50-269/270/287

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

January 5, 1999

Mr. W. R. McCollum, Jr.
Vice President, Oconee Site
Duke Energy Corporation
P. O. Box 1439
Seneca, SC 29679

SUBJECT: STAFF ASSESSMENT OF CRACKING IN UNISOLABLE SECTIONS OF HIGH PRESSURE INJECTION MAKEUP LINES AT OCONEE NUCLEAR STATION, UNITS 2 AND 3 AND OTHER BABCOCK AND WILCOX PLANTS (TAC NO. M98454)

Dear Mr. McCollum:

On April 22, 1997, Oconee Nuclear Station Unit 2 was shut down because of unidentified reactor coolant system leakage that exceeded the Technical Specification limit of 1 gallon per minute (gpm) by as much as 12 gpm. Duke Energy Corporation (Duke) subsequently identified an unisolable leak in the High Pressure Injection Makeup (HPI/MU) line 2A1 resulting from a through-wall crack in the weld connecting the HPI/MU pipe and the safe-end of the 2A1 reactor coolant loop nozzle. The thermal sleeve in this nozzle was also found to be loose and cracked. Duke also performed inspections of the HPI/MU lines in Oconee Units 1 and 3. No flaws were found in Unit 1 nozzles and sleeves. However, partial-wall flaws were found at the same location in nozzle 3A1 in Unit 3. Likewise, the thermal sleeve in this nozzle was also loose and cracked.

As a result of the findings at Oconee Units 2 and 3, the Babcock and Wilcox Owners Group (B&WOG) performed inspections of the HPI/MU nozzles in the following plants: Crystal River Unit 3, Davis Besse Unit 1, Arkansas Nuclear One Unit 1, and Three Mile Island Unit 1. No cracks were detected in any nozzles in these units.

The B&WOG submitted an interim report (Reference 1 of Assessment) describing the event at Oconee and the inspections performed at Oconee and the other B&WOG plants. Since the root cause of the cracking has not been established, the B&WOG also committed to perform further studies of the event. Results of these studies will not be available until the year 2000.

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Enclosed for your information is a staff assessment of the B&WOG interim report and the Oconee event.

Sincerely,

ORIGINAL SIGNED BY:

David E. LaBarge, Senior Project Manager
Project Directorate II-2
Division of Reactor Projects - I/II
Office of Nuclear Reactor Regulation

Docket Nos. 50-269, 50-270,
and 50-287

Enclosure: Assessment

cc w/encl: See next page

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Enclosed for your information is a staff assessment of the B&WOG interim report and the Oconee event.

Sincerely,

David E. LaBarge, Senior Project Manager
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Division of Reactor Projects - I/II
Office of Nuclear Reactor Regulation

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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

OFFICE OF NUCLEAR REACTOR REGULATION

ASSESSMENT ON THE OCONEE NUCLEAR STATION, UNITS 1, 2, AND 3 HIGH PRESSURE INJECTION SYSTEM MAKEUP LINE WELD CRACK AND RELATED BABCOCK AND WILCOX OWNERS GROUP RESPONSE

1.0 BACKGROUND

On April 22, 1997, Oconee Unit 2 was shut down because of unidentified reactor coolant system (RCS) leakage. The leakage was subsequently identified as an unisolable leak in the High Pressure Injection MakeUp (HPI/MU) line 2A1, resulting from a through-wall crack in the weld connecting the HPI/MU pipe and the safe-end of the 2A1 reactor coolant loop (RCL) nozzle.

Following this event, the NRC staff requested that the HPI/MU nozzles in all Babcock and Wilcox Owners Group (B&WOG) plants be assessed or examined for similar cracks. In Reference 1, the B&WOG submitted a report describing the inspection results, inspection histories, and details of the thermal sleeves in the B&WOG plants with the exception of the Oconee plants. However, the Oconee licensee, Duke Energy Corporation (Duke), submitted a Licensee Event Report (Reference 2) separately that described the circumstances of the failure at Oconee Unit 2 in detail.

2.0 EVENT DESCRIPTION

2.1 Oconee Unit 2

On April 22, 1997, at 12:50 p.m., Oconee Unit 2 was shut down because unidentified RCS leakage exceeded the Technical Specification limit of 1 gallon per minute (gpm). From the time of initial leak indications at approximately 10:45 p.m. on April 21, 1997, until reactor pressure was sufficiently reduced, the leakage rate rose from approximately 2 gpm to approximately 12 gpm. The leakage was subsequently identified as an unisolable leak in the HPI/MU line 2A1 resulting from a through-wall crack in the weld connecting the HPI/MU pipe to the safe-end of the 2A1 RCL nozzle.

The Oconee 2A1 HPI/MU nozzle assembly consists of the HPI/MU 2.5-inch diameter pipe/safe-end/thermal sleeve (see attached Figure 1 - Original Design). The sleeve is attached by contact rolling to the inner surface of the safe-end. A 1-inch diameter "warming" line taps into the bottom of the HPI/MU pipe immediately upstream of the pipe/safe-end weld.

In Reference 3, Duke submitted the results of a metallurgical examination of the weld and determined that the crack consisted of a 360-degree inside surface flaw. The flaw depth increased gradually from about 30 percent into the wall until it became through-wall over a 77-degree arc length (see attached Figure 2). The examination also found a gap in the contact area between the thermal sleeve and the safe-end, indicative of loss of contact that caused the thermal sleeve in this line to loosen (see attached Figure 1). The thermal sleeve was found to be cracked with portions missing from the end that extends into the RCS flow path. Significant wear damage was also found at both the upstream (the rolled end) and the downstream end. In addition, small cracks were found in the pipe in the vicinity of the "warming" line nozzle.

Duke also performed video examinations of the other thermal sleeves of the Unit 2 HPI system. No evidence of damage was found. Ultrasonic Testing (UT) and Radiographic Testing of the welds and the thermal sleeves in the other HPI nozzles showed no indications of cracking or loosening, or other signs of degradation.

Although the cause of the cracking is not well understood, Duke has identified a number of thermal/mechanical conditions that may have contributed to the through-wall cracking of the 2A1 pipe to safe-end weld. The precise contribution to cracking of each of these conditions is not presently known. However, Duke has hypothesized that, in addition to the thermal cycling experienced at the nozzle during heatup/cooldown and other plant transients, a likely contributor to the fatigue may have been the alternate heating and cooling of the weld by intermittent mixing of the hot reactor coolant causing turbulence at the penetration, the water flowing through the warming line, and the cooler normal makeup water flowing through the associated HPI/MU line. This had the effect of loosening the sleeve sufficiently to develop a gap in the contact area between the thermal sleeve and the safe-end. Once the gap developed, additional reactor coolant in-leakage is thought to have occurred through the gap. The growth of the gap may also have been influenced by flow-induced vibration of the sleeve due to vortex shedding in the reactor coolant flow. Although the precise contribution of the gap to the thermal cycling is unclear, it is believed that it accelerated the crack propagation rate in the piping.

This phenomenon was identified as the probable cause for similar safe-end cracking observed at Crystal River Unit 3 and other B&W plants (including Oconee) in the early 1980's. This issue had previously been addressed in Information Notice 82-09 (Reference 4) and Generic Letter (GL) 85-20 (Reference 5).

A reexamination of radiographs made in April 1996 of the Oconee 2A1 nozzle revealed that Duke had failed to identify the gap that had developed in the safe-end/thermal sleeve contact area. Duke had also failed to follow all the original recommendations in GL 85-20 for augmented UT programs. Duke had performed the recommended UT of the safe-ends of the HPI/MU lines; however, Duke did not inspect the adjacent piping as recommended. In addition, Duke failed to perform UT of the weld between the safe-end and adjacent pipe, a discontinuity where cracking could be expected to form.

2.2 Oconee Unit 3

Duke also reviewed the 1996 radiographs of the safe-ends in Oconee Unit 3. The 3A1 HPI/MU line was found to have a gap in the safe-end/thermal sleeve contact area. As a result of the gap in the 3A1 safe-end, Oconee Unit 3 was shut down on May 2, 1997. UT examinations

identified apparent cracking in the 3A1 safe-end. This safe-end was removed and metallurgically examined. A visual examination also revealed cracks in the thermal sleeve. Minor gaps in the other safe-end/thermal sleeve contact areas were determined not to have grown, the rolled area of the thermal sleeve was acceptable, and UT examinations of the other Oconee Unit 3 HPI nozzle assemblies revealed no cracking.

2.3 Oconee Unit 1

The Oconee Unit 1 nozzles have a double thermal sleeve design (see attached Figure 3). Radiographic inspection in the period from 1983 to 1989 indicated that no gap existed in three of the four thermal sleeves. A gap was found in the thermal sleeve in the 1B 2 HPI line, which had not grown during the inspection period. Advantages of the double thermal sleeve, as stated by Duke, include (1) greater stiffness, (2) greater thermal resistance, and (3) reduced flow area, with corresponding increased flow velocity. Duke concluded that this design resulted in the Unit 1 sleeves being less susceptible to thermal damage.

2.4 Compensatory Actions

As corrective action, Duke replaced the cracked safe-ends and the safe-end/pipe welds in Oconee Units 2 and 3. The thermal sleeves were also replaced with an improved sleeve design, also shown in Figure 1 - Original Design. In addition, Duke assembled a Failure Investigation Process (FIP) team to determine the root cause of the event in Unit 2. The team concluded that Duke had failed to implement an effective HPI nozzle inspection program based on available industry recommendations, and had failed to effectively evaluate known problems (industry and in-house experience) and implement appropriate corrective actions from 1982 to the present. The FIP team published its findings in a report dated July 24, 1997 (Reference 6). The staff has examined this report and finds it thorough and complete.

Duke also submitted a revision of the Oconee Units 1, 2, and 3 third interval 10-year Inservice Inspection (ISI) Program. This revision commits to meet or exceed the requirements in GL 85-20 previously committed to regarding examination of HPI system components. The staff reviewed the submittal and determined that the proposed ISI program is acceptable, with the condition that all future ultrasonic examinations should be performed based on the 1992 Edition, with the 1993 Addenda, of the American Society of Mechanical Engineers (ASME) Code Section XI, Appendix VIII requirements, or be based on calibration blocks with cracks that simulate the type of crack observed in Oconee Unit 2. Duke also agreed to submit the fourth interval 10-year ISI program for all three Oconee units 6 months prior to the start of this interval. The staff reviewed the proposed program and found it acceptable, subject to the condition as previously stated (Reference 7).

Other measures taken by Duke include the temporary installation of thermocouples in Oconee Units 2 and 3 to measure temperature versus time histories in the affected zones, and increasing the minimum make-up flow in these units. The make-up flow in Unit 1 was already higher than in the other two units.

2.5 Other B&WOG Plants

Subsequent to the event at Oconee Unit 2, other B&WOG plants also performed evaluations and inspections of the HPI/MU nozzles and attached piping. These were Davis-Besse Unit 1, Crystal River Unit 3, Arkansas Nuclear One Unit 1, and Three Mile Island Unit 1.

In response to a staff request for information dated May 27, 1997 (Reference 8), the B&WOG submitted an interim report (Reference 1) on the cracking found in Oconee Unit 2, and the results of the inspections of the other B&WOG plants. No indications were reported in any nozzles of these systems. The staff has reviewed this interim report and finds it generally acceptable.

The interim report did not attempt to determine the root cause of the cracking. As part of the generic investigation of this event, the B&WOG committed, through Framatome, to conduct a more detailed evaluation of the root cause of the cracking at Oconee Units 2 and 3. This evaluation will be based on analytical studies using computational fluid dynamics methodology. A final report describing the results of these studies is scheduled to be submitted sometime in 2000.

3.0 STAFF ACTIVITIES

On June 6, 1997, the staff of Region II completed a special inspection of Oconee, which focused on the integrated efforts by Duke to investigate the causes of the event and the corrective actions undertaken. The staff concluded that there had been a failure by Duke to adequately implement augmented inspections to detect cracks in HPI lines, and to correct known problems on a timely basis. The staff published its findings in a special inspection report dated June 27, 1997 (Reference 9).

On July 9, 1997, the staff published NRC Information Notice 97-46, "Cracking in High-Pressure Injection Piping," (Reference 10) to alert the industry of the circumstances of this event.

During the review of the inspections performed by Duke, the staff became aware that the ASME Section XI Code requires no volumetric (ultrasonic) examination of Class 1 piping in the range of 1-inch to 4-inch nominal pipe size. This is inconsistent with the requirement for Class 2 piping, which does specify volumetric examination for piping in this size range. To eliminate this inconsistency in the Code, the staff has requested that the ASME include volumetric examination of Class 1 piping in this size range. However, since publication of revised Code requirements cannot be expected in the near future, and considering the safety significance of the HPI system, the staff has included provisions for this examination in a currently proposed rulemaking.

4.0 CONCLUSION

Duke has replaced the cracked safe-end welds in Oconee Units 2 and 3, and has also installed improved thermal sleeves. Duke has also submitted an ISI plan, which the staff finds acceptable. Duke has also adopted other compensatory measures, such as increasing the minimum make-up flow and installing temporary thermocouples for monitoring nozzle temperatures at various locations on the injection line. Duke will use this information for design studies of temperature transients. The staff finds these measures acceptable.

Based on its evaluation of the B&WOG interim report, Duke's responses to various staff requests for information, and meetings between the staff and Duke, the staff concludes that B&WOG has satisfactorily and reasonably addressed potential cracking of the safe-ends in the HPI/MU nozzles in all B&WOG plants.

Attachments:
1. Figure 1 - Units 2 and 3 Thermal Sleeves
2. Figure 2 - Warming Line Flow and Crack Orientation
3. Figure 3 - Unit 1 Thermal Sleeve

REFERENCES

1. Letter of June 5, 1997, from W. W. Foster, Duke Energy Corporation, to the Document Control Desk with enclosed B&WOG Report "Interim B&W Owners Group Report on HPI/MU Nozzle Cracking" (FTI Document No. 51-5000239-00), dated June 5, 1997.

2. Oconee Nuclear Station, Unit 2, Licensee Event Report dated May, 21, 1997.

3. Metallurgical Analysis Report #2181, "ONS 2 & 3 HPI/MU Nozzle Components," Duke Energy Corporation, June 30, 1997.

4. NRC Information Notice 82-09, "Cracking in Piping of Makeup Coolant Lines at B&W Plants," dated March 31, 1982.

5. NRC Generic Letter 85-20, "Resolution of Generic Issue 69: High Pressure Injection/Make Up Nozzle Cracking in Babcock and Wilcox Plants," dated November 11, 1985.

6. Oconee Nuclear Station, Unit 2, Failure Investigation Process Final Report, "Pipe Weld Failure, 4/21/97, PIP 2-097-1324," dated July 24, 1997.

7. Letter of October 23, 1997, from D. E. LaBarge, NRC, to W. R. McCollum, Duke Energy Corporation, "High Pressure Injection System Augmented Inservice Inspection Program - Oconee Nuclear Station Units 1, 2 and 3."

8. Letter of May 27, 1997, from J. L. Birmingham, NRC, to W. W. Foster, Chairman, B&WOG Steering Committee.

9. Letter of June 27, 1997, from J. P. Jaudons, NRC, to J. W. Hampton, Duke Energy Corporation, with enclosed NRC Special Inspection Report.

10. NRC Information Notice 97-46, "Unisolable Crack in High Pressure Injection Piping," dated July 9, 1997.

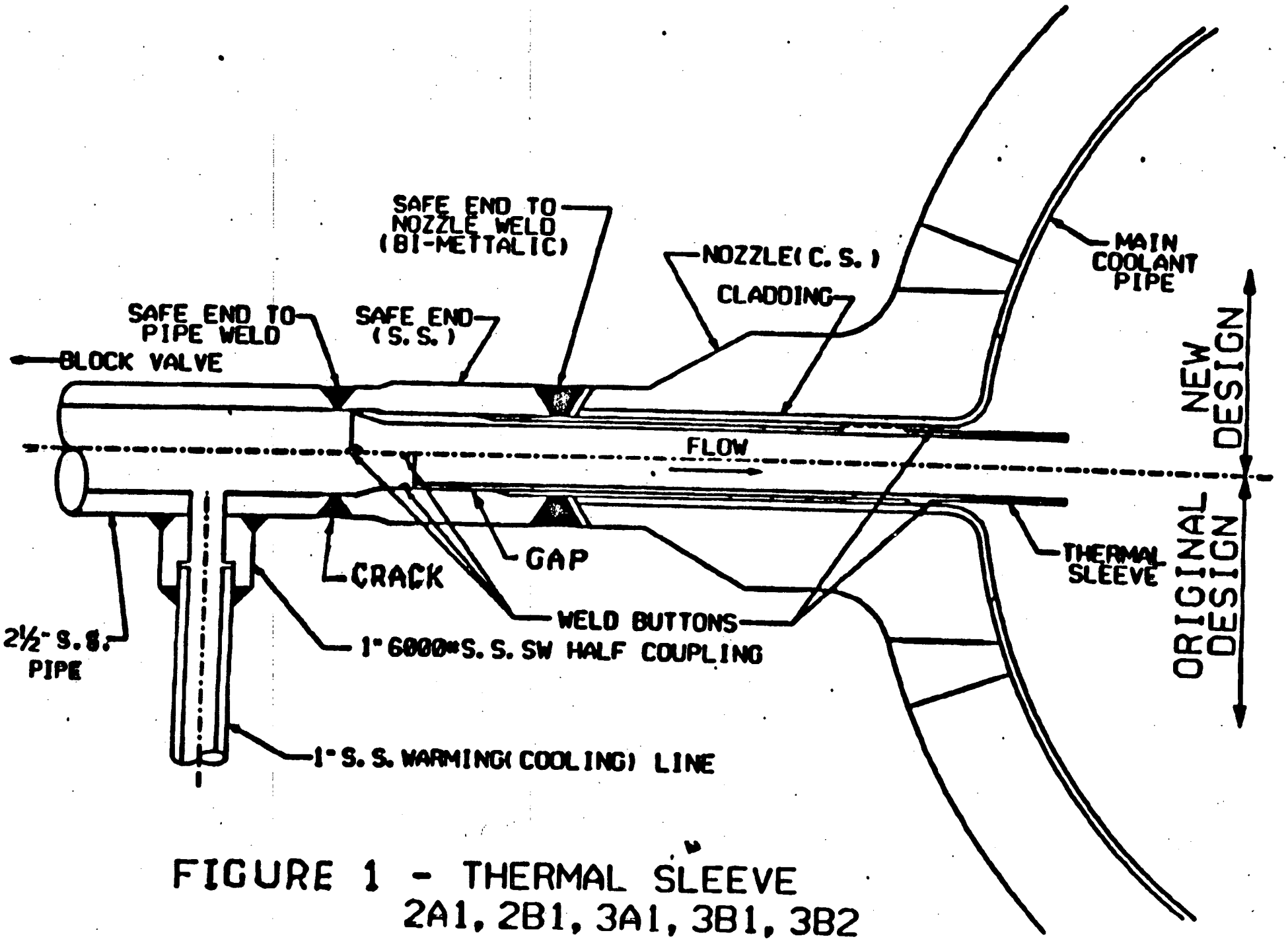

FIGURE 1 - THERMAL SLEEVE
2A1, 2B1, 3A1, 3B1, 3B2

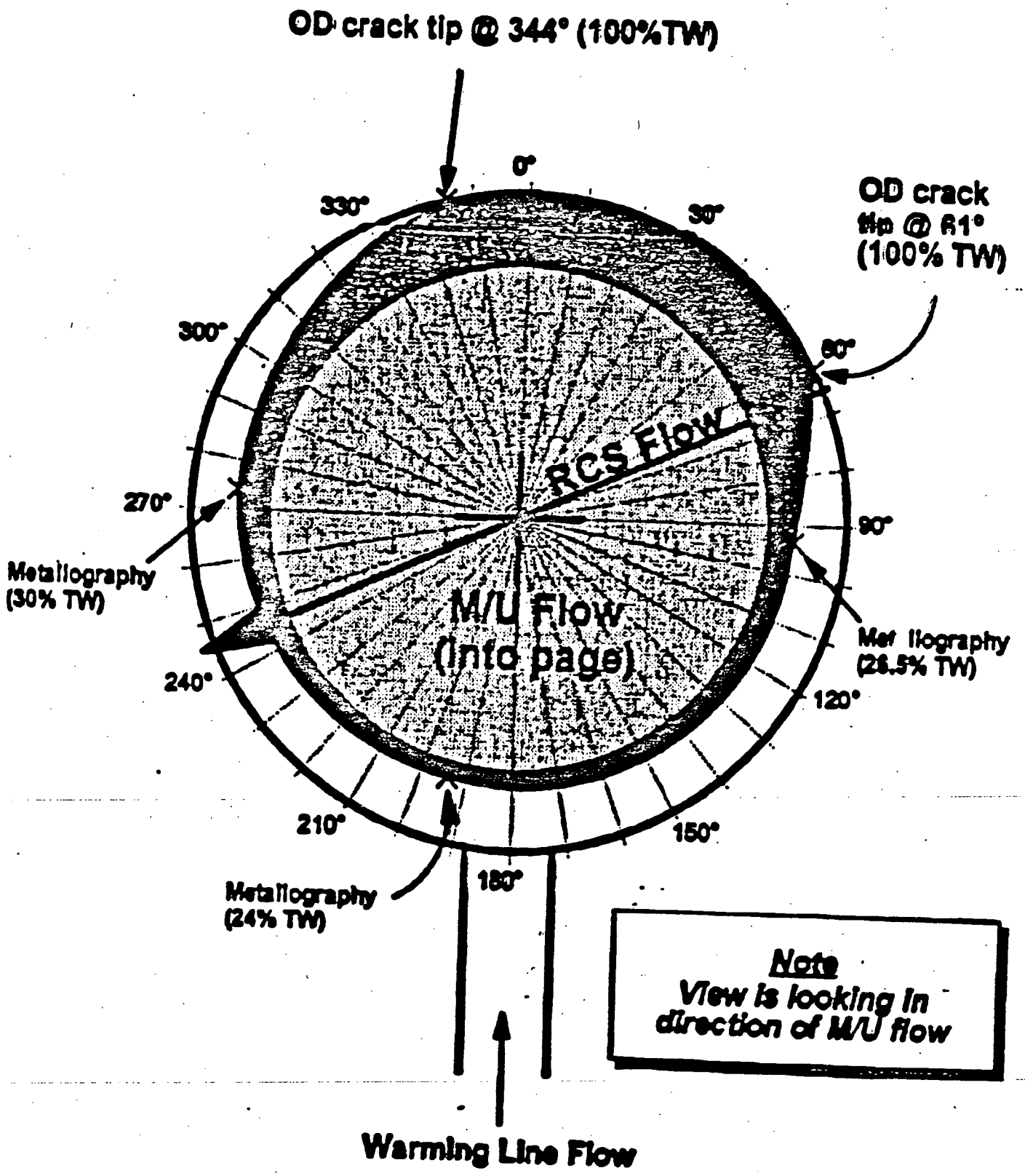
OD crack tip @ 344° (100%TW)
0°
30°
60°
90°
120°
150°
180°
210°
240°
270°
300°
330°
OD crack tip @ 61° (100% TW)
RCS Flow
M/U Flow (Into page)
Metallography (30% TW)
Metallography (26.5% TW)
Metallography (24% TW)
Note
View is looking in direction of M/U flow
Warming Line Flow

FIGURE 2

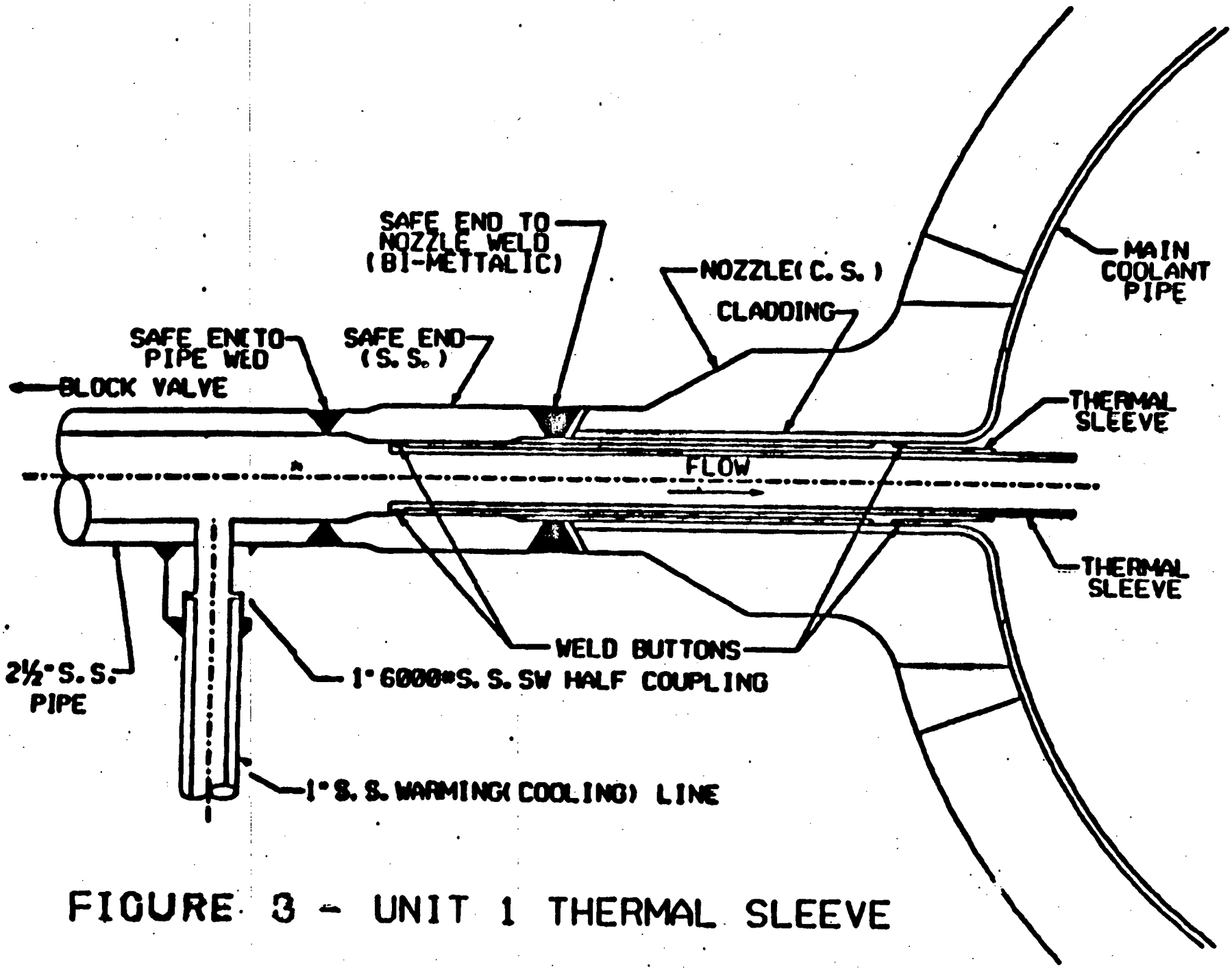

FIGURE 3 - UNIT 1 THERMAL SLEEVE