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United States Nuclear Regulatory Commission
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Subject: High Pressure Injection/Makeup Nozzle Thermal Sleeve

Gentlemen:

On July 2, 1988, during a combined ASME Section XI and pre-fueling visual inspection several 'loose parts' were discovered in the Davis-Besse Nuclear Power Station (DBNPS) Unit 1 reactor vessel. Among these loose parts were two metallic pieces resembling half cylinders. The most likely origin of the two metallic pieces was determined to be a high pressure injection (HPI) nozzle thermal sleeve. A fiberscope inspection revealed that approximately three inches had broken from the thermal sleeve for the HPI nozzle which is also used for normal makeup flow. The broken portion was from the end of the sleeve protruding into the reactor coolant system (RCS) cold leg.

This letter is being submitted to satisfy the:

- Requirements of ASME Section XI Article IWB 3000 for acceptance of flaw indication by evaluation,
- Commitment contained in LER No. 88-015 dated 8/1/88, and
- Commitment made by TE in a meeting with NRC on 8/16/88 on this subject.

A047
1/1

CHANGE:	LTR	ENCL
LPDR	1	1NP
NSIC	1	1NP
NRC PDR	1	1NP

APPENDIX C ATTACHMENTS CONTAIN
PROPRIETARY INFORMATION
PER 10 CFR 2.790
WITHHOLD FROM PUBLIC DISCLOSURE

WHEN SEPARATED FROM APPENDIX C ATTACHMENTS
HANDLE THIS DOCUMENT AS DECONTROLLED

THE TOLEDO EDISON COMPANY EDISON PLAZA 300 MADISON AVENUE TOLEDO, OHIO 43652

The four Appendices to this letter provide a detailed description of the activities associated with the thermal sleeve failure and subsequent inspections and repair. Appendix A provides information on the thermal sleeves including discussions on the field inspections, laboratory metallographic analysis and results, postulated cause of the failure, and replacement thermal sleeve design. Appendix B provides information on the HPI nozzle and associated piping design, NDE examinations (PT and UT), course of action, and near term actions. Appendix C provides the fracture mechanics analysis performed to assure no unacceptable crack growth would occur as a result of operating without removing the crack indications found on the inside of the HPI/makeup nozzle. Appendix D provides a discussion of the future monitoring of the HPI nozzles and thermal sleeves.

As discussed in more detail in Appendix C, inspection of the HPI/makeup nozzle interior clad surface showed crack-like indications throughout the area where the thermal sleeve had failed permitting cold water impingement directly on the cladding. A conservative analysis was performed of the nozzle using fracture mechanics techniques and the most limiting design transients. The analysis results indicate that with the thermal sleeve intact the expected crack growth is expected to be acceptable for the 40-year lifetime of the unit. Based on these results, Toledo Edison plans to operate the unit until the next refueling outage at which time the HPI nozzle will be re-examined, re-evaluated, and repaired as required. As requested during the August 16, 1988 meeting, Toledo Edison will provide an update to the NRC, about six months following restart from the current refueling outage, regarding the progress of evaluation of this problem and progress in preparation for the sixth refueling outage.

Enclosure 1 provides a list of commitments made within this submittal. The information provided in Appendix C, Attachments 1, 2, and 3 is considered proprietary as sworn to by B&W in the affidavit provided as Enclosure 2 and, therefore, should be controlled in accordance with 10 CFR 2.790.

If there are any further questions, please contact Mr. R. W. Schrauder, Nuclear Licensing Manager, at (419) 249-2366.

Very truly yours,

GBK/tlt

Attachments

cc: A. B. Davis, NRC Regional Administrator
A. W. DeAgazio, NRC/NRR DB-1 Project Manager
DB-1 Resident Inspector

**APPENDIX C ATTACHMENTS CONTAIN
PROPRIETARY INFORMATION
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Enclosure 1
Commitments

1. Six months following restart from fifth refueling outage, provide an update to NRC regarding the progress of the evaluation of the thermal sleeve and nozzle problem and progress of the actions to be taken during the sixth refueling outage.
2. Prior to restart provide for means of accurately setting the minimum by-pass flow.
3. Prior to restart provide procedures to clearly establish administrative control of by-pass flow.
4. Evaluate and increase minimum by-pass flow as practical.

AFFIDAVIT OF JAMES H. TAYLOR

A. My name is James H. Taylor. I am Manager of Licensing Services in the Nuclear Power Division of the Babcock & Wilcox Company, and as such I am authorized to execute this Affidavit.

B. I am familiar with the criteria applied by Babcock & Wilcox to determine whether certain information of Babcock & Wilcox is proprietary and I am familiar with the procedures established within Babcock & Wilcox, particularly the Nuclear Power Division, to ensure the proper application of these criteria.

C. In determining whether a Babcock & Wilcox document is to be classified as proprietary information, an initial determination is made by the Unit Manager, who is responsible for originating the document, as to whether it falls within the criteria set forth in Paragraph D hereof. If the information falls within any one of these criteria, it is classified as proprietary by the originating Unit Manager. This initial determination is reviewed by the cognizant Section Manager. If the document is designated as proprietary, it is reviewed again by Licensing personnel and other management within the Nuclear Power Division as designated by the Manger of Licensing Services to assure that the regulatory requirements of 10 CFR Section 2.790 are met.

D. The following information is provided to demonstrate that the provisions of 10 CFR Section 2.790 of the Commission's regulations have been considered:

(i) The information has been held in confidence by the Babcock & Wilcox Company. Copies of the document are clearly identified as proprietary. In addition, whenever Babcock & Wilcox transmits the information to a customer, customer's agent, potential customer or regulatory agency, the transmittal requests the recipient to hold the information as proprietary. Also, in order to strictly limit any potential or actual customer's use of proprietary information, the following provision is included in all proposals submitted by Babcock & Wilcox, and an applicable version of the proprietary provision is included in all of Babcock & Wilcox's contracts:

> "Purchaser may retain Company's proposal for use in connection with any contract resulting therefrom, and, for that purpose, make such copies thereof as may be necessary. Any proprietary information concerning Company's or its Supplier's products or manufacturing processes which is so designated by Company or its Suppliers and disclosed to Purchaser incident to the performance of such contract shall remain the property of Company or its Suppliers and is disclosed in confidence, and Purchaser shall not publish or otherwise disclose it to others without the written approval of Company, and no rights, implied or otherwise, are granted to produce or have produced any products or to practice or cause to be practiced any manufacturing processes covered thereby.
>
> Notwithstanding the above, Purchaser may provide the NRC or any other regulatory agency with any such proprietary information as the NRC or such other agency may require; provided, however, that

AFFIDAVIT OF JAMES H. TAYLOR (Cont'd.)

Purchaser shall first give Company written notice of such proposed disclosure and Company shall have the right to amend such proprietary information so as to make it non-proprietary. In the event that Company cannot amend such proprietary information, Purchaser shall, prior to disclosing such information, use its best efforts to obtain a commitment from NRC or such other agency to have such information withheld from public inspection.

Company shall be given the right to participate in pursuit of such confidential treatment."

(ii) The following criteria are customarily applied by Babcock & Wilcox in a rational decision process to determine whether the information should be classified as proprietary. Information may be classified as proprietary if one or more of the following criteria are met:

a. Information reveals cost or price information, commercial strategies, production capabilities, or budget levels of Babcock & Wilcox, its customers or suppliers.

b. The information reveals data or material concerning Babcock & Wilcox research or development plans or programs of present or potential competitive advantage to Babcock & Wilcox.

c. The use of the information by a competitor would decrease his expenditures, in time or resources, in designing, producing or marketing a similar product.

d. The information consists of test data or other similar data concerning a process, method or component, the application of which results in a competitive advantage to Babcock & Wilcox.

e. The information reveals special aspects of a process, method, component or the like, the exclusive use of which results in a competitive advantage to Babcock & Wilcox.

f. The information contains ideas for which patent protection may be sought.

The document(s) listed on Exhibit "A", which is attached hereto and made a part hereof, has been evaluated in accordance with normal Babcock & Wilcox procedures with respect to classification and has been found to contain information which falls within one or more of the criteria enumerated above. Exhibit "B", which is attached hereto and made a part hereof, specifically identifies the criteria applicable to the document(s) listed in Exhibit "A".

(iii) The document(s) listed in Exhibit "A", which has been made available to the United States Nuclear Regulatory Commission was made available in confidence with a request that the document(s) and the information contained therein be withheld from public disclosure.

(iv) The information is not available in the open literature and to the best of our knowledge is not known by Combustion Engineering, EXXON, General Electric, Westinghouse or other current or potential domestic or foreign competitors of Babcock & Wilcox.

(v) Specific information with regard to whether public disclosure of the information is likely to cause harm to the competitive position of Babcock & Wilcox, taking into account the value of the information to Babcock & Wilcox; the amount of effort or money expended by Babcock & Wilcox developing the information; and the ease or difficulty with which the information could be properly duplicated by others is given in Exhibit "B".

E. I have personally reviewed the document(s) listed on Exhibit "A" and have found that it is considered proprietary by Babcock & Wilcox because it contains information which falls within one or more of the criteria enumerated in Paragraph D, and it is information which is customarily held in confidence and protected as proprietary information by Babcock & Wilcox. This report comprises information utilized by Babcock & Wilcox in its business which afford Babcock & Wilcox an opportunity to obtain a competitive advantage over those who may wish to know or use the information contained in the document(s).

AFFIDAVIT OF JAMES H. TAYLOR (Cont'd.)

James H. Taylor
JAMES H. TAYLOR

State of Virginia)
)   SS. Lynchburg
City of Lynchburg)

James H. Taylor, being duly sworn, on his oath deposes and says that he is the person who subscribed his name to the foregoing statement, and that the matters and facts set forth in the statement are true.

James H. Taylor
JAMES H. TAYLOR

Subscribed and sworn before me
this 10th day of September 1988.

Joyce C. Koss
Notary Public in and for the City
of Lynchburg, State of Virginia

My Commission Expires April 5, 1992

Exhibit A

Makeup/High Pressure Thermal Sleeve

Toledo Edison Serial No. 1580

Exhibit B

Description of Material	Applicable Criteria
Attachments 1, 2, 3 to Appendix C	c, d, e

Attachments:

1. 32-1172763-04, "HPI Nozzle Flaw Evaluation"
2. 32-1172847-00, "Fracture Analysis of High Cycle Thermal Loading"
3. 32-1173039-01, "HPI Nozzle Flaw Eval. for Emergency/Faulted Conditions"

APPENDIX A - THERMAL SLEEVE

Note:

During the August 16, 1988, presentation by Toledo Edison to NRC, the makeup/HPI nozzle was referred to as HPI nozzle B1. This makeup/HPI nozzle is correctly designated as HPI nozzle A1 in this report.

Appendix A

Thermal Sleeve

Introduction

Appendix A contains discussions of the following items: the original thermal sleeve design and installation; thermal sleeve visual and dye penetrant inspections conducted on the sleeves; laboratory examinations and analysis of removed parts; postulated cause(s) of sleeve failure; and a description of the replacement sleeve (new) design.

Original Thermal Sleeve Design and Installation

On the Babcock & Wilcox (B&W) 177 fuel assembly (FA) plants, four HPI nozzles (one per cold leg) are used to: (1) provide a coolant source for emergency core cooling and (2) supply normal makeup (purification flow) to the primary system (Figure A-1). At Davis-Besse, one of the nozzles is used for both HPI and Makeup, while the remaining three nozzles are used for HPI alone.

The incorporation of a thermal sleeve into a nozzle assembly (Figure A-2) is to provide a thermal barrier between the cold HPI/MU fluid and the hot high pressure injection nozzle. This reduces thermal shock and fatigue of the nozzle.

The original design Davis-Besse thermal sleeves are 16 1/8 inches long and 1 3/4 inches (outside), 1 1/2 inches (inside) diameter. They are fabricated of ASTM A336, F8M solution-annealed stainless steel.

The sleeve was originally installed in the nozzle from the RCS end with a contact expansion at the safe-end. Axial movement of the sleeve was precluded by the installation of weld buttons in the nozzle near the RCS mouth which act against a machined collar on the thermal sleeve, restricting longitudinal motion. The raised collar was designed for a 0.010" to 0.015" diametrical clearance with the nozzle inside diameter. This clearance would provide venting of the crevice formed between the sleeve and nozzle.

During construction of Davis-Besse, it was noted that some of the sleeves were loose. In March, 1977, all four sleeves were "hard" rolled, i.e., rerolled to provide an interference fit at the original contact expansion region. It is noted that one of the four nozzles (B1) had originally been expanded such that further rolling did not change the inside diameter of the thermal sleeve.

The following table presents the data from the Davis-Besse March, 1977 hard rolling.

Thermal Sleeve No.	ID Before Re-roll (Inches)	ID After Re-roll (Inches)
A1	1.5060	1.5190
A2	1.5086	1.5162
B1	1.5178	1.5178
B2	1.5162	1.5183

Figure A-1

MU/HPI Flow Configuration

(Prior to the 5th RFO)

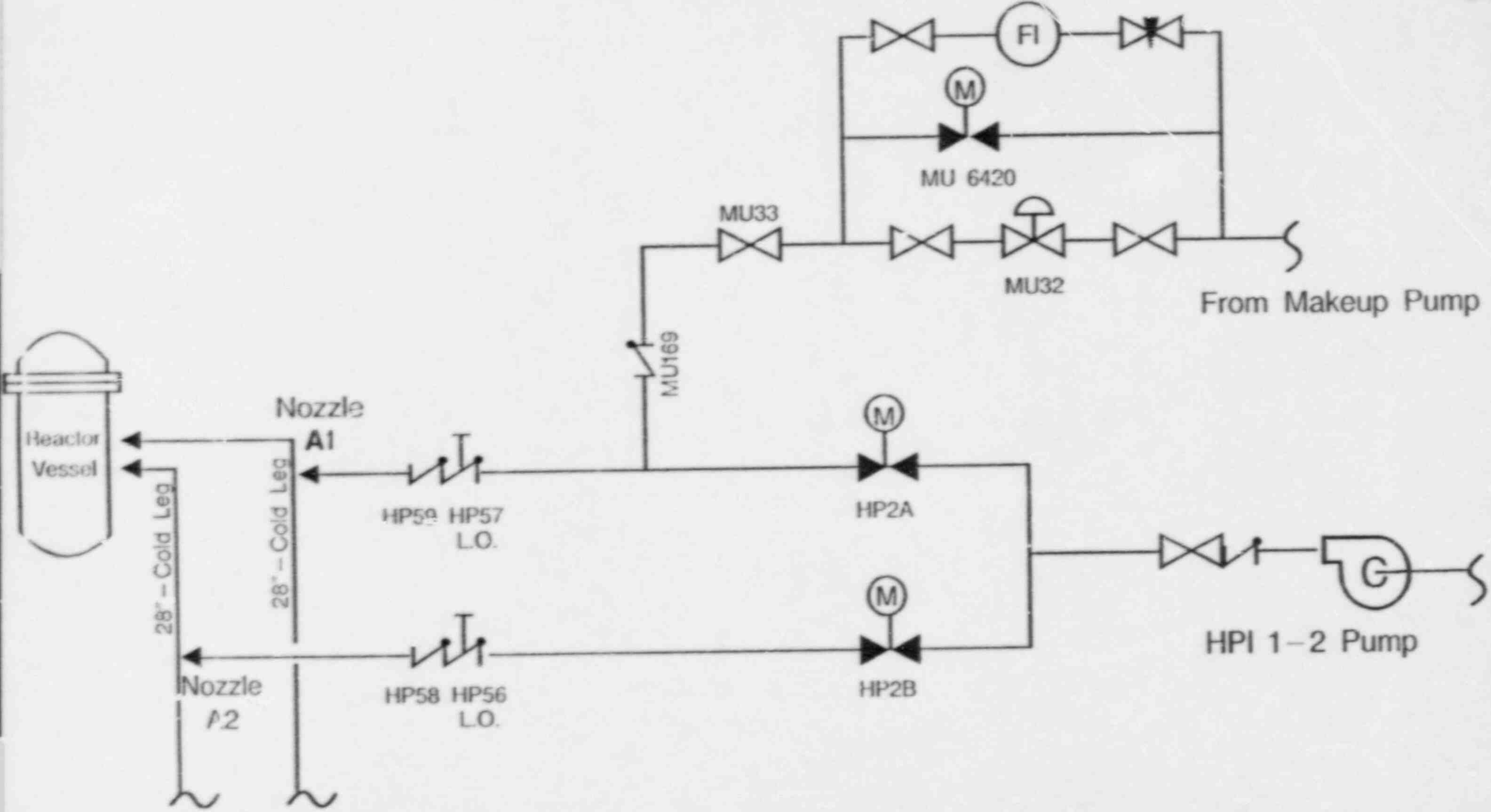
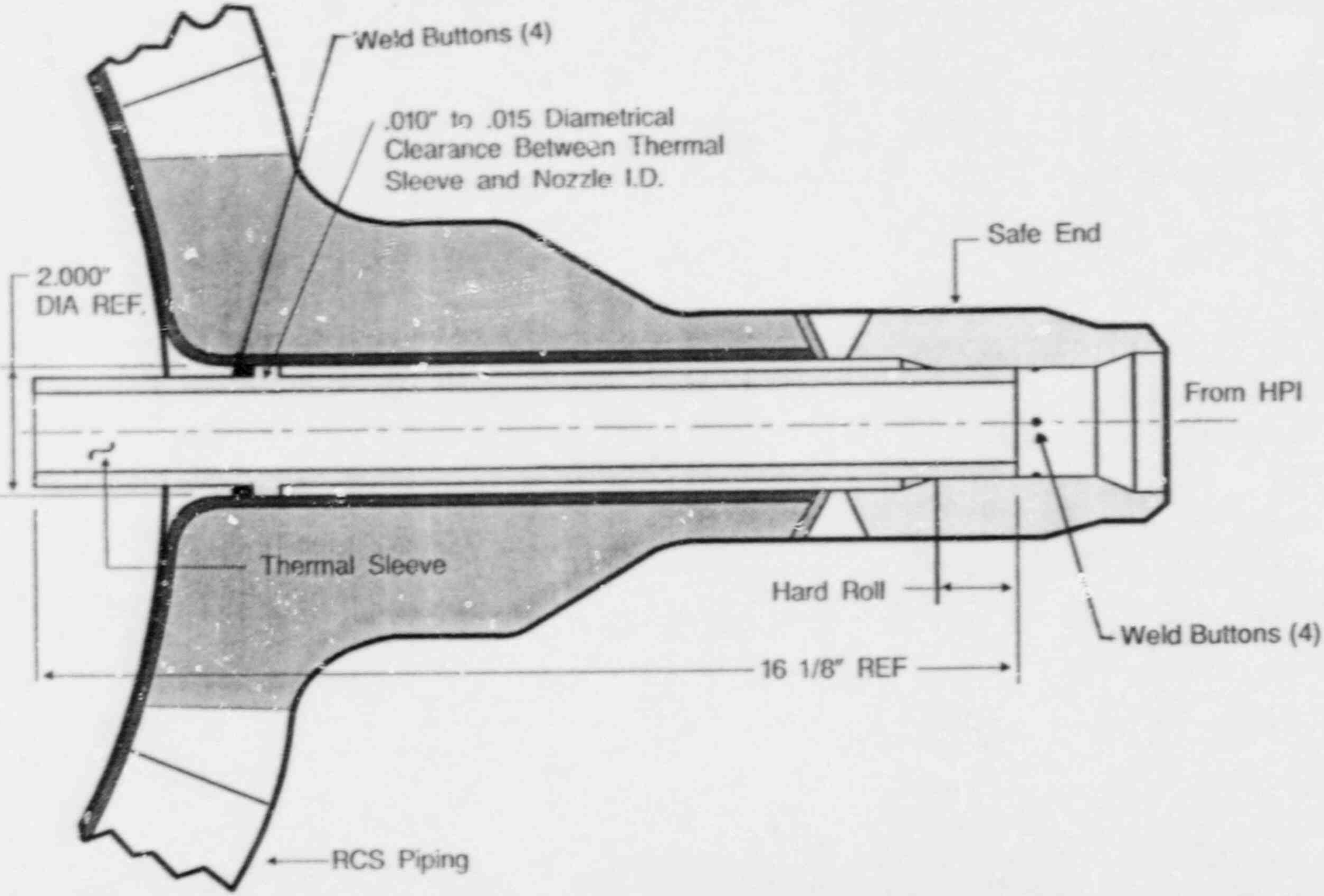


Figure A-2

Makeup/HPI Nozzle Original Thermal Sleeve Design



Thermal Sleeve Visual and Dye Penetrant Inspections

On July 6, 1988, fiberscopic examinations were conducted on all four thermal sleeves. An Olympus fiberscope was used with a 90° lens and self contained light source. An Elmo color camera recorder was used to record the inspection. The inspection was conducted through the open bonnet of the nearest swing check valve to the nozzle. These points of access were two to three feet from the nozzle and required the maneuvering of the scope through the valve, two 90° elbows and finally through the sleeve.

The ability to maneuver the scope was extremely limited by the area in which the operator was located, geometry of the piping and radiological protective measures. It was not possible to ascertain the relative position of the fiberscope within the sleeve. The distance of the scope from the surface being viewed could not be determined which precluded accurate sizing of the visual indications.

The fiberscope revealed the general condition of the sleeves. It confirmed that about three inches were missing from the RCS end of the A1 sleeve. The failed sleeve (A1) showed four linear indications at the RCS end approximately 90° from each other.

The other three sleeves were generally clean on the inside surface except for lines of boron deposits. One sleeve, A2, had what appeared to be a branched type linear indication that was located approximately three inches from the RCS end. This apparent indication appeared to be in the area where the failure of the A1 sleeve had occurred. This apparent indication was in an area of boron deposit. The A2 sleeve was removed and dye penetrant (PT) examined. The PT revealed no cracking in the sleeve; therefore, the apparent indication was considered to be either a shadow or an oxide discoloration.

Summary of Laboratory Analyses of the A1 and A2 Nozzle Thermal Sleeves After Removal

Visual and Liquid Penetrant Inspections

Visual inspections of the failed A1 nozzle thermal sleeve showed that the outlet end of the sleeve had separated from the inlet end piece by a circumferential crack at the thermal sleeve collar fillet. The 3 1/4 inch long outlet end piece was also separated into two sections by longitudinal cracks. These cracks were oriented in a plane roughly perpendicular to the reactor coolant flow direction and were approximately 180° apart. Liquid penetrant and further visual examinations showed that the two outlet end sections contained extensive additional through-wall and part-through-wall cracking. Cracking was primarily longitudinal and was concentrated on the ID surface close to the outlet end opening. In some cases longitudinal cracks were linked by short branch cracks with a circumferential component. Longitudinal ID cracking with multiple initiation sites is generally characteristic of a thermal fatigue cracking mechanism.

Two wear areas resulting from relative motion between the thermal sleeve and the nozzle weld pads were noted at the collar end of the outlet sections. A through-wall crack with both circumferential and longitudinal components extended from one of these wear areas a short distance into the inlet end section. This crack, an extension of the longitudinal split in the outlet end piece, and a small cluster of short linear defects (<59 mils in length) on the ID at the rolled portion of the sleeve were the only significant liquid penetrant test indications in the inlet section. In addition, the thermal sleeve collar contained impact and wear indications, providing evidence of vibration.

Visual and liquid penetrant examinations of the A2 nozzle thermal sleeve showed no cracking. No indications of wear or impact damage were present at the collar of the A2 nozzle thermal sleeve.

Fractography

Visual examination of the longitudinal fracture surface indicated that a number of independently initiated ID cracks near the outlet end of the sleeve had linked and propagated toward the thermal sleeve collar. The longitudinal fracture surfaces were badly damaged; thus, microscopic fractographic features were obscured. Fatigue striations were generally not well developed, and in most areas examined, striations were too small to be seen. However, it was clear that the fracture surface was entirely transgranular and in a region where striations were clearly evident (1 1/2 inches from the outlet end, 1/4 through-wall from ID) striation spacing was on the order of 1/4 micron. The striations also indicated that propagation was from ID to OD.

Because of the damage to this fracture surface, a section of another through-wall crack was opened for Scanning Electron Microscope (SEM) examination. A fine feathery structure, traversed by very faint fatigue striations was evident on this crack face. Striation orientation indicated propagation from ID to OD. Striation spacing was again less than 1 micron.

All of the fractographic features of the longitudinal crack surfaces were typical of high cycle, low stress intensity driven fatigue crack growth. Macroscopic observation of the circumferential crack surface features (beach marks and general microfeatures) indicated that cracks initiated at multiple location on both OD and ID surfaces and intersected to form the fracture surface. SEM examination confirmed the presence of multiple OD and ID initiation sites. The surface microfeatures included fanshaped markings with superimposed fatigue striations. Striation spacing ranged from submicron levels to above 1 1/2 microns.

The existence of multiple ID crack initiation sites in the collar region indicates the presence of thermal fatigue. The thermal fatigue initiated cracks in this region have a circumferential orientation due to the longitudinal stresses created by the expansion constraint of the collar which is thicker than the sleeve itself. The cracks appear to have originated independently from the longitudinal cracks that initiated near the outlet end of the thermal sleeve. The presence of OD initiation sites on the circumferential crack surfaces indicates that thermal fatigue was complemented by mechanically induced fatigue. The relative contribution of the two fatigue mechanisms has not yet been conclusively determined. Fractography is being performed on the circumferential fracture surface to determine which failure mechanism, thermal cycle versus mechanically induced fatigue, initiated the crack. The approach being utilized is level of oxidation on the fracture surfaces of interest. Analysis indicates that mechanically induced fatigue was complementary to thermal cycling.

Activation Studies

The two sleeve pieces removed from the lower reactor internals were analyzed by gamma spectroscopy to quantify the radioisotopes present in the material, and further analyzed by atomic absorption to quantify the amount of cobalt present in the bulk alloy. This data was then analyzed by comparing measured activity ratios with calculated activity ratios for various radioisotopes, using reasonable estimates of the neutron flux at the lower grillage where the pieces were found, material certifications for alloy compositions, and the measured cobalt level. The reactor power history was considered in this analysis in order to obtain an estimate of the core residence time. This analysis indicated that the more upstream (relative to reactor coolant flow) of the thermal sleeve outlet end pieces entered the reactor in January, 1987 while the downstream piece entered the reactor in November, 1987.

Conclusion

Preliminary laboratory investigations indicated that high cycle thermal fatigue was the probable cause of the A1 nozzle thermal sleeve failure. The submicron striation spacing indicates that a large number of thermal cycles (>10,000) preceded failure. The fact that striations were too small to be seen on most fracture surfaces indicates that the actual number of thermal stress cycles is likely to have been many times this number. The large number of thermal cycles indicates that thermal mixing of hot reactor coolant and relatively cold makeup flow at the outlet end of the sleeve during periods of low makeup flow may have generated the cyclic thermal stresses in the sleeve. Cyclic thermal stresses may also have resulted from periodic changes in makeup flow. In addition, mechanical fatigue due to vibration of the sleeve may have contributed to the failure. Because there was no evidence of vibration on the A2 nozzle thermal sleeve, it appears possible that the observed mechanical fatigue may have been related to the presence of existing extensive thermal fatigue damage in the sleeve.

Replacement Thermal Sleeve Design

The replacement thermal sleeve design provides the same thermal barrier as the original sleeve while eliminating causes which may have contributed to failure at Crystal River, Oconee, ANO and Rancho Seco as described in the B&W Owners Group Safe End Task Force Report on Generic Investigation of HPI/MU Nozzle Cracking (B&W 77-1140611-00).

[illegible] original sleeve material is ASTM A336 Class F8M. The replacement sleeve material is ASTM SA336 Class F316. Class F316 replaced Class F8M in later [illegible] of the ASTM code. The chemical and mechanical properties of Class F8M and F316 are the same. Both materials are solution annealed.

The overall length of the replacement thermal sleeve is slightly longer than the original design, 17-5/8 inches vs. 16-1/8 inches. The replacements sleeve projects into the RCS cold leg pipe approximately the same distance as the original design (± 1/8 inch depending on installation tolerances). The extra length of the replacement thermal sleeve is on the upstream HPI piping end in the safe-end.

The HPI piping end of the replacement thermal sleeve is bell shaped to prevent movement of the sleeve toward the RCS cold leg. Additionally, the upstream end is longer and thicker in the safe-end to provide more roll surface contact area and more metal to be cold worked during the hard roll into the safe-end.

The replacement thermal sleeve is provided with four notches in the HPI piping end. The four notches allow the placement of weld beads to provide additional protection against sleeve rotation.

The replacement sleeve is also contact rolled into the nozzle ID at the downstream end to reduce the effects of potential flow induced vibration. The 1-1/2 inches long contact rolled area is provided with seven slots which allow RCS fluid to fill in the gap between the thermal sleeve and the nozzle ID. The original thermal sleeve design has 0.010 to 0.015 diametrical clearance between the thermal sleeve retention collar and the nozzle ID. Thus, the two thermal sleeve designs maintain the same temperature gradients between the thermal sleeve ID and the nozzle surface and maintain the same flow characteristics.

In summary, the replacement thermal sleeve design has design improvements which facilitate installation from the safe-end side and which eliminate potential problems which may have contributed to failures at other B&W units. However, no design changes have been incorporated which would be expected to result in improved performance compared to the original thermal sleeve design for the thermal transients experienced by the failed A1 thermal sleeve.

APPENDIX B - HPI NOZZLE

Note:
During the August 16, 1988, presentation by Toledo Edison to NRC, the makeup/HPI nozzle was referred to as HPI nozzle B1. This makeup/HPI nozzle is correctly designed as HPI nozzle A1 in this report.

Appendix B

HPI Nozzle

Introduction

This appendix contains discussion of the following items: a description of the nozzle design; the course of action followed upon discovery of indications; and a summary of the near term actions planned. Attachment 1 of this Appendix provides a detailed description of the non-destructive examinations (NDE) conducted (PT and UT) on the nozzle.

HPI Nozzle Design

There are four HPI nozzles installed in the Reactor Coolant System, Cold Leg Piping. The RCS piping is clad with 308 SS weldment to carbon steel (SA106 GR.C) with an inside diameter of 28 inches and a thickness of 2 1/4 inches. Each nozzle is welded into the RCS piping and is clad with 308 SS weldment to carbon steel (SA105 GR.2). The nozzle inside bore is 2 inches. The thickness is 2 1/2 inches at the RCS pipe interface and 3/4 inch thickness at the safe-end.

Course Of Action

The A1 nozzle was dye penetrant (PT) inspected after the thermal sleeve remnant was removed. This PT revealed multiple indications between the RCS weld buttons and the nozzle knuckle region with some extending over the knuckle, into the cold leg piping. The indications are oriented both circumferentially and longitudinally. The indications are noted over the entire inside circumference of the region but are most heavily concentrated in the half of the nozzle that is considered downstream relative to reactor coolant flow direction. Ultrasonic testing (UT) of the nozzle and adjacent RCS piping was performed with no defects detected. Attachment 1 to this Appendix provides a detailed description of the non-destructive examinations performed.

Indication Removal

Removal of these indications was attempted by grinding away approximately 1/16 inch of the clad material. This was done using an air operated, manual grinder consisting of a 11 inch shaft extension and a flapper wheel type tool. In order to control the material removal rate, each tool operator was individually qualified to establish his average material removal rate. This material removal rate was used to determine the maximum allowable application time for removal of a maximum of 1/16 inch of clad material. Two applications of the tool was applied to remove the maximum of 1/16 inch in 1/32 inch increments. This method is very sensitive to operator technique. The amount of material removed is dependent on operator judgment and control. This type of tool could not be used to chase crack indications extending past the nozzle knuckle bend radius due to geometry. Additionally, tool failure was a major concern as a number of extension rods failed during operator qualification in the shop. This removal technique is only usable for removing minor surface indication. Therefore, since the technique did not remove the indications as demonstrated by subsequent PT efforts, the course of action considered three (3) options. The three (3) options were:

I) Leave and evaluate (attempt no further removal)

II) Remove all indications, i.e. grind off clad and nozzle base material as required to clear all indications.

III) Remove indications in accessible regions only

The following is a discussion of each option and the decision for the final course of action.

Option I - Leave and Evaluate (attempt no further removal)

A) A fracture mechanics analysis completed by B&W concludes that the maximum ASME Code allowable defect for brittle fracture considerations (0.5 inches) will not be exceeded for a pre-existing crack depth of about 0.3 inch. The pre-existing crack depth assumption of 0.3 inch exceeds the expected UT sensitivity (less than 0.1 inch) and is at least a factor of two greater than the self-limiting crack depth occurring due to high cycle thermal fatique which is considered to be the initiating mechanism for the observed crack indications. The low cycle analysis for crack growth for a pre-existing crack assumes 240 heatup/cooldown cycles (equivalent to 40 years operation) and was done in accordance with ASME Section XI, 1977 Edition, assuming a flaw perpendicular to the maximum stress field (most conservative direction).

B) There is high confidence that UT will detect cracks that have propagated into the base metal. Therefore, a program of enhanced in-service inspection can provide confidence that crack growth in the nozzle and adjacent reactor coolant piping will not affect the reactor coolant pressure boundary integrity.

C) While there is concern over thermal transients, fracture mechanics provides confidence that a minimum life of several fuel cycles remains, providing a basis for an in-service inspection frequency, even if no other action is taken.

D) This option provides continued protection of the base material, by the cladding, for corrosion and thermal cycling considerations.

Option II - Remove All Indications by Grinding/Machining

A) Removal of the indications would return the pressure boundary to the design conditions (i.e. no flaws) and erase any concerns over propogation of existing cracks.

B) Full removal of all cladding cracks is not possible with existing tools. Due to limited access through the nozzle, the available inspection techniques could not inspect the RCS wall adjacent to the nozzle. Crack indications were seen at the nozzle bend radius and appear to continue into the RCS piping adjacent to the nozzle.

C) Available machining techniques could only remove material within the nozzle bore and could not reach to the RCS internal surface. Machining operations necessary to remove all expected indications in a controlled fashion, such as eccentric grinding, electric discharge or spotface grinding would need to be developed. Development includes tool design, procedure development, qualification testing and training. Also techniques to verify the machined dimensions and surface conditions would need to be developed. The lead time for developing the machining process, measurement techniques, and associated inspection techniques is estimated to be several months.

D) Removal of the cracks would probably result in removal of the cladding, exposing the carbon steel base metal to the reactor coolant environment. Close monitoring of carbon steel corrosion in the flowing environment would be necessary to ensure continued satisfactory performance.

Option III - Remove Indications In Accessible Regions Only

A) Only indications in the nozzle bore would be removed with available machining capabilities, leaving the potential cracks on the RCS internal surface unaddressed.

B) Reliance on fracture mechanics analysis for the indications excepted to be remaining in the RCS would still be required.

C) Removal of the cracks would probably result in removal of the cladding, exposing the carbon steel base metal to the reactor coolant environment. Close monitoring of carbon steel corrosion in the flowing environment would be necessary to ensure continued satisfactory performance.

Applicable to All 3 Options

A) In each option the thermal sleeves removed had to be replaced, and the lifetime of the replacement thermal sleeve can be estimated from past Davis-Besse and industry experience, and improved through control of the makeup operations.

B) In each option, there is dependence on ultrasonic inspection techniques to monitor for potential degradation.

C) Each option offers the ability to operate safely for a number of fuel cycles.

Conclusions

The final course of action, Option I, was chosen based on the consideration that removal of all or accessible indications was not practically achievable within a reasonable outage time frame and that the cracks could be shown through analysis to be acceptable for at least one full operating cycle.

Near Term Planned Actions

The following near-term activities are directed toward the goal of maximizing the lifetime of the thermal sleeve. The activities involved include the following reviews and evaluations:

- past operations (makeup and minimum bypass),
- adequacy of current minimum bypass flow,
- makeup flow control,
- criteria for reinspection,
- acceptability of having operated with loose parts resulting from the thermal sleeve failure
- potential concerns for thermal sleeve damage from the enhanced makeup system (feed and bleed).

The composite results of these activities provide the bases for maximizing the life of the replacement thermal sleeve and thereby assure a high confidence level that the past Davis Besse thermal sleeve lifetime will be exceeded. Davis-Besse experience as well as that of other plants have demonstrated several fuel cycles of successful operation prior to a thermal sleeve failure. D-B had four complete fuel cycles before the failure.

Review of Past Operations (Minimum By-Pass and Make-up)

The review consisted of evaluation of the operations surrounding the failed thermal sleeve in nozzle A1 relative to both minimum by-pass and makeup flow. The minimum by-pass flow is controlled by a throttled needle valve and the flow indicator (FI-MU58) around MU32. The makeup flow is controlled by flow control valve (MU32) (Figure B-1). As shown on the figure the bypass provides a pegged minimum flow regardless of the flow demand imposed upon the makeup control valve.

The B&W Owners Group Safe-End Task Force recommended a minimum bypass flow of 1.5 gpm while recognizing that higher values would be beneficial. This recommendation was based on the results of instrumented testing conducted to determine the minimum by-pass flow required to prevent thermal stratification in the safe-end/piping region. At Davis-Besse, the bypass flow adjustment valve had been set with RCS pressure at 50 psig to obtain a rate of 3 gpm. This value corresponds to approximately 1 gpm at normal RCS operating pressure. The inspection of the safe-end and upstream piping associated with nozzle A1 having shown no flaws indicates that the recommended flow was adequate to protect that portion of the system. Toledo Edison considers this value to be insufficient to minimize thermal flow stratification within the thermal sleeve.

The makeup flow history was reviewed from the past operating fuel cycle (May 1987 to March 1988). Information or data prior to that period of time could not be reconstructed. Toledo Edison considers that the data reviewed is representative of the previous past history. The data reviewed showed that there may have been several hundred changes in makeup flow [zero to intermediate (10 to 20 gpm) or full flow (>30 gpm) and various combinations]. These are expected to have resulted from:

- reactor trips
- load changes - both escalation and runback
- erratic makeup valve behavior due to sticking and control settings

The valve sticking situation was experienced over a period of several days and is expected to have caused 89% of the zero to full flow changes, with the reminder being considered normal for the operating conditions.

Evaluate the Adequacy of the Current Continuous Minimum By-Pass Flow

Review of the data from other plants plus the instrumented experiments conducted for the B&W Owners Group along with Toledo Edison inspection the failed sleeve nozzle components demonstrated the adequacy of the 1.5 gpm for protecting the safe-end and upstream piping. The fact that the sleeve at Davis-Besse failed on the RCS side gives rise to consideration of a higher flow. The goal of the high flow would be to prevent thermal stratification of the makeup flow within the entire sleeve, thus minimizing circumferential temperature differences throughout the length of the thermal sleeve. Analysis indicates that a by-pass flow rate greater than 3.5 gpm is required to prevent thermal stratification in the line. The nominal by-pass flow rate will be set somewhat greater in order to provide a suitable margin for calculational uncertainties and for setting and maintaining the required flow rate. The control of the bypass flow will be accomplished by the existing system (i.e. throttled needle valve MU58A).

Evaluate Makeup Flow Control

In the situation of having a continuous bypass flow that is insufficient to preclude thermal stratification of flow throughout the sleeve, the cyclic changes in makeup flow will be a larger contributor to the thermal fatigue of the thermal sleeve. Even with increased minimum bypass flow, makeup flow variations may still contribute to thermal fatigue but to a lesser extent. Therefore, Toledo Edison is reviewing the makeup and purification system and the reactor makeup control in order to reduce the number of valve (MU32) position changes. The near term objective is a reduction in makeup flow variations through review of valve and control settings. The longer term corrective actions will address further improvements in makeup flow variations which may entail changes in equipment as well as control philosophy.

Evaluate Criteria for Reinspection

The Davis-Besse experience of having a thermal sleeve failure after four fuel cycles and the fact that the replacement thermal sleeve is functionally at least as good as the sleeve which failed provides confidence of being able to operate for a single fuel cycle without a failure. This is confirmed by the past experience accumulated at other B&W units which have been operating with thermal sleeves identical to the replacement sleeve.

Confirm the Acceptability of Having Operated with Loose Parts Resulting from the Thermal Sleeve Failure

The broken thermal sleeve introduced two metallic loose parts into the lower regions of the reactor vessel. One part was in the reactor vessel for approximately 400 full-power days which would indicate the time of failure to be around January 1987. The other part was estimated to have been in the reactor vessel slightly over 100 full-power days. Both of these estimates of residence time in the reactor vessel for the parts are based on activation analysis utilizing the operating history of the unit.

It was determined that there was no damage to any of the internals from the parts being in the vessel for these periods of time. It was further concluded that the parts could not have caused damage to the following:

- Reactor coolant pressure boundary
- Reactor control and protection system
- Reactor coolant pumps, and
- Connected fluid systems

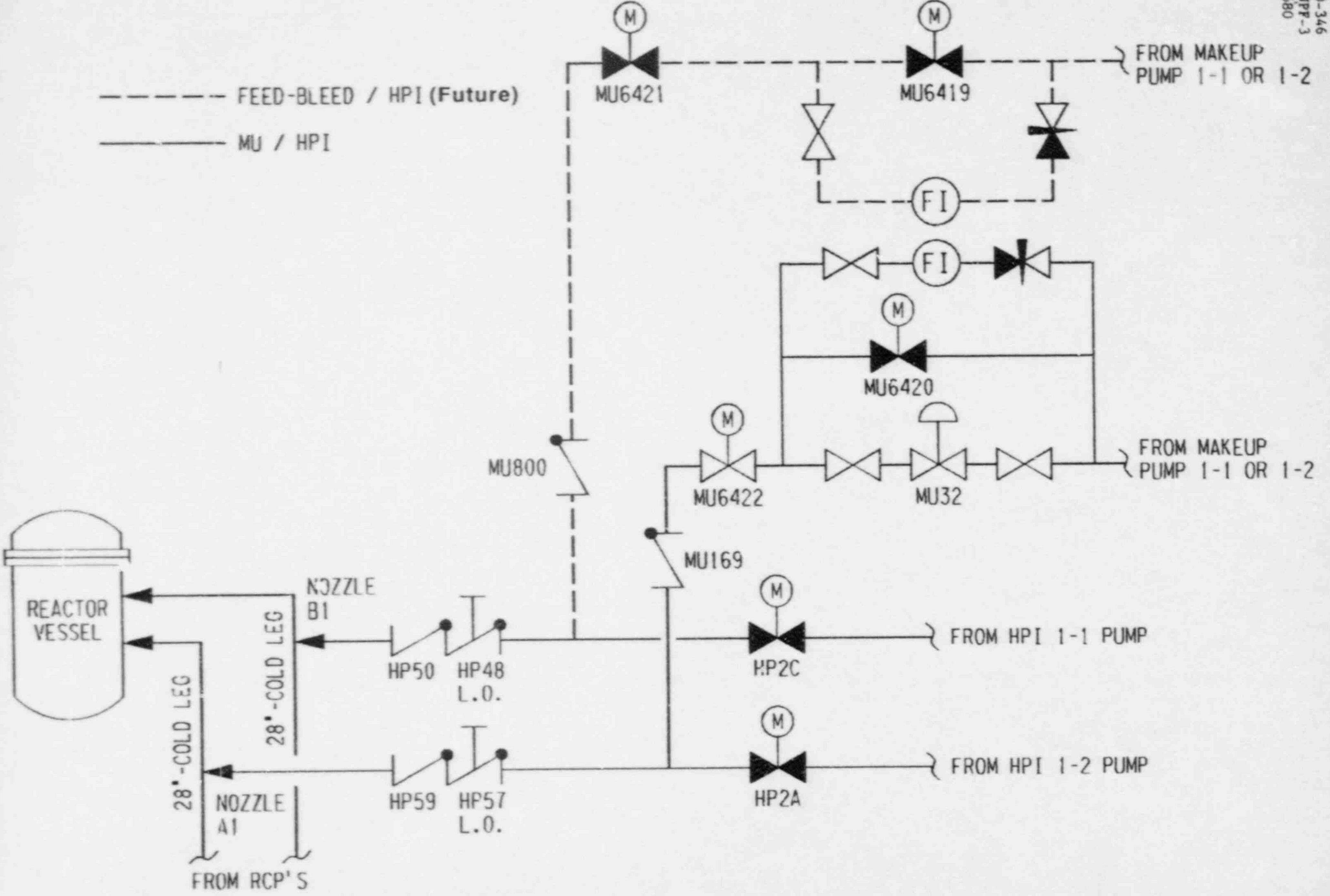
Evaluation of Potential Concerns of Thermal Sleeve Damage from the Enhanced Makeup System (Feed and Bleed Modification)

An additional path for makeup to the RCS has been added during the fifth refueling outage. Figure B-1 shows the flow paths for both the normal makeup and that associated with the enhanced feed and bleed capability. One path for feed and bleed flow to the RCS is through HPI nozzle B1 which contains a thermal sleeve of the original design. The inspection of the installed sleeve showed no evidence of any cracking. While it is not intended that this flow path be used for normal makeup duty, minimum flow bypass capability has been designed into the system.

The operating requirements for the enhanced feed and bleed capability will have the system in standby and isolated (no flow) until operation is required. With the system isolated and inoperative, the by-pass flow control will be set such that when placed in operation the required minimum by-pass flow commences immediately.

FIGURE B-1

MU / HPI AND FEED - BLEED / HPI FLOW CONFIGURATION



ATTACHMENT 1 - NON-DESTRUCTIVE EXAMINATIONS

Liquid Penetrant (PT) Examination of HPI/MU Nozzles A1 and A2

Between July 15 and July 21, 1988, liquid penetrant examinations were performed on the internal surfaces of high pressure injection/makeup nozzle A1. This was performed to inspect potential affected areas due to the failure of the thermal sleeve in A1. A similar inspection was performed on the A2 HPI nozzle for comparison. The examinations were performed from the nozzle to safe-end weld preparation to the inner knuckle radius of the nozzle. The method by which the examinations were performed is described below.

Pre-Examination Preparations

Since access to the area of interest was through the ~ 2 inch diameter open end of the nozzle, special tooling and techniques had to be developed. A spare nozzle was obtained as a mockup to develop these tools and techniques. Visible dye was the method chosen as the PT process to be utilized. Other methods would have been more affected by the accessibility to the area of interest. A tool comprised of a cylindrical piece of PVC with lint free cloth was made to apply and remove both the cleaner and penetrant (Figure B-2). To apply the developer, a pressurized spray system with a 360° spray centered in the nozzle was built (Figure B-3). This tooling proved to be successful in examining the area of interest by demonstration in the mock up. The limitation of the examination was that only approximately one-half of the radius of the knuckle could be examined due to the application process. Examination results were reviewed via a fiberscope and videc camera.

Examination of Nozzle A1

The examination process included the precleaning of the ID with approved solvent, the application of the penetrant, excess penetrant removal and developer being applied. The following are the indications that were found following the visual examinations for nozzle A1. All of these were rejectable using the acceptance standards of ASME Section III 1971 Edition which is the Davis-Besse repair and replacement base code:

- 3-linear indications ranging in length from 9/16 inch to 1-3/4 inches
- Approximately 40-linear indications ranging in length from 1/8 inch to 5/6 inch

A decision was made to attempt to remove these indications. Following the development and application of special equipment to remove these defects, another liquid penetrant examination was performed. The following indications remained of which all were rejectable per the acceptance standards used:

- 3-linear indications ranging in length from 1-1/2 inches to 1-3/4 inches
- Approximately 42-linear indications ranging in length from 1/8 inch to 3/8 inches

In both of the examinations, the three longer linear indications were oriented circumferentially in the nozzle with the remainder mixed both longitudinally and circumferentially.

The indications were sized by comparing the length to a steel ruler, which was also video recorded to provide a measurement standard by keeping the fiberscope in a fixed position in relationship to the surface of the nozzle. No indications were observed on the HPI side of the weld buttons.

Conclusions on the difference in length and number of the indications between the two exams cannot be drawn. Variables such as the bleed out from the start of exam could not be observed from the moment of developer application since the fiberscope insertion would disrupt the developer. Indications were analyzed following the time period required after applying the developer. Also, the buffing process could have aligned shorter indications into a longer one. However, the indications appeared more sharp and distinct following metal removal.

Examination of Nozzle A2

The examination process was conducted as detailed previously for A1 with the following results:

- 1 - 1" long linear indication approximately 1/2" from nozzle to safe-end weld prep
- 1 - 1/4" long linear indication at the base of weld button, HPI side of buttons
- 1 - 1/8" long linear located RCS side of weld buttons
- 1 - 1" long linear located RCS side of weld buttons
- 1 - 1 16" rounded located HPI side of weld buttons - acceptable indication
- 1 - 1/16" rounded located at base of weld buttons - acceptable indication

Metal removal was performed using the same techniques used on A1. Re-examination by liquid penetrant showed that only the two acceptable rounded indications remained. These indications are suspected to be pre-existing and [illegible] not to have been the result of thermal induced stresses since the thermal sleeve was intact in this line.

Additional NDE

Supplemental examinations were performed of the piping welds and adjoining piping base material from the nozzle safe-end to the HPI check valves to ensure no further flaws were present. The results were satisfactory and no flaws were detected.

Figure B-2

Applicator for the Penetrant and Cleaner

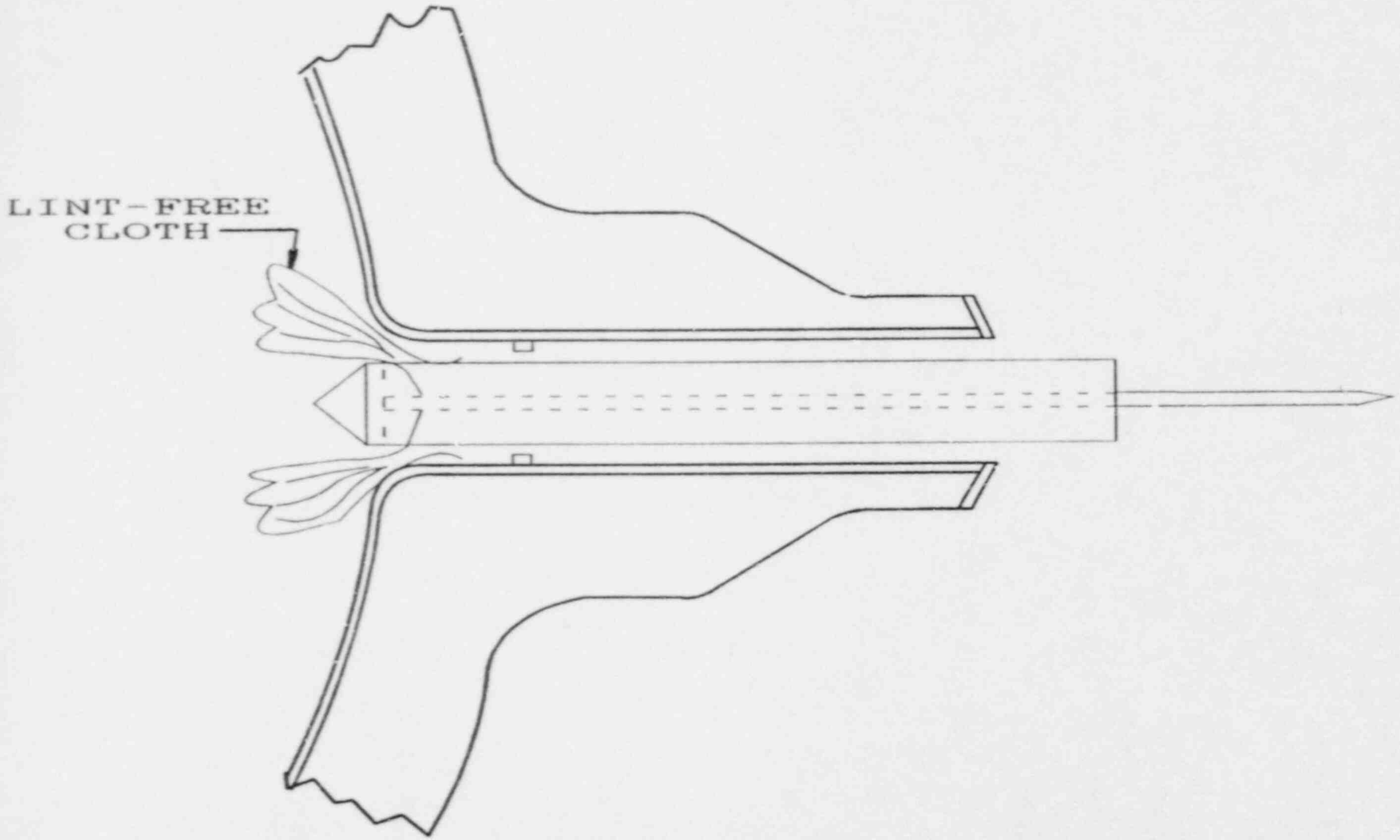
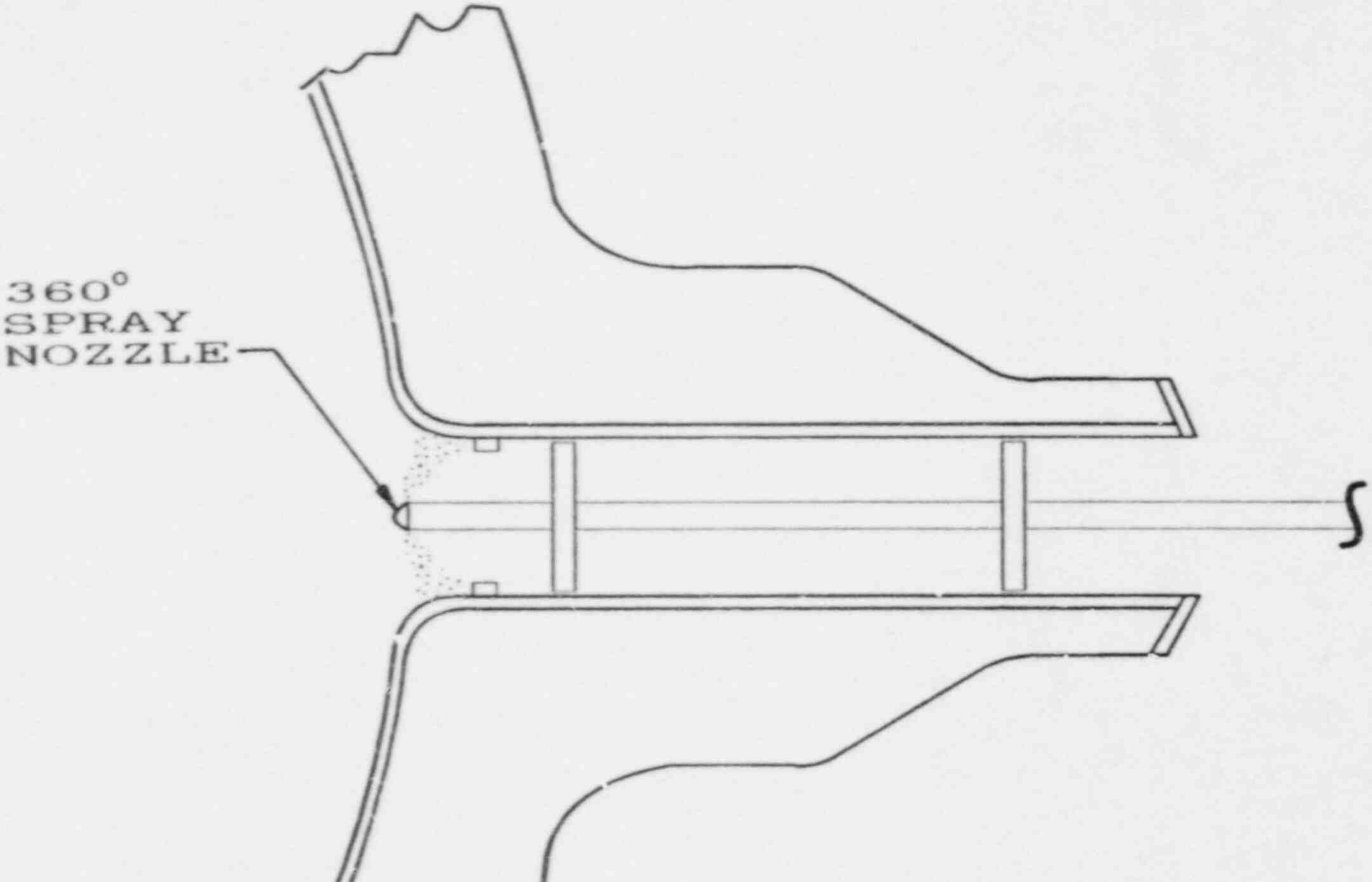


Figure B-3

Applicator for the Developer



Ultrasonic (UT) Examination Of HPI/MU Nozzle A1 And RCS Piping

On July 15, 1988, an ultrasonic (UT) examination was performed on the A1 High Pressure Injection nozzle in order to further characterize the liquid penetrant detected indications. The area of interest included both the accessible portions of the nozzle bore to the maximum extent practical limited by geometry and the surrounding base material of the reactor coolant system piping within a 12 inch radius. The extent of RCS examination was based on judgement devived from experience at Indian Point I. The examination was performed over 360 degrees to ensure full coverage (Figure B-4).

Toledo Edison evaluated the industry accepted volumetric NDE methods. A decision was made to employ ultrasonic examinations due to the following shortcomings of radiographic examination.

1) Very tight crack indications in heavy wall sections usually cannot be detected even when properly oriented.

2) Flaw depth cannot be accurately determined.

To increase the confidence level of the ultrasonic examinations, a UT procedure was used that was qualified using a mock-up of the nozzle with known artificial reflectors simulating flaw-like indications for calibration.

For the UT procedure to reliably detect the cracks discovered from the ID PT examinations of the nozzle bore, sufficient instrument gain was used (20dB above reference), multiple angle beam transducers were used, a requirement to record any indication of a suspected flaw regardless of amplitude was imposed and qualified personnel that had demonstrated ability to detect, size, and evaluate actual flaws were utilized.

The methodology and approach to the examination performed is as follows:

Calibration Blocks

The UT examination system calibrations were performed using two different calibration standards. The block used for the reactor coolant system pipe side examination was a standard ASME Section XI calibration block used for the reactor coolant system pipe at Davis-Besse. The block was manufactured from the same material specification of the pipe (A106) and included a cladded surface with a nominal clad thickness of 0.175 inches. Side-drilled holes of 0.188" in diameter at 1/4T, 1/2T and 3/4T locations are in the block and were used to establish a distance amplitude correction (DAC) curve for scanning. To ensure that the UT procedure scanning sensitivities were adequate, B&W machined different depth notches in the cladding ranging from 0.060 to 0.200 inches in another calibration block. Similar calibration levels established that a 0.060 inch notch was detectable (Figure B-5).

The calibration standard for the nozzle portion of the exam was an actual nozzle obtained by Rancho Seco from B&W. Notches were placed in the nozzle bore and at the inner radius corners to provide sensitivity levels. The two notches at the inner radius section were oriented in an axial direction and were one inch in length and 0.280 inches deep. Two notches in the circumferential direction further up in the throat of the nozzle bore were 0.335 to 0.340 deep.

A third circumferentially oriented notch 0.068 inches deep was placed in the bore in the approximate location of the largest liquid penetrant indications that were present in the A1 nozzle. This notch was solely in the cladding versus the remaining notches which penetrate the base material approximately 0.155 inches for the axial notches and approximately 0.210 inches for the radial notches (Figure B-6).

Equipment

UT equipment utilized in the examinations was a Krautkramer USK-6 and Epoch 2002, Ultragel II for couplant and the transducers were a 60 degree, 1 inch at 2.25 MHz; 60 degree, 0.5 inch at 5.0 MHz; 35 degree (longitudinal), 0.5 inch at 2.25 MHz; and a 45 degree, 1 inch at 2.25 MHz.

Calibration And Scanning

Ultrasonic examination was performed to evaluate the condition of the reactor coolant pipe adjacent to the HPI nozzle. The volume was scanned with 45 degree and 60 degree shear wave angle beam transducers due to the limitations of part geometry (Figure B-4). The sound beams were directed perpendicular, parallel, and tangent to the HPI nozzle inner radius. The tangential and parallel scans were performed with two opposing beam directions, separated by 180 degrees.

The test sensitivity was set at a minimum of 20dB over the reference level. In the case of the 60 degree examination the gain was increased even further to maintain the clad roll signal amplitude in the range of 10 to 20 percent of full screen height. Scanning at 20dB over reference level is equivalent to scanning at 10 percent of the DAC level. The criterion for recording was any signal which had a changing metal path with an amplitude above the nominal clad roll amplitude. This would have resulted in the recording of signals less than 10 percent of DAC.

For the purpose of defining the detection capability of the 45 degree and 60 degree examinations it is assumed that the flaws of interest were primarily perpendicular to the ID surface of the reactor coolant pipe. Assuming that the flaws of interest are smooth and planar in nature, the examinations would have detected flaws which were oriented within a plane extending from approximately 65 degree to 115 degree direction. This takes into account oscillation of the transducer and the beam spread of the sound beam.

Based on the demonstrated detection levels for the 45 degree and 60 degree examinations and the fact that there were no recordable indications, there is a high confidence level that there are no flaws which penetrate through the clad and into the base material in the areas examined or which exceed the initial flaw sizes utilized in the B&W fracture mechanics analysis.

A second ultrasonic examination was performed on the HPI nozzle to evaluate the condition of the HPI nozzle bore and inside radius in the region where the PT indications were observed. Scans were performed along the nozzle axis to detect circumferentially oriented flaws using 45 degree and 60 degree shear wave angle beams from the flat section of the nozzle (Figures B-7 and B-8).

In addition, a 45 degree angle beam was used to scan the tapered section of the nozzle (Figure B-7). A 35 degree longitudinal wave angle beam was also used to scan circumferentially around the nozzle from the OD radius to detect axially oriented flaws on the nozzle inner radius. The 35 degree angle beam was performed with two opposing scan directions (i.e., clockwise and counterclockwise).

The 60 degree angle beam was calibrated using the circumferential notches designated as A and B (Figure B-6). The 45 degree angle beam was calibrated using the notch designated as C. The 35 degree angle beam was calibrated using the notches designed as D and E. For each of the calibrations the notch amplitude was set to 80% of full screen height. The gain setting to achieve the 80% amplitude was considered the primary reference level.

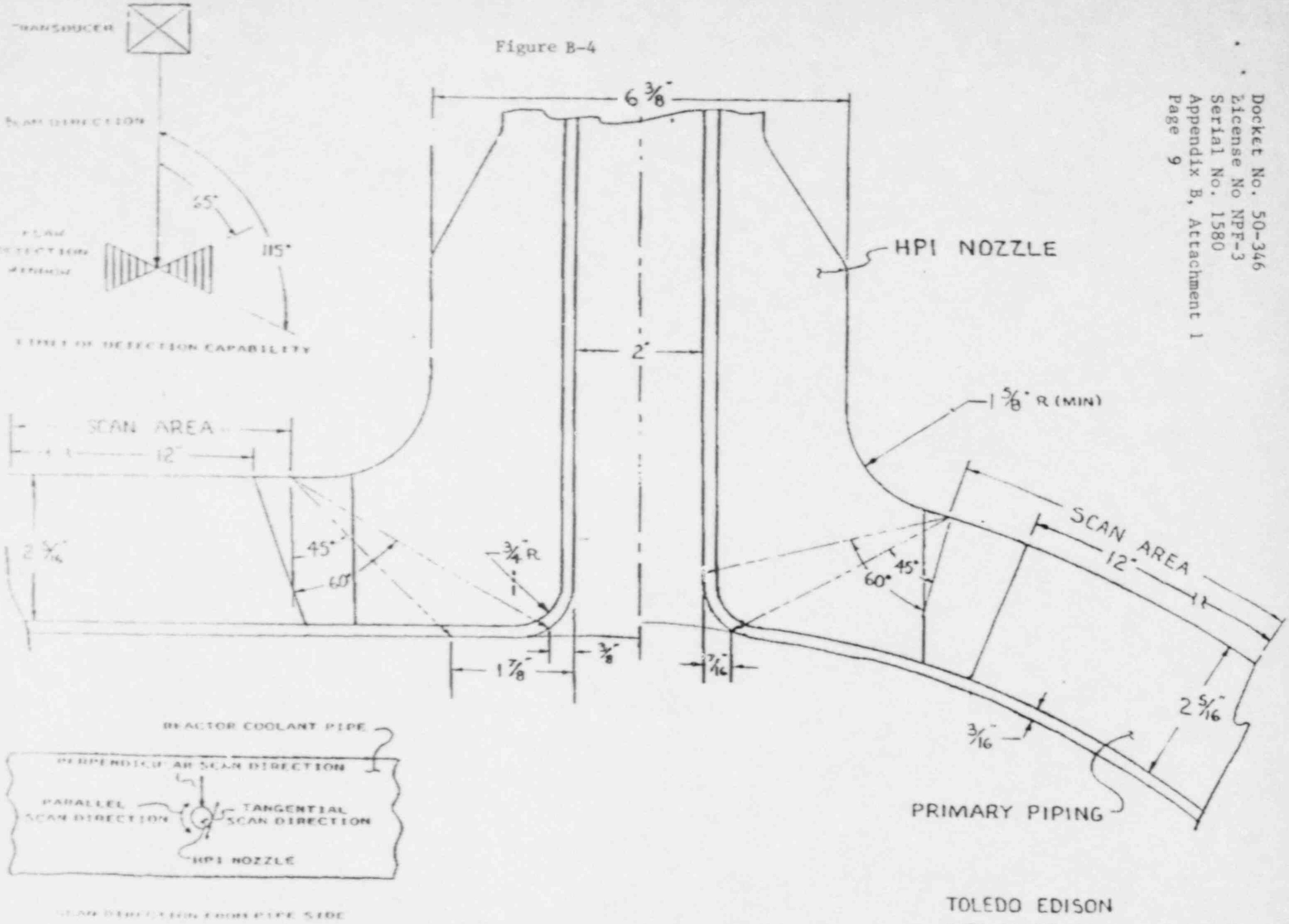
The test sensitivity was set at a minimum of 20dB over the reference level. In the case of the 60 degree examination the gain was increased even further to maintain the clad roll signal amplitude in the range of 10 to 20 percent of full screen height. Scanning at 20dB over reference level is equivalent to scanning at 10% of the DAC level. The criteria for recording was established as any signal which has a changing metal path with an amplitude above the nominal clad roll amplitude. This would have resulted in the recording of signals less than 10% of DAC.

An actual HPI nozzle mockup containing notches was used to qualify the detection capabilities of the examination performed from the nozzle side. Specifically, the notch designated as C (0.068 deep) is detectable from both the flat and tapered section of the nozzle. However, detectability is best using the 60 degree angle beam from the flat section of the nozzle.

For the purposes of defining the detection capability of the 45 degree and 60 degree examinations it is assumed that the flaws of interest are primarily perpendicular to the ID surface of the HPI nozzle bore. Assuming that the flaws of interest are smooth and planar in nature, the 45 degree and 60 degree examinations from the flat section of the nozzle would have detected flaws which were oriented within a plane extending from approximately 65 degrees to 115 degrees from a line drawn parallel to the beam direction. The 45 degree examination conducted from the tapered section of the nozzle and the 35 degree (longitudinal) examination conducted from the nozzle radius would have detected flaws which were oriented within a plane extending from approximately 75 degrees to 105 degrees from a line drawn parallel to the beam direction. This takes into account oscillation of the transducer and the beam spread of the sound beam.

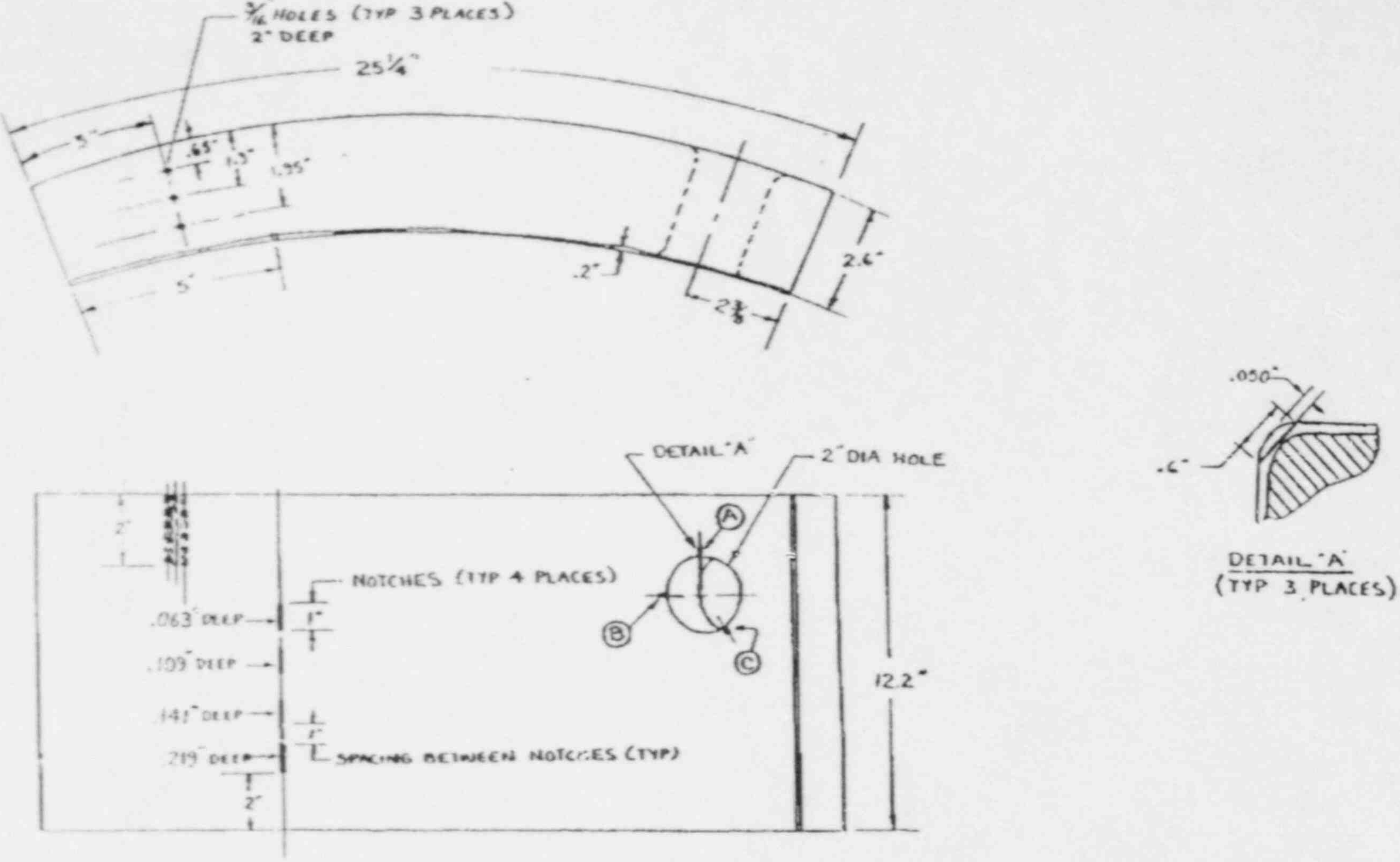
Based on the demonstrated detection levels for the 35 degree, 45 degree and 60 degree examinations and the fact that there were no recordable indications, there is a high confidence level that there are no flaws which penetrate through the clad and into the base material in the areas examined or which exceed the initial flaw sizes utilized in the B&W fracture mechanics analysis.

Figure B-4



TOLEDO EDISON
HPI NOZZLE
CROSS SECTIONAL
VIEW

Figure B-5



REACTOR COOLANT PIPE CALIBRATION BLOCK

Figure B-6

NOZZLE CALIBRATION BLOCK

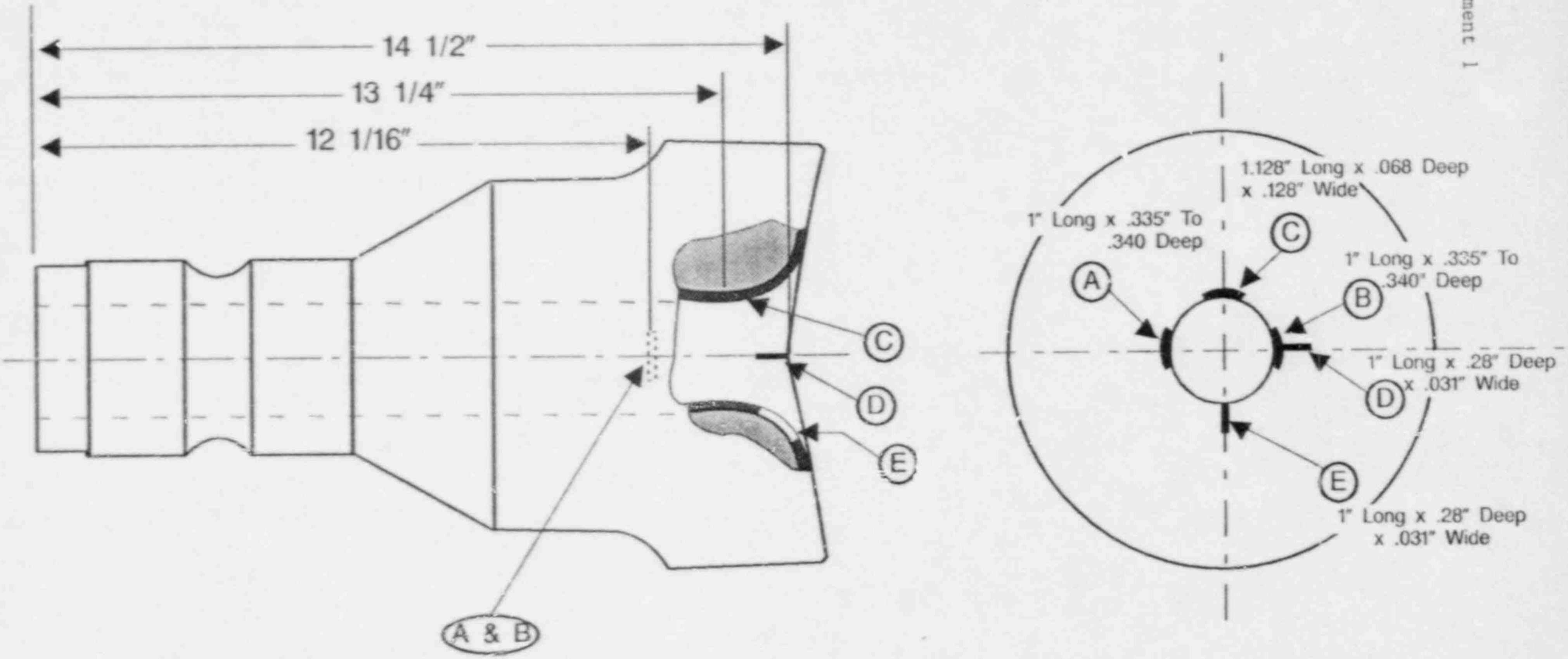


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Figure B-7