Point Beach Nuclear Plant

SOCKET-WELD FAILURES IN AUXILIARY FEEDWATER PUMP RECIRCULATION PIPING

<u>RCE *99-081, Revision 1*</u>
RCE 99-080
RCE 99-071

(<u>CR *99-1391*</u>)
CR 99-1368
CR 99-1163

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I. Executive Summary

Purpose:

The purpose of this investigation is to determine the root cause of three occurrences of socket-weld cracking in the mini-flow recirculation piping of the motor-driven Auxiliary Feedwater (AF) Pumps.

Event Synopsis:

Over a period of approximately one year, three leaks from cracked socket-welds were discovered in a specific section of AF Pump recirculation piping. The first of the leaks appeared approximately 7 years after the welds were installed as part of modification MR 88-099, to increase the AF Pump recirculation line flow capacity. Two of the leaks occurred in identical locations on the "A" and "B" recirc. lines at the socket weld connection to the respective recirc line manual isolation valve. The other leak occurred on the "A" line at the socket-weld joint on the horizontal portion of a 90° elbow.

(For convenience, the three cracked socket-weld events are referred to as Crack #1, 2 and 3 in order of occurrence.) The Crack #1 event (6/27/98) was evaluated as Level C CR #98-2550 due to consideration as an isolated incident. Crack #2 (4/24/99) was evaluated as Level B CR #99-1163 with RCE 99-071 assigned. Crack event #3 (5/19/99) was reported as CR #99-1368, also a Level B with RCE 99-080 assigned. Due to the common-mode failure nature of these events, Level B CR #99-1391, including an Operability Determination, was assigned as RCE 99-081. Therefore, this RCE 99-081 is intended to also satisfy the evaluation requirements of RCE 99-071 and 99-080.

Conclusions:

It is concluded that the failure mode responsible for the socket-weld failures was by cyclic fatigue created by vibration of the recirc. piping. Vibration and excessive noise are attributed to turbulence and cavitation resulting from flow conditions through restricting orifices RO-4008 and RO-4015.

Root Cause:

- **Design Deficiency:** *The restricting orifice design breakdown pressure was incorrectly specified.* The breakdown pressure rating, which dictates the number of internal breakdown stages, was specified in PO #184514 for restricting orifices RO-4008 and RO-4015 as 2190 feet @ 70 gpm and 100°F. Breakdown pressure of 2190 feet (≅ 948 psi) with only two breakdown stages is insufficient to avoid high turbulence and cavitation under the actual DP conditions of greater than 1200 psi. The resulting pipe vibration has imposed cyclic fatigue stresses on vulnerable socket-welds.

Contributing Factors:

- **QA Scope Change in MR 88-099**: *The QA boundary in the recirc. piping modification was re-scoped for an unapparent reason.* The QA boundary was moved from the second isolation valve in the recirc. line, which included the restricting orifice, to the first isolation valve, which excluded the orifice. The more timely non-QA procurement of the orifice may have been influenced by modification schedule, but it remains unknown why the scope change was made.

- **Orifice Omitted from 10CRF50.59 Evaluation:** *Use of the re-sized restricting orifice has not been addressed in the 50.59 Evaluation associated with MR 88-099B (SER 91-025-03).* The 50.59 provided the opportunity to realize the mis-match between the orifice characteristics and the AF System conditions.

- **Inadequate Weld:** *In one of the three cases of cracked welds, a void was found under the root pass of the weld.* It is concluded that the quality of the weld contributed to the initiation of the failure due to creation of a stress concentration. Noted slight concavity of the weld surface contributed to crack propagation. Identification of this deficient weld has not led to the suggestion that a programatic issue is involved.

Recommended Corrective Action Synopsis:

- Survey existing welds on AFP recirc. lines for excessive concavity.

- Obtain/analyze piping vibration data from the P-38A recirc. piping after tightening of the pipe support U-bolt to compare with previous data.

- Evaluate a resolution and process a design change to provide adequate pressure reduction in the AFP recirc. lines without cavitation and noise.

- Conduct Engineering training on the design deficiency associated with an inadequate specification of orifice differential breakdown pressure.

II. Event Narrative

Modification MR 88-099 was installed during June of 1991. The purpose of the modification was to increase the mini-recirculation flow capacity of the Auxiliary Feedwater (AF) Pumps from 30 gpm to 70 gpm for the motor-driven pumps, and from 30 gpm to 100 gpm for the turbine-driven pumps. These values are the result of a re-evaluation by the pump vendor. Prior to the modification, recirculation flow was limited to 30 gpm by restricting orifices within a 1 ½ inch line for each of the four AF pumps. For the motor-driven pump portion of the modification, new orifices to limit flow to 80 gpm were installed. The recirculation piping diameter for all pumps was increased to 2 inches. By the final QA scope document, the restricting orifices for all four pumps were installed as non-safety/non-QA.

On 2/27/91, restricting orifices RO-4008 and 4015 were ordered as non-QA items according to PO #184514.

The AF System Design Basis Document DBD-01 was issued 4/94, including a description of the safety-related functions of the restricting orifices.

A discrepancy was identified on 11/18/96 regarding the QA classification of the restricting orifices. Q-List discrepancy 96-058 was processed to upgrade the orifices to Safety-related / QA 04.

CR 97-0720 was submitted on 3/4/97 to address distracting noise in the Control Room, known to be due to operation of the AF Pumps during a mini-flow evolution.

On 6/27/98, a pinhole size leak (Crack #1) was discovered at the upstream socket-weld joint of globe valve AF-27 in the P-38A mini-flow line. The occurrence was reported in CR 98-2550 as a Level C condition. The pipe portion of the socket combination was removed by cutting the pipe and grinding out the root portion of the weld in order to leave valve AF-27 intact. The consequence of the necessary repair plan was that the entire weld was not available for examination. The failure specimen was sent to *Technimet Corporation* for a failure analysis. (Details of this analysis are discussed in the Data Analysis section.).

The repair of Crack #1 provided an opportunity to conduct an inspection of the internal condition of orifice RO-4008. With the orifice removed from the system, a boroscope inspection was performed on 6/29/98 and documented in CR 98-2589. The inspection revealed significant pitting damage, confirming the suspicion of orifice cavitation.

The Control Room noise issue reported earlier in CR 97-0720 was referred to EWR 99-031, submitted 12/8/98.

On 4/24/99, CRACK #2 was discovered on the P-38A mini-flow line at the socket-weld joint on the horizontal portion of the 90° elbow upstream of restricting orifice RO-4008. As with CRACK #1, the failed socket-weld joint was provided to *Technimet Corp.* for failure analysis. The configuration of the CRACK #2 weld allowed the entire weld to be removed intact. (Details of this analysis are discussed in the Data Analysis section.)

Before the results of the CRACK #2 failure analysis were complete, CRACK #3 was discovered on 5/19/99. This leak was observed on the P-38B line in the same relative position to globe isolation valve AF-40 as CRACK #1 was to valve AF-27. As with CRACK #1, removal of the failure specimen required separation of the weld root.

Immediately after discovery of CRACK #3, vibration data was obtained from various positions along the vertical portion of the P-38A mini-flow line. The data was provided to *Structural Integrity Associates* for vibration analysis.

When the potential common mode failure mechanism was realized, CR 99-1391 was submitted with the assignment of this RCE 99-081.

III. Data Analysis

Information & Fact Sources

Crack #1: P-38A Recirc line upstream of AF-27 (*Technimet* Report 100353)

The failure specimen provided to *Technimet* was a cut-out section of the pipe portion of the upstream socket joint with globe valve AF –27. In order to leave the valve intact and facilitate a practical repair, the root portion of the weld had to be ground out. Therefore, the analysis scope was limited and the weld quality could not be totally examined. *Technimet* Report #100353 discusses evidence of:

- **transgranular stress corrosion cracking:** supported by appearance of secondary crack branching visible from crack magnification
- crack propagation within the weld and the base metal
- minor evidence of fatigue fracture

Dye penetrant testing is partially responsible for masking evidence of the existence of a specific corrodant. However, it was concluded in the report that failure was due to stress corrosion cracking.

Crack #2: P-38A Recirc line downstream of FE-4050 (*Technimet* Report 101609)

Technimet's failure analysis report of Crack #2 discusses evidence of:

- existence of a void under the weld root providing a stress concentration for crack initiation
- 50% of weld length appeared slightly concave
- moderate degree of stress corrosion cracking
- crack propagation by corrosion fatigue and minor stress corrosion cracking

Based on the above, *Technimet* concluded that the crack was initiated by **cyclic stresses** at the **stress concentration** created by the void. Propagation continued by a combination of **corrosion fatigue** and **stress corrosion cracking**.

Crack #3: P-38B Recirc line upstream of AF-40

A detailed failure analysis has not been conducted for Crack #3 because of an apparent common cause pattern taking place and the expectation that no new information would be obtainable from the new failure. As with Crack #1, the weld quality could not be assessed due to the repair plan.

Following the discovery of Crack #3, pipe vibration data was obtained from eight probes positioned along the vertical portion of the P-38A recirculation line, upstream and downstream relative to the location of Crack #1. A vibration analysis of the recirculation piping, in conjunction with a review of the previous findings of *Technimet*, was conducted by *Structural Integrity*. It was noted that the magnification photographs are more representative of a typical fatigue mechanism rather than stress corrosion cracking. Based on the review, *Structural Integrity* concluded that all evidence indicated a fatigue cracking mechanism.

MR 88-099 and Restricting Orifices

The QA scope of MR 88-099 was initially defined to include the recirc. piping from the tie-in to the AF Pump discharge piping to the manual isolation globe valve (1AF-15, AF-27, AF-40, and 2AF-53), which included the restricting orifices. This scope satisfied the guidance given in NRC SER dated 9/16/86 for the piping to be Seismic Class 1 to the second isolation valve in series from the AF Pump discharge. For reasons not apparent in available documentation, the QA boundary was revised at the time of implementation to only include piping to the first isolation valve (control valves 1AF-4002, 2AF-4002, AF-4007, and AF-4014).

The restricting orifices were obtained from the pump vendor according to non-QA purchase order #184514. A differential pressure of 2190 ft (≅ 948 psi) at 70 gpm was specified, but the basis could not be determined. However, the value (948 psi) was subsequently utilized in Calculation N-91-063 (P-38A & B

Recir Line System Characteristics) as the value for orifice DP resulting from 70 gpm. It is not known whether pertinent documentation/drawings were received, but the technical information is not presently documented, particularly the number of internal breakdown stages. By telephone interview, it was learned that the orifices contain two stages. Also, use of the device was not addressed in the 10CFR50.59 Safety Evaluation (SER 91-025-03) associated with modification MR 88-099B.

The non-QA status of the installed orifices was not consistent with the later issued Auxiliary Feedwater System Design Basis Document DBD-01, which describes the safety-related functions of restricting orifices RO-4008, RO-4015, 1RO-4003, and 2RO-4003 as:

(1) Limiting recirculation flow in the event that the associated flow control valve fails to close during system accident response,

(2) Providing the necessary pressure drop from the AF Pump discharge to the atmospheric conditions of the Condensate Storage Tank, and

(3) Passively maintaining the AF System pressure boundary integrity.

The result of the re-scoping in 1991 was determined in 11/96 to be in error and prompted the initiation of Q-List Discrepancy #96-058 to restore the affected piping and components to QA/Safety-related. The need to upgrade the recirc. pipe portion between the control valve and the orifice to QA/Safety-related was realized when it was recognized that a postulated pipe break in that portion would not be sensed by the DP switch that controls positioning of the recirc. control valve.

At the CARB presentation of Revision 0 of this RCE, it was requested that the modification process, as it applies to the QA scope reduction that occurred in Modification 88-099, be compared between the 1991 timeframe and the present. It was determined that a process and mechanism were in place, but were not strictly followed in this particular application. Besides lacking a technical basis for the re-scoping, the change was not performed in accordance with QP 3-1, Rev. 5 (Modification Requests). The re-scoping failed to involve the use of either an MR Addendum or a new MR. Under the present administration, a similar situation would have resulted in the initiation of an Engineering Change Request (NP 7.2.1 and 7.2.3). No recommendations were made involving the modification process, as the current administrative procedures are considered adequate to prevent a similar occurrence.

For purposes of comparison, details of the AF recirc orifice in use at Braidwood Station were obtained. The overall length of the orifice device is 20.63 inches, contains 10 breakdown stages, with a design pressure differential of 2005 psi and design flow of 100 gpm. The Point Beach device is 7 ½ inches in length. The pressure differential imposed on the device is approximately 1100 psi. Based on the physical length and the perception from the boroscope inspection, it appears that only 3 or 4 breakdown stages are provided. Braidwood reported that even with their 10-stage device, flow noise during operation was very excessive. Consequently, a second device of unknown detail was added to the system in series with the restricting orifice for further pressure reduction.

Auxiliary Feedwater Pumps

The recirculation piping of the motor-driven AF Pumps (P-38A & B) has been more susceptible to induced fatigue stresses than the turbine-driven pumps 1/2 P-29, because of more frequent and longer operating periods. The motor-driven pumps are operated during all startup and shutdown activities. The approximate run time for the motor-driven pumps is 150-300 hours per year, compared with approximately 15 hours per year for the turbine-driven pumps.

Evaluation Methodology & Analysis Techniques

This Root Cause Evaluation utilized Event & Causal Charting (Attachment 1) to construct the sequence of events. A Failure Mode Diagram (Attachment 2) was then developed to examine the contributions from various identified failure modes and determine the predominant mode. A Cause & Effect technique was used to construct the failure scenario and identification of the root and contributing cause.

Failure Mode Identification

Transgranular Stress Corrosion Cracking (TGSCC)

TGSCC is not considered to be the predominant failure mode for the following reasons:

- This failure mechanism depends on the co-existence of a susceptible material, tensile stress, and an aggressive environment containing a corrodant. Although the material and the stresses (from vibration to be discussed later) are present, the positive presence of a corrodant such as chlorine cannot be established. Plant procedures to control and monitor secondary chemistry assure that the chloride level is maintained <2 ppb.
- Residual chlorine typical of stainless steel component manufacturing was adequately addressed during implementation of modification MR 88-099 by the addition of procedural notes in the associated IWPs to flush new components with demineralized water before installation.
- Since the SCC mechanism is promoted by system chemistry, failures would be expected to be more widespread. Multiple points of crack initiation (at the same joint) and multiple locations (throughout interconnected systems) would be expected. Although there have been three recent crack occurrences, their location within a specific section of piping, known to be subjected to abnormal vibration, suggests a different failure mechanism.
- Because SCC is not particularly stress-related, the recurrence within the high-vibration AF Pump recirc. lines suggests a different failure mechanism.

Corrosion Fatigue Cracking

Corrosion Fatigue Cracking is not considered to be the predominant failure mode, for the same reasoning given in the above discussion. The primary difference between Corrosion Fatigue Cracking and Stress Corrosion Cracking is in the application of stress, the former characterized by cyclic loading, and in the later by a static tensile stress. As in the above discussion, positive evidence of the existence of a corrodant has not been concluded and therefore this mechanism is also unsupported.

Welding Deficiency

A welding deficiency is not considered to be the predominant failure mode. Only one of the three cracked welds (Crack #2) was able to be removed from the system without separation of the weld root. All three welds appropriately received only VT (visual examination) during installation. It was apparent from the failure analysis of Crack #2 that the crack was initiated at a location of likely stress concentration created by a void under the weld root. Cyclic loading was determined to be the initiating mechanism. The void was also observed at a non-crack location along the length of the weld. Slight concavity at the surface of the weld in combination with the root void represented a reduction in the shear strength of the weld, providing the path of crack propagation.

Cyclic Fatigue

Cyclic fatigue was determined to be the predominant failure mode responsible for the socket-weld failures. The reasons for this conclusion are as follows:

- The *Technimet* Report on Crack #2 concluded that crack initiation was by cyclic stresses at a stress concentration created by the weld configuration.
- *Structural Integrity Associates* review of *Technimet's* analysis concludes that the fracture morphology observed in both CRACK 1 & 2 are representative of high cycle fatigue cracking.
- Abnormal high vibration of the recirc. piping is readily obvious by hand-touch.
- *Structural Integrity Associates* has verified from vibration data that stresses from low frequency displacement are sufficient to fail welds of poor to fair quality.
- The direct cause of the excessive vibration is attributed to evidence of flow cavitation within orifice device RO-4008. A boroscope examination of the orifice internals revealed significant pitting damage. Since comparable vibration and noise are typical of the recirc. piping of all four AF Pumps, it is reasonable to assume that cavitation is also occurring in the orifices not inspected.

Failure Mode Summary

Based on metallurgical failure analyses and vibration analysis, apparent contributions to the three cases of weld cracking have been identified from the following failure modes:

- Transgranular Stress Corrosion Cracking

- Corrosion Fatigue Cracking
- Welding Deficiency
- Cyclic Fatigue

IV. Root Causes & Contributing Factors

Root Cause

The root cause of socket-weld failures in the AF Pump recirculation piping has been determined to be a design deficiency because the restricting orifice design breakdown pressure was incorrectly specified. The breakdown pressure rating, which dictates the number of internal breakdown stages, was specified in PO #184514 for restricting orifices RO-4008 and RO-4015 as 2190 feet @ 70 gpm and 100°F (2190 ft ≅ 948 psi). The orifices obtained are constructed with only two breakdown stages. The two-stage devices that were provided and installed are insufficient to avoid high turbulence and cavitation under actual conditions. Typical AF Pump discharge pressure is approximately 1250 psig. A reduction to at least 50 psig is necessary to avoid lifting downstream relief valve AF-4035. Therefore, a differential pressure breakdown of at least 1200 psi (≅ 2771 feet) should have been specified. The pipe vibration resulting from installation of the undersized orifices, has imposed cyclic fatigue stresses on vulnerable socket-welds.

Contributing Factors

- In at least one of the three cases of cracked welds, it is concluded that the **quality of the weld** contributed to the initiation of the failure. The presence of a sub-root void served to create a stress concentration. Noted slight concavity of the weld surface contributed to crack propagation. Identification of this deficient weld has not led to the suggestion that a programatic issue is involved.
- **The QA boundary in the recirc. piping modification was re-scoped** for an unapparent reason. The QA boundary was moved from the second isolation valve in the recirc. line, which included the restricting orifice, to the first isolation valve, which excluded the orifice.
- The re-scoping of the QA boundary apparently contributed to **omission of any discussion concerning the restricting orifice in the 10CFR50.59** evaluation for the modification.

V. Corrective Actions

Actions Complete

- An AF System water sample was obtained and analyzed for chlorine concentration, the results indicating chlorine content to be < 5 ppb.
- The U-bolt on support DB3A-1003G was tightened to allow recirc. piping vibration data to be compared before and after the tightening. (WO Tag #152252)

Short Term Corrective Actions

- CA #1 Responsible Group: Maintenance, Completion Due Date: 8/1/99

  Evaluate the throat profile of socket-welds in the AF Pump recirculation lines, from the tie-in to the pump discharge pipe to the first manual isolation valve. WO's 9909185, 9909186, 9909187, and 9909188 have been submitted to perform this activity. Welds determined to be unacceptable should be replaced with an oversized 2/1 configuration as described in EPRI PR 107455 and 111188.

- CA #2, Responsible Group: NMS, Completion Due Date: 8/15/99

  Obtain vibration data from the vertical portion of the P-38A recirc. piping for comparison to the data obtained prior to the tightening of the U-bolt on support DB3A-1003G.

Long Term Corrective Actions

- CA #1, Responsible Group: SDM, Completion Due Date: 4th quarter 2000

  In coordination with EWR 99-031, evaluate a resolution and process an appropriate design modification request to provide adequate pressure reduction in the AF recirculation lines.

  The resulting modification should include replacement of recirc. line welds from the 90° elbow upstream of the restricting orifice to the upstream weld on the recirc. line manual isolation valve. The socket welds should be oversized in a 2/1 configuration as described in EPRI PR 107455 and 111188. The modification should identify vibration acceptance criteria for the design. If the criteria cannot be met, vibration data should be obtained/analyzed so that the piping can be re-supported to reduce the vibration.

  The modification should ensure that appropriate design documentation of the replacement pressure-reducing method or device is obtained and incorporated into controlled station documents. *Modifications MR 99-029*A(*B)(*C)(*D) have been assigned for this action.*

- CA #2, Responsible Group: SEP, Completion Due Date: 2nd quarter 2000

  Conduct Engineering Training on the modification aspects of this Root Cause Evaluation, particularly the design deficiency related to the inadequate specification of the orifice differential breakdown pressure.

VI. References

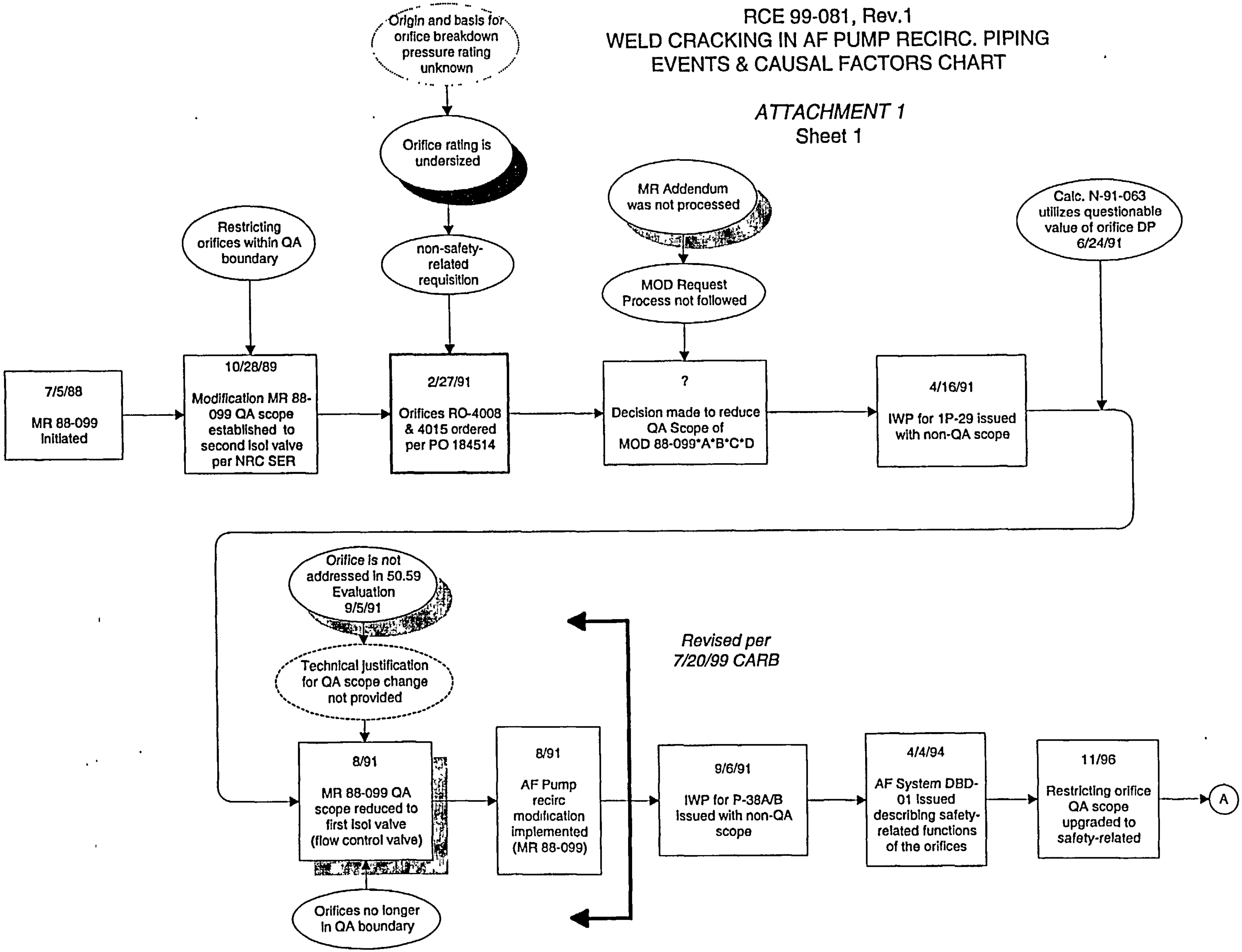
1. **MR 88-099*A, B, C, D,** *Increased Aux. Feedwater Pump Mini-Recirc Line Capacity*
2. **CR 99-1391,** *SCAQ on Potential Common Mode Failure Mechanism*
3. **CR 99-1368,** *P-38B crack at AF-40,* discovered 5/19/99 (Crack #3)
4. **CR 99-1163,** *P-38A crack at elbow,* discovered 4/24/99 (Crack #2)
5. **CR 98-2589,** *RO-4008 Pressure Reducing Orifice Damage*
6. **CR 98-2550,** *P-38A crack at AF-27,* discovered 6/27/98 (Crack #1)
7. **CR 97-0720,** *Control Room Background Noise Level*
8. **EWR 99-031,** *AF Pump Recirc Noise in Control Room*
9. Technimet Report No. 100353, *Failure Analysis of a Pipe Section,* 8/6/98
10. Technimet Report No. 101609, *Failure Analysis of a Pipe Section Weld,* 6/2/99
11. Letter from Larry Dorfman, Structural Integrity Associates, Inc., to John P. Schroeder,WE, 6/10/99
12. P&ID **M-217 Sheet 1,** *Auxiliary Feedwater System*
13. Bechtel Isometric Drawing **P-103**
14. Bechtel Isometric Drawing **P-159**
15. Primary ISI Isometric Drawing **ISI-PRI-1352**
16. Primary ISI Isometric Drawing **ISI-PRI-1353**
17. Primary ISI Isometric Drawing **ISI-PRI-1354**
18. Primary ISI Isometric Drawing **ISI-PRI-2338**
19. Drawing **SK-AFW-008/88-099,** Working Isometric for *P-38A Recirc Line to CST*
20. Drawing **SK-AFW-009/88-099,** Working Isometric for *P-38B Recirc Line to CST*
21. PBNP FSAR Section 10.2, *Auxiliary Feedwater System*
22. Design Basis Document **DBD-01,** *Auxiliary Feedwater System*
23. **NRC Bulletin 88-04,** *Potential Safety-Related Pump Loss*
24. NRC Generic Letter 89-04
25. Q-List Discrepancy 96-058
26. Calculation **N-91-063,** *P38A & B Recirc. Line System Characteristics*
27. Calculation **N-91-069,** *Impact of Higher Capacity Recirc. System for the ... Motor Driven AFW Pumps*
28. Structural Integrity Associates, Inc. Report No. SIR-99-136, November 1999, *Failure Assessment of the WEPCO – PBNP's Auxiliary Feedwater Recirculation Line Socket Weld Fatigue Failure*
29. **MR 99-029*A(*B)(*C)(*D),** *Aux. Feedwater Pumps Minimum Flow Recirc Line Orifice*

VII. Attachments

Attachment 1:	Event & Causal Factors Chart, Sheets 1 and 2
Attachment 2:	Failure Mode Diagram, Sheets 1 and 2

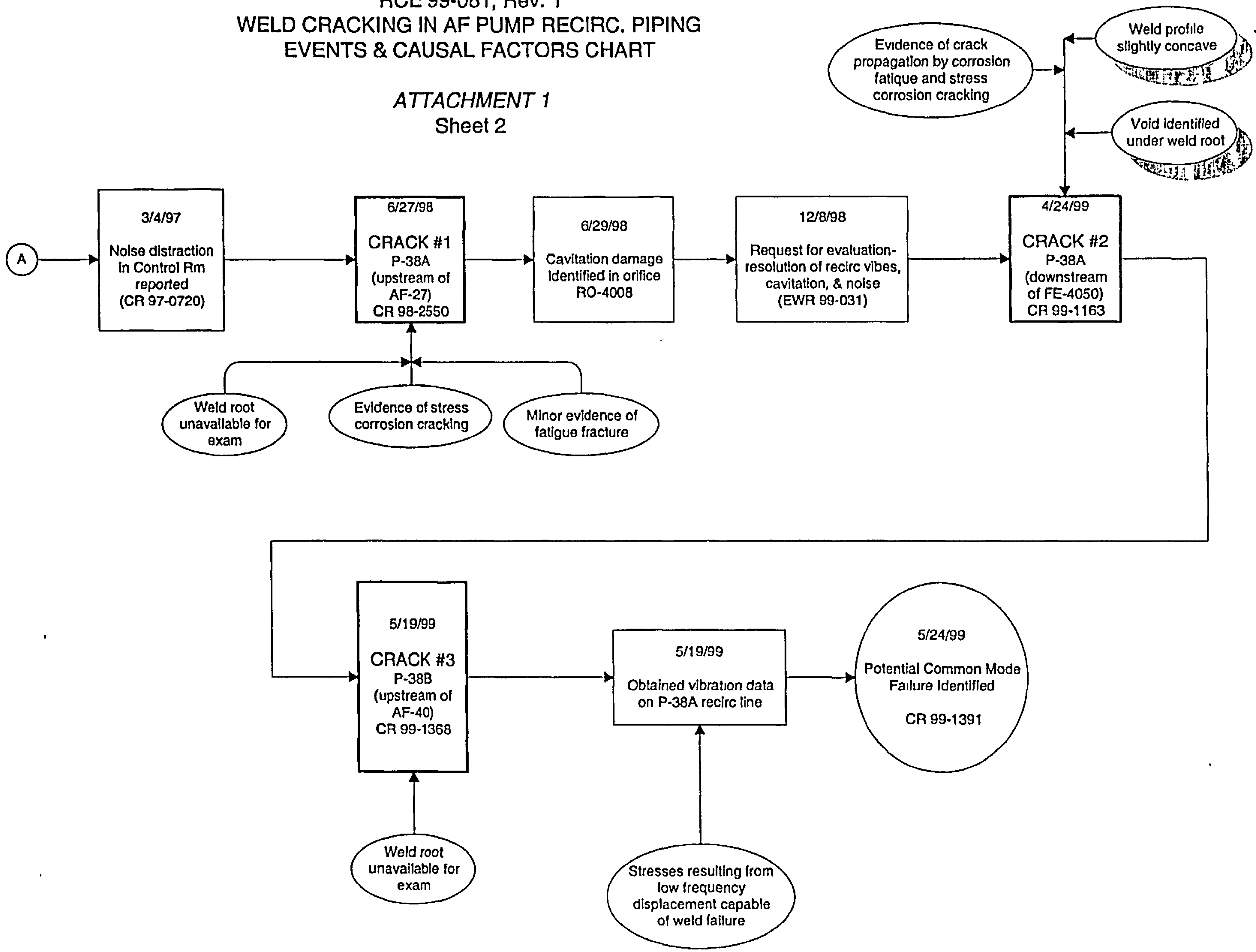
RCE 99-081, Rev.1
WELD CRACKING IN AF PUMP RECIRC. PIPING
EVENTS & CAUSAL FACTORS CHART

ATTACHMENT 1
Sheet 1



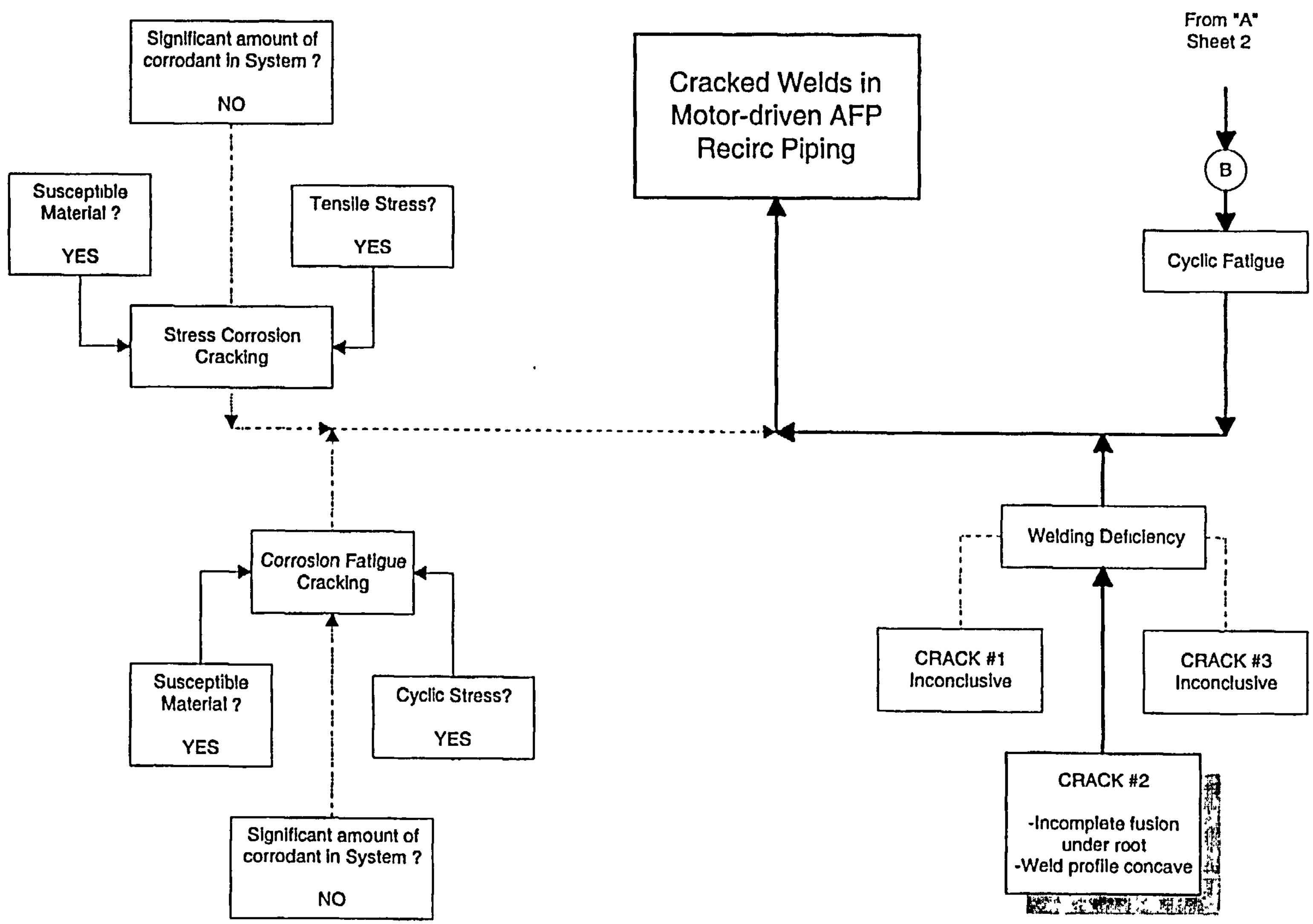
RCE 99-081, Rev. 1
WELD CRACKING IN AF PUMP RECIRC. PIPING
EVENTS & CAUSAL FACTORS CHART

ATTACHMENT 1
Sheet 2



RCE 99-081, Rev. 1
WELD CRACKING FAILURE MODE DIAGRAM

ATTACMENT 2
Sheet 1



RCE 99-081, Rev. 1
WELD CRACKING FAILURE MODE DIAGRAM

ATTACMENT 2
Sheet 2