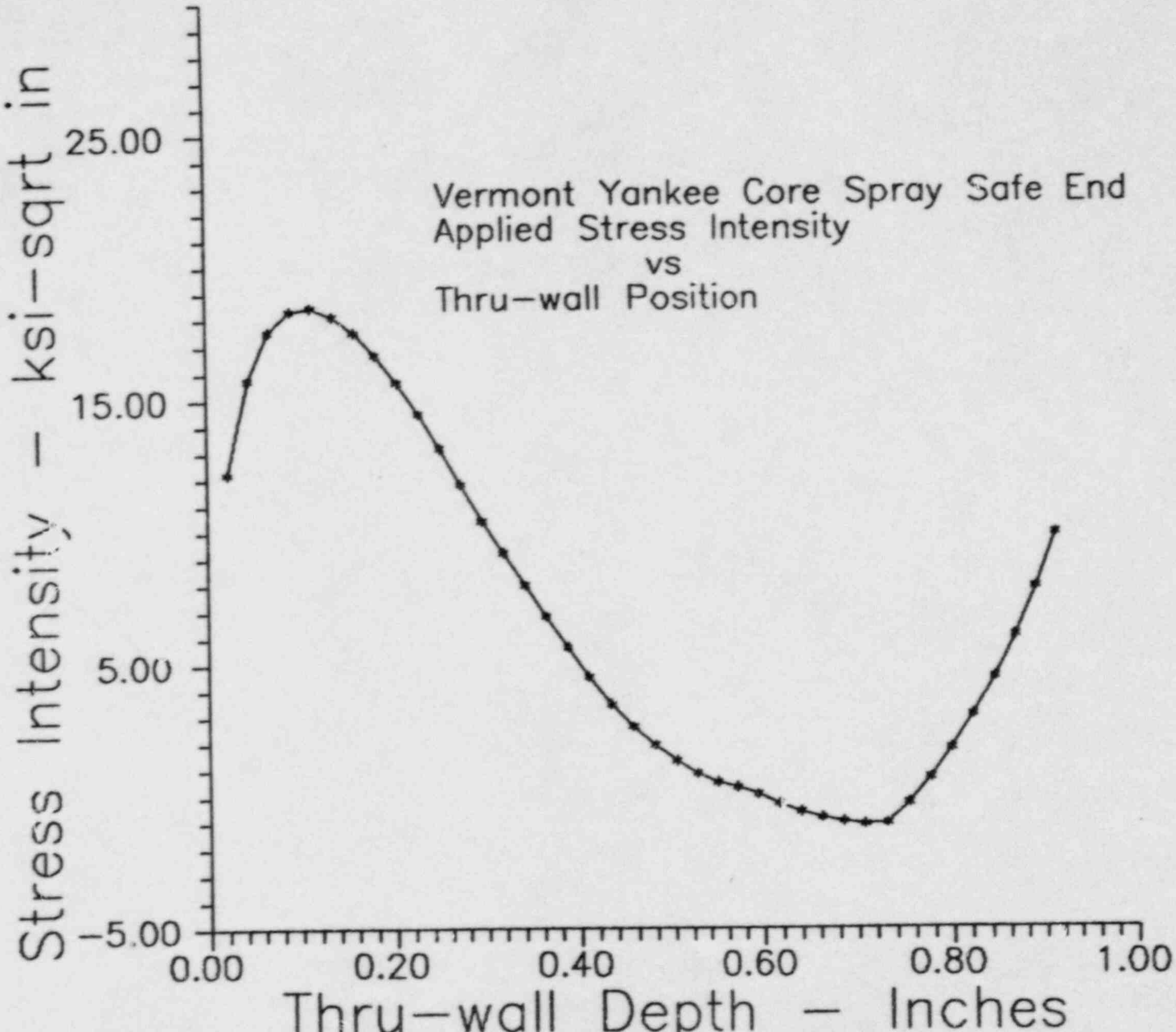


Fig. 4-2: Core Spray Safe End Axial Stress Intensity Profile

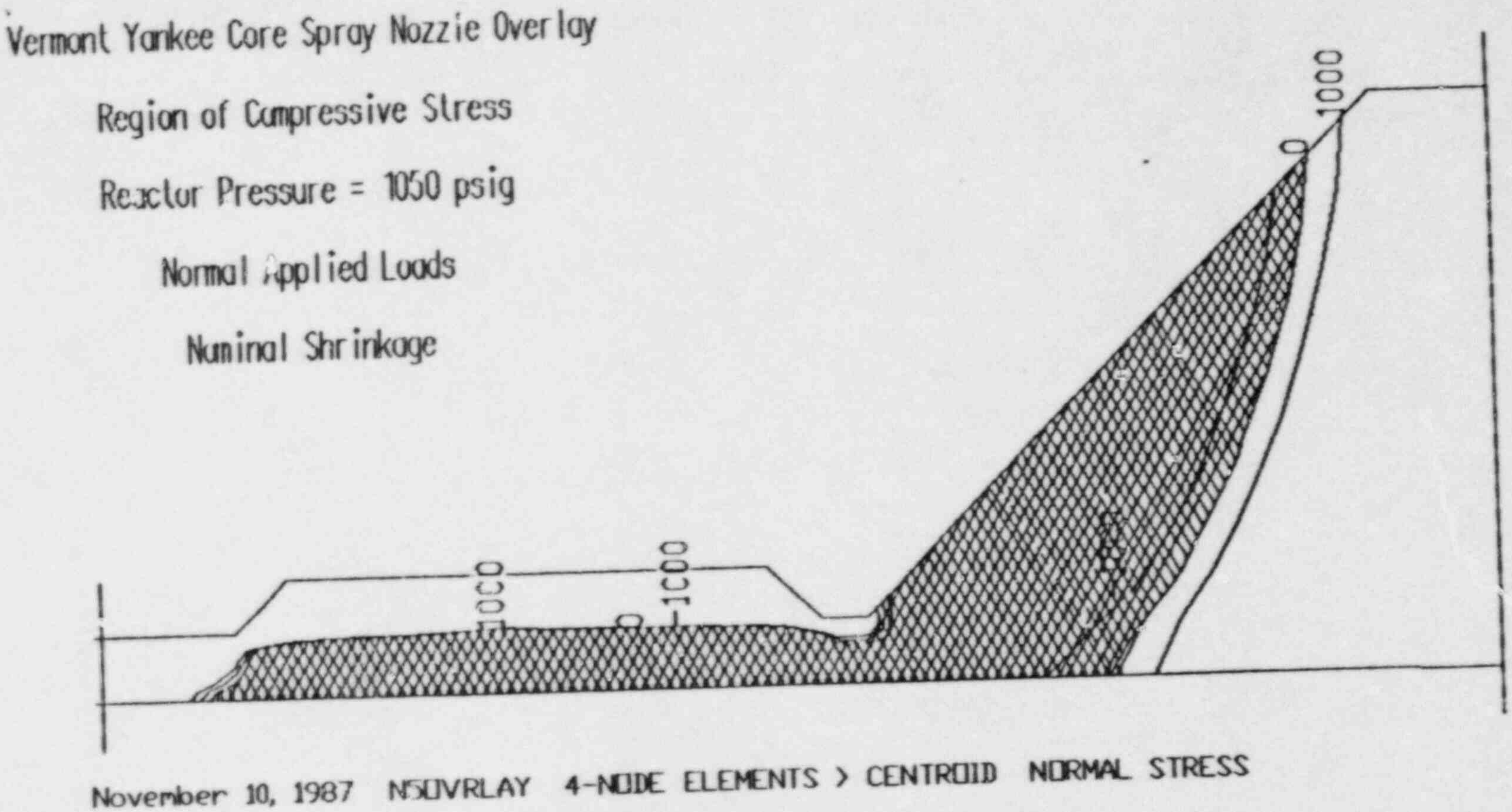


Fig. 4-3: Core Spray Nozzle Weld Overlay Stress Distribution

5. 1987 Refueling Outage Inspections

During the 1987 refueling outage, following Cycle 12, non-destructive examinations were conducted on the weld overlay, underlying basemetal and nozzle basemetal adjacent to the overlay. Liquid penetrant examination was performed on the overlay surface, the overlay end tapers and the nozzle and safe end base metal adjacent to the overlay. Ultrasonic examinations were conducted using techniques based upon the EPRI weld overlay inspection program with modifications demonstrated and qualified on the Vermont Yankee weld overlay nozzle mockup. The examinations were conducted by Level II and Level III personnel qualified in accordance with SNT-TC-1A and the EPRI weld overlay flaw examination qualification program. No relevant indications were detected.

Details of the inspection techniques were submitted to the USNRC.[13] A copy of the letter is included as Appendix E to this report.

6. Evaluation of Low Alloy Steel Stress Corrosion Cracking

In 1987, stress corrosion cracking was detected in the SA 508 low alloy steel portion of a reactor recirculation inlet of an overseas boiling water reactor. The cracking was initiated in the Inconel 182 weld butter and extended axially into the nozzle approximately ¼ inch, as shown in Figure 6-1.

In January 1988 cracking was reported in a recirculation inlet nozzle at a domestic boiling water reactor (Brunswick 2). The cracking initiated in the Inconel 182 cladding at the inside diameter of the nozzle and extended in a circumferential direction and through wall into the SA 508 nozzle base metal.

The significance of these discoveries will be discussed and their impact on the use of weld overlays on low alloy steel nozzles will be evaluated.

The existence of the foreign reactor flaw and the depth of penetration is consistent with the stress field and corrosion behavior of a field welded nozzle to safe end butt weld.[14] For a non-overlayed nozzle the maximum depth of penetration would be expected to be less than ¼ inch. The presence of a weld overlay would not increase the propensity to cracking or the flaw growth rate; in fact, the compressive stress field would tend to inhibit flaw growth.

The recirculation system at Brunswick 2 has a significant number of weld overlays. The normal operating stresses combined with the shrinkage stresses resulting from the weld overlays on the pipe welds are considered sufficient to cause stress corrosion cracking in Inconel 182 and SA 508[17], so the discovery of the flaw is not considered to be caused by a new phenomena.

Ultrasonic examinations conducted at Vermont Yankee in 1986 prior to the application of the weld overlays revealed no cracking in the nozzle or safe end basemetal; as stated in Section 5 the examinations in 1987 also revealed no evidence of basemetal cracking.

To evaluate the consequences of potential low alloy steel stress corrosion cracking in the core spray nozzles the following conservative evaluation was conducted:

1. assume an infinitely long longitudinal flaw
2. assume that the hoop stress equals the primary membrane plus bending stress
3. assume that the nozzle is not weld overlayed.

Using these assumptions, an 80 percent deep flaw would have a stress intensity factor of approximately 72 ksi-$\sqrt{in}$. A flaw this deep would be detectable by ultrasonic examination even through the weld overlay.

From Appendix A to ASME Section XI, this corresponds to a metal temperature 30F above RT_{NDT}. The nozzle material certification shows that the Charpy V-notch impact energy is equal or greater than 120 ft-lbs at 40F. This infers an RT_{NDT} well below 40F. Thus, at ambient conditions the required toughness would be achieved. Since the RT_{NDT} of the reactor vessel beltline is governing for Vermont Yankee (currently at an adjusted RT_{NDT} of 69F)[14], the structural integrity of the nozzle is not threatened.

In conclusion, low alloy steel stress corrosion cracking provides no special problems relative to weld overlays. Weld overlays will not initiate or accelerate flaw growth in the

nozzle welds to which they are applied; the realistic conclusion is that the overlay will suppress any flaw growth.

While it is true that a weld overlay makes volumetric inspection of the overlayed nozzle more difficult, flaw detection is assured long before the structural integrity of the nozzle would be affected. Thus, it is concluded that the nozzle cracking incidents provide no new concerns relative to the suitability of weld overlays as a long term stress corrosion cracking mitigation measure.

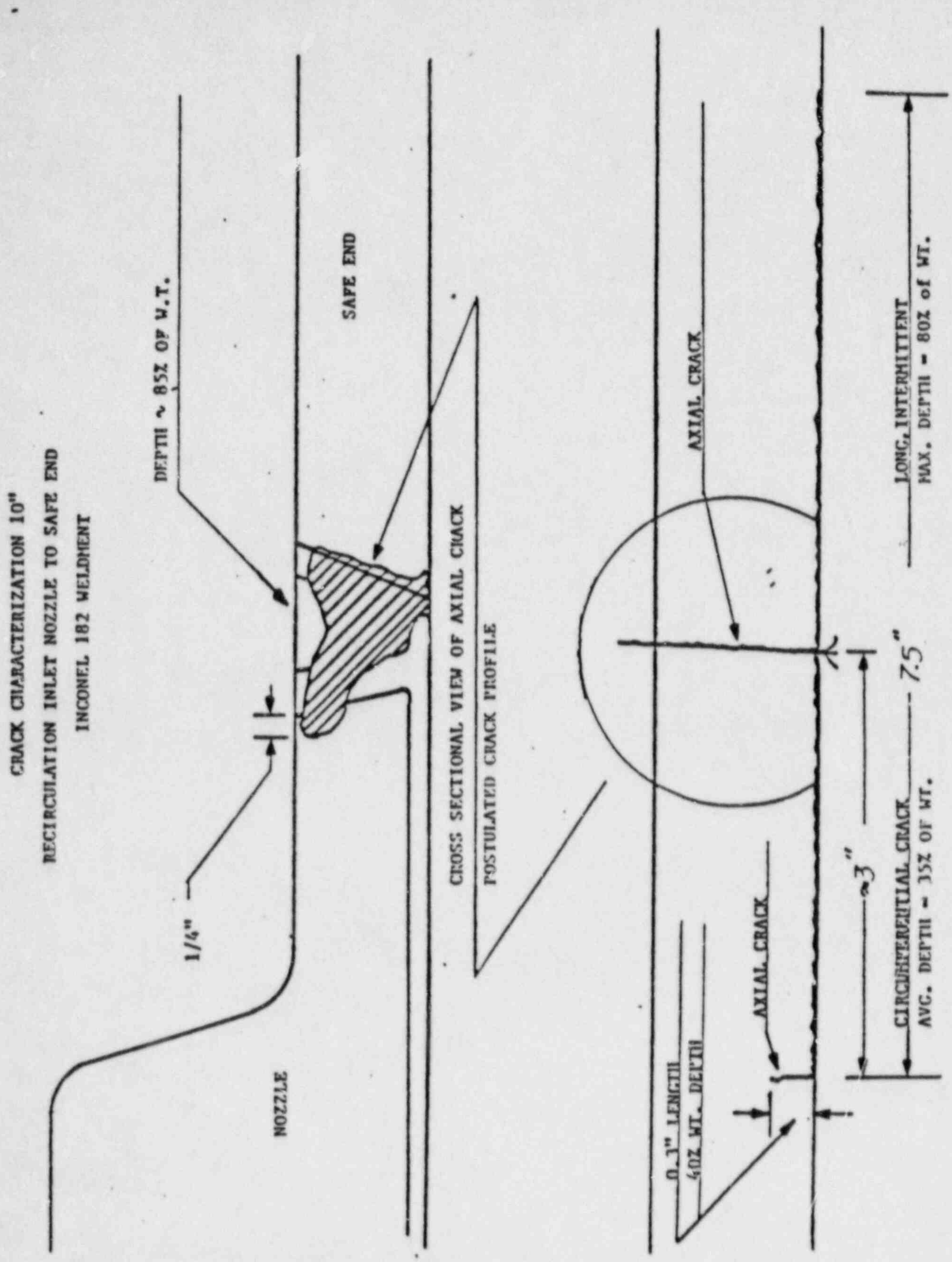


Fig. 6-1: Crack Profile in Low Alloy Steel BWR Nozzle

7. Summary of Conservatisms

The results presented above demonstrate that long term operation with core spray nozzle overlays is justified.

The significance of the results is enhanced by understanding the conservatisms that are present in the evaluations. To assist that understanding the conservatisms are presented below:

1. The ASME Section XI flawed pipe evaluation process is conservative.

2. Code minimum values are used for required material properties.

3. Bounding loads are used for the stress analysis.

4. The USNRC residual stress profile is a conservative approximation (i.e. underestimates) the probable as-welded compressive residual stress profile.

5. The overlay thickness used in the evaluation is the minimum value of 16 readings.

6. The flaw growth calculations assumed a full 360 degree flaw, even though the actual flaw was considerably smaller.

7. The flaw depth used in the studies is more than two times larger than the best estimate flaw size.

8. Unlike overlays on stainless steel pipe, the overlay welding does not sensitize the underlying Inconel or low alloy steel basemetal. Thus, the development of IGSCC parallel to the surface of the overlay (i.e. developing "lack of bond") is not a credible event.

9. The method used to assess the compressive stress due to the weld overlay significantly underpredicts the actual magnitude of the compressive stresses.

8. Conclusion

It has been demonstrated that continued operation with weld overlays on the core spray nozzles beyond Cycle 13 will not infringe on the Code required structural integrity of the weld overlays or the reactor pressure vessel.

The evaluation shows that unlimited life of the overlays is to be expected. Confirmation of that evaluation will be obtained by performing periodic ultrasonic examination of the weld overlays during refueling outages in accordance with NUREG-0313 Rev 2 requirements.

9. References

1. Letter from VYNPC to USNRC, dated May 5, 1986 (FVY 86-36).
2. Letter from USNRC to VYNPC, dated June 23, 1986 (NVY 86-113).
3. Letter from VYNPC to USNRC, dated January 12, 1987 (FVY 87-07).
4. Letter from USNRC to VYNPC, dated May 28, 1987 (NVY 87-81).
5. NUREG-0313 Revision 2, issued January 25, 1988.
6. Chicago Bridge and Iron Stress Report 9-6202-1, Section I-S-7, August 1969.
7. EPRI Report NP-3614, "Repair Welding of Heavy Section Steel Components in LWRs", July, 1984.
8. ASME Code Case N-432, "Repair Welding Using Automatic or Machine Gas-Tungsten Arc Welding (GTAW) Temperbead Technique, Section XI, Division 1, February 20, 1986.
9. Field Application of a Non-Post Weld Heat Treat Weld Overlay to an Alloy Steel Reactor Pressure Vessel Nozzle; Hoffman, Mullins, Willens, Darby; Presented at EPRI Seminar on Repair Welding Alternatives for Nuclear Power Plant Components, Charlotte, NC, March 11, 1987.
10. General Electric Company Report 23A4904, "Core Spray Nozzle Stress Report", December 13, 1985.
11. ASME Boiler and Pressure Vessel Code, Section XI, Subsection IWB-3641, 1983 Edition thru Winter 1986 Addenda.
12. EPRI Interim Report for Project EPRI-1566-2.
13. Letter from VYNPC to USNRC, dated October 20, 1987 (FVY 87-100)
14. General Electric Company Presentation to USNRC, Bethesda Maryland, September 22, 1987.
15. pc-CRACK User's Manual, Version 1.2, Structural Integrity Associates, San Jose, CA., March 1987.
16. Scott, Paul M., "Assessment of Design Basis for Load-Carrying Capacity of Weld-Overlay Repairs", NUREG/CR-4877, April 1987.
17. Meeting between Carolina Power & Light and USNRC at Bethesda, Maryland, January 27, 1988.
18. Vermont Yankee Technical Specifications.

A. Supporting Data for Figures

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VERSION 1.2

STRUCTURAL REINFORCEMENT SIZING EVALUATION

STRUCTURAL REINFORCEMENT SIZING FOR CIRCUMF. CRACK,WROUGHT/CAST STAINLESS

VERMONT YANKEE CORE SPRAY SAFE END WELD OVERLAY

WALL THICKNESS= 0.9140
MEMBRANE STRESS= 8507.0000
BENDING STRESS= 1666.0000
STRESS RATIO= 0.4366
ALLOWABLE STRESS=23300.0000
FLOW STRESS=69900.0000

	L/CIRCUM					
	0.00	0.10	0.20	0.30	0.40	0.50
FINAL A/T	0.7500	0.7500	0.7500	0.7500	0.7500	0.7441
REINFORCEMENT THICK.	0.3047	0.3047	0.3047	0.3047	0.3047	0.3143

END OF pc-CRACK

NRC NUREG-0313 Rev 2 Fracture Mechanics Spreadsheet

Thru-wall Position	Normalized Residual Stress	Actual Depth	Stress
0.00	1.00000	0.00	38.00
0.05	0.67614	0.05	25.69
0.10	0.39519	0.09	15.02
0.15	0.15631	0.14	5.94
0.20	-0.04160	0.18	-1.58
0.25	-0.19998	0.23	-7.60
0.30	-0.32055	0.27	-12.18
0.35	-0.40534	0.32	-15.40
0.40	-0.45669	0.37	-17.35
0.45	-0.47724	0.41	-18.14
0.50	-0.46994	0.46	-17.86
0.55	-0.43803	0.50	-16.64
0.60	-0.38506	0.55	-14.63
0.65	-0.31489	0.59	-11.97
0.70	-0.23169	0.64	-8.80
0.75	-0.13992	0.69	-5.32
0.80	-0.04434	0.73	-1.68
0.85	0.04997	0.78	1.90
0.90	0.13764	0.82	5.23
0.95	0.21297	0.87	8.09
1.00	0.27000	0.91	10.26

```
A1: 'NRC NUREG-0313 Rev 2 Fracture Mechanics Spreadsheet
A3: 'Thru-wall
C3: 'Normalized
A4: 'Position
C4: 'Residual Stress
A6: (F2) 0
C6: (F5) @SUM(1+(-6.91*A6)+(8.687*A6^2)+(-0.48*A6^3)+(-2.027*A6^4))
A7: (F2) 0.05
C7: (F5) @SUM(1+(-6.91*A7)+(8.687*A7^2)+(-0.48*A7^3)+(-2.027*A7^4))
A8: (F2) 0.1
C8: (F5) @SUM(1+(-6.91*A8)+(8.687*A8^2)+(-0.48*A8^3)+(-2.027*A8^4))
A9: (F2) 0.15
C9: (F5) @SUM(1+(-6.91*A9)+(8.687*A9^2)+(-0.48*A9^3)+(-2.027*A9^4))
A10: (F2) 0.2
C10: (F5) @SUM(1+(-6.91*A10)+(8.687*A10^2)+(-0.48*A10^3)+(-2.027*A10^4))
A11: (F2) 0.25
C11: (F5) @SUM(1+(-6.91*A11)+(8.687*A11^2)+(-0.48*A11^3)+(-2.027*A11^4))
A12: (F2) 0.3
C12: (F5) @SUM(1+(-6.91*A12)+(8.687*A12^2)+(-0.48*A12^3)+(-2.027*A12^4))
A13: (F2) 0.35
C13: (F5) @SUM(1+(-6.91*A13)+(8.687*A13^2)+(-0.48*A13^3)+(-2.027*A13^4))
A14: (F2) 0.4
C14: (F5) @SUM(1+(-6.91*A14)+(8.687*A14^2)+(-0.48*A14^3)+(-2.027*A14^4))
A15: (F2) 0.45
C15: (F5) @SUM(1+(-6.91*A15)+(8.687*A15^2)+(-0.48*A15^3)+(-2.027*A15^4))
A16: (F2) 0.5
C16: (F5) @SUM(1+(-6.91*A16)+(8.687*A16^2)+(-0.48*A16^3)+(-2.027*A16^4))
A17: (F2) 0.55
C17: (F5) @SUM(1+(-6.91*A17)+(8.687*A17^2)+(-0.48*A17^3)+(-2.027*A17^4))
A18: (F2) 0.6
C18: (F5) @SUM(1+(-6.91*A18)+(8.687*A18^2)+(-0.48*A18^3)+(-2.027*A18^4))
A19: (F2) 0.65
C19: (F5) @SUM(1+(-6.91*A19)+(8.687*A19^2)+(-0.48*A19^3)+(-2.027*A19^4))
A20: (F2) 0.7
C20: (F5) @SUM(1+(-6.91*A20)+(8.687*A20^2)+(-0.48*A20^3)+(-2.027*A20^4))
A21: (F2) 0.75
C21: (F5) @SUM(1+(-6.91*A21)+(8.687*A21^2)+(-0.48*A21^3)+(-2.027*A21^4))
A22: (F2) 0.8
C22: (F5) @SUM(1+(-6.91*A22)+(8.687*A22^2)+(-0.48*A22^3)+(-2.027*A22^4))
A23: (F2) 0.85
C23: (F5) @SUM(1+(-6.91*A23)+(8.687*A23^2)+(-0.48*A23^3)+(-2.027*A23^4))
A24: (F2) 0.9
C24: (F5) @SUM(1+(-6.91*A24)+(8.687*A24^2)+(-0.48*A24^3)+(-2.027*A24^4))
A25: (F2) 0.95
C25: (F5) @SUM(1+(-6.91*A25)+(8.687*A25^2)+(-0.48*A25^3)+(-2.027*A25^4))
A26: (F2) 1
C26: (F5) @SUM(1+(-6.91*A26)+(8.687*A26^2)+(-0.48*A26^3)+(-2.027*A26^4))
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VERSION 1.2

LEAST SQUARE CURVE FIT OF STRESS PROFILE

CURVE FIT FOR NUREG-0313 RESIDUAL STRESS

TERM	COEFFICIENT
C0	3.9137E+01
C1	-3.115E+02
C2	5.1432E+02
C3	-2.265E+02

COEFFICIENT OF DETERMINATION R^2= 0.9989
CORRELATION COEFFICIENT= 0.9978

X VALUE	Y VALUE	Y CALC	DIFF
0.0000E+00	3.8000E+01	3.9137E+01	-1.137E+00
5.0000E-02	2.5690E+01	2.4820E+01	8.7010E-01
9.0000E-02	1.5020E+01	1.5103E+01	-8.335E-02
1.4000E-01	5.9400E+00	4.9867E+00	9.5329E-01
1.8000E-01	-1.580E+00	-1.589E+00	9.3579E-03
2.3000E-01	-7.600E+00	-8.056E+00	4.5559E-01
2.7000E-01	-1.218E+01	-1.193E+01	-2.485E-01
3.2000E-01	-1.540E+01	-1.530E+01	-1.022E-01
3.7000E-01	-1.735E+01	-1.718E+01	-1.704E-01
4.1000E-01	-1.814E+01	-1.773E+01	-4.095E-01
4.6000E-01	-1.786E+01	-1.737E+01	-4.914E-01
5.0000E-01	-1.664E+01	-1.634E+01	-2.954E-01
5.5000E-01	-1.463E+01	-1.429E+01	-3.407E-01
5.9000E-01	-1.197E+01	-1.213E+01	1.6077E-01
6.4000E-01	-8.800E+00	-8.932E+00	1.3249E-01
6.9000E-01	-5.320E+00	-5.337E+00	1.7057E-02
7.3000E-01	-1.680E+00	-2.289E+00	6.0892E-01
7.8000E-01	1.9000E+00	1.5933E+00	3.0672E-01
8.2000E-01	5.2300E+00	4.6507E+00	5.7934E-01
8.7000E-01	8.0900E+00	8.2692E+00	-1.792E-01
9.1000E-01	1.0260E+01	1.0896E+01	-6.355E-01

END OF pc-CRACK

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VERSION 1.2

LINEAR ELASTIC FRACTURE MECHANICS EVALUATION

VY CORE SPRAY SAFE END K VS A

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

WALL THICKNESS=   1.4540

STRESS COEFFICIENTS

CASE ID	C0	C1	C2	C3
APPLIED	9.9020	0.0000	0.0000	0.0000
NUREG	39.1374	-311.4989	514.3236	-226.5071
NETSTRS	45.3620	-311.4989	514.3236	-226.5071

CRACK DEPTH	STRESS INTENSITY FACTOR CASE APPLIED	CASE NUREG	CASE NETSTRS
0.0228	2.928	10.379	12.220
0.0456	4.158	13.146	15.760
0.0684	5.114	14.322	17.537
0.0912	5.930	14.595	18.323
0.1140	6.658	14.266	18.451
0.1368	7.324	13.506	18.110
0.1596	7.971	12.485	17.496
0.1824	8.604	11.255	16.663
0.2052	9.213	9.840	15.631
0.2280	9.803	8.286	14.449
0.2508	10.378	6.631	13.154
0.2736	10.940	4.904	11.781
0.2964	11.510	3.178	10.413
0.3192	12.131	1.570	9.197
0.3420	12.750	-0.034	7.981
0.3648	13.368	-1.619	6.785
0.3876	13.985	-3.168	5.624
0.4104	14.602	-4.668	4.511
0.4332	15.220	-6.107	3.461
0.4560	15.886	-7.360	2.627
0.4788	16.564	-8.496	1.917
0.5016	17.246	-9.520	1.321
0.5244	17.933	-10.421	0.852
0.5472	18.624	-11.190	0.517
0.5700	19.320	-11.817	0.328
0.5928	20.041	-12.523	0.076
0.6156	20.790	-13.273	-0.304
0.6384	21.545	-14.154	-0.611

0.6612	22.307	-14.868	-0.846
0.6840	23.075	-15.518	-1.012
0.7068	23.850	-16.106	-1.113
0.7296	24.642	-16.564	-1.073
0.7524	25.525	-16.331	-0.285
0.7752	26.418	-15.948	0.660
0.7980	27.320	-15.412	1.762
0.8208	28.231	-14.726	3.021
0.8436	29.152	-13.890	4.435
0.8664	30.081	-12.907	6.003
0.8892	31.076	-11.708	7.827
0.9120	32.103	-10.337	9.844
0.9348	33.141	-8.820	12.013
0.9576	34.189	-7.165	14.327
0.9804	35.247	-5.379	16.779
1.0032	36.316	-3.471	19.359
1.0260	37.436	-1.847	21.686
1.0488	38.639	-0.904	23.385
1.0716	39.854	0.009	25.062
1.0944	41.082	0.871	26.696
1.1172	42.322	1.661	28.266
1.1400	43.575	2.356	29.748

END OF pc-CRACK

LINEAR ELASTIC FRACTURE MECHANICS EVALUATION

VERMONT YANKEE CORE SPRAY NOZZLE (ASSUME NO OVERLAY)

CRACK MODEL:LONGITUDINAL CRACK IN CYLINDER(T/R=0.1)

WALL THICKNESS= 0.9140

	STRESS COEFFICIENTS			
CASE ID	C0	C1	C2	C3
MYSURGE	16.7500	0.0000	0.0000	0.0000
NRC	38.8020	-309.6470	511.6590	-225.4730
NRCRESID	1.0211	-8.1486	13.4647	-5.9335
APPLIED	9.9020	0.0000	0.0000	0.0000

CRACK DEPTH	STRESS INTENSITY FACTOR CASE MYSURGE	CASE NRC	CASE NRCRESID	CASE APPLIED
0.0146	3.818	8.233	0.217	2.257
0.0292	5.519	11.070	0.291	3.263
0.0439	6.906	12.875	0.339	4.083
0.0585	8.143	14.102	0.371	4.814
0.0731	9.293	14.937	0.393	5.494
0.0877	10.387	15.482	0.407	6.140
0.1024	11.489	15.853	0.417	6.792
0.1170	12.588	16.050	0.422	7.442
0.1316	13.676	16.083	0.423	8.085
0.1462	14.757	15.974	0.420	8.724
0.1609	15.835	15.741	0.414	9.361
0.1755	16.914	15.398	0.405	9.999
0.1901	18.036	14.997	0.395	10.662
0.2047	19.209	14.547	0.383	11.356
0.2194	20.393	14.019	0.369	12.056
0.2340	21.588	13.420	0.353	12.762
0.2486	22.795	12.762	0.336	13.475
0.2632	24.014	12.051	0.317	14.196
0.2779	25.310	11.309	0.298	14.962
0.2925	26.823	10.535	0.277	15.857
0.3071	28.362	9.688	0.255	16.767
0.3217	29.927	8.773	0.231	17.692
0.3364	31.517	7.795	0.205	18.632
0.3510	33.132	6.762	0.178	19.586
0.3656	34.771	5.679	0.149	20.556
0.3802	36.743	4.543	0.120	21.721
0.3948	38.750	3.314	0.087	22.908

0.4095	40.793	1.994	0.052	24.115
0.4241	42.870	0.587	0.015	25.343
0.4387	44.981	-0.904	-0.024	26.591
0.4533	47.125	-2.478	-0.065	27.859
0.4680	49.809	-3.325	-0.088	29.445
0.4826	52.713	-3.945	-0.104	31.162
0.4972	55.670	-4.595	-0.121	32.910
0.5118	58.678	-5.271	-0.139	34.688
0.5265	61.737	-5.967	-0.157	36.497
0.5411	64.846	-6.677	-0.176	38.334
0.5557	68.262	-7.010	-0.184	40.354
0.5703	71.996	-6.919	-0.182	42.561
0.5850	75.790	-6.768	-0.178	44.804
0.5996	79.645	-6.547	-0.172	47.083
0.6142	83.559	-6.246	-0.164	49.397
0.6288	87.531	-5.853	-0.154	51.745
0.6435	91.699	-5.556	-0.146	54.209
0.6581	96.346	-5.779	-0.152	56.956
0.6727	101.061	-5.944	-0.156	59.744
0.6873	105.844	-6.039	-0.159	62.571
0.7020	110.693	-6.053	-0.159	65.438
0.7166	115.608	-5.978	-0.157	68.343
0.7312	120.587	-5.802	-0.153	71.287

END OF pc-CRACK

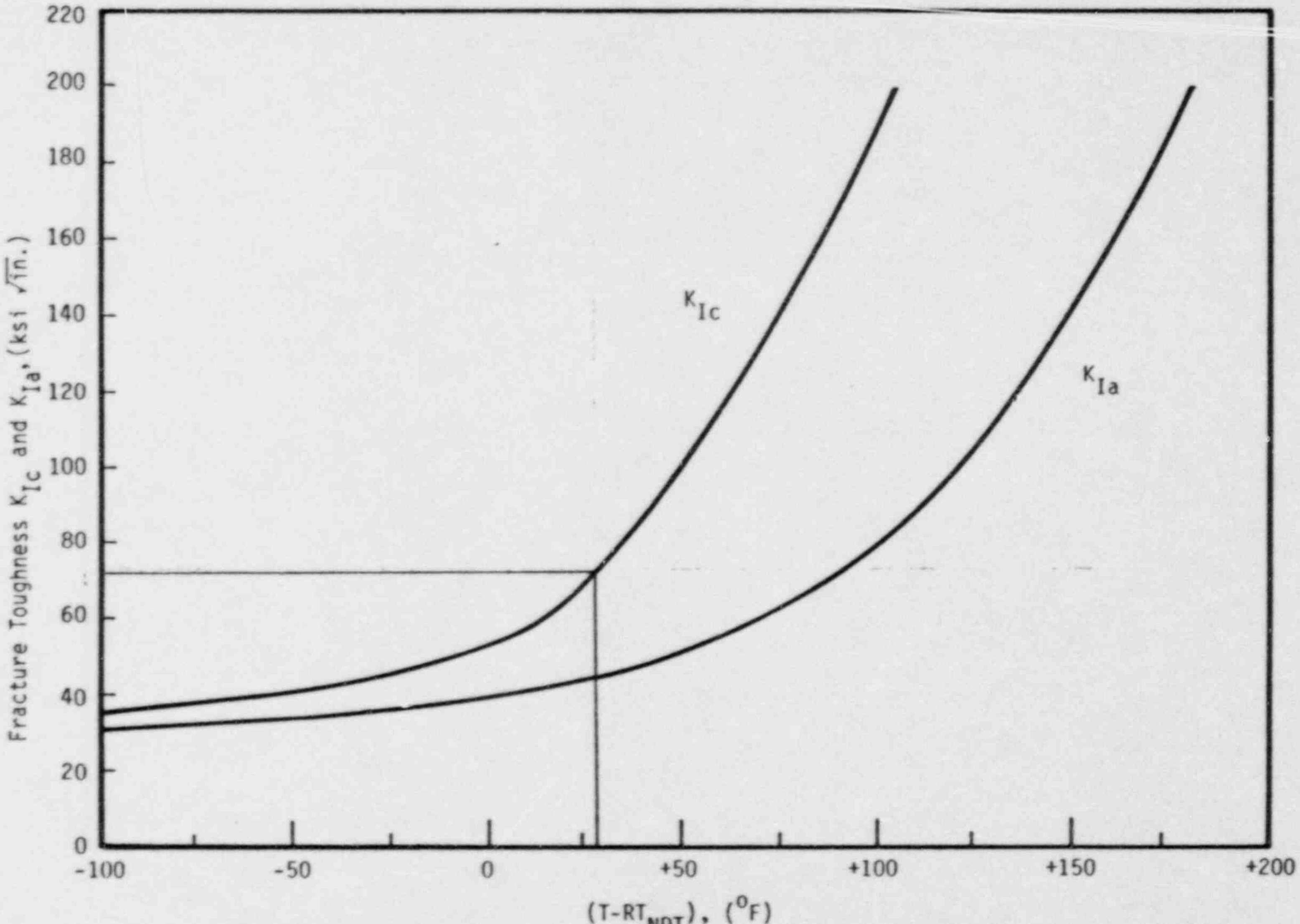

Figure 2.4 - Lower Bound Toughness Curves From Tests of SA-533B-1, SA-508-2, and SA-508-3 Steel (Section XI, Fig. A-4200-1).

tm

pc-CRACK

STRUCTURAL INTEGRITY ASSOCIATES, INC.
SAN JOSE, CA (408)978-8200

VERSION 1.2

STRUCTURAL REINFORCEMENT SIZING EVALUATION

STRUCTURAL REINFORCEMENT SIZING FOR CIRCUMF. CRACK,WROUGHT/CAST STAINLESS

COMPARISON WITH USER'S MANUAL PROBLEM FOR BENCHMARKING

WALL THICKNESS= 0.6100
MEMBRANE STRESS= 6.4870
BENDING STRESS= 13.1450
STRESS RATIO= 1.1582
ALLOWABLE STRESS= 16.9500
FLOW STRESS= 50.8500

	L/CIRCUM					
	0.00	0.10	0.20	0.30	0.40	0.50
FINAL A/T	0.7500	0.7500	0.7500	0.7383	0.6846	0.5889
REINFORCEMENT THICK.	0.2033	0.2033	0.2033	0.2162	0.2811	0.4259

END OF pc-CRACK

Table I-4

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

STRUCTURAL REINFORCEMENT SIZING EVALUATION

STRUCTURAL REINFORCEMENT SIZING FOR CIRCUMF. CRACK,WROUGHT/CAST STAINL
ESS

SAMPLE PROBLEM I

WALL THICKNESS= 0.6100
MEMBRANE STRESS= 6.4870
BENDING STRESS= 13.1450
STRESS RATIO= 1.1582
ALLOWABLE STRESS= 16.9500
FLOW STRESS= 50.8500

	L/CIRCUM					
	0.00	0.10	0.20	0.30	0.40	0.50
FINAL A/T	0.7500	0.7500	0.7500	0.7383	0.6846	0.5889
REINFORCEMENT THICK.	0.2033	0.2033	0.2033	0.2162	0.2811	0.4259

B. Stress Data for Core Spray Nozzle and Safe End

REVISION STATUS SHEET

23A4904			
CONT ON SHEET	2	SH NO.	1

GENERAL ELECTRIC

NUCLEAR ENERGY BUSINESS OPERATIONS

DOCUMENT TITLE CORE SPRAY NOZZLE

TYPE STRESS REPORT

LEGEND OR DESCRIPTION OF GROUPS

FMF REACTOR SYSTEM - VY

MPL ITEM NO. PRODUCT SUMMARY SECTION 7

REVISIONS		C
0	DMH-1960	

747LED				

PRINTS TO

MADE BY S.A. Kenreck 10/16/85	APPROVALS L.E. DeLaurentis	DEPT NEBO	LOCATION San Jose
CHKD BY G.W. Comstock 10/17/85	ISSUED G.A. Baylis DEC 13 1985	CONT ON SHEET 2	SH NO. 1

NEO 805 (REV 1/82)

CERTIFICATION OF STRESS REPORT

This certification with the documents listed below provides the basis for the Stress Report for a BWR Core Spray Nozzle Replacement Safe-End and Thermal Sleeve, required by Paragraph NA-3350 of the ASME Boiler and Pressure Vessel Code, Section III, 1980 Edition, with Addenda to and including Summer 1982. I certify that to the best of my knowledge and belief, the Stress Report for the Core Spray Nozzle Replacement Safe-End and Thermal Sleeve is correct and complete, and in compliance with the requirements of the certified Design Specification, General Electric Document 23A4322, Revision 0, and Article NB-3000 of the ASME Boiler and Pressure Vessel Code, Section III, 1980 Edition, with Addenda to and including Summer 1982.

LISTED DOCUMENTS

Type of Document	Title	Document Number	Revision Number
Stress Report	Reactor Vessel - Core Spray Nozzle	23A4904	0

REGISTERED PROFESSIONAL ENGINEER
No. M023575
MECHANICAL
STATE OF CALIFORNIA

Certified by: [signature]
Registered Professional Engineer

P.E. Number: M023575

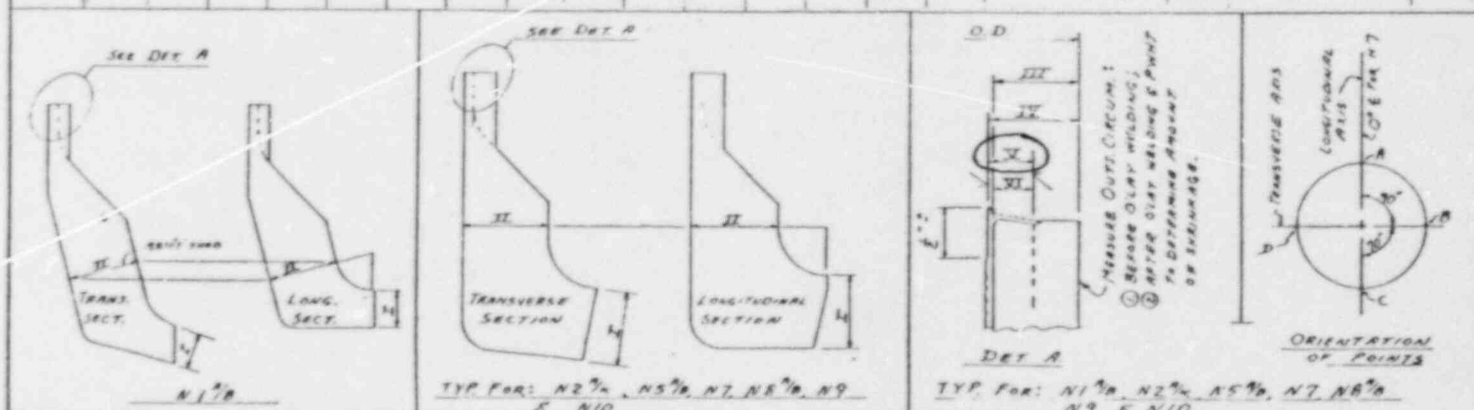
State: California

Date: 12/13/85

Orientation & Locations of Measurements of Forgings

Nozzle Mk.	Point "A" 0° ℄ N7 Only – Stations I	II	III	IV	V	VI	O'lay	Point "B" 90° ℄ N7 Only – Stations I	II	III	IV	V	VI	O'lay
N1A	5.562	10.129	3.112	3.267	1.639	1.484	.155	5.689	10.109	3.101	3.268	1.633	1.477	.161
N1B	5.625	10.114	3.087	3.247	1.627	1.467	.160	5.760	10.118	3.088	3.247	1.680	1.461	.159
N2A	5.468	7.11	2.384	2.583	.930	.731	.199	5.593	7.12	2.387	2.584	.930	.733	.197
N2B	5.687	7.12	2.364	2.577	.932	.719	.213	5.843	7.12	2.387	2.574	.932	.745	.187
N2C	5.625	7.11	2.389	2.582	.937	.741	.193	5.562	7.12	2.378	2.583	.934	.729	.205
N2D	5.656	7.14	2.386	2.579	.928	.741	.187	5.593	7.14	2.386	2.575	.927	.738	.189
N2E	5.468	7.13	2.388	2.580	.924	.732	.192	5.437	7.13	2.386	2.583	.924	.727	.197
N2F	5.500	7.11	2.353	2.548	.931	.736	.195	5.625	7.11	2.355	2.549	.931	.738	.193
N2G	5.500	7.09	2.362	2.573	.934	.723	.211	5.500	7.09	2.361	2.573	.934	.722	.212
N2H	5.500	7.15	2.410	2.597	.929	.742	.187	5.593	7.15	2.408	2.597	.929	.740	.189
N2J	5.531	7.12	2.345	2.551	.930	.724	.206	5.625	7.12	2.348	2.546	.929	.731	.198
N2K	5.531	7.11	2.365	2.583	.928	.710	.218	5.555	7.11	2.365	2.584	.928	.709	.219
N5A	5.687	6.16	2.387	2.560	.918	.745	.173	5.593	6.16	2.388	2.568	.918	.744	.174
N5B	5.718	6.15	2.386	2.559	.914	.741	.173	5.625	6.14	2.383	2.557	.914	.738	.176
N7	3.093	1.679	1.679	1.877	1.311	1.113	.198	3.093	1.679	1.679	1.877	1.308	1.110	.198
N8A	5.568	3.406	2.145	2.325	.943	.763	.180	5.625	3.406	2.145	2.324	.943	.764	.179
N8B	5.562	3.437	2.148	2.328	.940	.760	.180	5.625	3.437	2.147	2.328	.940	.759	.181
N9	5.562	3.921	2.073	2.266	.944	.751	.193	5.843	3.921	2.073	2.266	.945	.752	.193
N10	5.687	2.150	2.150	2.314	.920	.756	.164	5.687	2.150	2.150	2.318	.918	.756	.162

Nozzle Mk.	Point "C" 180° ℄ N7 Only – Stations I	II	III	IV	V	VI	O'lay	Point "D" 270° ℄ N7 Only – Stations I	II	III	IV	V	VI	O'lay	Outside Circumference Before O'lay	After O'lay
N1A	5.562	10.059	3.100	3.263	1.631	1.468	.163	5.724	10.112	3.100	3.264	1.640	1.476	.164	8'-5 3/8	8'-5 3/8
N1B	5.625	10.118	3.088	3.253	1.671	1.456	.165	5.716	10.116	3.088	3.250	1.626	1.464	.162	8'-5 13/32	8'-5 17/32
N2A	5.437	7.11	2.385	2.583	.930	.732	.198	5.593	7.11	2.384	2.582	.930	.732	.190	4'-11 1/4	4'-11 5/32
N2B	5.687	7.12	2.391	2.576	.932	.754	.178	5.687	7.12	2.358	2.575	.932	.715	.217	4'-11 3/16	4'-11 1/8
N2C	5.593	7.11	2.381	2.582	.932	.731	.201	5.656	7.12	2.342	2.583	.935	.744	.191	4'-11 9/32	4'-11 7/32
N2D	5.531	7.14	2.386	2.576	.929	.759	.190	5.562	7.14	2.387	2.574	.928	.742	.186	4'-11 1/4	4'-11 6/32
N2E	5.468	7.13	2.387	2.581	.924	.730	.194	5.437	7.13	2.388	2.582	.924	.730	.194	4'-11 9/32	4'-11 7/32
N2F	5.437	7.11	2.353	2.549	.931	.735	.196	5.500	7.12	2.354	2.549	.931	.736	.195	4'-11 1/16	4'-11
N2G	5.437	7.09	2.363	2.572	.933	.724	.209	5.531	7.09	2.361	2.572	.933	.722	.211	4'-11 3/16	4'-11 3/32
N2H	5.500	7.14	2.408	2.595	.929	.742	.187	5.562	7.14	2.407	2.596	.929	.740	.189	4'-11 11/32	4'-11 9/16
N2J	5.500	7.11	2.344	2.549	.930	.725	.205	5.531	7.12	2.345	2.550	.930	.725	.205	4'-11 1/16	4'-11
N2K	5.593	7.11	2.365	2.583	.928	.710	.218	5.593	7.11	2.366	2.582	.928	.712	.216	4'-11 9/32	4'-11 1/16
N5A	5.625	6.14	2.386	[illegible]	.918	.712	.176	5.562	6.15	2.388	2.560	.918	.746	.172	4'-4 31/32	4'-4 7/8
N5B	5.687	6.13	[illegible]	2.556	.914	.741	.175	5.593	6.15	2.384	2.558	.914	.740	.174	4'-4 15/16	4'-4 7/8
N7	3.093	1.677	1.679	1.877	1.308	1.110	.198	3.093	1.679	1.679	1.877	1.311	1.113	.198	1'-11 7/8	1'-11 27/32
N8A	5.562	3.406	2.144	2.324	.943	.763	.180	5.625	3.406	2.144	2.325	.943	.762	.181	2'-2 1/2	2'-2 1/2
N8B	5.562	3.437	2.149	2.328	.940	.761	.179	5.675	3.437	2.150	2.328	.940	.762	.178	2'-2 1/2	2'-2 1/2
N9	5.562	3.921	2.075	2.267	.946	.754	.192	5.875	3.921	2.075	2.267	.945	.753	.192	2'-1 7/8	2'-1 7/8
N10	5.687	2.150	2.150	2.318	.918	.756	.162	5.687	2.150	2.150	2.314	.919	.755	.164	1'-8 19/32	1'-8 5/8



1. Continued on Dwg. R5.

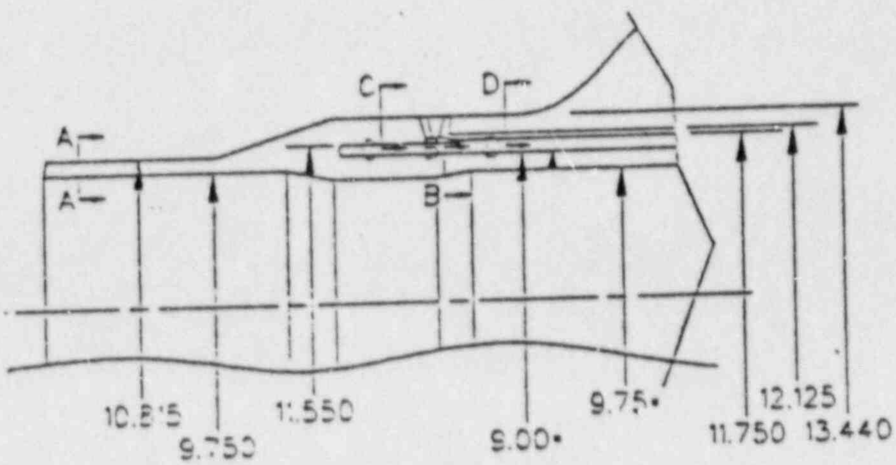


Figure 1 SAFE END GEOMETRY

PRIMARY STRESS ANALYSIS FOR SECTION C-C, DESIGN CONDITIONS

COMPONENT	MEMBRANE		MEMBRANE PLUS BENDING
b (in)*	6.717		6.717
a (in)*	5.778		5.778
c (in)*	6.248		-
t (in)	0.939		0.939
A (in**2)	36.860		36.860
Z (in**3)	115.791		107.697
L (in)	-	SAFE-END SLEEVE	14.50 20.56
SØ (ksi)	7.692		8.364
Sz (ksi)	3.663		8.515
Sx (ksi)	-0.578		-1.250
TAUØz (ksi)	0.		0.
TAUxØ (ksi)	0.199		0.199
PS1 (ksi)	7.702		8.652
PS2 (ksi)	3.653		8.226
PS3 (ksi)	-0.578		-1.250
SI13 = PS1 - PS3 (ksi)	8.280 < Sm = 17.3		9.902 < 1.5*Sm = 25.9
SI23 = PS2 - PS3 (ksi)	4.231		9.476
SI12 = PS1 - PS2 (ksi)	4.049		0.426

*These include corrosion allowance.

$P_m = 8.280$ ksi
$P_B = 9.902 - 8.280$ psi
$P_B = 1622$ psi

C. Method of Analysis for Weld Overlay Stresses

The analysis of the core spray nozzle weld overlay was performed using the IBM PC-based finite element program SUPERSAP,[C1] which is an enhancement of the well known SAP IV[C2] program.

A two-dimensional axisymmetric model of the nozzle and one quarter of the reactor pressure vessel was developed. The radius of the pressure vessel was adjusted to be 3.2 times the actual vessel radius to provide the proper stress concentration effects.[C3] In actuality, for the region of the nozzle in consideration for this study, the correction is not really necessary. The model is shown in Figure C-1.

The first analysis performed was the unmodified nozzle subjected to a pressure of 1050 psig to verify the model. The nozzle hoop stress agreed within 4 percent of the value compute using thin cylinder theory. The stress contours agree with typical nozzle analyses reported in References C4 and C5. See Figures C-2, C-3 and C-4.

The model was modified to incorporate the weld overlay, as shown in Figure C-5.

The measured axial shrinkage from the weld overlay application was obtained from the overlay data.[C6] The lower value from the two overlays was a shrinkage of 0.009 inches over an 8.362 gage length.

Due to the heat of welding and the associated reduced material strength the shrinkage is a combination of elastic and plastic deformation. Since SUPERSAP is a linear program the shrinkage was approximated by imposing a decreased temperature field across the weld overlay nodes.

If the constraint imposed by the surrounding nozzle and safe end is neglected, the required temperature differential can be obtained from the relationship $\delta l/l = E\alpha\delta T$, where E is Young's modulus, α is the thermal expansion coefficient and $\delta l/l$ is the normalized shrinkage.

A computed δT of 160F was applied to the appropriate nodes and a stress analysis performed.

The analysis considered the shrinkage stress, a pressure of 1050 psig and the steady state nozzle applied loads.

As can be seen from Figure C-6, a significant region of compressive stress is created in the hoop stress direction. Figure C-7 shows the same analysis in the maximum principal stress direction; there is still a significant region of compressive stress.

The conservatism of this approach can be verified by examining the displacements of the overlay nodes. The actual displacements from the analysis are only on the order of 0.002 inches, well smaller than the intended 0.009 inches, due to the constraint of the surrounding structure. Sensitivity studies showed that the region of compressive stress was not significantly altered by increasing the shrinkage, even though the magnitude of the peak compressive stress was directly proportional to the shrinkage. Compare Figures C-6 and C-8.

The above analyses demonstrate that the weld overlays apply a net compressive stress to a region of the nozzle and safe end significantly larger than that necessary to suppress future flaw growth.

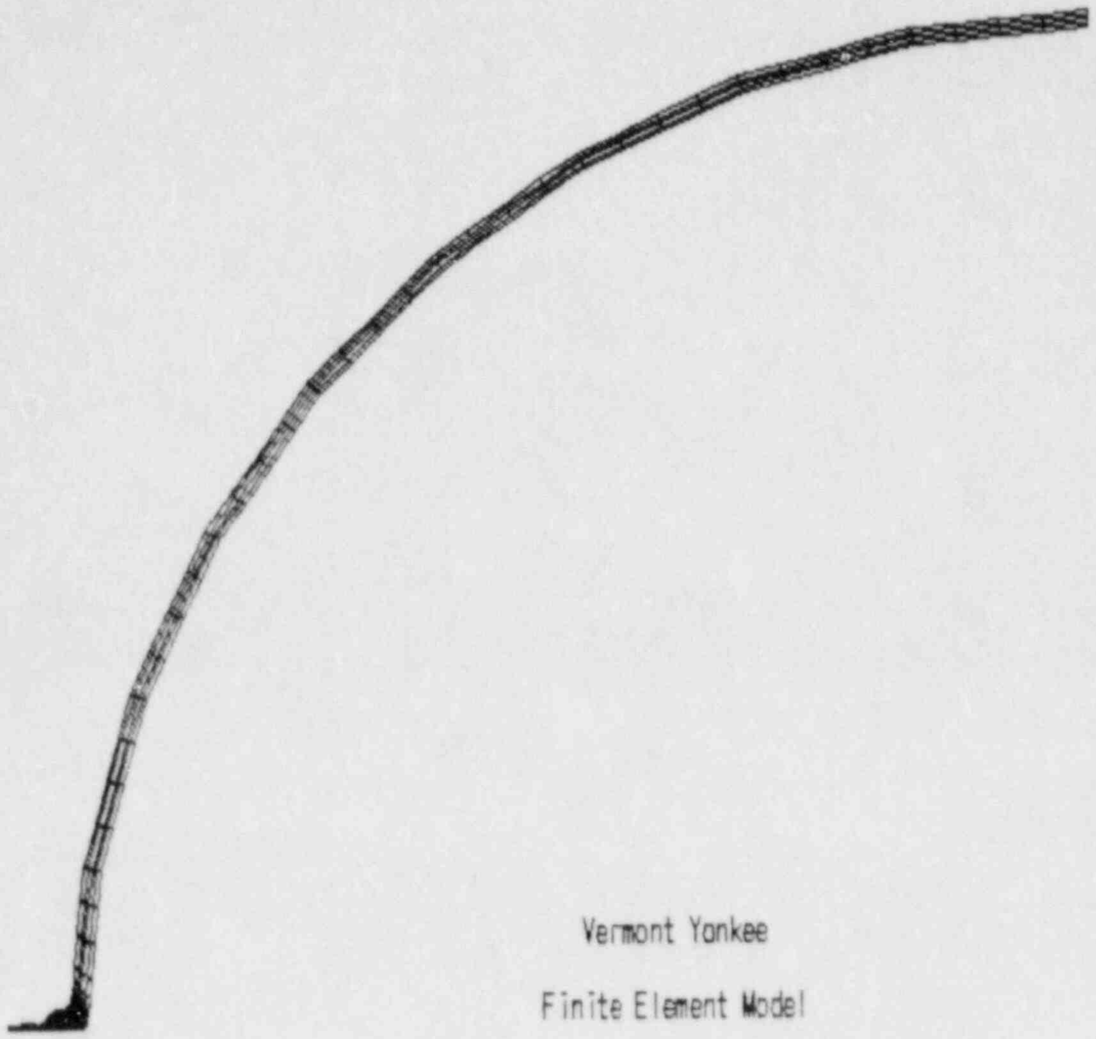
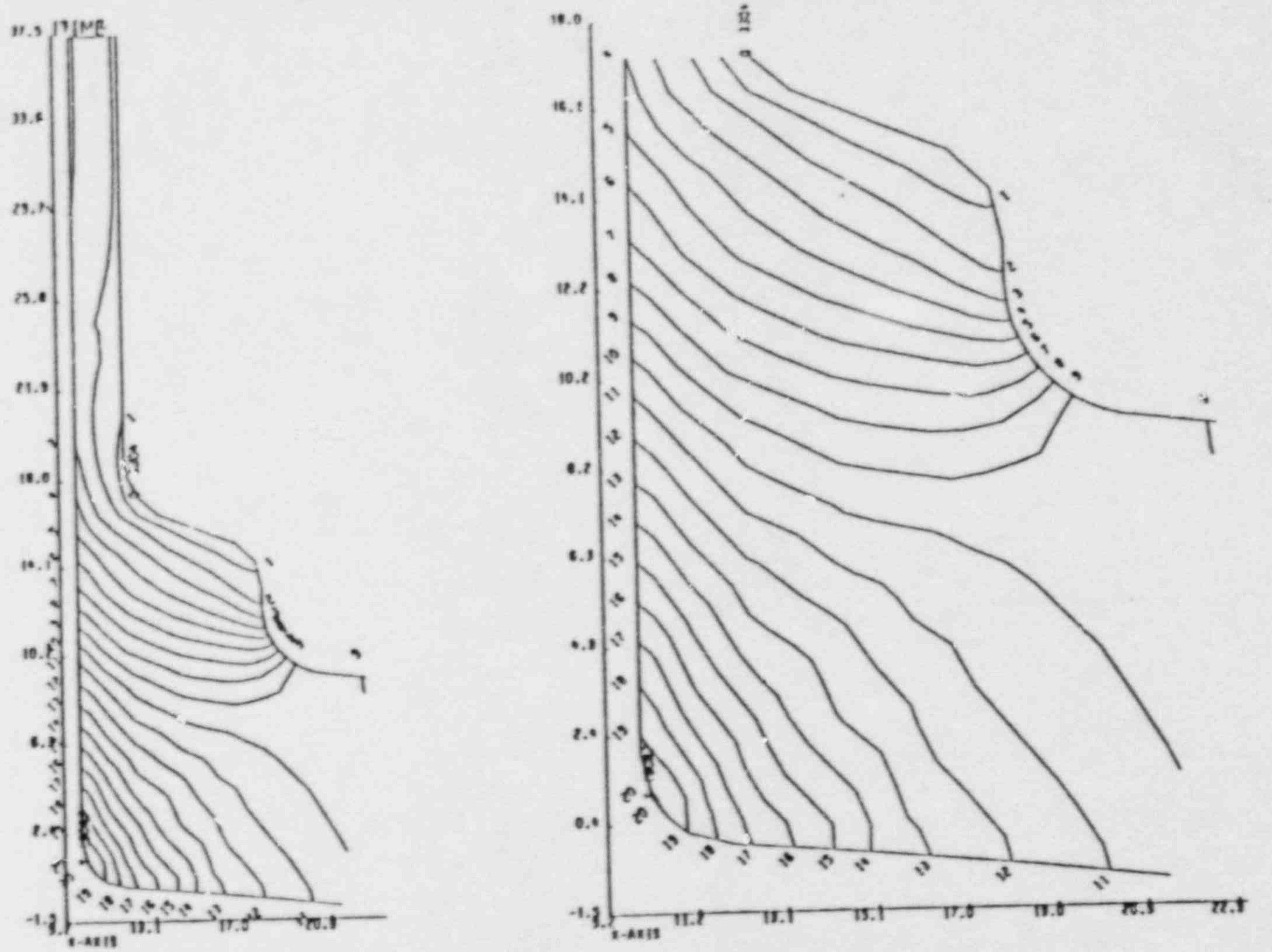


Fig C-1: Safe End, Nozzle and Reactor Pressure Vessel Finite Element Model



MINIMUM	3307
1	3750
2	4500
3	5250
4	6000
5	6750
6	7500
7	8250
8	9000
9	9750
10	10500
11	11250
12	12000
13	12750
14	13500
15	14250
16	15000
17	15750
18	16500
19	17250
20	18000
MAXIMUM	18094

Figure C-2 Inlet Nozzle - Principal (Hoop) Stress - 1000 psi Pressure Run

REF C5

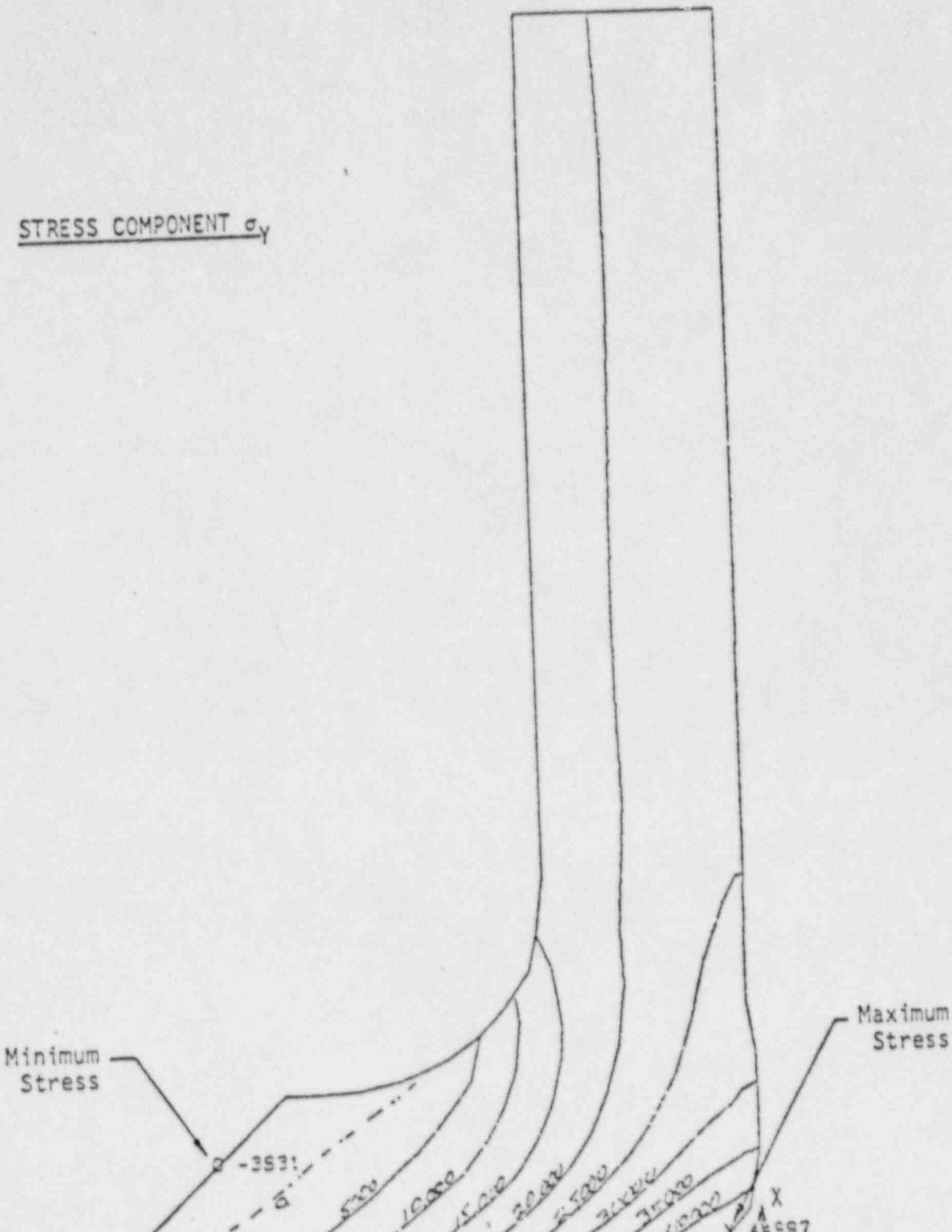


Figure C-3. Pressure Case, θ=0°
REF C4

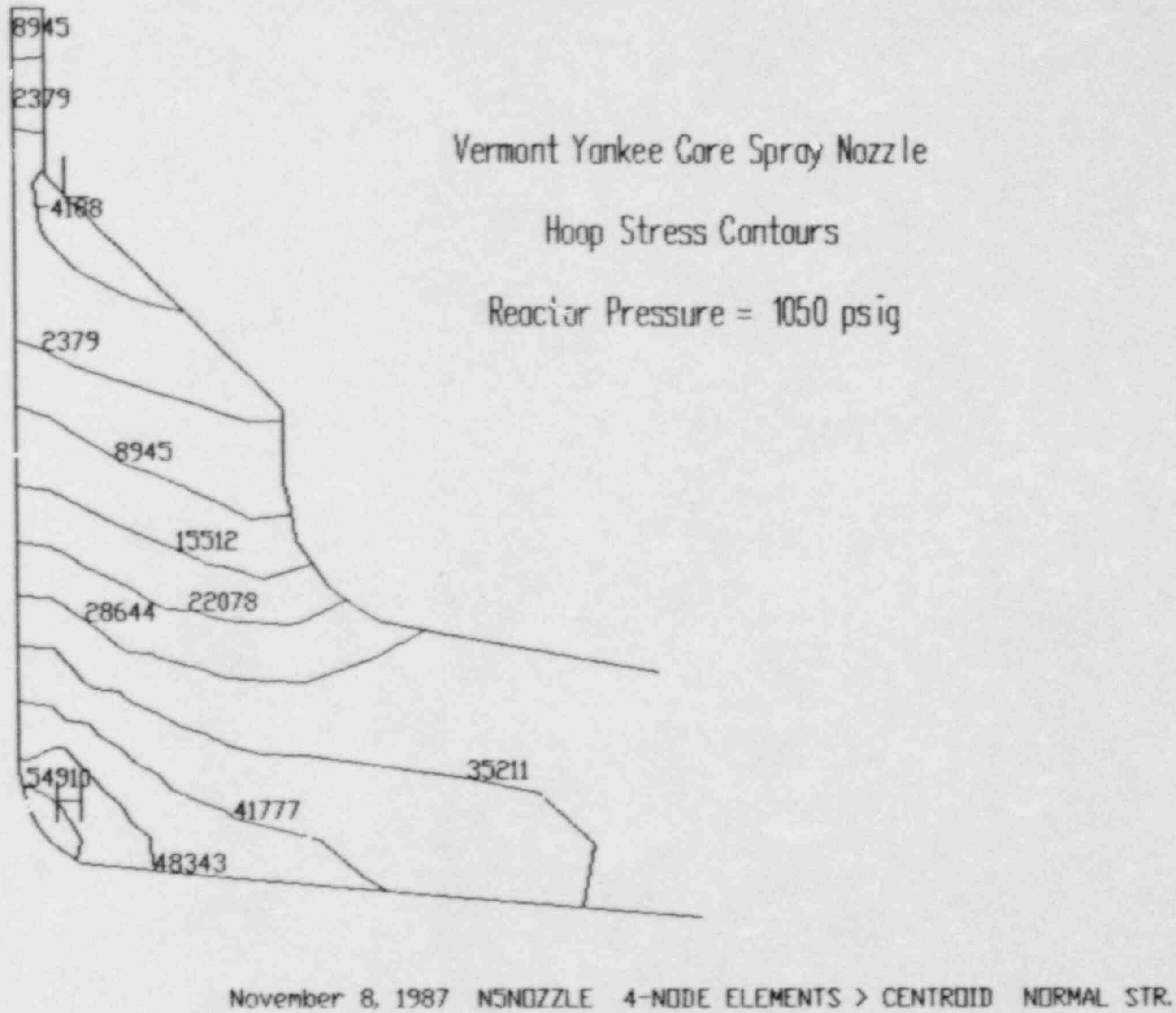


Fig. C-4: Vermont Yankee Core Spray Nozzle - Hoop Stress Contours

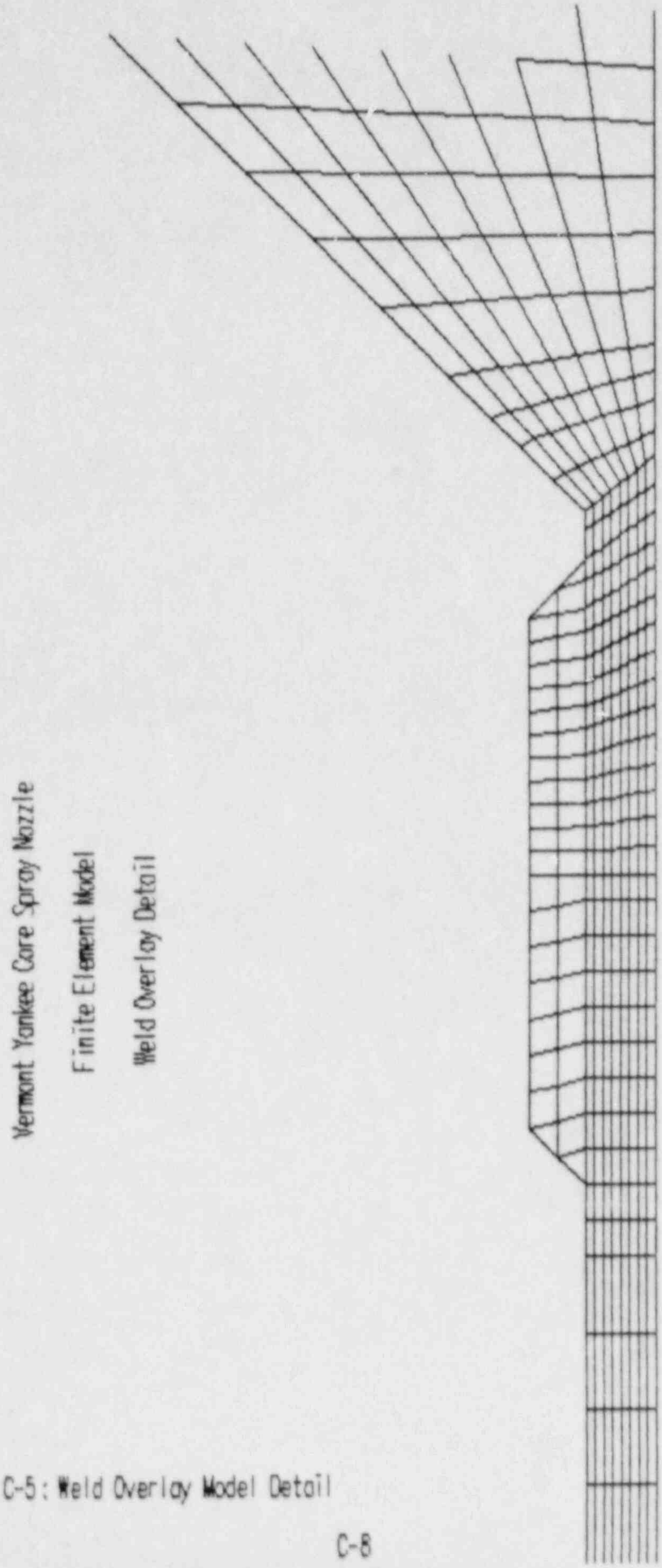


Fig. C-5: Weld Overlay Model Detail

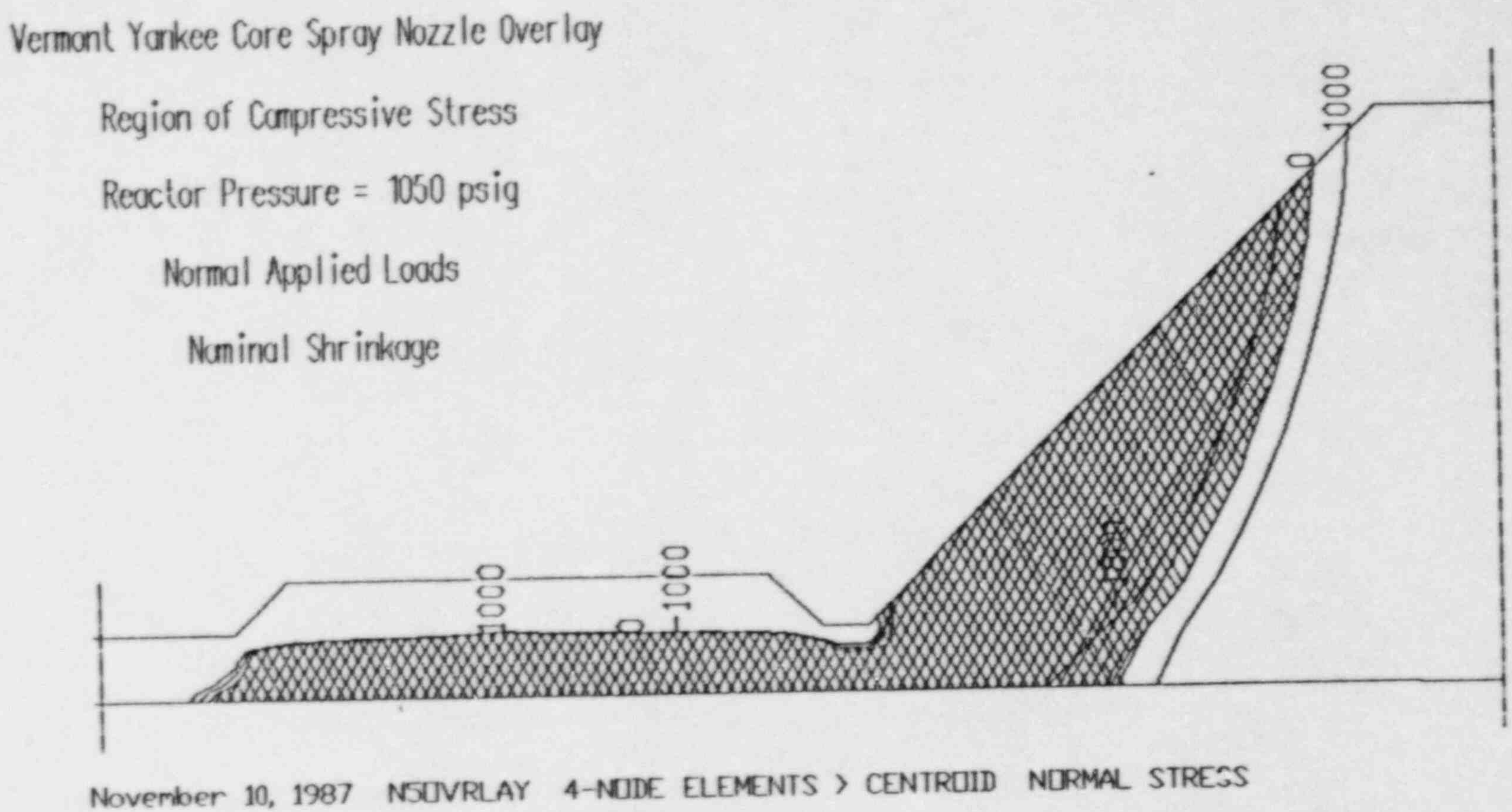


Fig. C-6: Vermont Yankee Core Spray Nozzle Weld Overlay - Compressive Stress

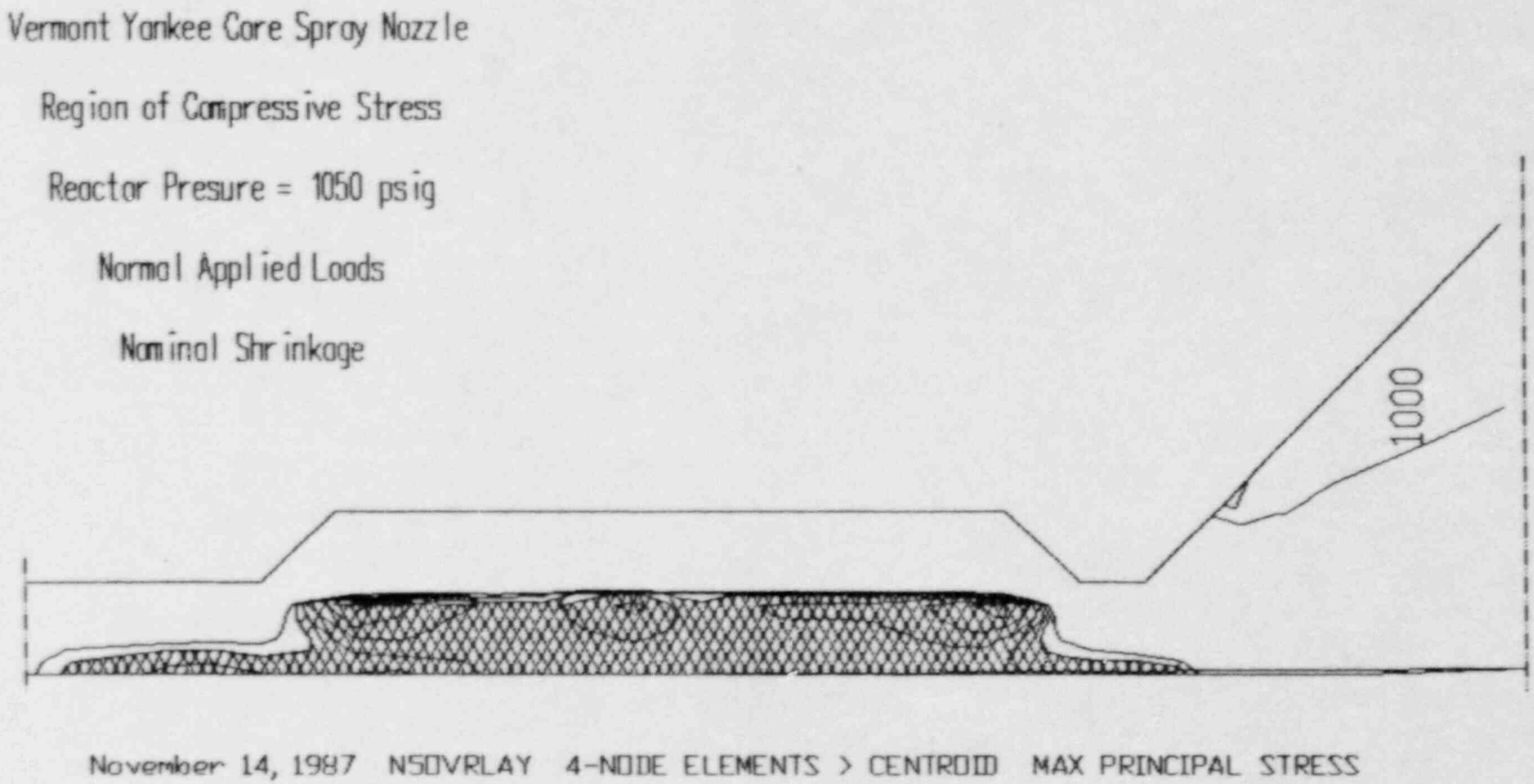


Fig. C-7: Vermont Yankee Core Spray Nozzle - Maximum Principal Stress

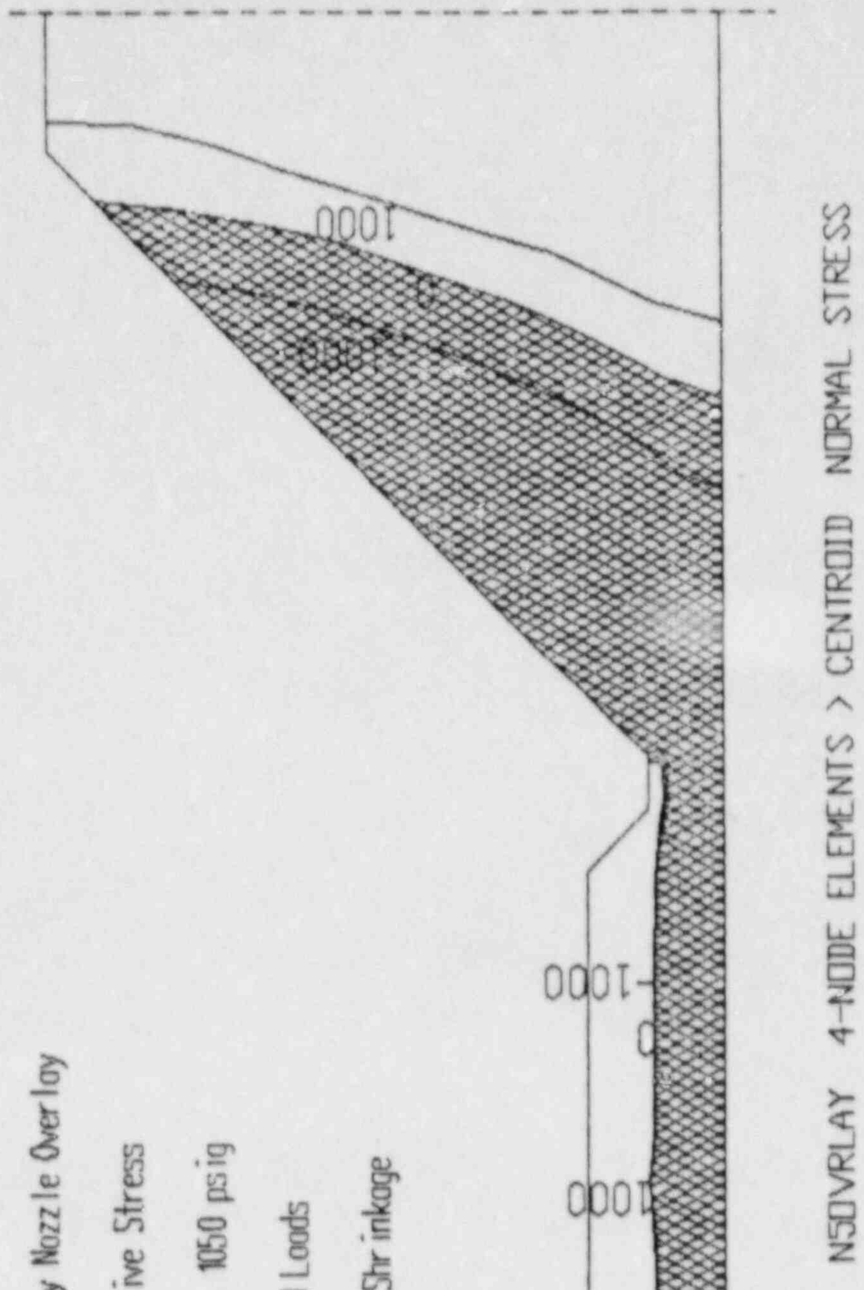


Fig. C-8: Vermont Yankee Core Spray Nozzle - One-half Nominal Shrinkage

References

C1. Algor Interactive Systems, Software User Guide for SUPERSAP.

C2. Bathe, K., Peterson, F., Wilson, E., "SAP IV - A Structural Analysis Program for Static and Dynamic Response of Linear Systems", EERC 73-11, Earthquake Engineering Research Center, University of California, Berkeley, California, April 1974.

C3. Raju, P.P., Truitt, J.B., "Three-Dimensional versus Axisymmetric Finite-Element Analysis of a Cylindrical Vessel Inlet Nozzle Subject to Internal Pressure - A Comparative Study", Transactions of the ASME, Volume 100, May 1978.

C4. EPRI Report NP-339, "Improved Evaluation of Nozzle Corner Cracking", March 1977.

C5. WCAP-10561, "Yankee Primary Nozzles: Transient Development, Thermal Analysis, Stress Analysis and Fracture Evaluation", Westinghouse Electric Corporation , May 1984.

C6. Vermont Yankee Engineering Design Change EDCR 85-1.

D. Benchmarking of SUPERSAP Computer Program

The computer program used for this study is the IBM PC-based finite element program SUPERSAP.[D1] It is an enhancement of the well known program SAP IV.[D2] The original SAP IV program has been utilized and expanded upon by many organizations, among them General Electric Company[D3] and Brookhaven National Laboratory.[D4]

The Brookhaven Laboratory version, called EPIPE is used as a benchmark program for piping analysis computer programs. The General Electric Company program SAP4G07 is fully benchmarked under a 10CFR50 Appendix B quality assurance program and is used for reactor design.

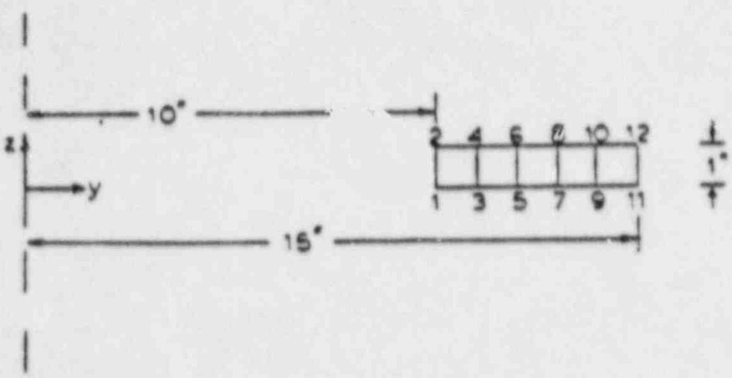
One of the program elements, called Type 4 (two dimensional axisymmetric solid) was used for the study. The suitability of the element is demonstrated by the following sample problem, the solution of a two dimensional axisymmetric pipe section subjected to thermal and pressure loadings.

VE04001

THICK WALLED CYLINDER, PRESSURE AND TEMPERATURE

Problem Definition

Ref: ASME Pressure Vessel and Piping 1972 Computer Programs Verification, ed. by I.S. Tuba and W.B. Wright, ASME Publication I-24, Problems 3 and 4.



$E = 28 \times 10^6$ psi

$\nu = 0.25$

$\alpha = 7.5 \times 10^{-6}$ in/in/°F

$p = 2000$ psi

$T_i = 100$°F

$T_o = 0$°F

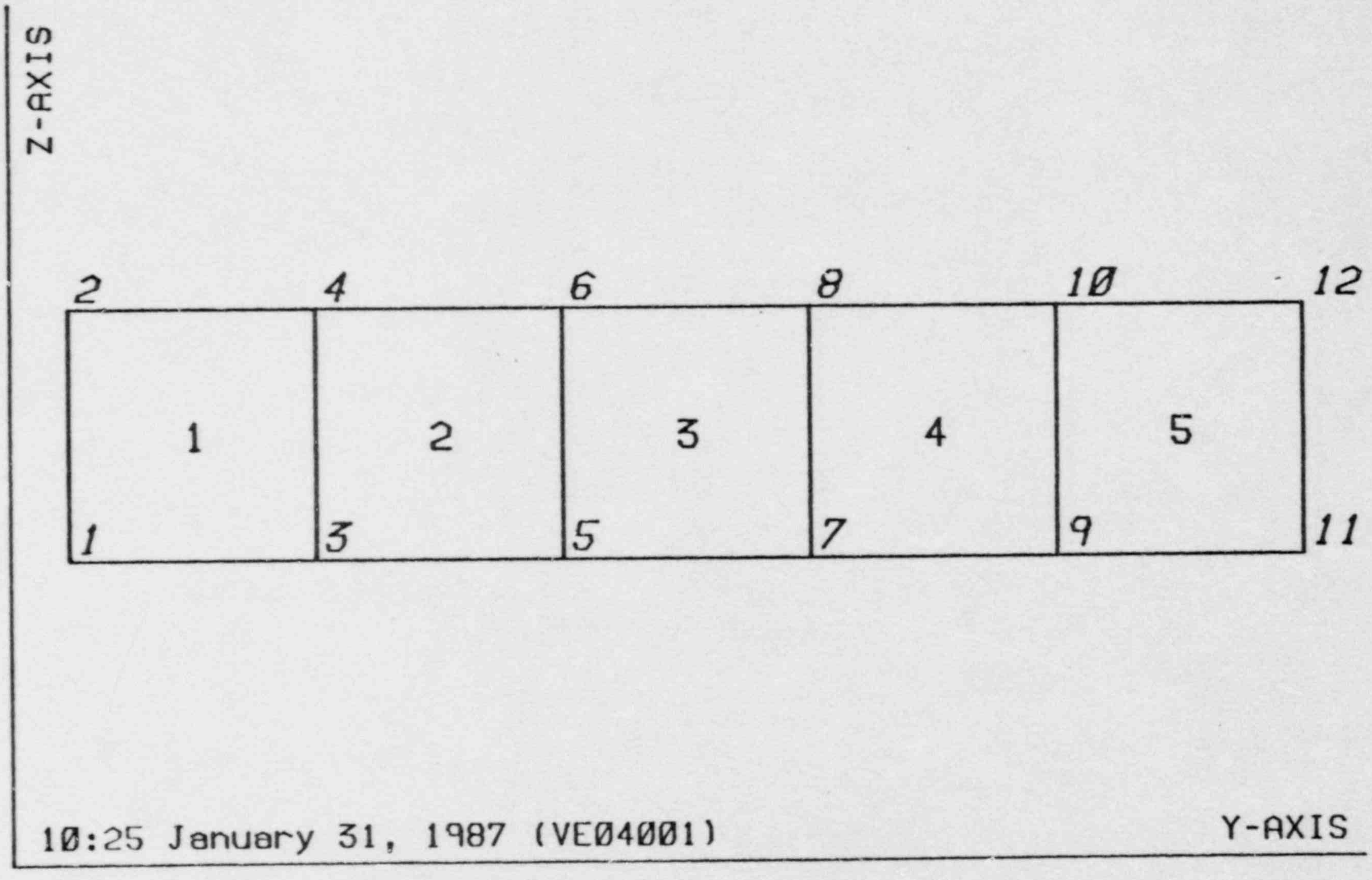
$$T = \frac{T_i}{\log(R_o/R_i)} \log\left(\frac{R_o}{R}\right)$$

Problem Formulation

Note that with element type 4 the pressure can be applied only to the I-J face, so the numbering sequence of the elements must take this into account. Since the temperature is variable, the temperature at each node must be input. Use of the element load multipliers provides for the pressure as load case 1, and the thermal load as load case 2. Since this is a portion of a long cylinder, the Z displacements are prohibited, so only the Y degrees of freedom are active.

Discussion of Results

	Classical	ANSYS	SAP IV	ALGOR	Error
Pressure: (psi)					
inside hoop stress	5200	5192	5199.3	5199	0.013%
outside hoop stress	3200	3197	3201.7	3202	0.053%
Temperature: (psi)					
inside hoop stress	-15,870	-15,723	-15,839	-15,840	0.20%
outside hoop stress	12,128	12,209	12,140	12,140	0.10%


Z-AXIS
2
4
6
8
10
12
1
2
3
4
5
1
3
5
7
9
11
10:25 January 31, 1987 (VE04001)
Y-AXIS

EXAMPLE VE04001

--- OUTPUT FILE ---

**** SUPERSAP ANALYSIS VERSION: 7.1
RELEASED: 7/30/85

DATE: February 5, 1987
TIME: 16:03:41
INPUT FILE........... VE04001

EXAMPLE VE04001 -- THICK WALLED CYLINDER, PRESSURE AND TEMPERATURE

**** CONTROL INFORMATION

NUMBER OF NODE POINTS	(NUMNP)	=	12
NUMBER OF ELEMENT TYPES	(NELTYP)	=	1
NUMBER OF LOAD CASES	(LL)	=	2
NUMBER OF FREQUENCIES	(NF)	=	0
GEOMETRIC STIFFNESS FLAG	(GEOSTF)	=	0
ANALYSIS CODE	(NDYN)	=	0
SOLUTION MODE	(MODEX)	=	0
NUMBER OF ITERATION VECTORS	(NAD)	=	0
EQUATIONS PER BLOCK	(KEQB)	=	0
TAPE10 SAVE FLAG	(N10SV)	=	0
NODAL DEFLECTION PRINTING	(DEFPCH)	=	0
OVERALL MATRIX PRINTING	(GENPRT)	=	0
ELEMENT MATRIX PRINTING	(ELPRT)	=	0
WEIGHT AND C.G. FLAG	(IWTCG)	=	0
BANDWIDTH MINIMIZATION FLAG	(MINBND)	=	0
FILE FORMAT FLAG	(IPLT)	=	0
NUMBER OF RESPONSE SPECTRA	(NRSC)	=	0
GRAVITATIONAL CONSTANT	(GRAV)	=	3.8640E+02
TOTAL BLANK COMMON	(MTOT)	=	30000

BANDWIDTH MINIMIZATION SPECIFIED

**** NODAL DATA

NODE	BOUNDARY CONDITION CODES						NODAL POINT COORDINATES			
NO.	DX	DY	DZ	RX	RY	RZ	X	Y	Z	T
1	1	0	1	1	1	1	.000E+00	1.000E+01	.000E+00	1.000E+02
2	1	0	1	1	1	1	.000E+00	1.000E+01	1.000E+00	1.000E+02
3	1	0	1	1	1	1	.000E+00	1.100E+01	.000E+00	7.649E+01
4	1	0	1	1	1	1	.000E+00	1.100E+01	1.000E+00	7.649E+01
5	1	0	1	1	1	1	.000E+00	1.200E+01	.000E+00	5.503E+01
6	1	0	1	1	1	1	.000E+00	1.200E+01	1.000E+00	5.503E+01
7	1	0	1	1	1	1	.000E+00	1.300E+01	.000E+00	3.529E+01
8	1	0	1	1	1	1	.000E+00	1.300E+01	1.000E+00	3.529E+01
9	1	0	1	1	1	1	.000E+00	1.400E+01	.000E+00	1.702E+01
10	1	0	1	1	1	1	.000E+00	1.400E+01	1.000E+00	1.702E+01
11	1	0	1	1	1	1	.000E+00	1.500E+01	.000E+00	.000E+00
12	1	0	1	1	1	1	.000E+00	1.500E+01	1.000E+00	.000E+00

**** TWO-DIMENSIONAL SOLID ELEMENTS

AXISYMMETRIC ANALYSIS

NUMBER OF ELEMENTS	=	5
NUMBER OF MATERIALS	=	1
MAXIMUM TEMPERATURES PER MATERIAL	=	1
ANALYSIS CODE	=	0
AXISYMMETRIC.....0		
PLANE STRAIN.....1		
PLANE STRESS.....2		
INCOMPATIBLE DISPLACEMENT MODES	=	0
INCLUDE..........0		
SUPPRESS.........1		

**** MATERIAL PROPERTIES

MATERIAL I.D. NUMBER	=	1
NUMBER OF TEMPERATURES	=	1
WEIGHT DENSITY	=	.0000E+00
MASS DENSITY	=	.0000E+00
BETA ANGLE	=	.0000E+00

TEMPERATURE	E(N)/ ALPHA(N)	E(S)/ ALPHA(S)	E(T)/ ALPHA(T)	NU(NS)	NU(NT)	NU(ST)	G(NS)
.0	2.800E-07	2.800E+07	2.800E+07	.250	.250	.250	1.120E+07
	7.500E-06	7.500E-06	7.500E-06				

**** ELEMENT LOAD MULTIPLIERS

	CASE A	CASE B	CASE C	CASE D
TEMP	.000E+00	1.000E+00	.000E+00	.000E+00
PRES	1.000E+00	.000E+00	.000E+00	.000E+00
X-DIR	.000E+00	.000E+00	.000E+00	.000E+00
Y-DIR	.000E+00	.000E+00	.000E+00	.000E+00
Z-DIR	.000E+00	.000E+00	.000E+00	.000E+00

**** ELEMENT CONNECTIVITY DATA

ELEM NO.	NODE I	NODE J	NODE K	NODE L	MAT'L INDEX	REFERENCE TEMP	I-J FACE PRESSURE	OP	THICKNESS
1	2	1	3	4	1	.000E+00	2.000E+03	20	.000E+00
2	4	3	5	6	1	.000E+00	.000E+00	20	.000E+00
3	6	5	7	8	1	.000E+00	.000E+00	20	.000E+00
4	8	7	9	10	1	.000E+00	.000E+00	20	.000E+00
5	10	9	11	12	1	.000E+00	.000E+00	20	.000E+00

**** BANDWIDTH MINIMIZATION

MINBND (BANDWIDTH CONTROL PARAMETER) = 1

**** MINIMIZER DID NOT NEED TO REDUCE BANDWIDTH

**** EQUATION PARAMETERS

TOTAL NUMBER OF EQUATIONS	=	12
BANDWIDTH	=	4
NUMBER OF EQUATIONS IN A BLOCK	=	12
NUMBER OF BLOCKS	=	1
BLOCKING MEMORY (KILOBYTES)	=	240
AVAILABLE MEMORY (KILOBYTES)	=	240

**** NODAL LOADS (STATIC) OR MASSES (DYNAMIC)

NODE NUMBER	LOAD CASE	X-AXIS FORCE	Y-AXIS FORCE	Z-AXIS FORCE	X-AXIS MOMENT	Y-AXIS MOMENT	Z-AXIS MOMENT

**** ELEMENT LOAD MULTIPLIERS

LOAD CASE	CASE A	CASE B	CASE C	CASE D
1	1.000E+00	.000E+00	.000E+00	.000E+00
2	.000E+00	1.000E+00	.000E+00	.000E+00

**** STIFFNESS MATRIX PARAMETERS

MINIMUM NON-ZERO DIAGONAL ELEMENT	=	1.4056E+08
MAXIMUM DIAGONAL ELEMENT	=	3.8364E+08
MAXIMUM/MINIMUM	=	2.7295E+00
AVERAGE DIAGONAL ELEMENT	=	2.8552E+08
DENSITY OF THE MATRIX	=	7.9167E+01

**** TWO-DIMENSIONAL SOLID ELEMENT STRESSES

FACE 0: CENTROID (GLOBAL Y-Z)
FACE 1: L-I SIDE (LOCAL)
FACE 2: J-K SIDE (LOCAL)
FACE 3: I-J SIDE (LOCAL)
FACE 4: K-L SIDE (LOCAL)

ELEM NO.	CASE (MODE)	FACE	STRESS COMPONENTS SIGMA-11	SIGMA-22	SIGMA-33	TAU-12	PRINCIPAL STRESSES (IN-PLANE) SIGMA-MAX	SIGMA-MIN
1	1	0	-1.678E+03	7.938E+02	4.853E+03	.000E+00	7.938E+02	-1.678E+03
1	1	1	7.993E+02	-1.673E+03	4.870E+03	-2.319E+02	8.209E+02	-1.694E+03
1	1	2	7.993E+02	-1.673E+03	4.870E+03	2.319E+02	8.209E+02	-1.694E+03
1	1	3	-1.979E+03	8.052E+02	5.199E+03	.000E+00	8.052E+02	-1.979E+03
1	1	4	-1.356E+03	8.046E+02	4.575E+03	.000E+00	8.046E+02	-1.356E+03
1	2	0	-5.951E+02	-2.164E+04	-1.183E+04	.000E+00	-5.951E+02	-2.164E+04
1	2	1	-2.165E+04	-6.086E+02	-1.187E+04	5.668E+02	-5.933E+02	-2.167E+04
1	2	2	-2.165E+04	-6.086E+02	-1.187E+04	-5.668E+02	-5.933E+02	-2.167E+04
1	2	3	-1.178E+02	-2.499E+04	-1.584E+04	.000E+00	-1.178E+02	-2.499E+04
1	2	4	-1.189E+03	-1.840E+04	-8.173E+03	.000E+00	-1.189E+03	-1.840E+04
2	1	0	-1.131E+03	7.958E+02	4.315E+03	.000E+00	7.958E+02	-1.131E+03
2	1	1	7.999E+02	-1.127E+03	4.327E+03	-1.881E+02	8.181E+02	-1.146E+03
2	1	2	7.999E+02	-1.127E+03	4.327E+03	1.881E+02	8.181E+02	-1.146E+03
2	1	3	-1.361E+03	8.037E+02	4.576E+03	.000E+00	8.037E+02	-1.361E+03
2	1	4	-8.868E+02	8.034E+02	4.100E+03	.000E+00	8.034E+02	-8.868E+02
2	2	0	-1.280E+03	-1.536E+04	-4.905E+03	.000E+00	-1.280E+03	-1.536E+04
2	2	1	-1.536E+04	-1.284E+03	-4.919E+03	2.151E+02	-1.281E+03	-1.536E+04
2	2	2	-1.536E+04	-1.284E+03	-4.919E+03	-2.151E+02	-1.281E+03	-1.536E+04
2	2	3	-1.160E+03	-1.840E+04	-8.185E+03	.000E+00	-1.160E+03	-1.840E+04
2	2	4	-1.475E+03	-1.239E+04	-1.852E+03	.000E+00	-1.475E+03	-1.239E+04
3	1	0	-7.108E+02	7.972E+02	3.899E+03	.000E+00	7.972E+02	-7.108E+02
3	1	1	8.003E+02	-7.077E+02	3.909E+03	-1.563E+02	8.163E+02	-7.237E+02
3	1	2	8.003E+02	-7.077E+02	3.909E+03	1.563E+02	8.163E+02	-7.237E+02
3	1	3	-8.898E+02	8.028E+02	4.101E+03	.000E+00	8.028E+02	-8.898E+02
3	1	4	-5.207E+02	8.026E+02	3.731E+03	.000E+00	8.026E+02	-5.207E+02
3	2	0	-1.342E+03	-9.597E+03	8.924E+02	.000E+00	-1.342E+03	-9.597E+03
3	2	1	-9.596E+03	-1.341E+03	8.945E+02	-3.472E+01	-1.341E+03	-9.596E+03
3	2	2	-9.596E+03	-1.341E+03	8.945E+02	3.472E+01	-1.341E+03	-9.596E+03
3	2	3	-1.456E+03	-1.239E+04	-1.860E+03	.000E+00	-1.456E+03	-1.239E+04
3	2	4	-1.278E+03	-6.857E+03	3.494E+03	.000E+00	-1.278E+03	-6.857E+03
4	1	0	-3.804E+02	7.981E+02	3.573E-03	.000E+00	7.981E+02	-3.804E+02
4	1	1	8.005E+02	-3.779E+02	3.580E+03	-1.326E+02	8.153E+02	-3.926E+02
4	1	2	8.005E+02	-3.779E+02	3.580E+03	1.326E+02	8.153E+02	-3.926E+02
4	1	3	-5.228E+02	8.022E+02	3.732E+03	.000E+00	8.022E+02	-5.228E+02
4	1	4	-2.298E+02	8.021E+02	3.438E+03	.000E+00	8.021E+02	-2.298E+02
4	2	0	-9.952E+02	-4.280E+03	5.846E+03	.000E+00	-9.952E+02	-4.280E+03
4	2	1	-4.276E+03	-9.912E+02	5.858E+03	-2.161E+02	-9.770E+02	-4.290E+03
4	2	2	-4.276E+03	-9.912E+02	5.858E+03	2.161E+02	-9.770E+02	-4.290E+03
4	2	3	-1.265E+03	-6.856E+03	3.489E+03	.000E+00	-1.265E+03	-6.856E+03
4	2	4	-7.583E+02	-1.737E+03	8.103E+03	.000E+00	-7.583E+02	-1.737E+03
5	1	0	-1.160E+02	7.987E+02	3.311E+03	.000E+00	7.987E+02	-1.160E+02
5	1	1	8.007E+02	-1.140E+02	3.317E+03	-1.143E+02	8.148E+02	-1.281E+02
5	1	2	8.007E+02	-1.140E+02	3.317E+03	1.143E+02	8.148E+02	-1.281E+02
5	1	3	-2.312E+02	8.018E+02	3.439E+03	.000E+00	8.018E+02	-2.312E+02
5	1	4	5.279E+00	8.017E+02	3.202E+03	.000E+00	8.017E+02	5.279E+00
5	2	0	-3.756E+02	6.578E+02	1.015E+04	.000E+00	6.578E+02	-3.756E+02
5	2	1	6.638E+02	-3.696E+02	1.017E+04	-3.499E+02	7.712E+02	-4.769E+02
5	2	2	6.638E+02	-3.696E+02	1.017E+04	3.499E+02	7.712E+02	-4.769E+02
5	2	3	-7.501E+02	-1.736E+03	8.100E+03	.000E+00	-7.501E+02	-1.736E+03
5	2	4	-2.350E+01	3.029E+03	1.214E+04	.000E+00	3.029E+03	-2.350E+01

**** STATIC ANALYSIS

LOAD CASE = 1

DISPLACEMENTS/ROTATIONS(DEGREES) OF UNRESTRAINED NODES

NODE NUMBER	X- TRANSLATION	Y- TRANSLATION	Z- TRANSLATION	X- ROTATION	Y- ROTATION	Z- ROTATION
1	.0000E+00	1.9668E-03	.0000E+00	.0000E+00	.0000E+00	.0000E+00
2	.0000E+00	1.9668E-03	.0000E+00	.0000E+00	.0000E+00	.0000E+00
3	.0000E+00	1.8565E-03	.0000E+00	.0000E+00	.0000E+00	.0000E+00
4	.0000E+00	1.8565E-03	.0000E+00	.0000E+00	.0000E+00	.0000E+00
5	.0000E+00	1.7704E-03	.0000E+00	.0000E+00	.0000E+00	.0000E+00
6	.0000E+00	1.7704E-03	.0000E+00	.0000E+00	.0000E+00	.0000E+00
7	.0000E+00	1.7031E-03	.0000E+00	.0000E+00	.0000E+00	.0000E+00
8	.0000E+00	1.7031E-03	.0000E+00	.0000E+00	.0000E+00	.0000E+00
9	.0000E+00	1.6505E-03	.0000E+00	.0000E+00	.0000E+00	.0000E+00
10	.0000E+00	1.6505E-03	.0000E+00	.0000E+00	.0000E+00	.0000E+00
11	.0000E+00	1.6097E-03	.0000E+00	.0000E+00	.0000E+00	.0000E+00
12	.0000E+00	1.6097E-03	.0000E+00	.0000E+00	.0000E+00	.0000E+00

**** STATIC ANALYSIS

LOAD CASE = 2

DISPLACEMENTS/ROTATIONS(DEGREES) OF UNRESTRAINED NODES

NODE NUMBER	X- TRANSLATION	Y- TRANSLATION	Z- TRANSLATION	X- ROTATION	Y- ROTATION	Z- ROTATION
1	.0000E+00	4.0721E-03	.0000E+00	.0000E+00	.0000E+00	.0000E+00
2	.0000E+00	4.0721E-03	.0000E+00	.0000E+00	.0000E+00	.0000E+00
3	.0000E+00	5.0115E-03	.0000E+00	.0000E+00	.0000E+00	.0000E+00
4	.0000E+00	5.0115E-03	.0000E+00	.0000E+00	.0000E+00	.0000E+00
5	.0000E+00	5.6400E-03	.0000E+00	.0000E+00	.0000E+00	.0000E+00
6	.0000E+00	5.6400E-03	.0000E+00	.0000E+00	.0000E+00	.0000E+00
7	.0000E+00	6.0085E-03	.0000E+00	.0000E+00	.0000E+00	.0000E+00
8	.0000E+00	6.0085E-03	.0000E+00	.0000E+00	.0000E+00	.0000E+00
9	.0000E+00	6.1551E-03	.0000E+00	.0000E+00	.0000E+00	.0000E+00
10	.0000E+00	6.1551E-03	.0000E+00	.0000E+00	.0000E+00	.0000E+00
11	.0000E+00	6.1090E-03	.0000E+00	.0000E+00	.0000E+00	.0000E+00
12	.0000E+00	6.1090E-03	.0000E+00	.0000E+00	.0000E+00	.0000E+00

References

D1. Algor Interactive Systems, Software User Guide for SUPERSAP.

D2. Bathe, K., Peterson, F., Wilson, E., "SAP IV - A Structural Analysis Program for Static and Dynamic Response of Linear Systems", EERC 73-11, Earthquake Engineering Research Center, University of California, Berkeley, California, April 1974.

D3. NEDO-10909, "User's Manual, SAP4G07, Static and Dynamic Analysis of Mechanical and Piping Components by Finite Element Methods", Revision 7, December 1979.

D4. Bezler, P., Hartzman, M., and Reich, M., "EPIPE - An Elastic Piping Program for Static and Dynamic Analysis, NUREG/CR-1698.

E. Results of 1987 Weld Overlay Inspections

VERMONT YANKEE NUCLEAR POWER CORPORATION

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

REPLY TO
ENGINEERING OFFICE
1671 WORCESTER ROAD
FRAMINGHAM, MASSACHUSETTS 01701
TELEPHONE 617-872-8100

October 20, 1987
FVY 87-100

United States Nuclear Regulatory Commission
Washington, DC 20555

Attention: Office of Nuclear Reactor Regulation
Mr. V. L. Rooney, Senior Project Manager
Project Directorate I-3
Division of Reactor Projects I/II

References:
(a) License No. DPR-28 (Docket No. 50-271)
(b) Letter, VYNPC to USNRC, FVY 86-36, dated May 5, 1986
(c) Letter, VYNPC to USNRC, FVY 86-49, dated June 2, 1986
(d) Letter, USNRC to VYNPC, NVY 86-113, dated June 16, 1986
(e) Letter, VYNPC to USNRC, FVY 87-07, dated January 12, 1987
(f) Letter, VYNPC to USNRC, FVY 87-50, dated May 7, 1987
(g) Letter, USNRC to VYNPC, NVY 87-81, dated May 28, 1987

Subject: 1987 Outage Core Spray Safe-End Weld Overlay Inspection Results

Dear Sir:

By letter dated May 28, 1987 [Reference (g)], the Nuclear Regulatory Commission (NRC) approved Vermont Yankee's plans to inspect the two overlay repaired core spray safe-ends instead of replacing them during the 1987 refueling outage. That letter also requested Vermont Yankee to provide the results of the inspection no later than three weeks after plant startup following the 1987 refueling outage. In accordance with that request, Vermont Yankee herein provides the 1987 refueling outage liquid penetrant and ultrasonic examination results of the Vermont Yankee Core Spray System safe-end to reactor vessel nozzle weld overlay repair welds. These examinations showed the weld overlays and the underlying nozzle, weld, and safe-end material to be free from new or propagating defects. The examination results are discussed below.

The liquid penetrant examination was conducted prior to ultrasonic examination. The solvent removable red dye technique was used to examine the weld overlay surface, the overlay end tapers, and the safe-end and nozzle base material immediately adjacent to the overlay. Examination parameters were consistent with ASME, Section XI, and Yankee Atomic Electric Company (YAEC) Procedure YA-PE-2. The examination was conducted by Level III personnel

qualified in accordance with SNT-TC-1A. Independent substantiating interpretation was conducted by a second Level III. Minor nonrelevant indications were noted between weld beads in the as-welded end tapers. These indications initiated the secondary substantiating interpretation and were determined not relevant to this examination, nor were they located so as to mask potentially relevant indications.

Ultrasonic examination to detect possible flaws was conducted using two Level II and one Level III examiner qualified at the EPRI NDE Center to examine weld overlay repairs. An additional Level III examiner qualified in accordance with the EPRI NDE Center program for sizing of planar flaws was also on staff to serve as technical reviewer and to aid in measuring indications if found.

Examination techniques were based upon the EPRI weld overlay inspection methodology with modifications and additions empirically demonstrated on the Vermont Yankee weld overlay mockup. The EPRI overlay ISI methodology relies on detection of crack faces utilizing 60° or 70° refracted longitudinal waves incident at, or nearly perpendicular to, an oriented, propagating crack face. Transducer size selection is a function of long-range overlay roughness. Transducer focal length is based on empirical calibration demonstration.

The program implemented at Vermont Yankee was significantly more in depth than the EPRI methodology, even though Vermont Yankee has determined the inspection of Inconel weld overlays to be somewhat less difficult than stainless steel overlays. Enhanced surface preparation requirements at installation allowed Vermont Yankee more latitude in transducer selection. Transducer size and focal length were selected based upon the parameters believed necessary for proper examination. Each transducer was then demonstrated capable of detecting diffracted signals within its focal range. Particular attention was paid to the WOL-base metal interface. By application of 70° (with accompanying OD creeping wave), 60°, and 45°F transducers nominally focused at 1.5", 1.7", and 1.9" of metal path, respectively, angle beam scans were conducted looking for both axial and circumferential flaws. In addition, a 0° (straight beam) interrogation of the entire volume was made to detect any developing indications as might be experienced at the weld overlay interface.

Based on the results of these examinations, wherein neither relevant liquid penetrant indications nor ultrasonic indications were found, Vermont Yankee concluded that acceptable overlay service had been demonstrated for this fuel cycle and that replacement of the core spray safe-ends during the 1987 outage was not warranted. We are currently updating our weld overlay documentation to incorporate the results of this inspection and the relevance of the BWR nozzle cracking detected in a foreign reactor. Upon completion of this effort, we will notify you of our evaluation results and future plans with regard to replacement of the safe-ends.

We trust that this information is acceptable; however, Vermont Yankee is available to meet with you to present additional information regarding the 1987 refueling outage inspection methodology and results at your convenience.

Very truly yours,

VERMONT YANKEE NUCLEAR POWER CORPORATION

R. W. Capstick

R. W. Capstick
Licensing Engineer

RWC/25.193

F. Development and Application of Weld Overlays

The EPRI/Utility BWR Owners Group for IGSCC Research was formed in 1977 to address the causes and cures for intergranular stress corrosion cracking in BWR piping systems. In 1985 EPRI and Georgia Power Company recognized that one potential area for IGSCC did not have a suitable mitigation approach other than replacement. This was the nozzle to safe end weld on the reactor pressure vessel.

In order to address this shortcoming EPRI, Georgia Power and Structural Integrity Associates initiated a research effort to develop a weld overlay repair process that would not require a post weld heat treatment.

EPRI had previously demonstrated that machine gas tungsten arc welding (GTAW) was superior to the Code-approved shielded metal arc (SMAW) half bead process[F1]. This new process was approved in ASME Code Case N-432[F2].

The research strategy was to apply the existing EPRI approach to a low alloy steel nozzle as a weld overlay, instead of a cavity repair. The details of the development program will be reported in an EPRI report scheduled for publication in 1988. The principal outcome of the project was demonstration that a weld overlay could be applied to a low alloy steel nozzle with adequate material tempering without post weld heat treatment. The researchers demonstrated that result on the same plate used in the earlier project identical tempering results were achieved.

When potential IGSCC was detected in the Vermont Yankee core spray nozzle to safe end welds a decision was made to apply weld overlays.

Plant specific development was performed at Vermont Yankee, first on carbon steel pipe and then on a fabricated mockup using SA 508 and Inconel 600. The purpose of the development program was to select equipment specific welding parameters and then verify that those parameters achieved the proper degree of tempering in the SA 508 material.

The overlay was designed to be applied in two portions. The first portion was the butter/temper layers. The purpose of this portion was to 1) achieve proper tempering of the base metal, 2) accommodate the dilution resulting from applying Inconel 82 on SA 508 and 3) provide the Code required "butter" to allow subsequent welding to be performed without post weld heat treatment.

The development program showed that a three layer butter/temper region of at least 0.125 inch thickness achieved all three goals.

Figure F-1 shows a plot of hardness in the low alloy steel after one and three layers of weld metal were applied. As can be seen, the third layer achieved a hardness reduction below the target value of Rockwell C35.

Figure F-2 shows the weld layer chemistry after one, two and three layers. The third layer has achieved a chemistry very close to Inconel 82, ensuring that subsequent layers will be undiluted Inconel 82.

Finally, the 0.125 inch thickness satisfies ASME Code requirements for welding on cladding[F3].

The second portion of the overlay is the actual structural overlay. The rules of ASME Section XI[F4] were used to design the overlay. The input loads were taken from the reactor vessel design report[F5].

Since the overlays were being applied at the end of the recirculation system replacement outage it was desired to have a minimum impact on the critical path. To support this need a study was performed to determine if the effect of applying the structural portion of the overlay without water in the nozzle (the butter/temper portion must be applied dry to ensure proper pre- and post heat). As can be seen from Figure F-3 the temperature pattern, and thus the residual stress pattern, in the nozzle under the overlay is the same with or without water inside the nozzle. For this reason the overlay was allowed to be applied wet or dry. (In actuality, plant conditions were such that the overlays were applied with the core spray nozzles flooded.)

In summary, it is Vermont Yankee's conclusion that a satisfactory weld overlay can be applied to a low alloy steel nozzle providing the following conditions are satisfied:

1. develop and qualify equipment and vendor specific welding procedures,
2. apply a three layer (minimum) butter/temper layer at least 0.125 inches thick, using the pre- and post heat requirements of ASME Code Case N-432,
3. apply a full structural overlay, designed in accordance with ASME Section XI, wet or dry,
4. observe the Code requirements for overlay length,
5. ensure a proper surface finish to allow ultrasonic examination, following the EPRI inspection guidelines.

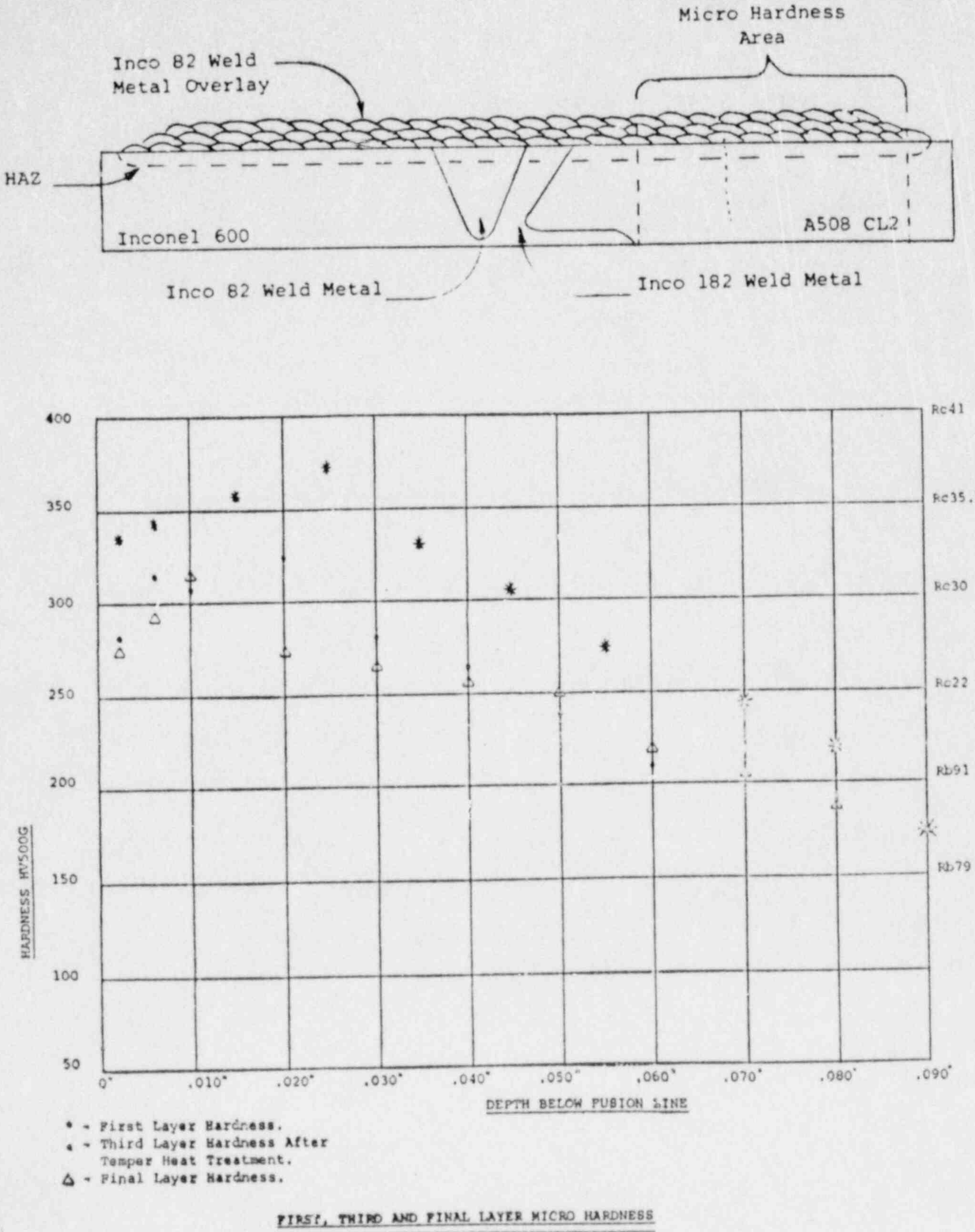
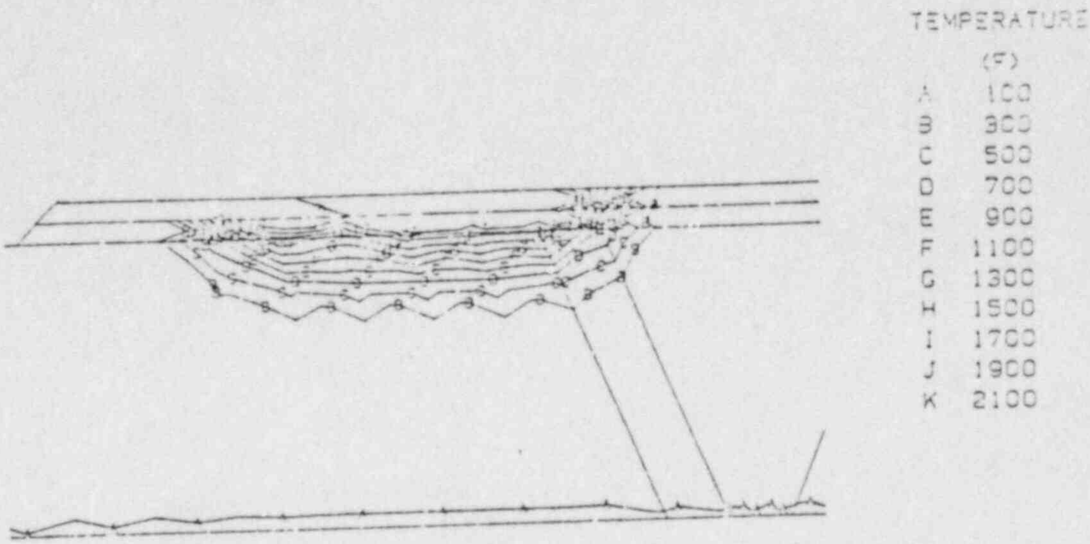


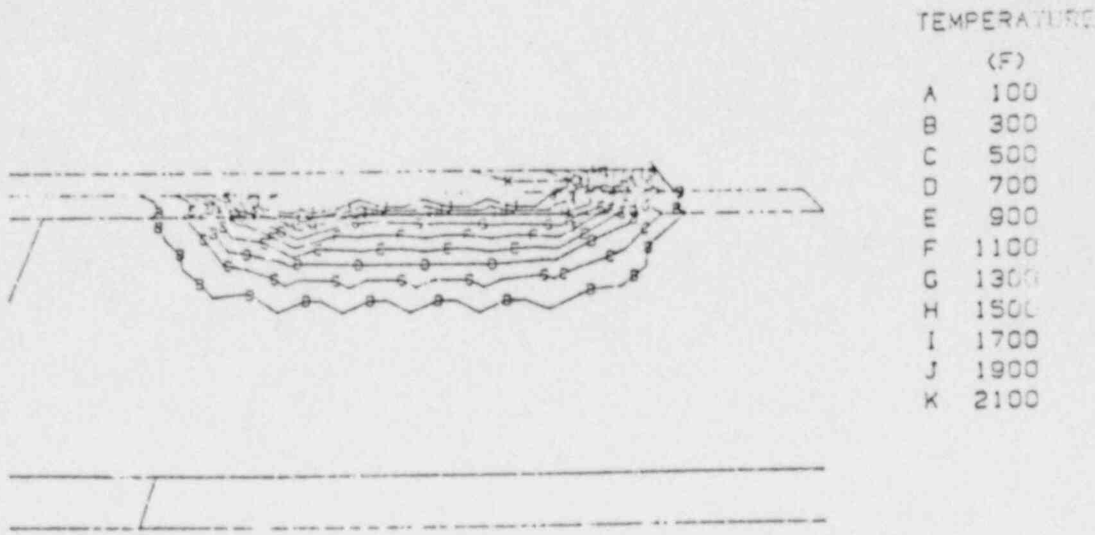
Fig. F-1: Base Metal Hardness Profiles After Overlay Welding

% XRF	SAMPLE A 1ST LAYER	SAMPLE C 2ND LAYER	SAMPLE C 3RD LAYER
FE	50.16	19.04	7.37
AL	.115	.220	.169
P	.010	.004	.004
SI	.144	.108	.130
TI	.147	.243	.274
CU	.070	.047	.040
MN	2.03	3.03	3.34
NI	35.70	57.86	66.61
CR	10.16	16.91	19.30
MO	.011	.029	.028
TA	.021	.007	<.002
NB	1.38	2.45	2.69

Fig. F-2: Weld Layer Chemistry - SA 508 Base Metal and Inconel 82 Weld Metal



Temperature Distribution During the Application of Second Weld Overlay Layer with Cooling Water Inside



Temperature Distribution During the Application of Second Weld Overlay Layer with No Cooling Water Inside

Fig. F-3: Thermal Profiles Under Overlay With and Without Water at ID Surface

References

F1. EPRI Report NP-3614, "Repair Welding of Heavy Section Steel Components in LWRs", July, 1984.

F2. ASME Code Case N-432, "Repair Welding Using Automatic or Machine Gas-Tungsten Arc Welding (GTAW) Temperbead Technique, Section XI, Division 1, February 20, 1986.

F3. ASME Boiler and Pressure Vessel Code, Section XI, Subsection IWB-3641, 1983 Edition thru Summer 1985 Addenda.

F4. Chicago Bridge and Iron Stress Report 9-6202-1, Section I-S-7, August 1969.