VERMONT YANKEE NUCLEAR POWER CORPORATION

1984 Refuel Outage Augmented In-Service Inspection Program - Final Report

Prepared by

Yankee Atomic Electric Company

TABLE OF CONTENTS

TABLE OF CONTENTS

V. LIST OF FIGURES

I. INTRODUCTION AND PROGRAM OVERVIEW

In response to the NRC's Generic Letter 84-11, dated April 19, 1984 [Reference (b)], Vermont Yankee Nuclear Power Corporation performed an augmented in-service reinspection of Recirculation and Residual Heat Removal System piping during the 1984 refueling outage.

This report contains our assessment of indications found in piping as a result of that inspection, as well as the repair and/or evaluation techniques utilized to ensure recirculation system integrity for the next operating cycle.

Contained within, as part of this report, are numerous Enclosures, Attachments, Figures, and Tables which provide the details of our 1984 Augmented ISI Program. The report also includes comparisons of our 1984 program with certain aspects of our 1983 program.

II. SUMMARY

- An extensive ultrasonic examination was conducted on welds in the recirculation and residual heat removal systems in accordance with the provisions of of Generic Letter 84-11, except as discussed in Item 7 of Enclosure 1. Results are contained in Section V and detailed in Enclosure 2 to this report.

- Weld overlays applied during the 1983 refueling outage were reinspected in accordance with the criteria of Generic Letter 84-11. The inspection included weld overlay integrity and bond of overlay to base metal.

  No indications were found in any overlay.

- Weld Joint 32 which had a mini-overlay applied at the 1983 refueling outage was further overlayed. The overlay at this joint is now structural.

- Weld Joint RHR-32-4, which had a small axial indication, was overlayed in accordance with appropriate criteria.

- In the 1984 inspection, no flaw indications were found in the 12" diameter welds. All 12" susceptible welds have been examined at least once during either the 1983 or 1984 inspection.

- In the 1984 inspection, only one small axial flaw was found in the 20" diameter welds. All 20" susceptible welds have been examined at least once during either the 1983 or 1984 inspection.

- In the 1984 inspection, no flaw indications were found on the 24" RHR piping. No flaw indications were found in the 1983 inspection.

- For the large diameter 22" header and 28" suction and discharge piping welds with indications of Intergranular Stress Corrosion Cracking (IGSCC), linear elastic fracture mechanics analyses have been conducted which show that flaw growth during the next cycle of operation is sufficiently small so as to permit operation without

repair. Acceptance criteria for the evaluation are established in Enclosure 2 to this report. All susceptible 22" piping has been inspected at least once during the 1983 and 1984 inspections. Twenty five out of 33 28" susceptible welds have been inspected at least once in the 1983 and 1984 inspection.

- In the 1984 inspection, the new flaw find rate was 18% (10 out of 57) as compared to 59% (34 out of 58) in 1983. These results confirm the assessment that the most susceptible welds were selected for inspection in 1983 and that the selection criteria are sound.

- The twenty-two weld overlays applied during the 1983 refueling outage are now all structural overlays of low carbon (.025%) and high ferrite content. The structural integrity of these overlays was demonstrated in our letters dated March 13, 1984 [Reference (c)] and May 15, 1984 [Reference (d)].

- Weld joints with indications of IGSCC were conservatively evaluated. These evaluations indicate that the flaws are relatively short and shallow. Predicted flaw growth is very small in the next cycle of operation.

- Our pipe replacement contractor studied the drywell arrangement, identified interferences, and established plans for the 1985 pipe replacement. Utilizing this extensive pre-planning, an efficient replacement effort with a minimum of personnel radiation exposure will be conducted.

III. ADDITIONAL EFFORTS TO ADDRESS IGSCC CONCERNS

- We are replacing all Recirculation System and stainless steel Residual Heat Removal (RHR) System piping with seamless Type 316 nuclear grade stainless steel during the 1985 refueling outage.

- Reactor Water Cleanup (RWCU) piping was replaced during the 1980 and 1981 refueling outages with low carbon stainless steel.

- Susceptible Core Spray piping was replaced in 1977 with low carbon stainless steel.

- Recirculation Bypass piping was replaced in 1976 with cast stainless steel.

- Sections of other nonsusceptible piping systems are also under consideration for replacement in 1985. These include:

  - Remaining Core Spray piping which operates at $<200^{o}$F, and

  - Vessel bottom head drain line.

- Plant procedures have been revised to require enhanced Reactor Coolant System leak rate monitoring, surveillance frequencies, and corrective actions consistent with those described in Enclosure 3 to this report.

- A local leak detection system will be installed to monitor eight (8) 28" uninspected joints. This system is discussed in Enclosure 3 to this report.

IV. JUSTIFICATION FOR CONTINUED OPERATION

The evaluation of the overlayed weld joints and affected large bore weld joints indicate that flaw growth is acceptable for all design conditions. The justification for operation for a second cycle of operation with weld overlays was provided in our letter, dated March 13, 1984 [Reference (c)]. The results of this inspection confirm the basis presented for the integrity of the overlays.

Acceptance criteria for the analyses of large and small bore piping are established in Enclosure 2 of this report. These analyses demonstrate that there is no loss of design safety margin over that provided by the rules for Class I piping in the ASME Boiler and Pressure Vessel Code, Section III.

For these reasons, we conclude that the operation of Vermont Yankee for another cycle of operation is justified.

ENCLOSURE 1

DETAILS OF THE 1984 AUMENTED

INSERVICE INSPECTION PROGRAM

ENCLOSURE 1

DETAILS OF THE VERMONT YANKEE AUGMENTED IN-SERVICE INSPECTION PROGRAM TO ADDRESS INTERGRANULAR STRESS CORROSION CRACKING

1. 1984 Inspection Techniques

The Ultrasonic Examination Program utilized in completion of the Vermont Yankee 1984 refuel outage was planned and executed with the following as its primary attributes:

a. Utilize both equipment and personnel demonstrated as qualified in accordance with the EPRI NDE Center course, "U.T. Operator Training for the Detection of IGSCC".

b. Utilize equipment capable of producing "hard copy" examination results.

c. Utilize equipment capable of manipulating examination data "off-line" allowing for analysis of data in a non-radiation environment.

d. Provide redundant levels of evaluation techniques to compliment the basic discrimination techniques.

e. Size detected and discriminated flaws in accordance with a program demonstrated capable of providing accurate through wall dimensions. The EPRI NDE Center, UT operator training for planar flaw sizing was utilized to provide assurances in this respect.

To this end an examination program significantly different than that used in 1983 (see Attachment A) was devised and implemented. The primary detection phase of the program was relegated to the P-Scan System as deployed by Independent Testing Laboratory (ITL) of Searcy, Arkansas (see Attachment B). The P-Scan System, used in conjunction with the MWS-2 semi-automatic scanner, provided the primary means for acquisition of detection and discrimination data. This system was coupled to standard, contact type 2.25 megahertz shear wave transducers. The primary detection angle used was 45° nominal with 52° nominal used for additional investigation and to a very limited extent to compensate for coverage limitations of the 45° probe. Individuals qualified through the EPRI NDE Center analyzed all P-Scan data and provided disposition. P-Scan dispositions were made primarily on spatial parameters all of which were compared to construction documentation and actual as-built measurements obtained during pre-examination investigation.

Calibration of the system is established using a 10% ID notch in a basic code calibration standard. Once basic reference is established P-Scan records the presence of all ultrasonic reflectors to approximately -64 Db of this 10% notch reference reflector.

It is the ability to look for flaws far below normal recording levels which permits P-Scan to detect small or off-axis flaws without swiveling the search unit. P-Scan presents a high confidence for detection of all indications having any circumferential component as is the case with most

IGSCC flaws. In EPRI tests P-Scan has demonstrated an ability to detect pure "axial" flaws without benefit of additional compensatory scans.

The information supplied by P-Scan can be further evaluated by several different methods. Examiners demonstrated qualified through the EPRI Program supply signal characteristic and echo dynamic information from basic A-Scan analysis as well as supportive full or half scale plots of specific areas. The ALN 4060, programmed to discriminate actual IGSCC may also be applied. This manually-applied system, programmed by EPRI, digitizes and analyzes received RF signals and provides a detailed analysis of this information. This equipment has again been demonstrated by personnel utilized at Vermont Yankee as a reliable means of discriminating IGSCC flaws from other perturbations at the weld root.

Evaluation scans, whether with the ALN or A-Scan units utilized probe motions intended to detect additional "axial" flaws in welds requiring further evaluation.

The WSY 70 probe, utilizing ID "creeping" waves was used to confirm flaws in a number of welds. This tool was only used in confirmation of flaws since it was felt that significant potential for false-negative flaw interpretations exists.

The examination with a P-Scan System is limited to some extent by the inspection fixture. The P-Scan System is capable of inspection of pipe-to pipe and pipe-to-elbow configurations on both sides of the weld. On pipe-to-tee, pipe-to-valve, and pipe-to-pump, only one-side exams were performed. Scan limitations are noted on the P-Scan data sheets. The areas not scanned with P-Scan were manually examined with qualified examiners where possible. All pipe-to-pipe and pipe-to-elbow configurations were scanned on both sides, with minor areas not scanned due to interference of integral supports or branch connections. All pipe-to-pump, pipe-to-valve, and pipe-to-tee configurations were completed on the pipe side only. The heavy sections of the fitting and necessary weld taper preluded any examinations in these areas. Because ultrasonic examination of the component side of the weld joint is not possible, no relevant ultrasonic information is available on the component side of the weld. Tables VIII, IX and X summarize both 1983 and 1984 examination restrictions.

<u>Sizing</u>

A number of different techniques were utilized in establishing through-wall flaw dimensions. These techniques fall into four primary categories. High Angle Longitudinal Beam Techniques (HALT), were utilized to integrate the outer 4/10's of the pipe wall for crack faces or crack tips which may have propagated to that region. Flaws found to be located in that region can be confirmed with a full-vee examination.

Pulse Arrival Time Techniques (PATT), are utilized to interrogate the remaining volume to determine crack tips below the O.D. region. As a complement to PATT, a similar Satellite Pulse Observation Technique (SPOT), can be used to both observe the crack tip and relate its position to the root of the flaw through observations of both pulses simultaneously.

Complementing the aforementioned techniques is the Multi-Pulse Observation Sizing Technique (MOST), which insonifies the entire pipe wall with several angles and modes of sound beam. Through observation of several constant and changing pulse relationships, determinations of through-wall depth can be made.

It is the combination of these techniques and their ability to complement one another in establishing a given flaw size which serves as the basis for the 1984 flaw sizing program.

All personnel utilized in sizing flaws at Vermont Yankee were trained in accordance with the EPRI UT Operator Training for Planar Flaw Sizing. Three individuals, providing the basis for all sizing calls, have been designated as having passed a final examination at EPRI, thus establishing their overall ability.

All flawed welds were evaluated on a weld-by-weld basis as to the need to grind for flaw sizing. Grinding, when necessary, was completed to enhance flaw sizing.

2. <u>1983 Inspection Techniques</u>

The examination program in 1983 consisted of total manual scanning and evaluation of the weld joints with methods qualified per IE Bulletin 83-02. These methods generally consisted of 1/2 vee path 45° shear wave examinations performed at 1.5 MHz. Supplemental examinations were performed using 60° shear wave examination techniques. Sizing was performed with dual element search units using the amplitude drop technique modified to include beam path geometry. Details of the 1983 exams were included in the 1983 I&E Bulletin 83-02 Final Report [Reference (e)]. Attachment A to this report is a summary of the 1983 examination.

Scan limitations in the 1983 program were noted on the data sheets. Pipe-to-component configurations were scanned on the pipe side only. The configurations were pipe-to-valve, pipe-to-tee, and pipe to pump. Pipe-to-pipe and pipe-to-elbow configurations were scanned from both sides with minor areas not scanned due to interference with integral supports. Because ultrasonic examination of the component side of the weld joint is not possible, no relevant ultrasonic information is available on the component side of the weld.

In 1983, welds were scanned for axial indications in full scope exams. Based on Vermont Yankee/NRC meetings, some large bore piping was scanned only at locations 90° apart. This was referred to as a cardinal point exam. These cardinal point exams only scanned for circumferential indications. The extent of the weld exams, including those with only cardinal point examine, are included in Table VIII to this report.

Cardinal point exams were performed by selecting four areas of the weld joint, 12" in length centered at 0°, 90°, 180°, and 270° around the joint. This was an initial sample of 48" of inspection. The inspections were on both sides of the weld joint where possible, as described above. When an indication was noted that extended beyond the original scan length, the examination was continued to determine the full extent of that indication.

3. Weld Overlay Examination Technique

The examinations following the weld clad repair at Vermont Yankee consisted of the following:

a. Clad Bond Examination
b. Clad Integrity Examination

The clad bond examination consisted of a straight beam examination from the clad surface. The principal area of concern is the clad-to-base metal interface. A 3/8" diameter flat-bottomed hole at the clad-to-base metal interface of a clad calibration standard was used as the reference reflector. Scanning sensitivity were at least +6 dB gain. The acceptance criteria was 50% of the 3/8" diameter hole reference signal or any indication with an area less than the reference reflector at reference sensitivity. This examination revealed no relevant indications.

The clad integrity examination consisted of an angle beam inspection of the clad and clad-to-base metal interface. The inspections were performed with a KB Aerotech gamma series, dual element, 3/8 x 3/4", 45^{o}, refracted longitudinal beam search unit, at a frequency of 1.5 MHz. The reference reflectors were 1/16" diameter side-drilled holes. The holes were positioned such that an examination zone contained weld metal, weld-to-base metal interface, and base metal. The calibration was performed on welded clad pipe of essentially the same material as the piping components in the plant. These calibration standards were manufactured in such a way as to duplicate the weld process and surface conditions of the actual repairs. Overlay calibration standards were fabricated at the minimum and maximum overlay thickness anticipated, thus bracketing the overlays examined. Acceptance criteria were any indication less than 50% of the reference reflector. No cracks, lack of penetration, or lack of fusion were allowed. No elongated indications greater than 1/4" were permitted. The results did not reveal any relevant indications in the overlay or overlay-to-base metal interface.

4. Flaw Evaluation Summary

- UT Indications were found at welds in Vermont Yankee piping as shown in Table 2-1 of Enclosure 2. Indications in the recirculation system welds were evaluated and found to be acceptable for another 14-month fuel cycle without repair. The axial indication at weld joint RHR-32-4 was repaired by weld overlay as described in Enclosure 2.

- UT indications were evaluated for acceptability by fracture mechanics analyses for crack growth and ASME Section XI, IWB-3640 flaw size limits. End-of-cycle limits were used which included a 2/3 factor on Table IWB-3641-1 flaw sizes and included thermal and prior repair shrinkage stresses in the IWB-3641-1 evaluation.

- Weld overlay thickness sizing is in accordance with ASME Section XI Table IWB-3641-1. The thicknesses recommended for circumferential flaws include an additional load factor margin of 1.5 for flaws less than 180^{o} in length. These factors are in addition to the safety factor of 2.773 incorporated in the above Section XI Table. This approximately corresponds to the inclusion of thermal stresses in

sizing overlays for less than 180°. This methodology was used to apply a full structural weld overlay to a previous repair at Weld Joint 32 of the Recirculation System.

- The width of the weld overlay for circumferential flaws is computed as 1.5 $(Rt)^{1/2}$. The width for axial flaws is centered on the axial flaw length and extend 0.5 $(Rt)^{1/2}$ past each end of he indication.

5. <u>Compliance with 10CFR50 General Design Criteria</u>

Appendix F to the Vermont Yankee Final Safety Analysis Report (FSAR) describes how Vermont Yankee satisfied the AEC General Design Criteria (Appendix A to 10CFR50) when the plant was constructed.

This discussion will demonstrate that IGSCC, weld overlays and/or the use of flawed pipe analysis have no effect on Vermont Yankee's compliance with the General Design Criteria.

Of the General Design Criteria identified in Appendix A to 10CFR50, this discussion will address only those criteria that could be affected by the existence of IGSCC in the reactor coolant pressure boundary.

<u>Criterion 14</u> - "The reactor coolant pressure boundary shall be designed, fabricated, erected, and tested so as to have an extremely low probability of abnormal leakage or rapidly propagating failure, and of gross rupture."

<u>Method of Compliance</u> - The potential for IGSCC will increase the probability that flaws may exist in reactor coolant piping. Vermont Yankee compensates for this probability by increasing the frequency of inspection.

The existence of IGSCC flaws does not necessarily result in system leakage. Many studies, supported by actual operating experience, have shown that IGSCC flaws will tend to arrest before penetrating the pipe wall.

Between 1983 and 1984, 90/113 weld joints have been inspected with very sensitive ultrasonic examination techniques. Indications in unrepaired joints are very shallow and have resulting very low probability of propagating (see Enclosure 2).

Structural weld overlays have been applied to weld joints which do not pass ASME Code flaw evaluation criteria. These overlays are performed with a material which is immune to IGSCC propagation.

Flaw evaluations on unrepaired joints were performed to the criteria recommended in Generic Letter 84-11. Several additional conservatisms were applied, as described in Enclosure 2. Large margin between sized flaws and acceptable flaws exists for one additional operating cycle.

We performed a Tearing Stability Analysis of the Recirculation System which demonstrated that assumed through wall flaws, having lengths which would result in readily detectable leaks, were stable under ASME Level D loads. Integrity is shown to exist with ample safety margins.

Flawed welds that are repaired by weld overlay or flawed welds that do not require repair because of compliance with limit load analysis techniques satisfy the design margins required by the ASME code. Thus, they are no more probable to experience rapidly propagating failure or gross rupture than an unflawed weld.

Thus, we conclude that GDC 14 is satisfied.

Criterion 30 - "Components which are part of the reactor coolant pressure boundary shall be designed, fabricated, erected, and tested to the highest quality standards practical. Means shall be provided for detecting, and to the extent practical, identifying the location of the source of reactor coolant leakage."

Method of Compliance - Testing for IGSCC is performed using ultrasonic testing methods that have been shown to have a high degree reliability in detecting and sizing IGSCC flaws. The details of the methods are described elsewhere in this report. In addition, as described in Enclosure 3, we have implemented more restrictive leakage detection provisions and will install a moisture sensitive tape system on eight (8) 28" uninspected weld joints.

Thus, we conclude that GDC 30 is satisfied.

Criterion 31 - "The reactor coolant pressure boundary shall be designed with sufficient margin to assure that when stressed under operating, maintenance, testing, and postulated accident conditions: (1) the boundary behaves in a nonbrittle manner, and (2) the probability of rapidly propagating fracture is minimized. The design shall reflect consideration of service temperatures and other conditions of the boundary material under operating, maintenance, testing, and postulated accident conditions and the uncertainties in determining: (1) material properties, (2) the effects of irradiation on material properties, (3) residual, steady state and transient stresses, and (4) size of flaws."

Method of Compliance - Stainless steel is very ductile material that is highly resistant to brittle behavior and rapidly propagating fracture. The limit load analysis technique accounts for the presence of flaws and the effect they may have on structural integrity. Compliance with limit load analysis requirements ensures that

unstable flaw propagation will not occur. The tearing stability analysis discussed in Enclosure 5 to this report demonstrates that even if a significant flaw should propagate through wall, the plant leakage limits will initiate corrective action well before the potential for unstable flaw propagation develops.

Thus, we conclude that GDC 31 is satisfied.

Criterion 32 - "Components which are part of the reactor coolant pressure boundary shall be designed to permit: (1) periodic inspection and testing of important areas and features to assess their structural and leaktight integrity, and (2) an appropriate material surveillance program for the reactor pressure vessel."

Method of Compliance - The application of weld overlays precludes the ability to inspect the pipe weld under the overlay. However, since the weld overlays are structural overlays only the integrity of the weld overlays needs to be inspectable. As described elsewhere in this report, the weld overlays are inspectable, and the requirements for inspection of overlays as defined by NRC Generic Letter 84-11 have been performed.

Thus, we conclude that GDC 32 is satisfied.

In summary, the existence of IGSCC in Vermont Yankee does not reduce Vermont Yankee's compliance with the General Design Criteria of Appendix A to 10CFR50.

5. Basis for Improved Inspection Results

The basis for better inspection results in 1984 is twofold. The validated examiner and examination procedure certainly provide the most significant reason for better performance. All personnel performing detection, discrimination, and sizing, who are Level II or III, are qualified on an individual basis using the EPRI-NDE Center qualification programs. The 1983 exams used a team approach to the qualification process, rather than qualification on an individual basis.

The multifaceted examination procedure, using P-Scan examinations, as well as manual evaluations, and the ability to compare results with 1983 examinations provide the second major reason for better 1984 examination results. The use of P-Scan equipment has allowed a greater examination work scope within the limits of available personnel and personnel exposure. Thus, more detail can be provided by the qualified manual examiners doing indication evaluations. A more detailed comparison of key examination variables is included as Table VI to this report.

In contrast, exposure levels in 1983 were such that total exposure limited exam scope to the point that only cardinal point scans for circumferential indications were performed on a large portion of large bore piping.

In summary, the 1984 examinations are performed with people who are better trained, with the training validated by performance exams. The equipment provides a greater amount of detail and a larger work scope, within the limits of total exposure.

Attachment C to this report provides graphic representation of improved sizing capability based on training and qualification of personnel.

6. <u>Weld Joint Sampling Criteria</u>

The sampling program was developed using four criteria for examination:

- o <u>Criterion 1</u>

  Inspect all unrepaired welds with IGSCC.

- o <u>Criterion 2</u>

  Inspect all overlayed riser weld joints with previous cracks longer than 10% of pipe circumference. The inspection is for bond integrity with the base metal and a weld metal examination.

- o <u>Criterion 3</u>

  Inspect 20% of previously inspected joints without indications in each pipe size (minimum of 2 weld joints).

- o <u>Criterion 4</u>

  Inspect 20% of the previously uninspected welds in each pipe size (minimum of 4 weld joints).

The table below depicts the criteria and the first and second additional samples if defects were found in the original sample.

If defects are found in the additional sample, then all remaining welds of that size in that line should be examined.

The original sample has been expanded to include those welds defined in Criteria 4 - 20", 22", and 28" lines.

The table also depicts the total number of welds in each criterion.

<u>Criterion 1</u> - All unrepaired welds with IGSCC indications in 1983.

Original Sample -	28" - 64	28" - 58
	28" - 1A	28" - 59
	28" - 2	22" - 16B
	28" - 9A	22" - 36B
	28" - 65A	22" - 30B
	28" - 15A	24" - RHR-31-1

Total - 12 Welds

Criterion 2 - Overlayed welds which had indications over 10% of circumference - overlay bond and weld integrity exams.

12" - 30*	12" - 16*	12" - 24	12" - 54
12" - 33*	12" - 23*	12" - 29	12" - 18
12" - 42*	12" - 36*	12" - 32	
12" - 45*	12" - 50*	12" - 35	
12" - 20*	12" - 53*	12" - 51	

*Denotes sweepolet to riser welds.

Criterion 3 - 1983 inspection - no indications; 20% or minimum of 2 welds.

	12"	20"	22"	28"
Original Sample	51A 54A 41 44	RHR-32-4	23A 30A	9B 17
Total Population	18	1	3	4

Criterion 4 - Remaining welds - not inspected; 20% or 4 welds minimum.

	20"	22"	24"	28"
Original Sample	RHR-32-2 RHR-32-F1 RHR-32-5 RHR-32-1	16A 47 48 36A	RHR-30-1 RHR-30-3 RHR-30-9 RHR-30-10	15 15B 27 26A 61
Total Population	6	6	20	23
First Additional Sample	RHR-32-6 RHR-32-7	23B 49		17A 15C 4 5A 17B
Second Additional Sample				5 6 8 26 56

7. Justification for Expanded Sample of 28" Pipe Welds

During the initial inspections during the 1984 refueling outage, IGSCC indications were detected. The sample population was increased as required by NRC Generic Letter 84-11 and as described in our letter dated July 6, 1984 [Reference (j)]. An additional 28-inch weld was found to have a flaw in the second sample population. Strict interpretation of Generic Letter 84-11 would require that all remaining 28-inch welds

(there are 13) be inspected. A third sample of five welds was selected for inspection. The five welds were selected to ensure that at least one of each susceptible weld location in either loop was inspected. The results of that sample showed that one weld was found with a small flaw (approximately 3 inches long). Vermont Yankee does not believe that additional inspections are warranted. Our justification is provided below.

During the inspections this year, the maximum cumulative flaw length in any weld is less than 25 percent of the pipe circumference; average flaw lengths are in the range of 1 to 4 inches. The maximum flaw depth detected in any flaw is less than 30 percent of wall thickness; average flaw depths are 15 to 20 percent of wall thickness. The weld sample population was selected to ensure that the welds most probable to contain IGSCC were inspected first. The sampling criteria addressed carbon content, service stresses, and fabrication-related repairs. The legitimacy of the selection criteria is supported by the fact that even though additional flaws were detected in the expanded samples, the size of the flaws is less than the first sample. Of the total length of all weld joints inspected, less than two (2) percent of the total contained flaws. Vermont Yankee believes there is sufficient evidence to suggest that the remaining 8 welds do not contain a flaw larger than the first 67 welds.

The safety significance of this situation can be shown to be negligible, as follows:

1. Using limit load analysis techniques, the allowable end of cycle flaw depth for a flaw 25 percent of circumference is in excess of 100 percent of wall thickness;

2. Based on limit load analysis, the allowable flaw length for a 30 percent deep flaw is in excess of 100 percent of pipe circumference;

3. The limit load evaluations account for potential flaw growth during the next operating cycle;

4. The limit load evaluations maintain full ASME Code design margins; and

5. EPRI studies have demonstrated that a multiply-flawed pipe system has at least the same margin of safety as a singly-flawed system. (In actuality, it can be shown that the multiply-flawed system has increased margin, but no credit is taken for that.)

Thus, Vermont Yankee believes that further inspections will result in no increase in safety margin. Increased inspections will have a significant radiological impact on the inspection personnel. Specifically, we estimate that an additional 22 man-rem would be expended to inspect the last eight (8) 28" weld joints, of which 16 man-rem would be to the UT personnel. There is approximately 12 man-rem remaining among the available UT personnel, which is insufficient to complete the exams. Further, it would take a week and a half to two weeks to obtain additional qualified personnel. Based on the principal of ALARA, we believe no further exposure to inspect the remaining 28" welds is justified.

As a compensatory measure for the lack of inspections, Vermont Yankee proposes to continue in effect the more stringent "unidentified leakage" limits adopted by management directive during the last operating cycle. These limits are discussed in detail in Enclosure 3 to this report. Further, a local leak detection system will be installed to monitor eight (8) 28" uninspected weld joints. This system is also discussed in Enclosure 3.

Finally, Vermont Yankee has conducted a tearing stability analysis on the recirculation system. This analysis includes consideration of the recently identified potential for low fracture toughness in austenitic submerged arc weldments. Even with these very conservative toughness considerations, it was demonstrated that structural stability was assured, even assuming a flaw of sufficient size to result in 10 gpm leakage (five times the control limit). The results of this analysis are provided in Enclosure 5 to this report.

ENCLOSURE 2

RECIRCULATION AND RESIDUAL HEAT REMOVAL (RHR)

PIPING FLOW INDICATION EVALUATIONS AND

WELD OVERLAY REPAIRS

ENCLOSURE 2

Report No. SIR-84-018
Revision 0
SI Project No. YAEC-04
July 1984

Recirculation and RHR Piping Flaw Indication Evaluations and Weld Overlay Repairs at Vermont Yankee

Prepared by

Structural Integrity Associates
San Jose, California

Prepared for

Yankee Atomic Electric Company

Prepared by: J.F. Copeland — J. F. Copeland — Date: 7/27/84

Prepared by: [signature] — S. S. Tang — Date: 7/27/84

Reviewed by: [signature] — P. C. Riccardella — Date: 7/27/84

Approved by: J.F. Copeland — Project Manager, J. F. Copeland — Date: 7/27/84

[signature] — Principal Associate, P. C. Riccardella — Date: 7/27/84

STRUCTURAL INTEGRITY ASSOCIATES

REVISION CONTROL SHEET

SECTION	PARAGRAPH(S)	DATE	REVISION	REMARKS
All	All	7/27/84	0	Initial Issue

TABLE OF CONTENTS

List of Tables

List of Figures

1.0 Introduction

During the current outage at Vermont Yankee, circumferential indications were observed by ultrasonic (UT) inspection at weld joints (listed in Table 2-1) of the recirculation system. An axial indication was observed at RHR weld joint 32-4. The indications are all located in weld heat affected zones and are judged to be intergranular stress corrosion cracking (IGSCC) in nature.

Fracture mechanics evaluations of the observed indications were performed in accordance with References 1 and 2, in order to determine any need for repairs. This assessment is for one fuel cycle (14 months) of operation. The crack growth evaluation was performed for as-welded residual stresses plus operating stresses and shrinkage stresses from previous weld overlay repairs. The flaw was conservatively grown in depth as a 360^{o} circumferential crack.

Results from the above evaluation are compared to the end-of-cycle (EOC) allowable flaw depth in ASME IWB-3640 (Ref. 1). A factor of 2/3 was placed on allowable EOC flaw depth to account for flaw sizing uncertainties, and thermal stresses and shrinkage stresses from previous overlays were considered as primary stresses in the IWB-3640 evaluation, to account for any possible low weld metal toughness. With these conservatisms included, a comfortable safety margin exists for the indications observed in the recirculation piping welds at the end of one fuel cycle (14 months).

Based on the above fracture mechanics evaluations, a weld overlay repair was performed on weld joint RHR 32-4.

Weld overlays have been successfully implemented on Type 304 austenitic stainless steel pipe welds for the repair of intergranular stress corrosion cracks (IGSCC) in boiling water reactors. These repairs consist of depositing a 360^{o} band of Type 308L weld metal (with controlled ferrite) on the pipe outer diameter and over the indication.

The weld overlay repair serves a number of purposes toward restoring the piping integrity: (1) structural reinforcement, (2) compressive residual stresses on the pipe inner diameter due to weld shrinkage, and (3) an IGSCC-resistant weld metal pressure boundary. Consideration of welding residual stresses is not necessary in cases of through-wall cracks. Structural reinforcement requirements are computed based upon the net section collapse criterion (NSCC), as justified by elastic-plastic fracture mechanics analysis (tearing modulus) to show that the NSCC is the controlling mechanism for fracture.

Weld overlay repairs of IGSCC have been performed on a large number of welds, including Vermont Yankee. Weld overlays were designed for Vermont Yankee as reported in this document, and bound the worst hypothetical cases (through-wall cracks in highly stressed weld joints).

2.0 Details of UT Indications and Weld Joint Stresses

The size, location and orientation of UT indications in the Vermont Yankee piping are presented in Table 2-1, along with the corresponding applied stresses at the weld joint. UT indications are described in Enclosure A.

Stresses for this analysis were taken from References 4 and 5, and are based on the piping design stress report (Ref. 3).

The values of weld shrinkage stresses (Ref. 6) from previous weld overlay repairs at Vermont Yankee have been determined (as shown in Table 2-1) and are added to residual plus operating stresses for flaw growth calculations. These shrinkage stresses were also included with primary and thermal stresses in the determination of allowable flaw sizes.

3.0 Fracture Mechanics Evaluation

3.1 Factors on Results

Certain factors were employed to account for uncertainties in flaw sizing and weld metal toughness in the analysis. References 7 and 8 recommend using a factor of 2/3 on the end-of-cycle (EOC) flaw size limit from ASME Table IWB-3641-1 (Ref. 1). Reference 8 recommends that thermal expansion stresses be considered as a primary stress in the use of IWB-3641-1 for end-of-cycle flaw size limits. Reference 8 also uses a conservative 360° circumferential crack model to predict growth in the crack depth direction, whereas such cracks are usually less than 360°. All these recommendations were included in this analysis.

3.2 Crack Growth Evaluation

Crack growth was computed using the methodology of Reference 8. This methodology is based on growth by intergranular stress corrosion cracking (IGSCC) under sustained loading during operation, and has been found to be consistent with cracking experience (Ref. 8).

Contributions of fatigue loading to crack growth are considered negligible in this case. A major contributor to crack growth is the welding residual stress, which enters heavily into sustained loading calculations, but has only a mean stress effect in fatigue cycling. Furthermore, the available data suggests that the contribution of the conventional design operating transients to crack growth is negligibly small (because they comprise such a relatively small fraction of the life) and that most of the crack growth occurs under the nominal steady-state operating conditions (Ref. 8). Small fluctuations in operating stresses are negligible from a fatigue standpoint (Ref. 8). Thus, in large diameter piping the fatigue crack growth associated with design loading histories is very small, and crack growth will be due primarily to IGSCC (Ref. 8).

3.2.1 Applied Stresses

Pressure, dead-weight and thermal stresses, for the weld joint being studied, were employed with shrinkage stresses from previous repairs and with the following residual stress distribution, crack model and crack growth law to predict crack growth in the pipe thickness direction. These applied stresses are tabulated in Table 2-1, as discussed previously, and are all conservatively treated as through-wall membrane tensile stresses in the crack growth analysis. The residual stress distribution through the pipe wall is described below.

3.2.2 Residual Stresses

The best estimate axial residual stress distribution as shown in Figure 3-1, was used with the above applied stresses for crack growth calculations. This residual stress curve is consistent with Reference 8.

Due to the non-linear nature of the residual stress profiles, a third order polynomial equation was used to curve fit the test data and analytical data. The third order polynomial equation has the form

$$\text{Stress} = C_0 + C_1X + C_2X^2 + C_3X^3 \qquad (1)$$

A least square curve-fit procedure was used to determine the coefficients in Equation 1, where X is location in the wall thickness direction.

3.2.3 Crack Model and Crack Growth Analysis

A full 360° circumferential crack on the pipe inside surface was conservatively assumed for crack growth computations in accordance with the practice of Reference 8, even though the observed indications were finite length. Accordingly, the fracture mechanics crack model was a 360° circumferential crack in a cylinder with a thickness to radius ratio (t/R) of 0.1. The best estimate severely weld sensitized crack growth law (Figure 3-2) was combined with the preceding stresses and crack model, and numerically integrated to predict flaw depth as a function of time. Results are shown in Appendix A.

3.2.4 Crack Length Growth

Crack growth was computed conservatively in the length direction by assuming a constant growth rate of 0.00025 in/hr (2.19 in/yr) at each crack end (Refs. 9 and 10).

Table 3-1 presents a summary of predicted crack growth for the Vermont Yankee UT indications in a 14-month operating period.

3.3 Allowable Flaw Size Determination

Based on the concept of net section plastic collapse (Ref. 11), ASME Section XI IWB-3640 contains end-of-evaluation period allowable flaw depths for circumferential flaws for normal and upset operation conditions for austenitic piping material (Table 3-2). Results for Vermont Yankee are shown in Appendix B.

3.3.1 Circumferential Flaws

Briefly, the net section collapse theory for circumferential flaws considers a given crack of length ℓ (corresponding to a crack angle 2θ), and depth a, with nominal primary membrane stress P_m and nominal primary bending stress P_b at force and moments equilibrium in the longitudinal direction and with stress at the net section location equal to the flow stress of the material, σ_f. This equilibrium is illustrated in Figure 3-3, along with β, the shift in neutral axis of the pipe due to loading the cracked pipe.

The following equations are derived from the above concepts (Ref. 11):

for $\theta + \beta \leq \pi$

$$\beta = \frac{(\pi - \theta a/t) - (P_m/\sigma_f)\pi}{2} \qquad (2)$$

$$P_b = \frac{2\sigma_f}{\pi}\left[2\sin\beta - (a/t)\sin\theta\right] \qquad (3)$$

for $\theta + \beta > \pi$

$$\beta = \frac{\pi(1 - a/t - P_m/\sigma_f)}{2 - a/t} \qquad (4)$$

$$P_b = \frac{2\sigma_f}{\pi}(2 - a/t)\sin\beta \qquad (5)$$

Using the above equations, the critical flaw size ($\frac{a}{t}$ & θ) can be determined through iteration.

The above basis leads to the formulation of the allowable end of evaluation period flaw depth for circumferential flaws for normal operating conditions in ASME Section XI Table IWB-3641-1 (shown in Table 3-2). Several assumptions are used in obtaining Table IWB-3641-1. The primary membrane stress is essentially due to operating pressure. It is assumed to be equal to half of the allowable stress intensity (S_m). A safety factor of 2.773, from the consideration of the minimum margin on primary membrane stress as required by the ASME Code and the safety margin for pure bending in pipes, is used.

An arbitrary cut-off at 75% for the allowable crack depth to thickness ratio is made for conservatism. Also, for crack lengths larger than 180^0, a full circumferential crack solution is conservatively used, as illustrated in Figure 3-4.

It can be seen that the allowable flaw depth in Table IWB-3641-1 (Table 3-2 and Figure 3-4) depends on the piping stress ratio $(P_m + P_b)/S_m$. In accordance with the latest NRC guidelines (Ref. 8), service level A thermal expansion stresses are included in the stress ratio calculation to account for possible low weld metal toughness. Therefore, weld joint stresses due to pressure, dead-weight, seismic (OBE), and thermal and prior repair shrinkage (shown in Table 2-1) were used to compute corresponding stress ratios with an S_m of 16.95 ksi. for austenitic stainless steel at 550^0F.

Stress ratios corresponding to the above stresses are shown in Table 2-1 and were used with Table IWB-3641-1 to determine the allowable end of cycle flaw depths. A factor of 2/3 is also included (Ref. 7 and 8), in the IWB-3641-1 results to establish the final allowable flaw size, in order to account for flaw sizing uncertainties. This results in an allowable flaw depth of 50% of the pipe wall thickness in all cases for the circumferential indications.

3.3.2 Axial Flaws

Table 3-3 presents the allowable end of evaluation period flaw depth to thickness ratio (a/t) for axial flaws for normal operation conditions. This table is formulated through emperical results for a through-wall flaw in pipe and extended to part-through-wall axial cracks with a curvature correction factor. Although an arbitrary flaw depth limit of a/t = 0.75 is shown in Table 3-3, Section XI IWB-3642 permits flaw acceptance based on applied stress and maintaining a factor of at least three against failure stress. Thus, the source equations (Ref. 2) for Table IWB-3641-2 (Table 3-3) can be solved, as shown below, to demonstrate a factor of at least three against plastic collapse for a through-wall axial flaw, 0.5 in. long, in Vermont Yankee 20 in. RHR piping.

$$\sigma_h = \frac{3\ S_m}{M} \qquad (6)$$

$$M = \left[1 + \frac{1.61\,\ell^2}{4\ Rt_m}\right]^{1/2} \qquad (7)$$

where: σ_h = hoop stress at failure

$3\ S_m$ = flow stress, with S_m = 16.95 ksi. at 550°F (from ASME Section III)

M = curvature correction factor

ℓ = through-wall axial flaw length

R = pipe radius (10 in. for RHR)

t_m = pipe min. wall thickness (1.095 in. for RHR)

The hoop stress, due to a design pressure of 1250 psi., in the 20 in. RHR pipe is given by:

$$\sigma_h = \frac{p\ R}{t_m} \qquad (8)$$

The above equation results in a design hoop stress of 11,416 psi. for the design pressure. Thus, the predicted failure stress should be at least three times the design hoop stress, or 34,248 psi., to give the required safety factor. Substituting a failure hoop stress of 34,248 psi. into Equation (6) and solving for ℓ in Equation (7) gives a through-wall axial flaw length of 5.72 in. This flaw length of 5.72 in. is significantly above realistic axial flaw lengths at piping welds, which are generally limited to the weld heat affected zone width of less than 0.5 in.

The above equations can also be solved for the more realistic through-wall axial flaw length of ℓ = 0.5 in. to show a predicted hoop stress at failure of 50,617 psi., and a corresponding safety factor of 50,617/11,416 = 4.43. Another way to look at this is that the material flow stress could be reduced as low as (3/4.43) (3 S_m) = 34,436 psi to still maintain a safety factor of three against plastic collapse for a 0.5 in. long through-wall axial flaw.

Thus, it can be seen that such an axial flaw is not a safety issue. The use of a thin weld overlay, simply to arrest further crack extension and to act as a seal against potential leakage, is considered adequate in this case. This conclusion is consistent with Reference 8, which states that analysis can be used to justify long-term operation with weld overlays for relatively short axial cracks. This is true because errors on crack depth measurement or flaw growth predictions will lead at worst to relatively small leaks, which will be easily detectable long before the crack can grow long enough to cause failure (Ref. 8).

4.0 Results and Disposition of Indications

A typical change in flaw size for one fuel cycle (14 months) is presented in Figure 4-1 and is compared to the final allowable flaw size as described in the preceding sections. The disposition of the Vermont Yankee UT indications is summarized in the following paragraphs.

4.1 Acceptable Indications

Even with the preceeding conservatisms considered in the analysis, there is still a comfortable margin (from the allowable flaw depth of a/t =0.5) at the end of one fuel cycle of operation (14 months), for the circumferential indications observed in the recirculation system. Thus, these indications are judged to be acceptable without repair for one 14-month period of operation.

4.2 Repairs

The axial indication at weld joint RHR 32-4 of the RHR system was dispositioned to be repaired by weld overlay, as described in the preceding section.

A full structural weld overlay (through-wall, 360° flaw assumed) was also applied to weld joint 32 of the recirculation system to add further margin to a previous repair. The weld overlay design methodology is described in the following section.

5.0 Weld Overlay Repairs

Weld overlay repairs for Vermont Yankee were designed as described in the following paragraphs, using IWB-3640 (Ref. 1) as a basis, and including appropriate conservatisms and factors.

5.1 Factors on Results

Weld overlay repairs were designed based on measured indication length assuming a flaw completely through the original pipe wall thickness (through-wall crack). This is conservative, based on the measured finite depth of UT indications (as shown in Table 2-1), but is done to account for any uncertainties in depth sizing. It also avoids the need to consider further defect growth as influenced by overlay induced residual stresses in the pipe (an effect that gives further margin).

As in the evaluation of UT indications for acceptability, thermal stresses were considered in the primary stress ratio for determining IWB-3640 table flaw limits. This is approximately equivalent to multiplying the primary stress ratio (pressure, dead-weight and OBE) by a factor of 1.5 to account for potential low weld metal toughness. Overlay thicknesses corresponding to a load factor of 1.5 or the inclusion of thermal stresses in the primary stress ratio were used for piping repairs when flaws of less than 180° length are assumed for overlay sizing. This is based on past experience with weld overlays, and results in reasonable thicknesses for the corresponding loads. This load factor is an extra level of conservatism to guard against any possible lower toughness in existing butt welds and is in addition to the margin of 2.773 on loads in Table 2-1. The factor of 1.5 becomes less important for larger flaws where more loading is supported in the controlled tougher weld overlay material. For flaws greater than 180° length, no credit is taken for the existing butt weld, and a load factor of 1.0 is considered adequate for the overlay deposited by the Tungsten Insert Gas (TIG) welding process. For flaws less than 180° length, the smaller overlay, based on sizing with actual flaw length and a load factor of 1.5 or by sizing with a 180°-360° length with a load factor of 1.0, may be used.

5.2 Repair Design Methodology and Results

The overlay designs are based on net section collapse theory, as described in the section of this report on allowable flaw size determination, and includes the preceding conservatisms.

Overlays for circumferential flaws were designed in thickness to meet the flaw limits of Table IWB-3641-1 (Table 3-2), and include additional factors, as discussed above. Two principal effects of the overlay are considered in using this table to size thicknesses of overlays: (1) reduction in pipe stresses due to increased wall thickness from the overlay and (2) reduction of the flaw depth/wall thickness, a/t, ratio as a result of the overlay. A maximum a/t of 0.75 is permitted.

A weld overlay design miminum thickness of 0.2 in. was computed for weld joint 32, based on an assumed through-wall 360° flaw in the 12 in. diameter, 0.53 in. thick pipe, and an enveloping primary stress ratio of 0.522.

The steps followed for the weld overlay thickness sizing, for through-wall cracks in the unrepaired pipe, are:

a. Obtain allowable a/t using the given $(P_m + P_b)/S_m$ ratio from Table 2-1.

b. Reduce $(P_m + P_b)/S_m$ proportional to the increase of wall thickness t due to the addition of assumed weld overlay thickness Δt.

c. Recalculate the allowable a/t corresponding to the adjusted $P_m + P_b$, due to the weld overlay.

If the calculated a/t from step c is larger than the allowable value given in Table 3-2 for the adjusted stress level, repeat steps b and c by increasing Δt until the solution converges to the allowable a/t at the adjusted stress level. If the calculated a/t is significantly smaller than the allowable value for the adjusted stress level, then the overlay thickness can be accordingly reduced.

The minimum width of the weld overlay was computed as 1.5 $(Rt)^{1/2}$ where R is the pipe radius and t is the pipe thickness. This is based on extending the overlay a sufficient distance from the crack that the effects of the local discontinuity (crack) on the structural reinforcement are dissipated. This weld overlay design is shown in Figure 5-1.

6.0 Summary

1. UT indications were found at welds in Vermont Yankee piping as shown in Table 2-1. Indications in the recirculation system welds were evaluated and found to be acceptable for another 14 month fuel cycle without repair. The axial indication at weld 32-4 was repaired by weld overlay as described in this report.

2. UT indications were evaluated for acceptability by fracture mechanics analyses for crack growth and IWB-3640 flaw size limits. End-of-cycle limits were used which included a 2/3 factor on Table IWB-3641-1 flaw sizes, and included thermal and prior repair shrinkage stresses in the IWB-3641-1 evaluation.

3. Weld overlay thickness sizing is in accordance with ASME Section XI Table IWB-3641-1. The thicknesses recommended for circumferential flaws include an additional load factor margin of 1.5 for flaws less than 180° in length. These factors are in addition to the safety factor of 2.773 incorporated in the above Section XI table. This approximately corresponds to the inclusion of thermal stresses in sizing overlays for less than 180°. This methodology was used to apply a full structural weld overlay to a previous repair at weld joint 32 of the recirculation system.

4. The width of the weld overlay for circumferential flaws is computed as $1.5\ (Rt)^{1/2}$. The width for axial flaws is centered on the axial flaw length, and extends $0.5\ (Rt)^{1/2}$ past each end of the indication.

7.0 References

1. ASME Boiler and Pressure Vessel Code, Section XI, W83 Edition.

2. Ranganath, S., and Norris, D.M., "Evaluation Procedure and Acceptance Criteria for Flaws in Austenitic Steel Piping", Draft No. 10, sponsored by subcommittee on Piping, Pumps, and Valves of PVRC of the Welding Research Council, July 1983.

3. Design Report, Recirculation System, 22A2615, June 1970, SIA File YAEC-02-200.

4. NUTECH Computer Run AFT-ACFV, June 13, 1983.

5. Transmittal, Recirculation Piping Stresses, R. E. White to J. F. Copeland, SIA File YAEC-04-102.

6. Telecon, R. E. White to J. F. Copeland, SIA File YAEC-04-102.

7. Dircks, W. J., "Staff Requirements for Reinspection of BWR Piping and Repair of Cracked Piping", NRC Policy Issue SECY-83-267C, Nov. 7, 1983.

8. NUREG-1061, Report of Pipe Study Group, Draft Report for Comment, received May 17, 1984.

9. "Guidelines for Flaw Evaluation and Remedial Action for Stainless Steel Piping Susceptible to Intergranular Stress Corrosion Cracking," Draft Report No. SIR-84-005, Rev. 3. Prepared by Structural Integrity Associates for EPRI BWR Owner's Group, April 13, 1984.

10. Bickford, R. L., et al, "Non-destructive Evaluation Instrument Surveillance Test on 26 in. Pipe," EPRI NP-3393, January 1984.

11. Ranganath, S., and Mehta, H. S., "Engineering Methods for the Assessment of Ductile Fracture Margin in Nuclear Power Plant Piping," Elastic-Plastic Fracture: Second Symposium, Vol. II, ASTM STP 803, C. F. Shih and J. P. Gudas, Eds., ASTM, 1983.

TABLE 2-1 Details of Circumferential UT Indications and Weld Joint Stresses

Pipe Size	Component	Weld ISI No.	Outer Dia. (in.)	Wall Thickness t(in.)	Stresses (psi.) Shrinkage	Therm.	Press.	DW	OBE	Shr.+Th. +P+DW	(Shr.+Th.+ P+DW +OBE/16,950	UT Indication a/t	Length ℓ(in.)	ℓ/circ.
28	ELBOW	1A	28.169	1.2	0	2122	5954	1177	155	9253	0.555	0.22	5	0.057
28	ELBOW	2	28.169	1.2	0	917	5954	635	371	7506	0.465	0.15	2	0.023
28	ELBOW	9A	28.337	1.29	600	393	5534	259	476	6786	0.428	0.20	5	0.057
28	TEE	15B	28.169	1.18	200	1887	6053	464	2164	8604	0.635	0.18	3	0.034
28	ELBOW	26A	28.169	1.15	0	958	6210	637	636	7805	0.498	0.15	19	0.22
28	ELBOW	27	28.169	1.15	0	735	6210	475	182	7420	0.449	0.19	4.5	0.051
28	VALVE	61	28.337	1.25	150	325	5711	83	1158	6269	0.438	0.20	24	0.27
28	PUMP	59	28.337	1.34	200	389	5330	54	1221	5973	0.424	0.21	18	0.15
28	TEE	65A	28.337	1.29	700	537	5534	461	1149	7232	0.495	0.23	15	0.17
22	TEE	16A	21.879	1.05	1190	2303	5614	1417	758	10,524	0.666	0.20	7	0.10
22	TEE	16B	21.879	1.03	1190	2909	5718	1422	758	11,239	0.708	0.12	1	0.015
22	CAP	30B	21.879	1.04	0	0	5666	0	0	5666	0.334	0.20	20	0.30
28	ELBOW	17B	28.169	1.27	250	537	6023	196	227	7006	0.427	0.20	6	0.068
22	VALVE	49	21.879	1.09	2400	1136	5408	546	230	9490	0.574	0.22	1.5	0.022
28	PUMP	6	28.337	1.26	200	435	6068	173	1320	6876	0.484	0.17	3	0.034
22	CAP	23B	21.879	1.09	0	0	5408	0	0	5408	0.319	0.27	6	0.087

TABLE 3-1

SUMMARY OF PREDICTED CRACK GROWTH

FOR A 14-MONTH OPERATING PERIOD

PIPE SIZE (IN.)	COMPONENT	WELD ISI NO.	CIRCUMFERENTIAL FLAW SIZE START DEPTH A/T	FINAL DEPTH A/T	START LENGTH (IN.)	FINAL LENGTH (IN.)	FINAL LENGTH L/CIRC.
28	ELBOW	1A	0.22	0.300	5	9.745	0.111
28	ELBOW	2	0.15	0.236	2	6.745	0.077
28	ELBOW	9A	0.20	0.261	5	9.745	0.111
28	TEE	15B	0.18	0.238	3	7.745	0.088
28	ELBOW	26A	0.15	0.246	9	23.745	0.270
28	ELBOW	27	0.19	0.268	4.5	9.745	0.111
28	VALVE	61	0.20	0.261	24	28.745	0.327
28	PUMP	59	0.21	0.245	18	22.745	0.202
28	TEE	65A	0.23	0.285	15	19.745	0.224
22	TEE	16A	0.20	0.294	7	11.745	0.171
22	TEE	16B	0.12	0.254	1	5.745	0.084
22	CAP	30B	0.20	0.244	20	24.745	0.35
28	ELBOW	17B	0.20	0.254	6	10.745	0.122
22	VALVE	49	0.22	0.287	1.5	6.245	0.091
28	PUMP	6	0.17	0.247	3	7.745	0.088
22	CAP	23B	0.27	0.286	6	10.745	0.015

TABLE 3-2

CIRCUMFERENTIAL FLAW SIZE LIMITS
(SECTION XI, IWB-3641-1)

TABLE IWB-3641-1
ALLOWABLE END-OF-EVALUATION PERIOD FLAW DEPTH[1] TO THICKNESS RATIO FOR CIRCUMFERENTIAL FLAWS — NORMAL OPERATING (INCLUDING UPSET AND TEST) CONDITIONS

$\frac{P_m + P_b}{S_m}$ [Note (2)]	Ratio of Flaw Length, ℓ_f, to Pipe Circumference [Note (3)]							
	0.0	0.1	0.167 (60°)	0.2	0.3	0.333 (120°)	0.4	0.5 (180-360°) or More
1.5	(4)	(4)	—	(4)	(4)	—	(4)	(4)
1.4	0.75	0.40	.273	0.21	0.15	—	(4)	(4)
1.3	0.75	0.75	.510	0.39	0.27	.253	0.22	0.19
1.2	0.75	0.75	.623	0.56	0.40	.373	0.32	0.27
1.1	0.75	0.75	.737	0.73	0.51	.480	0.42	0.34
1.0	0.75	0.75	.75	0.75	0.63	.570	0.51	0.41
0.9	0.75	0.75	.75	0.75	0.73	.683	0.59	0.47
0.8	0.75	0.75	.75	0.75	0.75	.727	0.68	0.53
0.7	0.75	0.75	.75	0.75	0.75	.75	0.75	0.58
≤ 0.6	0.75	0.75	.75	0.75	0.75	.75	0.75	0.63

NOTES:

(1) Flaw depth = a_n for a surface flaw
$2a_n$ for a subsurface flaw
t = nominal thickness
Linear interpolation is permissible.

(2) P_m = primary membrane stress
P_b = primary bending stress
S_m = allowable design stress intensity (in accordance with Section III)

(3) Circumference based on nominal pipe diameter.

(4) IWB-3514.3 shall be used.

TABLE 3-3

AXIAL FLAW SIZE LIMITS
(SECTION XI, IWB-3641-3)

TABLE IWB-3641-3
ALLOWABLE END-OF-EVALUATION
PERIOD FLAW DEPTH[1] TO THICKNESS RATIO FOR AXIAL FLAWS — NORMAL OPERATING (INCLUDING UPSET AND TEST) CONDITIONS

Stress Ratio [Note (2)]	Nondimensional Flaw Length [Note (3)] ($l_f/\sqrt{rt}$) 0.0	0.5	.6	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0 or Greater
≤0.4	0.75	0.75	.75	0.75	0.75	0.74	0.70	0.68	0.67	0.66	0.65	0.64	0.64	0.64	(4)
0.5	0.75	0.75	.75	0.75	0.72	0.65	0.61	0.59	0.58	0.57	0.56	0.55	(4)	(4)	(4)
0.6	0.75	0.75	.75	0.75	0.64	0.55	0.51	0.49	0.48	0.47	(4)	(4)	(4)	(4)	(4)
0.7	0.75	0.75	.74	0.73	0.53	0.44	0.40	0.38	0.37	(4)	(4)	(4)	(4)	(4)	(4)
0.8	0.75	0.75	.74	0.62	0.40	0.32	0.28	0.26	(4)	(4)	(4)	(4)	(4)	(4)	(4)
0.9	0.75	0.70	.64	0.42	0.23	0.17	0.15	0.14	(4)	(4)	(4)	(4)	(4)	(4)	(4)
1.0	(4)	(4)	.12	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)

NOTES:

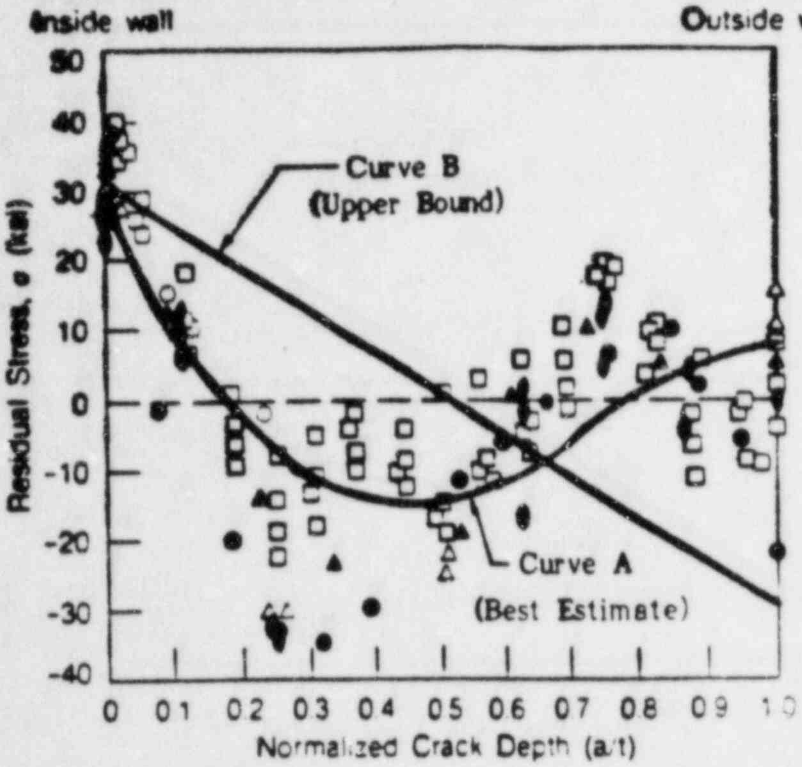
(1) Flaw depth = a_n for a surface flaw
$2a_n$ for a subsurface flaw
Linear interpolation is permissible.

(2) Stress ratio = $\frac{PD}{2t}/S_m$

where
P = maximum pressure for normal operating conditions
D = nominal outside diameter of the pipe
t = nominal thickness
S_m = allowable design stress intensity (in accordance with Section III)

(3) l_f = end-of-evaluation period for flaw length
r = nominal radius of the pipe
t = nominal thickness

(4) IWB-3514.3 shall be used.



LEGEND:

- ○ GE 26 in NP944-1
- □ GE 26 in IHSI ref. pipe (4 azimuths)
- △ ANL 26 in ND 944-2 (2 azimuths)
- ▲ ANL 26 in KRB
- ● ANL 20 in T-114
- ⬮ SWRI 28 in (3 azimuths)
- ——— Structural Integrity Curves Used in Analysis

FIGURE 3-1 RESIDUAL STRESS CURVES USED IN ANALYSIS AND SUPPORTING EXPERIMENTAL DATA

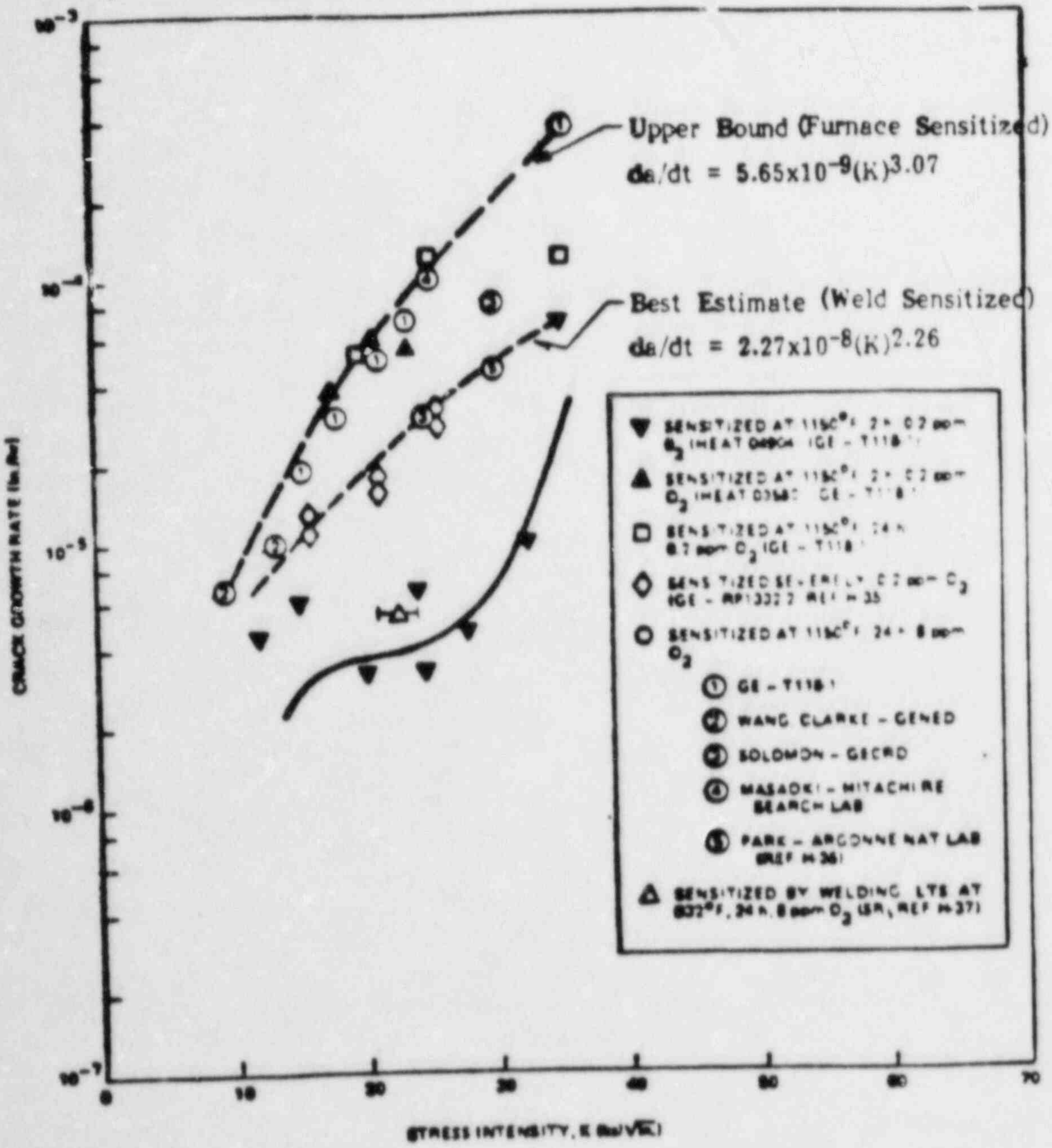


FIGURE 3-2 CRACK GROWTH RATE CURVES USED IN ANALYSIS AND SUPPORTING DATA (FROM EPRI NP-2472)

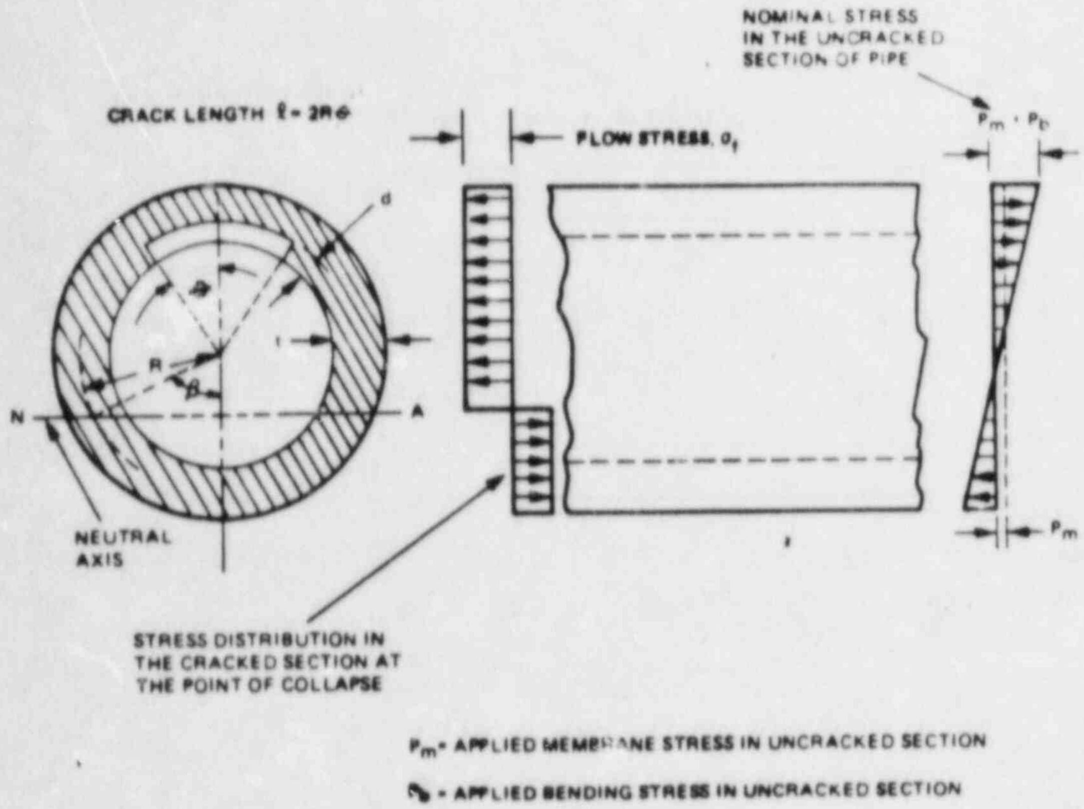


FIGURE 3-3. STRESS DISTRIBUTION IN A CRACKED PIPE -- BASIS FOR NET SECTION COLLAPSE EQUATIONS (REFERENCE 11)

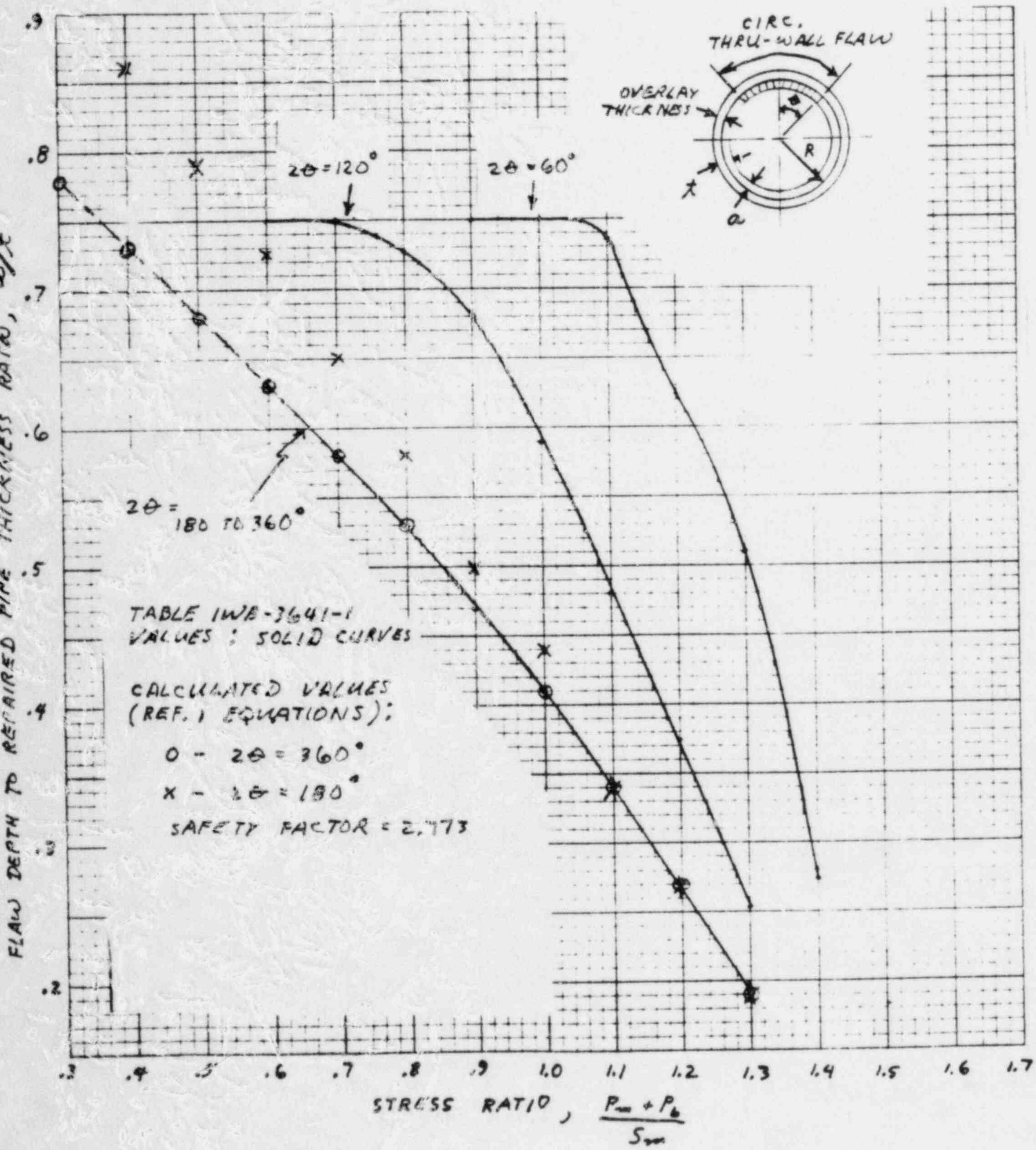


FIGURE 3-4. CIRCUMFERENTIAL FLAW SIZE LIMITS VERSUS STRESS

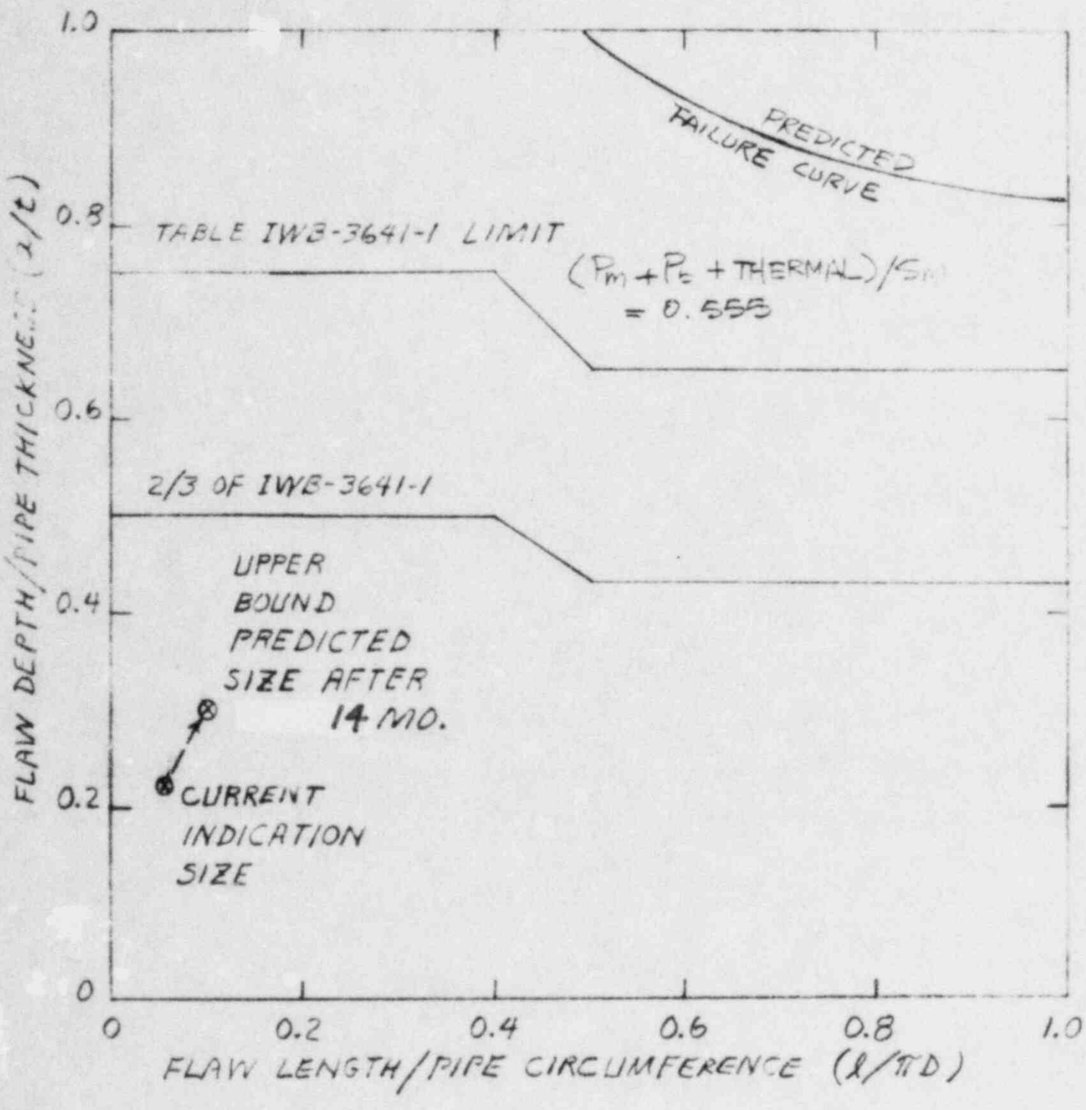
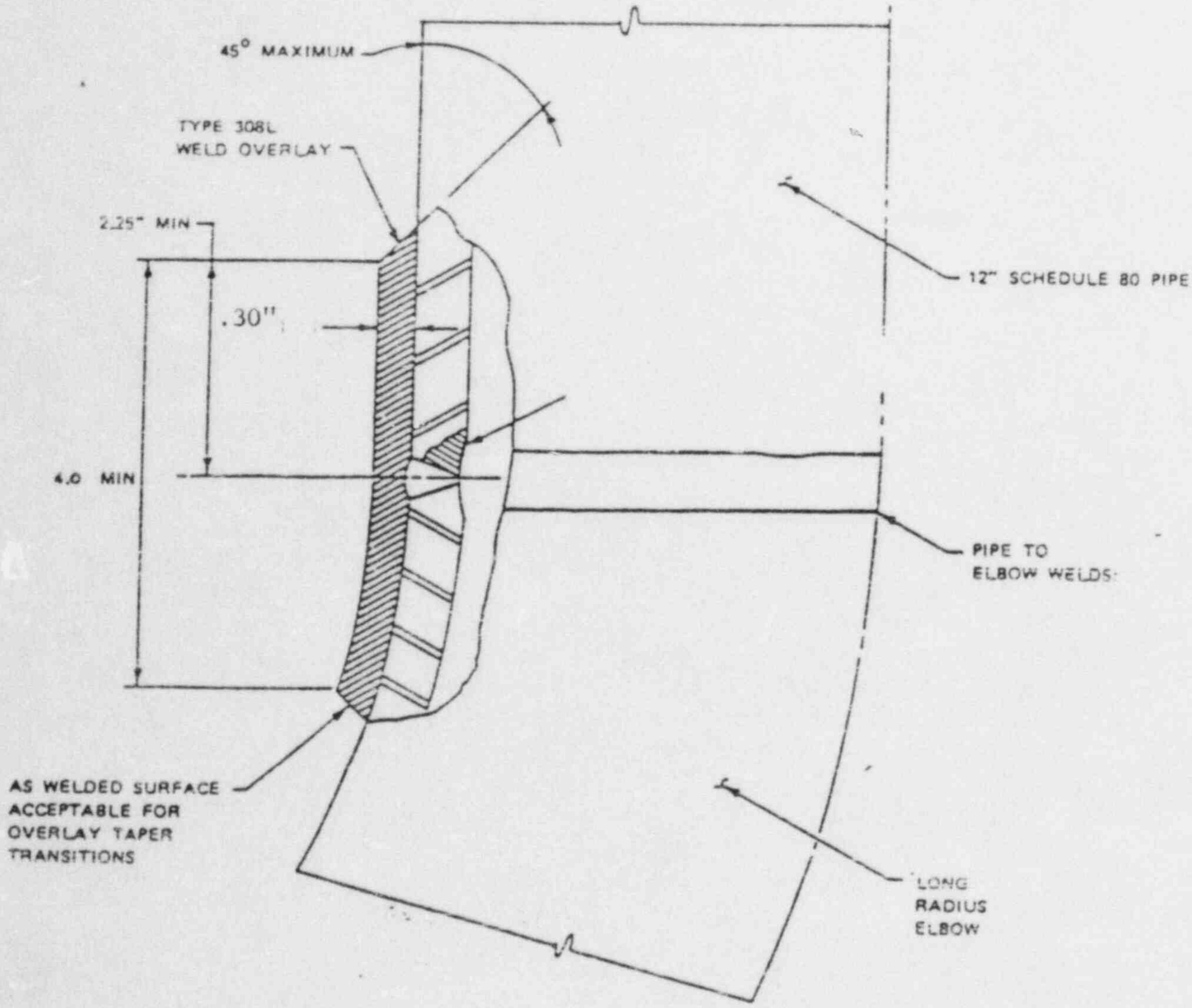


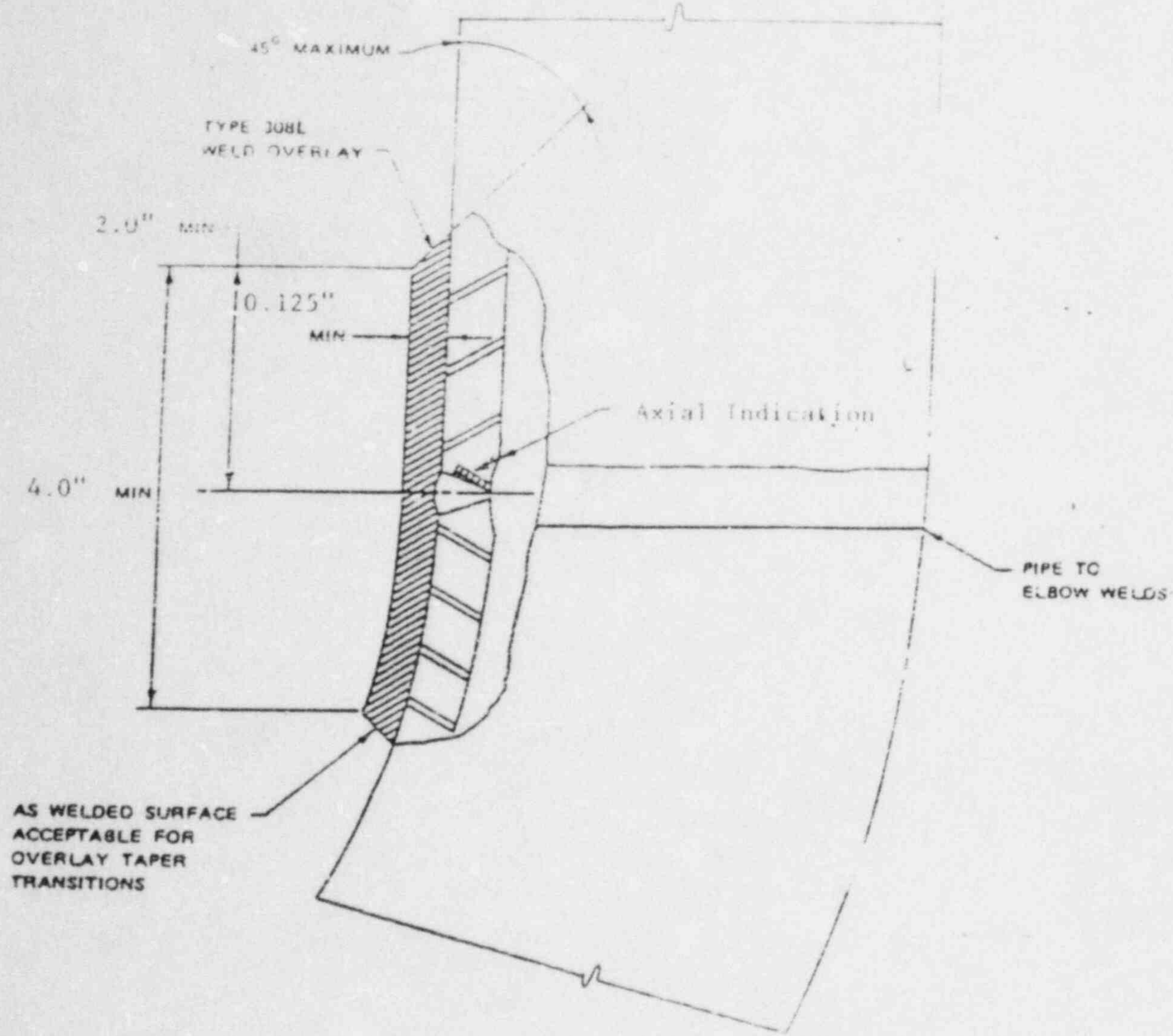
FIGURE 4-1. Vermont Yankee Weld 1A Flaw Evaluation



SCHEMATIC OF 12" ELBOW TO PIPE WELD OVERLAY

JOINT 32

Figure 5.1



Weld Joint RHR-32-4 [illegible]

Figure 5.2

APPENDIX A

CRACK GROWTH RESULT

STRUCTURAL INTEGRITY ASSOCIATES
STRESS CORROSION CRACK GROWTH ANALYSIS

TITLE: VERMONT YANKEE 28" SUCTION JOINT NO. 1A (NODE 8
INITIAL CRACK DEPTH= 0.2640
WALL THICKNESS= 1.2000
MAX CRACK DEPTH DESIRED FOR SCCG= 0.9000
MATERIAL CONSTANT C.N OF DA/DT=C(DK)^N
C= 2.27000E-8
N= 2.260

HOUR	KMAX	A	A/T	DA/DT	DA
1000.0	16.27	0.28	0.230	1.24163E-5	0.0124
2000.0	15.92	0.29	0.240	1.18187E-5	0.0118
3000.0	15.59	0.30	0.250	1.12638E-5	0.0113
4000.0	15.23	0.31	0.258	1.06913E-5	0.0107
5000.0	14.89	0.32	0.267	1.01634E-5	0.0102
6000.0	14.55	0.33	0.275	9.64386E-6	0.0096
7000.0	14.22	0.34	0.283	9.15866E-6	0.0092
8000.0	13.91	0.35	0.290	8.70267E-6	0.0087
9000.0	13.59	0.36	0.297	8.26714E-6	0.0083
10000.0	13.30	0.36	0.303	7.86492E-6	0.0079
11000.0	13.09	0.37	0.310	7.58542E-6	0.0076
12000.0	12.95	0.38	0.316	7.40696E-6	0.0074
13000.0	12.81	0.39	0.322	7.23498E-6	0.0072
14000.0	12.68	0.39	0.328	7.06976E-6	0.0071
15000.0	12.56	0.40	0.333	6.91168E-6	0.0069
16000.0	12.43	0.41	0.339	6.75906E-6	0.0068
17000.0	12.31	0.41	0.345	6.61165E-6	0.0066
18000.0	12.20	0.42	0.350	6.47409E-6	0.0065
19000.0	12.09	0.43	0.355	6.34184E-6	0.0063
20000.0	11.98	0.43	0.360	6.21376E-6	0.0062
21000.0	11.87	0.44	0.366	6.09052E-6	0.0061
22000.0	11.78	0.44	0.371	5.97864E-6	0.0060
23000.0	11.68	0.45	0.375	5.86994E-6	0.0059
24000.0	11.59	0.46	0.380	5.76429E-6	0.0058
25000.0	11.50	0.46	0.385	5.66215E-6	0.0057

STRUCTURAL INTEGRITY ASSOCIATES
STRESS CORROSION CRACK GROWTH ANALYSIS

TITLE: VERMONT YANKEE 28" SUCTION JOINT 2 (NODE 9)
INITIAL CRACK DEPTH= 0.1800
WALL THICKNESS= 1.2000
MAX CRACK DEPTH DESIRED FOR SCCG= 0.9000
MATERIAL CONSTANT C,N OF DA/DT=C(DK)^N
C= 2.27000E-8
N= 2.260

HOUR	KMAX	A	A/T	DA/DT	DA
1000.0	16.50	0.19	0.161	1.28130E-5	0.0128
2000.0	16.29	0.21	0.171	1.24386E-5	0.0124
3000.0	15.99	0.22	0.181	1.19288E-5	0.0119
4000.0	15.69	0.23	0.191	1.14390E-5	0.0114
5000.0	15.35	0.24	0.200	1.08778E-5	0.0109
6000.0	15.02	0.25	0.208	1.03588E-5	0.0104
7000.0	14.71	0.26	0.216	9.88692E-6	0.0099
8000.0	14.42	0.27	0.224	9.44843E-6	0.0094
9000.0	14.12	0.28	0.232	9.00880E-6	0.0090
10000.0	13.82	0.29	0.239	8.57698E-6	0.0086
11000.0	13.53	0.29	0.246	8.17681E-6	0.0082
12000.0	13.23	0.30	0.252	7.77506E-6	0.0078
13000.0	12.94	0.31	0.258	7.39859E-6	0.0074
14000.0	12.67	0.32	0.264	7.04998E-6	0.0070
15000.0	12.40	0.32	0.270	6.71065E-6	0.0067

STRUCTURAL INTEGRITY ASSOCIATES
STRESS CORROSION CRACK GROWTH ANALYSIS

TITLE: VERMONT YANKEE 28" DISCHARGE JOINT NO. 9A (NODE 52)
INITIAL CRACK DEPTH= 0.2580
WALL THICKNESS= 1.2900
MAX CRACK DEPTH DESIRED FOR SCCG= 1.0000
MATERIAL CONSTANT C.N OF DA/DT=C(DK)^N
C= 2.27000E-8
N= 2.260

HOUR	KMAX	A	A/T	DA/DT	DA
1000.0	14.80	0.27	0.208	1.00248E-5	0.0100
2000.0	14.50	0.28	0.215	9.56216E-6	0.0096
3000.0	14.21	0.29	0.222	9.13222E-6	0.0091
4000.0	13.91	0.30	0.229	8.71540E-6	0.0087
5000.0	13.61	0.30	0.235	8.29516E-6	0.0083
6000.0	13.33	0.31	0.242	7.90590E-6	0.0079
7000.0	13.05	0.32	0.247	7.53620E-6	0.0075
8000.0	12.76	0.33	0.253	7.17049E-6	0.0072
9000.0	12.49	0.33	0.258	6.83192E-6	0.0068
10000.0	12.24	0.34	0.263	6.51780E-6	0.0065
11000.0	11.98	0.35	0.268	6.21355E-6	0.0062
12000.0	11.73	0.35	0.273	5.92514E-6	0.0059
13000.0	11.49	0.36	0.277	5.65721E-6	0.0057
14000.0	11.27	0.36	0.281	5.40784E-6	0.0054
15000.0	11.05	0.37	0.285	5.17210E-6	0.0052
16000.0	10.83	0.37	0.289	4.94559E-6	0.0049
17000.0	10.62	0.38	0.293	4.73427E-6	0.0047
18000.0	10.42	0.38	0.296	4.53679E-6	0.0045
19000.0	10.23	0.39	0.300	4.35193E-6	0.0044
20000.0	10.05	0.39	0.303	4.17863E-6	0.0042
21000.0	9.94	0.39	0.306	4.07065E-6	0.0041
22000.0	9.83	0.40	0.309	3.97201E-6	0.0040
23000.0	9.72	0.40	0.312	3.87705E-6	0.0039
24000.0	9.62	0.41	0.315	3.78560E-6	0.0038
25000.0	9.52	0.41	0.318	3.69748E-6	0.0037

STRUCTURAL INTEGRITY ASSOCIATES
STRESS CORROSION CRACK GROWTH ANALYSIS

TITLE: VERMONT YANKEE 28" SUCTION JOINT NO. 15B (NODE 13)
INITIAL CRACK DEPTH= 0.3186
WALL THICKNESS= 1.1800
MAX CRACK DEPTH DESIRED FOR SCCG= 0.9200
MATERIAL CONSTANT C,N OF DA/DT=C(DK)^N
C= 2.27000E-8
N= 2.260

HOUR	KMAX	A	A/T	DA/DT	DA
1000.0	13.83	0.33	0.277	8.59195E-6	0.0086
2000.0	13.52	0.34	0.284	8.16788E-6	0.0082
3000.0	13.22	0.34	0.291	7.76269E-6	0.0078
4000.0	12.93	0.35	0.297	7.38038E-6	0.0074
5000.0	12.65	0.36	0.303	7.02685E-6	0.0070
6000.0	12.45	0.36	0.309	6.77456E-6	0.0068
7000.0	12.31	0.37	0.314	6.60717E-6	0.0066
8000.0	12.18	0.38	0.320	6.44616E-6	0.0064
9000.0	12.05	0.38	0.325	6.29121E-6	0.0063
10000.0	11.92	0.39	0.330	6.14203E-6	0.0061
11000.0	11.79	0.40	0.335	5.99832E-6	0.0060
12000.0	11.67	0.40	0.340	5.85980E-6	0.0059
13000.0	11.56	0.41	0.345	5.72648E-6	0.0057
14000.0	11.44	0.41	0.350	5.60082E-6	0.0056
15000.0	11.33	0.42	0.355	5.47943E-6	0.0055

STRUCTURAL INTEGRITY ASSOCIATES
STRESS CORROSION CRACK GROWTH ANALYSIS

TITLE: VERMONT YANKEE 28" SUCTION JOINT NO. 26A (NODE 208)
INITIAL CRACK DEPTH= 0.1725
WALL THICKNESS= 1.1500
MAX CRACK DEPTH DESIRED FOR SCCG= 0.8000
MATERIAL CONSTANT C,N OF DA/DT=C(DK)^N
C= 2.27000E-8
N= 2.260

HOUR	KMAX	A	A/T	DA/DT	DA
1000.0	16.95	0.19	0.162	1.36096E-5	0.0136
2000.0	16.76	0.20	0.173	1.32768E-5	0.0133
3000.0	16.49	0.21	0.185	1.27967E-5	0.0128
4000.0	16.20	0.22	0.195	1.22850E-5	0.0123
5000.0	15.87	0.24	0.205	1.17245E-5	0.0117
6000.0	15.55	0.25	0.215	1.12094E-5	0.0112
7000.0	15.26	0.26	0.224	1.07343E-5	0.0107
8000.0	14.95	0.27	0.233	1.02542E-5	0.0103
9000.0	14.64	0.28	0.242	9.77056E-6	0.0098
10000.0	14.33	0.29	0.250	9.31023E-6	0.0093
11000.0	14.01	0.30	0.258	8.84520E-6	0.0088
12000.0	13.70	0.30	0.265	8.41566E-6	0.0084
13000.0	13.39	0.31	0.272	7.99551E-6	0.0080
14000.0	13.09	0.32	0.279	7.59769E-6	0.0076
15000.0	12.81	0.33	0.285	7.23011E-6	0.0072
16000.0	12.53	0.33	0.291	6.87423E-6	0.0069
17000.0	12.26	0.34	0.296	6.54080E-6	0.0065
18000.0	12.00	0.35	0.302	6.23210E-6	0.0062
19000.0	11.79	0.35	0.307	5.98838E-6	0.0060
20000.0	11.65	0.36	0.312	5.83311E-6	0.0058
21000.0	11.52	0.36	0.317	5.68405E-6	0.0057
22000.0	11.39	0.37	0.322	5.54087E-6	0.0055
23000.0	11.26	0.38	0.327	5.40253E-6	0.0054
24000.0	11.14	0.38	0.331	5.26851E-6	0.0053
25000.0	11.02	0.39	0.336	5.13962E-6	0.0051

STRUCTURAL INTEGRITY ASSOCIATES
STRESS CORROSION CRACK GROWTH ANALYSIS

TITLE: VERMONT YANKEE 28" SUCTION JOINT NO. 27 (NODE 209)
INITIAL CRACK DEPTH= 0.2185
WALL THICKNESS= 1.1500
MAX CRACK DEPTH DESIRED FOR SCCG= 0.9000
MATERIAL CONSTANT C.N OF DA/DT=C(DK)^N
C= 2.27000E-8
N= 2.260

HOUR	KMAX	A	A/T	DA/DT	DA
1000.0	15.64	0.23	0.200	1.13519E-5	0.0114
2000.0	15.32	0.24	0.209	1.08358E-5	0.0108
3000.0	15.02	0.25	0.218	1.03642E-5	0.0104
4000.0	14.74	0.26	0.227	9.92427E-6	0.0099
5000.0	14.43	0.27	0.235	9.45969E-6	0.0095
6000.0	14.13	0.28	0.243	9.01632E-6	0.0090
7000.0	13.82	0.29	0.250	8.58703E-6	0.0086
8000.0	13.52	0.30	0.258	8.16254E-6	0.0082
9000.0	13.23	0.30	0.264	7.77013E-6	0.0078
10000.0	12.93	0.31	0.271	7.38788E-6	0.0074
11000.0	12.65	0.32	0.277	7.02465E-6	0.0070
12000.0	12.38	0.33	0.283	6.68872E-6	0.0067
13000.0	12.11	0.33	0.288	6.36916E-6	0.0064
14000.0	11.85	0.34	0.293	6.06401E-6	0.0061
15000.0	11.60	0.34	0.299	5.78123E-6	0.0058
16000.0	11.37	0.35	0.303	5.51862E-6	0.0055
17000.0	11.21	0.35	0.308	5.34226E-6	0.0053
18000.0	11.08	0.36	0.312	5.20382E-6	0.0052
19000.0	10.95	0.36	0.317	5.07091E-6	0.0051
20000.0	10.83	0.37	0.321	4.94324E-6	0.0049
21000.0	10.71	0.37	0.325	4.82008E-6	0.0048
22000.0	10.59	0.38	0.329	4.70055E-6	0.0047
23000.0	10.47	0.38	0.333	4.58559E-6	0.0046
24000.0	[illegible]	0.39	0.337	4.47497E-6	0.0045
25000.0	[illegible]	0.39	0.341	4.36846E-6	0.0044

STRUCTURAL INTEGRITY ASSOCIATES
STRESS CORROSION CRACK GROWTH ANALYSIS

TITLE: VERMONT YANKEE 28" DISCHARGE JOINT NO. 61 (NODE 265)
INITIAL CRACK DEPTH= 0.2500
WALL THICKNESS= 1.2500
MAX CRACK DEPTH DESIRED FOR SCCG= 1.0000
MATERIAL CONSTANT C,N OF DA/DT=C(DK)^N
C= 2.27000E-8
N= 2.260

HOUR	KMAX	A	A/T	DA/DT	DA
1000.0	14.57	0.26	0.208	9.66873E-6	0.0097
2000.0	14.27	0.27	0.215	9.23156E-6	0.0092
3000.0	13.99	0.28	0.222	8.82465E-6	0.0088
4000.0	13.71	0.29	0.229	8.42912E-6	0.0084
5000.0	13.42	0.29	0.235	8.02725E-6	0.0080
6000.0	13.14	0.30	0.241	7.65468E-6	0.0077
7000.0	12.87	0.31	0.247	7.30048E-6	0.0073
8000.0	12.59	0.32	0.253	6.94753E-6	0.0069
9000.0	12.32	0.32	0.258	6.62067E-6	0.0066
10000.0	12.07	0.33	0.263	6.31735E-6	0.0063
11000.0	11.82	0.34	0.268	6.02266E-6	0.0060
12000.0	11.57	0.34	0.273	5.74232E-6	0.0057
13000.0	11.33	0.35	0.277	5.48196E-6	0.0055
14000.0	11.11	0.35	0.281	5.23966E-6	0.0052
15000.0	10.89	0.36	0.285	5.01049E-6	0.0050
16000.0	10.68	0.36	0.289	4.78913E-6	0.0048
17000.0	10.47	0.37	0.293	4.58275E-6	0.0046
18000.0	10.27	0.37	0.296	4.39000E-6	0.0044
19000.0	10.08	0.37	0.300	4.20968E-6	0.0042
20000.0	9.90	0.38	0.303	4.04071E-6	0.0040
21000.0	9.78	0.38	0.306	3.93090E-6	0.0039
22000.0	9.67	0.39	0.309	3.83245E-6	0.0038
23000.0	9.57	0.39	0.312	3.73781E-6	0.0037
24000.0	9.46	0.39	0.315	3.64677E-6	0.0036
25000.0	9.36	0.40	0.318	3.55916E-6	0.0036

STRUCTURAL INTEGRITY ASSOCIATES
STRESS CORROSION CRACK GROWTH ANALYSIS

TITLE: VERMONT YANKEE 28" SUCTION JOINT NO. 59 (NODE 266)
INITIAL CRACK DEPTH= 0.2814
WALL THICKNESS= 1.3400
MAX CRACK DEPTH DESIRED FOR SCCG= 1.0000
MATERIAL CONSTANT C,N OF DA/DT=C(DK)^N
C= 2.27000E-8
N= 2.260

HOUR	KMAX	A	A/T	DA/DT	DA
1000.0	11.58	0.29	0.214	5.75274E-6	0.0058
2000.0	11.35	0.29	0.218	5.50453E-6	0.0055
3000.0	11.14	0.30	0.222	5.27273E-6	0.0053
4000.0	10.93	0.30	0.226	5.04605E-6	0.0050
5000.0	10.71	0.31	0.230	4.82800E-6	0.0048
6000.0	10.51	0.31	0.233	4.62438E-6	0.0046
7000.0	10.32	0.32	0.236	4.43393E-6	0.0044
8000.0	10.13	0.32	0.240	4.25551E-6	0.0043
9000.0	9.95	0.33	0.243	4.08810E-6	0.0041
10000.0	9.78	0.33	0.246	3.92385E-6	0.0039
11000.0	9.60	0.33	0.248	3.76886E-6	0.0038
12000.0	9.44	0.34	0.251	3.62327E-6	0.0036
13000.0	9.28	0.34	0.254	3.48630E-6	0.0035
14000.0	9.12	0.34	0.256	3.35728E-6	0.0034
15000.0	8.98	0.35	0.259	3.23560E-6	0.0032
16000.0	8.83	0.35	0.261	3.12069E-6	0.0031
17000.0	8.69	0.35	0.263	3.01068E-6	0.0030
18000.0	8.56	0.36	0.265	2.90485E-6	0.0029
19000.0	8.43	0.36	0.267	2.80474E-6	0.0028
20000.0	8.30	0.36	0.270	2.70994E-6	0.0027
21000.0	8.18	0.36	0.271	2.62006E-6	0.0026
22000.0	8.06	0.37	0.273	2.53477E-6	0.0025
23000.0	7.94	0.37	0.275	2.45374E-6	0.0025
24000.0	7.83	0.37	0.277	2.37671E-6	0.0024
25000.0	7.72	0.37	0.279	2.30339E-6	0.0023

STRUCTURAL INTEGRITY ASSOCIATES
STRESS CORROSION CRACK GROWTH ANALYSIS

TITLE: VERMONT YANKEE 28" DISCHARGE JOINT NO. 65A (NODE 250)
INITIAL CRACK DEPTH= 0.2967
WALL THICKNESS= 1.2?00
MAX CRACK DEPTH DESIRED FOR SCCG= 1.0000
MATERIAL CONSTANT C,N OF DA/DT=C(DK)^N
C= 2.27000E-8
N= 2.260

HOUR	KMAX	A	A/T	DA/DT	DA
1000.0	14.11	0.31	0.237	8.99564E-6	0.0090
2000.0	13.81	0.31	0.244	8.57103E-6	0.0086
3000.0	13.51	0.32	0.250	8.15694E-6	0.0082
4000.0	13.22	0.33	0.256	7.75786E-6	0.0078
5000.0	12.93	0.34	0.262	7.38863E-6	0.0074
6000.0	12.66	0.34	0.267	7.03964E-6	0.0070
7000.0	12.39	0.35	0.272	6.70110E-6	0.0067
8000.0	12.13	0.36	0.277	6.38746E-6	0.0064
9000.0	11.88	0.36	0.282	6.09627E-6	0.0061
10000.0	11.64	0.37	0.287	5.82019E-6	0.0058
11000.0	11.40	0.38	0.291	5.55668E-6	0.0056
12000.0	11.18	0.38	0.295	5.31145E-6	0.0053
13000.0	10.96	0.39	0.299	5.08278E-6	0.0051
14000.0	10.75	0.39	0.303	4.86921E-6	0.0049
15000.0	10.61	0.40	0.306	4.72397E-6	0.0047
16000.0	10.49	0.40	0.310	4.60725E-6	0.0046
17000.0	10.38	0.40	0.313	4.49498E-6	0.0045
18000.0	10.27	0.41	0.317	4.38693E-6	0.0044
19000.0	10.16	0.41	0.320	4.28290E-6	0.0043
20000.0	10.06	0.42	0.323	4.18268E-6	0.0042
21000.0	9.95	0.42	0.327	4.08641E-6	0.0041
22000.0	9.85	0.43	0.330	3.99356E-6	0.0040
23000.0	9.75	0.43	0.333	3.90398E-6	0.0039
24000.0	9.66	0.43	0.336	3.81749E-6	0.0038
25000.0	9.56	0.44	0.338	3.73397E-6	0.0037

STRUCTURAL INTEGRITY ASSOCIATES
STRESS CORROSION CRACK GROWTH ANALYSIS

TITLE: VERMONT YANKEE 22" JOINT NO. 16A (NODE 34)
INITIAL CRACK DEPTH= 0.2100
WALL THICKNESS= 1.0500
MAX CRACK DEPTH DESIRED FOR SCCG= 0.8000
MATERIAL CONSTANT C,N OF DA/DT=C(DK)^N
C= 2.27000E-8
N= 2.260

HOUR	KMAX	A	A/T	DA/DT	DA
1000.0	16.34	0.22	0.212	1.25331E-5	0.0125
2000.0	16.03	0.23	0.223	1.20073E-5	0.0120
3000.0	15.73	0.25	0.234	1.14912E-5	0.0115
4000.0	15.40	0.26	0.245	1.09555E-5	0.0110
5000.0	15.07	0.27	0.255	1.04336E-5	0.0104
6000.0	14.74	0.28	0.264	9.92260E-6	0.0099
7000.0	14.41	0.29	0.273	9.43527E-6	0.0094
8000.0	14.09	0.30	0.282	8.96723E-6	0.0090
9000.0	13.78	0.30	0.290	8.53105E-6	0.0085
10000.0	13.48	0.31	0.298	8.11330E-6	0.0081
11000.0	13.19	0.32	0.305	7.72682E-6	0.0077
12000.0	13.02	0.33	0.312	7.50308E-6	0.0075
13000.0	12.91	0.33	0.319	7.35539E-6	0.0074
14000.0	12.80	0.34	0.326	7.21221E-6	0.0072
15000.0	12.69	0.35	0.333	7.07958E-6	0.0071
16000.0	12.59	0.36	0.339	6.95172E-6	0.0070
17000.0	12.49	0.36	0.346	6.82744E-6	0.0068
18000.0	12.40	0.37	0.352	6.71671E-6	0.0067
19000.0	12.31	0.38	0.358	6.61003E-6	0.0066
20000.0	12.23	0.38	0.365	6.50597E-6	0.0065
21000.0	12.15	0.39	0.371	6.41551E-6	0.0064
22000.0	12.08	0.40	0.377	6.33061E-6	0.0063
23000.0	12.01	0.40	0.383	6.24746E-6	0.0062
24000.0	11.95	0.41	0.389	6.17401E-6	0.0062
25000.0	11.89	0.41	0.394	6.11116E-6	0.0061

STRESS CORR [illegible]

TITLE: VERMONT YANKEE 22" JOINT NO. 16B (NODE 36)
INITIAL CRACK DEPTH= [illegible]
WALL THICKNESS= 1.0300
MAX CRACK DEPTH DESIRED FOR SCCG= 0.8000
MATERIAL CONSTANT C,N OF DA/DT=C(DK)^N
C= 2.27000E-8
N= 2.260

HOUR	KMAX	A	A/T	DA/DT	DA
1000.0	18.08	0.14	0.135	1.57581E-5	0.0158
2000.0	18.14	0.16	0.151	1.58618E-5	0.0159
3000.0	18.07	0.17	0.166	1.57306E-5	0.0157
4000.0	17.90	0.19	0.181	1.53970E-5	0.0154
5000.0	17.65	0.20	0.195	1.49083E-5	0.0149
6000.0	17.31	0.22	0.209	1.42662E-5	0.0143
7000.0	17.00	0.23	0.223	1.36979E-5	0.0137
8000.0	16.70	0.24	0.235	1.31589E-5	0.0132
9000.0	16.36	0.25	0.248	1.25724E-5	0.0126
10000.0	16.02	0.27	0.259	1.19821E-5	0.0120
11000.0	15.68	0.28	0.270	1.14090E-5	0.0114
12000.0	15.32	0.29	0.281	1.08359E-5	0.0108
13000.0	14.98	0.30	0.291	1.03015E-5	0.0103
14000.0	14.64	0.31	0.300	9.78263E-6	0.0098
15000.0	14.33	0.32	0.309	9.31171E-6	0.0093
16000.0	14.22	0.33	0.318	9.14792E-6	0.0091
17000.0	14.11	0.34	0.327	8.98859E-6	0.0090
18000.0	14.00	0.35	0.335	8.83980E-6	0.0088
19000.0	13.90	0.35	0.344	8.69644E-6	0.0087
20000.0	13.81	0.36	0.352	8.56330E-6	0.0086
21000.0	13.72	0.37	0.360	8.44076E-6	0.0084
22000.0	13.63	0.38	0.369	8.32200E-6	0.0083
23000.0	13.56	0.39	0.377	8.22424E-6	0.0082
24000.0	13.49	0.40	0.384	8.12826E-6	0.0081
25000.0	13.43	0.40	0.392	8.04743E-6	0.0080

STRUCTURAL INTEGRITY ASSOCIATES
STRESS CORROSION CRACK GROWTH ANALYSIS

TITLE: VERMONT YANKEE 22" JOINT NO. 30B
INITIAL CRACK DEPTH= 0.2080
WALL THICKNESS= 1.0400
MAX CRACK DEPTH DESIRED FOR SCCG= 0.8000
MATERIAL CONSTANT C,N OF DA/DT=C(DK)^N
C= 2.27000E-8
N= 2.260

HOUR	KMAX	A	A/T	DA/DT	DA
1000.0	11.63	0.21	0.206	5.81419E-6	0.0058
2000.0	11.40	0.22	0.211	5.55386E-6	0.0056
3000.0	11.18	0.22	0.216	5.31139E-6	0.0053
4000.0	10.96	0.23	0.221	5.08512E-6	0.0051
5000.0	10.76	0.23	0.226	4.86953E-6	0.0049
6000.0	10.54	0.24	0.230	4.65159E-6	0.0047
7000.0	10.33	0.24	0.234	4.44859E-6	0.0044
8000.0	10.14	0.25	0.238	4.25916E-6	0.0043
9000.0	9.95	0.25	0.242	4.08209E-6	0.0041
10000.0	9.76	0.26	0.246	3.90911E-6	0.0039
11000.0	9.57	0.26	0.250	3.74300E-6	0.0037
12000.0	9.40	0.26	0.253	3.58772E-6	0.0036
13000.0	9.23	0.27	0.256	3.44231E-6	0.0034
14000.0	9.06	0.27	0.260	3.30594E-6	0.0033
15000.0	8.90	0.27	0.263	3.17786E-6	0.0032
16000.0	8.75	0.28	0.266	3.05206E-6	0.0031
17000.0	8.59	0.28	0.268	2.93331E-6	0.0029
18000.0	8.45	0.28	0.271	2.82165E-6	0.0028
19000.0	8.31	0.28	0.274	2.71652E-6	0.0027
20000.0	8.17	0.29	0.276	2.61740E-6	0.0026
21000.0	8.04	0.29	0.279	2.52383E-6	0.0025
22000.0	7.92	0.29	0.281	2.43541E-6	0.0024
23000.0	7.79	0.29	0.283	2.35047E-6	0.0024
24000.0	7.67	0.30	0.286	2.26873E-6	0.0023
25000.0	7.55	0.30	0.288	2.19135E-6	0.0022

STRUCTURAL INTEGRITY ASSOCIATES
STRESS CORROSION CRACK GROWTH ANALYSIS

TITLE: VERMONT YANKEE 28" SUCTION JOINT NO. 17B (NODE 214)
INITIAL CRACK DEPTH= 0.2540
WALL THICKNESS= 1.2700
MAX CRACK DEPTH DESIRED FOR SCCG= 1.0000
MATERIAL CONSTANT C.N OF DA/DT=C(DK)^N
C= 2.27000E-8
N= 2.260

HOUR	KMAX	A	A/T	DA/DT	DA
1000.0	13.88	0.26	0.207	8.65933E-6	0.0087
2000.0	13.58	0.27	0.213	8.25239E-6	0.0083
3000.0	13.30	0.28	0.220	7.87470E-6	0.0079
4000.0	13.04	0.29	0.225	7.52347E-6	0.0075
5000.0	12.76	0.29	0.231	7.16481E-6	0.0072
6000.0	12.49	0.30	0.236	6.82973E-6	0.0068
7000.0	12.24	0.31	0.242	6.51862E-6	0.0065
8000.0	11.99	0.31	0.246	6.22280E-6	0.0062
9000.0	11.74	0.32	0.251	5.93430E-6	0.0059
10000.0	11.50	0.32	0.256	5.66627E-6	0.0057
11000.0	11.27	0.33	0.260	5.41678E-6	0.0054
12000.0	11.06	0.34	0.264	5.18411E-6	0.0052
13000.0	10.84	0.34	0.268	4.95672E-6	0.0050
14000.0	10.63	0.34	0.272	4.74437E-6	0.0047
15000.0	10.43	0.35	0.275	4.54596E-6	0.0045
16000.0	10.24	0.35	0.279	4.36026E-6	0.0044
17000.0	10.06	0.36	0.282	4.18620E-6	0.0042
18000.0	9.88	0.36	0.285	4.02005E-6	0.0040
19000.0	9.71	0.37	0.288	3.86216E-6	0.0039
20000.0	9.54	0.37	0.291	3.71379E-6	0.0037
21000.0	9.38	0.37	0.294	3.57416E-6	0.0036
22000.0	9.23	0.38	0.297	3.44260E-6	0.0034
23000.0	9.08	0.38	0.299	3.31848E-6	0.0033
24000.0	8.93	0.38	0.302	3.20123E-6	0.0032
25000.0	8.83	0.39	0.304	3.11849E-6	0.0031

STRUCTURAL INTEGRITY ASSOCIATES
STRESS CORROSION CRACK GROWTH ANALYSIS

TITLE: VERMONT YANKEE 22" JOINT NO. 49 (NODE 17)
INITIAL CRACK DEPTH= 0.2398
WALL THICKNESS= 1.0900
MAX CRACK DEPTH DESIRED FOR SCCG= 0.8000
MATERIAL CONSTANT C,N OF DA/DT=C(DK)^N
C= 2.27000E-8
N= 2.260

HOUR	KMAX	A	A/T	DA/DT	DA
1000.0	14.33	0.25	0.229	9.31748E-6	0.0093
2000.0	14.02	0.26	0.237	8.86528E-6	0.0089
3000.0	13.72	0.27	0.244	8.44663E-6	0.0084
4000.0	13.43	0.27	0.252	8.04056E-6	0.0080
5000.0	13.14	0.28	0.259	7.65209E-6	0.0077
6000.0	12.86	0.29	0.266	7.29232E-6	0.0073
7000.0	12.58	0.30	0.272	6.94473E-6	0.0069
8000.0	12.32	0.30	0.278	6.61979E-6	0.0066
9000.0	12.07	0.31	0.284	6.31810E-6	0.0063
10000.0	11.82	0.32	0.289	6.03243E-6	0.0060
11000.0	11.59	0.32	0.295	5.76400E-6	0.0058
12000.0	11.36	0.33	0.300	5.51386E-6	0.0055
13000.0	11.15	0.33	0.304	5.28035E-6	0.0053
14000.0	11.04	0.34	0.309	5.16242E-6	0.0052
15000.0	10.94	0.34	0.314	5.05639E-6	0.0051
16000.0	10.84	0.35	0.318	4.95372E-6	0.0050
17000.0	10.74	0.35	0.323	4.85428E-6	0.0049
18000.0	10.65	0.36	0.327	4.76169E-6	0.0048
19000.0	10.56	0.36	0.332	4.67388E-6	0.0047
20000.0	10.48	0.37	0.336	4.58857E-6	0.0046
21000.0	10.39	0.37	0.340	4.50568E-6	0.0045
22000.0	10.31	0.37	0.344	4.42510E-6	0.0044
23000.0	10.24	0.38	0.348	4.35405E-6	0.0044
24000.0	10.16	0.38	0.352	4.28502E-6	0.0043
25000.0	10.09	0.39	0.356	4.21770E-6	0.0042

STRUCTURAL INTEGRITY ASSOCIATES
STRESS CORROSION CRACK GROWTH ANALYSIS

TITLE: VERMONT YANKEE 28" DISCHARGE JOINT NO. 6 (NODE 66)
INITIAL CRACK DEPTH= 0.2142
WALL THICKNESS= 1.2600
MAX CRACK DEPTH DESIRED FOR SCCG= 1.0000
MATERIAL CONSTANT C,N OF DA/DT=C(DK)^N
C= 2.27000E-8
N= 2.260

HOUR	KMAX	A	A/T	DA/DT	DA
1000.0	16.18	0.23	0.180	1.22594E-5	0.0123
2000.0	15.90	0.24	0.189	1.17744E-5	0.0118
3000.0	15.55	0.25	0.198	1.12044E-5	0.0112
4000.0	15.22	0.26	0.206	1.06735E-5	0.0107
5000.0	14.91	0.27	0.215	1.01859E-5	0.0102
6000.0	14.61	0.28	0.222	9.73390E-6	0.0097
7000.0	14.32	0.29	0.230	9.29518E-6	0.0093
8000.0	14.01	0.30	0.237	8.84729E-6	0.0088
9000.0	13.71	0.31	0.243	8.43240E-6	0.0084
10000.0	13.42	0.31	0.250	8.02810E-6	0.0080
11000.0	13.12	0.32	0.256	7.63561E-6	0.0076
12000.0	12.84	0.33	0.262	7.27245E-6	0.0073
13000.0	12.57	0.34	0.267	6.92930E-6	0.0069
14000.0	12.30	0.34	0.272	6.59459E-6	0.0066
15000.0	12.04	0.35	0.277	6.28461E-6	0.0063
16000.0	11.79	0.36	0.282	5.99692E-6	0.0060
17000.0	11.55	0.36	0.287	5.72366E-6	0.0057
18000.0	11.32	0.37	0.291	5.46226E-6	0.0055
19000.0	11.09	0.37	0.295	5.21913E-6	0.0052
20000.0	10.87	0.38	0.299	4.99257E-6	0.0050
21000.0	10.67	0.38	0.303	4.78109E-6	0.0048
22000.0	10.53	0.39	0.306	4.63807E-6	0.0046
23000.0	10.41	0.39	0.310	4.52031E-6	0.0045
24000.0	10.29	0.40	0.314	4.40716E-6	0.0044
25000.0	10.18	0.40	0.317	4.29839E-6	0.0043

STRUCTURAL INTEGRITY ASSOCIATES
STRESS CORROSION CRACK GROWTH ANALYSIS

TITLE: VERMONT YANKEE 22" JOINT NO. 23B
INITIAL CRACK DEPTH= 0.2943
WALL THICKNESS= 1.0900
MAX CRACK DEPTH DESIRED FOR SCCG= 0.8000
MATERIAL CONSTANT C.N OF DA/DT=C(DK)^N
C= 2.27000E-8
N= 2.260

HOUR	KMAX	A	A/T	DA/DT	DA
1000.0	7.27	0.30	0.272	2.01068E-6	0.0020
2000.0	7.17	0.30	0.274	1.94688E-6	0.0019
3000.0	7.07	0.30	0.275	1.88619E-6	0.0019
4000.0	6.97	0.30	0.277	1.82842E-6	0.0018
5000.0	6.88	0.30	0.279	1.77337E-6	0.0018
6000.0	6.79	0.31	0.280	1.72087E-6	0.0017
7000.0	6.70	0.31	0.282	1.67061E-6	0.0017
8000.0	6.61	0.31	0.283	1.62176E-6	0.0016
9000.0	6.53	0.31	0.285	1.57511E-6	0.0016
10000.0	6.44	0.31	0.286	1.53053E-6	0.0015
11000.0	6.36	0.31	0.287	1.48790E-6	0.0015
12000.0	6.29	0.31	0.289	1.44709E-6	0.0014
13000.0	6.21	0.32	0.290	1.40801E-6	0.0014
14000.0	6.14	0.32	0.291	1.37056E-6	0.0014
15000.0	6.07	0.32	0.293	1.33464E-6	0.0013
16000.0	6.00	0.32	0.294	1.30018E-6	0.0013
17000.0	5.93	0.32	0.295	1.26708E-6	0.0013
18000.0	5.86	0.32	0.296	1.23529E-6	0.0012
19000.0	5.80	0.32	0.297	1.20473E-6	0.0012
20000.0	5.73	0.33	0.298	1.17533E-6	0.0012
21000.0	5.67	0.33	0.299	1.14704E-6	0.0011
22000.0	5.61	0.33	0.300	1.11981E-6	0.0011
23000.0	5.56	0.33	0.301	1.09625E-6	0.0011
24000.0	5.52	0.33	0.302	1.07890E-6	0.0011
25000.0	5.48	0.33	0.303	1.06198E-6	0.0011

APPENDIX B

ALLOWABLE FLAW DEPTHS

STRUCTURAL INTEGRITY ASSOCIATES
CRITICAL FLAW SIZE EVALUATION

CRITICAL FLAW SIZE FOR CIRCUMFERENTIAL CRACK.

TITLE:VERMONT YANKEE 28" SUCTION JOINT NO. 1A (NODE 8)

WALL THICKNESS= 1.2000
STRESS RATIO= 0.555
LOAD FACTOR= 1.00

L/CIRCUM	.0	.1	.2	.3	.4	.5->1.0
ALLOWABLE A/T	0.7500	0.7500	0.7500	0.7500	0.7500	0.6525

TITLE:VERMONT YANKEE 28" SUCTION JOINT NO. 2 (NODE 9)

WALL THICKNESS= 1.2000
STRESS RATIO= 0.465
LOAD FACTOR= 1.00

L/CIRCUM	.0	.1	.2	.3	.4	.5->1.0
ALLOWABLE A/T	0.7500	0.7500	0.7500	0.7500	0.7500	0.6975

TITLE:VERMONT YANKEE 28" SUCTION JOINT NO. 15B (NODE 13)

WALL THICKNESS= 1.1800
STRESS RATIO= 0.635
LOAD FACTOR= 1.00

L/CIRCUM	.0	.1	.2	.3	.4	.5->1.0
ALLOWABLE A/T	0.7500	0.7500	0.7500	0.7500	0.7500	0.6125

TITLE:VERMONT YANKEE 28" SUCTION JOINT NO. 27 (NODE 209)

WALL THICKNESS= 1.1500
STRESS RATIO= 0.449
LOAD FACTOR= 1.00

L/CIRCUM	.0	.1	.2	.3	.4	.5->1.0
ALLOWABLE A/T	0.7500	0.7500	0.7500	0.7500	0.7500	0.7055

TITLE:VERMONT YANKEE 28" SUCTION JOINT NO. 59 (NODE 266)

WALL THICKNESS= 1.3400
STRESS RATIO= 0.424
LOAD FACTOR= 1.00

L/CIRCUM	.0	.1	.2	.3	.4	.5->1.0
ALLOWABLE A/T	0.7500	0.7500	0.7500	0.7500	0.7500	0.7180

TITLE:VERMONT YANKEE 22" JOINT NO. 1AA (NODE [illegible])

WALL THICKNESS= 1.0500
STRESS RATIO= 0.666
LOAD FACTOR= 1.00

L/CIRCUM	.0	.1	.2	.3	.4	.5->1.0
ALLOWABLE A/T	0.7500	0.7500	0.7500	0.7500	0.7500	0.5970

TITLE:VERMONT YANKEE 22" JOINT NO. 16B (NODE [illegible])

WALL THICKNESS= 1.0300
STRESS RATIO= 0.708
LOAD FACTOR= 1.00

L/CIRCUM	.0	.1	.2	.3	.4	.5->1.0
ALLOWABLE A/T	0.7500	0.7500	0.7500	0.7500	0.7444	0.5760

TITLE:VERMONT YANKEE 28" SUCTION JOINT NO. 26A (NODE 208)

WALL THICKNESS= 1.1500
STRESS RATIO= 0.498
LOAD FACTOR= 1.00

	L/CIRCUM					
	.0	.1	.2	.3	.4	.5->1.0
ALLOWABLE A/T	0.7500	0.7500	0.7500	0.7500	0.7500	0.6810

TITLE:VERMONT YANKEE 28" DISCHARGE JOINT NO. 61 (NODE 265)

WALL THICKNESS= 1.2500
STRESS RATIO= 0.438
LOAD FACTOR= 1.00

	L/CIRCUM					
	.0	.1	.2	.3	.4	.5->1.0
ALLOWABLE A/T	0.7500	0.7500	0.7500	0.7500	0.7500	0.7110

TITLE:VERMONT YANKEE 28" DISCHARGE JOINT NO. 65A (NODE 250)

WALL THICKNESS= 1.2900
STRESS RATIO= 0.495
LOAD FACTOR= 1.00

	L/CIRCUM					
	.0	.1	.2	.3	.4	.5->1.0
ALLOWABLE A/T	0.7500	0.7500	0.7500	0.7500	0.7500	0.6825

TITLE:VERMONT YANKEE 22" JOINT NO. 30B

WALL THICKNESS= 1.0400
STRESS RATIO= 0.334
LOAD FACTOR= 1.00

	L/CIRCUM					
	.0	.1	.2	.3	.4	.5->1.0
ALLOWABLE A/T	0.7500	0.7500	0.7500	0.7500	0.7500	0.7431

TITLE:VERMONT YANKEE 28" DISCHARGE JOINT NO. 9A (NODE 52)

WALL THICKNESS= 1.2900
STRESS RATIO= 0.428
LOAD FACTOR= 1.00

	L/CIRCUM					
	.0	.1	.2	.3	.4	.5->1.0
ALLOWABLE A/T	0.7500	0.7500	0.7500	0.7500	0.7500	0.7160

TITLE:VERMONT YANKEE 28" SUCTION JOINT NO. 17B (NODE 214)

WALL THICKNESS= 1.2700
STRESS RATIO= 0.427
LOAD FACTOR= 1.00

	L/CIRCUM					
	.0	.1	.2	.3	.4	.5->1.0
ALLOWABLE A/T	0.7500	0.7500	0.7500	0.7500	0.7500	0.7165

TITLE:VERMONT YANKEE 22" JOINT NO. 49 (NODE 17)

WALL THICKNESS= 1.0900
STRESS RATIO= 0.573
LOAD FACTOR= 1.00

	L/CIRCUM					
	.0	.1	.2	.3	.4	.5->1.0
ALLOWABLE A/T	0.7500	0.7500	0.7500	0.7500	0.7500	0.6433

TITLE:VERMONT YANKEE 28" DISCHARGE JOINT NO. 6 (NODE 6)

WALL THICKNESS= 1.2600
STRESS RATIO= 0.484
LOAD FACTOR= 1.00

	L/CIRCUM					
	.0	.1	.2	.3	.4	.5->1.0
ALLOWABLE A/T	0.7500	0.7500	0.7500	0.7500	0.7500	0.6883

TITLE:VERMONT YANKEE 22" JOINT NO. 23R

WALL THICKNESS= 1.0900
STRESS RATIO= 0.319
LOAD FACTOR= 1.00

	L/CIRCUM					
	.0	.1	.2	.3	.4	.5->1.0
ALLOWABLE A/T	0.7500	0.7500	0.7500	0.7500	0.7500	0.7462

ENCLOSURE 3

VERMONT YANKEE REACTOR COOLANT

LEAK DETECTION PROVISIONS

ENCLOSURE 3

VERMONT YANKEE REACTOR COOLANT LEAKAGE DETECTION PROVISIONS

1. Reactor Coolant Leakage Limits

By letter dated June 27, 1983 [Reference (1)], the NRC issued a Confirmatory Order which included provisions for reactor coolant leakage. These provisions were incorporated into plant procedures prior to restart from our 1983 refueling outage and will continue to be in effect during the 1984-1985 cycle of operation. These provisions are provided in Attachment D to this report.

In cases where these limits, frequencies, or corrective actions conflict with the current Technical Specification 3.6.c/4.6.c, it is our intent to follow the provisions of Attachment D in lieu of our present Technical Specifications.

2. Moisture Sensitive Tape System

As previously discussed between representatives of Vermont Yankee and members of your staff, a moisture sensitive tape leak-detection system will be installed during the current refueling outage. Six (6) detector locations have been selected such that the remaining eight (8) uninspected 28" weld joints in the Recirculation System will be monitored. The exact detector locations have been discussed in detail with the supplier of the system and assurance has been provided that the eight (8) weld joints will be adequately monitored.

Due to operational problems associated with the moisture sensitive tape detectors during the last operating cycle, a modified detector will be used. This modification consists of relocating the electronics portion of the detectors to a separate junction box such that the electronic devices will be remote from high temperatures at the detector locations. High temperatures at the detectors is caused by heat transfer from the Recirculation System piping to the stainless steel detector housing. As a result of this modification, we believe that the system should be more reliable.

Based on the above, we will verbally notify the Vermont Yankee NRC Project Manager of any significant changes in the status of the moisture sensitive tape system during the 1984-1985 operating cycle. Further, we will make every reasonable effort to maintain the system fully operable. In the event of partial or intermittent system operability (similar to the condition that existed during our last operating cycle), Vermont Yankee would be responsible for determining the frequency during which the system will be used to check for weld joint leakage.

ENCLOSURE 4

AUGMENTED INSERVICE INPSECTION ALARA INFORMATION

ENCLOSURE 4

AUGMENTED ISI ALARM INFORMATION

A total of 190 man-rem have been expended for work associated with the 1984 Augmented In-Service Inspection Program. The man-rem expsoure levels are as follows:

	Man-Rem
UT Inspections:	48
Repair:	9
Insulation:	62
Shielding:	26
Weld Preps:	33
Moisture Sensitive Tape System Installation	12
Total:	190

We estimate that an additional 22 man-rem would be expended to inspect the last eight (8) 28" welds, of which 16 man-rem would be to the UT personnel. There is approximately 12 man-rem remaining among the available UT personnel, which is insufficient to complete the exams. Further, it would take a week and a half to two weeks to obtain additional qualified personnel. Based on the principal of ALARA, no further exposure to inspect the remaining 28" welds is justified.

ENCLOSURE 5

RECIRCULATION LOOP PIPING TEARING STABILITY ANALYSIS

ENCLOSURE 5

YAEC Contract 104300

Final Report 84-345, Rev. 1
July 18, 1984

VERMONT YANKEE NUCLEAR POWER STATION
RECIRCULATION LOOP PIPING
TEARING STABILITY ANALYSIS

Prepared by

FRACTURE PROOF DESIGN CORPORATION
77 Maryland Plaza
St. Louis, MO 63108

Principal Investigators
Keyren H. Cotter
Steven W. Slocum

Prepared for

Yankee Atomic Electric Company
1671 Worcester Road
Framingham, MA 01671

YAEC Project Manager

Robert White

CONTENTS

TABLES

ILLUSTRATIONS

Section 1

INTRODUCTION

1-1 BACKGROUND

The Vermont Yankee Nuclear Power Station is a 540 Mw GE BWR design. Because of the implications of having flaws or undetected flaws in the recirculation loop piping at Vermont Yankee, it was decided that a safety analysis should be performed. And, the methods of evaluating the stability of any flaws in that piping, should be conservative.

Recent advances in crack stability criteria, based on structural ductility concepts, are appropriate for the analysis of ductile piping such as that found in the Vermont Yankee recirculation loop. Over the past four years, several criteria, based on elastic-plastic fracture mechanics, tearing stability methods and structural ductility, have been proposed for evaluating defects in piping. These are reviewed in the following paragraphs.

1-2 USNRC SAFETY ASSESSMENT CRITERIA

A review of recent criteria proposed for the analysis of nuclear piping is presented below.

1-2.1 USNRC SEP Criteria

In 1981, the USNRC developed criteria which permits plant operators to use alternative methods to obviate the need to consider pipe rupture events and the pipe-whip protection requirements (1) imposed on "older" plants being reviewed under the USNRC Systematic Evaluation Program (SEP). The complete USNRC Alternative Criteria (2) is presented in Appendix C and in abbreviated form below.

In order to be exempt from the requirement to protect against the effect of pipe whip and jet impingement resulting from postulated pipe breaks under SEP Topics III-5A+B, it must be demonstrated that the particular piping in question exhibits:

A) Detectability Requirements. Provide a system to detect leaks, resulting from both longitudinal and circumferential through-cracks having lengths equal to A_1t (A_1 times the wall thickness) under normal operating loads, where $A_1>2$ and A_1 is to be determined and depends on the method of leak detection; plus,

B.1) Integrity Requirements, Level D. Stability of both longitudinal and circumferential cracks that have a length equal to "$A_1t + 2t$" under Level D loads must be demonstrated; integrity of anchors is presumed; plus,

B.2) Integrity Requirements, Extreme Conditions. Stability of a circumferential crack that is the greater of "$A_1t + 2t$" or 90 degrees circumferential length under fully plastic bending loads; hangers are to be assumed ineffective; snubbers are to be assumed ineffective unless specially justified; integrity of anchors is presumed; plus,

B.3) Material Properties. Lower bound material properties are to be used.

C) Sub-critical Crack Growth. Consideration shall be given to the types of sub-critical cracks that might exist in the piping system.

D) Augmented ISI. An optional approach involving special inspection procedures may be used if other corrective measures are not practical. (Not considered applicable to primary coolant system cracking problems.)

The satisfaction of the USNRC Criteria A) requirement involves an analysis which utilizes linear-elastic fracture mechanics methodology and the computation of leak rates for longitudinal and circumferential cracks. The normal (or Level A) operating stresses(3) are used to compute the crack length that would result in a detectable leak rate. These calculations are reasonably straight forward and require the gathering of the stress analysis results and review of the plant Technical Specifications as to detectable leakage rates.

The USNRC Criteria B.1) calculations require the postulation of a crack having a length of "$A_1t + 2t$" (t = the wall thickness of the pipe). The "+ 2t" amount is included to permit a margin for sub-critical crack growth due to fatigue or stress-corrosion. The crack is assumed to be oriented longitudinally or circumferentially and extends through the wall of the pipe. It must be shown in USNRC Criterion B.2 that using lower bound material

properties, the piping will not exhibit instability under upper-bound loading. The upper-bound loading assumes that the section containing the crack is fully plastic and the crack is oriented circumferentially. The upper-bound loads are assumed (non-deterministically) to be equivalent to the bending moment required to induce a fully plastic section at the crack location. This upper-bound is one means of accounting for extremely low probability events such as water hammer and snubber failure under seismic loading. Note that such high load levels are not expected to occur, but are felt more realistic than the load inferred by the currently accepted method of postulating breaks for typical pipe-rupture analysis; namely, a load that occurs instantaneously and is equal to the ultimate strength of the uncracked section of the pipe.

1-2.2 USNRC PRC Proposed Criteria for Break Postulation

The SEP criteria described in Section 1-2.1 was developed with the specific intent of providing relief from compliance with current pipe rupture criteria for older design plants. The older plants were not designed to meet the current criteria and the imposition of such criteria on old designs is nearly impossible or impractical in certain cases. Thus, the criteria had a specific rather than general purpose. The Piping Review Committee (PRC), formed by the USNRC in 1983, assumed the responsibility for developing a break postulation criteria that could be applied to any class of plant.

The following "draft" criteria have been prepared by the PRC's Task Group on Break Postulation for use with primary coolant system analyses. The

current draft of the criteria is limited in application to sections of primary coolant systems that are not prone to IGSCC, thermal fatigue or water-hammer. It consists of a step-wise approach as follows:

1) Postulated Defect Sizes. Select the highest stress - poorest materials properties location in the pipe under consideration. Then, postulate a crack that may be missed during fabrication and pre-service inspections or would be permitted by Code, whichever is larger. And, demonstrate by analysis that the crack would not grow significantly during service either by fatigue, corrosion or impact forces (water-hammer).

2) Detectable Leakage Rate. Demonstrate that even if the crack propagated through the wall that: a) the leakage through the crack is significantly greater than the minimum leak detection capability under normal operating loads so that detection of the crack is assured; and, b) even if undetected prior to an earthquake, the crack is stable under normal plus SSE loads, and, (growth, if any, is minimal for long periods of time).

3) Safety Margin, Crack Sizes. Show that adequate safety margin exists based on crack sizes by: a) comparing the leakage crack size computed in 2a) with the critical crack size under normal plus SSE loads; and, b) demonstrating that there is adequate margin to account for uncertainties inherent in the analyses and leak detection.

4) Safety Margin, Loads. Demonstrate that the leakage size cracks of 2a) will not result in unstable crack growth even if larger loads are applied and that the final crack size is limited (that is, a double-ended pipe break will not occur).

1-3 VERMONT YANKEE CRITERIA

The following criteria ~~was~~ were selected for this analysis. This selection was made after reviewing the USNRC approaches described in Section 1-2. It was designed to be as conservative or more than any that would ultimately be approved as the USNRC Guidelines.

1) Detectability Requirements. Provide a method of detecting leaks, resulting from both longitudinal and circumferential through-cracks having lengths equal to A_1t (A_1 times the wall thickness) under normal operating loads, where $A_1>2$ and A_1 is to be determined and represents the minimum given the method of leak detection in operation at the plant in the area in question; plus,

2) Integrity Requirements, Necessary Conditions. Stability of both longitudinal and circumferential cracks that have a length equal to "$A_1t + 2t$" under loads equal to SSE plus Thermal plus Pressure must be demonstrated; integrity of anchors, supports, hanger and snubbers is presumed; plus,

3) Integrity Requirements, Sufficient Conditions. Stability of a circumferential crack that is the greater of "$A_1t + 2t$" or 90 degrees circumferential length under conditions that insure structural ductility; the loading for insuring structural ductility includes thermal, dead weight, pressure, ~~that resulting from~~ the effects of support failures and inertial; snubbers and other supports are to be assumed

ineffective unless specially justified; integrity of anchors is presumed, but verified; plus,

4) <u>Material Properties</u>. Representative material properties are to be used; and,

5) <u>Sub-critical Crack Growth</u>. Consideration shall be given to any sub-critical crack growth that might occur in the piping system.

Section 2

CRACK STABILITY CRITERIA

In order to analyze the stability of cracks in nuclear piping using fracture mechanics methodology, it is necessary that the material properties, distribution of crack sizes and shapes, applied loads (or stresses) and the crack stability criteria be specified. The crack stability criteria are discussed in this Section as the other factors or parameters follow directly from it.

2-1 CRACK DRIVING FORCE

Crack stability is usually evaluated by comparing the value of a crack driving force parameter with the resistance of the material to crack extension. The crack driving force parameters can be grouped into those applicable to cases involving limited (small) amounts of crack-tip plasticity and those with large amounts of crack-tip plasticity, including net-section yielding. The former is often referred to as small-scale yielding (ssy) and the latter as large-scale yielding (lsy). For ssy cases, the crack driving force is usually described in terms of the associated values of the crack-tip stress-intensity factor, K. For lsy cases, K is not applicable and the parameter is described in terms of the value of the J-integral, J_{app}. J_{app} is also valid for the ssy regime.

The analysis of crack problems is the ssy regime involves the use of the methods of linear-elastic fracture mechanics (LEFM). For the analysis of lsy problems, elastic-plastic fracture mechanics will be relied upon.

2-2 FRACTURE TOUGHNESS CONSIDERATIONS

Recall that for ssy problems the crack driving force based on LEFM is defined in terms of the stress-intensity factor, K. And, for stability, the K computed for the applied stress and crack size of interest must be less than the fracture toughness, K_{Ic}, of the piping material. Stability can also be defined in terms of the J-integral, which, for LEFM, can be computed from $J=(K^2/E')$ as further discussed in Section 3-1. The parameter J_{Ic} can be considered a toughness that is equivalent to the fracture toughness, K_{Ic}, or crack initiation toughness, and thus for $J<J_{Ic}$, stability is insured. Because J is used throughout this report, consideration of LEFM methods is presented in terms of J. A J_{Ic} approach to stability (that is, not including stable growth above J_{Ic}) is not acceptable for lsy problems because it is far too conservative.

Estimates of J for ssy conditions are developed for the crack geometries of interest using the accepted practice of basing J estimates on plastic zone corrected stress-intensity factor solutions (i.e., $K(a+r_y)$). (Note that estimates of J based upon K solutions, that is, LEFM, result in unconservative estimates of J as the limit moment of the cracked section is approached.)

2-3 TEARING STABILITY CONSIDERATIONS

2-3.1 Theory

Before considering the application tearing stability methods to a typical piping problem, it is worthwhile to review a bit of theory. In the application of LEFM to brittle materials, crack instability is assumed to be incipient when $K > K_{Ic}$. Physically, this is interpreted as an instability that accompanies the onset of crack extension. But, for tough materials, it is known that crack instability does not generally accompany the onset of crack extension. Rather, the K (or J) at instability can be well above the K_{Ic} (or J_{Ic}) point. It is important, from design and safety considerations, to be able to take advantage of the higher J values (or loads) that co-exist with the stable crack extension but, until the recent development of the tearing modulus concept, it was not possible. Analysts had been faced with the problem of using a J_{Ic} value for instability predictions unless representative R-curves could be developed which were typical of the significant material dimensions actually used in the structures of interest.

Solutions to problems that rely on the tearing stability approach involve expressing the intensity of the crack-tip deformation field by an appropriate elastic-plastic crack driving force parameter. Based on the fracture parameter, the behavior or growth of cracks can be expressed functionally. It follows that the use of a parameter like J infers that crack growth is controlled or determined by the value of the parameter. This logic leads to the term "J-controlled growth". Typically, the quantifying of the fracture parameter is accomplished by computing the value of the path independent J-integral, developed by Rice(4), either by use of direct integration around the crack-tip or by use of any one of a number of acceptable estimation schemes. Relative to any J computation, it is interesting to note that the phrase "elastic-plastic fracture

mechanics" infers that problems involving plasticity can be analyzed for any type of loading. But Rice(4) proved the path independence of J only for the idealized case of no crack growth and a material which exhibits "non-linear elastic" behavior. Unfortunately, real materials do not behave exactly as non-linear elastic materials and the problems of interest involve crack growth. However, the violation of this idealized behavior is not sufficient to invalidate the path independence of the J-integral if certain restrictions are met. Based on a need for these restrictions, Hutchinson and Paris(5) set forth strict theoretically based guidelines for J-controlled crack growth. Extensions beyond those limits are possible under the conditions discussed in Reference (6).

Although the value of J is indicative of the intensity of the crack-tip deformation field, it is not sufficient by itself for resolution of the question of stability. To resolve this, Paris, et al.(7) defined a non-dimensional parameter, called the tearing modulus, which assumed the validity of J-controlled growth. It is applicable to material property data and applied loads alike. For the applied case, it is expressed as

$$T_{app} = \frac{dJ_{app}}{da} \frac{E}{\sigma_o^2} \qquad (2\text{-}1)$$

where E is the elastic modulus, a is the crack length, σ_o is a flow stress, and J is the J-integral. J controlled growth requires that the crack extension, da, occurs under the equilibrium condition

$$J_{app} = J_{mat}, \qquad (2\text{-}2)$$

which applies whether or not stability of the crack extension is present.

In this expression, J_{mat} is the value of J on the material J-resistance curve, and the J_{app} is the computed value of the J-integral for a given load and crack length. For a crack under the preceeding equilibrium conditions stability is determined from

$$T_{app} < T_{mat} \quad \text{(stable)} \tag{2-3}$$

$$T_{app} > T_{mat} \quad \text{(unstable)} \tag{2-4}$$

where T_{mat} is determined from the material J-R curve and T_{app} is dependent upon the crack geometry and loading existing in the actual structure.

The very power of this approach stems, in part, from the fact that the use of tearing stability methods is applicable(6,8-11) to both the ssy and lsy regime.

This stability criteria has been experimentally verified for several specimen types. Paris, et al.(11), were the first to demonstrate applicability through experiments using A471 steel 3-point bend bars in a test system of variable compliance. The variable compliance feature was used as a means of controlling the T_{app}. Similarly, Zahoor and Kanninen(12) tested circumferentially cracked 4-inch diameter TP304 stainless steel pipes in 4-point bending, and Gudas and Joyce(13) evaluated several materials of varying degrees of toughness in 4-point bending.

2-3.2 The J-T Diagram

For safety assessments of nuclear piping systems that are based on the tearing modulus stability concept, it is convenient to present the results using the J-T diagram due to Paris(6). The J-T diagram compares the applied (or calculated) values of J and T with the material (invariant characteristic of a material) values. That is, the J_{app} vs. T_{app} response is compared with the J_{mat} vs. T_{mat} curve to determine whether the T_{app} value is less (or greater) than the T_{mat} value for the J_{app} value specified. If the $T_{app} < T_{mat}$, then stability is assured and, conversely for instability. A sample J-T diagram is shown in Figure 2-1.

The schematic material curve shown on Figure 2-1 was derived from a typical J-resistance curve. Note in Figure 2-1, that the T_{app} values are dependent upon the J_{app}. For cases where the T_{app} is less than the T_{mat} values, stable crack behavior is assured. On the other hand, a lower T_{mat} value corresponding to higher J_{app} values can cause unstable behavior.

2-3.3 Extrapolation of the J_{mat}-T_{mat} Curve

For applications that require J_{mat} values greater than those available from the J-resistance curve, the assessment of whether a system is stable or unstable based on a J-T diagram may require extrapolation of the material curve. One way of extrapolating the resistance curve is to assume that the material continues to tear with the same slope. This will mean that in the extrapolated regime, the T_{mat} remains constant. The extrapolation of the material curve on the J-T diagram would then be

the vertical line extending from the maximum J_{mat} value point on the material curve. This is shown as 1-C in Figure 2-1.

An alternative to this extrapolation is to assume that there is no further increase in the J-resistance with crack growth. Such a behavior would imply that the T_{mat} reduces to zero in the extrapolated regime. That is, on a J-T diagram, the extrapolated material curve would take the form of the horizontal line noted as 1-0 in Figure 2-1.

These two extrapolations represent the upper and lower bounds of resistance curve behavior for continued growth. In reality, the T_{mat} value is expected to decrease gradually with increase in the J_{mat} value, leading to the possibility of a zero value of the T_{mat} at some higher J_{mat} value. One accepted approach is to follow Paris(6) and construct a tangent to the material curve. This approach is noted as line 1-T in Figure 2-1.

The validity of J-controlled growth is dependent upon the satisfaction of several requirements(5). One of these is that ω be "large". For typical Type 304 stainless steel, valid J-resistance curves may have over 1 inch of crack growth, Δa, and ω values that range from 10 to 20. Considering T_{mat} to decrease abruptly to zero simply implies that the ω value, which is proportional to T, also decreases to zero. This would invalidate the assumptions of J-controlled growth, and any assessment of the stability of piping would be subject to serious error. J-resistance curves need to be developed to include extended amounts of crack growth while satisfying the J-controlled growth requirement. Because of these limitations, the

assumption of the tangent extrapolation of the T_{mat} curve is felt to be the most acceptable method.

2-4 STRUCTURAL DUCTILITY

Recent discussions of the criteria to be applied to the analysis of cracks in nuclear piping have resulted in Paris(14) proposing that such criteria must insure that "structural ductility" is maintained. Paris argued (14) that one of the fundamental tenants inherent in the ASME Code (3) that insures the safety of nuclear plants is the concept of structural ductility. In the simplest sense, this concept insures that the stored elastic energy in a structural system can be absorbed by plastic work. The plastic work takes the form of local or gross plastic deformation of sections of the structure. Its purpose is to provide assurances that no brittle type failure can occur should the loads portion of the analysis be in error. Paris repeatedly cited (14) examples that this is the basis used by Nathan Newmark in his work on the safe response of structures to seismic excitation (inertial loading).

For piping in typical nuclear plants, this criterion is always met, because of Code (3) requirements, if there are no cracks present. To insure that it is met when cracks are present, then Paris (14) and Paris and Cotter (30) showed that

$$T_{app} < \eta\, T_{mat} \qquad (2\text{-}5)$$

for

$$J_{app} = J_{local} + J_{global} \qquad (2\text{-}6)$$

where η is a constant between 1 and 2, J_{local} describes the response of the structure to the "worst-case" loads and J_{global} satisfies the requirement of absorbing the stored elastic energy.

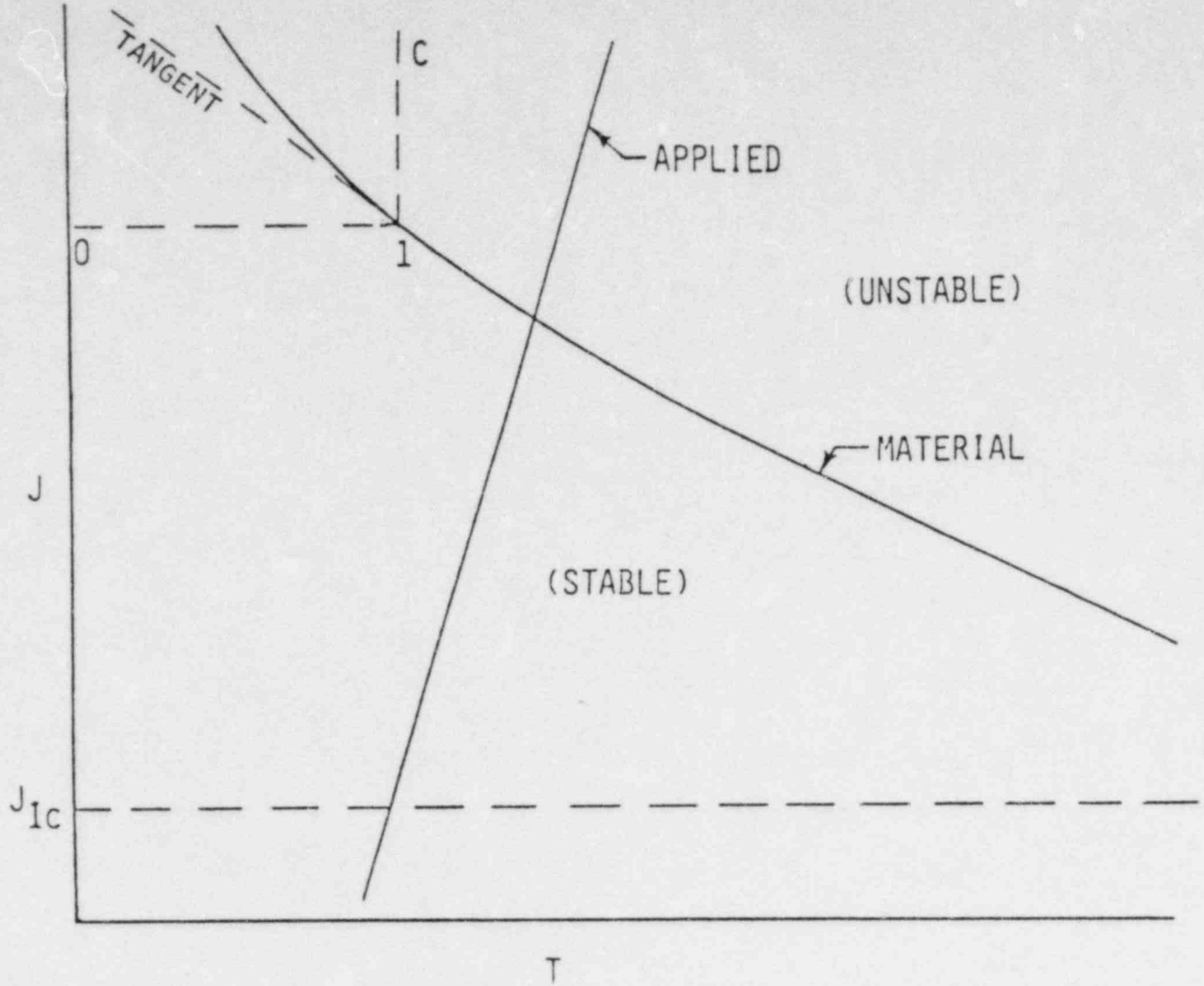


Figure 2-1 Schematic of J-T Stability Diagram

Section 3

SSY BASED ANALYSIS

3-1 J-INTEGRAL ESTIMATION

For the ssy regime, the J-integral, J_{app}, can be estimated using the relation

$$J_{app} = K_I^2/E' \qquad (3\text{-}1)$$

where $E'=E$ for plane stress, $E'=E/(1-\mu^2)$ for plane strain, K_I is the opening mode plastic zone corrected stress-intensity factor, E is the elastic modulus and μ is Poisson's ratio.

3-1.1 Circumferential Cracks

For circumferential cracks, the K_I consists of contributions from three types of loads: axial load, bending moment and membrane stress due to pressure. The K_I due to pressure loading, K_m, was obtained by utilizing the solutions from Reference (15), giving

$$K_m = \sigma_m \sqrt{\pi R \theta}\, F_m \qquad (3\text{-}2)$$

where σ_m is the membrane stress (axial) and F_m is a non-dimensional shell correction factor that depends upon the length of the crack and the geometrical dimensions of the shell.

The K_I due to the applied axial tension load is

$$K_t = \sigma_t\sqrt{\pi R\Theta}\ F_t \qquad (3\text{-}3)$$

where F_t depends upon the same parameters as F_m. The function F_t can be derived from the recent work of Erdogan and Delale(16). FPDC has developed its own approximate, but conservative, expression for F_t which was used in this study. σ_t is the stress (tension) due to the axial load F_{ax}

$$\sigma_t = F_{ax}/(2\pi Rt) \qquad (3\text{-}4)$$

Similar to the tension loading case, FPDC had previously developed an estimate of K for the externally applied bending load; and the K due to this loading is

$$K_b = \sigma_b\sqrt{\pi R\Theta}\ F_b \qquad (3\text{-}5)$$

where F_b is a correction factor for a circumferential crack in a shell subjected to a bending load. σ_b is the maximum bending stress due to the external moment, M,

$$\sigma_b = M/Z \qquad (3\text{-}6)$$

where Z is the elastic section modulus. The total K_I due to these three types of loading is

$$K_I = K_m + K_t + K_b \tag{3-7}$$

Equations (3-7) and (3-1), when combined together, give the functional form for J_{app}.

3-1.2 Longitudinal Cracks

The computation of crack stability for longitudinal flaws is based on plastic zone corrected stress-intensity factor solutions. For a longitudinal through crack in a pipe

$$K = \sigma_h \sqrt{\pi c}\, F(\lambda) \tag{3-8}$$

where σ_h is the hoop stress, c is half the crack length, $\lambda = c/\sqrt{Rt}$ and the shell correction term $F(\lambda) = (1. + 1.3\lambda^2)^{.5}$ for $\lambda < 1$ and $F(\lambda) = .5 + .9\lambda$ for $1 < \lambda < 4.45$. J_{app} can be found as before from Equation (3-1).

3-1.3 Tearing Stability for SSY Conditions

The form for T_{app} can be found by differentiating the equation for J_{app}, following Equations (3-1) and (3-7) or (3-8), with respect to crack length, giving

$$T_{app} = \frac{dJ_{app}}{da} \frac{E}{\sigma_o^2} \tag{3-9}$$

Then, using Equations (2-2) through (2-4), the stability of the crack can be determined.

3-1.4 Plastic Zone Instability Failure

Vasquez and Paris(17) have shown that situations exist in which the gradient with respect to the crack size of the elastic stress field at the tip of the crack becomes sufficiently large that the plastic zone cannot maintain stable static equilibrium and plastic zone instability occurs, followed by the propagation (or unstable extension) of the crack. This mode of unstable extension is called a "plastic zone instability failure" or PZIF). The functional form of the PZIF criterion is given by

$$K^2_{pzif} = 2\pi\sigma_0^2 c_{eff}/P_z \quad (3\text{-}10)$$

where $P_z = 1+2\lambda F'/F$, and c_{eff}, λ and $F(\lambda)$ are the plastic zone corrected terms described in Equation (3-8).

3-2 LEAK RATE ANALYSIS

The estimate of the leak rate for various cracks was based upon the LEFM based methods given in Reference (18). In general, the leak rate depends upon the applied stress and crack length. Thus, the calculation of leak rate necessitates the development of a fluid flow model for fluid leaking through a crack. It also requires consideration of the thermodynamics of the flow and the surface roughness of the crack.

Section 4

LSY BASED ANALYSIS

Tada, et al.(19) were the first to apply the tearing modulus stability criteria to actual structural problems using a rigid plastic idealization for the cracked section. They applied it to a piping system for the purpose of evaluating the stability of a circumferential crack in a BWR recirculation loop. The methods were subsequently refined using an elastic-plastic approach (32). In this Section, the method of analysis and the crack stability criteria are discussed. The analysis method is consistent with both References 19 and 32, but takes into account the behavior of structures having more complicated boundary conditions. Additionally, the dependence of T_{mat} on J_{mat} is included through the use of a J-T stability diagram. Details of the cracked section are shown in Figures 4-1 and 4-2. Only one through-the-thickness crack (TC) is assumed to exist and that crack is oriented circumferentially. Use of a TC assumption per Criteria 3 was justified, by Zahoor(20) for fully plastic bending. He considered circumferential vs. radial instability for part-through cracks (PTC) and concluded that the PTC becomes a TC. See Figure 4-3. Based on the approach that he used, this conclusion can be extended to cases of fully plastic bending having "small" axial loads.

Under the postulated loading, the following conditions are assumed:

a) The cross section containing the circumferential, through-the-thickness crack (Figure 4-2), is fully yielded.

b) The material local to the cracked section (or hinge) exhibits elastic perfectly plastic behavior.

4-1 STRUCTURAL RESPONSE AND T_{app}.

The behavior of the pipe is idealized as sections which behave elastically, separated by a plastic hinge. To compute T_{app}, there are two system parameters which must be evaluated. The first is the compliance of the elastic section and the second is the rotation of the plastic hinge at the assumed crack section under the prescribed loading.

4-1.1 Compliance.

By using finite element methods along with the assumption that a plastic hinge is developed at the cracked section of the pipe , the rotational compliance of the elastic section about the hinge location is determined using the JTPIPE program (21) described in Appendix A. Note that the elastic compliance does not depend on the crack size because the crack section has been idealized to behave as rigid perfectly plastic; thus, only the uncracked section of the pipe behaves elastically.

4-1.2 Plastic Hinge Behavior

The rotational response at the plastic hinge simulating the cracked section requires computing the finite discontinuity in rotation taking place at the cracked section, θ_{cr} (See Figure 4-2). The solution is developed by satisfying compatibility at the hinge. This discontinuous rotational angle is due to the localized deformation at the fully plastic cracked section.

4-2 CRACKED SECTION PARAMETERS

4-2.1 Plastic Limit Moment

The plastic limit moment of the cracked section, $(M_c)_p$, can be defined in terms of simple parameters. For a thin pipe, $(t/R) \ll 1$, Tada, et al.(19) have shown that the $(M_c)_p$ can be expressed as

$$(M_c)_p = 4\sigma_o R^2 t(\cos\beta - 1/2\ \sin(\theta)) \qquad (4\text{-}1)$$

where

$$\beta = (\sigma + \pi\ S_t)/2\ ,\ S_t = \sigma_t/\sigma_y$$

and σ_o is the flow stress and R, t, and θ are, respectively, the mean radius and thickness of the pipe and the angle defined by the through wall crack. (See Figure 4-1).

4-2.2 J-Integral

For the fully yielded cracked section and the rigid-perfectly plastic material behavior assumed above, the J-integral can be expressed as follows

$$J_{app} = \sigma_o\ R\ F_j\ \phi_{cr}, \qquad (4\text{-}3)$$

where ϕ_{cr} is the rotational angle caused by the plastic hinge at the cracked section, and

$$F_j = \sin\beta + \cos\theta \qquad (4\text{-}4)$$

The above estimate of J_{app} based on a rigid plastic idealization was shown to be valid (32) for $\phi_{cr}>1^{\circ}$ without including the elastic-plastic effects.

4-3 STABILITY ANALYSIS

The approach used to determine stability of a crack is based on a procedure similar to that developed in Reference (19). It is assumed that for a fixed displacement loading, the sum of the displacement changes at the cracked section, which can be separated into the elastic part and the plastic part, should be equal to zero. Carrying through with the mathematics, we find

$$T_{app} = F_1(\theta)L_{eff}/R + F_2(\theta)J_{app}E/(\sigma_0^2 R) \quad (4-5)$$

where

$$F_1(\theta) = 2F_j/\pi$$

$$F_2(\theta) = (\cos\beta - 2\sin\theta)/2F_j$$

$$L_{eff} = EI/[K], \quad [K] = \text{min. stiffness at hinge}$$

and F_j is given by Equation (4-4).

Note that Equation (4-5) depends upon the geometric configuration as well as the boundary conditions of the piping system and J_{app}.

4-4 THE J-T DIAGRAM

For a given piping system and material, the pipe diameter, wall thickness and flow stress are known. Then, for any given pair of θ and ϕ_{cr}, F_j can be calculated using Equation (4-4) and J can be found from Equation (4-3). The rotation caused by the plastic hinge at the crack section, ϕ_{cr}, depends upon the interaction between the various segments of the piping and the boundary conditions imposed.

The T_{app} values corresponding to the computed J_{app} are obtained via Equation (4-5). In this Equation, the only quantity that is unknown is L_{eff}, the effective length of the piping. Since actual piping systems are typically 3-dimensional structures, it is not always easy to compute the effective length (of an equivalent straight-pipe) by simple analysis methods. Hence, a elastic-plastic finite element analysis of the piping system is performed using JTPIPE (21) from which the elastic compliance is computed to determine L_{eff}. For the particular loading, J_{app} is computed based on the structural response. The computed (applied) values, J_{app} and T_{app}, are then used to generate the applied curve shown in Figure 2-1. Note that the applied J-T curve shown does not account for crack growth, that is, 2θ is assumed constant throughout. The error resulting from this approximation is small and allows conservative conclusions to be drawn from the analysis.

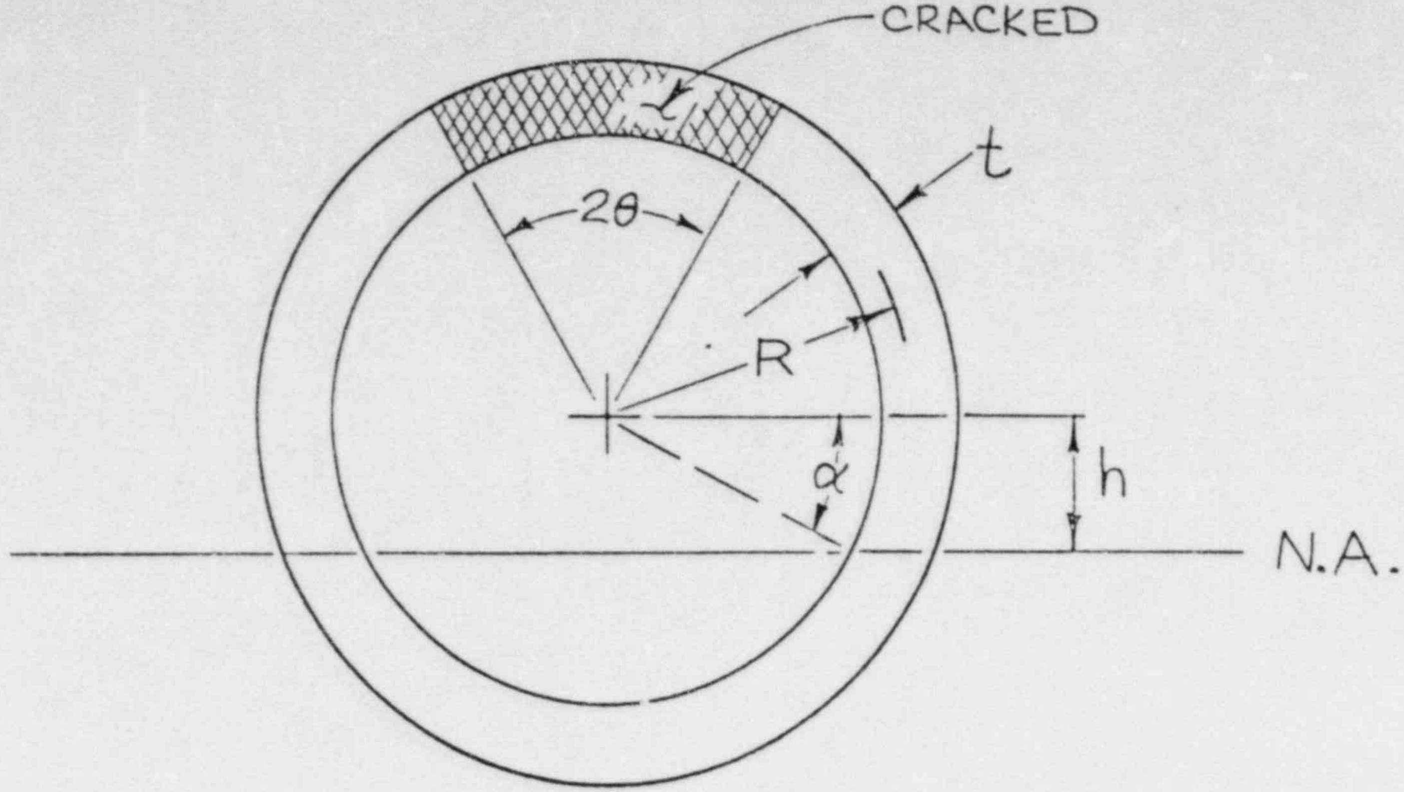


Figure 4-1 Geometry of Cracked Cross-section of a Pipe

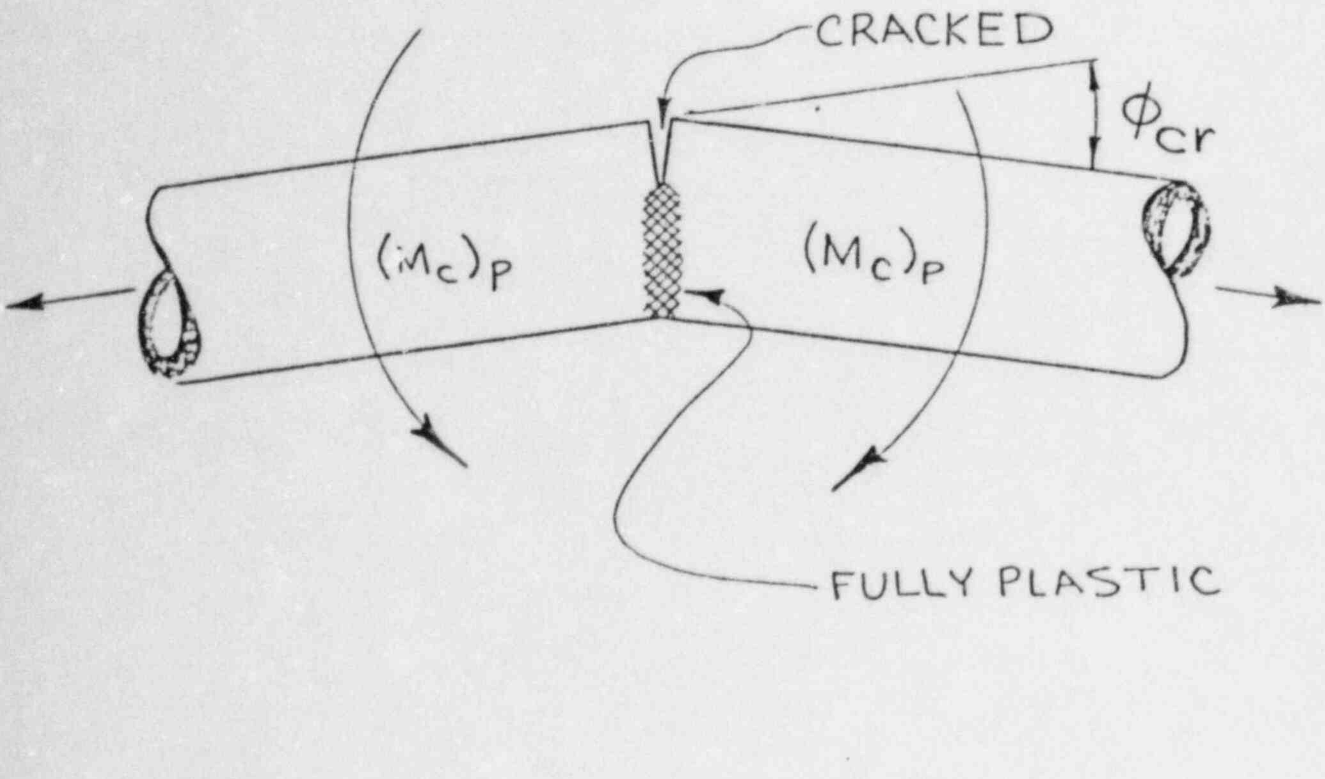


Figure 4-2 Fully Plastic Bending of a Pipe with Axial Load

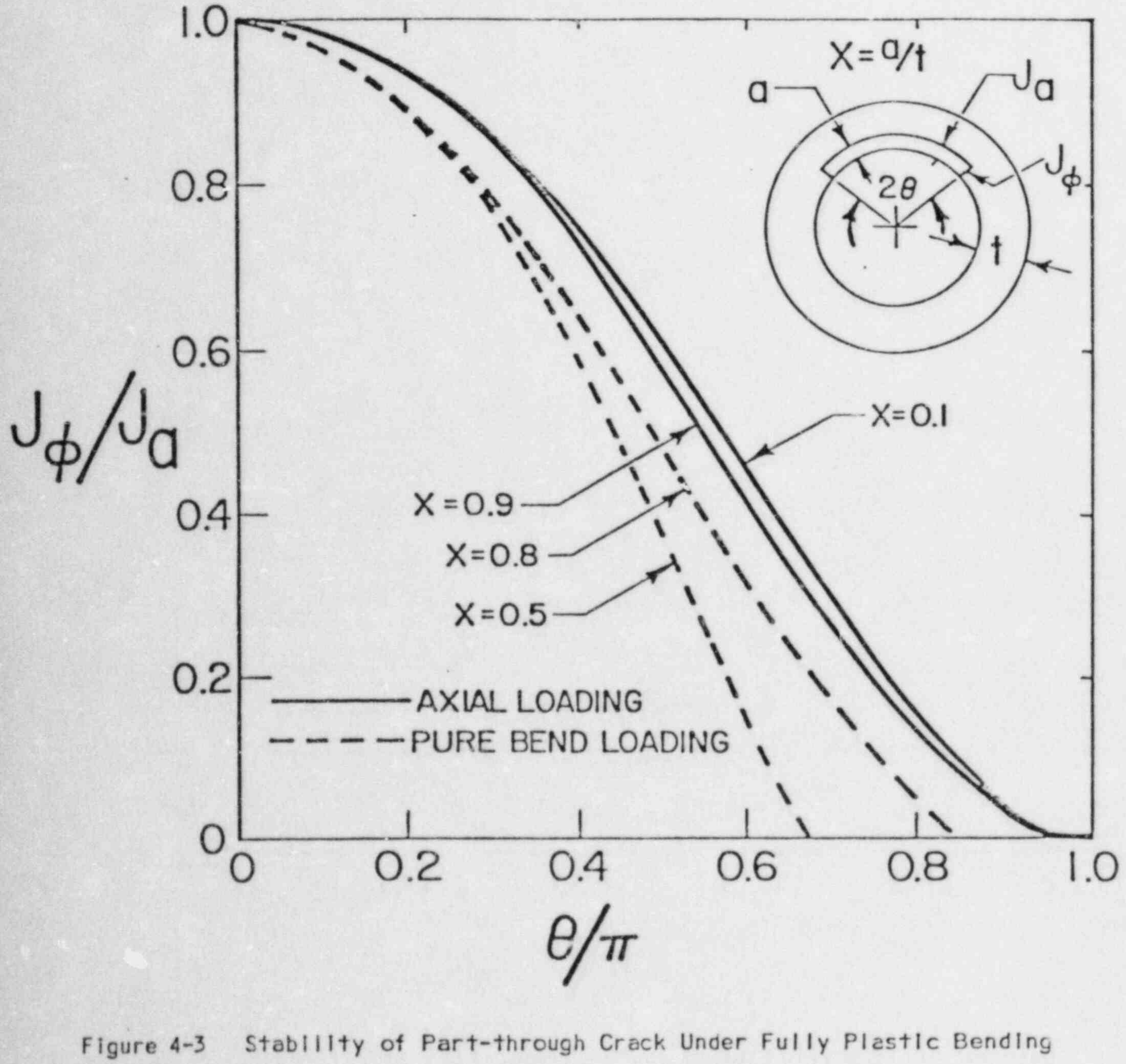


Figure 4-3 Stability of Part-through Crack Under Fully Plastic Bending

Section 5

RECIRCULATION SYSTEM, RESULTS AND DISCUSSION

The safety of the recirculation system piping at the Vermont Yankee Nuclear Power Station focuses on the postulated existence of large cracks in the piping. The evaluation of this system begins with a thorough description thereof including the code stresses, pipe geometry and operating pressures as well as the appropriate isometrics.

The application of the criteria used for the analysis of the recirculation system piping is based on that of Section 1-3. The approach used is described in the following Sections. The reference to Criterion 1) through 5) in the following Sections refers to those defined in Section 1-3. The material properties used in the following Sections were developed in Appendix B according to Criterion 4.

5-1 RECIRCULATION LOOP PIPING SYSTEM

The recirculation system provides a continuous flow of coolant through the RPV in order to achieve heat transfer rates greater than that possible by natural convection. The system is composed of 2 similar loops which are referred to as loops A and B. In this study, only loop A is considered. Loops A and B are the same except for the RHR return line attached to the loop A suction line.

The portion of the recirculation loop piping system that is of interest in this study is limited to the the suction, discharge, header and riser piping portions of the loop. The RHR piping, etc. is not considered except that it is included in the structural idealization as the stiffness of the RHR piping effects the crack stability calculations.

5-1.1 System Description

Following the isometric view of loop A, shown in Figure 5-1, the system can be readily explained. Flow from the RPV is via the 28in suction line at a pressure of 1040 psig under normal conditions. The normal operating temperature for the suction line and the rest of the system is 528F. The coolant flows through the suction line to the pump and exits at a pressure of 1130 psig under normal conditions. The discharge line is also 28 in and provides coolant to the 22in header. From the header, coolant is distributed to the RPV through 5-12 in risers located at 30° intervals.

The location of existing anchors, supports and pipe-whip restraints are shown in Figure 5-2. Locations for the snubbers and hangers are omitted because their effect is neglected in this study. The 5 riser nozzles and the suction nozzle are the anchor points for this system. Quasi-static vertical movement of the pump is not inhibited, but large vertical displacements are limited. The loop A header is connected to the loop B header. For structural idealization, an elastic spring is included to properly include the stiffness of loop B in the loop A analysis.

5-1.2 Piping Code Structural Analysis

Because a stress analysis had already been performed by General Electric (24), as part of the design of the NSSS, it was not necessary to perform another. The GE stress analysis (GESA) results (24) used herein are taken directly from the stress report. The leak rate computation required by Section 1-3, Criterion 1 uses normal operating stresses. But, the normal stresses in the GESA were not directly applicable to this analysis. Thus, a conservative approach was taken. For purposes of computing leak rates, the portion of the stress due to dead weight and thermal effects was neglected and only the pressure term was used.

For the crack stability calculations of Section 1-3, Criterion 2, Level D stresses are required. These could be taken directly from the GESA report, but with some judgement. The GESA Level D stresses are based on the resolved moments about 3 principal axes and an assumption that SSE = 2OBE. Because one term is a torsional component, it does not contribute to circumferential crack extension. Thus, it can be removed for computing J_{app}. The pressure stress used corresponds to the maximum pressure during the bonding transient. The stress terms result from dead weight, thermal and SSE. The stresses used are given in Table 5-1 and their components are given in Table 5-2. For computational simplicity, the maximum value of the Level D stress along any line segment is used in lieu of point by point documentation. This approach tends to be conservative but greatly simplifies the comprehension of the analysis.

Table 5-1 also lists the pipe section properties used for this study along with a tabulation of operating and design limits on pressure and temperature. Minimum wall thicknesses are used for the crack stability calculations which follow.

5-2 LEAK DETECTABILITY

Criterion 2 of Section 1-3 requires the demonstration of the stability of a crack that has a length equal to that which would result in detectable leakage rate as determined under Criterion 1. For this analysis, rates of 1 and 10 gpm, under normal operating loads, were selected as being representative of a leak that is detectable using existing sensors.

5-2.1 Circumferential Flaws

The leakage rate computation is conservatively based on normal operating stresses that result from the suction side operating pressure (1,040 psi) component(28) alone. As the suction side has a lower operating pressure than the discharge side, the cracks sizes computed will be longer than what would actually exist on the discharge side. The dead weight plus thermal components of stress were conservatively ignored. No dynamic loads are used in developing the normal stresses. It is noted that the lower the stress, the lower the leak rate, and the longer the crack must be in order to have a detectable leak. Leakage rates were computed for a series of crack sizes based on the computed operating stresses. Crack lengths ranging from 6.3 to 12.9 inches corresponding to rates of leakage between 1 and 10 gpm. The results are shown in Figure 5-3 and Table 5-3.

5-2.2 Longitudinal Flaws

The leak rate for longitudinal flaws was computed using a hoop stress again conservatively based on a normal operating pressure of 1,040 psi(28). The range of flaw sizes considered, ranged from 3.8 inches for the 1 gpm leak rate to 7.6 inches for the 10 gpm rate as shown in Figure 5-4 and Table 5-3.

5-3 CRACK STABILITY; PRESSURE + THERMAL + SSE LOADS

This assessment of crack stability relies on the small scale yielding (ssy) theories discussed in Section 3 and Criterion 2 of Section 1-3.

5-3.1 Circumferential Flaws

The solution of Equations (3-1) through (3-7) for circumferential flaws was obtained using the computer program, "OYCJT"(22), which performed the necessary iterations on K to obtain the plastic zone corrected K values. From the $K(a+r_y)$ values, the appropriate J_{app} estimates were determined. This evaluation was performed using the pressure plus thermal plus SSE stresses (24) and the results are included in Appendix D.

Crack lengths corresponding to the lengths that cause leak rates of 1 and 10 gpm plus 2t were considered. For the 1 gpm cases, $J_{app} < J_{Ic}$ assuming J_{Ic} = 1300 for SMAW welds (or field welds). This insures stability and compliance with Criterion 2. This conclusion also holds for a 10 gpm

rate for all cases except the riser. If SAW (or shop welds) are assumed, then J_{Ic}=500, and a small amount of crack extension might occur. For the levels of J_{app} computed, only small amounts of crack extension would occur and T_{app} is small (<7). Thus, no crack instability is indicated for any location. Refer to the results in Appendix D.

5-3.2 Longitudinal Flaws

Crack stability, as evidenced by $J<J_{Ic}$ and $J<J_{pzif}$, was checked using the hoop stress at the pipe wall mid-plane. Upon substituting the appropriate crack lengths (2c(10 gpm) plus 2t) and stresses into Equation (3-8), we find, for the 10 gpm crack, that the maximum value of the plastic zone corrected value of J_{app} = 340in-lb/in^2, which is much less than J_{Ic} for either weld type, thereby insuring crack stability and no crack extension. Having satisfied the fracture toughness criterion, a check for a plastic zone instability failure (PZIF) was made following the methods of Vasquez and Paris (17). J_{pzif} was computed using the relation of Equation (3-10) and it was found, that $J_{app}<J_{pzif}$ thereby satisfying the PZIF criterion. The results are included in Appendix D. These computations were made using the "PZIF"(23) computer code.

5-4 CRACK STABILITY, UPPER BOUND LOADS

In this section, the methods used were based on large scale yielding (lsy) theories and structural ductility. These satisfy Criterion 3 of Section 1-3.

5-4.1 Applied Loads

The intent of the Criterion 3 of Section 1-3 is to insure that brittle behavior of the piping system does not occur. This is accomplished by demonstration of structural ductility (30) in the presence of cracks. To prove this, the cracked section of the pipe must be capable of absorbing large amounts of energy.

It is important to consider the maximum load that can be applied to a structure within the intent of current laws, namely, 10CFR50, App. A, Criterion 2(1). Criterion 2 and other Criteria of 10CFR50, App. A require that the uncertainty in predicting the magnitude of loads resulting from natural phenomena, such as seismic events, must be included in design of the plant. Thus, it is prudent to use conservative assessments of the magnitude of maximum loads. To do this, postulated "upper-bound" loads, based on a structural ductility approach (30) to assess crack stability, are used for the analysis. As a result of this approach, the methods being used herein are, in essence, demonstrating that the recirculation system piping is safe under extreme accident conditions.

5-4.2 Crack Stability Calculations

Using Criterion 3 of Section 1-3 and the applied loads determined in accord with Reference 30 and Section 5-4.1, the stability of several crack sizes was examined. The analysis was performed using the JTPIPE(21) program and the J_{app} value was computed using the foregoing

load assumptions. JTPIPE has several analysis options. The option selected accounts for the interaction of the piping with surrounding structure. The material property values used were obtained from Reference 29 as discussed in Appendix B. A temperature of 550F was assumed at every crack location.

The stability of circumferential cracks having lengths of 2θ = 60 and 120° are considered under the application of the upper-bound loads described in Section 5-4.1.

The piping system was idealized for analysis using the JTPIPE code (21). Structural details were taken from appropriate drawings (25-27). Nodal locations are shown in Figure 5-5 and the elements corresponding to crack location are shown in Figure 5-6. The results of the analysis are shown in Figure 5-7 and 5-8 for circumferential crack lengths, $2\theta = 60$ and 120° respectively. The J-T stability diagram approach due to Paris (6) was used. The material data is based on the J-modified method developed by Ernst (31).

The total J_{app} is composed of displacement controlled loads plus inertial loads following Equation 2-6. The latter were computed using a structural ductility approach (30).

It is concluded that the most critical locations, which correspond to elements 74, 75, 81 and 82, can tolerate large defects and safisfy the ductility criteria for Equation 2-5.

Table 5-1 Section Properties and Maximum Stresses

Line	Dia (in)	t_{wall} (in)	P_{oper} (psi)*	P_{des} (psi)*	σ_{LevD} (psi)**
Suction	28.17	1.151	1040.	1148.	19751.
Discharge	28.34	1.235	1130.	1233.	18007.
Header	21.88	0.976	1130.	1233.	19413.
Riser	12.75	0.687	1130.	1233.	19413.

* Temperatures: T_{oper}=528F; T_{des}=575F

** Maximum at any point along line

Table 5-2 Summary of GESA Results

Line	P_{des} (psi)	F_{axial} (kip)	M_B (in-kip)	M_C (in-kip)	M_{eff} (in-kip)
Suction	1148.	0*	2376.	1371.	2743.
Discharge	1233.	20.1	1770.	2938.	3403.
Header	1233.	16.1	1343.	1802.	2248.
Riser	1233.	0*	1436.	788.	1638.

$F_{axial} = F_{dw} + F_{th} + 2F_{obe}$

$M_{eff} = \sqrt{M_B^2 + M_C^2}$; $M_i = [\, M_{dw} + M_{th} + 2M_{obe} \,]_i$, i=B,C

*Compressive Load Conservatively Ignored.

Table 5-3 J_{app} for Leak Rates of 1.0 and 10.0 gpm

Leak Rate (gpm)	Line	Crack Orientation	Crack Length, 2c (inches)	J_{app} in.-lb/in^2
1.0	Riser	LONGITUDINAL	3.8	97
1.0	Header	LONGITUDINAL	4.1	116
1.0	Discharge	LONGITUDINAL	4.6	155
1.0	Suction	LONGITUDINAL	4.3	138
10.0	Riser	LONGITUDINAL	5.9	277
10.0	Header	LONGITUDINAL	6.8	340
10.0	Discharge	LONGITUDINAL	7.6	333
10.0	Suction	LONGITUDINAL	7.2	300
1.0	Riser	CIRCUMFERENTIAL	6.3	540
1.0	Header	CIRCUMFERENTIAL	7.0	110
1.0	Discharge	CIRCUMFERENTIAL	7.6	85
1.0	Suction	CIRCUMFERENTIAL	7.2	65
10.0	Riser	CIRCUMFERENTIAL	9.9	1700
10.0	Header	CIRCUMFERENTIAL	11.7	260
10.0	Discharge	CIRCUMFERENTIAL	12.9	190
10.0	Suction	CIRCUMFERENTIAL	12.3	151

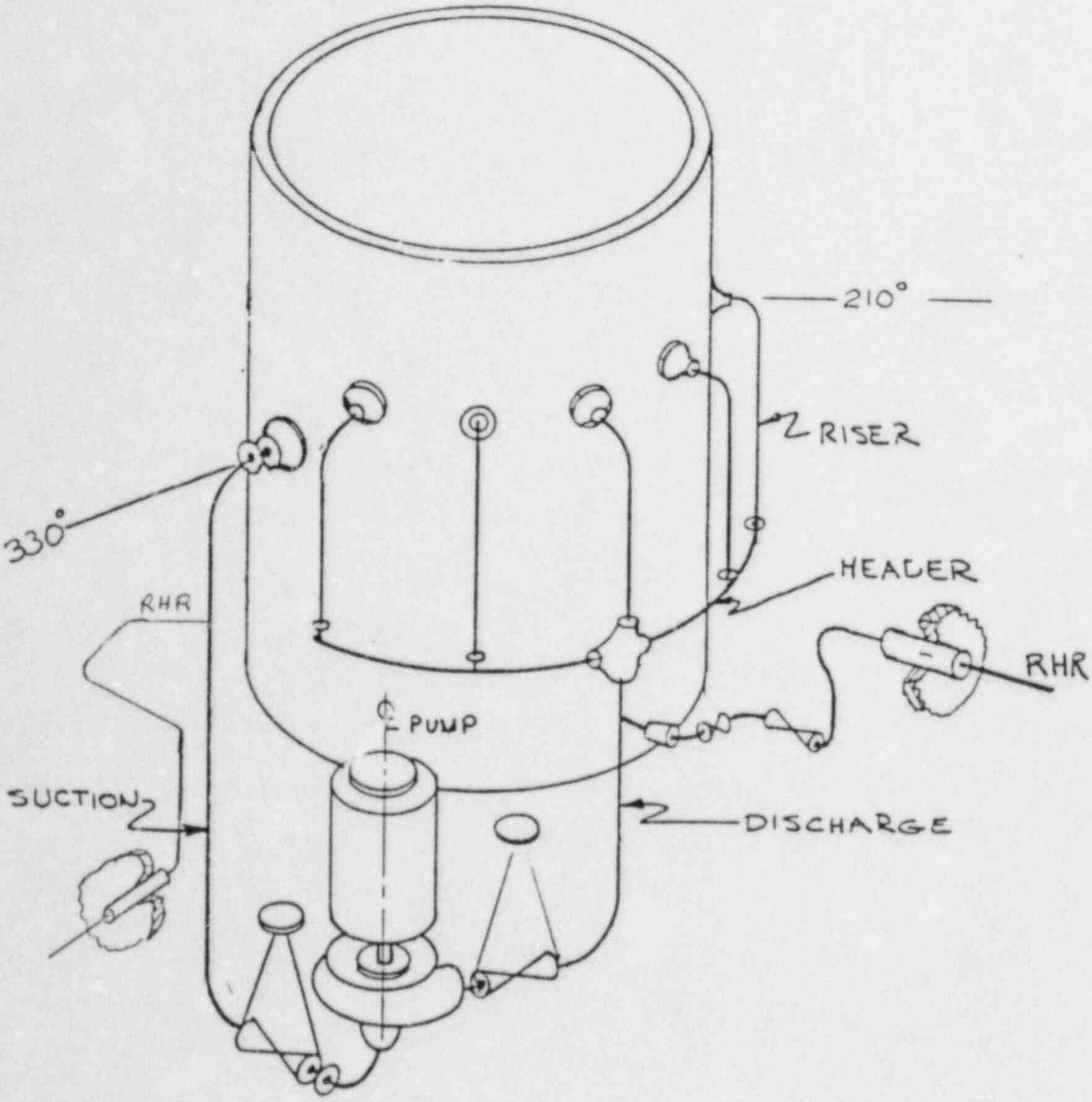
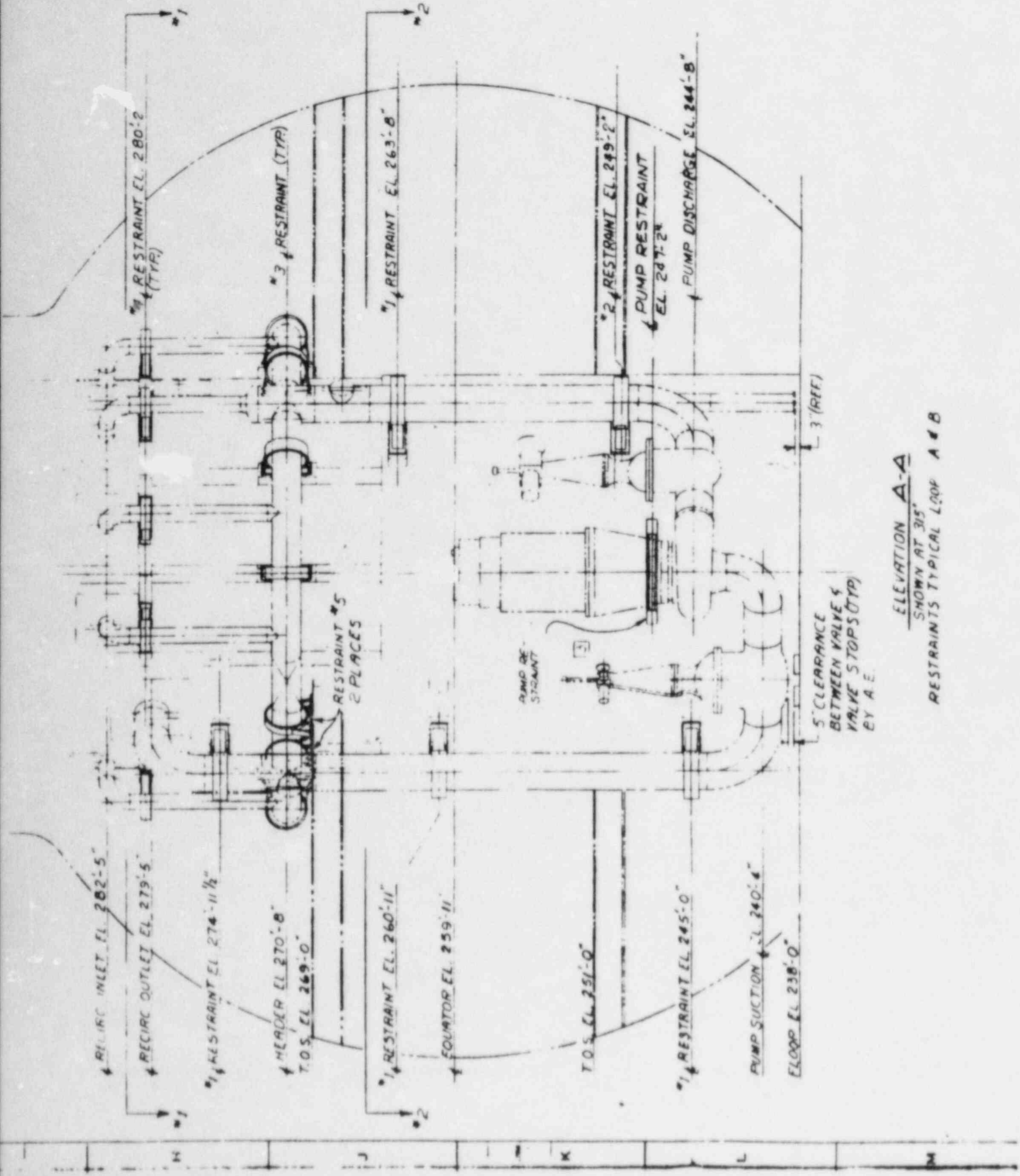


Figure 5-1 Isometric View of Recirculation System, Loop A

Figure 5-2 Location of Loop A Anchors, Supports and Pipe-whip Restraints



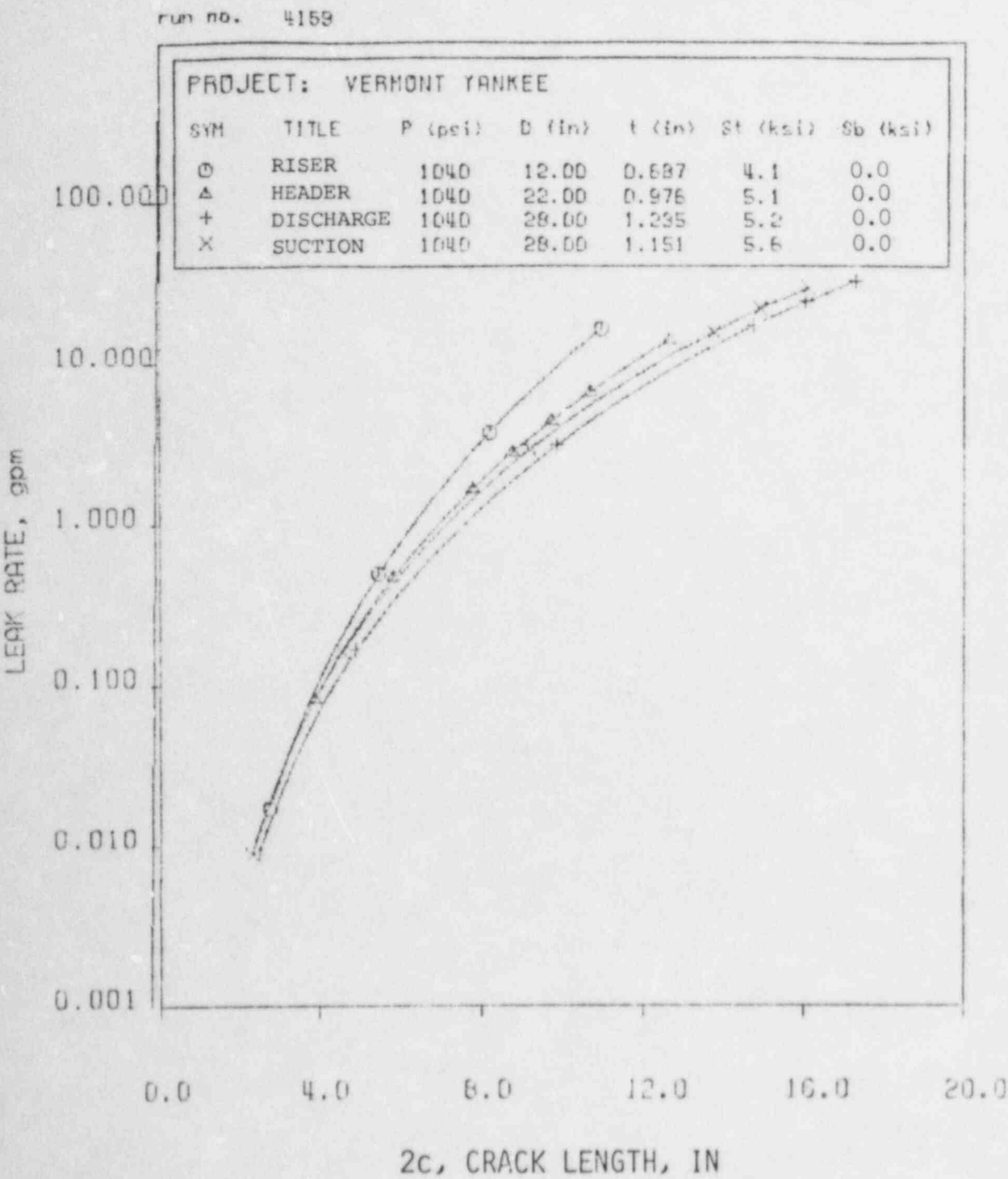


Figure 5-3 Leak Rates for Circumferential Cracks

run no. 4171

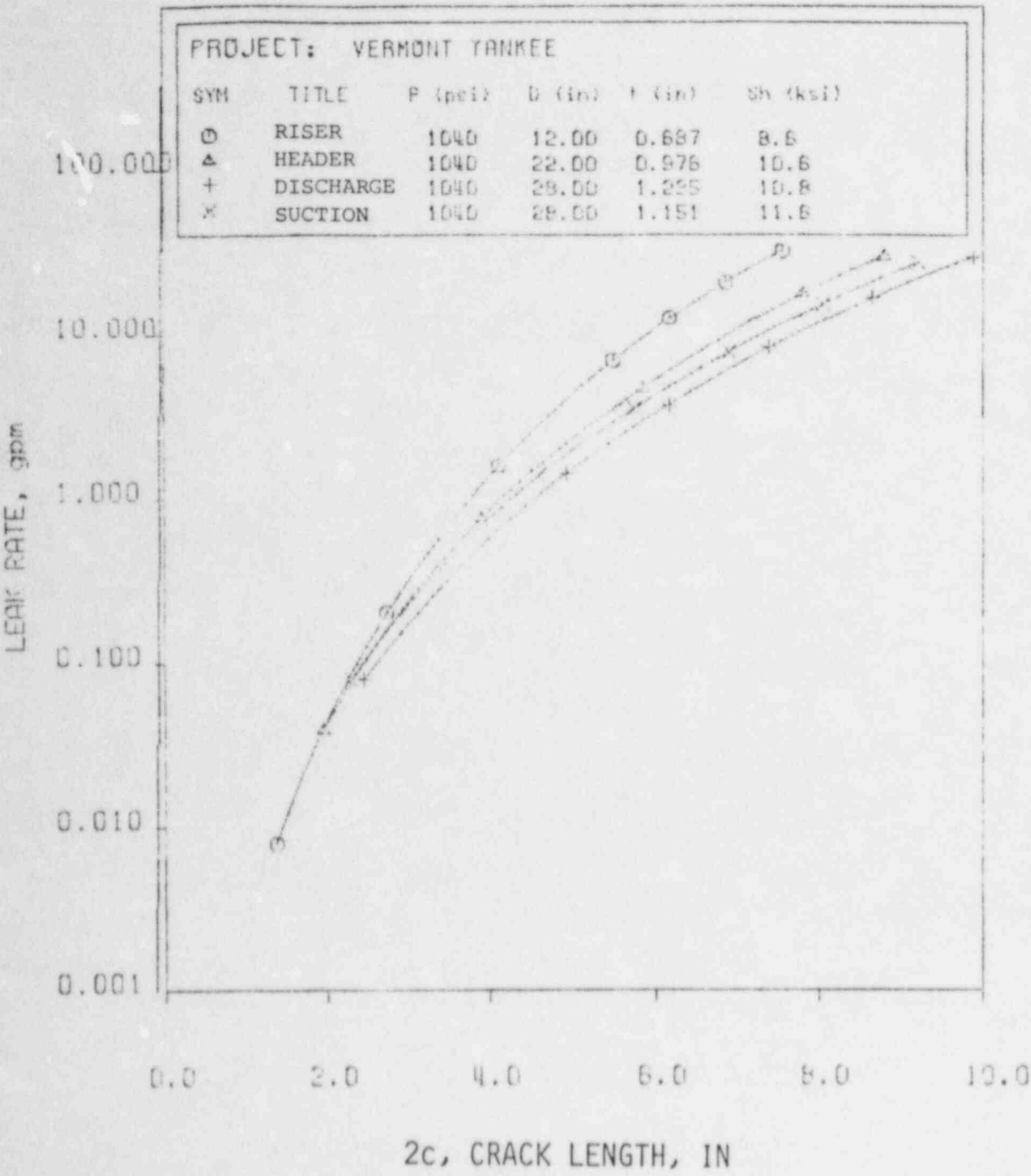


Figure 5-4 Leak Rates for Longitudinal Cracks

VERMONT YANKEE RECIRC - NODES

PLOT REFERS TO RUN NO = 4102

THIS IS RUN NO = 4103

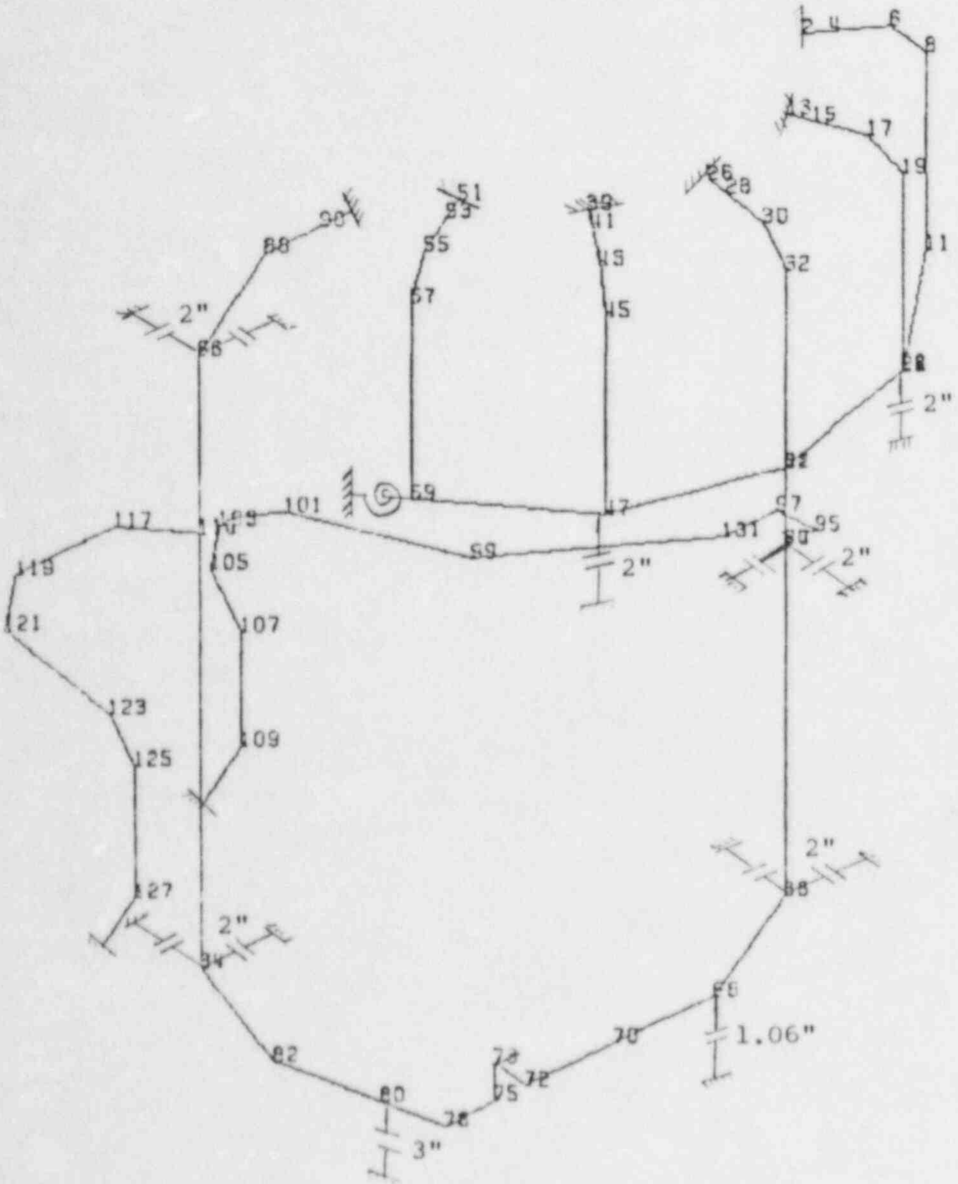


Figure 5-5 Idealization of Recirculation System Piping

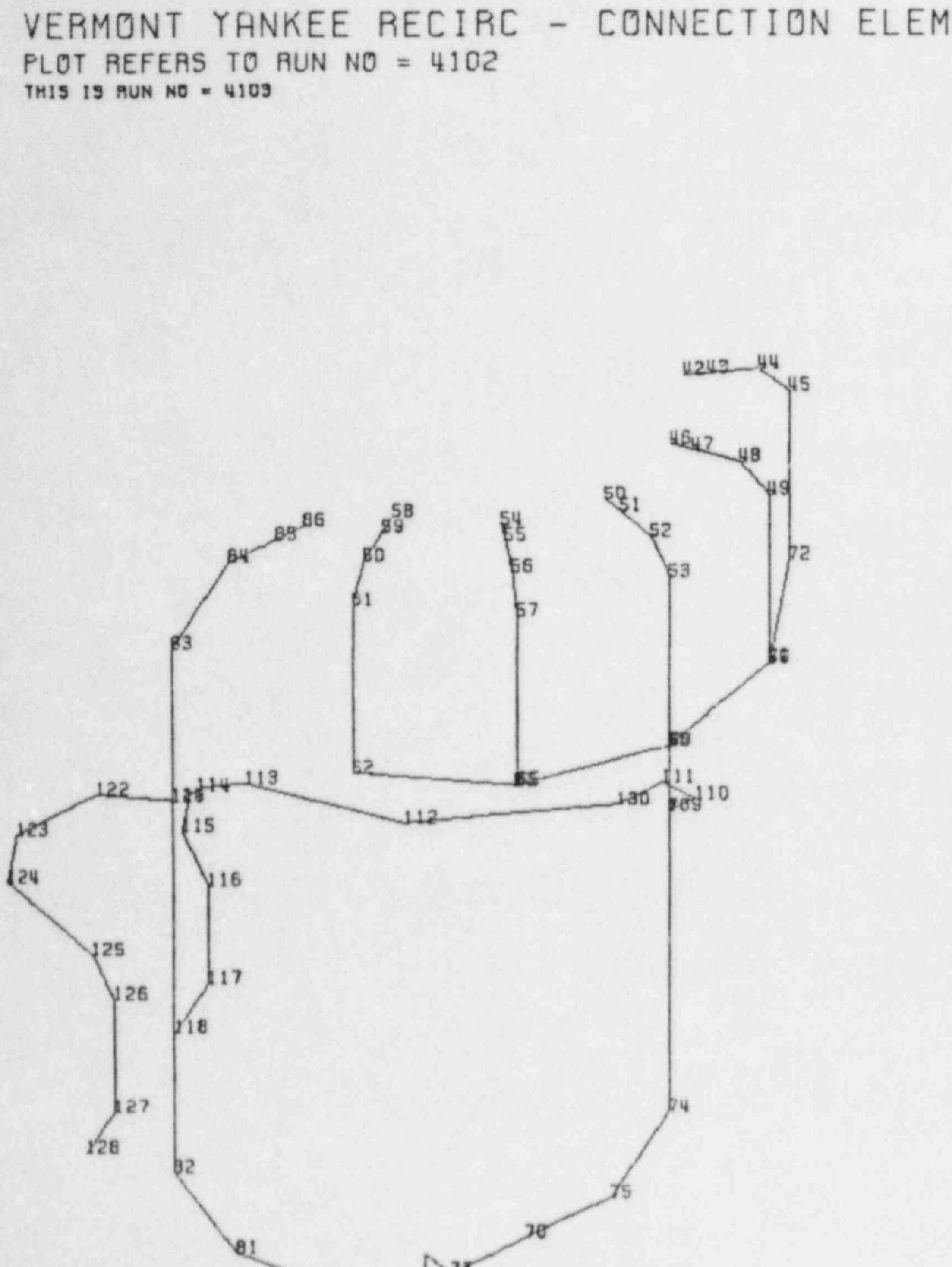
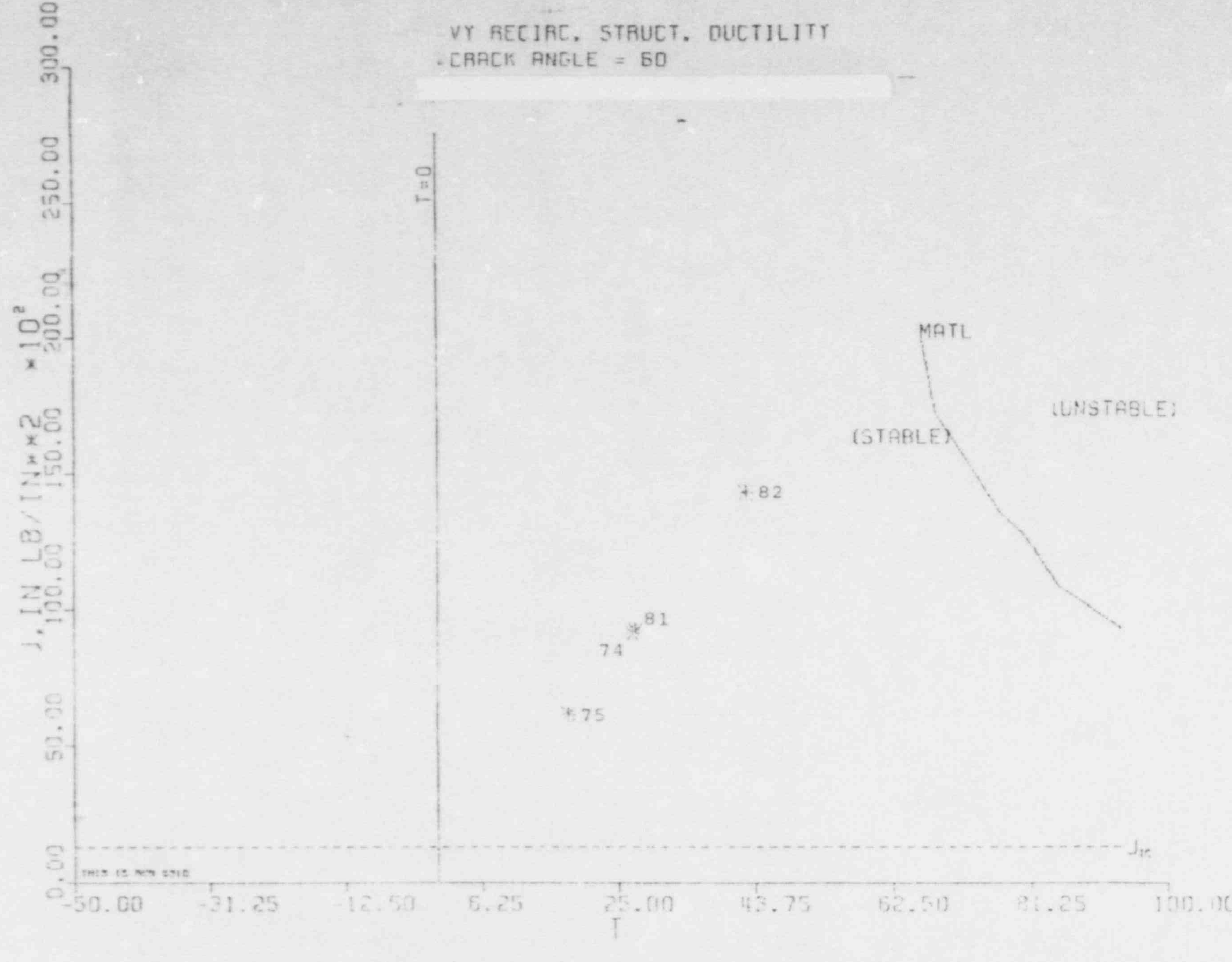
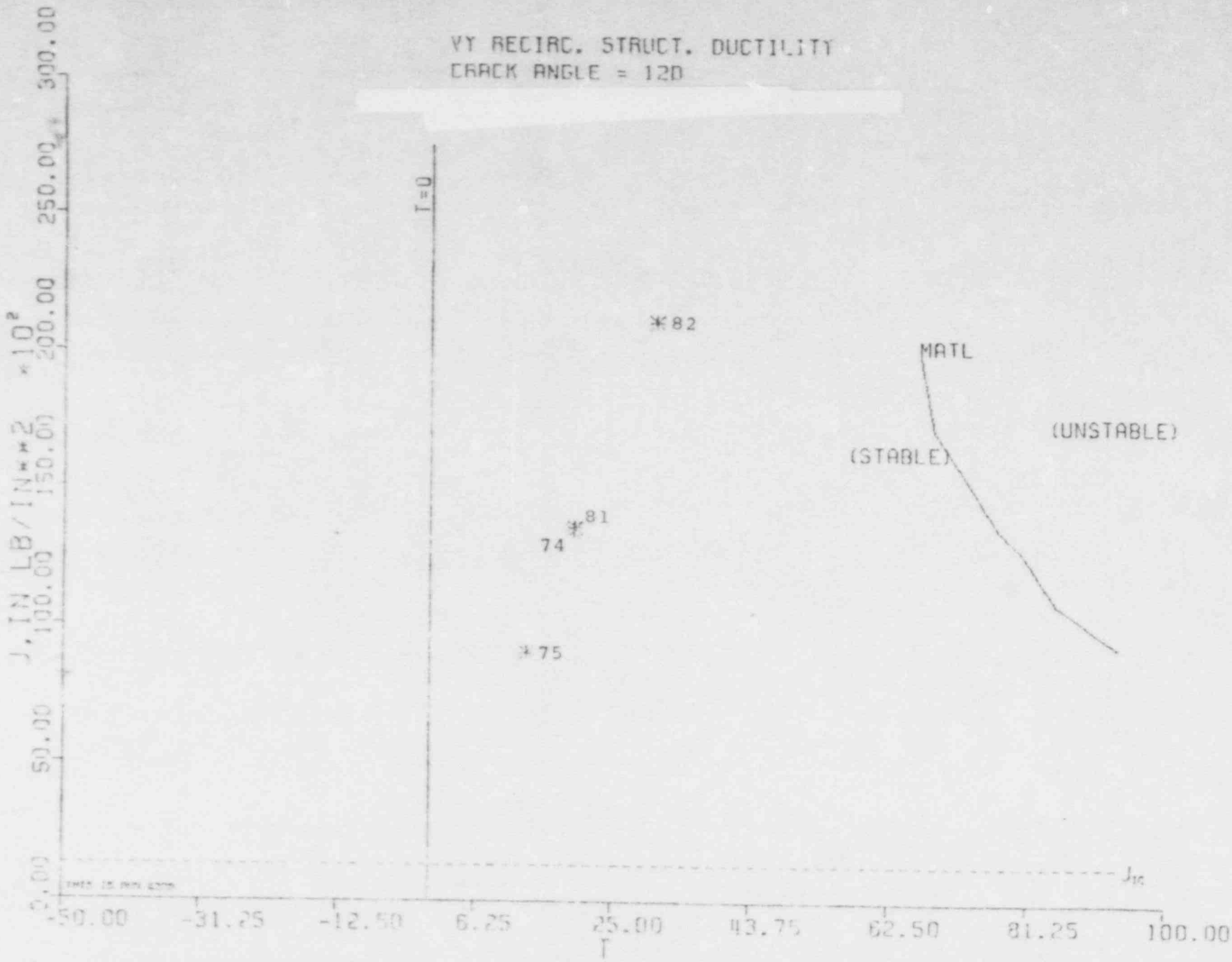


Figure 5-6 Crack Locations at Connection Elements


VY RECIRC. STRUCT. DUCTILITY
CRACK ANGLE = 60
T=0
MATL
(STABLE)
(UNSTABLE)
82
81
74
75
J, IN LB/IN**2 *10²
T
-50.00
-31.25
-12.50
6.25
25.00
43.75
62.50
81.25
100.00
0.00
50.00
100.00
150.00
200.00
250.00
300.00



VY RECIRC. STRUCT. DUCTILITY
CRACK ANGLE = 120
J, IN LB/IN**2 *10²
T
T=0
*82
*81
74
*75
MATL
(STABLE)
(UNSTABLE)
J_{IC}
300.00
250.00
200.00
150.00
100.00
50.00
0.00
-50.00
-31.25
-12.50
6.25
25.00
43.75
62.50
81.25
100.00

Section 6

SUMMARY AND CONCLUSIONS

The Vermont Yankee recirculation loop piping was analyzed using structural ductility methods ("sdm") in addition to the conventional leak-before-break ("lbb") approach. Integrity of the piping containing postulated flaws was demonstrated for both of these.

Using the lbb approach, it was shown that cracks, having lengths which would result in readily detectable leaks, were stable under Code loads (Level D or faulted conditions). Stability was shown for both longitudinal and circumferential cracks.

The sdm approach also demonstrated integrity. For the sdm analysis, upper-bounds on local plus global (or inertial) loads were used for circumferential cracks having lengths of 60 and 120°. As a conservatism, it was assumed that all snubbers and hangers were not intact. Integrity was shown to exist with ample margins of safety.

This analysis demonstrated that the sdm approach is valid for BWR systems. It was previously demonstrated for a PWR system (30). It further proved that it could be used to evaluate flaws found during ISI. This conclusion is limited however, because the boundary conditions play an important role in J_{app} and T_{app}, and they are plant specific.

In summary, it was concluded that the Vermont Yankee recirculation loop piping has large margins of safety against failure due to the presence of flaws.

Section 7

REFERENCES

1. Title 10-Chapter 1, Code of Federal Regulations, United States Nuclear Regulatory Commission, Part 50, Appendix A, General Design Criteria for Nuclear Power Plants (Abbreviated 10CFR50, App. A.)

2. USNRC Letter to Consumers Power dated 12 December, 1981.

3. ASME Boiler and Pressure Vessel Code, Section 3, 1974 (and subsequent ed).

4. Rice, J.R., Jour. Appd. Mech., Vol. 35, 1968, pp. 379-388.

5. Hutchinson, J.W. and Paris, P.C., "Stability Analysis of J-Controlled Crack Growth", ASTM STP-668, 1979, pp. 37-64.

6. Paris, P.C., "A Method of Application of Elastic-Plastic Fracture Mechanics to Nuclear Vessel Analysis", USNRC Report NUREG-0744, App. A, April 1981.

7. Paris, P.C., et al., "A Treatment of the Subject of Tearing Instability", NUREG-0311, Aug. 1977.

8. Paris, P.C. and Tada, H., "Further Results on the Subject of Tearing Instability - I", NUREG/CR-1220, Vol. I, Jan. 1980; and Zahoor, A. and Paris, P.C., "Further Results on the Subject of Tearing Instability - II", NUREG/CR-1220, Vol. II, Jan. 1980.

9. Tada, H. and Paris, P.C., "Tearing Instability Analysis Handbook", NUREG/CR-1221, Jan. 1980.

10. Johnson, R.E., et.al., "Resolution of the Reactor Vessel Materials Toughness Safety Issue", USNRC Report NUREG-0744, April 1981.

11. Paris, P.C., Tada, H. and Baldini, S.E., "Fracture Proof Design", in "CSNI Specialists Meeting on Plastic Tearing Instability", USNRC Report, NUREG/CP-0010, Jan. 1980.

12. Zahoor, A. and Kanninen, M.F., "A Plastic Fracture Mechanics Prediction of Fracture Instability in a Circumferentially Cracked Pipe in Bending", July 1980, ASME Paper 80-WA/PVP-3, Accepted for Publication in the ASME J. of P. Vessel and Technology, 1981.

13. Gudas, J.P. and Joyce, J.A., "Degraded Pipe Experimental Program", HSST Review - VIRG Meeting, 23 + 24 July 1980, Silver Spring, MD.

14. "A Critical Review of Methods of Alleviating the Requirement to Postulate Guillotine Breaks," Paris, P.C. and Cotter, K.H., CSNI Specialists Meeting on Leak-before-break, Monterey, CA, September, 1983.

15. Folias, E.S., "A Circumferential Crack in a Pressurized Cylindrical Shell", Intl. J. of Fracture Mechanics, Vol. 3, pp. 1-11, 1967.

16. Erdogan, F. and DeLale, F., "Ductile Fracture of Pipes and Cylindrical Containers with a Circumferential Flaw", ASME J. of Pressure Vessel Technology, Vol. 103, May 1981, pp. 160-168.

17. Vasquez, J. and Paris, P.C., "The Application of the Plastic Zone Instability Criterion to Pressure Vessel Failure", Journadas Metalurgicas, Sociedad Argentina de Metales, Cordoba, Argentina, Nov. 1970, (also in NUREG/CP-0010, Sept. 1979.)

18. "LKRATE", USNRC computer code for determining leakage rates through cracks in nuclear piping and pressure vessels. Transmitted by M. Boyle, USNRC/SEP to FPDC on Sept. 9, 1982.

19. Tada, H., Paris, P.C. and Gamble, R., "Stability Analysis of Circumferential Cracks in Reactor Piping Systems", NUREG/CR-0838, June 1979.

20. Zahoor, A., Monthly Progress Report, EPRI Project T118-9-1.

21. "JTPIPE", A Finite Element Program for Computing the Stability of Circumferential Cracks in Piping, Version 2, Level 3, FPDC, St. Louis, MO (PROPRIETARY).

22. "OYCJT", A Computer Program for Computing Values of J_{app} for Circumferential Cracks in Pipes, Version 1, Level 5, FPDC, St. Louis, MO.

23. "PZIF", A Computer Program for Computing Values of the J_{app} and J_{pzif} for Longitudinal Cracks in Pipes, Version 1, Level 3, FPDC, St. Louis, MO.

24. GE Stress Analysis Report 22A2615 6/10/7?: reviewed by KHC at Vt. Yankee 06/26/84.

25. Recirculation Loop Piping, YAEC Drawing 5920-268, Rev. 9, 6/83.

26. Recirculation Loop Pipe-Whip Restraints, YAEC Drawing 5920-424, Rev. 5.

27. RHR Piping, Ebasco Drawings G-191210, Rev. 9 and G-191211, Rev. 11.

28. Miscellaneous information obtained by KHC during June 26, 1984 trip to Vt. Yankee; includes Materials, Operating Tempertures and Pressures.

29. "Development of Material Proprty Data for the Tearing Stability Analysis of the Indian Point 3 Primary Coolant System", FPDC Report 83-104, Rev. 1, September 28, 1983 (PROPRIETARY).

30. "Summary of the Tearing Stability Analysis of the Indian Point 3 Primary Coolant System", K.H. Cotter and Paul C. Paris, FPDC Report 83-75, Rev. 1, May 4, 1984 (PROPRIETARY).

31. "Material Resistance and Instability Beyond J-Controlled Growth", H. A. Ernst in Elastic-Plastic Fracture: Second Symposium, ASTM STP 803, C. F. Shih and J. P. Gudas, Eds., ASTM, 1983.

32. The Application of Fracture Proof Design Methods Using Tearing Instability Theory to Nuclear Piping Postulating Circumferential Through Wall Cracks," Paris, P.C. and Tada, H., USNRC Report NUREG/CR-3464, Sept. 1983.

APPENDIX A

JTPIPE

A FINITE ELEMENT PROGRAM FOR COMPUTING PIPING SYSTEM CRACK STABILITY PARAMETERS

CONTENTS

A-1 INTRODUCTION

In NUREG/CR-0838, Tada, et al., applied tearing modulus stability concepts to a selected nuclear reactor piping system geometry and concluded that the piping system was "fracture proof"; that is, unstable ductile crack extension was shown to be unlikely. This was a major breakthrough for the inelastic fracture mechanics analysis of piping. However, in Tada's analysis, the piping system was idealized as a straight beam with simple boundary conditions and the value of J_{app} was specified. In general, the geometry and the boundary conditions of a nuclear piping system are complicated. To extend the application of Tada's approach to actual piping systems, it became necessary that a finite element program be developed to overcome the structural complexities of typical piping systems and to compute the value of J_{app} for the case of interest. The JTPIPE program was developed for that purpose.

This Appendix summarizes the capabilities of the current version of the JTPIPE computer program. The detailed theory and the numerical techniques used in JTPIPE are not presented in this Appendix.

The piping systems to be analyzed with JTPIPE can be modeled by combinations of four different types of finite elements. The four element types are:

a) 3-d straight beam element

b) 3-d curved beam element

c) Flexible connection element

d) Special element

A-2 APPROACH

The program determines the elastic compliance of the piping system at specified locations for use in the crack stability analysis. The location of the maximum compliance is also identified. The computed compliance values are then used to determine principal stiffnesses at each location to be analyzed. From the minimum stiffness at each location, the L_{eff}/R is determined. The L_{eff}/R data is stored for post-processing.

Using the aforementioned L_{eff}/R data, J_{app} and T_{app} are computed using Equations (3-3) and (3-5) for each postulated crack location in another program. These latter values are tabulated for a series of circumferential through-wall cracks having included angles of 60 to 300 degrees in 60 degree increments. Alternately, specific angles can be selected. All J vs. T data is saved and later utilized for computer plotting the stability diagram where corresponding material resistance in the form of J_{mat} vs. T_{mat} is also included.

A-3 ANALYSIS AND IDEALIZATION OF THE STRUCTURE

In this section, a brief description of the method of idealization of the structure is presented. The direct stiffness method is used to analyze the structural systems.

A-3.1 Formulation of Structural Matrices

A piping system is basically a three dimensional frame. It can be idealized as a number of discrete beam (straight or curved) elements, flexible connection

elements and special elements. The beam elements are two node elements with six degrees of freedom at each node. The stiffness matrices of the elements are 12 x 12 symmetrical matrices which can be directly formulated from beam theory. After the transformation from the local element coordinate system to the global coordinate system, the total system stiffness matrix can be formed by direct addition of the element matrices according to the index of the degree of freedom. It can be expressed in the following manner:

$$K_{ij} = \sum_{m=1}^{N} K_{ij}^{(m)} \qquad \text{(A-1)}$$

where K_{ij} is the stiffness matrix component of the total system, $K_{ij}^{(m)}$ is the stiffness matrix component of the m^{th} element and N is the total number of elements in the system.

The external force can be expressed in the form:

$$F_i = \sum_j K_{ij} * U_j \qquad \text{(A-2)}$$

where F_i is the external force applied at the i^{th} degree of freedom and U_j is the displacement at the j^{th} degree of freedom.

A-3.2 Boundary Conditions

To simplify the programing problems associated with the specific displacements on the boundary, a spring that is very stiff in comparison with the structure, is assumed to connect the boundary nodal point to a fixed point. If the applied nodal displacement component is zero, the node will be restrained by the stiff

spring. If a non-zero displacement component is specified, it can be replaced by an equivalent force applied at that nodal point. The equivalent force is evaluated by the specified displacement applied on the stiff spring with the system structure stiffness ignored. Since the spring is much stiffer than the structure, the error introduced is negligible.

Gap elements are included as a feature of the program. These elements may have any one of the principal directions. Displacements limits can be specified in either the ±X, ±Y or ±Z directions.

A-3.3 Compliance Computation At Cracked Section

In the stability analysis of a through-wall circumferential crack in a piping system, the rotational compliance at the pipe cracked section is required for the computation of the applied tearing modulus, T_{app}. This is because of the fact that the cracked section of the pipe is idealized as a plastic hinge. The rotational compliance at the pipe cracked section is due to the flexural rigidity of two elastic piping sections joined by the hinged section.

From the total system stiffness, including the boundary conditions, as formulated in Section A-3.1 and A-3.2, the rotational compliance at the pipe cracked section can be obtained by applying unit moments on opposite sides of the hinged section. The principal rotational compliance at that section and the maximum rotational compliance of the selected locations in the piping system are both calculated.

A-4 PROGRAM ORGANIZATION

The computation process in the JTPIPE program is basically divided into five distinct phases plus post-processing.

A-4.1 Nodal Point And Element Data Input

In this phase, the control information and nodal point geometry data are input and nodal points are generated by the program as required. The indices of the degrees of freedom at each nodal point are established. The element data are input and element groups generated, the element connection arrays and the element coordinate transformation matrices are calculated and all element information is stored in a disc file for use in the second and third phases.

A-4.2 Assemblage Of System Stiffness Matrix

JTPIPE uses a compacted storage scheme in which the system stiffness matrix is stored as a one-dimensional array. In the second phase, the index of the storage is established, then the system stiffness matrix is assembled and modified to satisfy the boundary conditions.

A-4.3 Compliance Calculations

In the third phase, the locations of the postulated crack locations desired for the compliance computation, are input. The rotational compliances and minimum stiffnesses at each cracked nodal point is calculated based on the response of the structure to the imposed load. The status of gap elements (open or closed) are

taken into account at this point. Next, the L_{eff}/R are calculated and stored for post-processing.

A-4.4 Computation of J_{app}

J_{app} can be specified by an input value such as J_{Ic} or an input value for rotation at the cracked section. Alternately, J_{app} can be determined from the response of the structure. This latter method is the preferred approach but involves considerably longer computer run times.

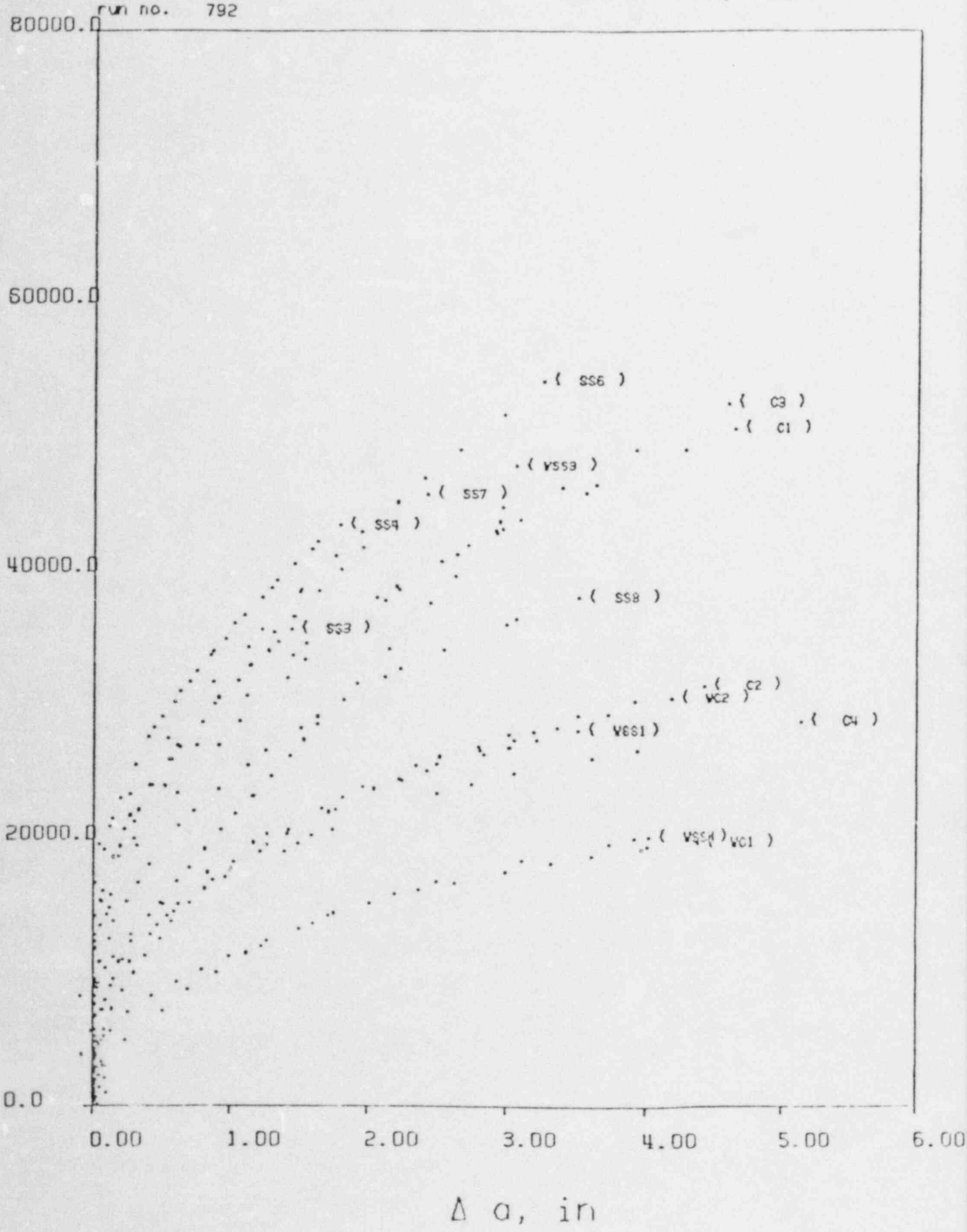
A-4.5 Computation of T_{app}

Finally, a post-processor is used to compute T_{app} for specified crack sizes and crack rotations. The data is displayed in tabular form and is stored on a disk for subsequent post-processing: namely, the generation of J vs. T diagrams.

APPENDIX B

MATERIAL PROPERTY DATA

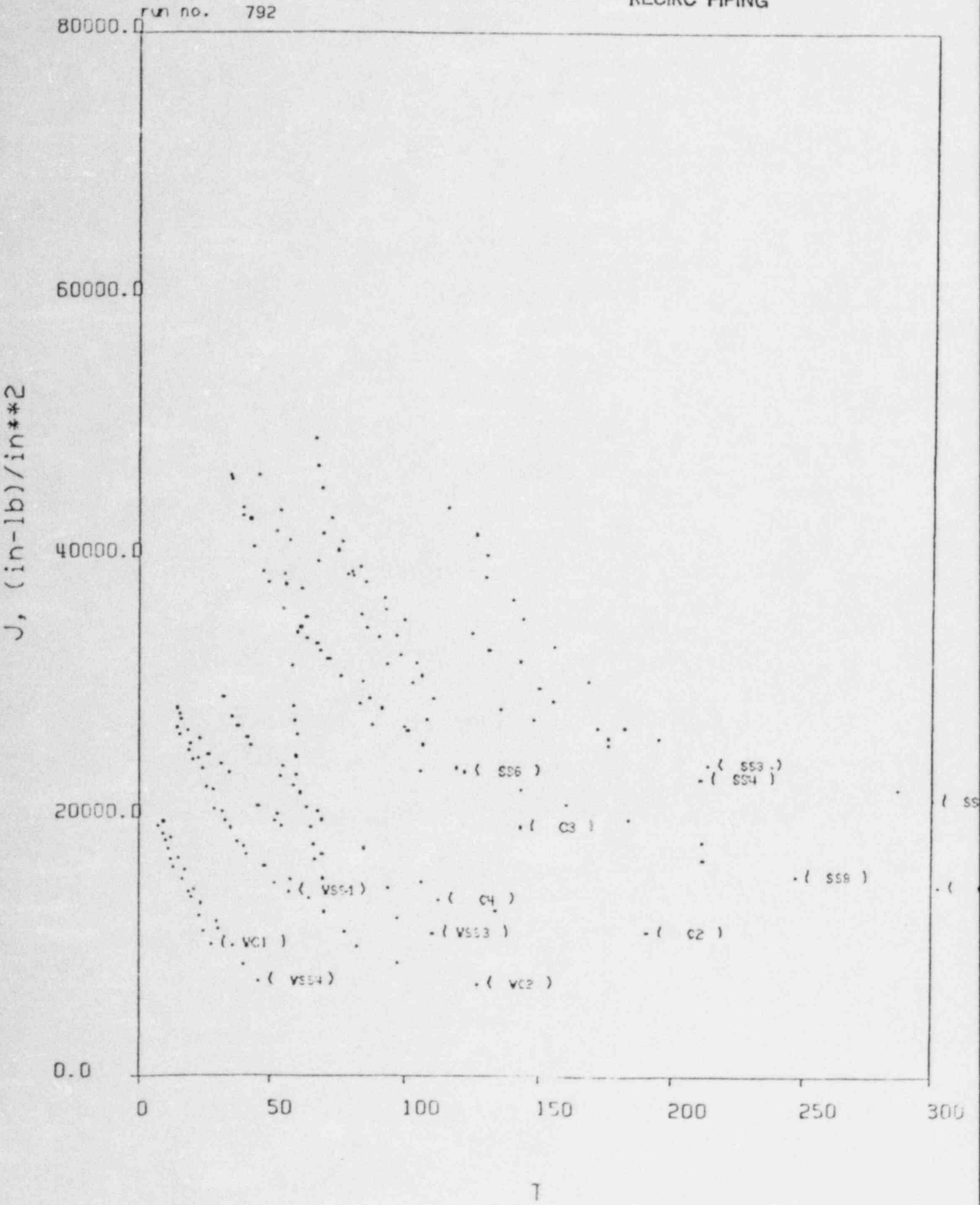
smoothed VERMONT YANKEE RECIRC PIPING



smoothed

VERMONT YANKEE

RECIRC PIPING



COMMITTEE CORRESPONDENCE

—Keep ASME Codes and Standards Department Informed—

Attachment #1

AGENDA
Task Group on Piping Flaw Analysis
San Antonio, Texas April 23,1984

==

Approval of Minutes/Agenda/Elect Secretary	Chairman
EPRI/W Weldment JR Tests and Data Summary	John Landes
NRC/DTNSRDC JR Curves From Pipes and Data Summary	Mike Vasseleros
Effect of Weld Procedures on Initiation and Toughness	Fred Copeland
Round Robin QA Calculations Summary	Douglas Norris
o Resolution of Differences	All
Low Toughness Weldment Issue - New Calculations	
o Sensitivity of Instability Load to Yield Stress	Asao Okamoto
o Consideration of Secondary Loads/New Results	Har Mehta
o New Results	Ron Gamble and Akram Zahoor
o New Results	Fred Copeland
o New Results	Joe Bloom
Other Speakers on the Low Toughness Weldment/Secondary Loads Issue	Paul Paris
Conclusions and Recommendations	All

==

Technical Support Document Recommendations	Douglas Norris
Other Issues	
o Recommendations for Changes to Table IWB-3641-2	Fred Simonen
o Ligament Collapse	Gery Wilkowski
o Other New Issues	

294

April 23, 1984
Presented by John Landes

Attachment =3

CONTENTS OF PACKAGE

A. Tables

1. Weldment Types

2. Table of Properties

B. Data Curves

1. Stress-Strain 304 Base, TIG RT, 550^{O}F

2. J_D vs. Δa R Curves All Data

3. J_m vs. Δa R Curves All Data

C. Comparison Plots - R Curves, 550^{O}F

1. Base vs. Weld

2. All Welds

3. CL vs. CR Direction (Compact vs. Bend Bar)

WELDMENT TYPES

SS Type	Type	Practice	Source	Identification
304	Submerged Arc	Shop	J.A. Jones	SA (A)
304	TIG	Automatic Field	J.A. Jones	TIG (B)
304	Shielded Metal Arc	Manual Field	J.A. Jones	SMAW (C)
316	Submerged Arc ?	Shop	Battelle (Nine Mile Point)	SW (E)
304 Base				4B (B)
				4CB (C)
316 Base				6B (E)

Material	Code	Test Temp.	Y.S. ksi	T.S. ksi	CVN ft-lbs	J_{Ic} $\frac{in.-lb}{in.^2}$	da/dJ (from J_D) psi
SA - WM	A	75°F	50.4	87.0	49/81	580	25500
	A	550°F	36.0	61.8	46/109	556	7600
	A	75°F	Bend Bar			570	21950
	A	550°F	Bend Bar			360	11600
SA - HAZ	A	75°F	--	--	--	5200	69600
	A	75°F	--	--	--	4360	54400
304 - BM	4B	75°F	38.2	81.0	239	5000	67900
	4B	550°F	23.1	61.3	221	4000	37900
TIG - WM	B	75°F	68.9	90.5	140	2314	81400
	B	550°F	53.9	63.4	239	4480	33000
TIG - HAZ	B	75°F	--	--	--	3700	50400
	B	75°F	--	--	--	6000	65500
316 - BM	E	550°F	33.2	72.7	239	4000	38400
WM	E	75°F	60.0	91.8	34/65	690	21100
WM	E	550°F	40.8	70.3	35/96	650	9400
HAZ	E	75°F	--	--	--	1700	57800
HAZ	E	550°F	--	--	--	4000	19800
304 - BM	C	75°F	42.3	86.2	239	5900	60200
	C	550°F	25.3	61.5	228	4580	22800
WM	C	75°F	62.6	87.8	71	1530	26800
WM	C	550°F	46.9	61.4	84	990	14500
HAZ	C	75°F	--	--	--	1900	61700
HAZ	C	550°F	--	--	--	4200	25100

Attachment #4

NRC PIPING MATERIALS PROGRAM

M. G. VASSILAROS
R. A. HAYS DTNSRDC
J. P. GUDAS

- o STAINLESS STEEL COMPACT DATA

  CF8A WELD + BASE PLATE

  304 WELD + BASE PLATE

- o 4 INCH DIAMETER WELDED 304 STAINLESS STEEL PIPE

  CIRCUMFERENTIAL THOUGH FLAW

  LOAD VERSUS DEFLECTION

MECHANICAL PROPERTIES OF STAINLESS STEEL BASE METAL AND WELD

		Temp (°F)	Y.S. (ksi)	U.T.S. (ksi)	% Elong. (2 in.)	% R.A.
Type 304 Stainless Steel	Base Metal	RT	36.6	89.0	68	77
		300	27.0	71.8	54	77
		550	22.0	69.9	50	72
	Weld (Transverse)	RT	67.4	88.7	38	65
		300	51.6	69.1	29	59
		550	49.0	65.6	25	55
CF8A Stainless Steel	Base Metal	RT	43	81	57	67
		300	29	67	45	70
		550	45	78	40	52
	Weld (Longitudinal)	RT	64	85	48	46
		300	48	73	33	59
		550	50	67	34	53

PREPARED BY GLG	DATE 7/18/84	FPDC	PAGE
CHECKED		TITLE VERMONT YANKEE RECIRC PIPING	REV.
APPROVED			CALC NO.

Material	Test Temp (°F)	Flow Stress (KSI)	J_{IC} $\left(\frac{in \cdot lb}{in^2}\right)$
SA-WM	550	48.9	556
304-BM	550	42.2	4000
TIG-WM	550	58.6	4480
316-BM	550	53.0	4000
316-WM	550	55.6	650
304-BM	550	43.4	4580
304-WM	550	54.2	990
304 STAINLESS BASE METAL	550	46.0	—
304 STAINLESS TRANSVERSE WELD	550	57.3	—
CF8A STAINLESS LONGITUDINAL WELD	550	58.5	—

APPENDIX C

USNRC ALTERNATIVE CRITERIA

USNRC ALTERNATIVE SAFETY ASSESSMENT FOR SELECTED HIGH ENERGY PIPE BREAK LOCATIONS AT SEP FACILITIES*

This assessment is required only if a LWR high energy piping system (i.e., 275 psi or higher) is being considered. It is only required if a postulated double ended pipe break would impair safe system shutdown by pipe whip (lacking pipe whip constraints) consequences, or by the consequences of the implied leakage or its jet action. The following guidance is for a safety assessment that may be permitted as an alternative to other system modifications or alterations for locations where the mitigation of the consequences of high energy pipe break (or leakage) have been shown to be impractical.

Guidance for Alternate Safety Assessment

The suggested guidance are as follows:

A. Detectability Requirements

Provide a leak detection system to detect through-cracks of a length of twice the wall thickness for minimum flow rates associated with normal (Level A) ASME B+PV Code operating condition. Both circumferential and longitudinal cracks must be considered for all critical break or leak locations. Methods for estimation of crack opening areas are attached in Appendix 2(not included). Surface roughness of the crack should be considered.

B. Integrity Requirements

(1) Loads for Which Level D is Specified

(a) Show that circumferential or longitudinal through-cracks of four wall thicknesses in length subjected to maximum Level D loading conditions do not exhibit substantial monotonic loading crack growth (e.g., staying below J_{Ic} or K_{Ic} by plastic zone corrected linear-elastic fracture mechanics methods or a suitable alternative. For 4t flaws that are calculated to be greater than K_{Ic} or J_{Ic}, consideration will be given to: (1) flaw growth arguments, (2) postulation of small flaw sizes than 4t if justified by leak detection sensitivity. Also assure that local or general plastic instability does not occur for these loading conditions and crack sizes.

(b) Under conditions in "B.(1)", show that the flow through the crack and the action of the jet through the crack will not impair safe shutdown of the system. Acceptable methodology for the estimation of crack opening area for a circumferential through crack in a pipe in tension and bending and for longitudinal cracks subject to internal pressure are attached.

(2) Extreme Conditions to Preclude a Double-Ended Pipe Break

Using elastic-plastic fracture mechanics or suitable alternative, show that circumferential through-cracks will remain stable for local fully plastic large-deformation bending conditions under the following additional conditions:

(a) Fully plastic bending of the cracked section is to be assumed, unless other load limiting local conditions (such as elbow collapse) dictate maximum bending loads, for all critical locations.

C Letter to Consumer's Power dated 12/12/81.

(b) Assume all system anchors are effective. To simplify the analysis, supports may conservatively be considered inoperative. If supports are included, consideration should be given to the adequacy of the support to resist large loads.

(c) Other "as built" displacement limits or constraints may be assumed as especially justified (such as displacement limits of a pipe running through a hole in a sufficiently strong concrete wall or floor, etc.).

(d) Assume a through-crack size of 4t or 90^{o} total circumferential length, whichever is greater, or a larger crack only if especially justified.

(e) Assume large deformations means deformations proceeding to "as built" displacement limits or other especially justified limits.

(3) Material Properties

Conservative material properties should be used in the analyses. Sufficient justification must be provided for the properties, both weldment and base metal, used in the analyses.

C. Subcritical Crack Development

Consideration should be given to the types of subcritical cracks which may be developed at all locations associated with this type of analysis. From prior experience and/or direct analysis, it should be shown that:

(1) There is a positive tendency to develop through-wall cracks.

(2) If there is a tendency to develop long surface cracks in addition to through-wall cracks, then it should be further demonstrated that the long surface crack will remain sufficiently shallow.

D. Augmented Inservice Inspection

Piping system locations for which corrective measures are not practicable should be inspected volumetrically in accordance with ASME Code, Section XI for a Class 1 system regardless of actual system classification.

DRAFT 11/29/83

STEP-WISE APPROACH, LEAK-BEFORE-BREAK (LBB) ANALYSIS

1. Describe the line(s) for which LBB is to be applied.

   a. Provide a discussion to support a conclusion that this line or lines is(are) very unlikely to experience stress corrosion cracking or excessive loads such as might occur from thermal or mechanical low and high cycle fatigue or a water-hammer.

   b. Identify the types of materials and materials specifications used for base metal, weldments and safe-ends and provide the materials properties including the J-R curve used in analyses, long term effects such as thermal aging and other limitations such as limits to valid data (e.g., maximum J, maximum crack growth).

   c. Specify the type and magnitude of the loads applied (forces, bending and torsional moments), their source(s) and method of combination. Identify the location(s) at which the highest stresses coincident with poorest material properties occurs for base materials, weldments and safe-ends. For geometrically complex lines or systems, it may be necessary to analyze several locations to assure that the more vulnerable locations are identified. At this location or these locations, postulate a crack that may be missed during fabrication and preservice inspections or would be permitted by code, whichever is larger. Demonstrate by fatigue analysis that the crack will not grow significantly during service.

2. Postulate leakage size crack(s).

   a. Even though Step 1 should demonstrate that a leaking pipe is unlikely, postulate a through-wall crack at the selected location(s). The size of the crack should be large enough so that the leakage is assured of detection with adequate margin using the minimum installed leak detection capability when the pipe(s) is(are) subjected to normal operational loads. If auxiliary leak detection systems are relied on, they should be described.

   b. Further, assuming that a safe shutdown earthquake (SSE) occurs prior to detection of the leak, demonstrate that the postulated leakage crack is stable under normal plus SSE loads for long periods of time; that is, crack growth if any is minimal during an earthquake.

3. Determine crack size margin by comparing leakage size crack to critical size crack. Using normal plus SSE loads, demonstrate that there is adequate margin between the leakage size crack and the critical size crack to account for the uncertainties inherent in the analyses and leak detection capability. In some cases, a limit-load analysis may suffice for this purpose, however, an elastic-plastic fracture mechanics (tearing instability) analysis is preferable.

4. Determine margin in terms of applied loads by a crack stability analysis. Demonstrate that the leakage size that crack(s) will not experience unstable crack growth even if larger loads (larger than design loads) are applied. Demonstrate that crack growth is stable and the final crack size is limited such that a double-ended pipe break will not occur.

NOTE: Steps 1 through 4 are illustrated in the attached figure.

GENERAL DISCUSSION

The preceding analytical steps assume that circumferentially oriented postulated cracks are limiting. If this is not the case, then the analyses described in Steps 1 through 4 should also include the postulation of axial cracks and/or elbow cracks. Also if applied moments are quite low and axial forces dominate, it may be necessary to consider relatively long part-through-wall cracks in Step 1 and demonstrate that they are unlikely to result in unstable axial or elbow splits or a double-ended pipe break.

In general, the LBB approach does not rely on crack detection by inservice inspections (ISI). If, however, conclusions reached via the LBB analyses are marginal, then augmented ISI at potentially vulnerable locations may be necessary.

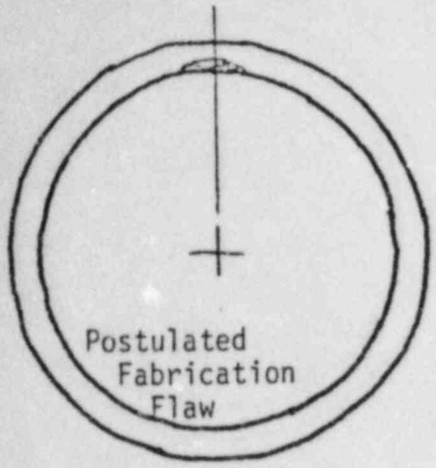
Positive conclusions reached via the LBB approach, will allow the removal of or non-installation of protective devices such as pipe whip restraints and jet impingement shields and thus obtain the benefits in both cost and man-rem saved as well as other safety benefits. If it can be demonstrated that large pipes will not fail catastrophically, then reconsideration can be given to design requirements for other safety systems such as containment and emergency core cooling systems. The latter approach, however, will involve consideration of other systems, component or operator failures affecting the design requirements of these systems and which must be addressed in any request for reconsideration.

LEGAL/ADMINISTRATIVE CONSIDERATIONS

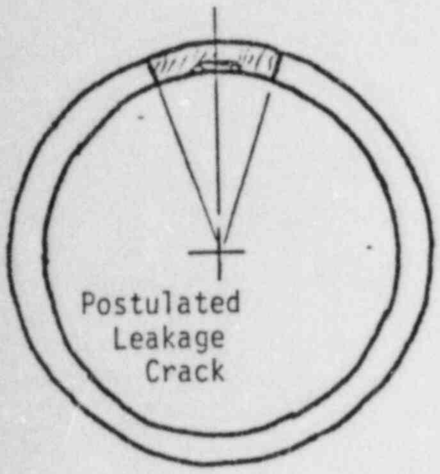
The utilization of LBB technology to demonstrate that protective devices are not required and possibly that other safety system design requirements can be relaxed will require an exemption from the current NRC regulations, particularly GDC-4 and/or the definition of a LOCA. To justify such an exemption, applicants or licensees should provide a sufficient basis for such exemptions until the regulations are modified, including the cost and man-rem benefits to be accrued at a specific facility versus any potential additional risks that might occur. The NRC, in the meantime, will initiate rule-making activities to remedy the situation in the long run.

The elimination of large LOCA loads can also affect the future design requirements for support systems. This aspect is under consideration by the staff. For all facilities currently operating or under construction, applicants and licensees should retain the present design requirements. Similarly, the current requirement to postulate specific intermediate break locations in various lines is affected by LBB and is being reconsidered by the staff.

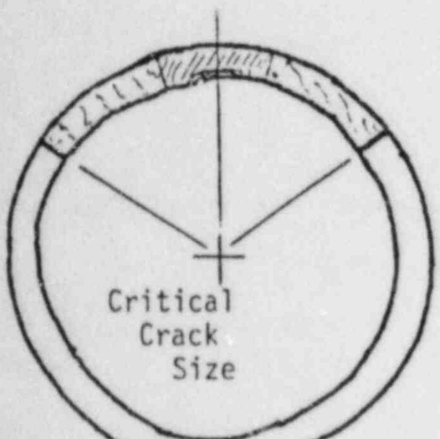
STEP-WISE APPROACH, LEAK-BEFORE-BREAK ANALYSIS



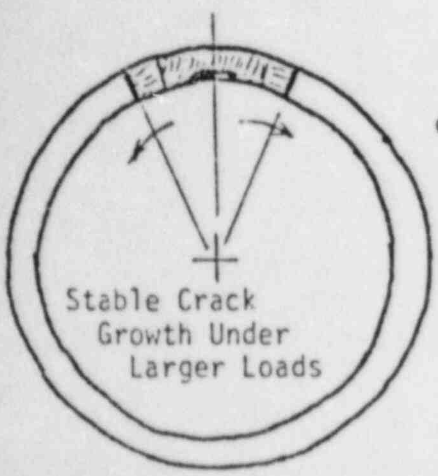
- Select highest stress, poorest material properties location in pipe under consideration.
- Postulate crack that may be missed during fabrication and preservice inspections or would be permitted by Code, whichever is larger.
- Demonstrate by analysis that crack will not grow significantly during service either by fatigue, corrosion or impact forces (water-hammer).



- Demonstrate that even if crack propagated through wall that:
  - Leakage through crack is significantly greater than minimum leak detection capability under normal operating loads so that detection of crack is assured and
  - even if undetected prior to an earthquake, crack is stable under normal plus earthquake loads (growth, if any, is minimal for long periods of time).



- Demonstrate margin via crack sizes
  - Compare leakage crack size to critical crack size under normal plus earthquake loads.
  - Demonstrate that there is adequate margin to account for uncertainties inherent in analyses and leak detection.



- Demonstrate margin via loads
  - Demonstrate that leakage size cracks will not experience unstable crack growth even if larger loads are applied and that final crack size is limited (that is, a double-ended pipe break will not occur.

APPENDIX D

CRACK STABILITY CALCULATIONS

VYNPS RECIRCULATION SYSTEM PIPING
12" RISER LONGITUDINAL CRACK STABILITY

**************** CASE = 1 ********************

LONGITUDINAL CRACK LEAK RATE, LEVEL A
Leak Rate = 0.1 gpm

Soper	2c
8.823	2.300

LONGITUDINAL CRACK STABILITY, LEVEL D LOADS

Sleak = 8823. psi Shoop = 10191. psi

PIPE OD = 12.750 in THICKNESS = 0.687 in Sflow = 45000. psi

	CRACK LENGTH, IN	RY IN	Ceff	J IN-LB/IN**2	Jpzif
1	3.67	0.000	0.18370E+01	0.43355E+02	0.40483E+03
2	3.67	0.097	0.19340E+01	0.48188E+02	0.41570E+03
3	3.67	0.108	0.19448E+01	0.48750E+02	0.41691E+03
4	3.67	0.109	0.19461E+01	0.48816E+02	0.41705E+03
5	3.67	0.109	0.19462E+01	0.48824E+02	0.41707E+03

***** CONVERGENCE ACHIEVED *****

**************** CASE = 2 ********************

LONGITUDINAL CRACK LEAK RATE, LEVEL A
Leak Rate = 1.0 gpm

Soper	2c
8.823	3.800

LONGITUDINAL CRACK STABILITY, LEVEL D LOADS

Sleak = 8823. psi Shoop = 10191. psi

PIPE OD = 12.750 in THICKNESS = 0.687 in Sflow = 45000. psi

	CRACK LENGTH, IN	RY IN	Ceff	J IN-LB/IN**2	Jpzif
1	5.17	0.000	0.25870E+01	0.80136E+02	0.48355E+03
2	5.17	0.179	0.27663E+01	0.94150E+02	0.51108E+03
3	5.17	0.211	0.27976E+01	0.96756E+02	0.51589E+03
4	5.17	0.216	0.28034E+01	0.97245E+02	0.51678E+03
5	5.17	0.218	0.28045E+01	0.97337E+02	0.51695E+03

***** CONVERGENCE ACHIEVED *****

**************** CASE=3 ********************

LONGITUDINAL CRACK LEAK RATE, LEVEL A
Leak Rate = 10.0 gpm

Soper	2c
8.823	5.900

LONGITUDINAL CRACK STABILITY, LEVEL D LOALS

Sleak = 8823. psi Shoop = 10191. psi

PIPE OD = 12.750 in THICKNESS = 0.687 in Sflow = 45000. psi

	CRACK LENGTH, IN	RY IN	Ceff	J IN-LB/IN**2	Jpzif
1	7.27	0.000	0.36370E+01	0.18528E+03	0.64376E+03
2	7.27	0.414	0.40515E+01	0.24384E+03	0.70650E+03
3	7.27	0.545	0.41825E+01	0.26461E+03	0.72630E+03
4	7.27	0.592	0.42289E+01	0.27225E+03	0.73331E+03
5	7.27	0.609	0.42460E+01	0.27509E+03	0.73589E+03
6	7.27	0.615	0.42524E+01	0.27616E+03	0.73686E+03
7	7.27	0.618	0.42547E+01	0.27656E+03	0.73722E+03
8	7.27	0.619	0.42556E+01	0.27671E+03	0.73735E+03

***** CONVERGENCE ACHIEVED *****

VYNPS RECIRCULATION SYSTEM PIPING
22" HEADER LONGITUDINAL CRACK STABILITY

**************** CASE = 1 ********************

LONGITUDINAL CRACK LEAK RATE, LEVEL A
Leak Rate = 0.1 gpm

Soper	2c
10.997	2.400

LONGITUDINAL CRACK STABILITY, LEVEL D LOADS

Sleak = 10997. psi   Shoop = 12573. psi

PIPE OD = 21.879 in   THICKNESS = 0.976 in   Sflow = 45000. psi

	CRACK LENGTH, IN	RY IN	Ceff	J IN-LB/IN**2	Jpzif
1	4.35	0.000	0.21760E+01	0.60878E+02	0.55501E+03
2	4.35	0.136	0.23122E+01	0.67831E+02	0.57092E+03
3	4.35	0.152	0.23277E+01	0.68660E+02	0.57272E+03
4	4.35	0.154	0.23296E+01	0.68760E+02	0.57293E+03
5	4.35	0.154	0.23298E+01	0.68772E+02	0.57296E+03

***** CONVERGENCE ACHIEVED *****

**************** CASE = 2 ********************

LONGITUDINAL CRACK LEAK RATE, LEVEL A
Leak Rate = 1.0 gpm

Soper	2c
10.997	4.100

LONGITUDINAL CRACK STABILITY, LEVEL D LOADS

Sleak = 10997. psi   Shoop = 12573. psi

PIPE OD = 21.879 in   THICKNESS = 0.976 in   Sflow = 45000. psi

	CRACK LENGTH, IN	RY IN	Ceff	J IN-LB/IN**2	Jpzif
1	6.05	0.000	0.30260E+01	0.11441E+03	0.65128E+03
2	6.05	0.256	0.32819E+01	0.11625E+03	0.63840E+03
3	6.05	0.260	0.32860E+01	0.11659E+03	0.63905E+03
4	6.05	0.261	0.32868E+01	0.11665E+03	0.63916E+03

***** CONVERGENCE ACHIEVED *****

**************** CASE = 3 ********************

LONGITUDINAL CRACK LEAK RATE, LEVEL A
Leak Rate = 10.0 gpm

Soper	2c
10.997	6.800

LONGITUDINAL CRACK STABILITY, LEVEL D LOADS

Sleak = 10997. psi Shoop = 12573. psi

PIPE OD = 21.879 in THICKNESS = 0.976 in Sflow = 45000. psi

	CRACK LENGTH, IN	RY IN	Ceff	J IN-LB/IN**2	Jpzif
1	8.75	0.000	0.43760E+01	0.22934E+03	0.80736E+03
2	8.75	0.513	0.48890E+01	0.30076E+03	0.88578E+03
3	8.75	0.673	0.50488E+01	0.32566E+03	0.91012E+03
4	8.75	0.728	0.51045E+01	0.33465E+03	0.91860E+03
5	8.75	0.749	0.51246E+01	0.33793E+03	0.92166E+03
6	8.75	0.756	0.51319E+01	0.33914E+03	0.92278E+03
7	8.75	0.759	0.51346E+01	0.33958E+03	0.92319E+03
8	8.75	0.760	0.51356E+01	0.33975E+03	0.92334E+03

***** CONVERGENCE ACHIEVED *****

VYNPS RECIRCULATION SYSTEM PIPING
28" DISCHARGE LONGITUDINAL CRACK STABILITY

**************** CASE = 1 *********************

LONGITUDINAL CRACK LEAK RATE, LEVEL A
Leak Rate = 0.1 gpm

Soper	2c
11.295	2.600

LONGITUDINAL CRACK STABILITY, LEVEL D LOADS

Sleak = 11295. psi Shoop = 12899. psi

PIPE OD = 28.337 in THICKNESS = 1.235 in Sflow = 45000. psi

	CRACK LENGTH, IN	RY IN	Ceff	J IN-LB/IN**2	Jpzif
1	5.07	0.000	0.25350E+01	0.69792E+02	0.68024E+03
2	5.07	0.156	0.26911E+01	0.77222E+02	0.69942E+03
3	5.07	0.173	0.27077E+01	0.78046E+02	0.70142E+03
4	5.07	0.175	0.27096E+01	0.78138E+02	0.70164E+03
5	5.07	0.175	0.27098E+01	0.78148E+02	0.70167E+03

***** CONVERGENCE ACHIEVED *****

**************** CASE = 2 *********************

LONGITUDINAL CRACK LEAK RATE, LEVEL A
Leak Rate = 1.0 gpm

Soper	2c
11.295	4.600

LONGITUDINAL CRACK STABILITY, LEVEL D LOADS

Sleak = 11295. psi Shoop = 12899. psi

PIPE OD = 28.337 in THICKNESS = 1.235 in Sflow = 45000. psi

	CRACK LENGTH, IN	RY IN	Ceff	J IN-LB/IN**2	Jpzif
1	7.07	0.000	0.35350E+01	0.12793E+03	0.79606E+03
2	7.07	0.286	0.38212E+01	0.14977E+03	0.82807E+03
3	7.07	0.335	0.38700E+01	0.15375E+03	0.83355E+03
4	7.07	0.344	0.38789E+01	0.15449E+03	0.83455E+03
5	7.07	0.346	0.38806E+01	0.15463E+03	0.83473E+03

***** CONVERGENCE ACHIEVED *****

****************** CASE = 3 ***********************

LONGITUDINAL CRACK LEAK RATE, LEVEL A
Leak Rate = 10.0 gpm

Soper	2c
11.295	7.600

LONGITUDINAL CRACK STABILITY, LEVEL D LOADS

Sleak = 11295. psi Shoop = 12899. psi

PIPE OD = 28.337 in THICKNESS = 1.235 in Sflow = 45000. psi

	CRACK LENGTH, IN	RY IN	Ceff	J IN-LB/IN**2	Jpzif
1	10.07	0.000	0.50350E+01	0.23899E+03	0.94653E+03
2	10.07	0.535	0.55696E+01	0.30446E+03	0.10287E+04
3	10.07	0.681	0.57161E+01	0.32425E+03	0.10511E+04
4	10.07	0.725	0.57603E+01	0.33039E+03	0.10579E+04
5	10.07	0.739	0.57741E+01	0.33231E+03	0.10600E+04
6	10.07	0.743	0.57784E+01	0.33291E+03	0.10607E+04
7	10.07	0.745	0.57797E+01	0.33310E+03	0.10609E+04

***** CONVERGENCE ACHIEVED *****

VYNPS RECIRCULATION SYSTEM PIPING
28" SUCTION LONGITUDINAL CRACK STABILITY

**************** CASE = 1 ********************

LONGITUDINAL CRACK LEAK RATE, LEVEL A
Leak Rate = 0.1 gpm

Soper	2c
11.188	2.400

LONGITUDINAL CRACK STABILITY, LEVEL D LOADS

Sleak = 11188. psi Shoop = 12888. psi

PIPE OD = 28.169 in THICKNESS = 1.151 in Sflow = 45000. psi

	CRACK LENGTH, IN	RY IN	Ceff	J IN-LB/IN**2	Jpzif
1	4.70	0.000	0.23510E+01	0.63019E+02	0.64394E+03
2	4.70	0.141	0.24920E+01	0.69405E+02	0.66172E+03
3	4.70	0.155	0.25063E+01	0.70077E+02	0.66348E+03
4	4.70	0.157	0.25078E+01	0.70148E+02	0.66367E+03
5	4.70	0.157	0.25079E+01	0.70156E+02	0.66368E+03

***** CONVERGENCE ACHIEVED *****

**************** CASE = 2 ********************

LONGITUDINAL CRACK LEAK RATE, LEVEL A
Leak Rate = 1.0 gpm

Soper	2c
11.188	4.300

LONGITUDINAL CRACK STABILITY, LEVEL D LOADS

Sleak = 11188. psi Shoop = 12888. psi

PIPE OD = 28.169 in THICKNESS = 1.151 in Sflow = 45000. psi

	CRACK LENGTH, IN	RY IN	Ceff	J IN-LB/IN**2	Jpzif
1	6.60	0.000	0.33010E+01	0.11565E+03	0.75542E+03
2	6.60	0.259	0.35597E+01	0.13440E+03	0.78435E+03
3	6.60	0.301	0.36016E+01	0.13764E+03	0.78904E+03
4	6.60	0.308	0.36089E+01	0.13821E+03	0.78985E+03
5	6.60	0.309	0.36102E+01	0.13831E+03	0.78999E+03

***** CONVERGENCE ACHIEVED *****

**************** CASE = 3 *********************

LONGITUDINAL CRACK LEAK RATE, LEVEL A
Leak Rate = 10.0 gpm

Soper	2c
11.188	7.200

LONGITUDINAL CRACK STABILITY, LEVEL D LOADS

Sleak = 11188. psi   Shoop = 12888. psi

PIPE OD = 28.169 in   THICKNESS = 1.151 in   Sflow = 45000. psi

	CRACK LENGTH, IN	RY IN	Coef	J IN-LB/IN**2	Jpzif
1	9.50	0.000	0.47510E+01	0.21864E+03	0.89660E+03
2	9.50	0.489	0.52401E+01	0.27633E+03	0.97185E+03
3	9.50	0.618	0.53691E+01	0.29305E+03	0.99164E+03
4	9.50	0.656	0.54065E+01	0.29802E+03	0.99738E+03
5	9.50	0.667	0.54177E+01	0.29951E+03	0.99908E+03
6	9.50	0.670	0.54210E+01	0.29996E+03	0.99959E+03
7	9.50	0.671	0.54220E+01	0.30009E+03	0.99974E+03

***** CONVERGENCE ACHIEVED *****

VERMONT YANKEE RECIRC LINE CRACK STABILITY

(RISER, 12 in) STRESSES FROM GE/SAR 22A2615

UN = 4147

Faxial =	0.	Mapplied =	0.16380E+07	Poper =	1479. psi
Saxial =	0.	Sbending =	21979.	Smem =	5774. psi
PIPE OD =	12.750	THICKNESS =	0.687	Sflow =	70000. psi
ALFA =	2.	ELAS MOD =	0.256E+08	Jic =	4500. in-lb/in**2

CRACK LENGTH, IN	LEAK AREA IN**2	L/Dh	J IN-LB/IN**2	T
1.27	0.002	0.18434E+03	0.57827E+02	0.56075E+00
1.89	0.005	0.11929E+03	0.91456E+02	0.62746E+00
2.51	0.009	0.86565E+02	0.12921E+03	0.70634E+00
3.12	0.015	0.66878E+02	0.17178E+03	0.79722E+00
3.72	0.023	0.53767E+02	0.21985E+03	0.90027E+00
4.31	0.032	0.44452E+02	0.27412E+03	0.10159E+01
4.88	0.042	0.37533E+02	0.33530E+03	0.11445E+01
5.45	0.055	0.32227E+02	0.40416E+03	0.12866E+01
5.99	0.070	0.28059E+02	0.48147E+03	0.14429E+01
6.52	0.086	0.24725E+02	0.56807E+03	0.16139E+01
7.03	0.104	0.22021E+02	0.66479E+03	0.18004E+01
7.52	0.124	0.19802E+02	0.77254E+03	0.20029E+01
7.99	0.145	0.17966E+02	0.89225E+03	0.22222E+01
8.44	0.167	0.16438E+02	0.10249E+04	0.24591E+01
8.85	0.190	0.15160E+02	0.11715E+04	0.27141E+01
9.25	0.214	0.14089E+02	0.13330E+04	0.29880E+01
9.61	0.237	0.13191E+02	0.15107E+04	0.32816E+01
9.94	0.260	0.12440E+02	0.17056E+04	0.35955E+01
10.24	0.282	0.11816E+02	0.19188E+04	0.39306E+01
10.50	0.303	0.11304E+02	0.21517E+04	0.42876E+01
10.73	0.321	0.10891E+02	0.24055E+04	0.46671E+01
10.91	0.337	0.10569E+02	0.26814E+04	0.50701E+01
11.05	0.349	0.10331E+02	0.29809E+04	0.54971E+01
11.14	0.357	0.10175E+02	0.33053E+04	0.59491E+01
11.19	0.361	0.10099E+02	0.36560E+04	0.64266E+01
11.19	0.361	0.10104E+02	0.40346E+04	0.69306E+01

***** EXCEEDED BY MAX SIZE = [illegible] *****

VERMONT YANKEE RECIRC LINE CRACK STABILITY

(HEADER, 22 in) STRESSES FROM GE/SAR 22A2615

RUN = 4144

Faxial = 16110. Mapplied = 0.22480E+07 Poper = 1479. psi
Saxial = 251. Sbending = 7010. Smem = 7448. psi

PIPE OD = 21.879 THICKNESS = 0.976 Sflow = 70000. psi
ALFA = 2. ELAS MOD =0.256E+08 Jic = 4500. in-lb/in**2

CRACK LENGTH, IN	LEAK AREA IN**2	L/Dh	J IN-LB/IN**2	T
1.91	0.003	0.34731E+03	0.22230E+02	0.15171E+00
2.86	0.006	0.22469E+03	0.35273E+02	0.16932E+00
3.81	0.011	0.16304E+03	0.49829E+02	0.18891E+00
4.76	0.018	0.12589E+03	0.66059E+02	0.21045E+00
5.70	0.026	0.10107E+03	0.84121E+02	0.23397E+00
6.64	0.037	0.83350E+02	0.10418E+03	0.25948E+00
7.58	0.050	0.70095E+02	0.12639E+03	0.28703E+00
8.51	0.066	0.59842E+02	0.15093E+03	0.31668E+00
9.44	0.085	0.51707E+02	0.17797E+03	0.34847E+00
10.36	0.107	0.45121E+02	0.20768E+03	0.38247E+00
11.27	0.133	0.39704E+02	0.24025E+03	0.41873E+00
12.18	0.162	0.35191E+02	0.27587E+03	0.45732E+00
13.09	0.195	0.31390E+02	0.31472E+03	0.49831E+00
13.99	0.232	0.28159E+02	0.35701E+03	0.54175E+00
14.88	0.274	0.25392E+02	0.40293E+03	0.58771E+00
15.77	0.320	0.23005E+02	0.45269E+03	0.63626E+00
16.64	0.371	0.20935E+02	0.50651E+03	0.68746E+00
17.51	0.428	0.19129E+02	0.56461E+03	0.74138E+00
18.38	0.489	0.17546E+02	0.62720E+03	0.79809E+00
19.23	0.555	0.16154E+02	0.69452E+03	0.85765E+00
20.07	0.628	0.14923E+02	0.76681E+03	0.92012E+00
20.91	0.706	0.13833E+02	0.84430E+03	0.98558E+00
21.73	0.789	0.12862E+02	0.92724E+03	0.10541E+01
22.55	0.878	0.11997E+02	0.10159E+04	0.11257E+01
23.35	0.972	0.11222E+02	0.11105E+04	0.12005E+01
24.14	1.071	0.10527E+02	0.12113E+04	0.12786E+01
24.92	1.176	0.99028E+01	0.13186E+04	0.13600E+01
25.69	1.285	0.93399E+01	0.14326E+04	0.14447E+01
26.45	1.399	0.88315E+01	0.15537E+04	0.15329E+01
27.19	1.518	0.83716E+01	0.16821E+04	0.16247E+01
27.92	1.640	0.79547E+01	0.18181E+04	0.17199E+01
28.63	1.766	0.75762E+01	0.19620E+04	0.18189E+01
29.33	1.895	0.72320E+01	0.21141E+04	0.19215E+01
30.01	2.027	0.69186E+01	0.22747E+04	0.20280E+01
30.68	2.162	0.66330E+01	0.24442E+04	0.21382E+01
31.33	2.298	0.63723E+01	0.26227E+04	0.22524E+01
31.96	2.435	0.61342E+01	0.28107E+04	0.23705E+01
32.58	2.574	0.59165E+01	0.30085E+04	0.24927E+01
33.17	2.712	0.57174E+01	0.32164E+04	0.26189E+01
33.75	2.851	0.55352E+01	0.34347E+04	0.27494E+01
34.31	2.988	0.53695E+01	0.36538E+04	0.28840E+01
34.85	3.124	0.52159E+01	0.39040E+04	0.30230E+01
35.26	3.257	0.50762E+01	0.41557E+04	0.31663E+01

35.86	2.388	0.49485E+01	0.44192E+04	0.33140E+01
36.37	2.516	0.48318E+01	0.46950E+04	0.34662E+01

***** EXCEEDED LIMIT MOMENT*****

VERMONT YANKEE RECIRC LINE CRACK STABILITY

(Discharge, 28 in) STRESSES FROM GE/SAR 22A2615

UN = 4145

Faxial = 20110. Mapplied = 0.34300E+07 Poper = 1479. psi
Saxial = 191. Sbending = 5023. Smem = 7583. psi

PIPE OD = 28.337 THICKNESS = 1.235 Sflow = 70000. psi
ALFA = 2. ELAS MOD =0.256E+08 Jic = 4500. in-lb/in**2

CRACK LENGTH, IN	LEAK AREA IN**2	L/Dh	J IN-LB/IN**2	T
2.43	0.004	0.40427E+03	0.21066E+02	0.11417E+00
3.64	0.008	0.26146E+03	0.33524E+02	0.12781E+00
4.85	0.015	0.18970E+03	0.47454E+02	0.14280E+00
6.06	0.024	0.14647E+03	0.62997E+02	0.15911E+00
7.26	0.037	0.11760E+03	0.80290E+02	0.17677E+00
8.46	0.052	0.96981E+02	0.99473E+02	0.19578E+00
9.66	0.070	0.81556E+02	0.12069E+03	0.21618E+00
10.85	0.092	0.69619E+02	0.14407E+03	0.23799E+00
12.04	0.118	0.60142E+02	0.16978E+03	0.26125E+00
13.22	0.149	0.52464E+02	0.19796E+03	0.28599E+00
14.40	0.185	0.46144E+02	0.22877E+03	0.31224E+00
15.58	0.225	0.40873E+02	0.26236E+03	0.34004E+00
16.74	0.272	0.36429E+02	0.29890E+03	0.36943E+00
17.91	0.324	0.32648E+02	0.33855E+03	0.40044E+00
19.06	0.383	0.29405E+02	0.38148E+03	0.43311E+00
20.21	0.449	0.26604E+02	0.42787E+03	0.46748E+00
21.36	0.522	0.24172E+02	0.47788E+03	0.50359E+00
22.49	0.603	0.22047E+02	0.53171E+03	0.54146E+00
23.62	0.692	0.20183E+02	0.58953E+03	0.58115E+00
24.75	0.789	0.18540E+02	0.65154E+03	0.62268E+00
25.86	0.895	0.17086E+02	0.71792E+03	0.66610E+00
26.97	1.010	0.15795E+02	0.78887E+03	0.71144E+00
28.06	1.133	0.14645E+02	0.86460E+03	0.75873E+00
29.15	1.266	0.13617E+02	0.94531E+03	0.80803E+00
30.23	1.409	0.12695E+02	0.10312E+04	0.85935E+00
31.30	1.560	0.11867E+02	0.11225E+04	0.91274E+00
32.36	1.721	0.11121E+02	0.12194E+04	0.96824E+00
33.40	1.891	0.10447E+02	0.13221E+04	0.10259E+01
34.44	2.072	0.98375E+01	0.14309E+04	0.10857E+01
35.46	2.260	0.92842E+01	0.15459E+04	0.11477E+01
36.48	2.458	0.87812E+01	0.16675E+04	0.12120E+01
37.48	2.665	0.83233E+01	0.17958E+04	0.12786E+01
38.47	2.880	0.79054E+01	0.19310E+04	0.13475E+01
39.44	3.103	0.75236E+01	0.20735E+04	0.14187E+01
40.40	3.334	0.71741E+01	0.22235E+04	0.14924E+01
41.35	3.571	0.68536E+01	0.23812E+04	0.15684E+01
42.28	3.816	0.65595E+01	0.25468E+04	0.16470E+01
43.20	4.067	0.62890E+01	0.27207E+04	0.17280E+01
44.10	4.323	0.60401E+01	0.29030E+04	0.18116E+01
44.99	4.584	0.58106E+01	0.30941E+04	0.18977E+01
45.86	4.850	0.55989E+01	0.32942E+04	0.19865E+01
46.71	5.119	0.54033E+01	0.35036E+04	0.20779E+01
47.55	5.391	0.52225E+01	0.37225E+04	0.21720E+01

[illegible]	5.665	0.50552E+01	[illegible]	0.22688E+01
[illegible]	5.941	0.49003E+01	0.41901E+04	0.23683E+01
49.35	6.218	0.47566E+01	0.44394E+04	0.24706E+01
50.71	6.495	0.46235E+01	0.46994E+04	0.25757E+01

***** EXCEEDED LIMIT MOMENT*****

VERMONT YANKEE RECIRC LINE CRACK STABILITY

(Suction, 28 in) STRESSES FROM GE/SAR 22A2615

UN = 4146

Faxial =	0.	Mapplied =	0.27430E+07	Poper =	1375. psi
Saxial =	0.	Sbending =	4326.	Smem =	7396. psi
PIPE OD =	28.169	THICKNESS =	1.151	Sflow =	70000. psi
ALFA =	2.	ELAS MOD =	0.256E+08	Jic =	4500. in-lb/in**2

CRACK LENGTH, IN	LEAK AREA IN**2	L/Dh	J IN-LB/IN**2	T
2.27	0.003	0.44364E+03	0.16370E+02	0.94784E-01
3.41	0.007	0.28728E+03	0.26021E+02	0.10580E+00
4.54	0.012	0.20873E+03	0.36780E+02	0.11779E+00
5.67	0.019	0.16143E+03	0.48740E+02	0.13074E+00
6.79	0.029	0.12983E+03	0.61993E+02	0.14466E+00
7.92	0.041	0.10725E+03	0.76634E+02	0.15955E+00
9.04	0.055	0.90352E+02	0.92757E+02	0.17544E+00
10.16	0.073	0.77259E+02	0.11046E+03	0.19233E+00
11.27	0.093	0.66850E+02	0.12984E+03	0.21025E+00
12.39	0.117	0.58406E+02	0.15099E+03	0.22922E+00
13.49	0.145	0.51443E+02	0.17402E+03	0.24927E+00
14.60	0.177	0.45625E+02	0.19904E+03	0.27040E+00
15.70	0.213	0.40710E+02	0.22614E+03	0.29265E+00
16.80	0.254	0.36520E+02	0.25544E+03	0.31603E+00
17.89	0.300	0.32918E+02	0.28705E+03	0.34058E+00
18.98	0.352	0.29801E+02	0.32108E+03	0.36630E+00
20.07	0.409	0.27088E+02	0.35764E+03	0.39324E+00
21.14	0.473	0.24712E+02	0.39686E+03	0.42139E+00
22.22	0.543	0.22623F+02	0.43885E+03	0.45080E+00
23.29	0.619	0.20778E+02	0.48373E+03	0.48148E+00
24.35	0.703	0.19142E+02	0.53163E+03	0.51345E+00
25.41	0.794	0.17686E+02	0.58267E+03	0.54675E+00
26.46	0.893	0.16385E+02	0.63698E+03	0.58138E+00
27.51	0.999	0.15220E+02	0.69470E+03	0.61737E+00
28.55	1.113	0.14174E+02	0.75594E+03	0.65475E+00
29.58	1.236	0.13231E+02	0.82085E+03	0.69354E+00
30.61	1.367	0.12380E+02	0.88957E+03	0.73375E+00
31.62	1.506	0.11610E+02	0.96223E+03	0.77541E+00
32.63	1.654	0.10911E+02	0.10390E+04	0.81855E+00
33.64	1.810	0.10276E+02	0.11199E+04	0.86318E+00
34.63	1.975	0.96977E+01	0.12053E+04	0.90933E+00
35.62	2.142	0.91696E+01	0.12951E+04	0.95701E+00
36.60	2.330	0.86867E+01	0.13897E+04	0.10063E+01
37.57	2.520	0.82444E+01	0.14890E+04	0.10571E+01
38.53	2.719	0.78387E+01	0.15933E+04	0.11095E+01
39.48	2.925	0.74658E+01	0.17028E+04	0.11636E+01
40.42	3.139	0.71226E+01	0.18175E+04	0.12193E+01
41.35	3.361	0.68062E+01	0.19377E+04	0.12766E+01
42.28	3.590	0.65142E+01	0.20634E+04	0.13357E+01
43.19	3.826	0.62443E+01	0.21950E+04	0.13964E+01
44.09	4.069	0.59946E+01	0.23325E+04	0.14589E+01
44.95	4.315	0.57631E+01	0.24761E+04	0.15232E+01
45.[illegible]	4.572	0.55464E+01	0.26259E+04	0.15892E+01

46.72	4.833	0.53490E+01	0.27822E+04	0.16570E+01
47.57	[illegible]	0.51636E+01	0.29451E+04	0.17266E+01
48.41	5.369	0.49910E+01	0.31148E+04	0.17980E+01
49.24	5.642	0.48302E+01	0.32915E+04	0.18713E+01
50.06	5.919	0.46802E+01	0.34753E+04	0.19465E+01
50.86	6.200	0.45402E+01	0.36665E+04	0.20236E+01
51.65	6.483	0.44094E+01	0.38652E+04	0.21026E+01
52.42	6.769	0.42871E+01	0.40715E+04	0.21835E+01
53.18	7.055	0.41726E+01	0.42858E+04	0.22664E+01

***** EXCEEDED LIMIT MOMENT*****

ATTACHMENT A

VERMONT YANKEE I&E BULLETIN 83-02 EXAMINATION PROGRAM

ATTACHMENT A

VERMONT YANKEE I&E BULLETIN 83-02 EXAMINATION PROGRAM

UTILIZED DURING THE 1983 AUGMENTED ISI PROGRAM

Ultrasonic Examination Technique

I&E Bulletin 83-02 requires that we demonstrate the effectiveness of the detection capability of the ultrasonic examination technique to be used for examining weld joints in our recirculation system piping. The bulletin also establishes provisions for demonstration tests to be performed at the EPRI-NDE Center in accordance with specific criteria. This includes equipment/procedure similarity, personnel participation, pipe sample size, acceptance criteria, demonstration time limit, and procedures review.

On March 11, 1983, Vermont Yankee and its contractor, Magnaflux, successfully passed the demonstration. A copy of the form used to document this demonstration is provided as Figure A-1.

The examination methodology made use of dual element, 1.5 MHz, 45^{o} and 60^{o} shear wave search units coupled with pulse-echo ultrasonic instrumentation. The equipment was set up in a master-slave configuration, allowing maximum use of qualified examiners with minimum radiation exposure.

Detection of IGSCC was based on signal characteristics and location with respect to the weld root geometry.

Sizing was performed on indications in 12", 22", and 28" pipe. Although sizing was performed on the 12" pipe, all 12" welds with flaw indications, regardless of size, were overlayed.

The primary method utilized for sizing ultrasonic indications of IGSCC at Vermont Yankee was the "Amplitude Drop Method" using dual element 1.5 MHz transducers having a nominal shear wave beam angle of 45^{o}. The through-wall dimension of the indication is compared to that of a 10% notch in a basic calibration block.

The sweep changes corresponding to the maximum amplitude from the 10% notch and the leading and trailing ray half maximum amplitudes (6 dB drop) are recorded during the evaluation calibration. During evaluation scanning, the sweep changes are recorded for the noted indications. The recorded sweep readings are then plotted on full size sketches of the weld joint section as determined by actual field measurement. A linear relationship is maintained in comparison to the 10% notch. Through-wall dimensions are calculated to the next higher full percent and reported for engineering evaluation. No beam spread correction was applied to the depth sizing.

Linear extent was plotted similarly. Linear extent was considered at an end point when the amplitude of the signal dropped to 50% of the average maximum signal for a given indication when scanned in a manner intended to determine linear extent. Beam spread correction was not used.

In order to determine the reliability of the "Amplitude Drop Technique" for the sizing of IGSCC flaws, two investigations were performed.

Initially, Vermont Yankee assessed sizing capability by evaluating indications on a cracked specimen of large diameter Nine Mile Point-1 (NMP-1) pipe. Three teams measured the through-wall dimension of specified flaws. These measurements were compared to the through-wall dimension of a crack which was exposed on the edge of the block. The examiners sized the flaw between 10 and 15%. Physical measurement after liquid penetrant exam indicated a crack depth at that location of 15% through-wall.

Additional confirmation of sizing accuracy was felt to be necessary; and, as a result, two areas of the same NMP-1 specimen were selected and sized by the examiner responsible for a large portion of ultrasonic examinations at Vermont Yankee.

Following ultrasonic flaw sizing, two areas of the circumferential weld joint 1D-SW-19-4 (MP-01 specimen), were sectioned, liquid penetrant examined and dimensioned for through-wall dimension. Selection of the areas to be sectioned was based upon indication location in an effort to minimize impact on the sample. These were not considered as maximum flaws and are instead average flaws. The results of this effort are tabulated as follows:

	Destructive Testing		Ultrasonic Measurement	
Indication No.	Measured	% TWD	Measured	% Error
1	.170	12%	.227	+25%
2	.150	12%	.170	+12%

NRC IE BULLETIN 83-02
Demonstration of UT Performance Capability
EPRI NDE Center
Charlotte, NC

Demonstration Results

Date: ____________________ Procedure No.: ____________________

Utility: ______________________________

ISI Contractor: ______________________________

NRC Region: ______________________________

Demonstration Team Members and Levels:

1. ______________________________
2. ______________________________
3. ______________________________
4. ______________________________
5. ______________________________
6. ______________________________

Results: Acceptable ( ) Unacceptable ( ) Pending ( )

Basis for Failure: Crack Detection ( ) False Calls ( )

Comments: ______________________________

NRC Representative

____
(Signature)

Utility Representative

____
(Signature)

cc: NDE Center
NRC IE

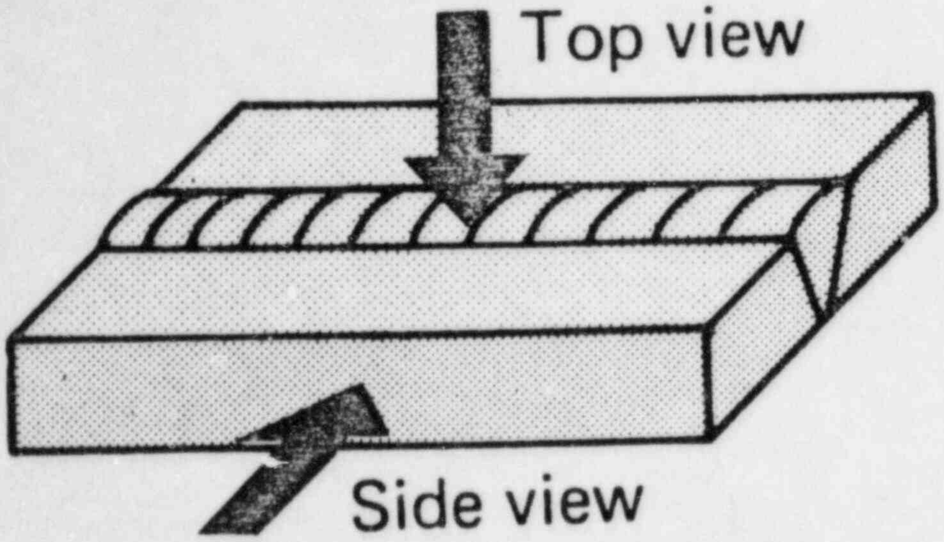
FIGURE A-1

ATTACHMENT B

PROJECTION IMAGE SCANNING TECHNIQUE INFORMATION

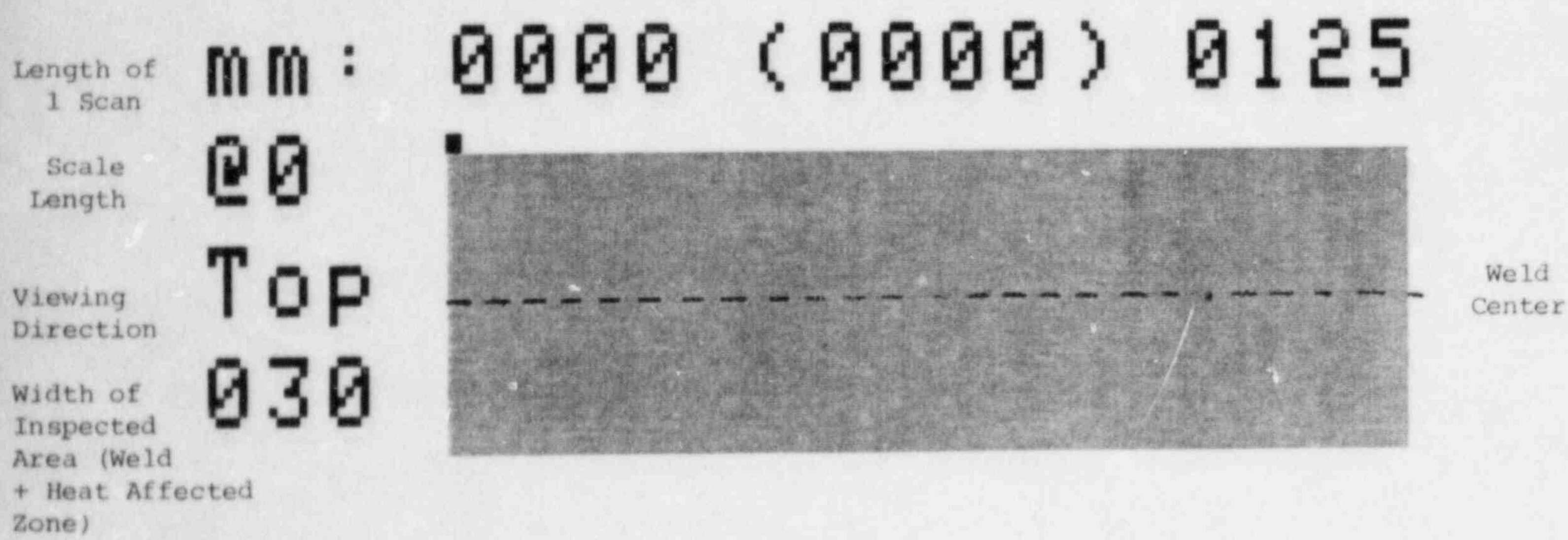
P-Scan Principle

In the P-Scan technique (Projection image SCANning technique), echoes from weld defects are recorded together with their corresponding positions. Defect positions are then visualized on two projection planes: One plane parallel to the surface and another normal to the surface, parallel to the weld. In other words, defects appear as seen from a Top View and Side View (see illustration below). By using two projection planes a complete three-dimensional location of weld defects is obtained.

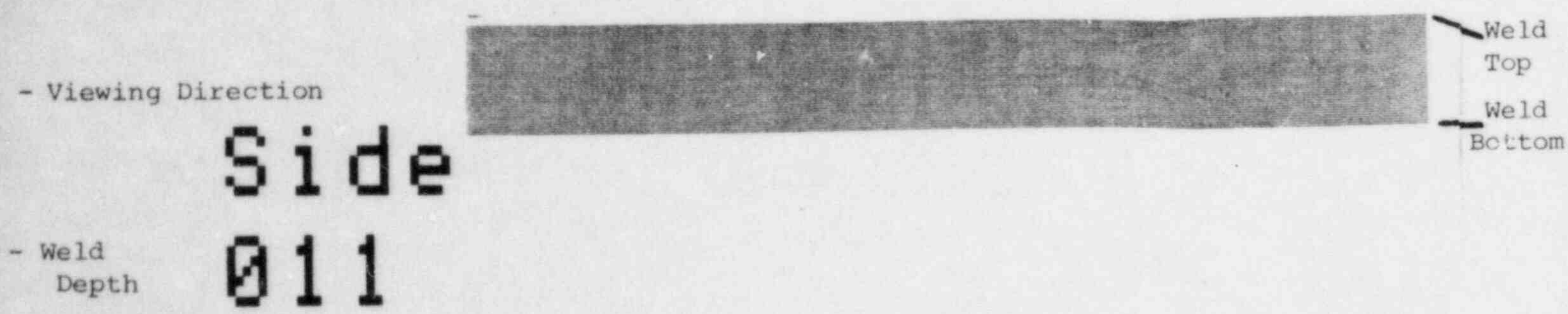


The P-Scan display for weld inspection can be divided into 3 sections:

(1) Top View -

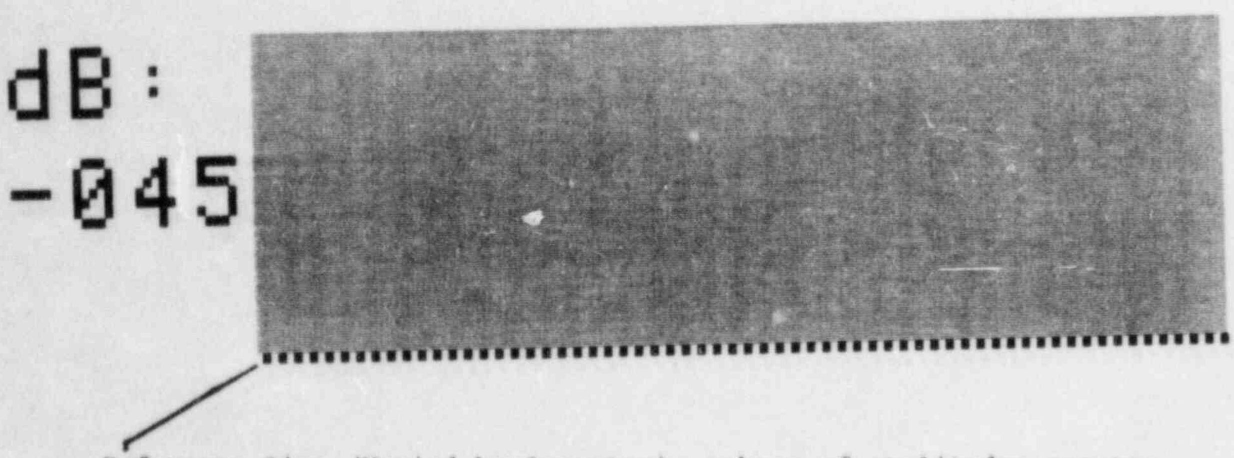


(2) Side View -



(3) Echo Amplitude -

Indicates amplitude of echoes received, scaled in dB, for comparison with defects shown.

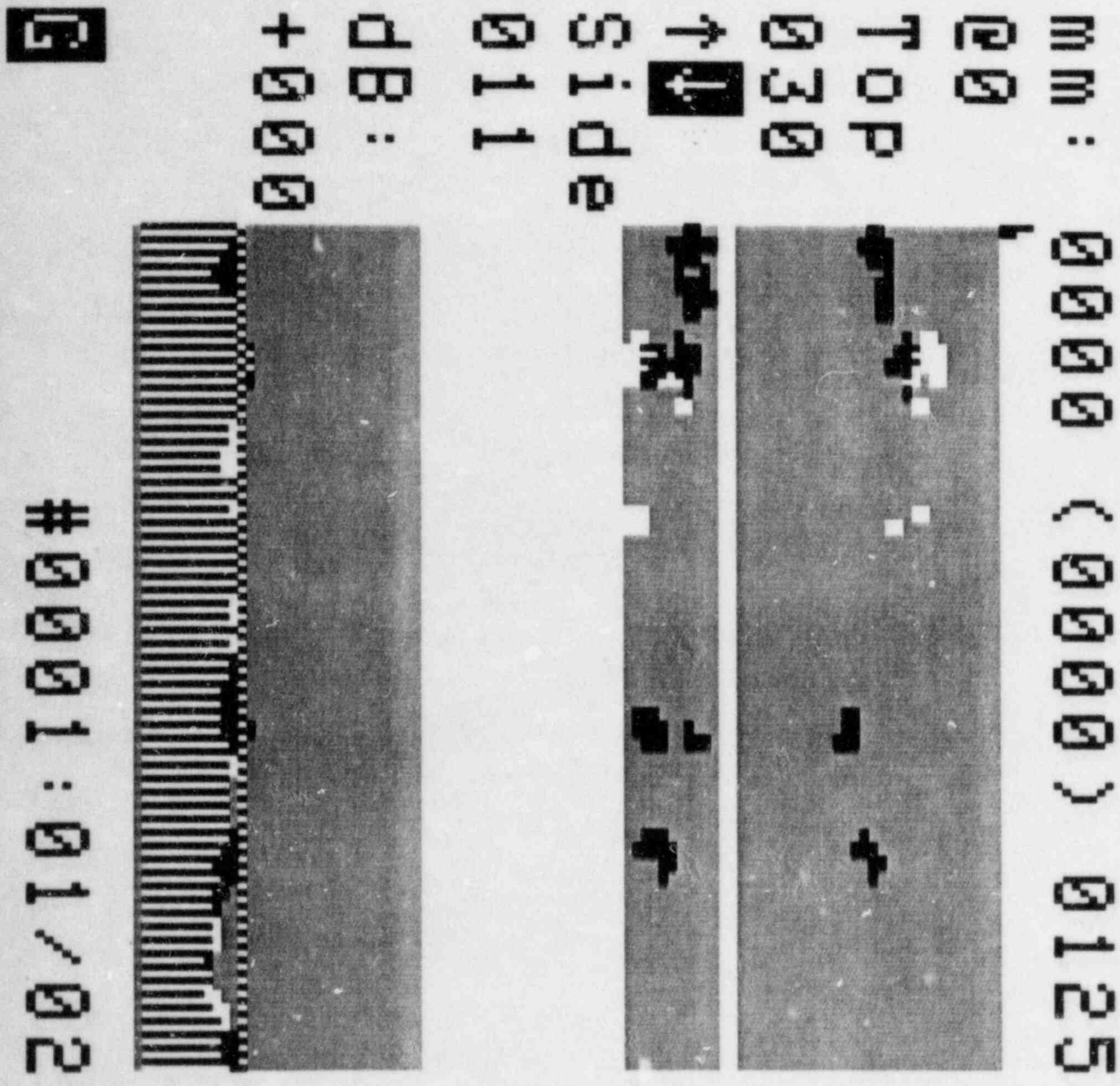


Reference Line (Varied by Operator), echoes of amplitudes greater than reference are shown on top and side views.

Figure 1 shows the complete P-Scan image with weld inspection data.

COMPLETE P-SCAN IMAGE

WITH WELD INSPECTION DATA

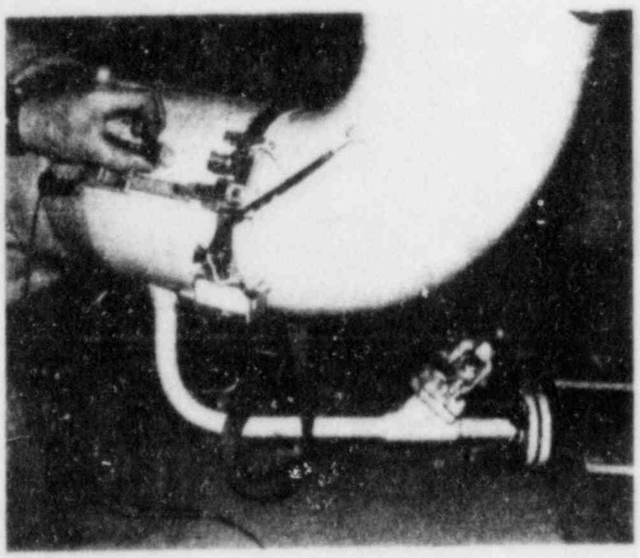


A recent addition to the P-Scan System used at Vermont Yankee, includes the ability to evaluate the end view as well as the top, side, and amplitude displays. This view imposes the information displayed by the top and side views at any given cross section of the base material and weld nugget, thus aiding the examiner with additional information as to the development and nature of an indications.

The P-Scan System is sensitive to the input parameters entered at the start of examination. Extensive pre-exam reviews of construction conditions are necessary to assure correct parameters are established. Additional assurance are achieved by measuring O.D. profiles and thickness gauging of the examination area. The qualified examiners are also capable of recognizing the effects of incorrect parameters and adjustments or re-examination may be necessitated.

P-Scan MWS-2 Scanner

The MWS-2 scanner provide a compact, reliable means of obtaining all necessary positional information and served as the only scanner used with P-Scan. This scanner was ineffective only in extremely tight configurations or difficult geometries.



Miniature manual scanner for the inspection of pipe welds, where accessibility is at minimum.

The scanner is capable of covering 125 mm per scan increment employing a circumferential scan raster and index perpendicular to the weld for complete, effective coverage of the weld volume.

ATTACHMENT C

IMPROVEMENTS IN FLAW SIZING CAPABILITY

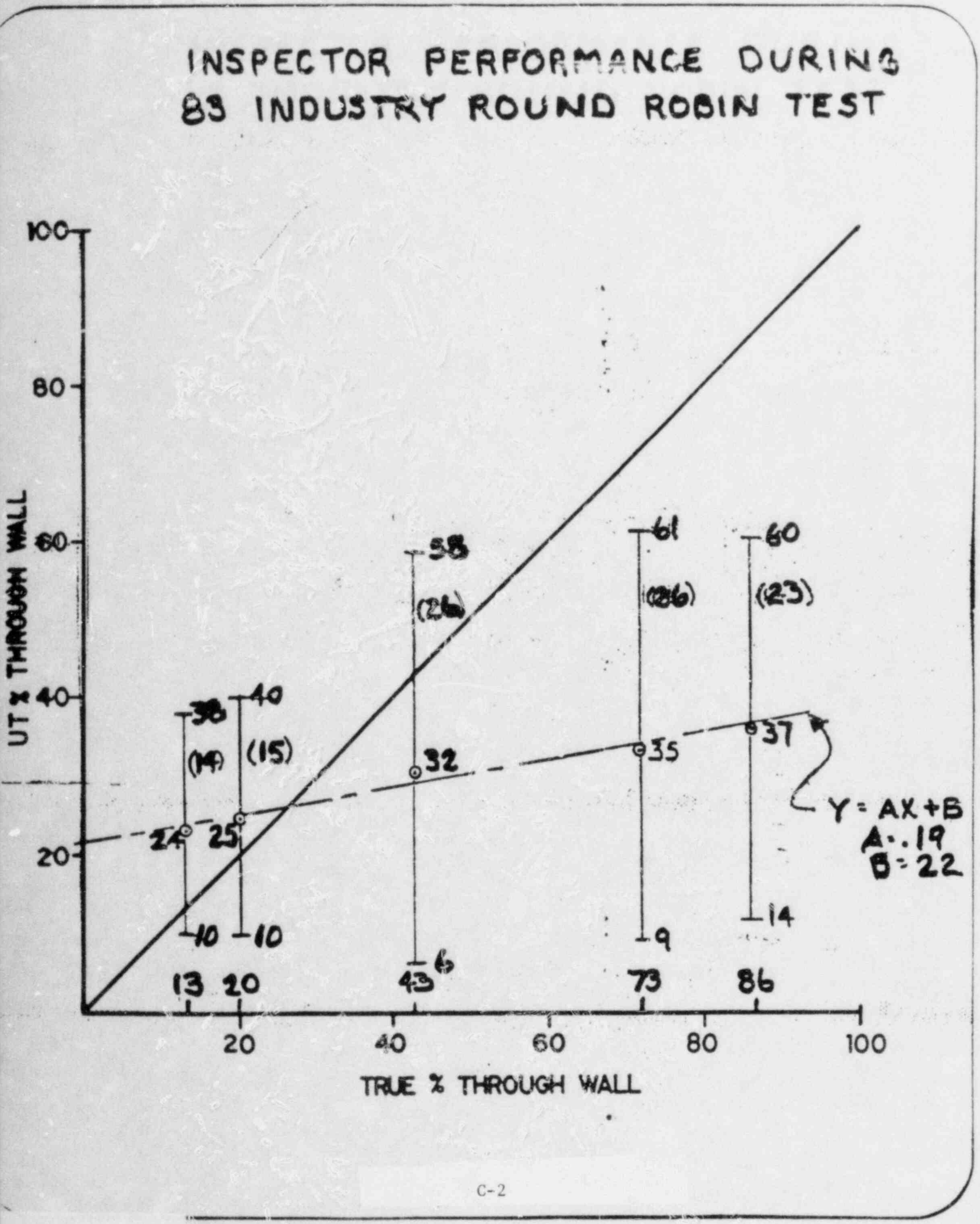
IMPROVEMENT IN FLAW SIZING CAPABILITY

Page C-2 represents the results of the original flaw sizing round robin held at the NDEC on August 4, 1983. This chart indicates the need for corrective action.

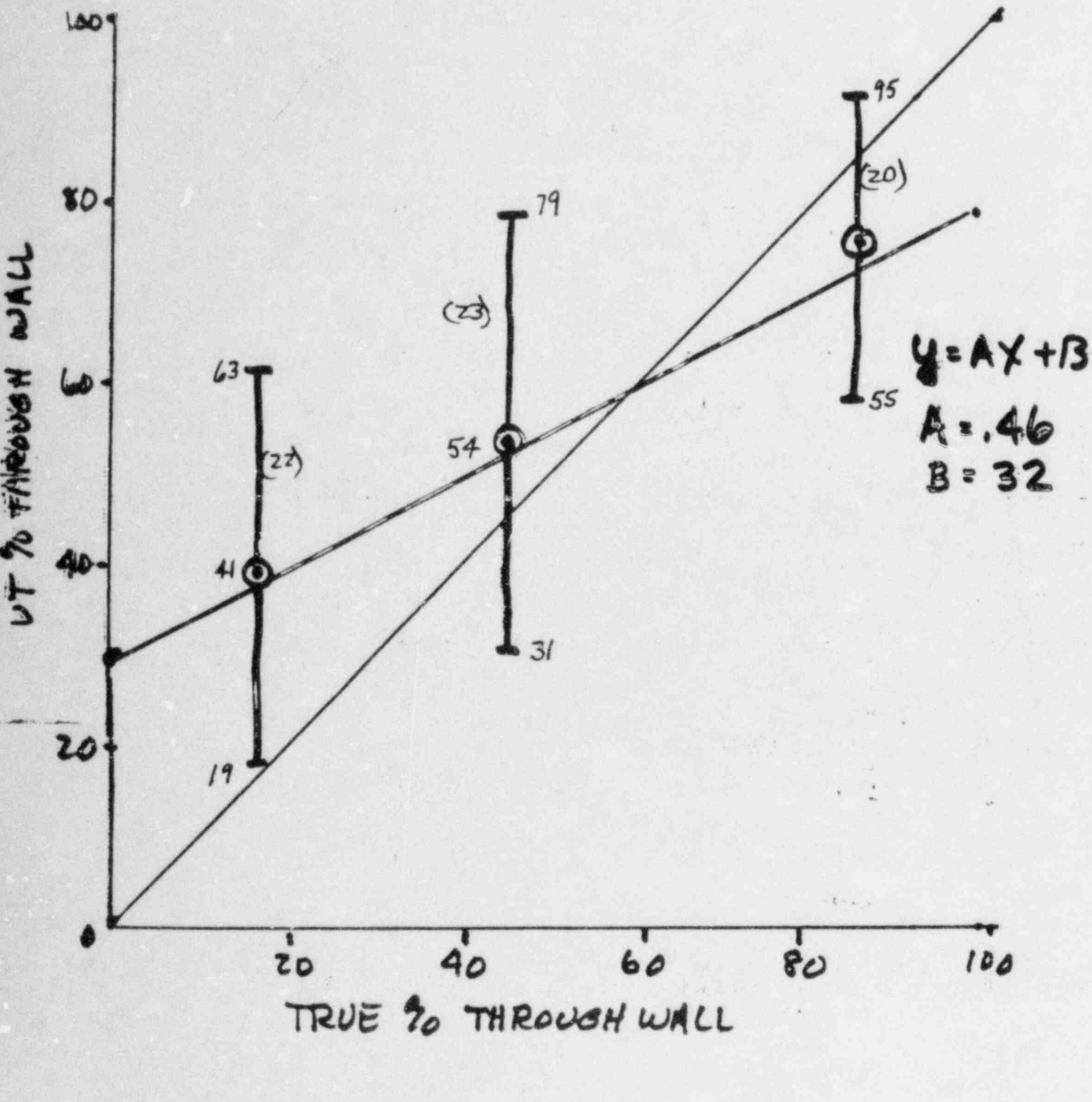
Page C-3 represents the improvement of flaw sizing ability after the first four workshops on flaw sizing at the NDEC during the period April/June 1984.

Page C-4 represents a sub-set of flaw sizing examiners which met the then proposed acceptance criteria for flaw sizing.

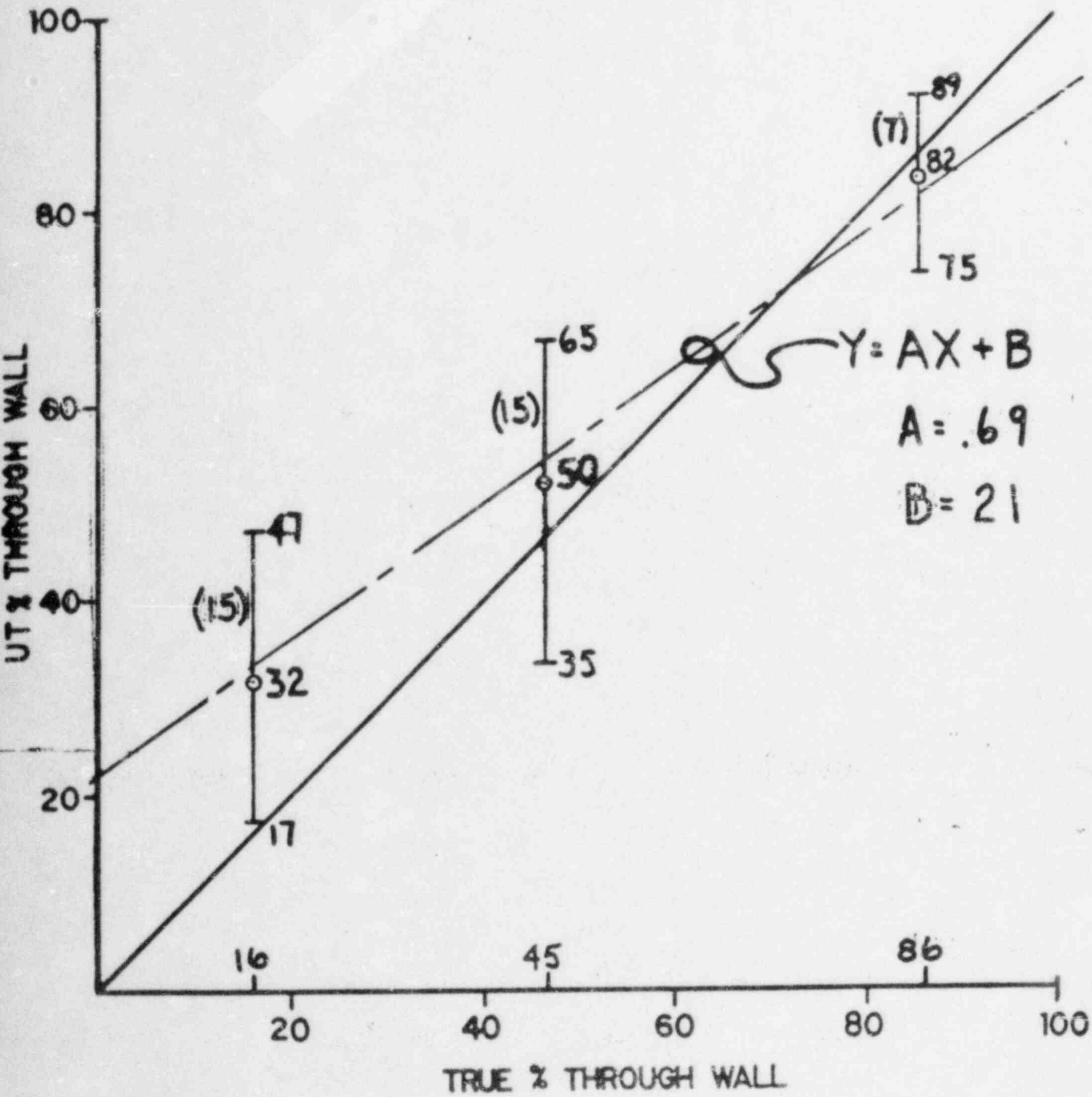
O.


INSPECTOR PERFORMANCE DURING
83 INDUSTRY ROUND ROBIN TEST
UT % THROUGH WALL
TRUE % THROUGH WALL
100
80
60
40
20
20
40
60
80
100
13
20
43
73
86
38
(14)
24
10
40
(15)
25
10
58
(26)
32
6
61
(36)
35
9
60
(23)
37
14
Y = AX + B
A = .19
B = 22

PERFORMANCE OF 48 CLASS MEMBERS



PERFORMANCE OF 16 INSPECTOR SUBSET WHO PASSED PROPOSED SIZING CRITERIA



ATTACHMENT D

VERMONT YANKEE REACTOR COOLANT LEAKAGE LIMITS

ATTACHMENT D

VERMONT YANKEE REACTOR COOLANT LEAKAGE LIMITS

COOLANT LEAKAGE

1. During power operation, Reactor Coolant System leakage into the primary containment shall be limited to:

   a. 5 GPM unidentified leakage when averaged over the previous 24-hour period; and

   b. 20 GPM identified leakage when averaged over the previous 24-hour period.

2. Any time the reactor is in the run mode, Reactor Coolant System leakage into the primary containment from unidentified sources shall be limited to:

   a. 2 GPM increase in unidentified leakage within the previous 24-hour period (see Note 1).

3. If the requirements of Item 1 cannot be met, initiate action as follows:

   a. With any Reactor Coolant System leakage greater than any one of the limits specified in Item 1.a or 1.b reduce the leakage rate to within the limits or be in at least hot shutdown in 12 hours and in cold shutdown in the next 24 hours.

4. If the requirements of Item 2 cannot be met, initiate action as follows:

   a. With any increase in unidentified leakage of greater than or equal to 2 GPM, averaged over the previous 24-hour period, identify the source of leakage or be in at least hot shutdown in 12 hours and in cold shutdown in the next 24 hours.

5. Both the drywell sump and air sampling systems shall be operable during power operation. From and after the date that one of theses systems is made or found inoperable for any reason, reactor operation is permissible only during the succeeding 7 days.

6. If the requirements of Item 5 cannot be met, an orderly shutdown shall be initiated and the reactor brought to a cold shutdown condition within 24 hours.

NOTE 1: During the first 24 hours in the run mode following startup, the limits of Item 2 may be waived provided the requirements of Item 1 are met.

COOLANT LEAKAGE (Surveillance)

Reactor Coolant System leakage shall be demonstrated to be within the limits of Items 1 and 2 by checking and logging the leakage collected in the primary containment floor and equipment sumps at least once per 4 hours. In addition, the primary containment atmosphere activity shall be checked and logged at least once per 8 hours.

TABLE I

VERMONT YANKEE WELD JOINT INSPECTION MATRIX

1983 - 1984

TABLE 1

VERMONT YANKEE

WELD INSPECTION

MATRIX

Date 7/30

12 INCH-REPAIRED

WELD #	83 INSP	FLAW	84 INSP	FLAW
12-24	1	1	1	
12-32	1	1	1	
12-29	1	1	1	
12-54	1	1	1	
12-51	1	1	1	
12-18	1	1	1	
12-35	1	1	1	
12-33	1	1	1	
12-30	1	1	1	
12-16	1	1	1	
12-53	1	1	1	
12-36	1	1	1	
12-34	1	1		
12-25	1	1		
12-42	1	1	1	
12-45	1	1	1	
12-50	1	1	1	
12-20	1	1	1	
12-23	1	1	1	
12-40	1	1		
12-31	1	1		
12-52	1	1		
TOTALS	22	22	17	0

TABLE 1

12 INCH - UNREPAIRED

Date 7/30

WELD #	83 INSP	FLAW	84 INSP	FLAW
12-54A	1		1	
12-51A	1		1	
12-18A	1			
12-21A	1			
12-40A	1			
12-43A	1			
12-44	1		1	
12-41	1		1	
12-21	1			
12-24A	1			
12-31A	1			
12-19	1			
12-28A	1			
12-34A	1			
12-28	1			
12-43	1			
12-22	1			
12-55	1			
TOTALS	18	0	4	0

Date 7/30

20 INCH

WELD #	83 INSP	FLAW	84 INSP	FLAW
20-ARHR32-1			1	
20-ARHR32-2			1	
20-ARHR32-F-1			1	
20-ARHR32-5			1	
20-ARHR32-4	1		1	1
20-ARHR32-6			1	
20-ARHR32-7			1	
TOTALS	1	0	7	1

TABLE 1

Date 7/30

22 INCH

WELD #	83 INSP	FLAW	84 INSP	FLAW
22-16B	1	1	1	1
22-30B	1	1	1	1
22-23A	1		1	
22-30A	1		1	
22-36B	1	1	1	
22-46	1			
22-16A			1	1
22-47			1	
22-48			1	
22-36A			1	
22-49			1	1
22-23B			1	1
TOTALS	6	3	11	5

TABLE 1

Date 7/30

24 INCH

WELD #	83 INSP	FLAW	84 INSP	FLAW
24-BRHR31-1	1	1	1	
24-CRHR30-1			1	
24-CRHR30-3			1	
24-CRHR30-9			1	
24-CRHR30-10			1	
TOTALS	1	1	5	0

TABLE 1

Date 7/30

28 INCH

WELD #	83 INSP	FLAW	84 INSP	FLAW
28-38	1			
28-2	1	1	1	1
28-9A	1	1	1	1
28-65A	1	1	1	1
28-1A	1	1	1	1
28-9B	1		1	
28-64	1	1	1	
28-15A	1	1	1	
28-17	1		1	
28-58	1	1	1	
28-59	1	1	1	1
28-66	1			
28-61			1	1
28-15			1	
28-15B			1	1
28-27			1	1
28-26A			1	1
28-17A			1	
28-15C			1	
28-4			1	
28-5A			1	
28-17B			1	1
28-5			1	
28-6			1	1
28-8			1	
28-56			1	
28-26			1	
TOTALS	12	8	25	11

TABLE 1

Date 7/30

SUMMARY

PIPE SIZE	83 INSP	FLAW	84 INSP	FLAW
12 INCH-REPAIRED	22	22	17	
12 INCH-UNREPAIRED	18		4	
20 INCH	1		7	1
22 INCH	6	3	11	5
24 INCH	1	1	5	
28 INCH	12	8	25	11
TOTALS	60	34	69	17

TABLE II

DETAILS OF UT INDICATIONS AND WELD JOINT STRESSES

TABLE II

Details Of UT Indications And Weld Joint Stresses

Pipe Size	Weld ISI No.	(P+DW+OBE+Th) / S_m (4)	Orient A=Axial C=Circumferential	a/T (2) (%)	a/T (3) (%)	L/circ* (1) (in)	L/2πR
28"	1A	0.56	C	22	22	5.0	.057
	2	0.47	C	15	15	2.0	.023
	15B	0.64	C	18	18	3.0	.034
	26A	0.50	C	15	20	19.0	.216
	27	0.45	C	19	20	4.5	.051
	61	0.44	C	20	20	24.0	.273
	59	0.43	C	20	20	18.0	.148
	65A	0.49	C	23	25	15.0	.160
	9A	0.43	C	20	22	5.0	.057
	17B	0.43	C	20	20	7.0	.060
	6	0.48	C	17	19	3.0	.034
22"	16A	0.67	C	20	20	12.0	.101
	16B	0.71	C	12	12	0.8	.012
	30B	0.34	C	20	25	20.0	.300
	49	0.58	C	22	23	1.5	.022
	23B	0.34	C	27	27	6.0	.087
20"	RHR-32-4		A		>10	NA	NA

(1) Total length of all circumferential indications at the weld.
(2) Weighted Average Dept of all flaws.
(3) Maximum Dept of any one flaw.
(4) Allowable Stress at 550°F.

TABLE III

SUMMARY OF PREDICTED GROWTH DURING THE NEXT CYCLE OF OPERATION

TABLE III

Summary of Predicted Crack Growth
For A 14-Month Operating Period

Pipe Size	Weld ISI No.	Circumferential Flaw Size: Start Depth a/t(%)	Circumferential Flaw Size: Start Length (in)	Allowable Flaw Size: Start Of Cycle Depth a/t	Allowable Flaw Size: End Of Cycle Depth a/t
28"	1A	22	5.0	0.42	0.5
	2	15	2.0	0.40	0.5
	15B	18	3.0	0.43	0.5
	26A	15	19.0	0.39	0.5
	27	19	4.5	0.42	0.5
	61	20	24.0	0.47	0.5
	59	20	18.0	0.47	0.5
	65A	23	15.0	0.45	0.5
	9A	20	5.0	0.44	0.5
	17B	20	7.0	0.44	0.5
	6	17	3.0	0.44	0.5
22"	16A	20	12.0	0.43	0.5
	16B	12	0.8	0.35	0.5
	30B	20	20.0	0.47	0.5
	49	22	1.5	0.47	0.5
	23B	27	6.0	0.47	0.5

TABLE IV

DISPOSITION OF UT INDICATIONS

TABLE IV

Disposition of UT Indications

Pipe Size	Weld ISI No.	Disposition: Accept For 14-Mo. By Analysis (X)	Disposition: Weld Overlay Repair
28	1A	X	
	2	X	
	15B	X	
	26A	X	
	27	X	
	61	X	
	59	X	
	65A	X	
	9A	X	
	17B	X	
	6	X	
22	16A	X	
	16B	X	
	30B	X	
	49	X	
	23B	X	
20	RHR-32-4		X*

*Mini-Overlay on axial indication.

TABLE V

COMPARISON OF 1983 TO 1984 REINSPECTION RESULTS (LARGE BORE PIPING)

TABLE V

Large Diameter Piping
Comparison of 1983 to 1984 Inspection Results

Pipe Size	Weld ISI No.	1983 L(1)	1983 A/T(2) (% TWD)	1984 L(1)	1984 A/T(2) (% TWD)
28"	64	4"	10-15	No Flaw	N/A
	1A	38"	15	5"	22
	2	360° (intermittent)	10	2"	15
	9A	360° (intermittent)	10	5"	20
	65A	9.5"	15	15"	23
	15A	11"	15	No Flaw	N/A
	58	17.5"	15	No Flaw	N/A
	59	3"	15	13"	20
22"	16B	4.5"	10	0.8"	12
	36B	12.0"	10	No Flaw	N/A
	30B	4.5"	15	24.0"	20
24"	RHR-31 Weld 1	4.0"	7	No Flaw	N/A

(1) L - Total length of all circumferential indications.
(2) A/T - Flaw depth as a percentage of wall thickness (based on weighted average depths of all flaws).

TABLE VI

VERMONT YANKEE STRESS INFORMATION

TABLE VI

Vermont Yankee Stress Information

Weld Joint Number	Actual Wall Thickness (inches)	Pressure (psi)	Deadweight (psi)	OBE (psi)	Thermal (psi)	Overlay Shrinkage Stress (OS) (psi)	$\frac{P+DW+OBE+TH+OS}{S_m}$
1A	1.2	5954	1177	155	2122	0	.557
2	1.2	5954	635	371	917	0	.466
15B	1.18	6053	464	2164	1887	200	.637
26A	1.15	6210	637	636	958	0	.499
27	1.15	6210	475	182	735	0	.450
61	1.25	5711	83	1158	325	150	.439
59	1.34	5330	54	1221	389	200	.426
65A	1.29	5534	461	1149	537	700	.484
9A	1.29	5534	259	476	393	600	.430
17B	1.27	6023	196	227	537	250	.428
6	1.26	6068	173	1320	435	200	.485
16A	1.05	5614	1417	758	2303	1190	.668
16B	1.03	5718	1422	758	2909	1190	.710
30B	1.04	5666	N/A	N/A	N/A	0	.340
23B	1.09	5408	N/A	N/A	N/A	0	.340
49	1.09	5408	546	230	1136	2400	.575

TABLE VII

COMPARISON OF 1983 TO 1984 UT PROGRAM

TABLE VII

Comparison of 1983 to 1984 UT Program

	1983 Details	1984 Details
Equipment	P710B	P-Scan ALN 4060 USIP 11 USL 30 (Series) P710
Probes	45°S Dual 1.5 MHz 60°S Dual 1.5 MHz	45°S 1.5 MHz 52°S 1.5 MHz 45°S 2.25 MHz 52°S 2.25 MHz RTD 70° RL 4 MHz RTD 70° RL 2 MHz WSY 70-2 WSY 70-4 52° 5 MHz SLIC 40
Calibration	10% NOTCH - 6 Db	10% NOTCH - 64 Db
Scan	-10 Db	Unlimited
Positional Recording	Manual	Auto - MSW-2 Manual
Plotting	Manual	P-Scan SHARP 600 Manual
Personnel	1 Level III 4 Level II Approx. 30 Level I	3 Level III 8 Level II Approx. 25 Level I
Sizing Qualification	None	EPRI Program
Training	In-House	EPRI
Qualifying Exam	83-02 Team	EPRI Individual
Sizing	Db Drop	HALT PATT SPOT MOST Full Vee

TABLE VIII

1983 FLAW SUMMARY

TABLE VIII

1983 Flaw Summary

Weld Number	Size	Configuration	Exam Restrictions	Cardinal Point?	Flaw Length	Flaw Depth
16B	22"	P/CRS	Pipe Side Only	No	4.5"	10%
30B	22"	P/EC		No	3.0"	15%
					1.0"	7-1/2%
					.7"	<10%
					1.0"	<10%
					1.0"	15%
					1.0"	15%
					3.6"	15%
					1.0"	10%
					1.5"	≤15%
					3.0"	---
2	28"	P/EL	No	No	Int. 360	≤10%
9A	28"	P/EL	No	No	Int. 360	10%
58	28"	/MP	Elbow Side Only	Yes	1.5"	7%
					5.0"	7%
					.25"	7%
					17.5"	15%
					7.0"	15%
64	28"	P/EL	No	No	1.5"	<15%
					1.5"	<15%
					2.75"	<15%
					2.0"	<15%
					4.0"	<15%
					4.0"	<15%
					2.0"	<15%
36B	22"	P/CRS	Pipe Side Only	No	14.3"	10%
65A	28"	P/T	Pipe Side Only	No	9.5"	15%
59	28"	PMP/P	Pipe Side Only	Yes	3"	13%
					33"	9%
1A	28"	P/EL	No	No	10"	15%
					38"	15%
15A	28"	P/T	Pipe Side Only	Yes	5"	15%
					7"	15%
					11"	15%

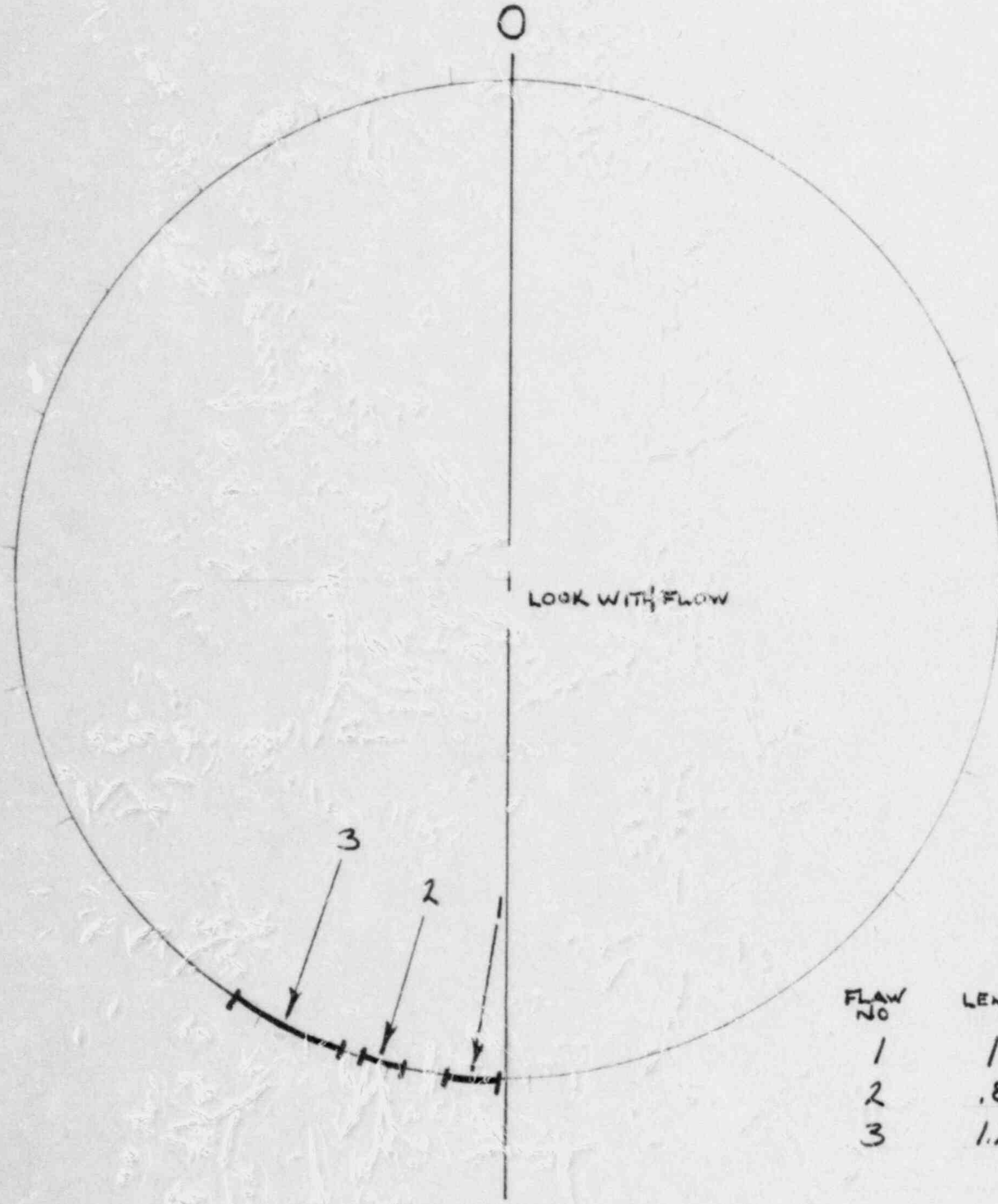
TABLE IX

1984 FLAW SUMMARY

VY 1984 FLAW SUMMARY

WELD NO. 1A

VIEW ELBOW SIDE

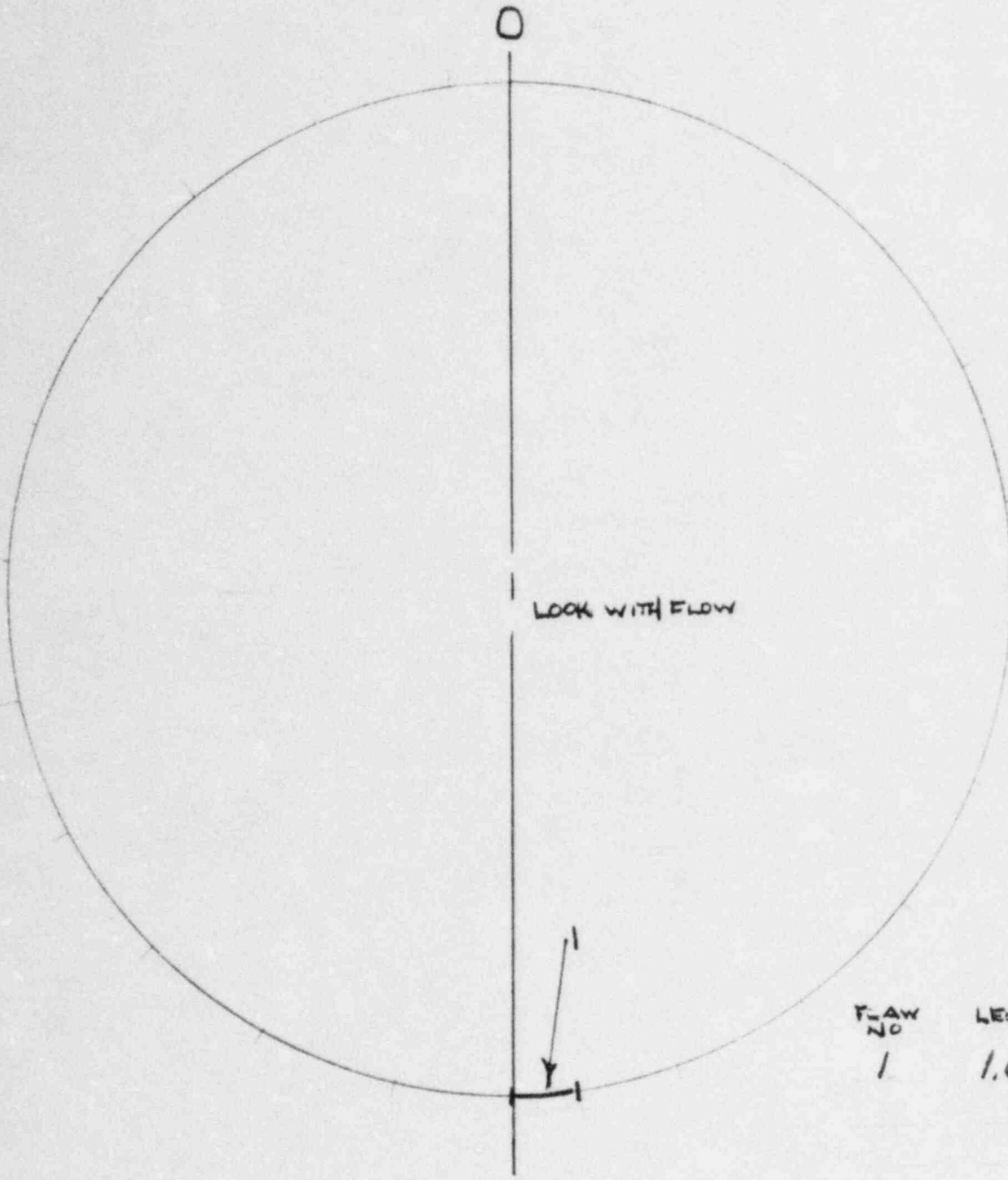


FLAW NO	LENGTH	% THRU-WALL
1	1	22
2	.8	
3	1.2	20

VY 1984 FLAW SUMMARY

WELD NO. 2

VIEW PIPE

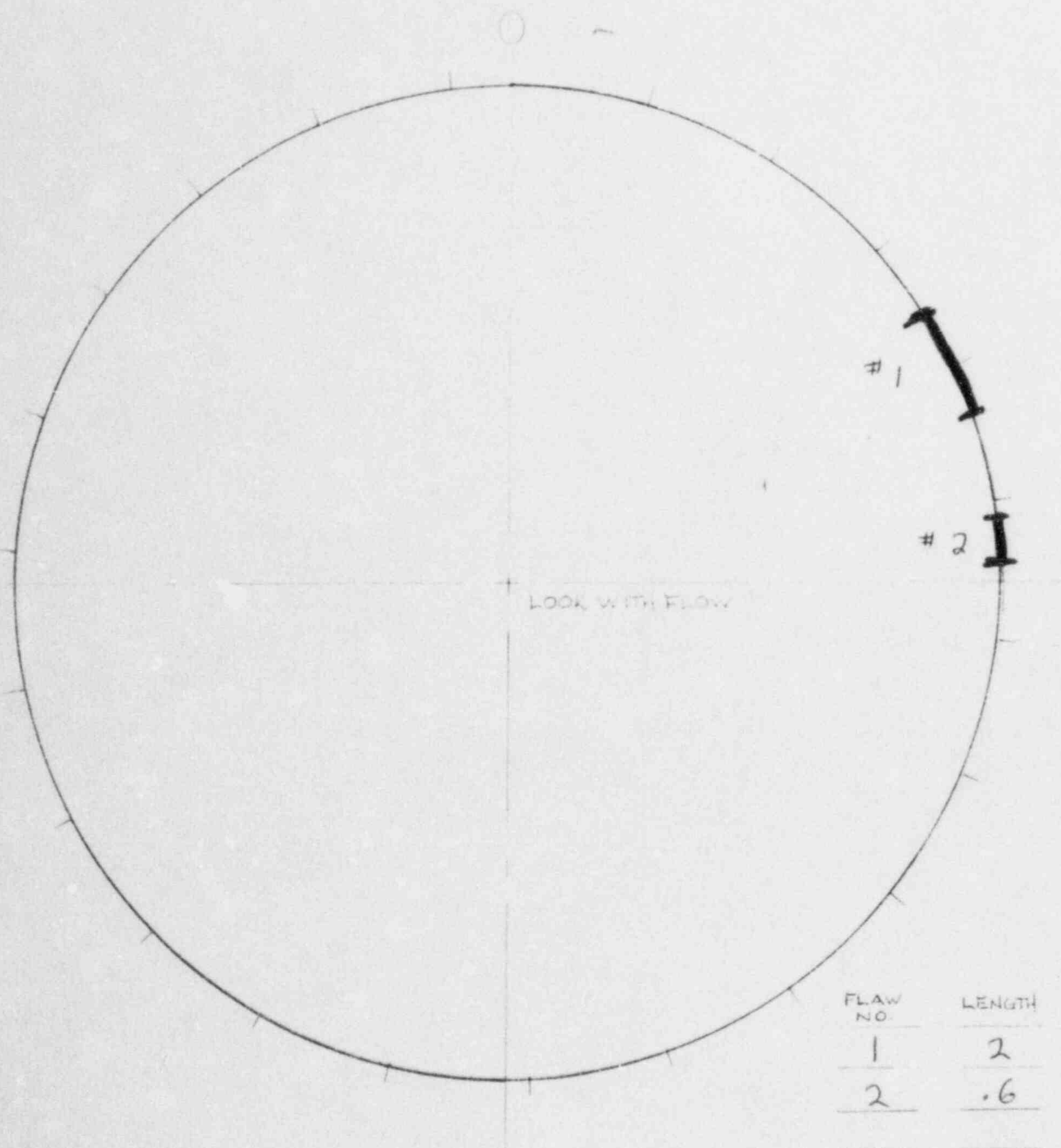


FLAW NO	LENGTH	% THRU-WALL
1	1.6	15

VY 1984 FLAW SUMMARY

6

Pipe

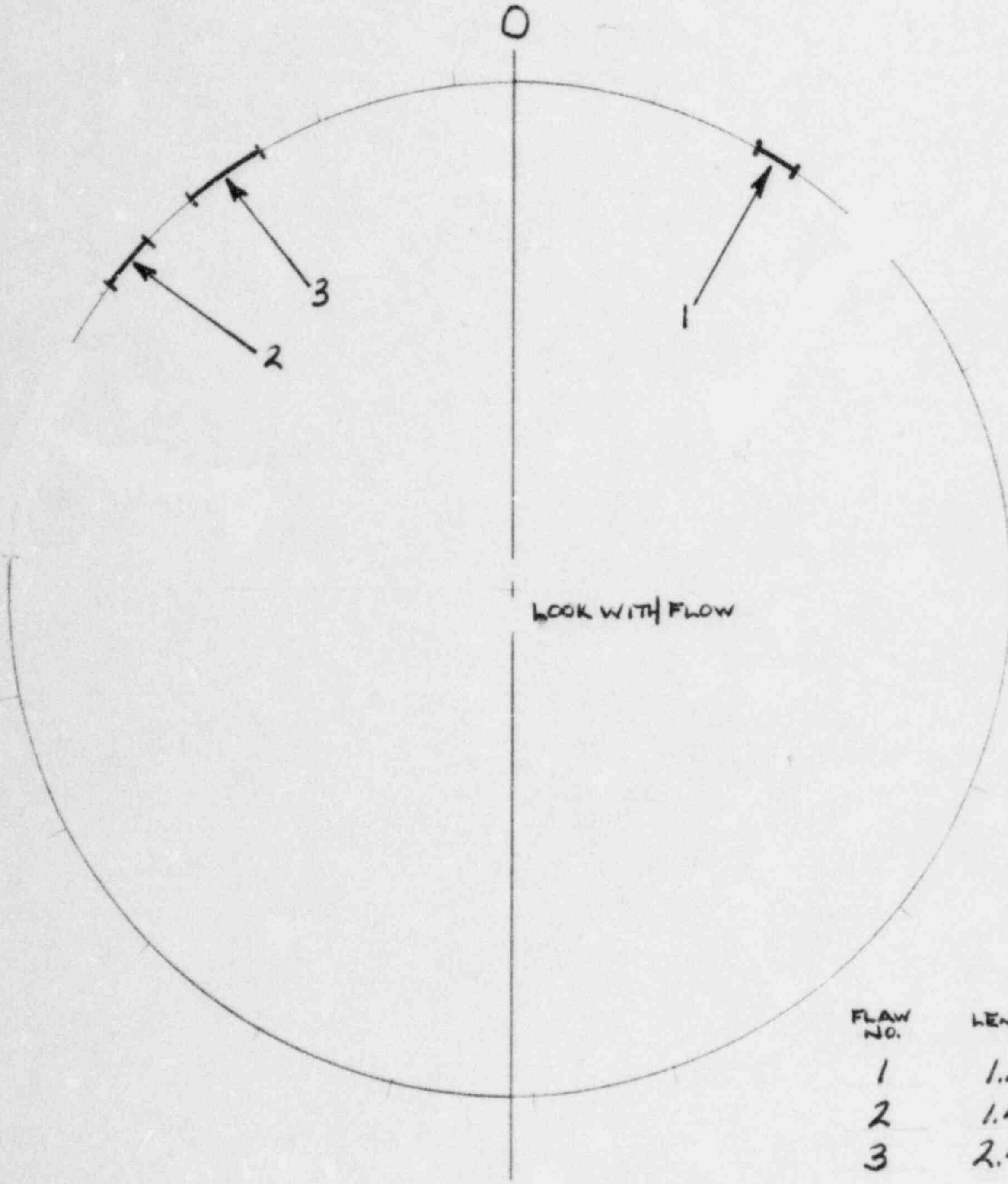


FLAW NO.	LENGTH	% THRU-WALL
1	2	19%
2	.6	19%

VY 1984 FLAW SUMMARY

9A

ELBOW SIDE

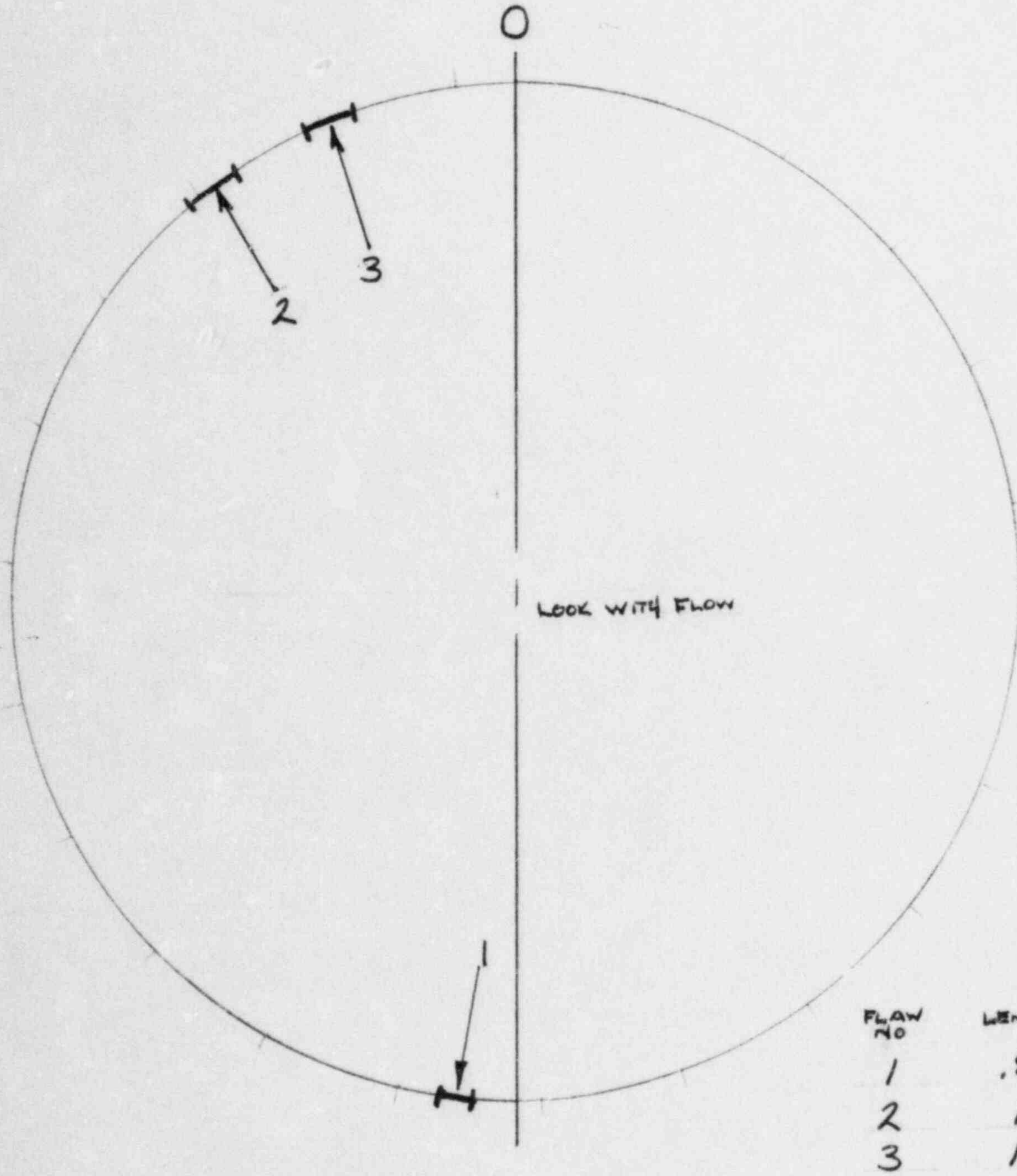


FLAW NO.	LENGTH	% THRU-WALL
1	1.2	18
2	1.4	
3	2.4	16

VY 1984 FLAW SUMMARY

WELD NO 15 B

VIEW PIPE

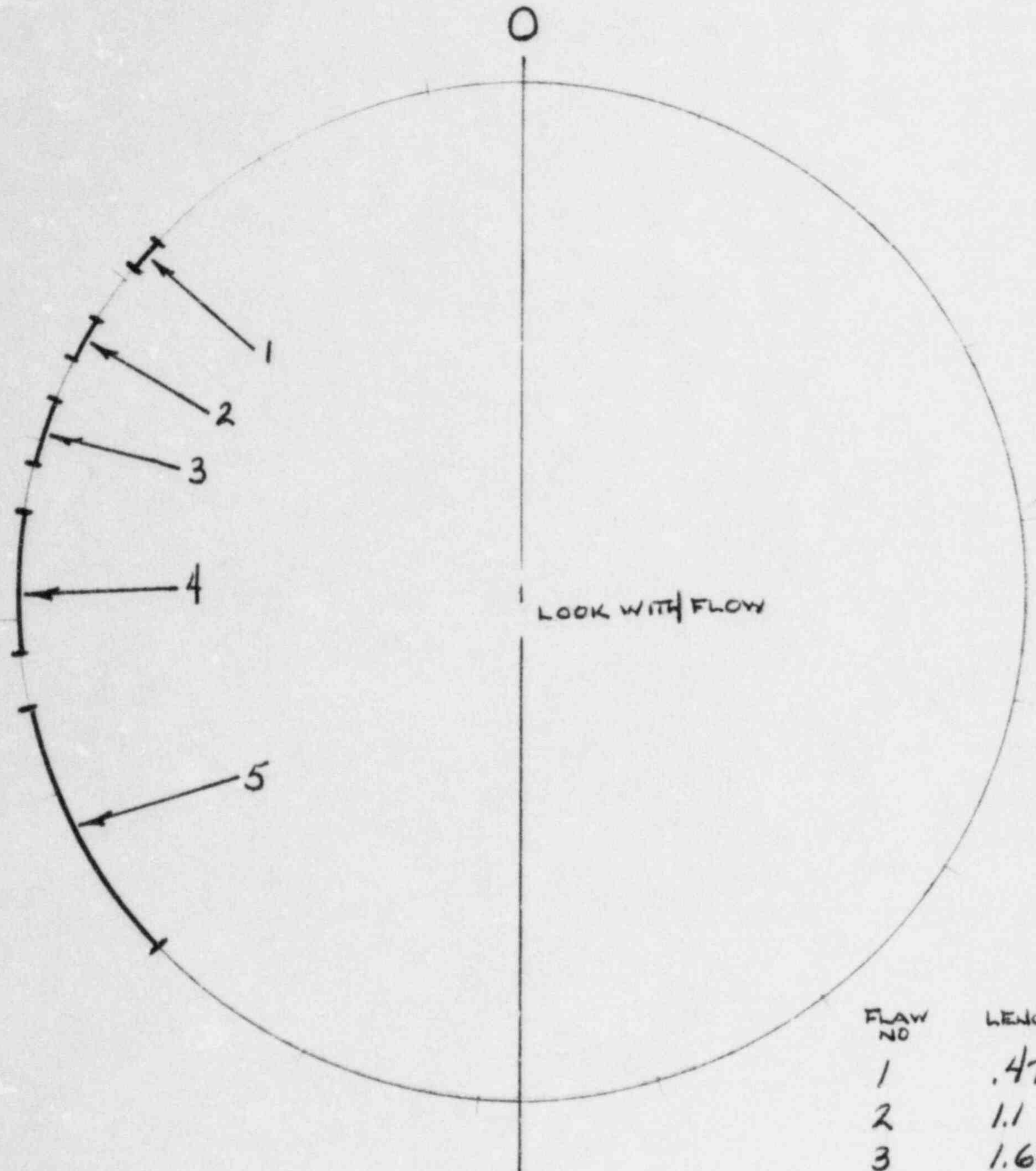


FLAW NO	LENGTH	% THRU-WALL
1	.8	18
2	1	18
3	1	16

VY 1984 FLAW SUMMARY

16A

PIPE SIDE

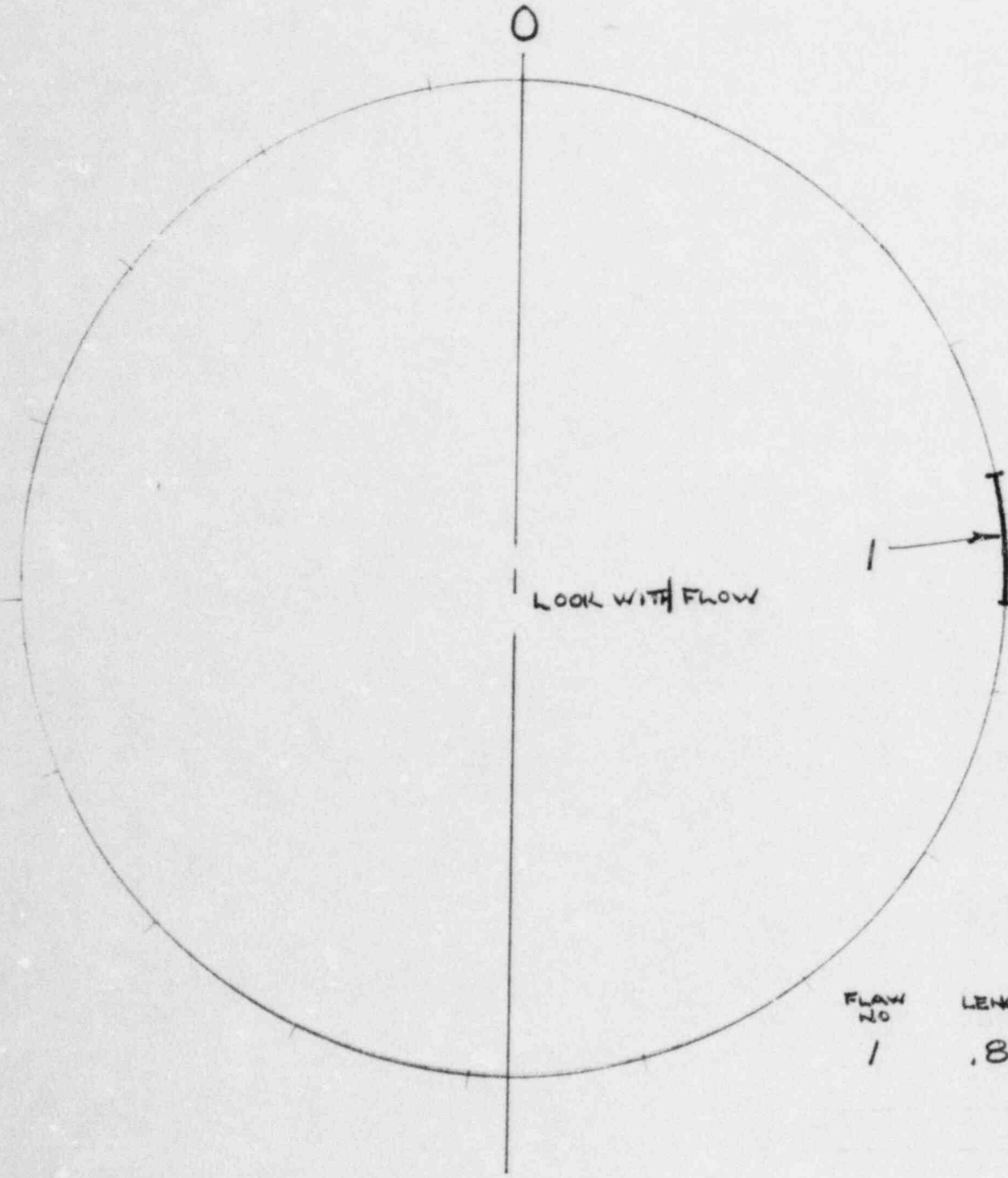


FLAW NO	LENGTH	% THRU-WALL
1	.47	20
2	1.1	15
3	1.65	18
4	3.6	20
5	5.9	20

VY 1984 FLAW SUMMARY

WELD NO 16B

VIEW PIPE SIDE

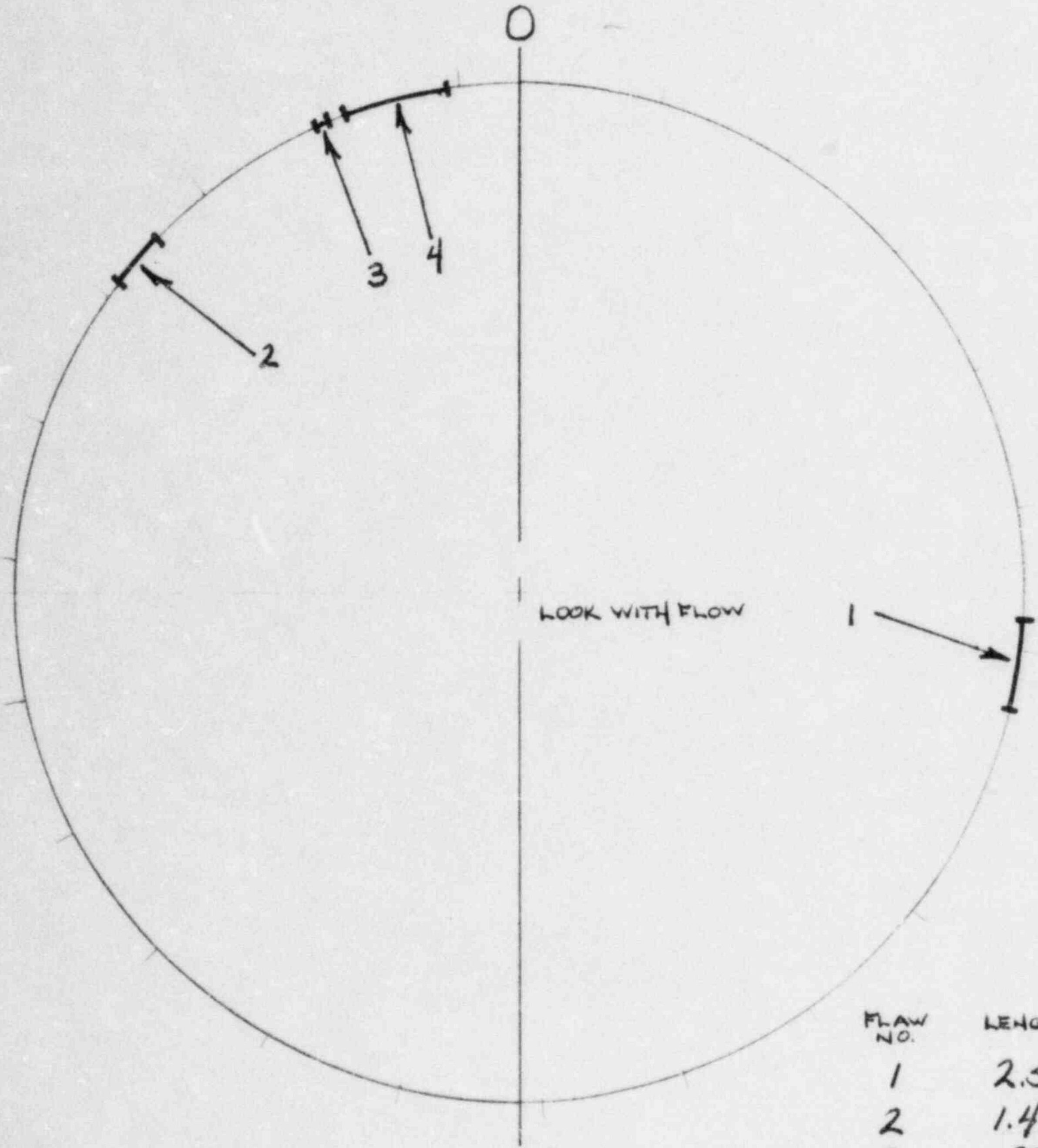


FLAW NO	LENGTH	% THRU-WALL
1	.8	12

VY 1984 FLAW SUMMARY

17B

PIPESIDE

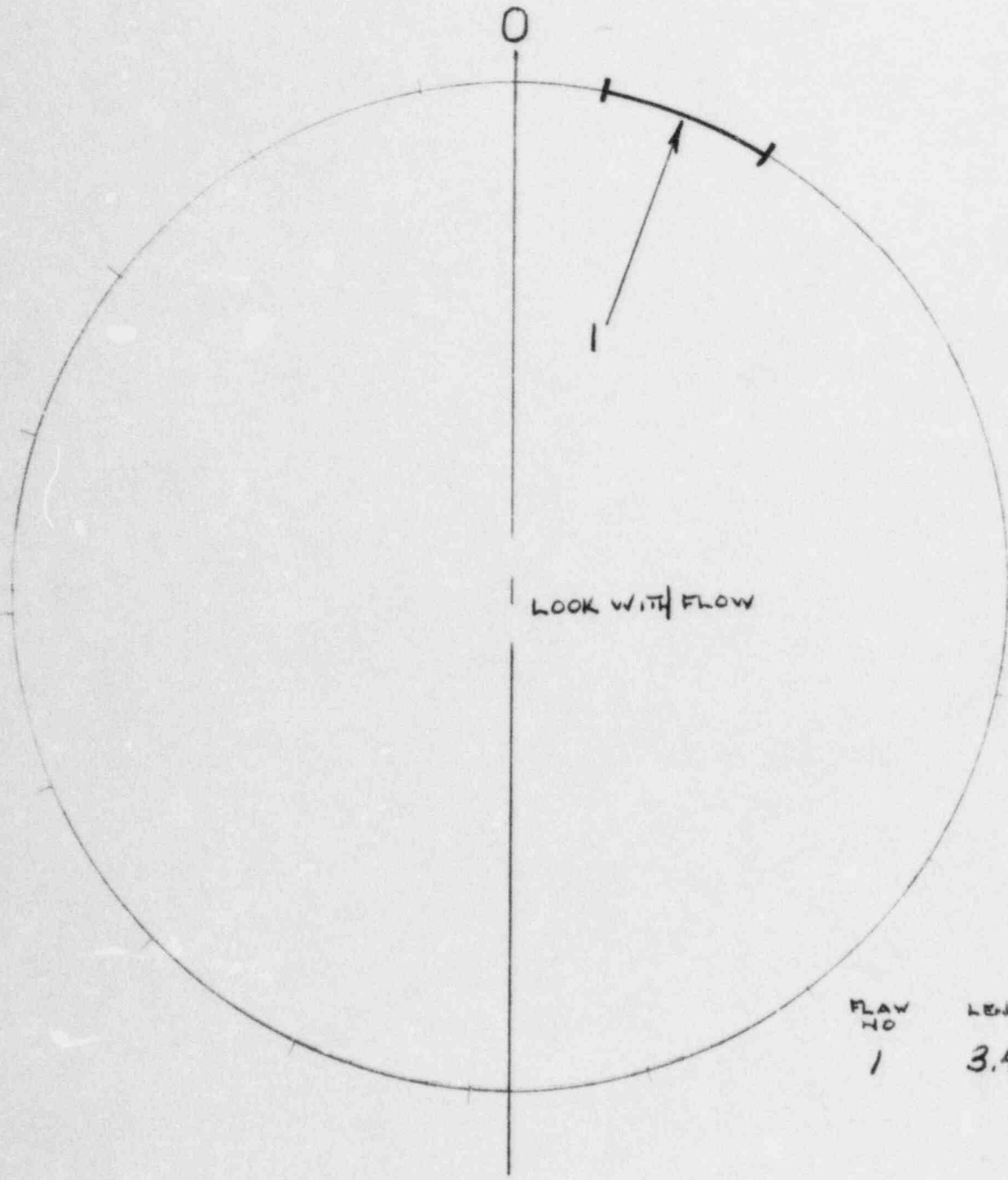


FLAW NO.	LENGTH	% THRU-WALL
1	2.5	
2	1.4	20
3	.25	
4	3.1	18-20

VY 1984 FLAW SUMMARY

WELD NO. 23B

VIEW END CAP

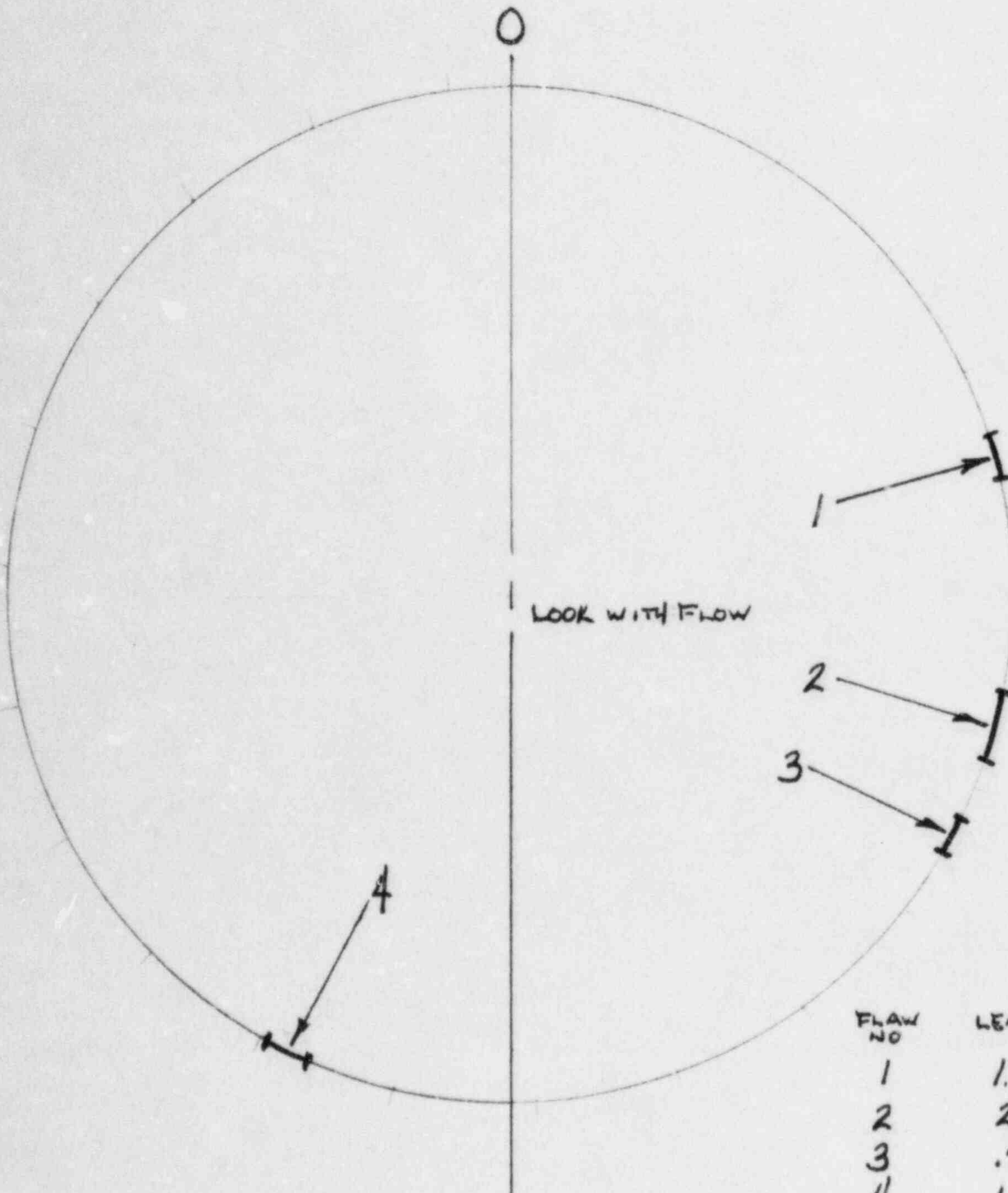


FLAW NO	LENGTH	% THRU-WALL
1	3.4	27-30

VY 1984 FLAW SUMMARY

WELD NO 26A

VIEW ELBOW SIDE



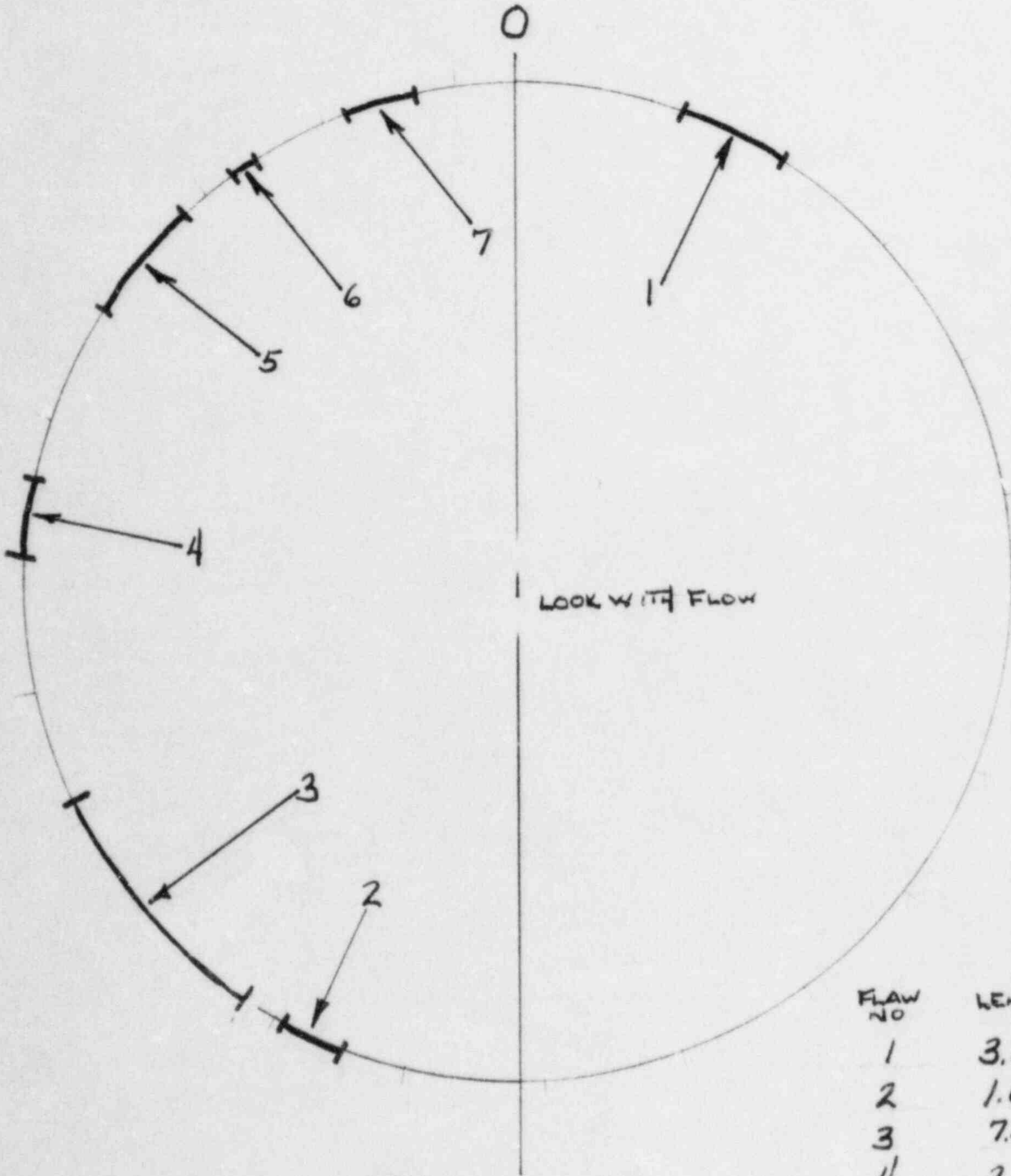
FLAW NO	LENGTH	% THRU-WALL
1	1.2	18-20
2	2	18
3	.75	
4	1.2	

F

VY 1984 FLAW SUMMARY

WELD NO 26A

VIEW PIPE SIDE

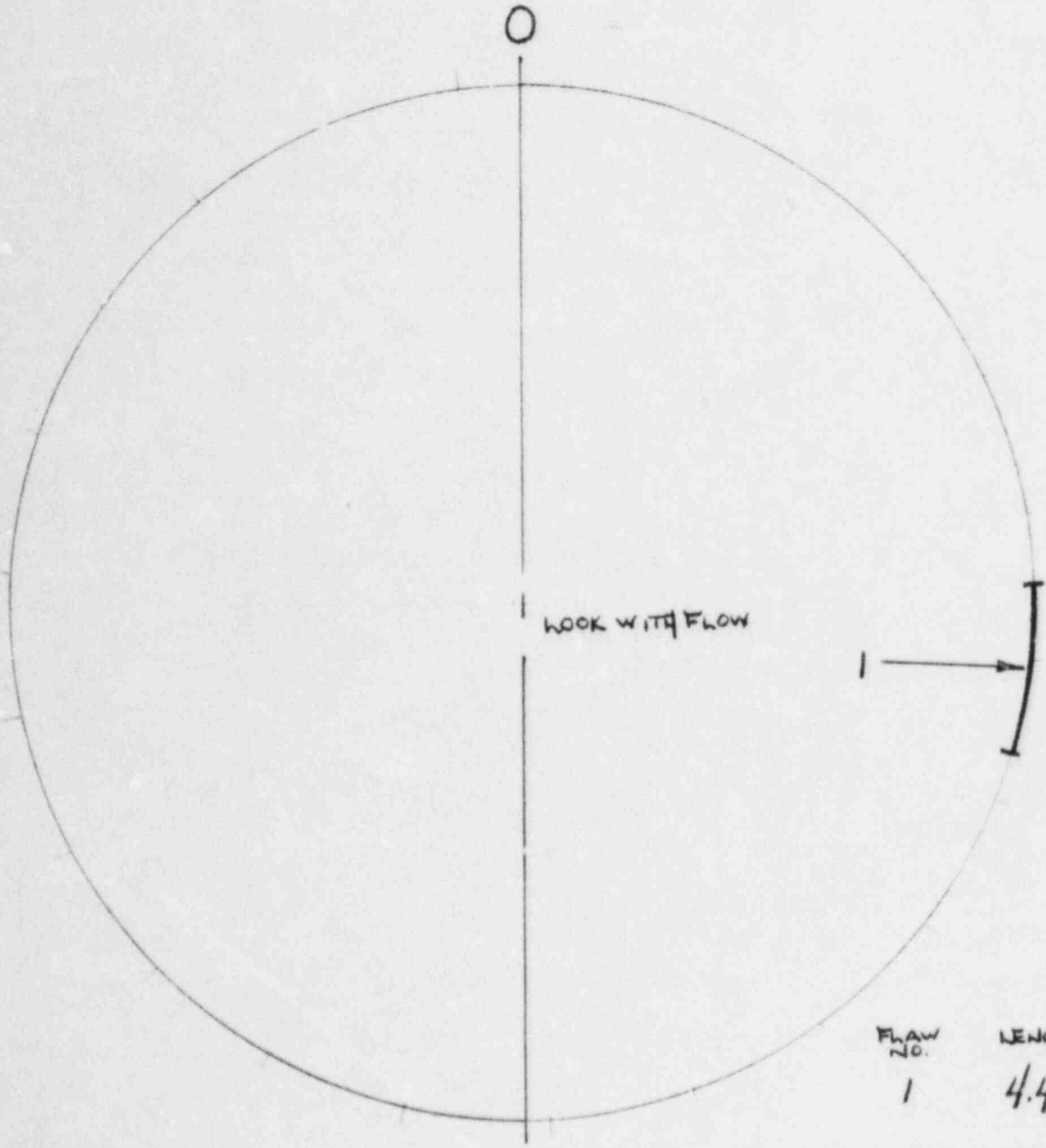


FLAW NO	LENGTH	% THRU-WALL
1	3.2	
2	1.6	
3	7.5	12
4	2.4	
5	3.1	13
6	.4	
7	1	

VY 1984 FLAW SUMMARY

WELD NO 27

VIEW PIPE SIDE

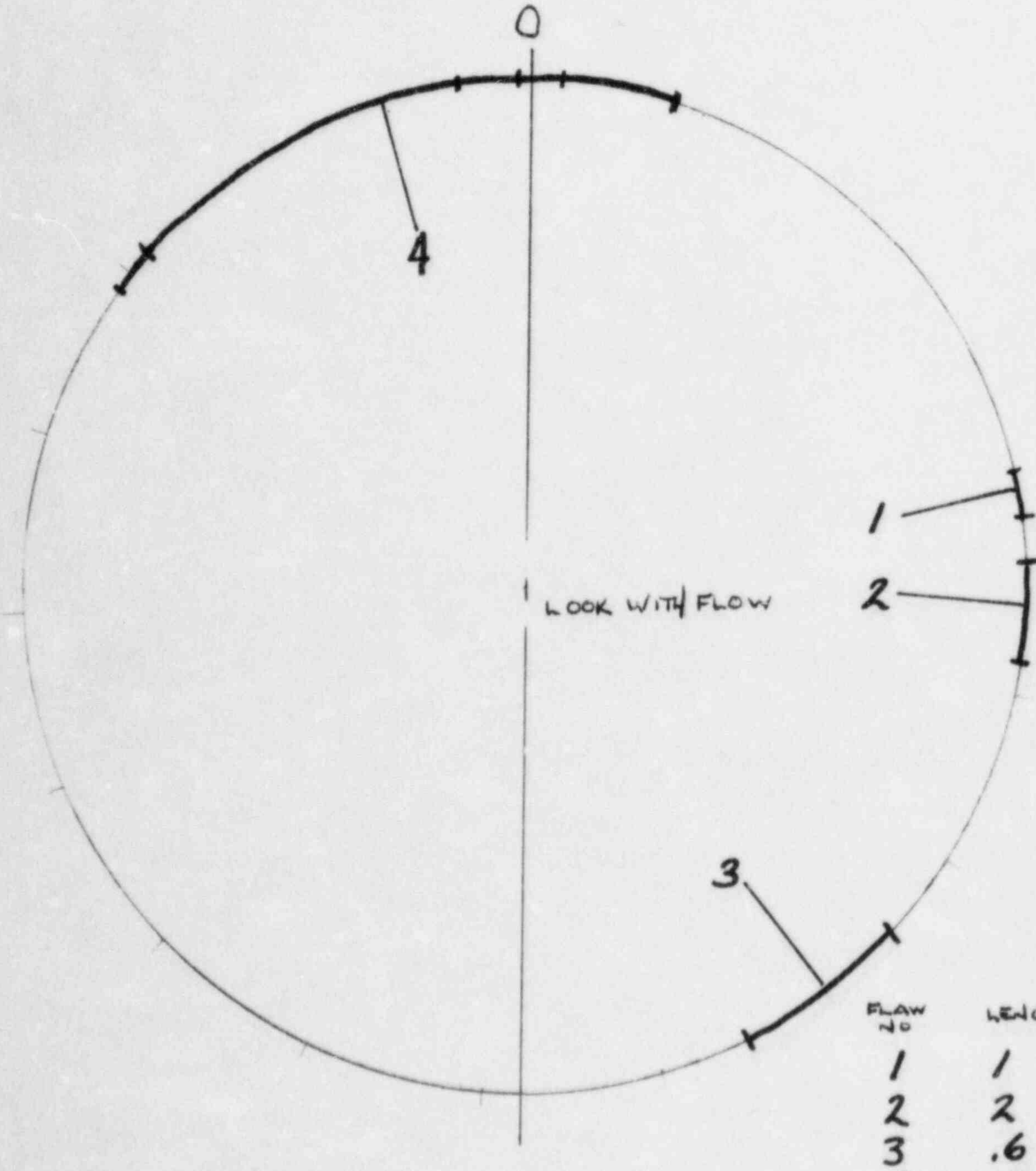


FLAW NO.	LENGTH	% THRU-WALL
1	4.4	18

VY 1984 FLAW SUMMARY

WELD NO. 30B

VIEW END CAP

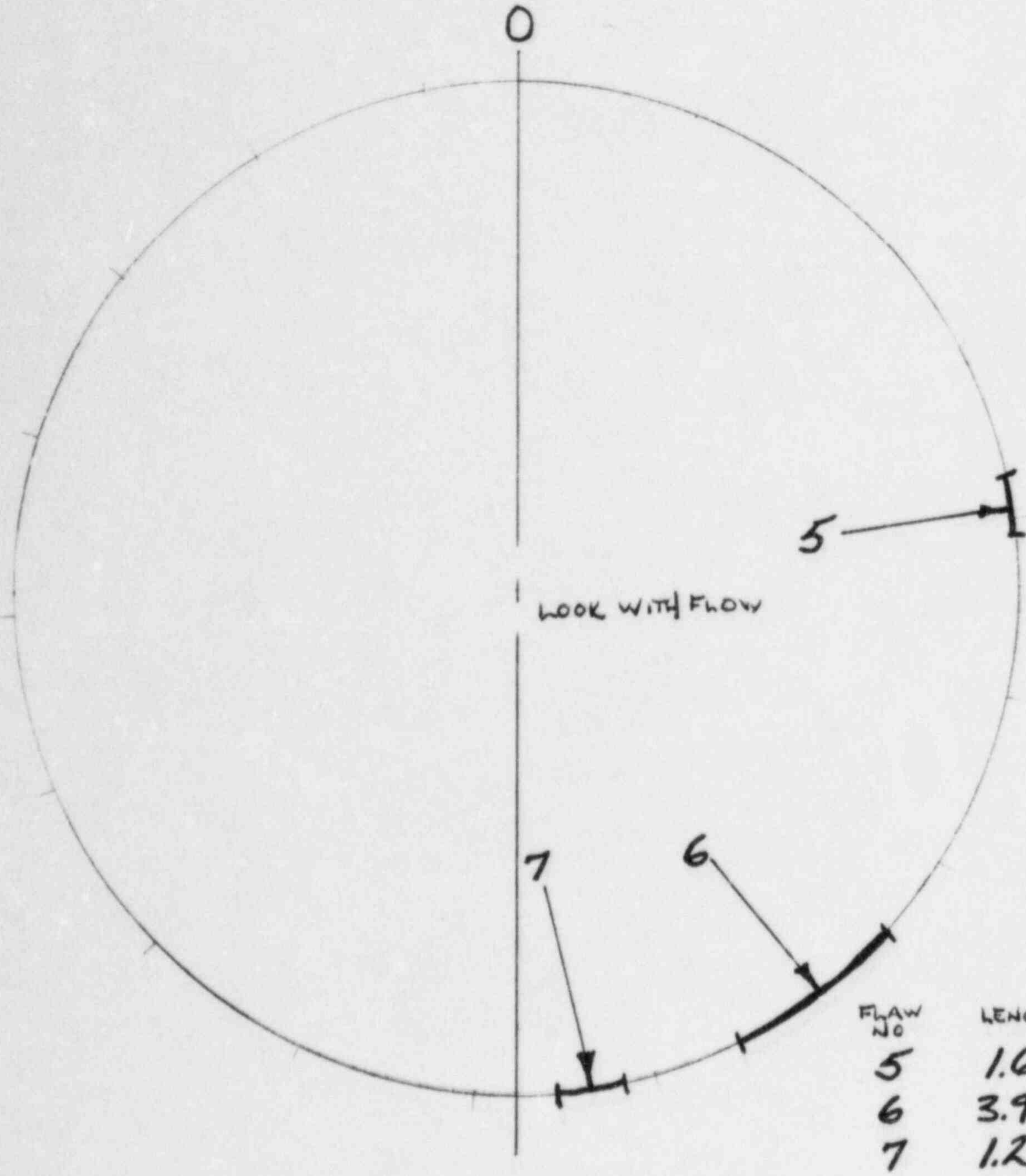


FLAW NO	LENGTH	% THRU-WALL
1	1	20
2	2	24
3	.6	
4	13	19-25

VY 1984 FLAW SUMMARY

WELD NO. 30B

VIEW PIPE

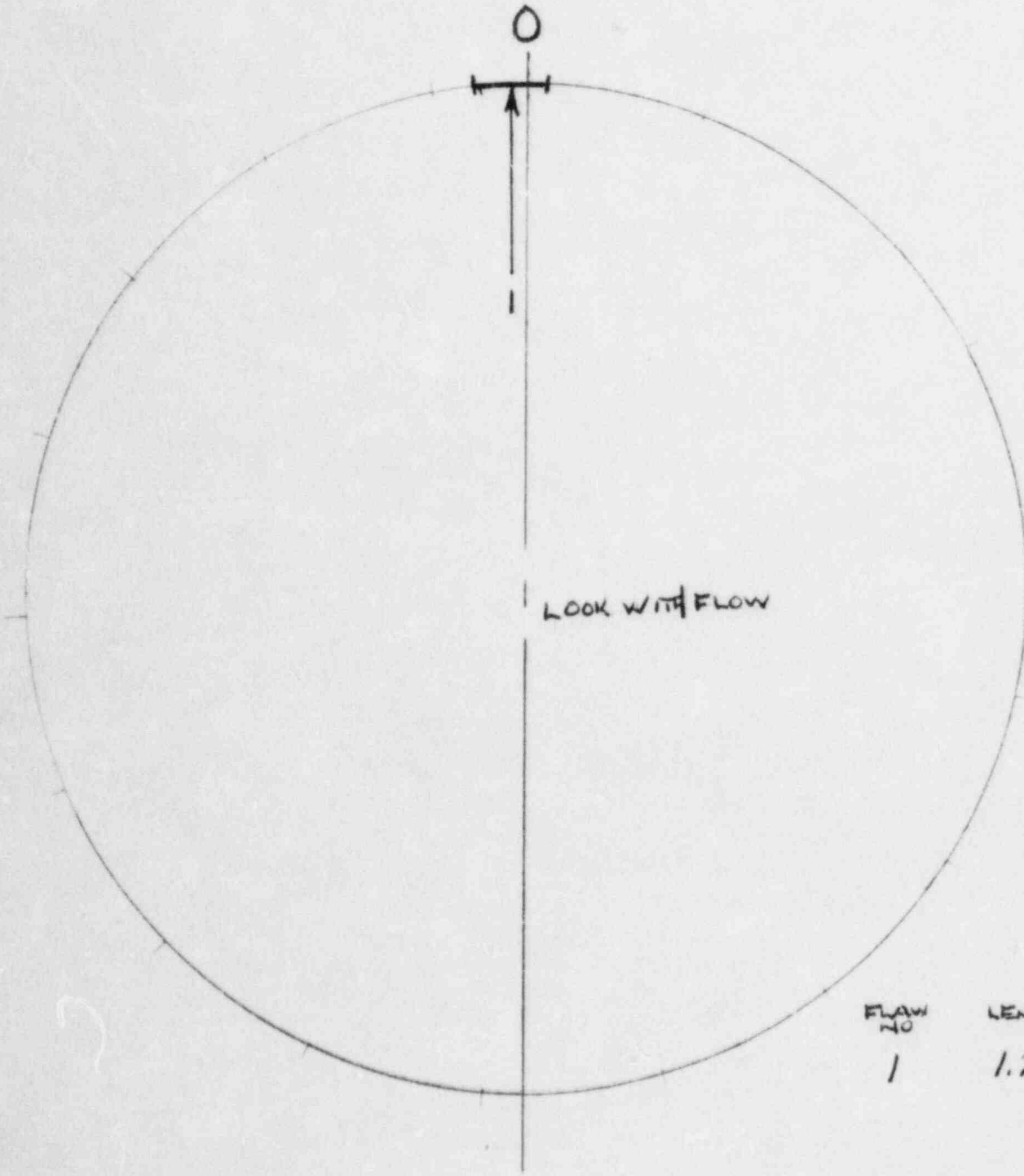


FLAW NO	LENGTH	% THRU-WALL
5	1.6"	
6	3.9	20
7	1.2	

VY 1984 FLAW SUMMARY

WELD NO. 49

PIPESIDE

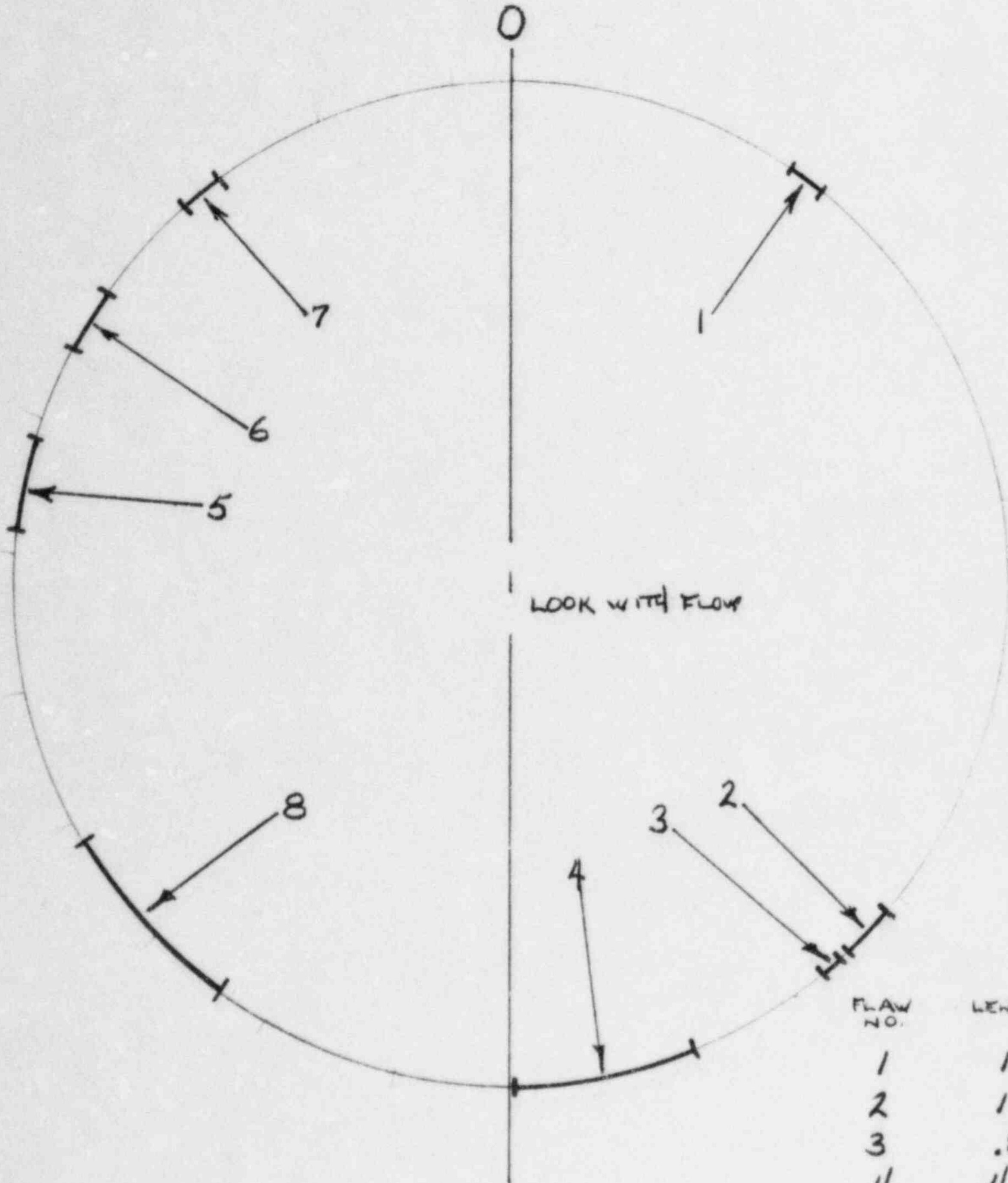


FLAW NO	LENGTH	% THRU-WALL
1	1.25	23

VY 1984 FLAW SUMMARY

WELD NO. 59

VIEW PIPE

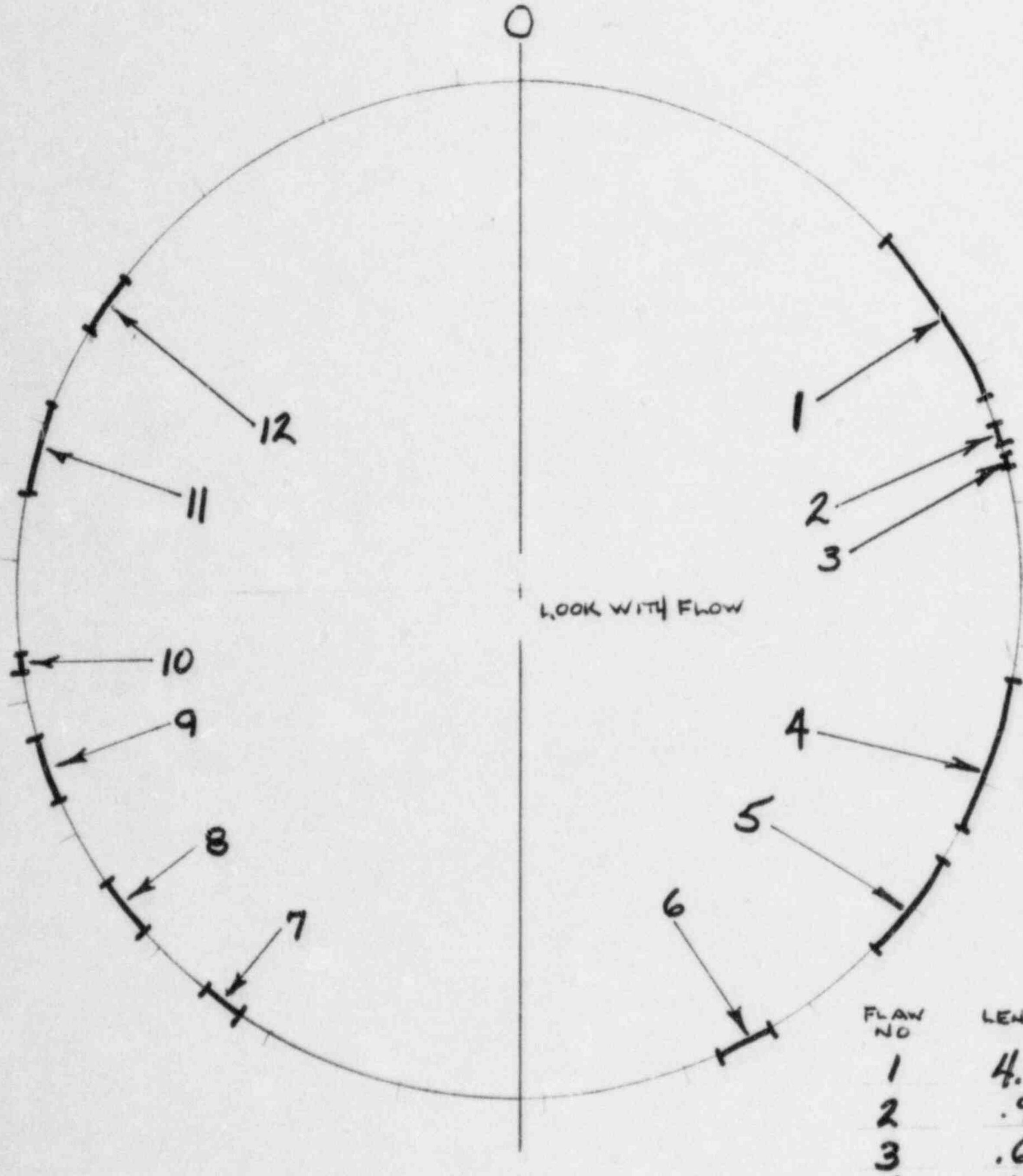


FLAW NO.	LENGTH	% THRU-WALL
1	1	20
2	1	15
3	.8	15
4	4.7	20
5	2.4	
6	1.4	20
7	1.2	
8	6	18

VY 1984 FLAW SUMMARY

WELD NO. 61

VIEW PIPE SIDE

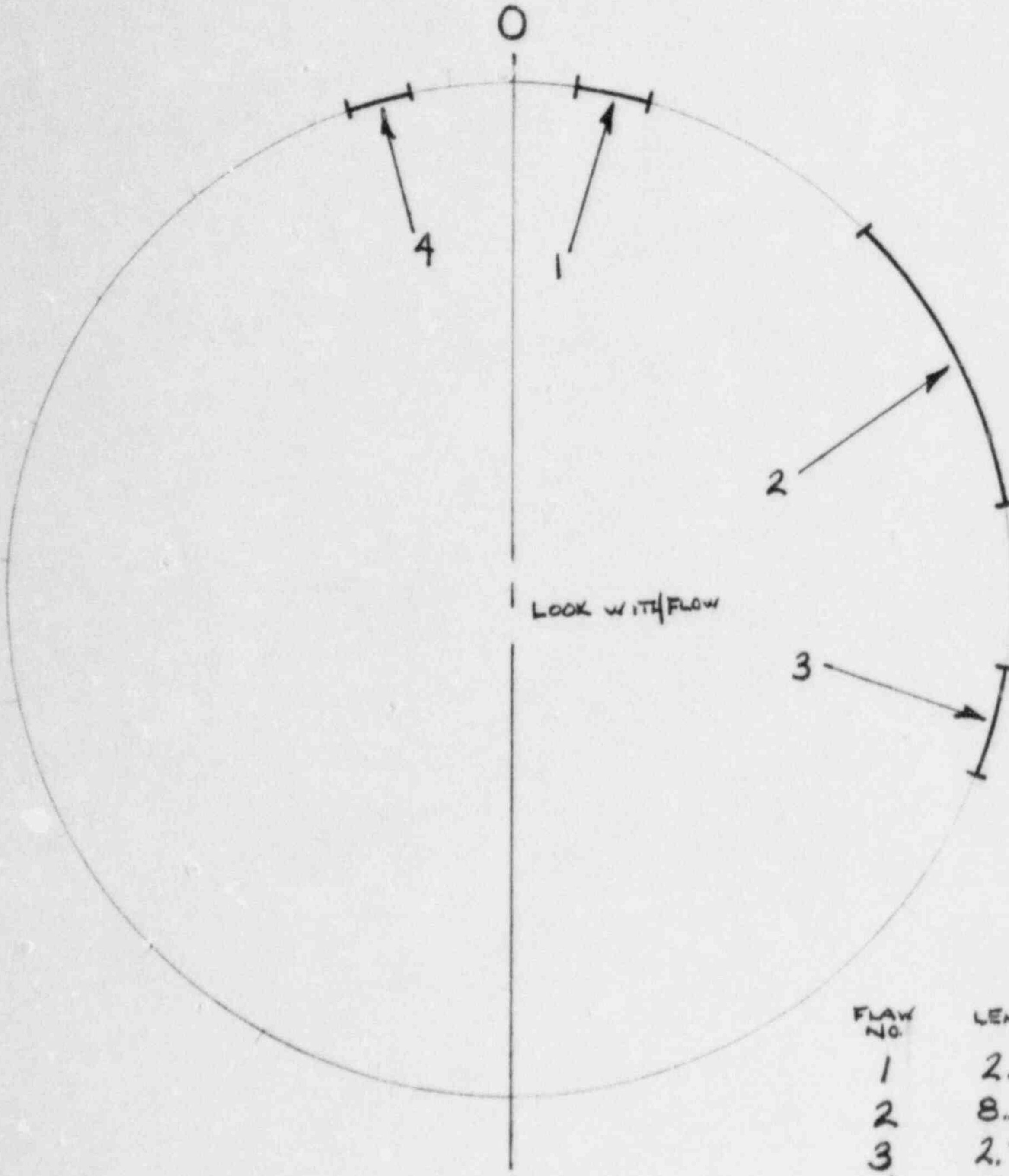


FLAW NO	LENGTH	% THRU-WALL
1	4.8	10-20
2	.9	
3	.6	
4	4.5	18
5	3.5	18
6	1.4	18
7	.6	
8	1.9	21
9	1.7	21
10	.27	
11	2.2	24
12	.9	

VY 1984 FLAW SUMMARY

65A

PIPE SIDE



FLAW NO.	LENGTH	% THRU-WALL
1	2.2	18
2	8.5	18
3	2.75	20
4	1.4	25

TABLE X

1984 EXAMINATION RESTRICTION SUMMARY

TABLE X

1984 Examination Restriction Summary

System	Weld Number	Size	Configuration	Method	Restriction
Recirc	1A	28	H.Pipe/Elbow	P-scan	None
	2	28	Elbow/V.Pipe	P-scan	None
	4	28	Valve/H.Pipe	P-scan	No Scan Valve Side
	5	28	Elbow/Pump	P-scan	No Scan Pump Side
	5A	28	H.Pipe/Elbow	P-scan	No Scan Pipe Side 625-750 mm & 1550-1590 mm
					No Scan Elbow Side 0-375 mm & 2000-0 mm
				Manual	Areas not Scanned by P-scan
	6	28	Pump/H.Pipe	P-scan	No Scan Pump Side
	8	28	H.Pipe/Valve	P-scan	No Scan Valve Side
					No Scan Pipe Side 500-625 mm & 1625-1750 mm
				Manual	No Scans
	9A	28	Elbow/V.Pipe	P-scan	None
	36B	22	Cross/Header	P-scan	Not Scanned Cross Side 0-375 mm 625-1250 mm 1500-1875 mm Due to Geometry
					Not Scanned Header Side 0-250 mm
				Manual	Scanned 0-250 mm Header side

TABLE X
(Continued)

1984 Examination Restriction Summary

System	Weld Number	Size	Configuration	Method	Restriction
Recirc (Cont'd)	41	12	V.Pipe/Elbow	P-scan	None
				Manual	None
	44	12	V.Pipe/Elbow	P-scan	Not Scanned Elbow Side 375-750 mm
				Manual	Elbow Side Scanned 375-750 mm
	47	22	Valve/Header	P-scan	No Scan Valve Side
	48	22	Valve/Header	P-scan	No Scan Valve Side
	49	22	Header/Valve	Manual	No Scan Valve Side
	51A	12	Elbow/H.Pipe	P-scan	No Scan Elbow Side 375-500 mm
	16B	22	Cross/Header	P-scan	No Scan Cross Side
					Header Side Not Scanned 0-250 mm 875-1000 mm
				Manual	Areas Not Scanned By P-scan
	17	28	V.Pipe/V.Pipe	P-scan	None
	17A	28	V.Pipe/V.Pipe	P-scan	None
	17B	28	V.Pipe/Elbow	P-scan	None
	23A	22	Header/Sweepolet	Manual	No Scan Sweepolet Side
	23B	22	Header/Cap	P-scan	None
	26	28	Safe End/H.Pipe	P-scan	No Scan Safe End Side
	26A	28	H.Pipe/Elbow	P-scan	None
	27	28	Elbow/V.Pipe	P-scan	None

TABLE X
(Continued)

1984 Examination Restriction Summary

System	Weld Number	Size	Configuration	Method	Restriction
Recirc (Cont'd)	30A	22	Header/Sweepolet	Manual	No Scan on Sweepolet
	30B	22	Header/Cap	P-scan	None
	36A	22	Cross/Header	P-scan	No Scan On Cross
	9B	28	V.Pipe/RHR Tee	P-scan	No Scan On Tee
	15	28	V.Pipe/RHR Tee	P-scan	No Scan On Tee
	15A	28	RHR Tee/V.Pipe	P-scan	No Scan On Tee
	15B	28	V.Pipe/V.Pipe	P-scan	No Scan 0-125 mm Either Side HVAC Interfers
				Manual	No Scan
	15C	28	V.Pipe/Elbow	P-scan	No Scan 0-125 mm
				Manual	Areas Not Scanned By P-scan
	16A	22	Cross/Header	P-scan	No Scan Cross Side
					No Scan On Header Side 0-250 mm 875-1250 mm 1625-0 mm
				Manual	Areas Not By P-scan
	54A	12	Elbow/H.Pipe	P-scan	Elbow Side Not Scanned 135-180^{o} Shielded (hot spot)
				Manual	Scanned 135-180^{o} plus evaluations
	56	28	Elbow/Valve	P-scan	No Scan Valve
					Elbow Side Not Scanned 0-125 mm 125-0 mm Permanent Interference

TABLE X
(Continued)

1984 Examination Restriction Summary

System	Weld Number	Size	Configuration	Method	Restriction
Recirc (Cont'd)	58	28	Elbow/Pump	P-scan	No Scan On Pump
	59	28	Pump/H.Pipe	P-scan	No Scan On Pump
	61	28	Pipe/Valve	P-scan	No Scan On Valve
	64	28	Elbow/V.Pipe	P-scan	None
	65A	28	V.Pipe/RHR Tee	P-scan	No Scan On Tee
	45	12	Sweepolet/V.Pipe w/Overlay	Manual	None
	50	12	Sweepolet/V.Pipe w/Overlay	Manual	None
	51	12	V.Pipe/Elbow w/Overlay	Manual	None
	53	12	Sweepolet/V.Pipe w/Overlay	Manual	None
	54	12	V.Pipe/Elbow w/Overlay	Manual	None
	16	12	Red Cap/V.Pipe w/Overlay	Manual	None
	18	12	V.Pipe/Elbow w/Overlay	Manual	None
	20	12	Sweepolet/V.Pipe w/Overlay	Manual	None
	23	12	Sweepolet/V.Pipe w/Overlay	Manual	None
	24	12	V.Pipe/Elbow w/Overlay	Manual	None
	29	12	V.Pipe/Elbow w/Overlay	Manual	None

TABLE X
(Continued)

1984 Examination Restriction Summary

System	Weld Number	Size	Configuration	Method	Restriction
Recirc (Cont'd)	30	12	Sweepolet/V.Pipe w/Overlay	Manual	None
	32	12	V.Pipe/Elbow After Overlay Build-up	Manual	None
	35	12	V.Pipe/Elbow w/Overlay	Manual	None
	36	12	Red Cap/V.Pipe w/Overlay	Manual	None
	42	12	Sweepolet/V.Pipe w/Overlay	Manual	None
RHR-30	1	24	Elbow/Tee	Manual	No Scan On Tee
	3	24	Pipe/Elbow	P-scan	No Scan On Elbow Side
	9	24	Pipe/Elbow	P-scan	Weld Inaccessible 750-1125 mm No Scan Either Side
	10	24	Elbow/Pipe	P-scan	Weld Inaccessible 875-1125 mm No Scan Either Side
RHR-31	1	24	Elbow Tee	Manual	No Scan On Tee
RHR-32	1	20	Tee/Elbow	Manual	No Scan On Tee
	2	20	Elbow/V.Pipe	P-scan	No Scan On Elbow
	F1	20	Pipe/Sweepolet	Manual	No Scan On Sweepolet
	4	20	Pipe/Elbow	P-scan	No Scan 1125-1375 mm Permanent Interference
	5	20	Elbow/Valve	Manual	No Scan Valve Side 6 In. Obstruction (Permanent Support)

TABLE X
(Continued)

1984 Examination Restriction Summary

System	Weld Number	Size	Configuration	Method	Restriction
RHR-32 (Cont'd)	6	20	Valve/Pipe	P-scan	No Scan Valve No Scan Pipe Side 500-1125 mm Permanent Interference
	7	20	Pipe/Valve	P-scan	No Scan Valve Side No Scan Pipe Side 500-1125 mm Permanent Interference
	4	20	Pipe/Elbow After Overlay	Manual	None

ASSOCIATED FIGURES

FIGURE 1

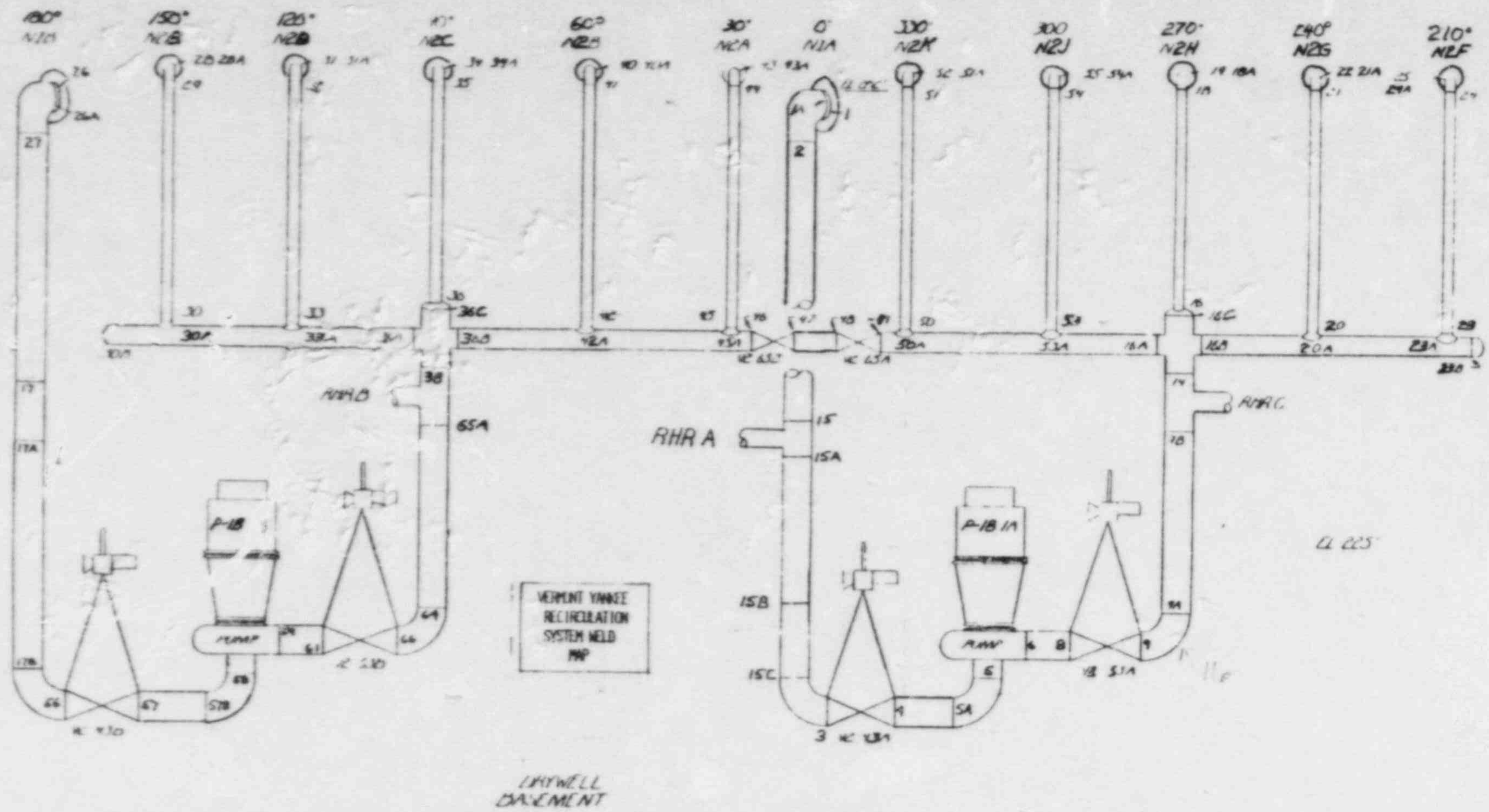
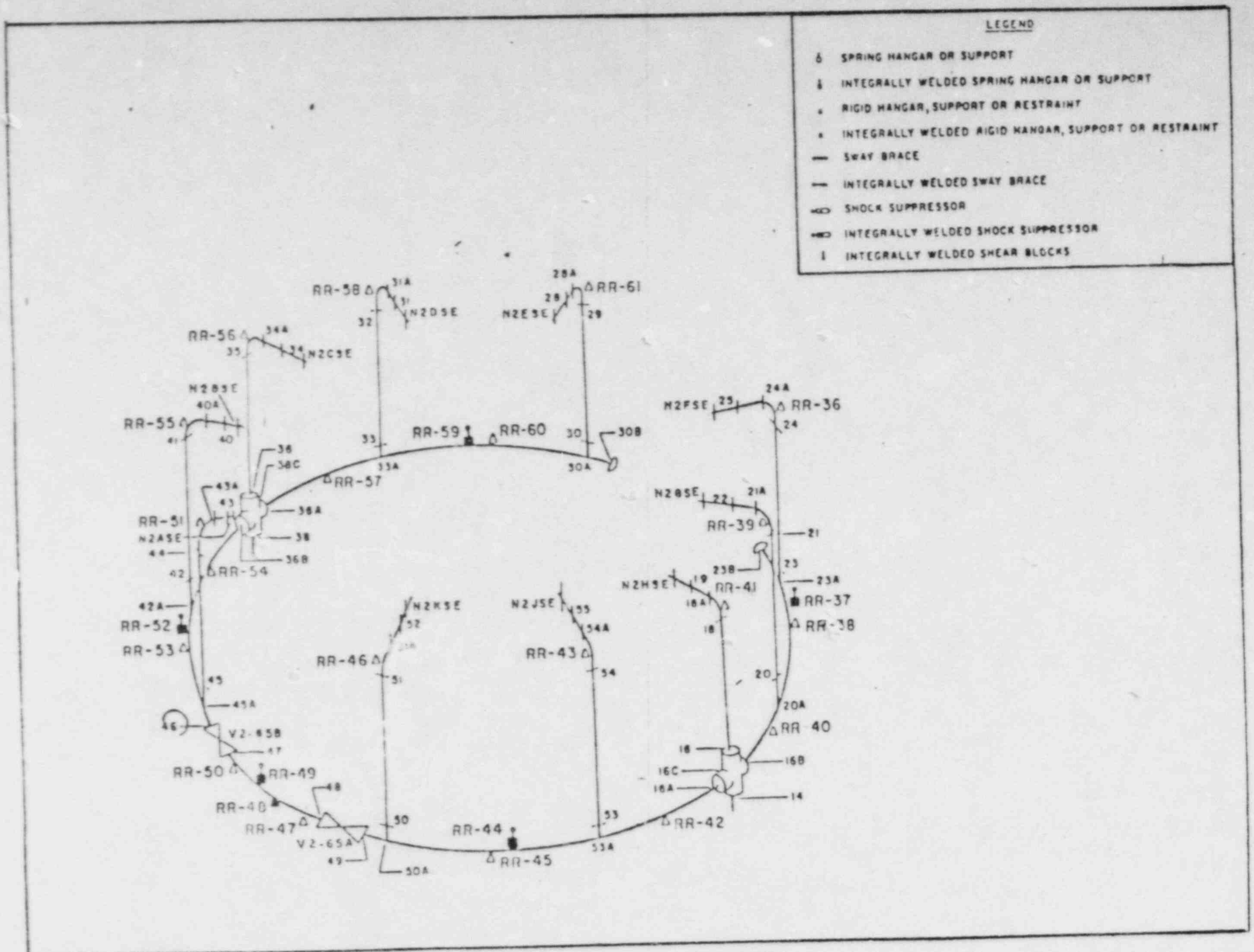

180°
150°
N2B
120°
60°
30°
0°
N1A
N2K
300
N2J
270°
N2H
240°
N2G
210°
N2F
RHR A
RHR B
RHR C
P-1B
P-1B 1A
PUMP
15
15A
15B
15C
65A
VERMONT YANKEE
RECIRCULATION
SYSTEM WELD
MAP
DRYWELL
BASEMENT

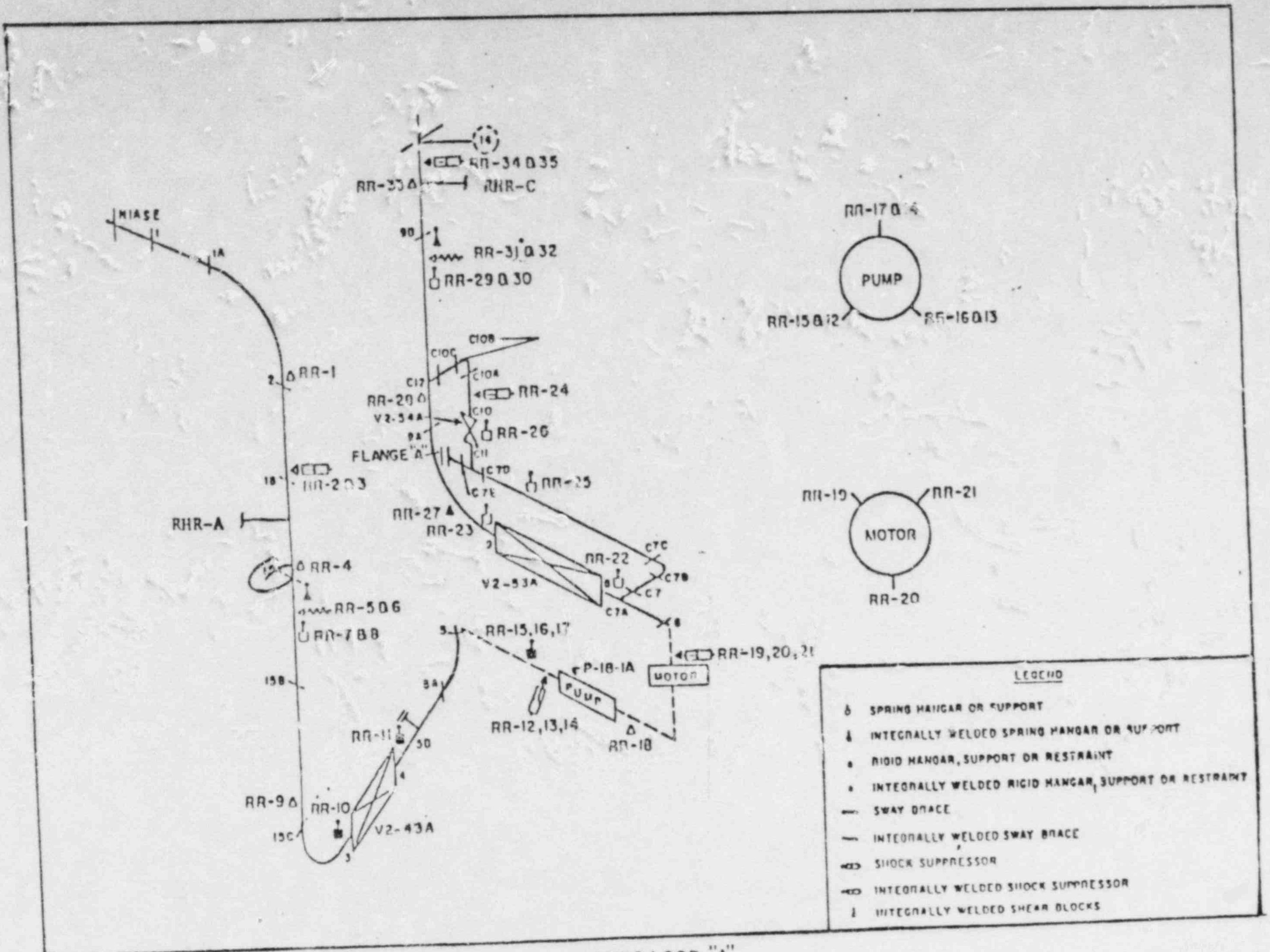
FIGURE 2



RECIRC RING HEADER & INLETS

REF EDASCO DWG. 5920-FS-133

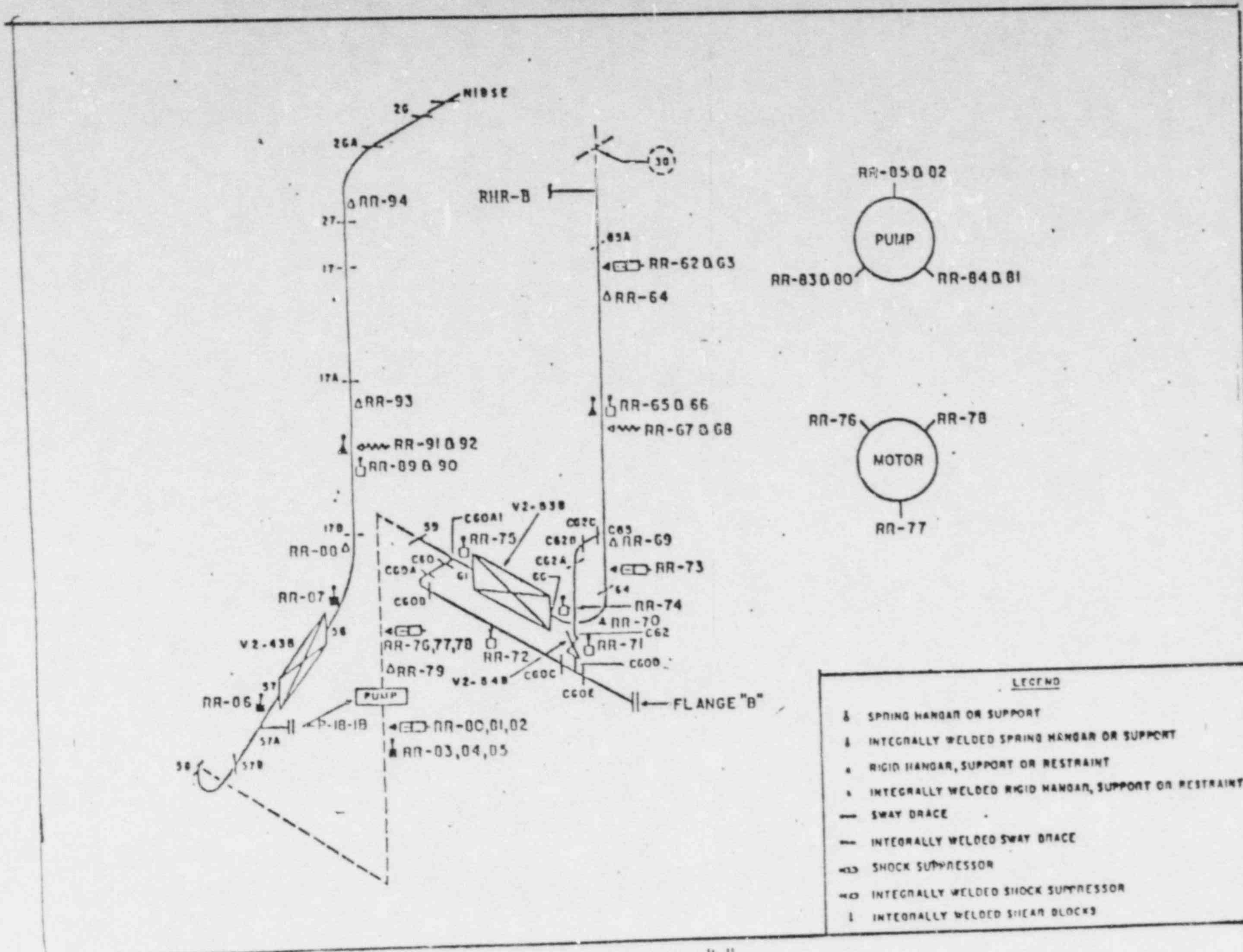
FIGURE 3



RECIRC LOOP "A"

REF EBASCO DWG. 5920-FS-133

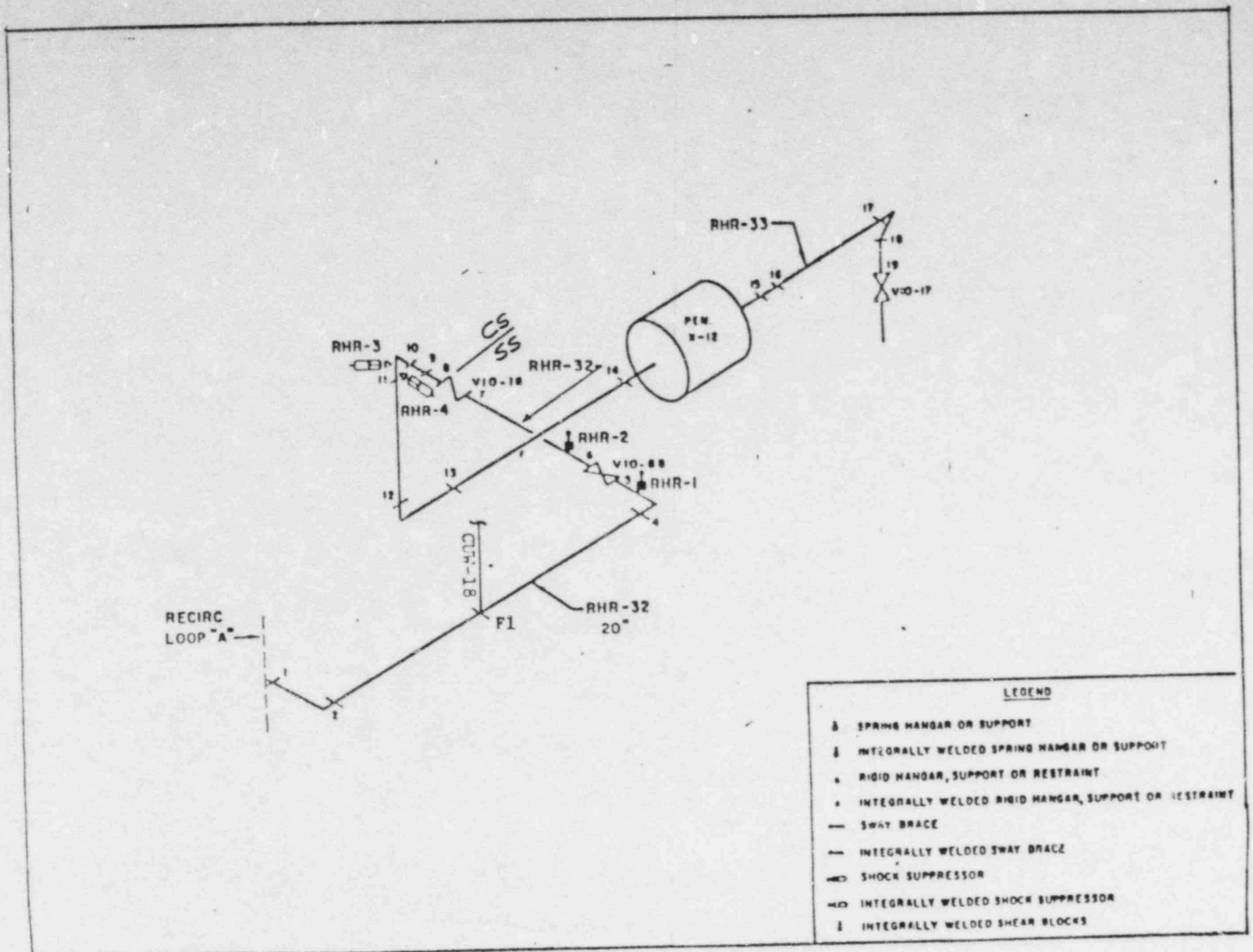
FIGURE 4



RECIRC LOOP "B"

REF. EUASCO DWG. 5920-FS-135

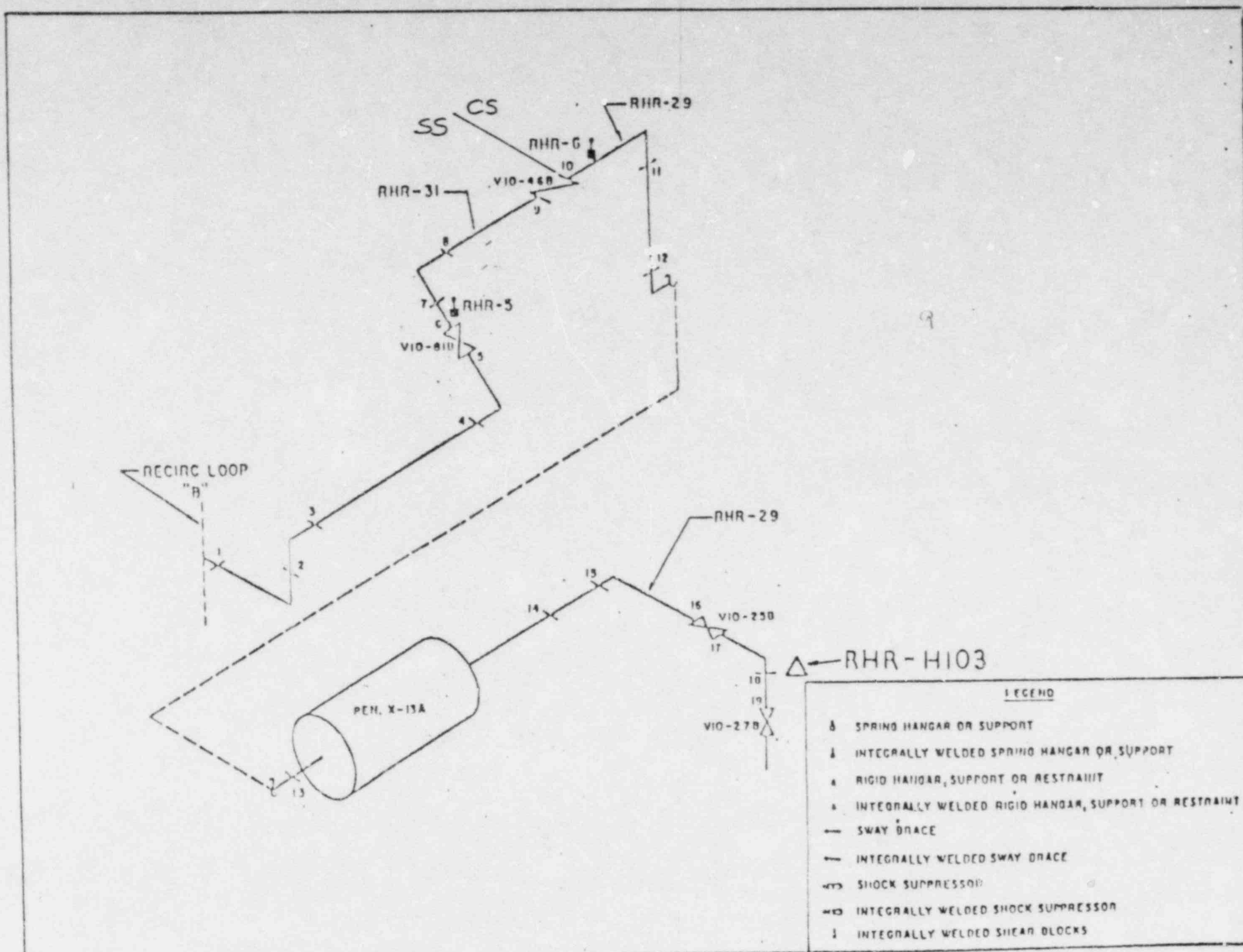
FIGURE 5



RHR PIPING LINE "A"

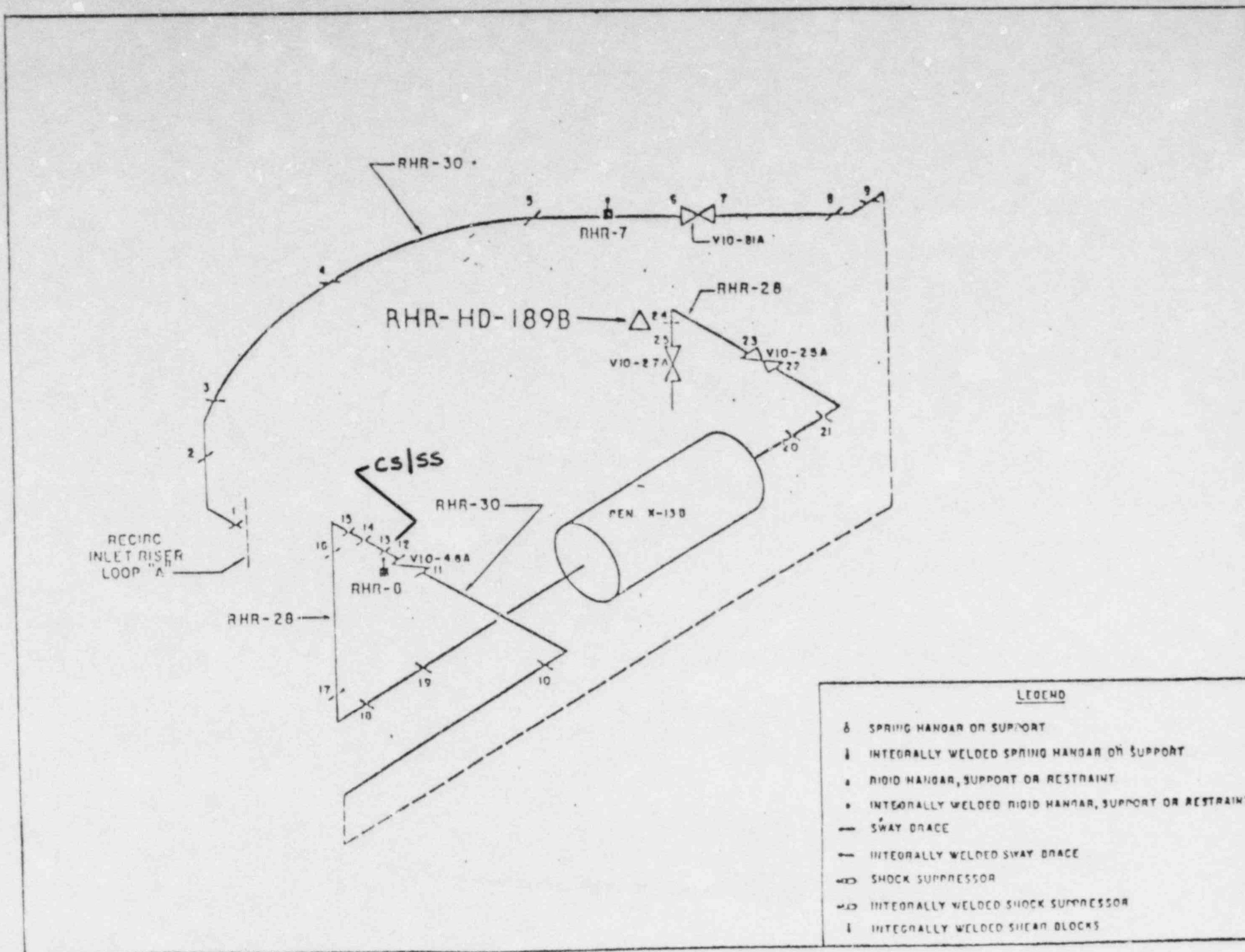
REF. EBASCO DWG. 5920-FS-1438

FIGURE 6



RHR PIPING LINE "B"

FIGURE 7



RHR PIPING LINE "C"