Attachment 2

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Applicability of Pipelocks as a Remedy for Intergranular Stress Corrosion Cracking in BWRs

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ABSTRACT

Design, analyses and first application of the Pipelock as a novel long-term multicycle protection for piping systems in Boiling Water Reactor plants damaged by Intergranular Stress Corrosion Cracking in BWRs is described. Confirmatory tests simulating all design and operating conditions including LOCA are also discussed.

Pipelocks are mechanical devices which prevent pipe break even if it is assumed that intergranular stress corrosion cracking penetrates through-the-wall and around the entire circumference of the pipe weldment. With a fully cracked weldment, the entrapped wedges lock the pipes together, preventing the ends from separating.

In addition to providing defense-in-depth against pipe breaks, pre-tightening of the Pipelock bolts produces axial and circumferential com-

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pressive stresses in the pipe wall at the weldment, thus tending to retard or eliminate crack growth during operation after installing the Pipelock.

Pipelocks are designed to meet regulatory requirements 10CFR50—Appendix B and ASME Code Section III requirements for long-term multicycle operation.

Installed Pipelocks can be disassembled to permit inservice inspection of the weldment. They therefore can be used through several outages subsequent to the installation, thereby eliminating or postponing the need for pipe changeout. The design of the Pipelock also enables their use on weldments which were previously overlaid.

INTRODUCTION

Intergranular stress corrosion cracking of weldments in 304 stainless steel piping systems first occurred in the fall of 1974. Various remedies not requiring pipe changeout have been proposed in order to provide assurance of structural integrity and reliability. Pipe changeout requires new piping, human resources and capabilities which must be thoroughly planned and scheduled well in advance of the project. There are major advantages in being able to operate through several scheduled outages prior to changeout so that the long outage required for such a massive project can be scheduled at an opportune time, and adequate preparations can be made for evaluating all of the related plant changes. The Pipelock meets this need and provides certain advantages over other remedies which have been proposed.

The use of weld overlays provides a valuable option. At present, the use of overlays is restricted to a limited time period due to uncertainties related to crack growth and inspectability of overlaid welds. Research efforts are underway to eliminate these uncertainties.

Pipelocks on the other hand are designed to retain the pipe ends even in the hypothetical case of full degradation of the welded joint. The load path is redirected around the degraded weldment through the Pipelock rings which act in a manner analogous to split loose flanges. The Pipelock studs carry the axial tensile loads. The positive locking mechanism holding the rings on the pipe operates without the benefit of friction. Pipelocks are designed for application with or without weld overlays. The Pipelock and overlay functions are complementary. The Pipelock ensures strength and safety while the overlay seals through-the-wall cracks which may exist prior to the application of the Pipelock.

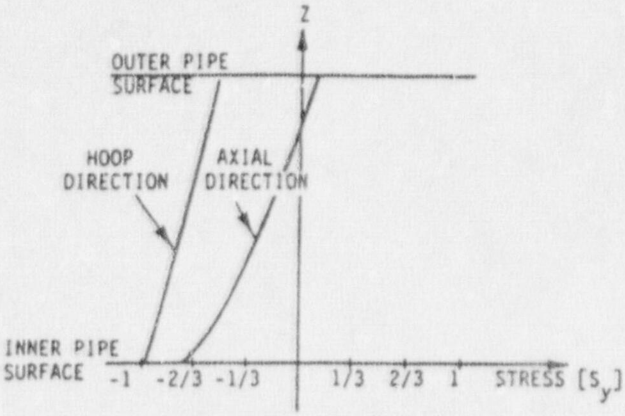

Fig. 1. Typical compressive stress distribution for pretightened Pipelocks.

The Pipelock is not only capable of holding the joint together, but also provides compression at the inner surface of the pipe in the weld and heat-affected zone (HAZ). Tightening of the studs holding the Pipelock rings on opposite sides of the weldment provides compressive stresses in the axial and hoop directions which remain compressive at the inner surface also after pressurizing the pipe. A typical stress distribution in the HAZ due to pretightening the studs is shown in Fig. 1. The Pipelock thus retards or eliminates crack growth, and provides defense-in-depth against catastrophic failure.

DESCRIPTION

An isometric view of the Pipelock is shown in Fig. 2. Figure 3 shows its typical cross section. The Pipelock consists of mating wedge-shaped inner locking rings and intermediate wedge rings. The inner locking rings clamp the pipe by wedge action and are held in place on the pipes on either side of the welded joint by shear rings even in the absence of friction. The shear rings are positioned in circular grooves that are machined on the corresponding inside and outside surfaces of the locking rings and pipes, respectively. The locking rings on both sides of the weldment are held firmly by the intermediate wedge rings that are tightened together by nuts and bolts.

Spherical washers or nuts with spherical bottom surfaces are used to provide the proper bearing surface and to ensure that the Pipelock bolts are not subjected to bending. Contact between the inner and intermediate

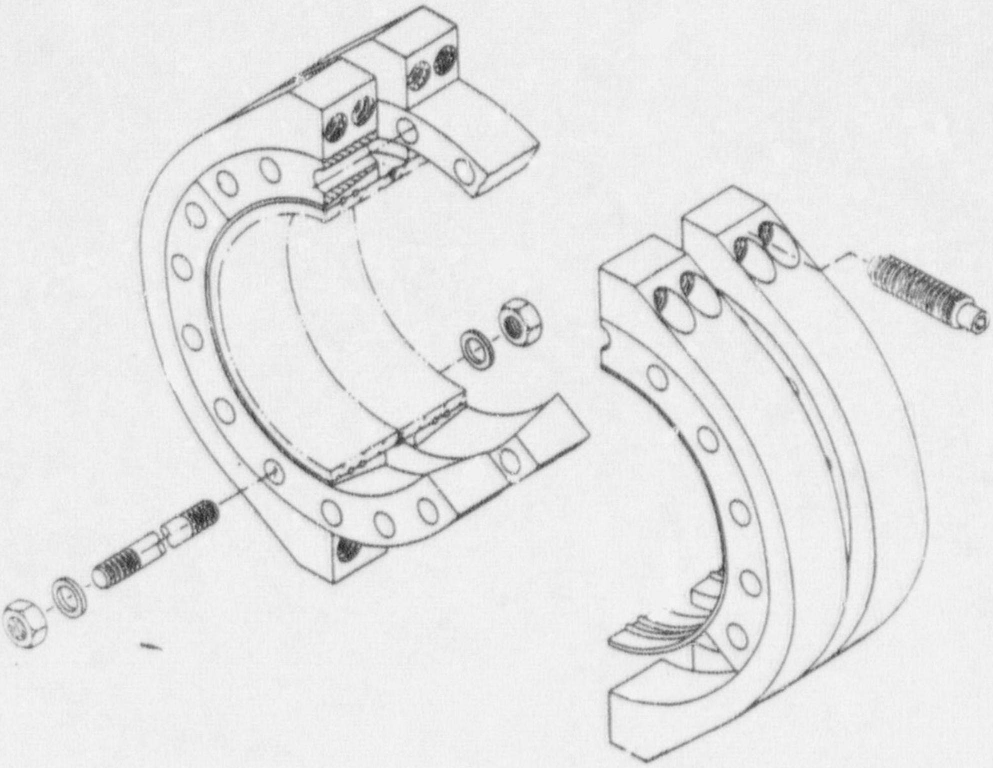

Fig. 2. Pipelock for stress corrosion cracking.

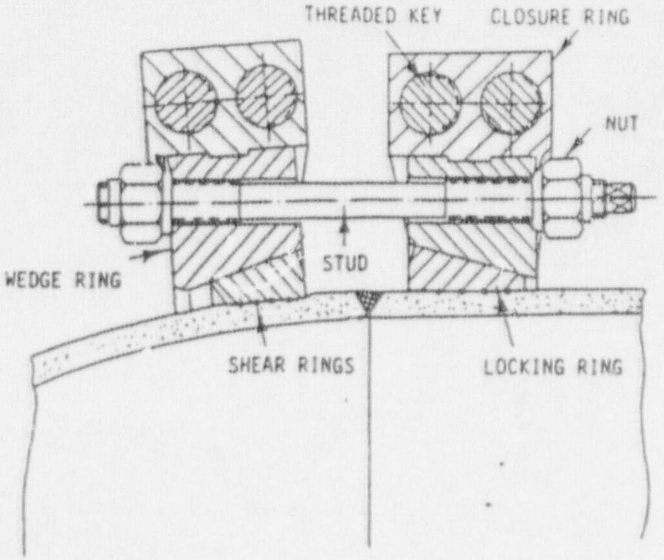

Fig. 3. Characteristic cross-section for Pipelock installed on elbow.

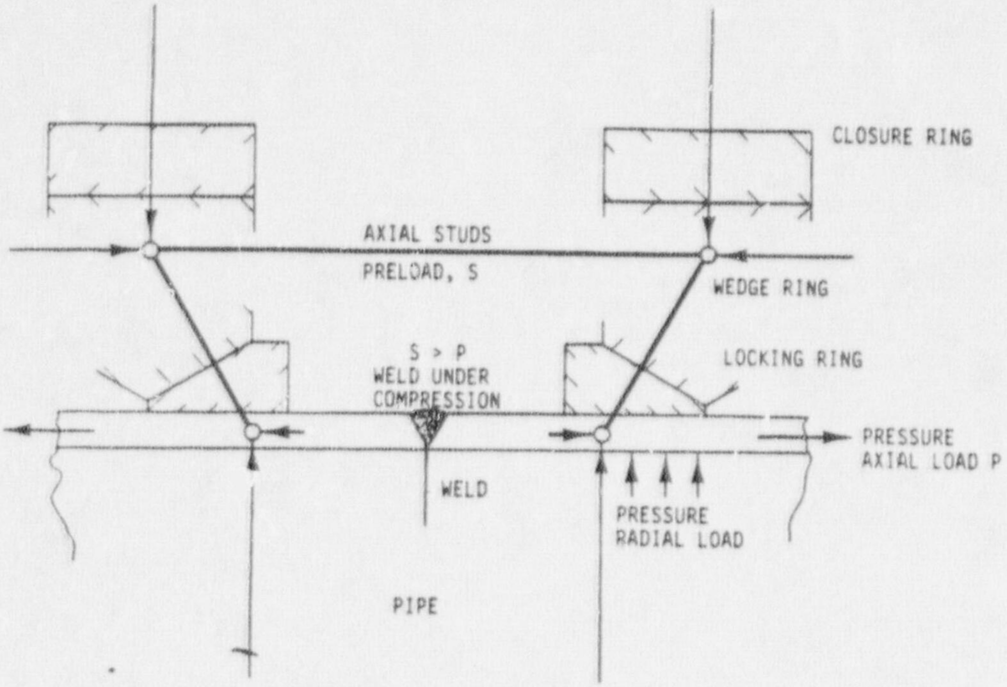

Fig. 4. Equilibrium and kinematics of Pipelock.

rings occurs on a conical surface. All of these wedge-shaped rings and the shear rings are split so that they may be assembled around the pipes. The necessary radial constraint is provided by the outer closure rings which also secure the Pipelock assembly in place. Closure of the outer rings is provided by threaded keys.

The equilibrium conditions and kinematic interaction of the pipe and rings resulting in self locking of the Pipelock are explained diagrammatically in Fig. 4. The preloaded bolts draw the ends of the pipe together, creating axial compressive stress and circumferential compressive stress in the pipe through action of the wedges. Even if the bolts were not preloaded and if the weldment were fully cracked, the axial motion of the pipes moving apart locks the entrapped wedges, preventing the ends from separating.

The original design included shear rings located in grooves machined in the pipe on both sides of the weldment. A current improved design option shown in Fig. 5 provides shallow contour threads on the pipe surface and flexible pads which adjust to the outer profile of the pipe during tightening of the studs. Use of multiple threads guided by the surface of the pipe simplify machining and significantly facilitate installation of the Pipelock.

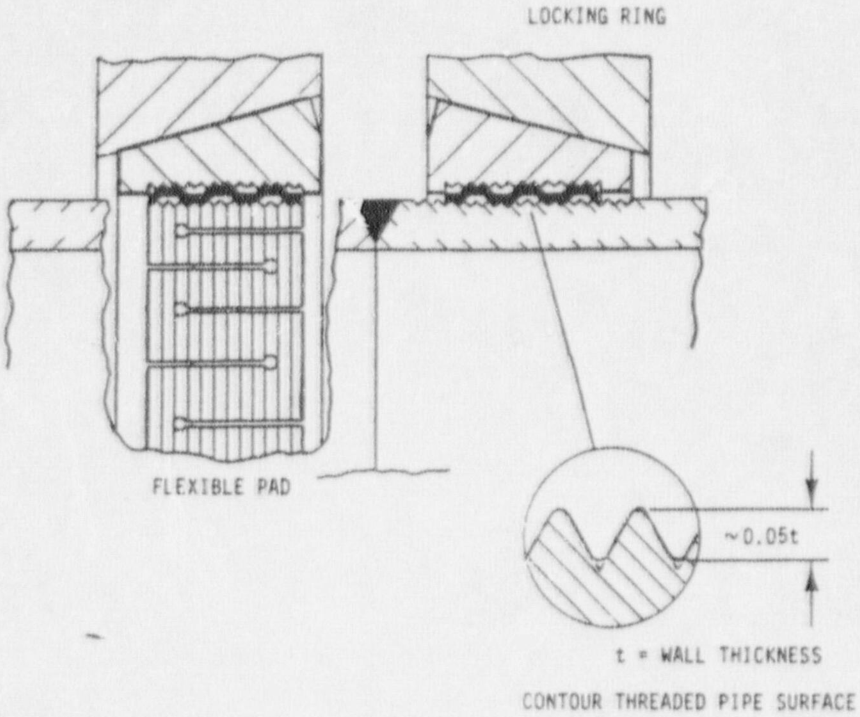

Fig. 5. Contour thread on pipe surface with flexible pad as axial retainer of locking rings.

TABLE 1

Functions and Benefits of the Pipelock

Provides positive mechanical protection against pipe break
Imposes axial compression on weldment to retard circumferential crack growth
Imposes circumferential compression on weldment to retard growth of deep axial cracks which can cause leaks
Eliminates need to inspect welds and quantify crack depths to ensure structural integrity
Provides for safe operation with extensive IGSCC
Can be used with or without weld overlay (Fig. 6)
Can be applied for joints between straight pipes or for joints between pipes and pipe fittings
Enables installation on the existing piping systems: rings are split to enable assembly
Can be disassembled to enable inspection of the welds
Causes no axial shrinkage or distortion in the piping system
Meets ASME Section III criteria and regulatory requirements for multicycle long-term service

DESIGN AND FUNCTIONAL REQUIREMENTS

The Pipelock, when installed on a cracked piping weldment, functions as a structural part of the primary system pressure boundary of the Nuclear Steam Supply System (NSSS). As such, it is to be designed and constructed to the requirements for Safety Class I piping as set forth in the applicable ASME Code and the owner's Design Specification.

The Pipelock is designed in accordance with Section III, Division 1 requirements of the ASME Boiler and Pressure Vessel Code for safe, long-term multicycle operation. The Pipelock and pipe must therefore be shown to satisfy the stress limits given therein.

The functional requirements for the Pipelock are listed in Table 1. The positive locking mechanism of the Pipelock provides sufficient strength to hold the free ends of a pipe separated by a 360° through-the-wall crack even without taking credit for friction. Friction generated by the wedge locking mechanism provides dual protection.

The Pipelock materials are listed in Table 2. Selection of materials of lower coefficients of thermal expansion for the Pipelock than for the 304 SS pipe enhances the generation of compressive stresses at the operating temperature, thus retarding crack growth.

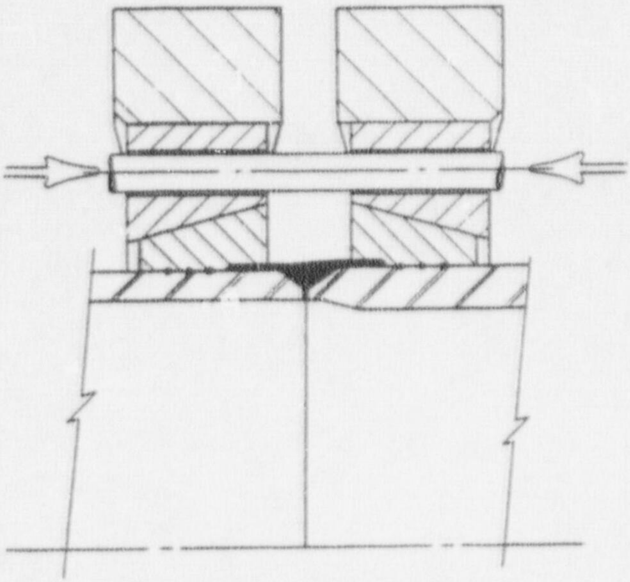

Fig. 6. Use of Pipelock to extend life of overload weldment: mini-overlay repair meets ASME Code Section XI IWB 3640 criteria; Pipelock meets ASME Code Section III criteria for long-term service.

TABLE 2
Pipelock Materials

Component	*Product form*	*Material specification*	*Grade or type*
Closure ring	Forging	SA-508	Class 2a
Locking ring	Forging	SA-705	Class 630
Wedge ring	Forging	SA-508	Class 2a
Threaded keys	Bar	SA-637	Type 718
Studs[a]	Bar	SA-637	Type 718
Nuts	Bar	SA-637	Type 718
Spherical washers	Bar	SA-637	Type 718
Shear rings	Bar	SA-637	Type 718
Guide pins	—	304 SS	Commercial

[a] SA540 Grade B23 Class 2 steel can also be used as an alternative bolting material.

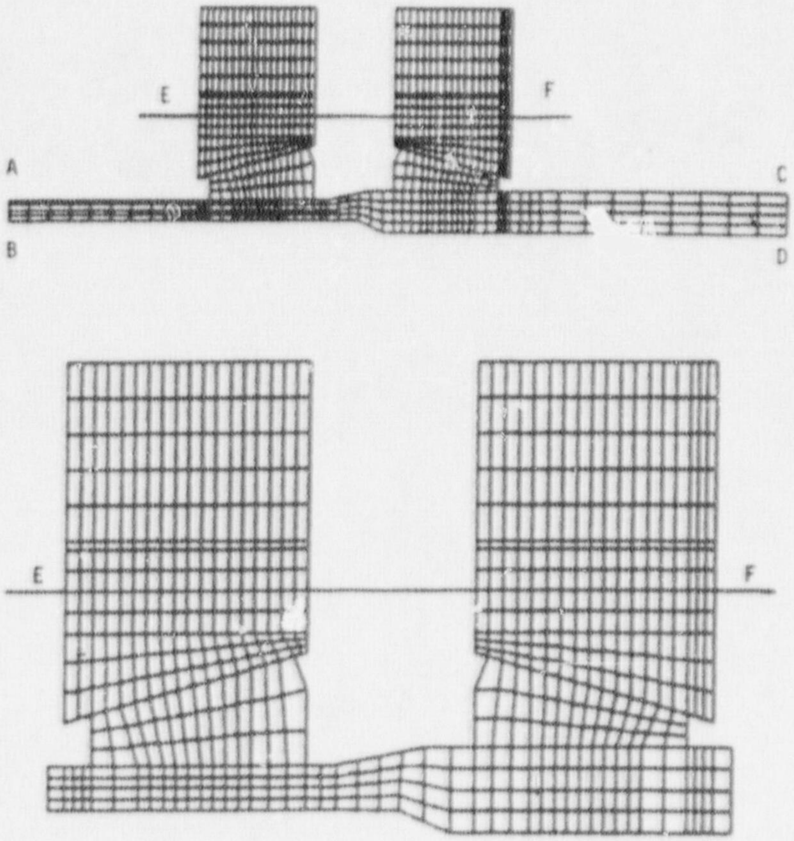

Fig. 7. Two-dimensional finite element model of 12 in Pipelock.

DESIGN EVALUATION

Detailed two-dimensional and three-dimensional finite element stress analyses were performed to verify that the Pipelock can be designed to the ASME Code Section III requirements for typical BWR recirculation system service conditions. Figures 7 and 8 show examples of two-dimensional and three-dimensional models for a 12 in (30 cm) safe-end

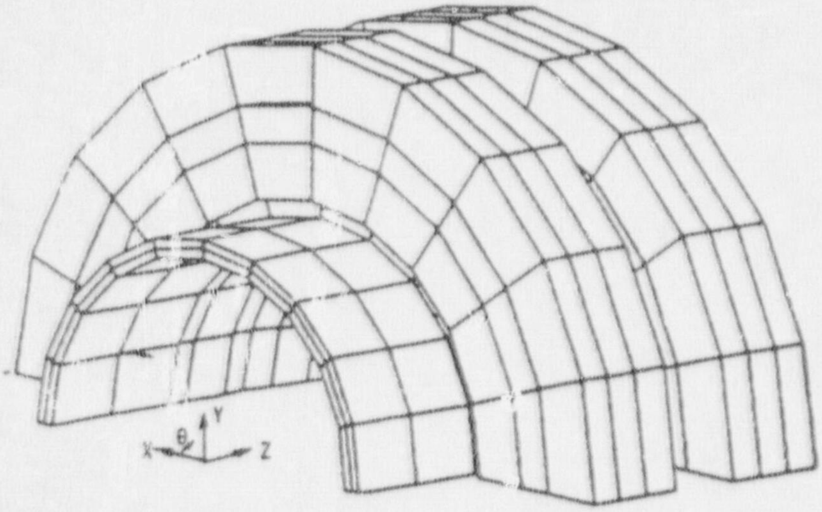

Fig. 8a. Three-dimensional finite element model of 12 in Pipelock.

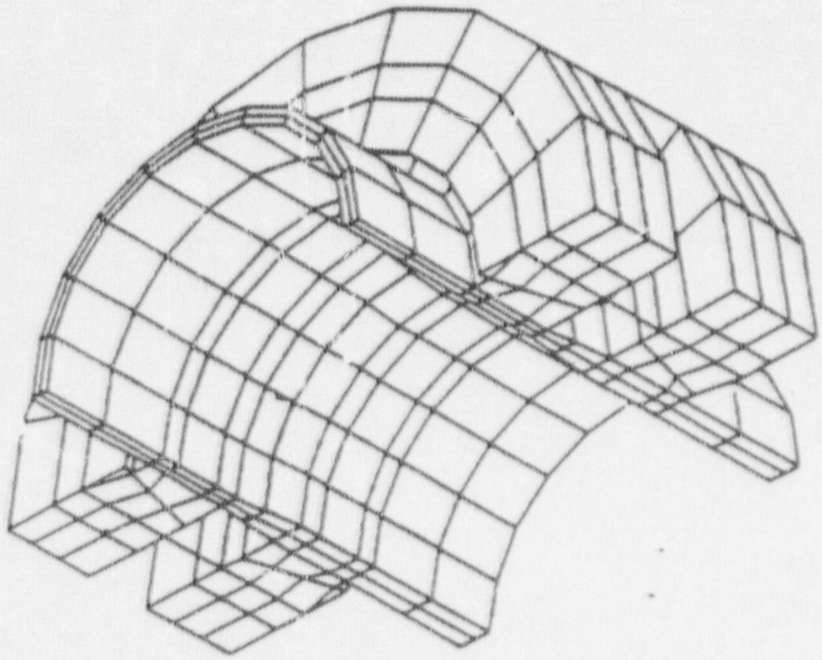

Fig. 8b. Three-dimensional model—bottom view.

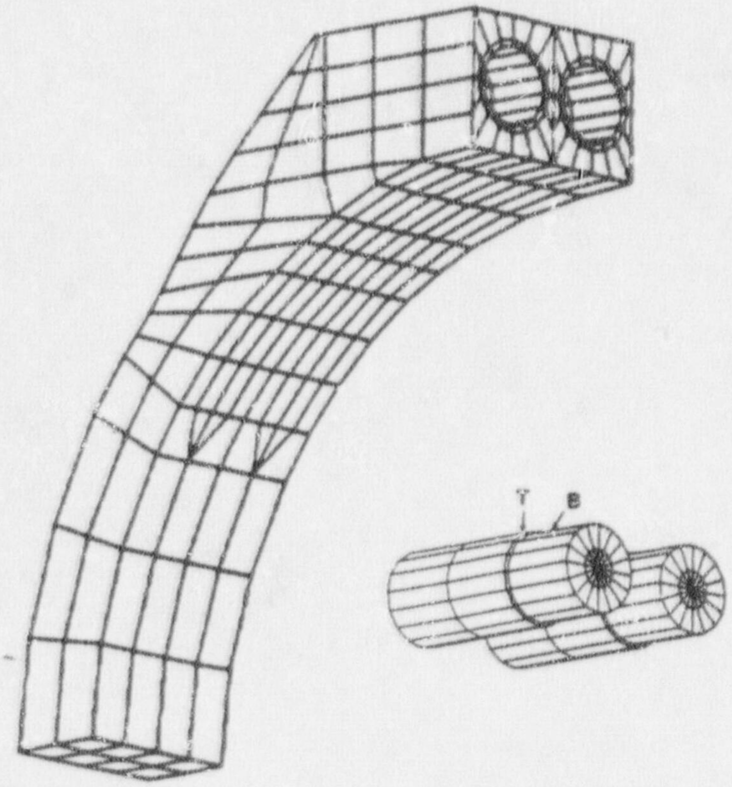

Fig. 9. Three-dimensional finite element model of split closure ring T, threads; B, bolt.

Pipelock. In this case, the two-dimensional analysis was used for evaluating the symmetric loadings while the three-dimensional analysis was used for evaluating the bending loads. Figure 9 is a three-dimensional model of the split closure ring analyzed to ensure that the threaded key connection is strong enough to adequately satisfy stress limits, while Fig. 10 is an example of the three-dimensional model used in the analysis of the 12 in elbow Pipelock.

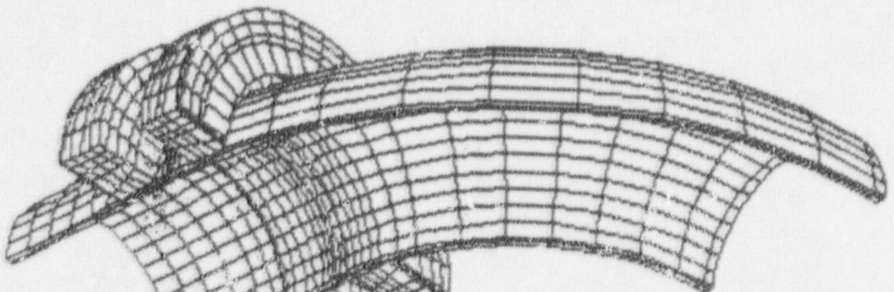

Fig. 10. Three-dimensional model of Pipelock on elbow.

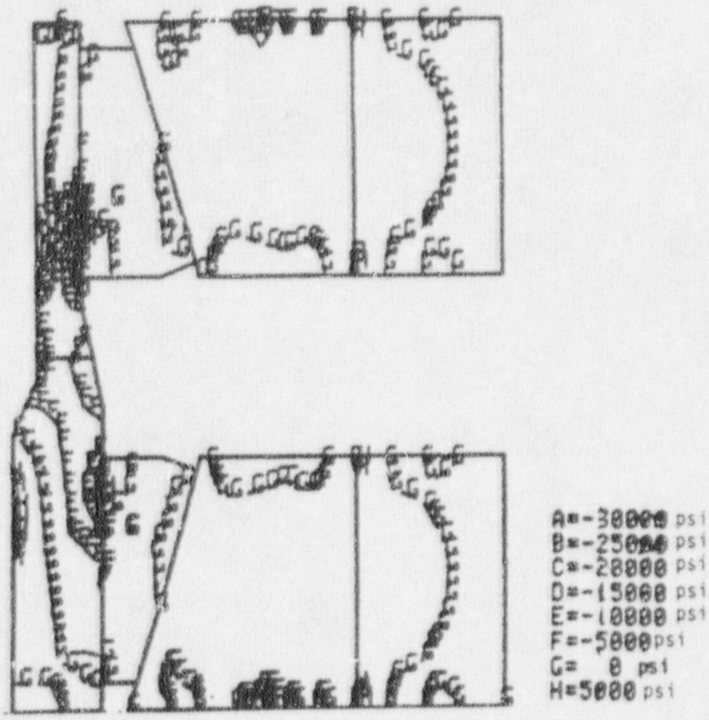

Fig. 11. Axial stress distribution due to bolt preload. (−, Compression; +, tension.)

All analyses including those for design and operating conditions were performed for the Pipelock on a fully cracked weldment. Zero friction was assumed for all analyses. This provides conservative results, since friction improves the clamping action of the Pipelock.

Some typical results for the 12 in safe-end Pipelock on the fully cracked pipe are illustrated in Figs 11–14. Figures 11 and 12 show the axial and hoop stress contours due to bolt preload (15 000 psi per bolt). Figures 13 and 14 show the corresponding contours when pressure (1250 psi) is included in the analysis. In all cases, the inside pipe surface remains in compression at the weld location.

The temperature distribution at the end of the startup transient is shown in Fig. 15. The analysis included pretightening of studs, startup, steady operation and shutdown transient. The effect of the fast down-transient (LOCA) was also analyzed. Operating conditions, including transients, produce only moderate changes in the stud loads. (See also Fig. 22 comparing analysis with test results.)

As stated, the Pipelock is designed to meet ASME Section III, Division 1 Code limits. The corresponding calculated stresses for the worst locations based on the loading conditions of Table 3 are summarized

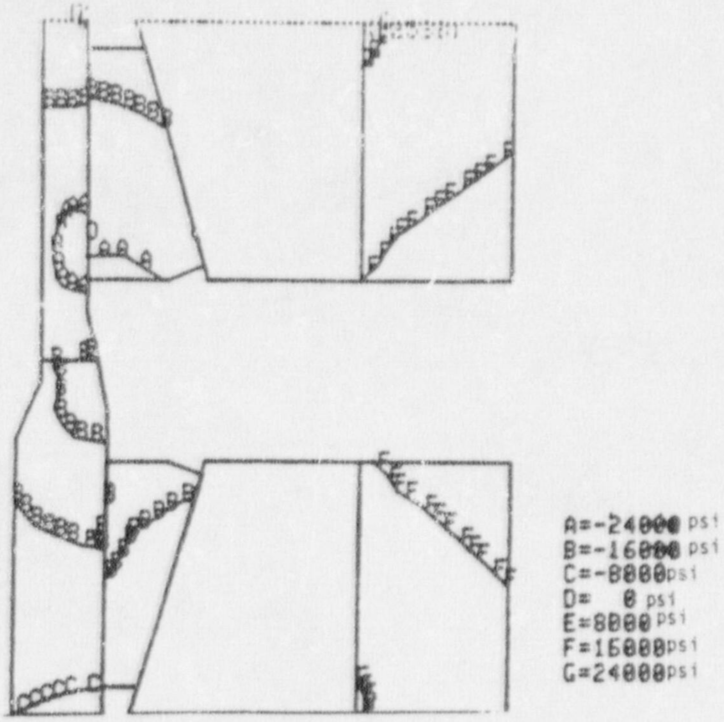

Fig. 12. Hoop stress distribution due to bolt preload. (−, Compression; +, tension.)

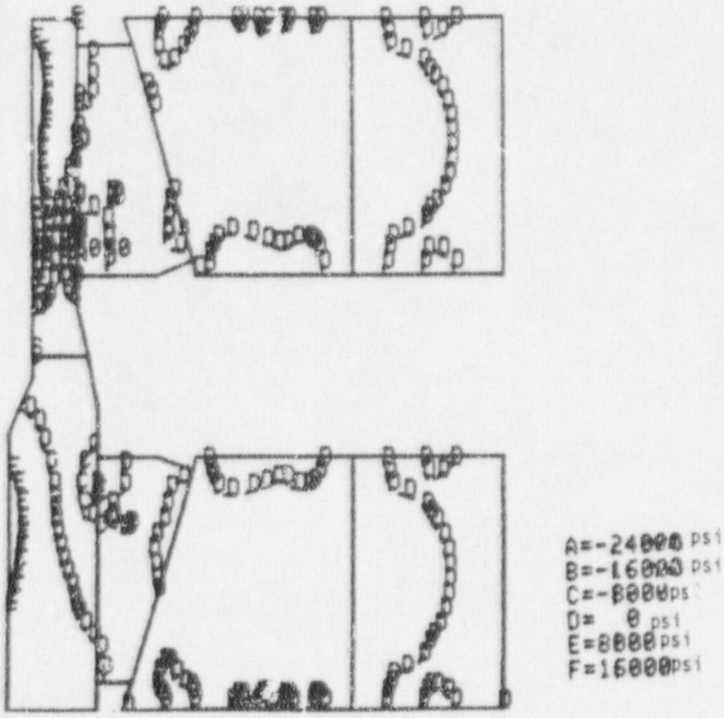

Fig. 13. Axial stress distribution due to bolt preload and internal pressure. (−, Compression; +, tension.)

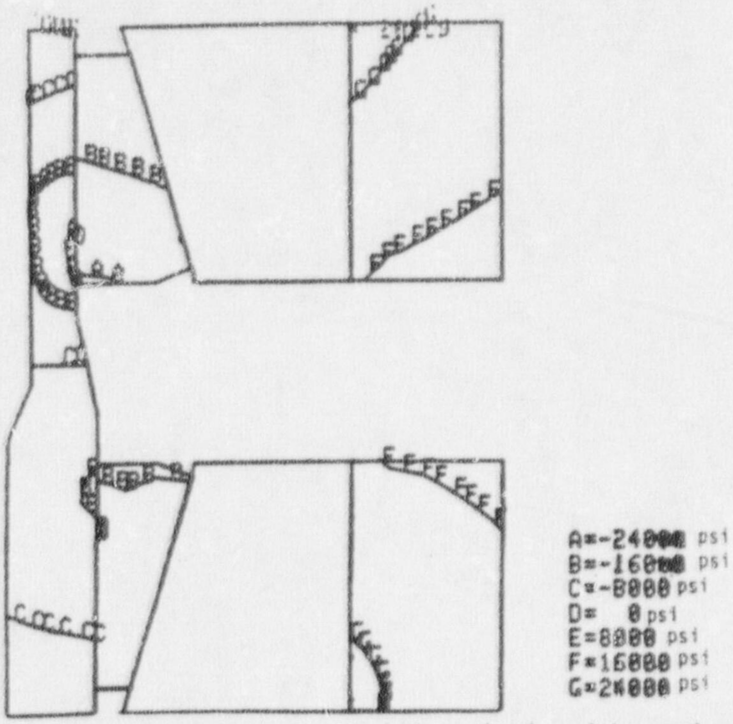

Fig. 14. Hoop stress distribution due to bolt preload and internal pressure. (−, Compression; +, tension.)

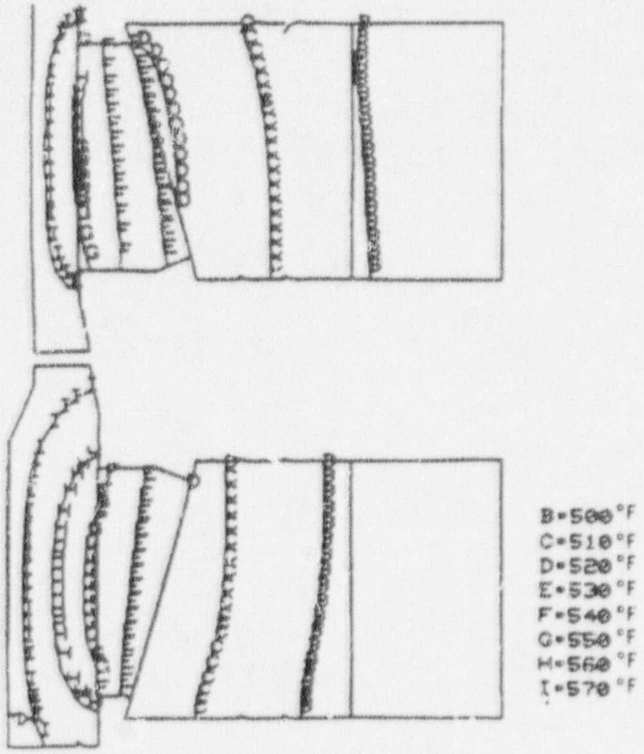

Fig. 15. Temperature distribution at end of startup transient.

TABLE 3
12 in (30 cm) Pipelock Loading Conditions

Category	*Loading*
Design	1 250 psi (internal pressure) + 50 000 ft lb
Levels A and B	1. 50 000 ft lb (thermal expansion bending moment) 2. 1 250 psi (internal pressure) + 50 000 ft lb + 100°F h^{-1} transient
Level C	1 250 psi (internal pressure) + 50 000 ft lb
Level D	1 250 psi (internal pressure) + 50 000 ft lb

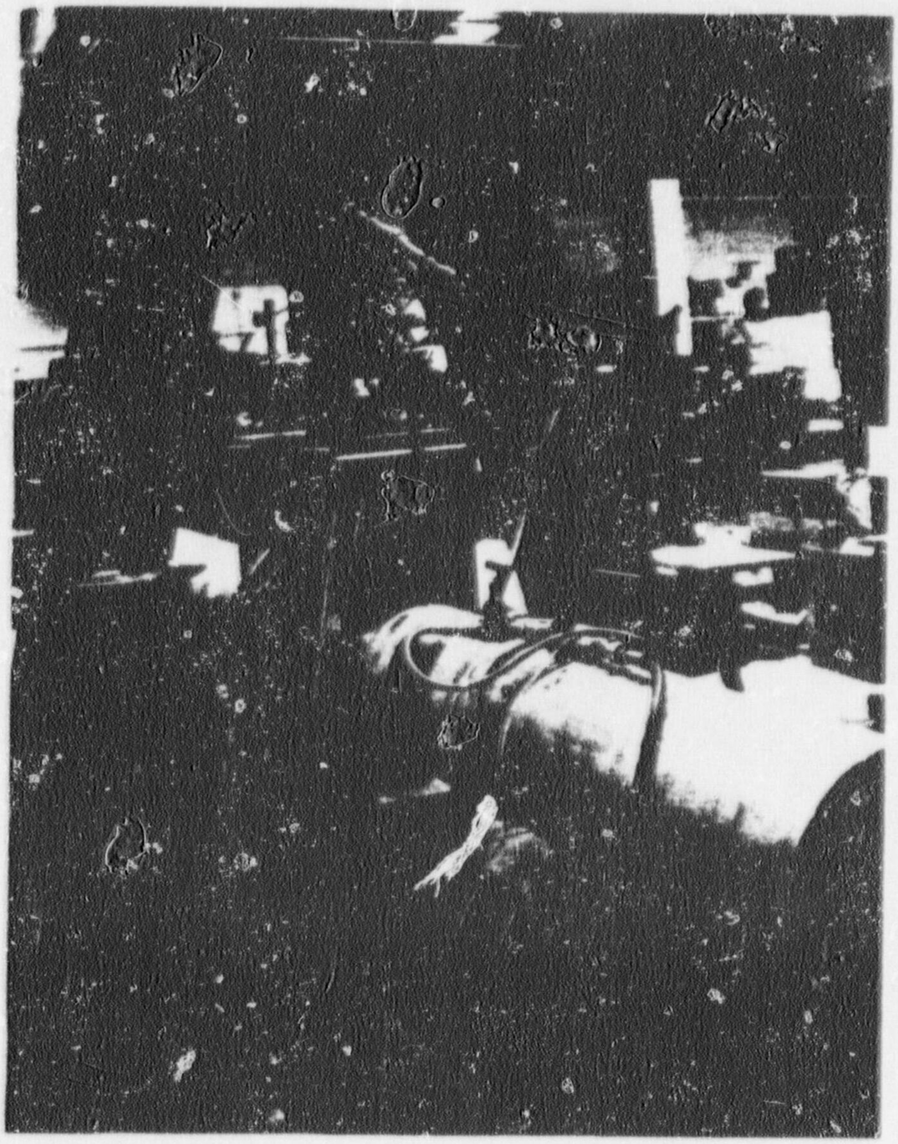

Fig. 16. 12 in Safe-end Pipelock test assembly.

TABLE 4

Basic ASME Code Evaluation of 12 in (30 cm) Pipelock[a]

ASME Code condition	Pipe (SA-312 TP 304) $S_m = 16\,900$ psi $S_y = 18\,000$ psi $S_u = 63\,700$ psi	Locking ring (SA-705 CL 630) $S_m = 45\,475$ psi $S_y = 101\,550$ psi	Lock closure ring (SA-508 Class 2a) $S_m = 30\,000$ psi $S_y = 57\,550$ psi	Bolts (SA-637 Type 718) $S_m = 45\,225$ psi $S_y = 136\,000$ psi	Shear rings (SA-637 Type 718) $S_m = 45\,225$ psi $S_y = 136\,000$ psi	Threaded keys (SA-637 Type 718) $S_m = 45\,225$ psi $S_y = 136\,060$ psi
Design	$P_m < S_m$ $13\,450 < 16\,900$	$P_m < S_m$ $44\,300 < 45\,475$	$P_m < S_m$ $23\,600 < 30\,000$	Bolt area $> A_{min}$(total) $12\,in^2 > 6{\cdot}063\,in^2$	$\tau < 0{\cdot}6S_m$ $11\,750 < 27\,135$	$A_{Act} \geq A_{min}$ $3{\cdot}16\,in^2 > 3{\cdot}14\,in^2$
	$P_L + P_b < 1{\cdot}5S_m$ $16\,200 < 25\,350$		$P_L + P_b < 1{\cdot}5S_m$ $36\,400 < 45\,000$	$\bar{S}_{avg} < S_m$ $11\,000 < 45\,225$		$S_{ave} < S_m$ $44\,250 < 45\,225$
Levels A & B service limits	$P_e < 3S_m$ $15\,800 < 50\,700$	$P_e < 3S_m$ $10\,100 < 136\,425$	$P_e < 3S_m$ $6\,200 < 90\,000$	$S_{avg} < 2S_m$ $19\,600 < 90\,450$		$S_{avg} < 2S_m$ $50\,400 < 90\,450$
	$P_L + P_b + Q < 3S_m$ $26\,900 < 50\,700$	$P_L + P_b + Q < 3S_m$ $51\,300 < 136\,425$	$P_L + P_b + Q < 3S_m$ $34\,600 < 90\,000$		$P_L + P_b + Q < 3S_m$ $26\,800 < 135\,675$	$S_{max} < S_m$ $77\,000 < 90\,450$
Level C service limits	$P_m < 1{\cdot}2S_m$ or S_y $13\,450 < 20\,280$	$P_m < 1{\cdot}25_m$ or S_y $44\,300 < 101\,550$	$P_m < 1{\cdot}2S_m$ or S_y $23\,600 < 57\,550$	$S_{avg} < 2S_m$ $16\,800 < 90\,450$	$\tau_m < 0{\cdot}6\ (1{\cdot}2S_m)$ $11\,750 < 32\,562$	$S_{avg} < 2S_m$ $44\,250 < 90\,450$
	$P_L + P_b < 1{\cdot}8S_m$ or $1{\cdot}5S_y$ $16\,200 < 30\,420$		$P_L + P_b < 1{\cdot}8S_m$ or $1{\cdot}5S_y$ $36\,400 < 86\,325$			$S_{max} < 2S_m$ $64\,350 < 90\,450$
Level D service limits	$L_A < 0{\cdot}673L_L$	$L_A < 0{\cdot}471L_L$	$L_A < 0{\cdot}575L_L$	$L_A < 0{\cdot}144L_L$	$L_A < 0{\cdot}251L_L$	$L_A < 0{\cdot}55L_L$

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[a] Except in the case of areas, all units are psi (1 psi = 70·3 g cm^{-2}). Areas are expressed in in^2 (1 in^2 = 6·45 cm^2).

TABLE 5
Testing Program

6 in (15 cm) Pipelock tests	*12 in (30 cm) elbow and safe-end Pipelock tests*
Pressure cycled to 1 275 psi and 2 500 psi	Pressure cycled to 1 250 psi and 1 600 psi
Bending in both directions to $1{\cdot}5S_m$ limit	Bending cycled in both upward and downward directions to $1{\cdot}5S_m$ limit
Design pressure plus bending to $1{\cdot}5S_m$ limit	Pressure plus bending cycled in both directions to $1{\cdot}5S_m$ limiter
Pressure cycled with one shear ring	Sinusoidal and random noise excitation
Thermal cycling—slow and fast down transients	Thermal cycling—slow and fast down transients

in Table 4. In all cases the calculated values are well within allowable limits.

Tests

Tests were performed on 6 in (15 cm) prototype and on full-size 12 in (30 cm) Pipelocks for safe-ends and elbows. The Pipelocks were installed on fully severed pipes. For pressure tests the pipe joint was sealed by an omega seal. The test assembly used for the 12 in Pipelock on a safe-end is shown in Fig. 16. The test assemblies were extensively strain-gaged to monitor the response of the Pipelock and pipe during the tests. The program of tests run on the 6 in and 12 in Pipelocks is outlined in Table 5. The scope of the pressure, bending and pressure plus bending tests is summarized in Table 6. Curves illustrating typical response of the elbow Pipelock assembly are shown in Figs 17–20.

Vibration and thermal tests were also performed on the Pipelocks. The vibration test included sinusoidal and random noise excitation. The loading history for the thermal test is shown in Fig. 21. The bolt stress variation is shown in Fig. 22 and correlates well with the analytically predicted results. Since the austenitic pipe expands more than the ferritic material of the bolts, the initial preload finally reaches a somewhat higher value during steady operation at elevated temperature. During the down-transient, since the thermal response of the pipe is much faster than that of the Pipelock, the pipe contracts more than the Pipelock. Thus, immediately at the end of the down-transient, the bolt preload drops slightly and then builds up again to its initial value as the

TABLE 6

Summary of Tests on Pipelocks in which a Fully Cracked Pipe was Simulated by Abutting Pipes (6 in) or Pipe and Elbow (12 in)

Pipelock size	*Maximum test loads*		*Nominal stress in 6 in pipe and 12 in Sch 80 elbow at max. test loads*			*ASME Code allowable stresses*		
	P (*psi*)	M (*in kips*)	S_p (*ksi*)[a]	$S_p + S_b$ (*ksi*)[b]	S_e (*ksi*)[c]	S_p (*ksi*)[d]	$S_p + S_b$ (*ksi*)[e]	S_e (*ksi*)[f]
6 in	2 550	—	22·8	—	—	20	—	—
	—	342	—	33·5	67	—	30	60
	1 325	262·2	—	37·5	—	—	30	—
12 in	1 600	—	14	—	—	20	—	—
	—	799	—	42·8	—	—	30	—
	—	705	—	38·84	81·64	—	30	60
	1 250	470	—	36·24	—	—	30	—

[a] $S_p = PD_m/2t_n$ where D_m = mean pipe diameter, t_n = nominal wall thickness for 12 in Sch 80 pipe. For 6 in pipe, OD = 6·6 in, ID = 5·9 in.

[b] $S_b = M/Z$ where Z = section modulus of pipe and 12 in Sch 80 elbow (includes stress index for elbow).

[c] S_e = Range due to cycling bending.

[d] $S_p = S_m = 20$ ksi for 304 material at room temperature. This is the basic allowable stress intensity.

[e] $S_p + S_b = 1{\cdot}5S_m = 30$ ksi for 304 material at room temperature.

[f] $S_e = 3S_m = 60$ ksi for 304 material at room temperature.

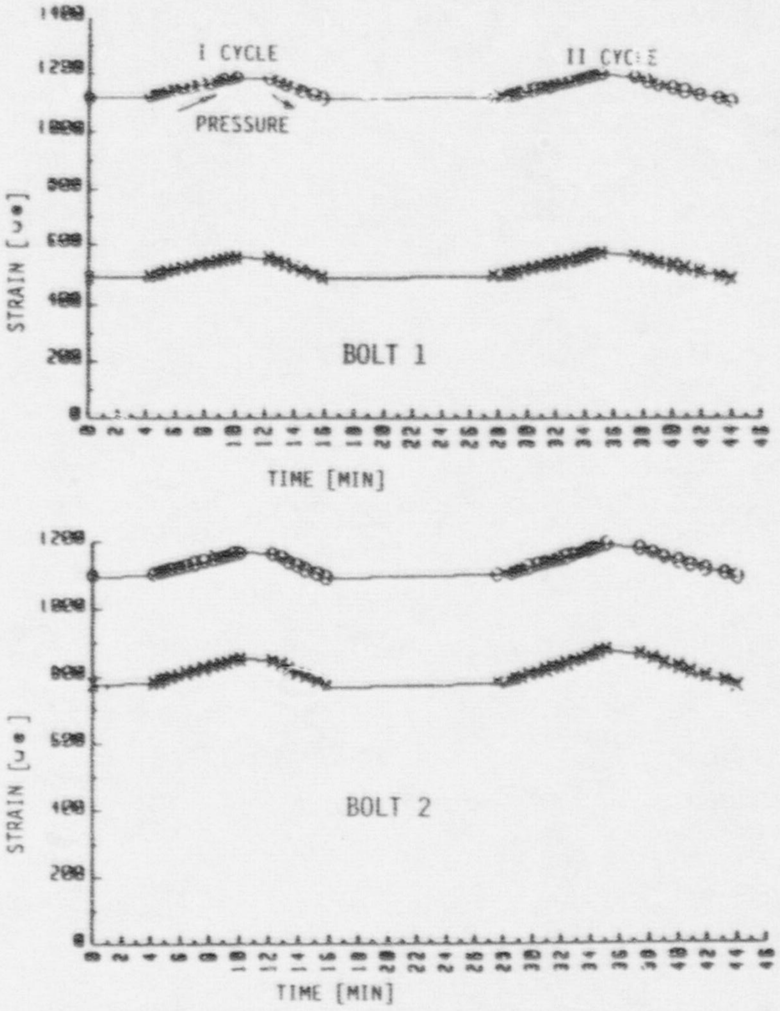

Fig. 17. Axial strain in bolts for pressure cycles: ×——× Channel 41 (Bolt 1), 45 (Bolt 2); ○——○ Channel 44 (Bolt 1), 48 (Bolt 2).

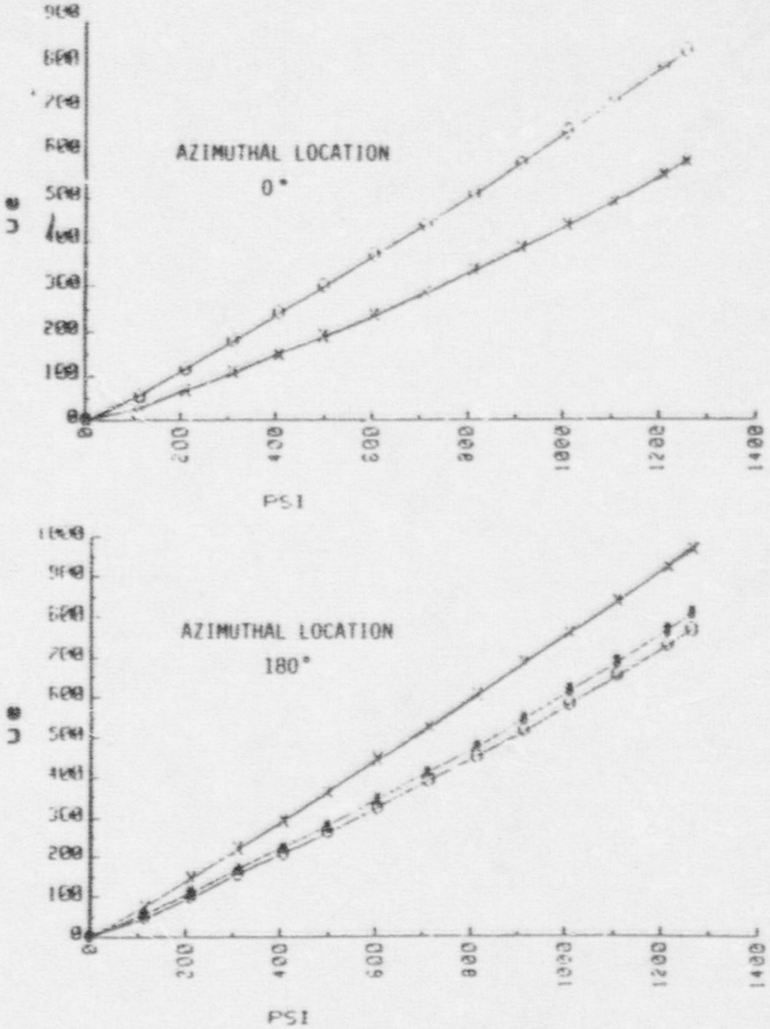

Fig. 18. Axial strain range at crack for increasing pressure to 1250 psi: ×——× Channel 1 (0°), 9 (180°); ○——○ Channel 60 (0°), 61 (189°); —— Channel 63 (180°).

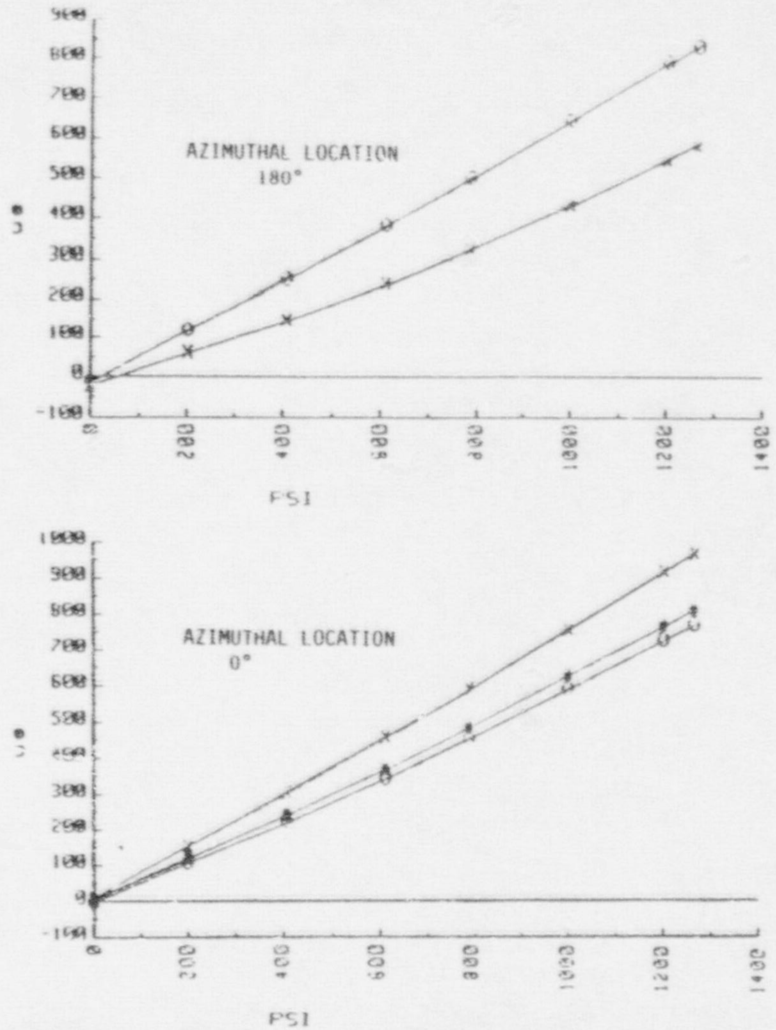

Fig. 19. Axial strain range at crack for decreasing pressure from 1250 psi: ×——× Channel 1 (180°), 9 (0°); ○——○ Channel 60 (180°), 61 (0°); —— Channel 63 (0°).

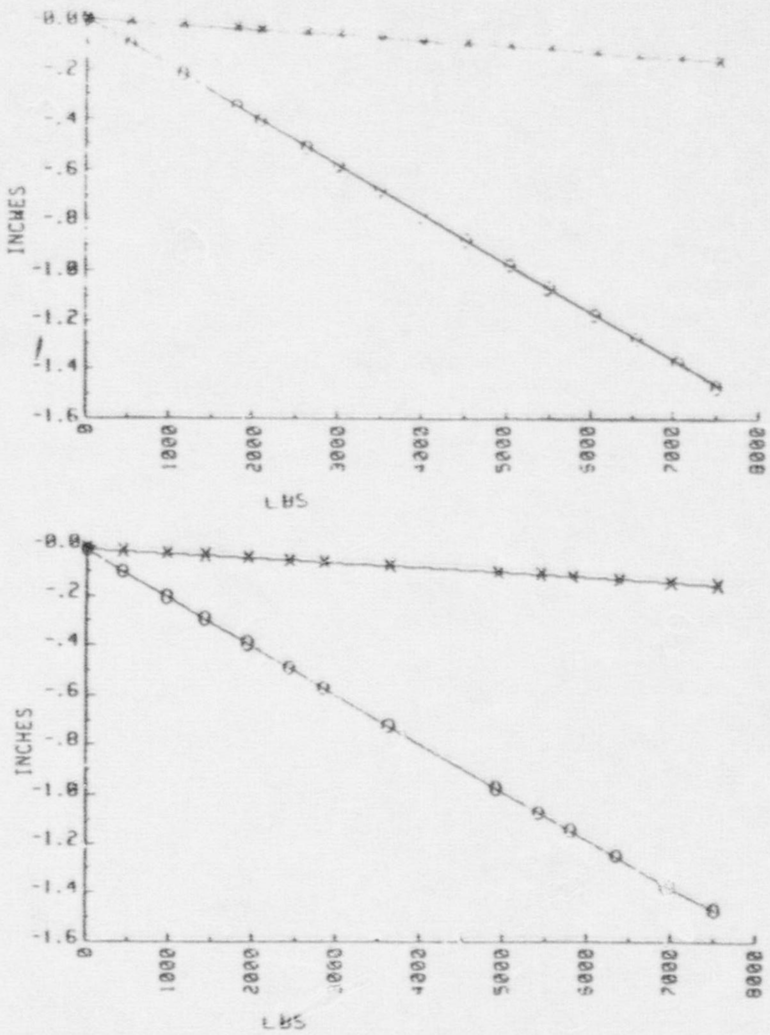

Fig. 20. (a) Displacement increasing inward bend: ×——× Channel 86; ○——○ Channel 87. (b) Displacement decreasing inward bend: key as (a).

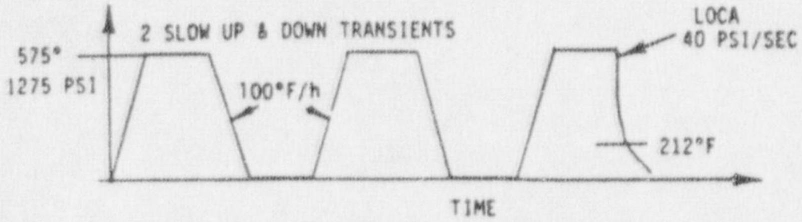

Fig. 21. Load transient for thermal test.

temperature becomes more uniform. These results show that the Pipelock maintains its integrity and prevents the pipe ends from coming apart throughout.

The tests confirmed that the Pipelock fulfills the desired functional requirements and maintains the structural integrity of the severed joint. The response remains linear with loading, returning to the initial state on unloading. Also, no significant loss of preload was observed during repeated load cycling. Thorough inspections after the tests indicated no permanent deformations either in the pipe or in the Pipelock.

Fabrication and installation

Installation of Pipelocks is carried out in four phases as follows:

(1) Preparation of the site, including removal of insulation and potential obstacles such as pipe restraints, cables, etc., installation of platforms and services such as light lifting devices, shields, power, etc., and inspection of weldment.
(2) Survey of pipe at specific locations, area preparation and machining the surface of the pipe.
(3) Assembly of Pipelock.
(4) Refurbishment of site including reinstallation of insulation, removal of construction materials and preparation for return to operational condition.

The first Pipelock was designed for Commonwealth Edison Company, fabricated by Westinghouse Electric Corporation and assembled at Commonwealth Edison Company's Quad Cities station by Power Cutting, Inc., Chicago, Illinois. The Pipelock was installed based on the repair plan issued under provisions of the Code of Federal Regulations 10CFR5059 and ASME Code Section XI. After thorough training on mockup, installation progressed as planned, confirming the proficiency of QA approved procedures. A close-up in Fig. 23 illustrates the last

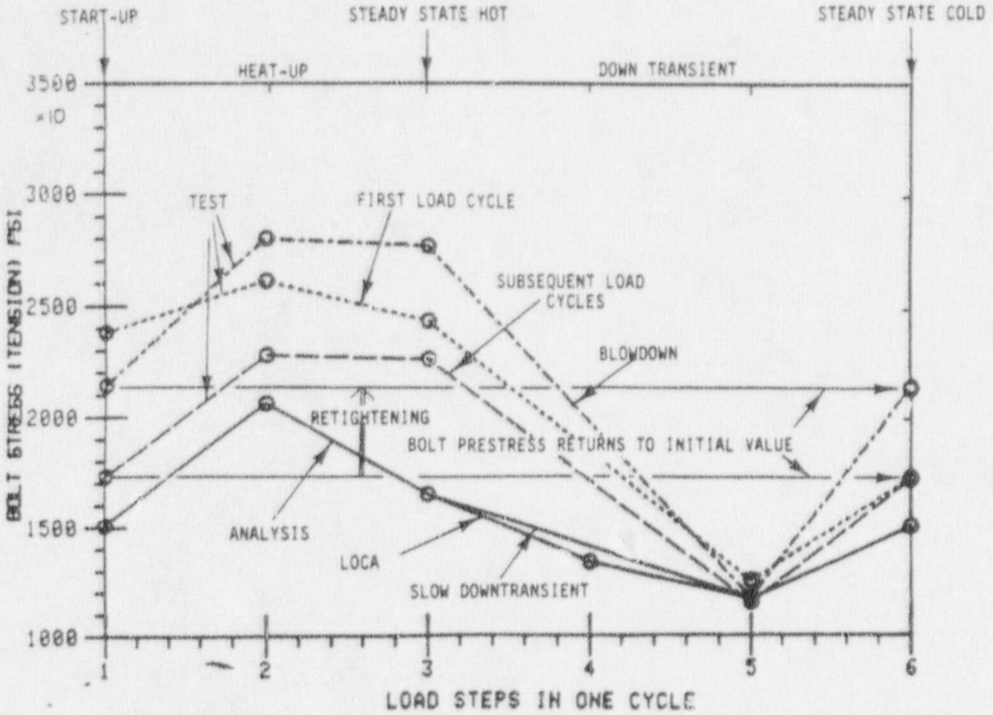

Fig. 22. Bolt stress for transient loading.

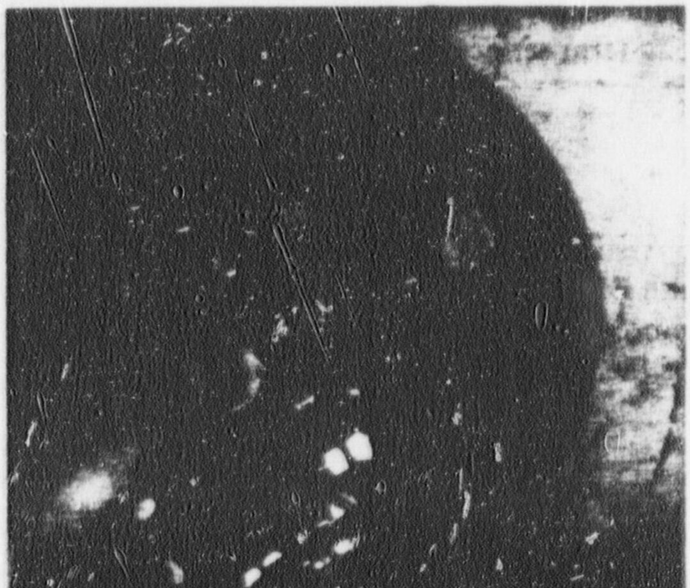

Fig. 23. Pipelock installed in drywell.

phase of installation of the Pipelock on the 12 in riser elbow in the drywell.

CONCLUSIONS

The applicability of Pipelocks as a practical and effective long-term multicycle remedy for intergranular stress corrosion cracking in BWR piping systems has been demonstrated.

Analysis and testing have shown that the Pipelock provides positive mechanical protection against pipe breaks and that pretightening of the Pipelock bolts produces axial and circumferential compressive stresses in the pipe wall at the weldment, thus retarding or eliminating crack growth during subsequent operation.

The installation of Pipelocks does not raise any unreviewed safety questions nor does it bring into question any previously reviewed safety questions. Pipelocks can be implemented without requiring changes in the Technical Specifications. While Pipelocks can be readily disassembled in order to inspect the weldments and reassembled after completing the inspection, they eliminate the need to inspect the weld and quantify crack depths for safety purposes. Pipelocks meet ASME Section III criteria for long-term service.

ACKNOWLEDGEMENTS

O'Donnell & Associates, Inc. gratefully acknowledges the support of Commonwealth Edison Company, Chicago, Illinois; Northeast Utilities, Hartford, Connecticut and Electric Power Research Institute, Palo Alto, California, for the total plan for Pipelock application in BWR plants.

ATTACHMENT 4

REQUEST FOR ADDITIONAL INFORMATION

QUESTION:

What is the affect of shrinkage caused by application of weld overlays on total applied stress in the piping systems?

RESPONSE:

During application of weld overlays, axial shrinkage of the pipe occurs. This shrinkage can change (increase or decrease) the total applied stresses in the piping system. These shrinkage induced stresses are usually very small when compared to the stress resulting from internal pressure, dead weight and thermal expansion. Shrinkage stresses resulting from weld overlays have always been considered during design of weld overlays. Results of these evaluations have been included in our design reports to the NRC concerning repair of IGSCC flaws. The concerns raised by NRR technical reviewers are related to the effectiveness of Stress Improvements (SI). Section 4.5 of NUREG-0313, Revision 2 states that mitigation by SI is not recommended for weldments with service stresses over 1.0 S_m, cracks deeper than 30% of the wall, circumferential cracking longer than 10% of the circumference, or axial cracks of any extent.

Commonwealth Edison has developed and is currently implementing an IGSCC Integrated Program. This program includes application of a standard weld overlay on all flawed welds, both circumferential and axial. For unflawed welds, stress improvement should be considered fully effective provided total sustained stresses are less than 1.5 S_m. This was recognized in the draft version of NUREG-0313, Revision 2.

Attachment 4 is a summary of sustained stresses at each weldment, including shrinkage induced stresses. All weld locations in IGSCC-susceptible systems have sustained stresses less than 1.0 S_m, except one weld in the RHR Loop A (10AD-F1), one weld in the RHR Loop B (10BD-F1), one weld in the Shutdown Cooling System (10S-F1) and six welds on the recirculation system (02D-F2, 02G-F2, 02J-F2, 02L-F2, 02L-S3, and 02M-F2). Of these, 02L-F2 has sustained stress greater than 1.5 S_m.

The recirculation system has been evaluated from a weld overlay shrinkage standpoint to determine ways of reducing the shrinkage stresses. As a result of this evaluation, one weld overlay will be applied on an unflawed weld (02L-S4) during the upcoming outage to reduce the sustained stress at 02L-F2 below 1.5 S_m.

ATTACHMENT 4

Quad Cities Unit 1
Sustained Stresses at IGSCC Susceptible Weld Locations

Introduction

This evaluation is limited to those susceptible systems listed in CECo's response to Generic Letter 88-01, for Quad Cities Unit 1. These systems are as follows:

- A) Recirculation System
- B) Shutdown Cooling
- C) RHR Lines
- D) Core Spray
- E) Reactor Water Clean-up
- F) CRD Return System
- G) Jet Pump Instrumentation
- H) Head Vent
- I) Spare Nozzles

Summary of Evaluation Results

Sustained stress level at a weld location consists of unintensified internal pressure, dead weight, thermal expansion and weld overlay shrinkage stresses. In performing this evaluation, the possibility was explored whether for systems without weld overly repairs, the sustained stress limits specified in NUREG-0313 are bounded by the code allowables used in the design of these systems. It was realized that for plants, designed under USAS B31.1, a general statement to this effect cannot be made because the design allowables are not related to S_m. Furthermore, stress intensification factors used in the design make such evaluation incompatible with the requirements of NUREG-0313. The sustained stresses were therefore calculated on a system unique basis for the susceptible systems listed above. Excluded in this evaluation are the jet pump instrumentation, head vent and spare nozzles which are affected only by internal pressure stress which is less than 1.0 S_m.

A - Recirculation System

Welds contained in this evaluation are those contained in the suction and discharge lines, the risers and all the N1 and N2 nozzle-to-safe end welds. Excluded in the evaluation are all the saddle welds which are assumed to be solution heat treated and therefore are Category A weldments under NUREG-0313. Most welds in this system have received SI treatment. A total of twenty-four (24) flawed welds in this system have been repaired with weld overlays. The locations of these overlays are shown in Figures 1 and 2.

These overlays have introduced shrinkage stress that contribute to the total sustained stress at unrepaired weld locations. Sustained stress for welds in this system therefore consist of internal pressure, deadweight, thermal expansion and weld overlay shrinkage stresses. The sustained stresses calculated for the various weld locations are shown in Table 1. It can be seen from this table that six (6) welds have sustained stress greater than 1.0 S_m. These are welds 02D-F2, 02G-F2, 02J-F2, 02L-F2, 02L-S3, and 02M-F2. Of these only 02L-F2 has sustained stress greater than 1.5 S_m. Weld overlay shrinkage stresses contribute significantly to the sustained stresses of these weld locations. Weld overlay repairs will be performed on several welds of the recirculation system during the upcoming outage. These repairs could introduce additional shrinkage in the system which could significantly change the shrinkage stresses at the various weld locations which could in turn change the sustained stresses. The magnitude of the shrinkage stresses is affected by the distribution of weld overlay repairs in the system. Non-uniform distribution of those repairs in the system has the potential of introducing significant stresses. Therefore weld overlay repairs are being applied at unflawed locations to provide uniform distribution of weld overlays and reduce the shrinkage stresses.

B - Shutdown Cooling

The welds considered in this evaluation are contained in the piping between drywell penetration X-12 and the connection the recirculation system loop B. There are no weld overlay repairs on this system, hence sustained stresses consist of internal pressure, dead weight and thermal expansion stresses. The sustained stresses are shown in Table 2. Other than weld 10S-F1 which has a sustained stress of 1.09 S_m, all other welds have sustained stresses no greater than 1.0 S_m.

C. - RHR Lines

The welds considered in this evaluation are contained in the piping between drywell penetration X-13A and X-13B to the recirculation system discharge for Loops A and B respectively. There are no weld overlay repairs on these lines and the effect of weld overlay shrinkage from the recirculation system is negligible on these lines. There is one unrepaired flawed weld (10BD-S13) on this system; the location of this weld is shown in Figure 3. The sustained stresses consisting of internal pressure, dead weight and thermal expansion stresses are shown in Table 3. It can be seen from this table that with the exception of welds 10AD-F1 and 10BD-F1, the sustained stresses at all weld locations are less than 1.0 S_m. Welds 10AD-F1 and 10BD-F1 are unflawed and have sustained stresses of 1.37 S_m and 1.09 S_m respectively which are below 1.5 S_m.

D - Core Spray

The welds considered in this evaluation are between the reactor pressure vessel and penetrations X-16A and X-16B for loops A and B respectively. There are four weld overlay repairs on A loop and two on the B loop as shown in Figures 4 and 5. Total sustained stresses therefore consist of internal pressure, dead weight, thermal expansion and weld overlay shrinkage stresses as shown in Table 3. From this table it can be seen that for all weld locations, the sustained stresses are below 1.0 S_m. Additional weld overlay repairs will be performed on these lines during the upcoming outage which could change the shrinkage stresses. However, due to the flexibility of these lines, shrinkage stresses do not contribute significantly to the sustained stresses as can be seen from Table 4.

E - Reactor Water Clean-up

The welds considered in this evaluation are contained between the attachment to the shutdown cooling and penetration X-14. There are no weld overlays present on this system hence sustained stresses consist of internal pressure, dead weight and thermal expansion stresses. These are summarized in Table 5. As can be seen from this table, sustained stresses for all welds are less than 1.0 S_m.

F - CRD Return Line

Welds considered in this evaluation are contained between the reactor pressure vessel and penetration X-36. No weld overlay repairs have been performed on this system hence sustained stresses consist of internal pressure, dead weight and thermal expansion stresses. These stresses are summarized in Table 6. The sustained stresses for all welds in this evaluation are below 1.0 S_m.

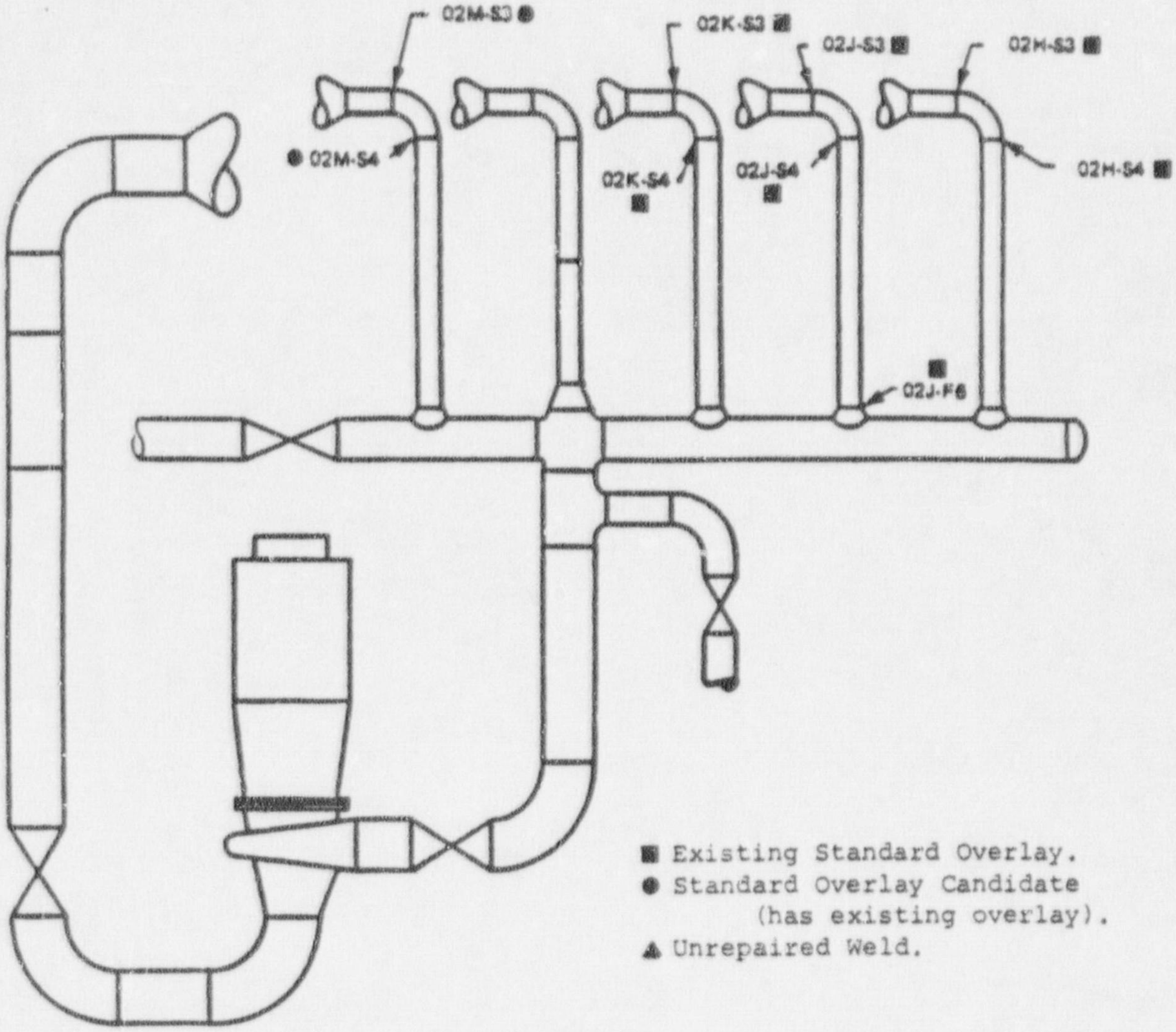

Figure 1

QUAD CITIES UNIT 1

FLAWED WELD LOCATIONS

REACTOR RECIRCULATION SYSTEM LOOP "A"

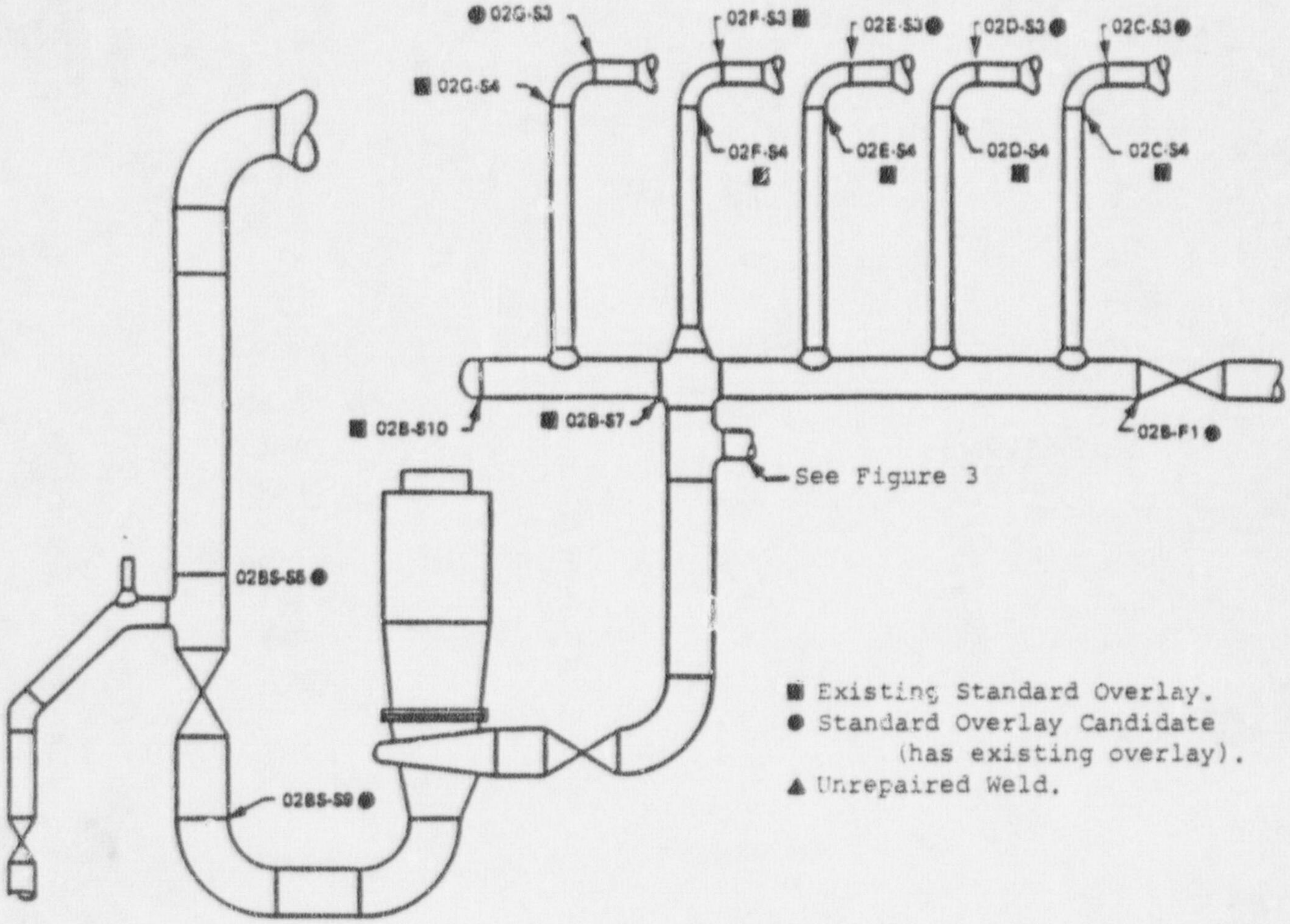

Figure 2

QUAD CITIES UNIT 1

FLAWED WELD LOCATIONS

REACTOR RECIRCULATION SYSTEM LOOP "B"

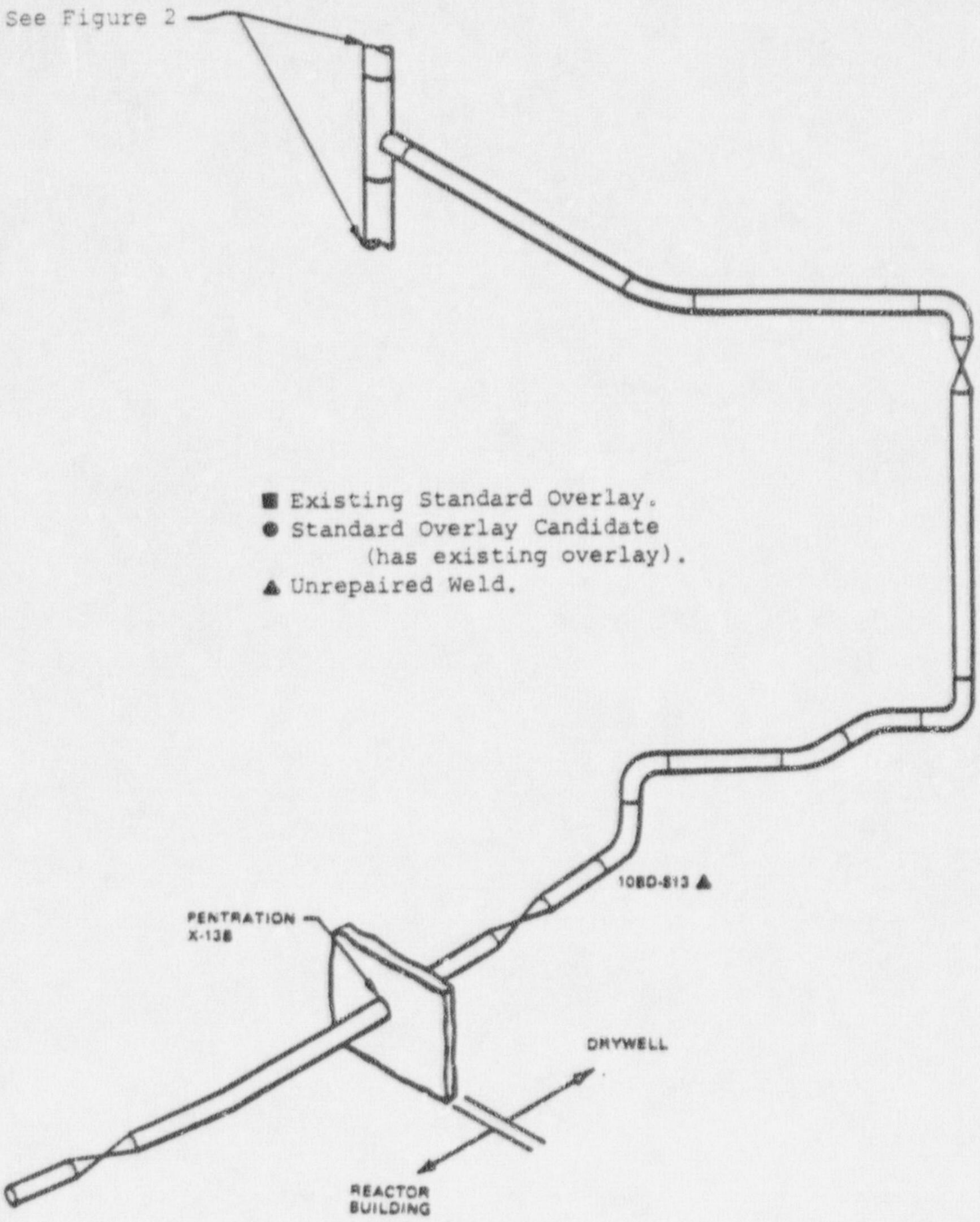

Figure 3

QUAD CITIES UNIT 1

FLAWED WELD LOCATIONS

RESIDUAL HEAT REMOVAL (RHR) SYSTEM LOOP "B"

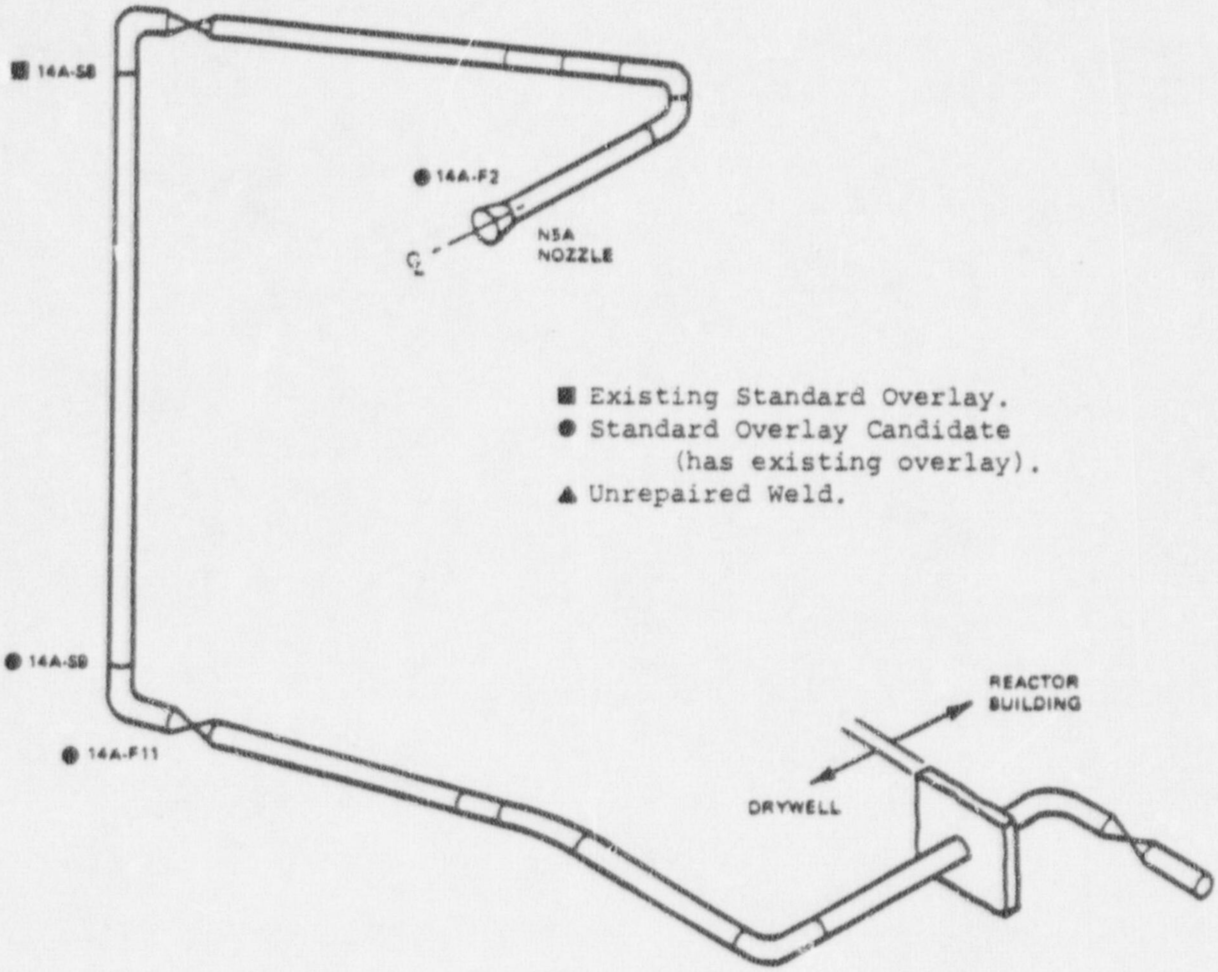

Figure 4

<u>QUAD CITIES UNIT 1</u>

<u>FLAWED WELD LOCATIONS</u>

<u>CORE SPRAY SYSTEM LOOP "A"</u>

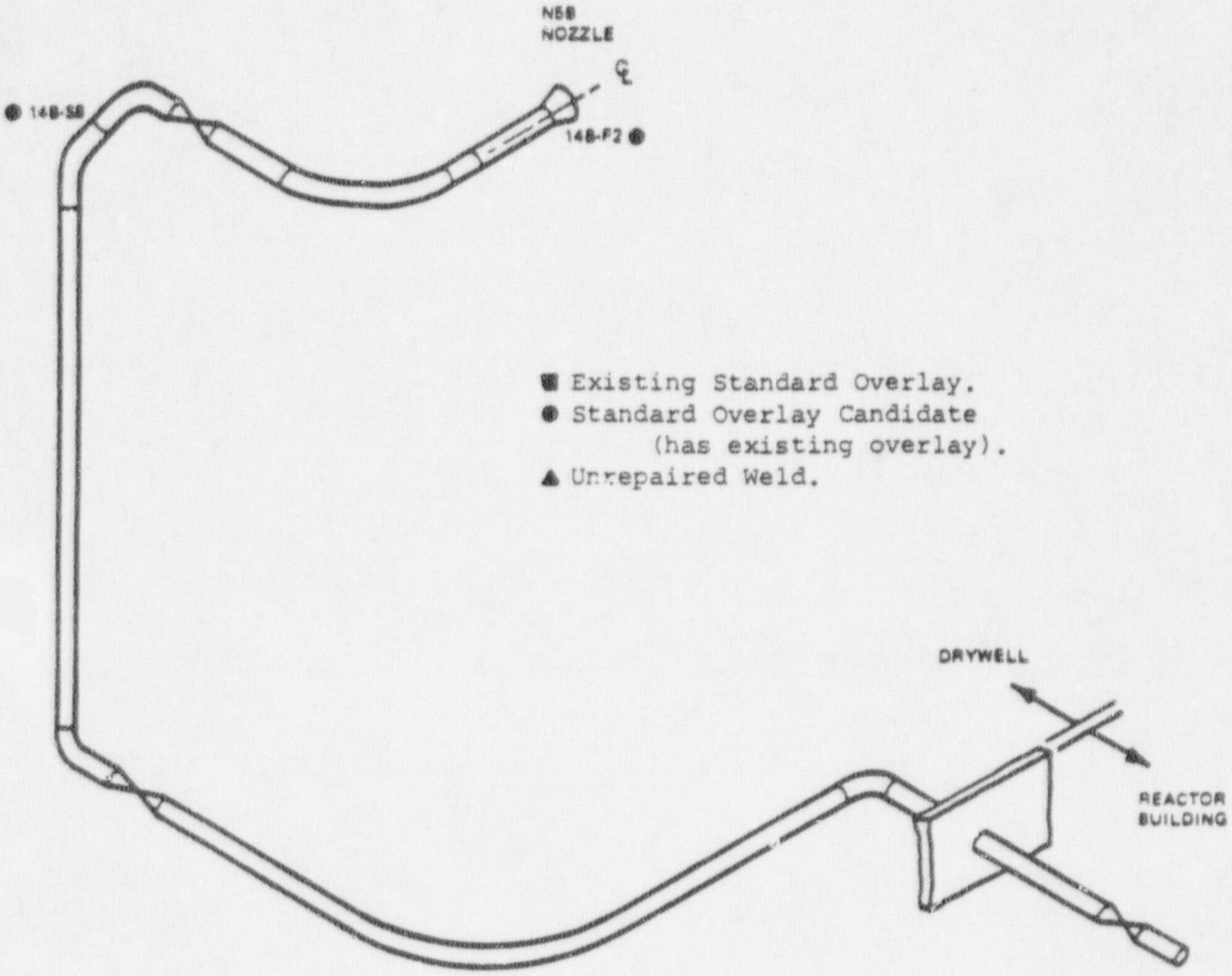

Figure 5

QUAD CITIES UNIT 1

FLAWED WELD LOCATIONS

CORE SPRAY SYSTEM LOOP "B"

Table 1

QUAD CITIES UNIT 1

SUSTAINED STRESSES

RECIRCULATION SYSTEM

WELD NO.	PRESSURE STRESS (PSI)	DW STRESS (PSI)	THERMAL STRESS (PSI)	SHRINKAGE STRESS (PSI)	SUSTAINED STRESS (PSI)	RATIO TO Sm
02AS-F1	6439	225	101	250	7015	0.41
02AS-F2	6439	225	101	250	7015	0.41
02AS-S3	6439	162	101	266	6967	0.41
02AS-S4	6439	88	90	276	6892	0.41
02AS-F5	6439	88	90	268	6885	0.41
02AS-S6	6439	223	23	182	6867	0.41
02AS-F8	6439	223	23	152	6837	0.40
02AS-F9	6439	200	39	156	6834	0.40
02AS-S12	6439	48	50	136	6672	0.39
02AS-F14	6439	50	50	118	6657	0.39
02AS-S15	6439	56	41	99	6635	0.39
02AD-F12	6439	330	37	94	6898	0.41
02AD-F9	6439	582	31	35	7087	0.42
02AD-F8	6439	185	30	20	6673	0.39
02AD-S6	6439	48	25	62	6573	0.39
02AD-S2	6439	111	62	460	7071	0.42
02AD-F1	6439	111	62	592	7203	0.42
02BS-F1	6439	112	5629	245	12425	0.73
02BS-F2	6439	112	5629	245	12425	0.73
02BS-S3	6439	68	4371	207	11085	0.65
02BS-F4	6439	68	4371	207	11085	0.65
02BS-S5*	6439	64	3055	220	9778	0.58
02BS-F6*	6439	215	3568	241	10462	0.62
02BS-F7	6439	210	2408	273	9329	0.55
02BS-S9	6439	90	634	322	7484	0.44
02BS-S12	6439	56	614	291	7400	0.44
02BS-F14	6439	56	630	283	7408	0.44
02BS-S15	6439	37	409	245	7130	0.42
02BD-F12	6439	448	1873	231	8991	0.53
02BD-F9	6439	607	1881	122	9048	0.53
02BD-F8	6439	237	1962	29	8667	0.51
02BD-S6	6439	46	1832	91	8408	0.50
02BD-S2	6439	76	4606	264	11384	0.67
02BD-F1	6439	76	4606	210	11330	0.67
02B-F6	6439	20	154	237	6850	0.40
02A-F1	6290	199	674	1403	8567	0.51
02A-S3	6290	101	366	4192	10948	0.65
02A-F5	6290	186	324	7469	14269	0.84
02A-S9	6290	0	0	0	6290	0.37
02B-F1*	6290	334	508	1330	8461	0.50

Table 1
(Continued)

QUAD CITIES UNIT 1

SUSTAINED STRESSES

RECIRCULATION SYSTEM

WELD NO.	PRESSURE STRESS (PSI)	DW STRESS (PSI)	THERMAL STRESS (PSI)	SHRINKAGE STRESS (PSI)	SUSTAINED STRESS (PSI)	RATIO TO Sm
02B-F5	6290	404	5979	715	13388	0.79
02B-S7*	6290	395	3154	173	10012	0.59
02B-S9*	6290	0	0	0	6290	0.37
02-F1	6290	66	674	1373	8403	0.50
02-F1D	6290	459	566	1372	8687	0.51
02-F1E	6290	459	566	1372	8687	0.51
02-F2	6290	459	566	1367	8682	0.51
02C-F1	3558	579	758	1938	6832	0.40
02C-F2	5800	1096	1435	3669	11999	0.71
02C-S3*	5800	535	1292	1855	9482	0.56
02C-S4*	5800	348	666	2765	9579	0.57
02C-F6	5800	319	2237	3095	11451	0.68
02D-F1	3558	280	1849	3946	9633	0.57
02D-F2	5800	531	3502	7474	17306	1.02
02D-S3*	5800	317	2623	4797	13537	0.80
02D-S4*	5800	143	757	2540	9240	0.55
02D-F6	5800	223	3415	3050	12487	0.74
02E-F1	3558	237	3566	1044	8404	0.50
02E-F2	5800	448	6754	1093	14095	0.83
02E-S3	5800	251	4283	1105	11439	0.67
02E-S4	5800	149	1769	754	8472	0.50
02E-F6A	5800	462	3957	856	11075	0.65
02E-F6	5800	462	3957	1977	12195	0.72
02F-F1	3558	548	1697	1472	7274	0.43
02F-F2	5800	1038	3215	2786	12838	0.76
02F-S3*	5800	529	2277	1547	10153	0.60
02F-S4*	5800	283	1465	2231	9779	0.58
02F-F6	5800	191	1495	1677	9163	0.54
02G-F1	3558	249	2909	2885	9601	0.57
02G-F2	5800	472	5509	5464	17245	1.02
02G-S3*	5800	258	3862	1665	11585	0.68
02G-S4*	5800	103	1141	895	7939	0.47
02G-F6	5800	205	3036	1764	10805	0.64
02H-F1	3558	94	192	4762	8605	0.51
02H-F2	5800	177	363	9018	15359	0.91
02H-S3*	5800	81	315	6506	12702	0.75
02H-S4*	5800	76	245	2623	8743	0.52
02H-F6	5800	163	462	8903	15327	0.90
02J-F1	3558	116	202	6647	10522	0.62
02J-F2	5800	219	382	12587	18988	1.12
02J-S3*	5800	144	306	6835	13085	0.77

Table 1
(Concluded)

QUAD CITIES UNIT 1

SUSTAINED STRESSES

RECIRCULATION SYSTEM

WELD NO.	PRESSURE STRESS (PSI)	DW STRESS (PSI)	THERMAL STRESS (PSI)	SHRINKAGE STRESS (PSI)	SUSTAINED STRESS (PSI)	RATIO TO Sm
02J-S4*	5800	103	140	8483	14526	0.86
02J-F6*	5800	364	352	3959	10475	0.62
02K-F1	3558	151	394	2018	6120	0.36
02K-F2	5800	285	747	3818	10649	0.63
02K-S3*	5800	196	544	3963	10503	0.62
02K-S4*	5800	62	126	2773	8761	0.52
02K-F6	5800	359	641	9905	16704	0.99
02L-F1	3558	545	269	9933	14304	0.84
02L-F2	5800	1032	510	18810	26151	1.54
02L-S3	5800	577	502	11962	18841	1.11
02L-S4	5800	236	365	9051	15452	0.91
02L-F6	5800	271	808	6993	13872	0.82
02M-F1	3558	1023	362	6443	11386	0.67
02M-F2	5800	1938	685	12201	20624	1.22
02M-S3*	5800	1020	660	7707	15186	0.90
02M-S4*	5800	512	480	5493	12285	0.72
02M-F6	5800	366	1042	8482	15689	0.93
02M-F7	5800	366	1042	8482	15689	0.93
4031-5-A7	4173	0	0	0	4173	0.25
4031-5-A8	4173	0	0	0	4173	0.25
4031-5-A5	4173	0	0	0	4173	0.25
4031-5-A6	4173	0	0	0	4173	0.25
4031-5-B3	4173	0	0	0	4173	0.25
4013-5-B4	4173	0	0	0	4173	0.25
4031-5-B1	4173	0	0	0	4173	0.25
4031-5-B2	4173	0	0	0	4173	0.25

* These welds have been overlay repaired. The overlay thickness is not included in the stress evaluation.

Table 2

QUAD CITIES UNIT 1

SUSTAINED STRESSES

SHUTDOWN COOLING

WELD NO.	P+DW STRESS (PSI)	THERMAL STRESS (PSI)	SUSTAINED STRESS (PSI)	RATIO TO Sm
10S-F1	10033	8463	18496	1.09
10S-S3	6631	5902	12533	0.74
10S-S4	6845	8541	15386	0.91
10S-F5	6710	8989	15699	0.93
10S-F6	6977	9926	16903	1.00
10S-S7	6688	8824	15512	0.92
10S-F8	6710	9223	15933	0.94
10S-S9	6929	8794	15723	0.93
10S-S11	6815	8927	15742	0.93
10S-S12	6570	9555	16125	0.95
10S-F13	6608	8929	15537	0.92

Table 3

QUAD CITIES UNIT 1

SUSTAINED STRESSES

RHR LINES

	WELD NO.	P+DW STRESS (PSI)	THERMAL STRESS (PSI)	SUSTAINED STRESS (PSI)	RATIO TO Sm
A LOOP					
	10AD-F1	6138	17027	23165	1.37
	10AD-S3	6016	8412	14428	0.85
	10AD-F4	5952	8868	14820	0.87
	10AD-F5	5963	8315	14278	0.84
	10AD-S6	5982	10178	16160	0.95
	10AD-S7	6035	7881	13916	0.82
	10AD-S8	6048	3893	9941	0.59
	10AD-F9	5993	7633	13626	0.80
	10AD-S10	6067	5353	11420	0.67
	10AD-F12	6196	3054	9250	0.55
	10AD-F13	6007	8496	14503	0.86
B LOOP					
	10BD-F1	9098	9382	18480	1.09
	10BD-S2	5976	8891	14867	0.88
	10BD-S3	5994	8498	14492	0.85
	10BD-S4	6007	8062	14069	0.83
	10BD-F5	6004	6445	12449	0.73
	10BD-F6	6015	5164	11179	0.66
	10BD-S7	6056	6278	12334	0.73
	10BD-S8	6092	5735	11827	0.70
	10BD-F9	6104	3521	9625	0.57
	10BD-S10	6095	2090	8185	0.48
	10BD-F11	6094	2106	8200	0.48
	10BD-S12	6114	4960	11074	0.65
	10BD-S13	6025	4837	10862	0.64
	10BD-F15	6581	2117	8698	0.51
	10BD-F16	6691	2726	9417	0.56

Table 4

QUAD CITIES UNIT 1

SUSTAINED STRESSES

CORE SPRAY SYSTEM

WELD NO.	PRESSURE STRESS (PSI)	DW STRESS (PSI)	THERMAL STRESS (PSI)	SHRINKAGE STRESS (PSI)	SUSTAINED STRESS (PSI)	RATIO TO Sm
14A-F1	5733	225	6787	1707	14453	0.85
14A-F2*	5733	508	6787	1689	14717	0.87
14A-F3R	5733	508	6787	1629	14658	0.86
14A-F4AR	5733	508	6787	1182	14211	0.84
14A-S4AR	5733	508	6787	1110	14139	0.83
14A-S4BR	5733	508	6787	1000	14029	0.83
14A-F4CR	5733	508	6787	1000	14029	0.83
14A-S4DR	5733	508	6787	1000	14029	0.83
14A-F4ER	5733	508	6787	716	13745	0.81
14A-F6	5733	471	5862	679	12745	0.75
14A-F7	5733	420	8140	794	15088	0.89
14A-S3*	5733	151	8458	1207	15548	0.92
14-S9*	5733	135	7026	1716	14610	0.86
14A-F11*	5733	315	5553	1757	13358	0.79
14A-F12	5733	549	3573	1252	11108	0.66
14A-F12A	5733	549	3573	1202	11057	0.65
14A-S13	5733	163	2102	543	8541	0.50
14A-S14	5733	18	2149	358	8258	0.49
14A-S15	5733	275	4888	1099	11995	0.71
14A-F17	5733	218	5955	1214	13119	0.77
14B-F1	5733	1091	6373	440	13637	0.80
14B-F2*	5733	1091	6373	434	13631	0.80
14B-F4R	5733	1091	6373	415	13612	0.80
14B-F5R	5733	1091	6373	315	13512	0.80
14B-S5AR	5733	1091	6373	328	13525	0.80
14B-F5BR	5733	1091	6373	305	13502	0.80
14B-F6AR	5733	350	9052	250	15385	0.91
14B-F7	5733	421	7196	133	13483	0.80
14B-S8*	5733	195	4988	80	10996	0.65
14B-S9	5733	195	4988	180	11096	0.65
14B-S10	5733	191	2978	397	9299	0.55
14B-F12	5733	308	2350	475	8866	0.52
14B-F13	5733	602	2357	377	9069	0.54
14B-S14	5733	300	6037	169	12238	0.72
14B-F15	5733	224	6600	198	12756	0.75

* These welds have been overlay repaired. The overlay thickness is not considered in the stress evaluation.

Table 5

QUAD CITIES UNIT 1

SUSTAINED STRESSES

REACTOR WATER CLEAN-UP SYSTEM

WELD NO.	P+DW STRESS (PSI)	THERMAL STRESS (PSI)	SUSTAINED STRESS (PSI)	RATIO TO Sm
12S-S1	7801	5780	13581	0.80
12S-F3R	5296	5370	10666	0.63
12S-F2R	5296	5370	10666	0.63
12S-F4R	5446	4748	10194	0.60
12S-F4AR	5446	4748	10194	0.60
12S-F4CR	5116	2964	8080	0.48
12S-S4DR	5079	946	6025	0.36
12S-S5R	5073	1692	6765	0.40
12S-F6R	5688	4125	9813	0.58
12S-S6AR	6038	6679	12717	0.75
12S-S7R	6065	6739	12804	0.76
12S-S8R	6409	4315	10724	0.63
12S-S9R	6507	4107	10614	0.63
12S-S9AR	6656	3571	10227	0.60
12S-F10R	6495	2178	8673	0.51
12S-S11R	6543	2308	8851	0.52
12S-S12R	6463	2082	8545	0.50
12S-S13R	6689	3260	9949	0.59
12S-S14R	6671	3247	9918	0.59
12S-S15R	6196	1912	8108	0.48
12S-S16R	6192	1573	7765	0.46
12S-S17R	7033	2295	9328	0.55
12S-S18R	6690	2359	9049	0.53
12S-S19R	5762	1862	7624	0.45
12S-F20R	5559	1603	7162	0.42
12S-F21R	5330	1838	7168	0.42
12S-F22R	5316	2249	7565	0.45
12S-F23R	5663	2287	7950	0.47

Table 6

QUAD CITIES UNIT 1

SUSTAINED STRESSES

CRD RETURN LINE

WELD NO.	P+DW STRESS (PSI)	THERMAL STRESS (PSI)	SUSTAINED STRESS (PSI)	RATIO TO Sm
03-F8	4661	945	5606	0.33
03-F7	5555	1104	6659	0.39
03-F6	5813	1187	7000	0.41
03-F5	9009	2965	11974	0.71
03-F4	9009	2965	11974	0.71
03-S3	6586	4904	11490	0.68
03-S2	6615	5689	12304	0.73
03-F1	9537	6654	16191	0.96
03-F1A	9537	6654	16191	0.96