ENCLOSURE 1

Hatch Unit 1 Recirculation, RHR, and
RWCU Weld Joint Inspection Program -
1984 Maintenance/Refueling Outage

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1.0 REVIEW OF HATCH UNIT 1 STATUS AS OF LAST REFUELING OUTAGE (FALL 1982)

1.1 Inspections Performed

During the Fall 1982 maintenance/refueling outage, nineteen (19) circumferential and branch connection welds in the recirculation system were ultrasonically examined by Southern Company Services (SCS), its contractor, Lambert-MacGill-Thomas, Inc. (LMT), and Southwest Research Institute (SwRI) personnel. As a result of observing crack-like indications in the original scope of examinations, additional welds in the subject system were examined pursuant to ASME Section XI Code requirements. Ultimately, a total of fifty-one (51) circumferential and branch connection welds were examined to the requirements of NRC I&E Bulletin 82-03, Rev. 1. In addition, eleven (11) welds in the RHR system and six (6) welds in the RWCU system were examined. The welds examined were picked on the basis of ASME Section XI Code, NUREG-0313, Rev. 1 guidance (high stress welds with Sm $\geq$ 2.4), commitments to NRC resulting from the Spring 1982 chloride intrusion, high stress rule index numbers, and/or high carbon content.

Procedures utilized during the examinations were provided by SCS and SwRI. While LMT personnel performed examinations, they were under contract to SCS and were subsequently tested to and used the SCS procedure. The following is a summary description of procedures and techniques used during the examination of the recirculation, RHR, and RWCU piping at Hatch Unit 1.

A. Procedures

The procedures required a 3/8" diameter, 1.5 MHz 45° angle beam transducer to be used during the ultrasonic examination of the subject austenitic stainless steel piping.

B. Calibration Standards

Stainless steel curved calibration blocks incorporating 1/8" or 3/16" diameter side drilled holes at 1/4T, 1/2T, and 3/4T depths were utilized.

C. Scanning Sensitivity

For manual ultrasonic (UT) examinations, scanning was performed at 14dB above the Primary Reference Level. However, upon concurrence of a NDE Level III, this level could be reduced if baseline screen noise hindered the interpretation of the UT scope CRT. This scanning level was always at least 6dB above the Primary Reference Level. For mechanized examinations, scanning was performed at 6dB above the Primary Reference Level.

D. Recording Criteria

All indications which produced a response greater than 20% of the Distance Amplitude Curve (Primary Reference Level) which were not determined to be caused by outside diameter geometry were recorded. In addition, the examiners were instructed that any indication interpreted to be significant should be recorded.

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Pursuant to the requirements of NRC I&E Bulletin 82-03, Rev. 1, SCS and SwRI personnel ultrasonically examined at Battelle-Columbus Laboratories (BCL) five Nine Mile Point recirculation system piping weld specimens containing intergranular stress corrosion cracking (IGSCC) indications. The purpose of the examinations was to evaluate crack detection capabilities of UT procedures and techniques of the various utilities and/or examination agencies. SCS and SwRI examination personnel demonstrated to the satisfaction of the NRC inspectors in attendance at the qualification their ability to adequately detect and evaluate IGSCC. As noted above, LMT personnel were tested to and utilized the SCS procedures qualified at BCL for examination at Plant Hatch. All final reviews were performed by BCL-qualified Level IIIs. These examinations at BCL and the UT examination procedures and techniques were representative of examinations that were performed at Hatch Unit 1. While the SwRI remotely operated mechanized UT equipment procedures and techniques were not demonstrated at BCL, review of their procedures and techniques by SCS personnel indicated they were adequate in the detection of IGSCC.

1.2 Inspection Results and Actions Taken

1.2.1 End Cap-to-Manifold Welds

Ultrasonic examination results indicated IGSCC in the vicinity of four end cap-to-manifold welds:

1) 1B31-1RC-22AM-1 with a maximum depth of 63% of wall
2) 1B31-1RC-22AM-4 with a maximum depth of 72% of wall
3) 1B31-1RC-22BM-1 with a maximum depth of 64% of wall
4) 1B31-1RC-22BM-4 with a maximum depth of 67% of wall

All of the indications were axial and all had lengths of approximately 1/2".

These four welds were repaired using structural weld overlays. The design overlay thickness was 0.25". The actual minimum thickness of the completed overlays was 0.275". The overlays were required to extend a minimum of 3.0" from the original joint on the pipe side of the repair and a minimum of 3.5" on the end cap side of the repair.

One of the end cap-to-manifold welds was later found to have a through-wall crack as evidenced by leakage observed during the weld overlay application.

Porosity was observed during overlay welding of the welds 22AM-4, 22BM-1, and 22BM-4. The regions with porosity were later repaired by grinding to the base metal and then filling the cavities with shielding metal arc welding.

1.2.2 Elbow-to-Pipe Welds

Ultrasonic examination results indicated IGSCC in elbow-to-pipe weld 1E11-1RHR-20BD-3. Five axially oriented flaws and two circumferentially oriented flaws were indicated. The deepest axial flaw had an indicated depth of 94% of wall. The axial length of this flaw was approximately 3/8". The circumferentially oriented flaws were each approximately 1 1/2" length with a maximum depth of 33% of wall.

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A structural weld overlay was applied to this weld. The overlay had design thickness of 0.4" and was required to extend to either side of the original joint by at least 3.5".

1.2.3 Pipe-to-Pipe Weld

Pipe-to-pipe weld 1E11-1RHR-24B-R-13 was indicated by UT inspection to have an axially oriented flaw with a depth of 47% of wall and a length of 1/2".

This weld was selected for a structural overlay weld repair with the overlay design thickness being 0.3". The overlay was required to extend a minimum of 4.0" to either side of the original pipe joint.

1.2.4 Sweepolet-to-Manifold Weld

Sweepolet-to-manifold weld 1B31-1RC-22AM-1BC-1 was found to have seven ultrasonic indications suspected to be IGSCC. The indications were small flaws and all were transverse to the weld (similar to an axial flaw in a piping girth weld). The largest flaw was determined to be approximately 12% of the wall in depth and approximately 1/2" long.

This weld was not repaired since analysis showed that the weld would continue to meet all code requirements for at least five more years of operation.

1.3 Inspection Adequacy

While the examination of the Hatch Unit 1 austenitic stainless steel piping welds was not performed to the more stringent examination requirements of the later-issued NRC I&E Bulletin 83-02, the examinations conducted were adequate and met the intent of the aforementioned bulletin. The following table summarizes the NRC I&E Bulletin 83-02 examination requirements versus the examinations performed during the Hatch Unit 1 Fall 1982 maintenance/refueling outage.

NRC I&E Bulletin 83-02 Examination Requirements	Hatch Unit 1 Fall 1982 Examinations
Minimum of 10 welds $\geq$ 20" diameter	26 welds $\geq$ 20" diameter examined in recirculation and RHR systems
Minimum of 10 welds in 12" risers and safe ends	23 recirculation riser piping welds (including safe ends) examined
Minimum of 2 sweepolet-to-manifold welds	8 recirculation sweepolet-to-manifold welds examined
Increase scope of examinations pursuant to ASME Code Section XI, IWB-2430	As a result of observing crack-like indications in the original scope of

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NRC I&E Bulletin 83-02 Examination Requirements	Hatch Unit 1 Fall 1982 Examinations
if crack-like indications observed	examinations, the scope was expanded pursuant to ASME Code, Section XI, IWB-2430

In addition to the quantity and size/type of welds examined, similar personnel, procedures, techniques, and equipment as that used during the Hatch Unit 1 examinations were later used in the successful detection and interpretation of IGSCC during the I&E Bulletin 83-02-required examinations at Hatch Unit 2. Therefore, it can be reasonably concluded that the Hatch Unit 1 examinations were adequate and met the intent of NRC I&E Bulletin 83-02.

2.0 CURRENT OUTAGE INSPECTION PLANS

2.1 Proposed Inspection Scope

Georgia Power Company intends to include thirty-seven (37) welds of the recirculation, RHR, and RWCU systems in the initial sample selected for examination during the 1984 maintenance/refueling outage at Hatch Unit 1. The sample size has been determined based upon the following table.

Condition	Available Population	Percent in Initial Sample	Number of Resultant Examinations
Overlays of repaired welds with IGSCC	6	100	6
Unrepaired welds with suspected IGSCC	1	100	1
Previously inspected welds (in recirculation, RHR, and RWCU systems) with no indications of IGSCC	60	20	15
Previously uninspected (in recirculation, RHR, and RWCU systems)	71	20	15
		TOTAL	37

Further distribution of the sample set will include assurance that the different pipe sizes are represented in the sample.

The welds proposed to be examined will be chosen based on crack experience, where available. Where such information is not available, high stress rule index number and/or high carbon content will be used for selecting the welds to be examined.

If additional IGSCC is detected in the samples representing the welds not previously inspected or the previously inspected welds not found to contain IGSCC, the sample size will be increased in accordance with ASME Section XI, IWB-2430 as defined in NRC I&E Bulletin 83-02.

The proposed inspection of thirty seven welds in the recirculation, RHR, and RWCU systems meets the intent of proposed examination criteria in the following documents:

- Hatch Unit 1 Safety Evaluation Report (dated February 11, 1983),
- NRC I&E Bulletin 83-02,
- NRC letter SECY-83-267C, and
- NRC Generic Letter 84-11.

2.2 Inspection Procedure and Personnel Qualification

The stainless steel weld examinations to be performed during the 1984 maintenance/refueling outage will be conducted using a SCS procedure similar to those discussed above which were previously qualified at BCL. Since the inspection of welds in 1982, the procedure has been revised slightly and was successful in the detection of IGSCC at Hatch Unit 2 during its 1983 outage. Changes made to the procedure were editorial in nature. The latest approved revision of the procedure technically meets or exceeds the originally BCL-qualified procedure, e.g., calibration requirements, recording requirements, etc.

With regard to personnel qualification, all examination personnel will be qualified to basic levels I, II, and III of American Society for Nondestructive Testing document SNT-TC-1A as applicable. Additionally, all examination personnel will be demonstrated to be qualified to a level of competence commensurate with their functions. Examiners involved in equipment setup or scanning operations will be trained and demonstrated proficient to assure both their technical ability and their ability to perform activities consistent with the principles of keeping radiation exposure as low as reasonably achievable (ALARA).

The process of qualification of all personnel who will perform evaluations will be that process presently in effect at the EPRI NDE Center. Currently, there are five (5) Levels II and III SCS personnel who have qualified at that facility by practical demonstration. NDE personnel under contract to SCS who have qualified at the EPRI NDE Center in the detection and interpretation of IGSCC may also perform examinations and evaluations, as appropriate.

2.3 Inspection of Overlays

The existing weld overlays in the inspection program as well as any necessary new overlays, will be ultrasonically examined to verify the integrity of both the weld metal and its bond to the pipe base material, in a manner consistent with ASME Code, Section V, Paragraph T550. In addition, a liquid penetrant examination will be conducted on the weld overlay and 1" of base material on either side of the weld overlay.

2.4 Criteria for Flaw Evaluation and Weld Overlay Repair

Flaw evaluation and weld overlay repair, if required, will be performed to criteria consistent with those specified in Attachment 2 of NRC Generic Letter 84-11 dated April 19, 1984.

Should any new unacceptable, crack-like indications or any significant growth of old IGSCC cracks be observed during the inspection, information concerning the following will be submitted to NRC for its review and approval:

- Flaw evaluations, and re-evaluation, and
- Weld overlay design and analyses techniques, if required.

2.5 Leak Detection and Leakage Limits for Next Fuel Cycle

By letters dated February 10 and 11, 1983, Georgia Power Company proposed Technical Specification changes to augment then existing reactor coolant leakage detection requirements. NRC reviewed and approved the Technical Specification changes as discussed in the Hatch Unit 1 Safety Evaluation Report dated February 11, 1983. The changes meet the intent of the leak detection and leakage limits discussed in Attachment 1 of NRC Generic Letter 84-11.

On unrepaired sweepolet-to-manifold weld 1B31-1RC-22AM-1BC-1, two local acoustic emission devices were installed to monitor for any potential leakage from that particular weld. Acoustic emission devices are very sensitive and capable of detecting very tiny steam leaks. In the unlikely event of a through-wall crack, these devices will provide an early warning to operations personnel to initiate appropriate correction action.

In addition to the above actions, a visual examination for leakage of the reactor coolant piping will be performed during each plant outage in which the containment is deinerted. The examination will be performed consistent with the requirements of IWA-5241 and IWA-5242 of the 1980 Edition of the ASME Section XI Code. The system boundary subject to this examination will be in accordance with IWA-5221. This examination is consistent with that identified in Attachment 1 of NRC Generic Letter 84-11.

3.0 JUSTIFICATION FOR CONTINUED OPERATION WITH EXISTING WELD OVERLAYS

3.1 Current Overlay Design Details

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3.1.1 Overlay Design Approach

The design approach used at Hatch Unit 1 resulted in repaired welds which meet or exceed the margins of safety which are inherent in the ASME Section III Design Rules (Reference 2). Also, since the repairs involved leaving known flaws in the welds, the design approach also reflected the requirements of ASME Section XI, Article IWB-3640 (Reference 3). All overlays were required to have a design life in excess of five years.

Structural load capacity of the overlay weld repairs with respect to internal pressure and applied mechanical loads was demonstrated via an ASME Boiler and Pressure Vessel Code Section III, Class 1 analysis. The design pressure of 1325 psi was obtained from Reference 4. The dead weight and seismic loads were obtained from Reference 5.

The designs also comply with the secondary stress and fatigue limits of ASME Section III. The thermal expansion loads were obtained from Reference 5 and were conservatively combined into three composite transients. The first is a startup/shutdown transient with a heatup/cooldown rate of 100^{o}F/hour. The second composite transient consists of a 50^{o}F step temperature change and the third is an emergency event with a 416^{o}F step temperature change. Fatigue resistance for the five-year design life of the repairs was evaluated by combining the stresses from the above strength evaluation with the thermal and other secondary stresses and performing a conventional fatigue analysis per Reference 2. A fatigue strength reduction factor of 5 was applied to account for the existing cracks. The fatigue usage factor was conservatively calculated assuming 38 startups, 25 small temperature change cycles and 1 emergency cycle within the design life of 5 years, and was found to be negligible for all overlays.

Crack growth due to both fatigue and IGSCC was determined using Linear Elastic Fracture Mechanics crack growth analysis techniques. The beneficial effect of overlay weld induced residual stresses was incorporated into these calculations. An allowable crack length and depth was established for each repair based on the net section collapse criteria of Reference 3. Crack growth due to fatigue during the 5-year design life was calculated to be less than 0.01" for all of the repaired flaws and for the unrepaired sweepolet.

IGSCC crack growth was calculated using a conservative, empirically based crack growth law. The calculated crack lengths and depths were compared to the previously established allowable (based on the net section collapse criteria of Reference 3) and determined to be acceptable.

3.1.2 Overlay Design Perspective

A total of six joints were repaired using weld overlays. Five of these six contained only axially oriented flaws. Since these flaws are due to IGSCC and thus depend on the presence of sensitized material for continued growth, their growth in the axial direction is restricted to the weld heat affected zone. This means that axial flaws cannot grow axially and thus will never present a significant pipe break threat.

The overlay welds consist of 308L weld metal with controlled ferrite which has been demonstrated to be highly resistant to IGSCC. With this barrier to continued IGSCC at the outer pipe surface and the resistant 304 SS base metal limiting the axial growth, the axial flaws are effectively contained.

The only indicated circumferential flaws were relatively short (1.5" each) with the deepest having a maximum depth of 33% of the unrepaired wall. With the beneficial effect of the overlay weld induced residual stresses, calculations predict that these circumferential cracks will have essentially no growth during the five-year design life. However, even if these calculations or the 33% through wall sizing are significantly in error, the overlay for this joint is substantially overdesigned and would accommodate much longer, deeper circumferential flaws with no loss in safety margin. (IWB-3640 calculations for weld 1E11-1RHR-20-BD-3 indicate the acceptable circumferential flaw size for the overlaid weld to be a through-the-original-pipe-wall flaw of length equal to 30% of the circumference, or 18.8 inches.)

3.2 Weld Overlay Residual Stress Data

A wide body of analytical and experimental overlay weld residual stress data exists and is continually growing. The analytical data are primarily from finite element calculations using the BCL-developed WELDS-II program. Experimental data consist of surface as well as through thickness stress measurements from such techniques as hole-drilling, chip removal and layer removal. All overlays for which data are presented below had water inside the pipe during the overlay application.

3.2.1 EPRI/J.A. Jones 24" Overlay Mock-Up

A 24" pipe with a 1.48" wall thickness was weld overlaid at the J. A. Jones Applied Research Company. The overlay consisted of 5 weld layers for a total thickness of approximately 0.35". The overlay process was simultaneously modeled by NUTECH Engineers, Inc. using the WELDS-II program (Reference 6). The results (both experimental and analytical) are shown in Figures 3.1 through 3.4. They demonstrate that the axial and hoop stresses were compressive at the inner surface and remained compressive for a depth of about 50% to 70% of the repaired wall thickness. The beneficial compressive hoop and axial stress was present after the first weld layer in much the same form as after all five layers which shows that a thick overlay was not necessary in order to establish inner surface compression.

3.2.2 NUTECH/Georgia Power Company 12" Weld Overlay Mock-Ups

Georgia Power Company, in conjunction with NUTECH Engineers (Reference 17) fabricated three weld overlay test specimens in conjunction with recent repair activities at Plant Hatch. A total of three specimens were fabricated, one each for a 0.20" overlay, a 0.23" overlay and a Last Pass Heat Sink Weld (LPHSW). The weld overlay lengths were 4". The weld overlays were applied to butt welds in short sections of 12-inch, Schedule 100, Type 304 stainless steel pipe using the same procedures, operators and equipment as were used for the in-plant repair work. The calculated axial residual stresses are shown in Figure 3.5 and the measured values (for a

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representative measurement location) are shown in Figure 3.6. Both the calculated and the measured results indicate that the inner half of the repaired section is in axial compression. The calculated residual stress magnitudes are, however, significantly smaller than the measured values.

3.2.3 Structural Integrity/TVA Sweepolet Overlay Design Report

Four sweepolets of the TVA Browns Ferry Unit 1 recirculation system were repaired with weld overlays during the July 1983 outage. An integral part of the design analysis (Reference 7) was the simulation of the weld overlay repair with the finite element program WELDS-II.

A sweepolet mock-up was welded by Welding Services, Inc. and used for both surface and through thickness residual stress measurements at J. A. Jones Applied Research Company. The unrepaired wall was approximately 1.125" thick and the overlay was 0.25" thick by 4.0" long.

Computed and measured transverse (to the weld) residual stresses are plotted in Figure 3.7 for a section at the top of the manifold and on the sweepolet side of the weld. The sweepolet mock-up had a free edge near to the overlay at this section and thus the model was exercised for two cases. The first case was for a sweepolet attached to a long section of manifold and the second case was for a sweepolet with a very short manifold (without hoop constraint). It is seen that the measurements are generally between the two calculated curves, and indicate compressive stresses on the inner portion of the pipe wall.

Computed and measured transverse residual stresses are plotted in Figure 3.8 for a section located at 90 degress to the section of Figure 3.7 (i.e., on the side of the manifold). Unfortunately, the measurements at this section contain considerable uncertainty due to the lack of strain data for the first two stress relaxation cuts. However, there is still qualitative agreement between the calculations and the measurements and both suggest that compressive stresses exist within the inner half wall thickness for this section as well.

3.2.4 Overlay Residual Stress Perspective

All of the above evidence indicates that the application of weld overlays (with water inside the pipe to act as a heat sink during welding) results in favorable residual stress patterns in terms of preventing IGSCC initiation and in terms of slowing or arresting the growth of any existing IGSCC. Results are available for a variety of pipe sizes and schedules and for a variety of special configurations including sweepolets, endcaps, and safe ends and all show favorable residual stress patterns.

3.3 Weld Overlay Materials Considerations

3.3.1 Weld Metal Resistance to IGSCC

Until recently, types 308 and 308L weld metals have generally been considered as immune to IGSCC. This review has been supported by the fact that no field leakage has ever been observed in any BWR welds due to cracks

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growing through the weld metal even though the residual stresses are generally higher in the weld than in the weld heat affected zone in which the cracking has generally been experienced.

Some experimental data is now becoming available which suggests that under some circumstances, 308 welds and to a lesser extent 308L welds may be susceptible to environmentally assisted crack propagation. The degree of susceptibility appears to correlate with the levels of ferrite and carbon in the weld metals as will be illustrated in several of the following examples.

General Electric Test Program

As part of the GE experimental study to evaluate the structural stability of large diameter pipes containing intergranular stress corrosion cracks, fracture mechanics (1T-WOL) specimens were fabricated from Type 304 SS plates welded using either Type 308 or Type 308L containing varying ferrite levels (Reference 8). The specimens were cycled in high temperature water and 6 ppm O_2 with an initial crack tip stress intensity factor range of 26 ksi (in)1/2 and an R of 0.05, where R is the ratio of minimum to maximum cyclic load. The specimens were tested for 5448 hours.

It was found that intergranular stress corrosion cracks which had initiated in the base metal had grown into the weld metal in six of the seven specimens. For the 308L weld metal specimens, all of the weld metal cracks arrested within .031 inches of the point of entry into the weld metal. (Branches of the cracks in the base metal continued to grow). These 308L welds contained from 5.5 to 11.5% ferrite and 0.025 wt% carbon.

Two of the 308 weld specimens had ferrite levels of less than 9%. For the specimen with the lowest ferrite (1.9 - 3.3%) the crack arrested after growing 0.104 inches into the weld. For the specimen with ferrite in the range of 7.0 to 8.5% the crack grew to 0.101 inches into the weld and showed no signs of arresting.

The single 308 weld specimen with ferrite greater than 9% (9.5 - 11.5%) had the crack grow .045 inches into the weld and then arrest. The carbon level for all the 308 weld metal was 0.053 wt%.

Weld Metal Cracking in Inverse IHSI Sample

Several 12 inch pipe samples of 304 SS were fabricated by Ishikawajima Harima Heavy Industries using girth welds which were induction heated so as to produce IGSCC when exposed to high purity, oxygenated, 550°F water (Reference 9). One of these samples developed an intergranular stress corrosion crack which grew into the weld several millimeters before arresting. The weld was examined metallurgically to determine the level of sensitization and the ferrite content. The weld metal, which was 308 was found to be highly sensitized, due probably to a 500°C/24 hour sensitization treatment. The crack entered the weld metal at a point with approximately 5% ferrite and appeared to arrest at a point with approximately 9% ferrite.

Constant Extension Rate Tests (CERTs)

Test results from CERTs (References 10 and 11) for low carbon Types 308 and 308L are shown in Table 3.1. The CERT is similar to a tensile tests, performed at slow strain rates (constant extension rate) in an aggressive environment (550°F, 8 ppm oxygen water) to force fracture. The fracture is then examined for IGSCC characteristics. No indications of IGSCC were found for the Types 308 and 308L specimens, even for the cases where the weld metal was given a severe furnace sensitizing treatment.

Constant Load Tests

Constant load tensile test results at 550°F in 0.2 to 100 ppm oxygen content water for 308 and 308L are given in Reference 12. Loads are as high as 125% of the yield strength at 550°F. Results include as-deposited and furnace sensitized conditions. No failures resulted for 308L specimens regardless of ferrite content and no failures resulted for Type 308 specimens with ferrite levels greater than 8%. Other constant load tests are reported in Reference 12 for 308L in chloride environments. Type 308L weld overlays on Type 304 stainless steel were tested at 125% of the 75°F yield strength in an aqueous environment of 100 ppm Cl- at 200°F. No cracking or attack was found after test times of 178 and 138 hr., even for a specimen given a sensitizing treatment of 10 hr. at 1150°F.

Ferrite Effect on 308 and 308L Sensitivity to IGSCC

A laboratory study investigating the interaction effects among carbon level, ferrite level and ferrite distribution on the IGSCC susceptibility and sensitization immunity to Types 308 and 308L weld metal is described in Reference 13. It was observed that although chromium carbide precipitation occurs intergranularly during heat treatment (at sensitization temperatures) of Types 308 and 308L weld metal, the precipitation occurs solely along the austenitic ferrite grain boundaries. Since the ferrite is rich in chromium, and the diffusion of chromium in ferrite is faster than in austenite by approximately a factor of 1000, the chromium for this precipitation is supplied principally from the ferrite phase. The modest chromium depletion in the austenite is replenished in time by diffusion of chromium from within the austenite grain. After this "healing", the material is thought to be immune to IGSCC.

The model developed in Reference 13 predicts the required amount and distribution of ferrite for the above described immunization as a function of the carbon content. For as-deposited Type 308L SS containing 0.03wt% carbon, the model suggests that approximately 3% ferrite is required for immunity to IGSCC; whereas for Type 308L containing 0.015wt% carbon, essentially no ferrite is required for immunity to IGSCC.

It is seen from the above data that the 308L weld metal specified for the Hatch Unit 1 overlay repairs has been subjected to many severe tests. The results of these tests have either been that no IGSCC occurred in the weld

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metal or that IGSCC (which initiated in the base metal and propagated into the weld) arrested within a short distance from the cracks entry into the weld metal.

The above data indicates that 308 weld metal is more susceptible to IGSCC than 308L and that ferrite levels in excess of 8-9% may be required for 308 to have IGSCC immunity comparable to 308L. Since many of the welds in existing piping systems are 308 with ferrite levels significantly below 9% and since no leaks have resulted from IGSCC in these welds, this suggests that the Hatch Unit 1 overlays, made with 308L weld metal and greater than 8% ferrite possess a high degree of confidence in their ability to arrest any IGSCC.

3.3.2 Weld Metal Fracture Toughness

The overlay design report for Hatch Unit 1 (Reference 1) includes analyses to determine the failure loads for the repaired sections using a tearing modulus approach. These analyses involved calculating the fracture mechanics parameter J as a function of axial crack length for the geometry of interest and for a number of load levels using elastic-plastic constitutive relations. With this information it is then possible to construct a curve of J versus T (the material tearing modulus as defined in Reference 14) in which each point on the curve represents a different level of applied load (increasing loads correspond to increasing values of J). The straight lines in Figure 3.9 which intersect at the origin are applied J/T curves for the weld repairs at Hatch Unit 1 taken from Reference 1.

The failure load for a given crack configuration is determined by the intersection of the appropriate applied J versus T (J/T) curve with a material J/T curve. Material J/T curves are plotted in Figure 3.9 for a variety of stainless steels (Reference 15). Base metals as well as weld metals are included. The material curve of Reference 16 which was used in the Hatch Unit 1 overlay design report (Reference 1) is also included.

It is seen from Figure 3.9 that the material J/T curves represent a wide range of material toughnesses. The materials with curves closest to the origin are the least tough and these curves are generally curves for weld metals rather than base metals. It is clear that some of these welds metals have been found to be less tough than the base material curve of Reference 18.

The least tough materials in Figure 3.9 are the CF8A welds tested by Gudas and the submerged arc welds on 304 SS base metal tested by Westinghouse. While more toughness testing of welds is needed to clarify this weld metal toughness issue, the data of Figure 3.9 seems to indicate that the submerged arc weld process results in less tough welds than the GTAW/TIG welding process used in the Hatch Unit 1 overlay repairs

If one considers only the weld data of Figure 3.9 for 308L and TIG or GTAW welding processes, and extrapolates the lowest toughness curve as indicated in Figure 3.9 one obviously get factors of safety which are smaller than were reported in the Hatch Unit 1 design report using the curve from

Reference 16. However, the decrease in these factors is not as large as one might expect due to the very nonlinear relationship between applied load and J. For example, the text of Reference 1 states that the factors of safety for the end cap overlay designs (as given by the J/T analysis) are in excess of 4. This is still true if the extrapolated 308L/GTAW material toughness curve of Figure 3.9 is used. Similarly, the factor of safety for the unrepaired sweepolet was stated as being greater than 3.3 and is still greater than 3.3 with the lower material curve.

The factor of safety for the pipe-to-pipe overlay design was greater than 4 with the material data of Reference 16 and is slightly less than 4 for the lower material toughness curve of Figure 3.9. Of all the J/T analyses reported in Reference 1, the elbow-to-pipe overlay design had the smallest calculated factor of safety of about 3. With the lower toughness curve, this is reduced to a factor of safety slightly greater than 2.5. Becaus these are axial flaws which must grow through the much tougher 304 base metal before posing a serious threat to the integrity of the pipe, and because of the conservatism of the postulated 0.8" semicircular flaw used in the J/T analysis, this factor of safety is considered adequate.

3.4 Weld Overlay Inspectability

One concern which has been raised regarding long-term operability of BWR pipe welds with weld overlay repairs is the relative difficulty of conducting confirmatory, non-destructive examinations on such welds. Conventional ultrasonic inspection techniques have had only limited success at inspecting through weld overlays to identify and size the underlying IGSCC in the original pipe joint.

In discussing this concern relative to Hatch Unit 1, however, it is important to note that the Hatch Unit 1 overlay designs, being full structural overlays, applied for the most part to axial cracks, do not require inspection of the material underneath the overlay for assurance of structural integrity. The only requirement is to demonstrate that the cracks have not grown into the weld overlay material itself. A very careful, ultrasonic baseline examination of the Hatch Unit 1 overlays was conducted following their application, and subsequent examination during the upcoming refueling outage will be conducted using similar procedures and equipment and equally qualified personnel. Such an examination is expected to produce a highly reliable inspection for any crack growth or other service induced degradation of the weld overlay itself.

With respect to inspection under the weld overlay, recent work at the EPRI NDE Center has demonstrated considerable success with the use of refracted longitudinal ultrasonic waves, rather than the more usually applied shear wave propagation mode (Reference 17). The results obtained to date demonstrate the ability to verify overlay integrity and measure crack length. Additional work is underway to define crack depth sizing ability with this approach.

With respect to crack length measurement, the work at the EPRI NDE Center has demonstrated that, if the overlay has suitable surface finish, and if

the crack is detectable, then the techniques for length measurement (with refracted L-waves) are i ical to the case where there is no overlay. The preliminary data show that e .ors in length measurement are on the order of the probe dimension, and that the length estimates are quite repeatable.

Since there were only two circumferentially oriented indications in Hatch Unit 1 at the last inspection (Weld 1E11-1RHR-20-BD-3) and these indications were quite short (1.5 inches each), the length measurement procedure described above should be more than adequate to ensure the continued integrity of this weld. As noted above, the overlay design on Weld 1E11-1RHR-20-BD-3 can accommodate a considerable increase in length, assuming a full through-wall crack depth, before violating IWB-3640. Also, as described above, there is no significant possibility of length crack growth on the axially oriented indications since they would very rapidly run out of sensitized heat affected zone into a material which is not susceptible to IGSCC in BWR environments.

3.5 On-going Programs

In addition to the data cited above, EPRI, the Nuclear Regulatory Commission and the nuclear power industry are supporting a wide range of programs to further qualify the weld overlay as a long term repair. Included among these are a pipe test program and destructive examination of several weld overlaid joints removed from service. These programs, described in more detail below, will provide additional data to support continued operation of the Hatch Unit 1 weld overlays in a time frame consistent with the planned startup of the plant following the upcoming refueling outage.

3.5.1 General Electric Pipe Test Laboratory Overlay Test Plans

EPRI is sponsoring a series of pipe tests in which the beneficial effect of overlay induced residual stresses on crack growth will be quantified experimentally (Reference 18). The first objective is to produce data to further support the use of overlay repairs for two fuel cycles (36 months). This first objective will be met by the end of July 1984. The second objective is to define the effective life of remedies applied to IGSCC cracked pipe, including weld overlay, induction heating stress improvement (IHSI) and last pass heat sink welding (LPHSW). The program will end in December 1985.

The main thrust of this program will be the performance of pipe tests in the GE Pipe Test Laboratory (PTL). A total of approximately 70 weldments will be tested under varying loads in a simulated BWR environment. The testing is similar to that used to statistically quantify the factor of improvement associated with the use of Type 316NG stainless steel as an alternate alloy for BWR piping. Test variables will include initial IGSCC, weld overlay design and applied stress level.

In addition to the pipe testing, several overlays which have been taken out of service will be examined under this program. Two full thickness overlays removed from Monticello will be examined. Both overlays were applied to riser pipes. One was applied to a circumferential flaw and the other to an

axial flaw. Two mini-overlays from Hatch Unit 2 will also be examined. Both of these overlays were applied to risers with circumferential cracks. The examination will include determinations of sensitization due to the overlay weld, weld residual stress via $MgCl_2$, and crack depth by metallography.

3.5.2 Weld Overlay Test Plans for Overlays from Hatch Unit 2

A second program of destructive examination of overlaid welds removed from service is currently underway at Argonne National Laboratory. This program (Reference 19) has the following objectives:

- Determine if the overlay process causes cracks to grow during application.
- Determine if additional crack growth has occurred during the approximately 12 months of plant operation after the overlays were applied.
- Measure residual stress on the I.D. surface at several locations to determine general state of stress.
- Determine how much sensitization of pipe base metal occurred as a result of overlay application
- Accurately determine ferrite content of the overlay material.
- Determine if cracks will propagate into the weld overlay material.

The scheduled completion date for this program is the end of 1984.

Table 3.1

Constant Extension Rate Test (CERT) Results

For Types 308L and 308 Weld Metal (References 10 and 11)

Heat No./Sample	Type	Heat Treatment	%C	Nominal Strain Rate(min^{-1})	IGSCC	Notes
M7616/26-B	308L	As-Deposited	.03	4.5×10^{-5}	No	1
M7616/27-B	308L	Solution Heat Treated	.03	4.5×10^{-5}	No	2
L-B7	308	1350°C/1 Hr.	.04	1.0×10^{-3}	No	3
L-B7	308	1350°C/1 Hr.	.04	2.0×10^{-4}	No	3
L-B7	308	1350°C/1 Hr.	.04	2.0×10^{-5}	No	3
L-B7	308	1350°C/1 Hr. + 475°C/10 Hr.	.04	1.5×10^{-4}	No	2
L-B7	308	1350°C/1 Hr. + 475°C/100 Hr.	.04	1.3×10^{-4}	No	2
L-B7	308	1350°C/1 Hr. + 475°C/1000 Hr.	.04	1.3×10^{-4}	No	2
L-B7	308	1350°C/1 Hr + 600°C/1 Hr.	.04	1.0×10^{-5}	No	2
L-B7	308	1350°C/1 Hr. + 600°C/2 Hr.	.04	1.3×10^{-5}	No	2
L-B7	308	1350°C/1 Hr. + 600°C/10 Hr.	.04	1.3×10^{-5}	No	2
L-B7	308	1350°C/1 Hr. + 600°C/20 Hr.	.04	1.3×10^{-5}	No	2
L-B7	308	1350°C/1 Hr. + 600°C/20 Hr.	.04	1.6×10^{-5}	No	2
L-B7	308	1350°C/1 Hr. + 600°C/100 Hr.	.04	1.4×10^{-4}	No	2
L-B7	308	1350°C/1 Hr. + 700°C/1 Hr.	.04	1.3×10^{-4}	No	2

Notes: 1 - Corrosion resistant clad overlay; procedure specification requires a ferrite content of at least 8 FN.

2 - No ferrite content given.

3 - 20% volume ferrite for this treatment.

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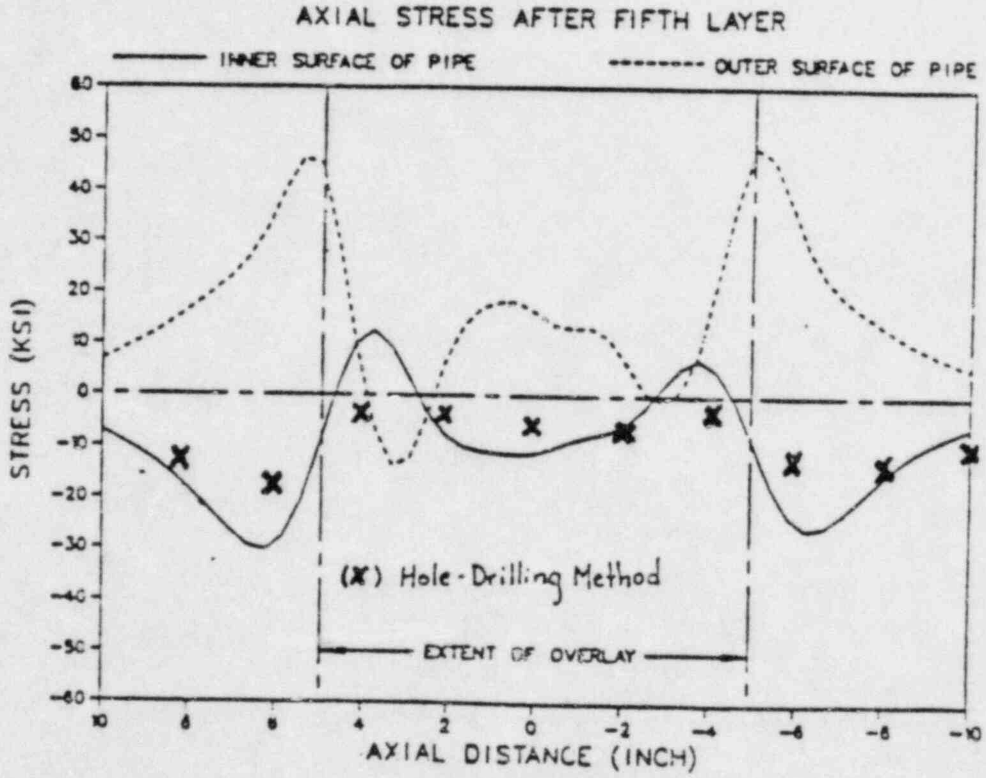

Figure 3.1 Calculated Inner and Outer Surface Axial Overlay Stresses for a 24 in. Pipe with 1.48 in. Wall. (Overlay contains five weld layers for a total thickness of 0.35 in.) Experimental Results Also Shown for Comparison.

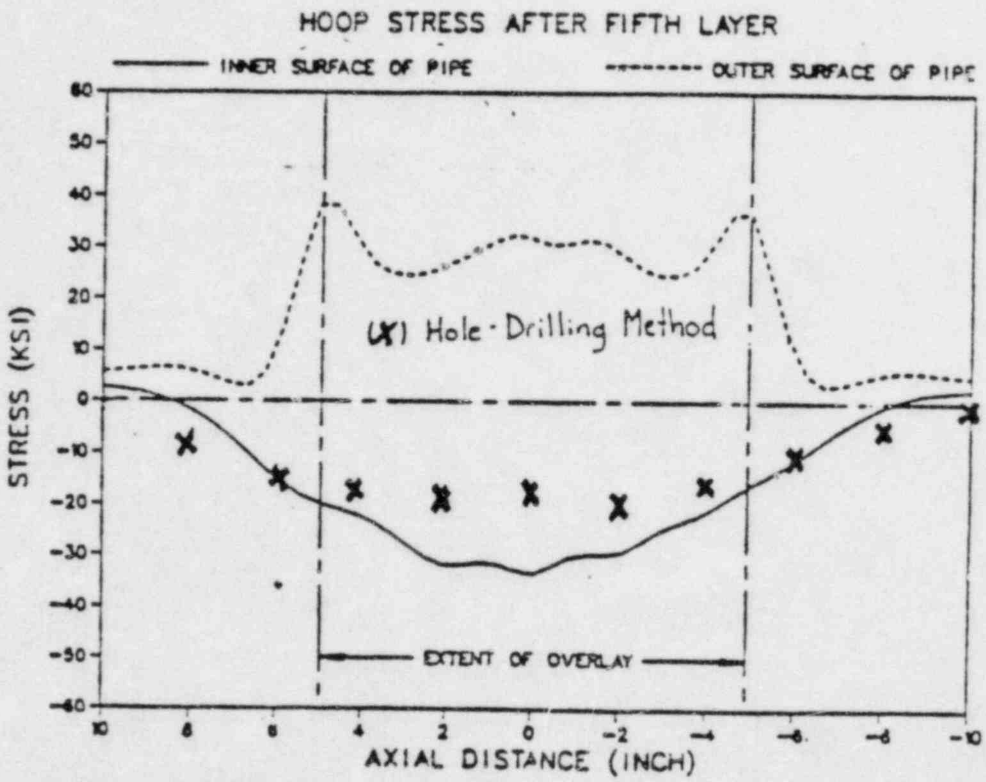

Figure 3.2 Calculated Inner and Outer Surface Hoop Overlay Stresses for a 24 in. Pipe with 1.48 in. Wall. (Overlay contains five weld layers for a total thickness of 0.35 in.) Experimental Results Also Shown for Comparison.

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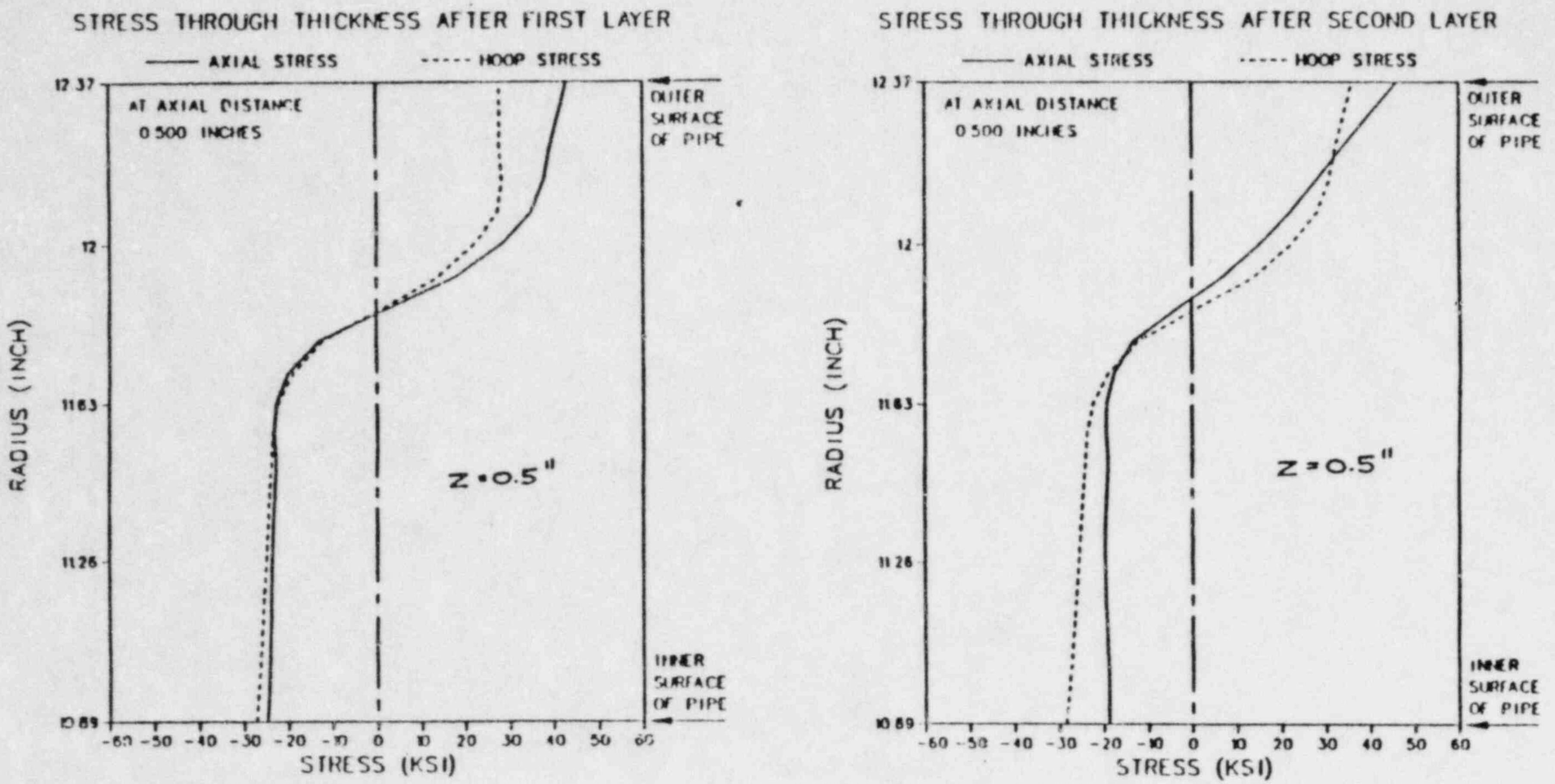


Figure 3.3 Calculated Through Wall Stresses After the First and Second Weld Overlay Layers for a 24 in. Pipe with 1.48 in. Wall. (Overlay contains five weld layers for a total thickness of 0.35 in.)

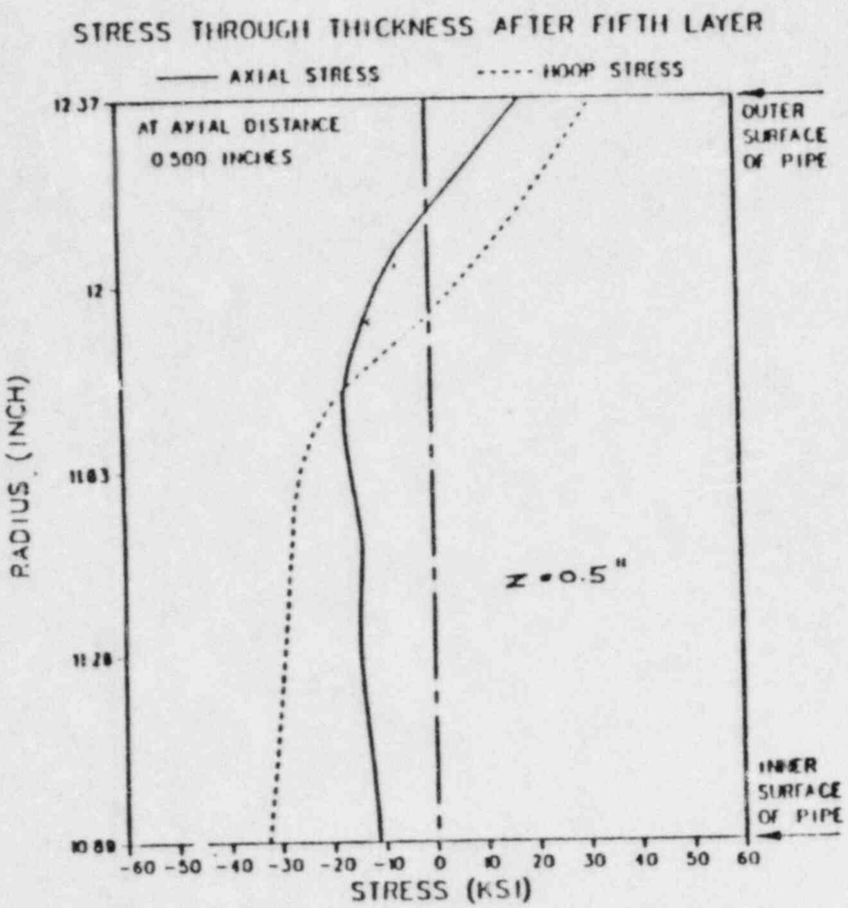
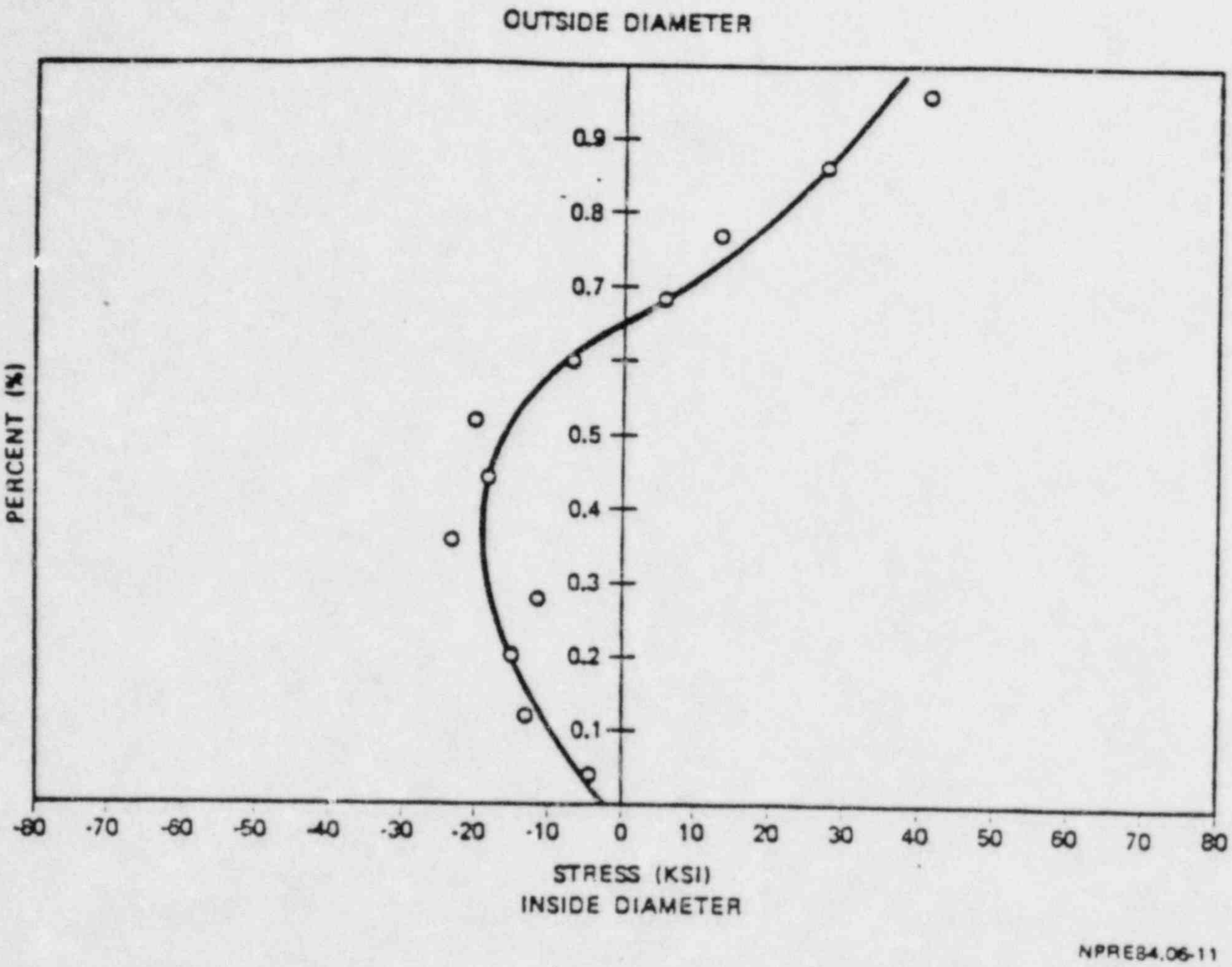


Figure 3.4 Calculated Through Wall Stresses After the Fifth and Final Weld Overlay Layer for a 24 in. Pipe with 1.48 in. Wall. (Overlay contains five weld layers for a total thickness of 0.35 in.)

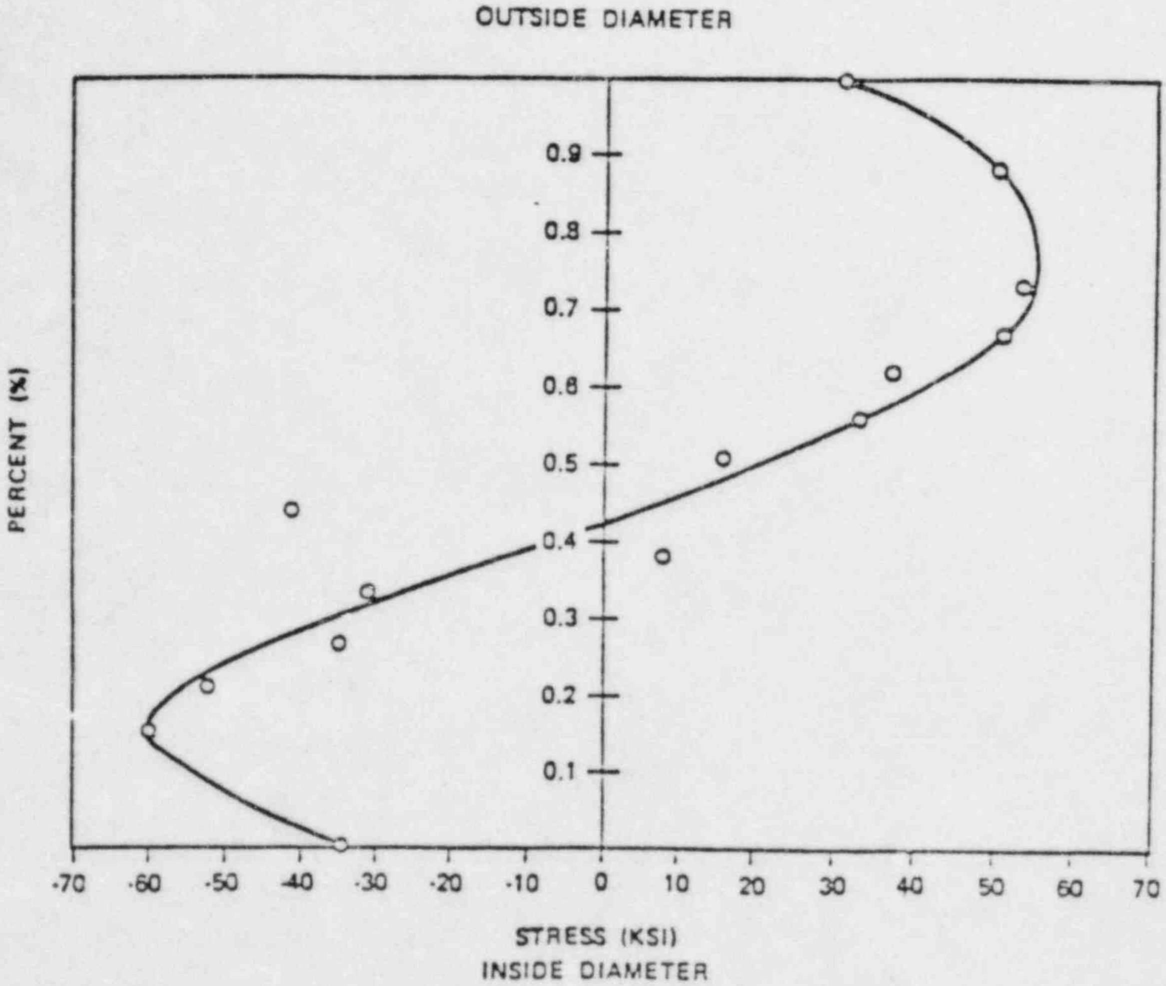
WELD OVERLAY TESTS



.20" OVERLAY
HATCH-1 (LONG) WELD PREP
20mm FROM CENTERLINE

Figure 3.5 Calculated Through-Wall Axial Residual Stress of 12" Schedule 100 Pipe

WELD OVERLAY TESTS



.20" OVERLAY
HATCH-1 (LONG) WELD PREP
20mm FROM CENTERLINE

NPRE84.06-02

Figure 3.6 Measured Through-Wall Axial Residual Stress of 12" Schedule 100 Pipe

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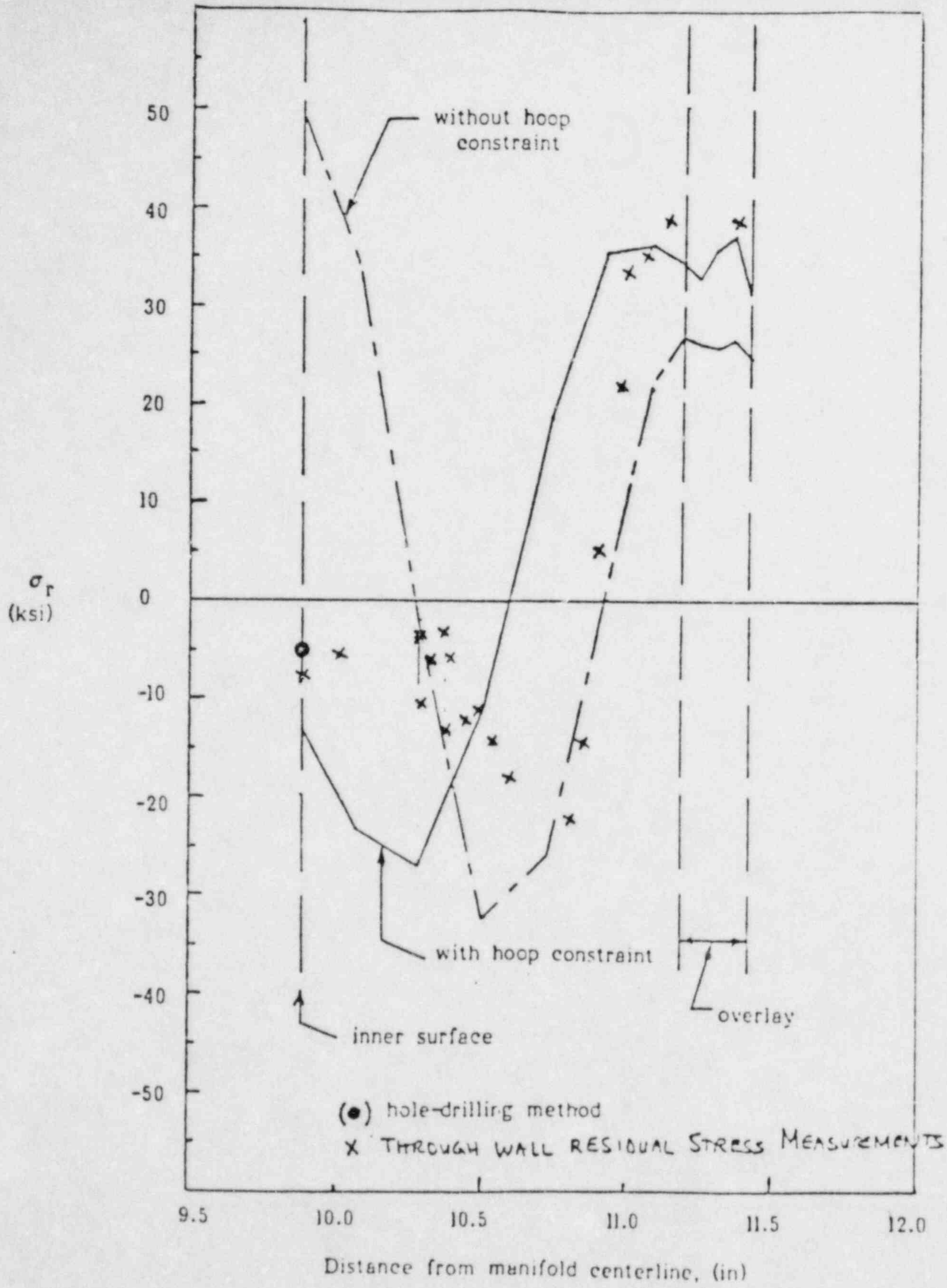

Figure 3.7 Comparison of Through-Wall Stress from TVA Sweepolet Longitudinal Section Models (with and without hoop constraint) and Experimental Results.

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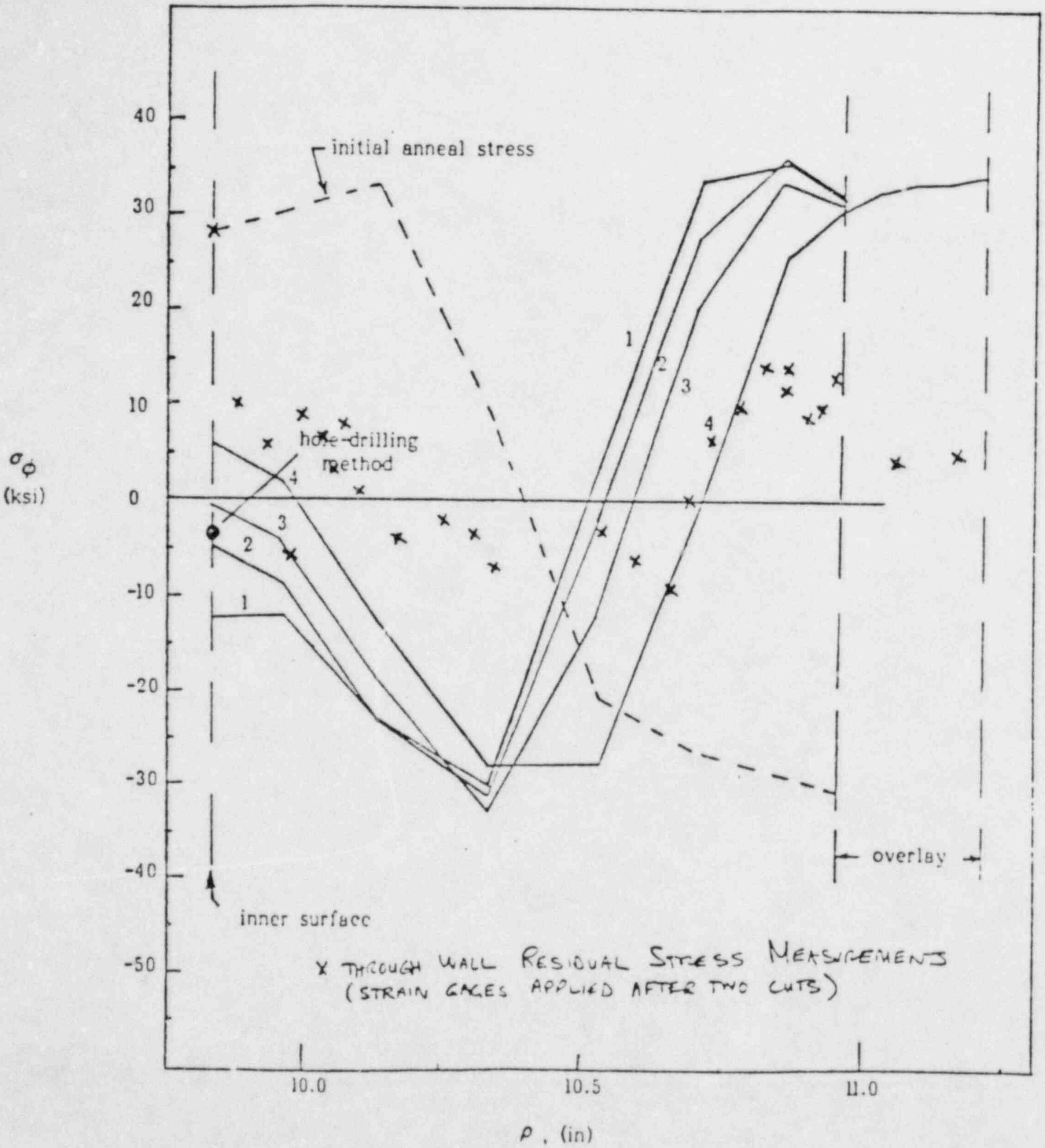

Figure 3.8 Comparison of Through-Wall Stress from TVA Sweepolet Transverse Section Model After Each Overlay Layer and Experimental Results

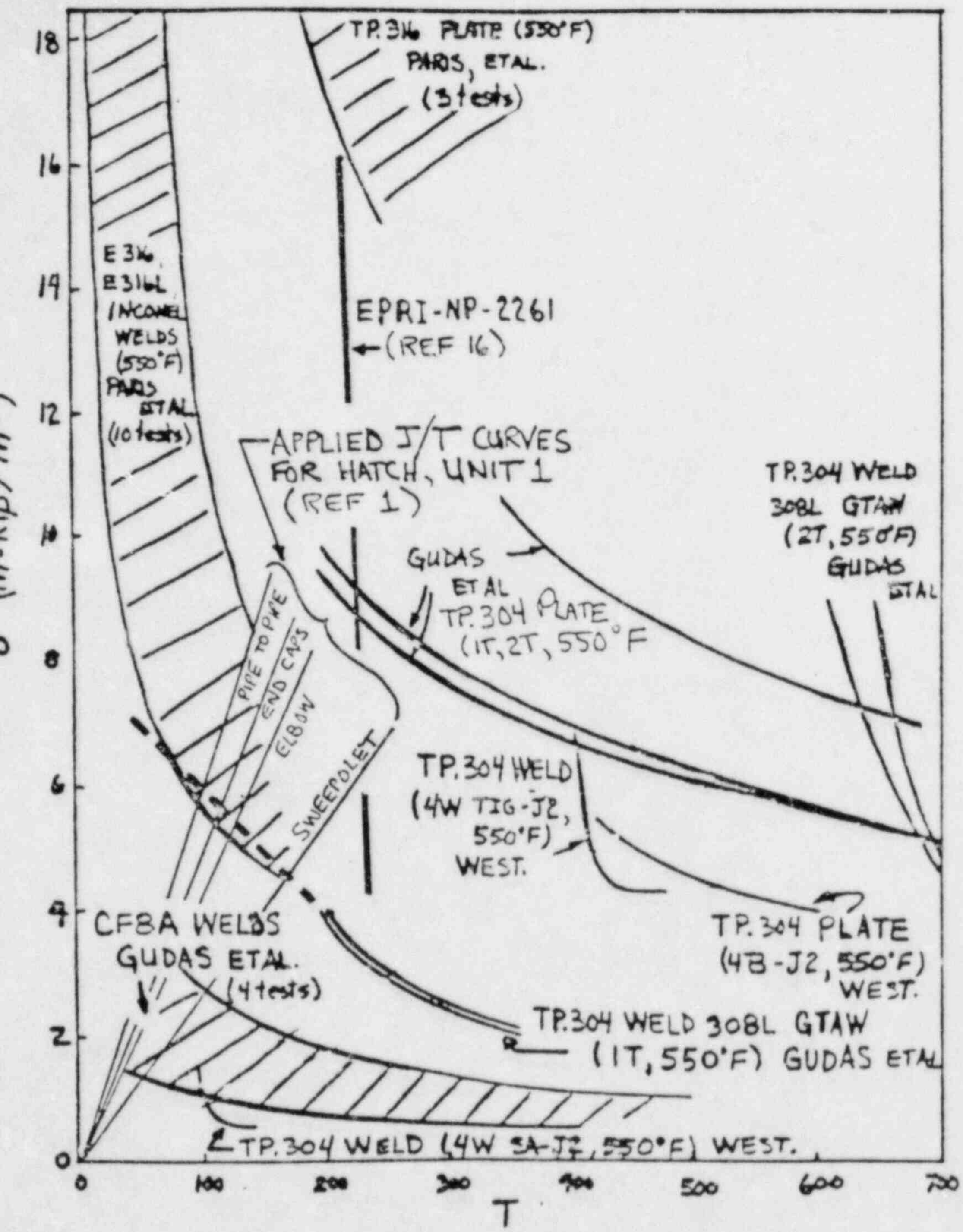

Figure 3.9 Weld and Base Metal Toughness Data with Applied J/T Curves for Hatch Unit 1 Weld Overlays

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4.0 CONCLUSIONS

- Inspections proposed for the recirculation, RHR, and RWCU systems during the Fall 1984 maintenance/refueling outage meet the intent of the Hatch Unit 1 SER, NRC I&E Bulletin 83-02, NRC letter SECY-83-267C, and NRC Generic Letter 84-11.

- Continued operation with the existing six overlay repaired recirculation and RHR piping welds and the unrepaired recirculation sweepolet weld is acceptable for an additional cycle because:

  - A large amount of test data shows that Type 308L weld metal is not susceptible to IGSCC. Ferrite contents of 8% or greater provide additional margin against IGSCC.

  - Theoretical predictions support the test data and show that Type 308L with at least 8% ferrite is virtually immune to IGSCC.

  - IGSCC cracks should not propagate into the 308L weld overlays applied to the six affected recirculation and RHR piping welds at Hatch Unit 1.

  - The unrepaired sweepolet-to-manifold weld was previously shown by analysis to continue to meet all code requirements for at least five years of operation.

  - Since the overlays at each weld joint provide structural adequacy, and the overlays are essentially immune to further crack growth, operation for an additional cycle will not reduce Safety Margins below those intended by the ASME Code, Section III.

  - Numerous tests of weld overlays are on-going; early results show favorable residual stress patterns.

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