VIRGINIA ELECTRIC AND POWER COMPANY
RICHMOND, VIRGINIA 23261

November 16, 2001

United States Nuclear Regulatory Commission
Attention: Document Control Desk
Washington, D.C. 20555

Serial No. 01-638B
NL&OS/ETS R0
Docket No. 50-339
License No. NPF-7

Gentlemen:

VIRGINIA ELECTRIC AND POWER COMPANY
NORTH ANNA POWER STATION UNIT 2
ALTERNATIVE REPAIR TECHNIQUES-RELIEF REQUESTS NDE-048 and NDE-049
REQUEST FOR ADDITIONAL INFORMATION

Virginia Electric and Power Company (Dominion) responded to NRC Bulletin 2001-01, "Circumferential Cracking of Reactor Pressure Vessel Head Penetration Nozzles," in a letter dated August 31, 2001 (Serial No. 01-490). In our response, we provided information regarding the inspections that we were planning to perform on the reactor vessel head penetrations for North Anna and Surry Power Stations Units 1 and 2. In a subsequent letter dated October 18, 2001 (Serial No. 01-638), Dominion requested relief to use alternative repair techniques in the event that any instances of cracking requiring repair were discovered during the inspection of the North Anna Unit 2 reactor vessel head penetrations (RVHPs). The bases to permit the use of the alternative repair techniques were provided in relief requests NDE-048 and 049, which were included as attachments to that letter.

During the NRC's review of the relief requests for alternative repair techniques, the staff identified a need for additional information to facilitate the review of relief requests NDE-048 and NDE-049. Mr. Stephen Monarque, the NRC North Anna Project Manager, provided the staff's questions on November 5, 2001. An additional question regarding NDE-049 was provided by the NRC staff on November 15, 2001.

Information, requested by the staff regarding NDE-049, was provided in a November 9, 2001 letter (Serial No. 01-638A). Attachment 1 to this letter provides the remaining information regarding NDE-048 and NDE-049. Attachment 2 to this letter is a revised NDE-048. Please use the revised NDE-048 to complete your review.

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If you have any questions or require additional information, please contact us.

Very truly yours,

Leslie N. Hartz
Vice President - Nuclear Engineering

Attachments

Response to Request for Additional Information NDE-048 and NDE-049
Revised Relief Request NDE-048

Commitments made in this letter:

1. Submit WCAP-14552, "Structural Integrity Evaluation of Reactor Vessel Head Penetrations to Support Continued Operation: North Anna and Surry Units"

cc: U.S. Nuclear Regulatory Commission
Region II
Sam Nunn Atlanta Federal Center
61 Forsyth St., SW, Suite 23T85
Atlanta, Georgia 30303-8931

Mr. M. J. Morgan
NRC Senior Resident Inspector
North Anna Power Station

Mr. J. E. Reasor, Jr.
Old Dominion Electric Cooperative
Innsbrook Corporate Center, Suite 300
4201 Dominion Blvd.
Glen Allen, Virginia 23060

Mr. M. M. Grace
Authorized Nuclear Inspector
North Anna Power Station

ATTACHMENT 1

Response to NRC Request for Additional Information
Relief Request NDE-048 and NDE-049
North Anna Power Station Unit 2

Virginia Electric and Power Company
(Dominion)
North Anna Power Station Unit 2

Response to NRC Request for Additional Information
North Anna Power Station Unit 2 Relief Requests NDE-048 and NDE-049

NRC Question 12

For Code requirements, state the specific paragraph, subparagraph, subsubparagraph, etc. that the repair will not meet. For instance, NB-4453 (1989Ed), "Requirements for Making Repairs of Welds," NB-4453.1 states that defects be removed. The effectiveness of the removal is evaluated according to the PT acceptance criteria in NB-5352 (a) not to exceed 1/16" or NB-5352(b) any cracks or linear indications.

Response: Incorporated into the revised relief request.

NRC Question 13

For the specific requirements in Question 12 above, state the proposed alternatives. Provide a table, if it simplifies the understanding of the different situations applicable to the alternative.

Response: Incorporated into the revised relief request.

NRC Question 14

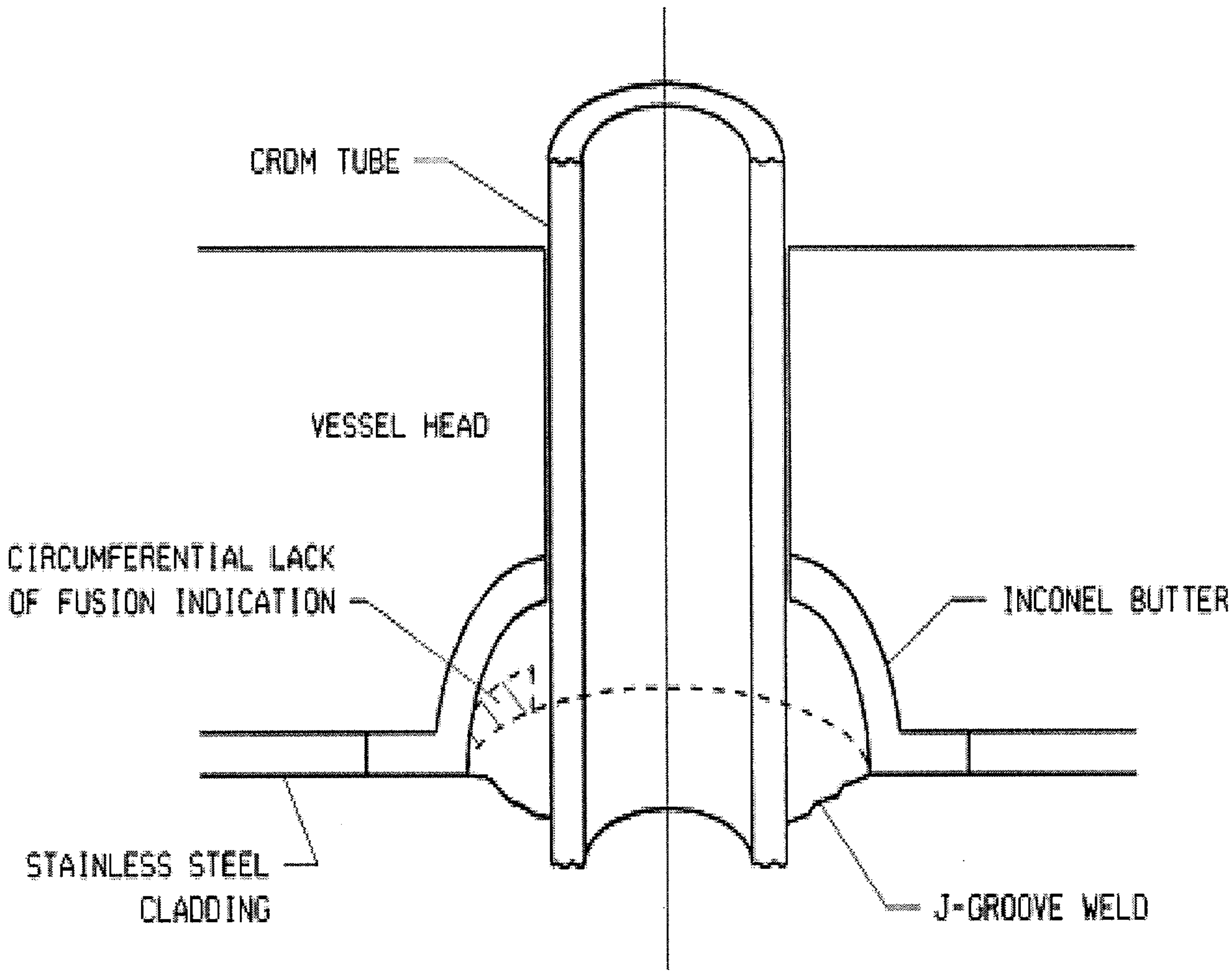
In Section V of the submittal, the second paragraph discusses a postulated ID repair. Are you asking for anything different from what the staff has already authorized in its safety evaluation dated 2-5-96? If so, explain.

Response
No, however, the revised relief (NDE-048) does not involve any ID repairs because the inspections have revealed that the only repairs required at this time are repairs to the J-groove welds of three CRDM penetrations and this relief will expire at the end of the second interval (December 14, 2001).

NRC Question 15

In Section V (page 4) of the submittal, there is a discussion on a postulated circumferential OD flaw in the J-groove weld. Provide a sketch of this crack configuration.

Response



NRC Question 16

The staff does not consider the repair to be a partial penetration weld repair. This is because the configuration is not contained in NB-4244(d). Instead, the staff believes that this is a special non-structural weld overlay. Code Case N-504-1(i) and (j) provides criteria for preservice and NDE examinations of a weld overlay. Discuss the use of N-504-1(i) and (j) criteria for this application and the applicability of WCAP-13998, Revision 1, 9.1.4, "ASME Code Approach to Weld Repair" for baseline volumetric inspections and the frequency of re-inspections.

Response

The welds, to be repaired, are of a configuration depicted in NB-4244(d). Code Case N-504-1 applies to structural overlays in austenitic stainless steel piping and as such is not directly applicable to the proposed repairs to the Alloy 182 partial penetration J-groove welds attaching the CRDM penetrations to the reactor vessel head. There are no preservice examination requirements for the existing partial penetration welds or for repairs to them as discussed in the Relief Request. The final welds will be examined by liquid penetrant inspection. Volumetric examination of these repairs is not feasible because the configuration of the welds makes radiography and effective ultrasonic inspection impractical as discussed in Relief Request NDE-049 (Letter Nos. 01-638 and 01-638A).

NRC Question 17

For flaws located at or above the J-groove weld in the OD of the CRDM, discuss the effectiveness for detecting and sizing them. Include in the discussion any demonstrations on mockups.

Response

Information previously provided in our letter 01-450C, dated September 27, 2001, demonstrates that the ultrasonic inspection techniques which have been used to inspect the OD of the CRDM penetrations from the ID of the penetration are capable of detecting small circumferential flaws in the penetration material that may have initiated above the J-groove weld or that may emanate from the root region of the weld. No such flaws were detected on the penetrations for which repairs are being proposed. (This UT detection capability was also observed/evaluated by NRC personnel in conjunction with the North Anna Unit 1 reactor vessel head inspection activities).

NRC Question 18

Provide a discussion on the ability to detect and size flaws in the CRDM segment or J-groove weld adjacent to each other from the CRDM ID, from the J-groove weld surface, from the RPV head OD.

Response

It has been shown that UT inspection from the CRDM ID will detect circumferential flaws on the OD of the CRDM segment below the weld and above the weld including flaws that might emanate from the root of the weld into the tube itself. UT inspection of the volume of the J-groove weld has not yet been demonstrated to be effective from the ID of the tube.

Specific questions were raised relative to the detectability of flaws emanating from the penetration tube J-groove weld fusion zone into the tube material itself. During Wesdyne's original NDE effectiveness demonstration under the auspices of the EPRI MRP Alloy 600 ITG, which was conducted coincident with the start of the North Anna Unit 1 outage, it was shown that circumferential cracks above and below the J-groove weld could be detected with 45° shear wave techniques both on the EPRI mockup containing EDM notches and on samples from Oconee. These techniques are not optimal for detecting cracks that would emanate from the weld fusion zone. Subsequent demonstration work undertaken by Framatome and overseen by EPRI showed that fusion zone cracks could be detected with time of flight diffraction (TOFD) techniques. The demonstration setup during the Wesdyne demonstration was not conducive to effective TOFD testing but was later improved, facilitating Framatome's demonstration. However, the TOFD examination techniques being employed in the field are essentially the same for both contractors and it is concluded that the ultrasonic examinations conducted at both North Anna Units 1 and 2 were capable of detecting circumferential flaws that might grow into the penetration tube from the tube to J-groove weld fusion zone.

Inspection from the OD surface utilizing liquid penetrant and eddy current has been demonstrated to be effective in discovering surface connected flaws on the weld surface and tube OD. UT examinations from the surface of the weld are not practical because of the configuration of the weld to tube which make the required examination from two directions impossible.

It is not practical to inspect the CRDM tube or the J-groove weld from the OD of the head, in part because of the gap between the tube and head that exists just above the J-groove weld, which is one area of interest, and in part because the configuration of the head is such that the sound path distance would be so long that only gross defects could be detected.

NRC Question 19

In Section V (page 4) of the submittal, a discussion is presented on the three essential conditions necessary for PWSCC to occur. The following will eliminate the possibility for PWSCC: isolating the environment from the crack, minimizing residual stresses, and using a material with low susceptibility for PWSCC. By applying an Alloy 52 (690) weld overlay on Alloy 600 material, the overlay surface is in contact with a cracking environment, is in tension (shrinkage), and is assumed to be not susceptible to PWSCC. Provide supporting information that the weld overlay surface is not susceptible to PWSCC.

Response: Incorporated into revised relief request.

NRC Question (NDE-049 received November 15, 2001)

Provide additional detail regarding the geometry of the J-groove weld, which prohibits effective UT examination/inspection of the weld repair.

Response

Inspection/examination of the J-groove weld by UT techniques is limited by the oblique configuration of the three penetration nozzles in question relative to the curved ID surface of the vessel head. The flaws in these penetrations lay along the J-groove weld to butter fusion line, which make selection of appropriate UT scan angles impractical for most of the weld. In addition, the distance of the fusion zone from the OD of the penetration tube varies from as little as about 0.85 inches to only about 1.7 inches, insufficient space for access for typical UT transducers.

ATTACHMENT 2

Revised Relief Request NDE-048
North Anna Power Station Unit 2

Virginia Electric and Power Company
(Dominion)
North Anna Power Station Unit 2

REQUEST TO USE EMBEDDED FLAW REPAIR TECHNIQUE NORTH ANNA POWER STATION UNIT 2 RELIEF REQUEST NDE-048

I. Identification of Components

Drawings: 12050-WMKS-RC-R-1.2 Class 1

Control rod drive mechanism (CRDM) penetrations (65) and a head vent penetration (1) on the upper reactor vessel head, which are ASME Class 1 components.

II. Current Code Requirements

The Construction Code of record for the North Anna Unit 2 Reactor vessel and heads is the 1968 Edition of ASME Section III with Addenda through the Winter of 1968. North Anna Unit 2 is currently in its second inspection interval using the 1986 Edition of ASME Section XI. ASME Section XI, paragraph IWA-4120 specifies the following:

> "Repairs shall be performed in accordance with the Owner's Design Specification and the original Construction Code of the component or system. Later Editions and Addenda of the Construction Code or of Section III, either in their entirety or portions thereof, and Code Cases may be used."

Consequently, the proposed repairs will be conducted in accordance with the 1989 Edition of ASME III and the alternative requirements proposed below.

III. Code Requirements for Which Alternatives Are Requested

Per paragraph IWA-4120, repairs, if required, would be performed in accordance with Section III. Prior to welding, the repair excavation would require examination per paragraph NB-4453 with the acceptance criteria of NB-5351 and NB-5352. In neither case would it be permissible to weld over, or embed, an existing flaw.

Specifically, alternatives are being proposed for the following parts of ASME Section III, NB-4453:

NB-4453.1 addresses defect removal and requires liquid penetrant or magnetic particle examinations of the repair excavation with acceptance criteria per NB-5340 or NB-5350. In the proposed cases defects will not be removed. Instead, it is proposed that the defects be embedded with a weld overlay which will prevent further growth of the defects by isolating them from the reactor coolant which might cause them to propagate by primary water stress corrosion cracking (PWSCC). Structural integrity of the affected vessel head penetration J-groove weld will be maintained by the remaining unflawed portion of the weld.

NB-4453.2 discusses requirements for welding material, procedures, and welders. The requirements of this part will be satisfied by the proposed embedded flaw repair process.

NB-4453.3 requires that the repaired areas be uniformly blended into the surrounding surface. The proposed repairs will satisfy this requirement.

NB-4453.4 stipulates that the repairs be examined in accordance with requirements for the original weld. In the proposed cases where excavation of the original weld has occurred, the repairs will be subject to progressive liquid penetrant examination per the requirements of NB-5245. If no excavation has occurred prior to repair welding so that a temper bead procedure is not required, the weld overlay will be examined by liquid penetrant on the final surface. In both cases acceptance criteria will be per NB-5350.

NB-4453.5 requires the repairs be post weld heat treated per NB-4620. In the proposed cases, for repairs in the excavations that would require PWHT per NB-4620, a temper bead welding procedure will be used instead. Repairs where the remaining thickness of original weld buttering and/or the existing cladding maintain at least 1/8 inch between the overlay weld and the ferritic base material will not require PWHT per NB-4620.

Article IWB-3600, "Analytical Evaluation of Flaws," is not applicable to the proposed embedded flaw repairs because it contains no acceptance criteria for the components and material type in question. As a consequence, we have proposed and the NRC has previously accepted criteria discussed in WCAP-13565, Rev. 1 for North Anna Unit 1 in 1996. We do not believe paragraphs IWB-3132 and IWB-3142 are applicable to the proposed embedded flaw repairs because these paragraphs discuss requirements related to Code imposed examinations, as is clear from their location in sub-subarticle IWB-3130, "Inservice Volumetric and Surface Examinations." The examinations that are being performed, which may occasion the need to perform embedded flaw repairs, are in excess of the Code mandated inspection for the reactor head penetrations and attachment welds. As stated in the body of the relief request, the inservice examination requirements of Table IWB-2500-1 mandate a visual examination from above the insulation for 25% of the penetration welds with IWB-3522 as the acceptance standard. There is no ISI requirement for the penetration tubes or repairs to them. As a consequence of the inapplicability of paragraphs IWB-3132 and IEB-3142, it is concluded that sub-subarticle IWB-2420 dealing with successive inspections is not applicable either, since it specifically discusses flaw evaluations performed in accordance with IWB-3132.4 or IWB-3142.4.

IV. <u>Basis for Relief</u>

A request to use the embedded flaw technique to repair cracks on the inside diameter (ID) of control rod drive mechanism (CRDM) penetration tubes was previously submitted and approved by the NRC (see references 6.1-6.4). This current request expands the scope of the previous submittal to include repair of cracks on the J-groove attachment welds of these penetrations.

The 1995 Edition of Section XI with 1996 Addendum, subparagraph IWA-461.1, permits the use of Section XI flaw evaluation criteria which would not require the complete removal of a flaw unless repairs were being undertaken per the temperbead welding procedures of paragraph IWA-4620, or paragraphs IWA-4630 and IWA-4640 with the flaw penetrating the base metal. The flaw evaluation criteria of Section XI (refer to Table IWB-3514-2) establishes acceptance criteria for surface connected and embedded flaws.

North Anna Unit 2 has performed qualified visual inspections under the insulation on the reactor vessel head during a mid cycle outage in response to NRC Bulletin 2001-01. The identification of potentially leaking penetrations resulted in inspections under the vessel head. These inspections, which included eddy current and ultrasonic examination of the CRDM penetration IDs and liquid penetrant examination of the penetration ODs and J-groove weld, discovered flaws at the J-groove weld to butter interface on three penetrations which require repair because they exceed Section XI acceptance criteria. The flaws appear to be associated with lack of fusion defects existing in the welds since original construction. Excavation of several of the flaws performed to date indicate they are confined to the fusion zone between the welds and the buttering. This relief request will permit the flaws on J-groove attachment welds to be repaired with techniques documented in WCAP-13998, Revision 1, "RV Closure Head Penetration Tube ID Weld Overlay Repair," (Reference 6.1) using an embedded flaw repair technique. Evaluation of the structural integrity of the welds has shown that in the worst case only 15% of the fused area of the J-groove weld between the weld and the vessel head is required to satisfy Code strength requirements. This evaluation is documented in WCAP-14552, Revision 2, (Reference 6.9) to be forwarded separately and is essentially equivalent to the analysis documented in the ASME paper attached hereto. For the three penetrations in question (63, 62, and 51), the worst case flaws (63) appear to involve an aggregate of approximately 30% to 40% of the penetration weld fusion zone leaving 60% to 70% fused.

The embedded flaw repair technique is considered a permanent repair lasting through plant life extension for the following reasons: first, as long as a Primary Water Stress Corrosion Cracking (PWSCC) flaw remains isolated from the primary water (PW) environment, it cannot propagate. Since Alloy 52 (690) weldment is considered highly resistant to PWSCC, a new PWSCC crack should not initiate and grow through the Alloy 52 overlay to reconnect the PW environment with the embedded flaw. The resistance of the alloy 690 material has been demonstrated by laboratory testing for which no cracking of the material has been observed in simulated PWR environments, and in approximately 10 years of operational service in steam generator tubes, where likewise no PWSCC has been found. This experience has been documented in EPRI Report TR-109136, "Crack Growth and Microstructural Characterization of Alloy 600 PWR Vessel Head Penetration Materials," (Ref. 6.10) and other papers. Second, the residual stresses produced by the embedded flaw technique have been measured and found to be relatively low (Reference 6.1). This implies that no new cracks should initiate and grow in the area adjacent to the repair weld. Third, there are no other known mechanisms for significant crack propagation in this region because the cyclic fatigue loading is considered negligible. Cumulative Usage Factor (CUF) in the upper head region was calculated in aging management review report (WCAP-15269, Rev.1 for North Anna, dated September 2001) as 0.068.

The thermal expansion properties of Alloy 52 weld metal are not specified in the ASME Code, as is the case for other weld metals. In this case, the properties of the equivalent base metal (Alloy 690) should be used. For that material, the thermal expansion coefficient at 600°F is 8.2 E-6 in/in/degree F as found in Section II Part D. The Alloy 600 base metal has a coefficient of thermal expansion of 7.8 E-6 in/in/degree F.

The effect of this small difference in thermal expansion is that the weld metal will contract more than the base metal when it cools, thus producing a compressive stress on the Alloy 600 tube or the attachment weld, where the crack may be located. This beneficial effect has already been accounted for in the residual stress measurements reported in the technical basis for the embedded flaw repair.

The small residual stress produced by the embedded flaw weld will act constantly, and therefore, will have no impact on the fatigue effects in the CRDM region. Since the stress would be additive to the maximum as well as the minimum stress, the stress range would not change, and the already negligible usage factor, noted above, for the region would not change at all.

Therefore, the embedded flaw repair technique is considered to be an alternative to Code requirements that provides an acceptable level of quality and safety, as required by 10 CFR 50.55a(a)(3)(i).

V. Alternate Requirements

The embedded flaw repair method will be used as an alternative to 1986 ASME Section XI and 1989 Section III Code requirements.

Specifically, alternatives are being proposed for the following parts of ASME Section III, NB-4453:

NB-4453.1 addresses defect removal and requires liquid penetrant or magnetic particle examinations of the repair excavation with acceptance criteria per NB-5340 or NB-5350. In the proposed cases, defects will not be removed. Instead, it is proposed that the defects be embedded with a weld overlay which will prevent further growth of the defects by isolating them from the reactor coolant which might cause them to propagate by primary water stress corrosion cracking (PWSCC). Structural integrity of the affected vessel head penetration J-groove weld will be maintained by the remaining unflawed portion of the weld.

NB-4453.2 discusses requirements for welding material, procedures, and welders. The requirements of this part will be satisfied by the proposed embedded flaw repair process.

NB-4453.3 requires that the repaired areas be uniformly blended into the surrounding surface. The proposed repairs will satisfy this requirement.

NB-4453.4 stipulates that the repairs be examined in accordance with requirements for the original weld. In the proposed cases where excavation of the original weld has occurred, the repairs will be subject to progressive liquid penetrant examination per the requirements of NB-5245. If no excavation has occurred prior to repair welding so that a temper bead procedure is not required, the weld overlay will be examined by liquid penetrant on the final surface. In both cases acceptance criteria will be per NB-5350.

NB-4453.5 requires the repairs be post weld heat treated per NB-4620. In the proposed cases, for repairs in the excavations that would require PWHT per NB-4620, a temper bead welding procedure will be used instead. Repairs where the remaining thickness of original weld buttering and/or the existing cladding maintain at least 1/8 inch between the overlay weld and the ferritic base material will not require PWHT per NB-4620.

The proposed repairs will involve one of two approaches. For cases where the J-groove weld has been partially excavated either to obtain a "boat" sample for analysis or in conjunction with previously undertaken flaw exploration, the excavation will be rewelded with Alloy 52 flush with the existing weld surface, using a temper bead weld technique if necessary. As previously described, these repairs will be examined by progressive liquid penetrant inspection. The entire weld will then be overlaid with 1/8 inch of Alloy 52 weld material. For cases where no weld excavation has occurred, the existing weld will be overlaid with 1/8 inch of Alloy 52 material. All final weld surfaces will be liquid penetrant inspected.

Per the 1986 Edition of ASME Section XI, paragraph IWB-2200(a), no preservice examination is required for repairs to the partial penetration J-grove welds between the vessel head and its penetrations (Examination Category B-E) or for the penetrations themselves. However, the NDE performed after welding will serve as a preservice examination record as needed in the future. Furthermore, the inservice inspection requirements from Table IWB-2500-1, "Examination Category B-E...," is a VT-2 visual inspection of the external surfaces of 25% of the nozzles each interval with IWB-3522 as the acceptance standard. There are no ISI requirements for the penetration tubes or repairs to the tube. Currently, we perform visual examination, VT-2, of 100% of the nozzles each refueling outage. Ongoing vessel head penetration inspection activities undertaken as a result of NRC Bulletin 2001-01 and ongoing deliberations in Code committees will be monitored to determine the necessity to perform any additional or augmented inspections.

Relative to the need for successive examinations in accordance with IWB-2420, we have concluded that no such examinations are required by the Code, as discussed above. Regardless of the applicability of the ASME Code article, it is important to ensure that the repair is effective in isolating the cracking from the PWR environment permanently. The first step in ensuring this is the choice of a weld material not susceptible to PWSCC, which has been done with the Alloy 52 weldment. After the weld repair is completed, its integrity is verified by liquid penetrant inspection.

There are no known mechanisms for any further potential cracking of the weld used to embed the flaw, or the surrounding region, except for fatigue. As mentioned earlier, the calculated fatigue usage in this region is very low, because the reactor vessel head region is isolated from the transients which affect the hot leg or cold leg piping. The thickness of the weld has been set to provide a permanent embedment of the flaw, without adding sufficient weld to increase the residual stresses. This ensures that the embedded flaw repair will not affect areas nearby to the repair.

Therefore, there is no need for follow-up inspections of the repaired area from a technical point of view. However, we consider it prudent to demonstrate the effectiveness of the repairs. Therefore, for the proposed embedded flaw repairs involving the J-groove weld, we will perform an ultrasonic examination of the OD of the penetration immediately above the weld in the next inspection period to verify that no OD connected circumferential flaws exist and will perform a liquid penetrant inspection of the weld overlays.

Using the provisions of this request relief as an alternative to Code requirements will produce sound, permanent repairs and an acceptable level of quality and safety, as required by 10 CFR 50.55a(a)(3)(i).

References

1. WCAP-13998, "RV Closure Head Penetration Tube ID Weld Overlay Repair," March 1994

2. VEPCO Letter to NRC from James P. O'Hanlon, "Virginia Electric and Power Company, North Anna Power Station Unit 1, Reactor Vessel Head Penetrations Use of an Alternative Repair Technique," Serial Number 95-605, November 22, 1995

3. VEPCO Letter to NRC from James P. O'Hanlon, "Virginia Electric and Power Company, North Anna Power Station Unit 1, Reactor Vessel Head Penetrations Supplemental Information For Use of an Alternative Repair Technique," Serial Number 95-605A, January 26, 1996

4. NRC SER to J. P. O'Hanlon from David B. Matthews, "North Anna Unit 1- Use of an Alternate Repair Technique for Reactor Vessel Head Penetrations," Serial Number 96-079, February 5, 1996

5. VEPCO Letter to the NRC from Leslie N. Hartz , "Virginia Electric and Power Company, North Anna Power and Surry Power Stations - Response to NRC Bulletin 2001-01, Circumferential Cracking Of Reactor Vessel Head Penetration Nozzles," Serial Number 01-490, August 31, 2001

6. WCAP-15268, Rev.1, "Aging Management Review and Time Limited Aging Analysis for the Surry Units 1 and 2 Reactor Pressure Vessels," September 2001

7. WCAP-15269, Rev.1, "Aging Management Review and Time Limited Aging Analysis for the North Anna Units 1 and 2 Reactor Pressure Vessels," September 2001

8. VEPCO Letter to NRC from Leslie N. Hartz, "Virginia Electric and Power Company, Surry and North Anna Power Station Units 1, AMSE Section XI Inservice Inspection Program Revised Relief requests Alternative Repair Technique, Serial No. 01-450C, dated September 27, 2001

9. WCAP-14552, "Structural Integrity Evaluation of Reactor Vessel Head Penetrations to Support Continued Operation: North Anna and Surry Units"

10. TR-109136, "Crack Growth and Microstructrual Characterization of Alloy 600 PWR Vessel Head Penetration Materials, EPRI, December 1997

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Nuclear, Fossil, and Petrochemical Plants
ASME 1994

EXPERIENCES WITH DETECTION AND DISPOSITION OF INDICATIONS IN HEAT PENETRATIONS OF SWEDISH PLANTS

J. Lagerström, B. Wilson, and B. Persson
Vattenfall AB Ringhals
Väröbacka, Sweden

W. H. Bamford and B. Bevilacqua
Westinghouse Energy Systems
Pittsburgh, Pennsylvania

ABSTRACT

In November of 1991, a number of cracks were found in the reactor vessel head penetrations of a french plant. In the spring of 1992, an inspection of the head penetration region led to the identification of several small indications in the Ringhals Unit 2 in southwestern Sweden. This paper describes the disposition of these indications as well as the results of a subsequent inspection in spring of 1993. The inspections and the integrity evaluations led to the ultimate conclusion that the plant could safely return to power, and that process is described herein.

1. INTRODUCTION

In the fall of 1991, a hydrotest was underway at a plant in France, and leakage was detected in the reactor vessel upper head region. Investigation showed that the leak was originating from a through-wall flaw in one of the control rod drive mechanism head penetrations. These are heavy wall Alloy 600 tubes about 102 mm (four inches) in outside diameter which penetrate the reactor vessel head, and are secured by partial penetration welds at the inside surface, as shown for example in Figure 1. Detailed inspections revealed additional cracks in the penetration which had leaked, and cracks in some of the other penetrations in the same reactor vessel. This led to inspections of other plants in France, and additional cracking was found, although it was not widespread.

In May of 1992, the first inspection of a Swedish plant to look for this type of cracking took place at Ringhals Unit 2, and several small cracks were discovered. One of these was removed by electric discharge machining (EDM), while the remaining few were left in place, and their safety was justified by an integrity analysis. A follow-up inspection was done in May of 1993, and a few additional indications were found. The propagation of the old cracks was negligible. However, a new type of indication, located between the weld preparation J-groove buttering and the low alloy steel of the head was observed in one of the penetrations. This led to significant further investigations. This paper will discuss the details of these investigations, and the conclusions reached.

2. INSPECTION FINDINGS

The inspections performed on the head penetrations were aimed primarily at finding cracks in the penetrations themselves, since such cracks had been found in several other European plants. The inspection began with an eddy current technique, which is designed to identify the presence of cracks, and to characterize their length. If cracks are detected, the inspection is supplemented by ultrasonic tests to determine the depth of the cracks, and to verify the length.

In the 1992 inspection, indications were found in five penetrations, with four of the five being very shallow. The largest crack was removed by EDM, and the others were allowed to remain inservice, with a follow-up inspection planned for May 1993. The 1993 inspection revealed that the indications may have increased slightly in length, but no growth in depth was evident. The judgement of the inspectors was that the crack propagation was negligible, since the differences in the characterized flaw sizes were within measurement tolerances. The indications were therefore allowed to remain in place again, since generous safety margins were demonstrated to exist.

In addition to the inspections of the penetrations, surface inspections of the attachment welds were carried out. In 1992, three attachment welds were inspected with liquid penetrant, and no indications found. In 1993, six penetrations were inspected, and indications were found in the cladding at one of the six, penetration number 62, shown schematically in Figure 2. Shallow boat samples were removed and the cracks were confirmed to be very shallow, but extended intermittently through the thickness of the cladding, about 5 mm (0.188 in).

The penetrant test was supplemented by ultrasonic tests, which were very difficult to accomplish because of the geometry, as seen in Figure 2. The UT results indicated an area of lack of fusion in the attachment weld just above the surface cracks, as shown in Figure 2. Because of the difficulty of the UT exam, it was decided to remove larger boat samples to examine the weld fusion zone. The boat samples confirmed the lack of fusion identified by the UT, and plans were made to determine the extent of lack of fusion which might exist on all 65 of the head penetrations of Ringhals Unit 2.

To accomplish this task, specialized UT methods were developed to enable coverage of both the fusion zone with the head and the fusion zone with the penetration tube. The latter zone could only be inspected with a probe designed to fit between the thermal liner and the penetration itself, a gap of only a few millimeters. The UT methodology involved focused probes, to examine the immediate vicinity of each of the fusion zones, and the technique was verified by tests on a head penetration mockup with deliberate defects. The development and verification of these advanced UT methods required nearly two months, and was done while the plant remained down.

All the penetrations were inspected, and a few other penetrations with minor weld lack of fusion were detected. The lack of fusion discovered is a totally separate issue from the primary water stress corrosion cracking (PWSCC) discovered earlier. The attachment weld lack of fusion appears to be fabrication related.

The next step was to determine the acceptability of the various regions of lack of fusion, to enable decisions to be made on repairs which might be required.

3. INTEGRITY ASSESSMENT

As the inspection techniques were being developed, an integrity assessment was underway to determine the acceptability of the areas of lack of fusion, as well as to provide input to the proper disposition of the boat sample sites on penetration 62.

Three-dimensional finite element analyses were carried out, modelling the outermost row of penetrations. This row is typically the highest stressed, because of the larger angle of intersection with the vessel head. Penetration 62 is in the outermost row, so it would be covered by these models, but a separate model was made with the boat sample geometry, to enable a detailed study of the periphery of this discontinuity.

The stress analysis considered a number of thermal transient conditions in addition to the steady state condition. Results showed that the internal pressure generates the majority of the stresses. The boat sample cavity only alters the stress pattern in a very localized area. The stresses in the weld and the penetration tube are controlled by the displacement of the vessel head, which in turn is controlled by the internal pressure.

3.1 Boat Sample Region

The analysis carried out for this location was used as input to a decision on whether a repair was required here. The criteria chosen were those of the ASME code. The key criteria were the design stress limits of ASME Section III. A fatigue analysis was also carried out to investigate the likelihood of flaws initiating around the periphery of the excavations. The boat sample region is shown schematically in Figure 3, along with the finite element model showing the excavation.

The stress results were compared with the code design allowables, and found to be acceptable at virtually all locations around the periphery of the cutout. The fatigue analysis considered all the design transients for the plant, and resulted in the conclusion that the excavation would not initiate any new flaws in the surrounding materials, either the Alloy 600 or the SA533 ferritic base metal. The maximum calculated usage factor was 0.05 in the Alloy 600, and 0.34 in the ferritic steel. These usage factors included a stress concentration factor of 2.0 imposed on the finite element peak stresses.

These analyses led to the conclusion that the boat sample excavations did not require repair, since all the design rules were met. The only requirement coming from this analysis was that the excavations must be sealed, to ensure no leak path existed through any of the areas of lack of fusion uncovered by their presence. The other key element of the integrity evaluation was the acceptability of the areas of lack of fusion.

3.2 Fusion Zones

There are two fusion zones of interest for the head penetration attachment welds, the penetration itself (Alloy 600) and the reactor vessel head material (A533B ferritic steel). The operating temperature of the upper head region of the Ringhals plant is 319°C (610°F), so both materials will be very ductile. The toughness of both materials is quite high, so any flaw propagation along either of the fusion zones will be totally ductile.

To determine the driving force for a crack in the fusion zones, a two dimensional finite element model was prepared of a center penetration. A flaw was introduced in the fusion zone with the vessel head, extending half way up the total length of the fusion zone as shown in Figure 4. This was considered the governing location for the stress intensity factor calculation, and a good approximation for all penetrations. The loading was elastic plastic, and considered the original welding process followed by a hydrotest and then loading with design pressure and temperature. The calculated stress intensity factor was 56 ksi$\sqrt{in}$ (62 MPa$\sqrt{in}$) for this case, which included the residual stress from the welding process. This analysis showed that the stress intensity factor remained below the allowable value of 63.2 ksi $\sqrt{in}$ even for this worst case situation. The allowable value is the fracture toughness reduced by the $\sqrt{10}$, or $200 \div \sqrt{10} = 63.2$ ksi $\sqrt{in}$, as taken from Section XI of the ASME code for the ferritic head material.

To provide a more realistic estimate of the critical flow size for the fusion zones, a ductile failure calculation was used. A second calculation was made for the allowable flaw size, which includes the margins required in the ASME code. The simpler case is the Alloy 600 fusion zone, where the potential failure will be a pure shearing of the penetration as the pressurized penetration tube tries to push itself out of the head, as may be seen in Figure 2.

The failure criterion will be that the average shear stress along the fusion line exceeds the limit shear stress. For the critical flaw size, the limiting shear stress is the shear flow stress, which is equal to half the tensile flow stress, according to the Tresca criterion. The tensile flow stress is the average of the yield stress and ultimate tensile stress of the material. The criterion for Alloy 600 at 319°C (606°F) is:

Average shear stress < shear flow stress = 26.85 ksi

The above value was taken from the ASME Code, Section III, Appendix I, at 600°F.

For each penetration the axial force which produces this shear stress results from the internal pressure, and since each penetration has the same outer diameter, the axial force is the same. The average shear stress increases as the load carrying area decreases (the area of lack of fusion increases), and when this increasing lack of fusion area increases the stress to the point at which it equals the flow stress, failure occurs. This point may be termed the critical flaw size. This criterion is actually somewhat conservative. Alternatively, use of the Von Mises failure criterion would have set the shear flow stress equal to 60 percent of the axial flow stress, and would therefore have resulted in larger critical flaw sizes.

The allowable flaw size, as opposed to the critical flaw size discussed above, was calculated using the allowable limit of Section III of the ASME Code, paragraph NB 3227.2. The criterion for allowable shear stress then becomes:

Average shear stress < 0.6 S_m = 13.98 ksi

where S_m = the ASME Code limiting design stress from Section III, Appendix I.

The above approach was used to calculate the allowable flaw size and critical flaw size for the outermost and center penetrations. The results show that a very large area of lack of fusion can be tolerated by the head penetrations, regardless of their orientation. These results can be illustrated for the outermost presentation.

The total surface contact area for the fusion zone on the outermost head penetration is 17.4 in^2. The calculations above result in a required area to avoid failure of only 1.45 in^2, and using the ASME Code criteria, the area required is 2.79 in^2. These calculations show that as much as 83.9 percent of the weld may be unfused, and the code acceptance criteria can still be met.

To envision the extent of lack of fusion which is allowable, Figure 5 was prepared. In this figure, the weld fusion region for the outermost penetration has been shown in an unwrapped, or developed view. The figure shows the extent of lack of fusion which is allowed, in terms of limiting lengths for a range of circumferential lack of fusion. This figure shows that the allowable vertical length of lack of fusion for a full circumferential unfused region is 84 percent of the weld length. Conversely, for a region of lack of fusion which extends the full vertical length of the weld, the circumferential extent is limited to 302 degrees. The extent of lack of fusion which would cause failure is labelled "critical" on this figure, and is even larger. The dimensions shown on this figure are based on an assumed rectangular area of lack of fusion.

The full extent of this allowable lack of fusion is shown in Figure 6, where the axes have been expanded to show the full extent of the tube-weld fusion line. This figure shows that a very large area of lack of fusion is allowable for the outer most penetration. Similar results were found for the center penetration, where the weld fusion area is somewhat smaller at 16.1 in^2.

A similar calculation was also carried out for the fusion zone between the weld and the head, and the result is shown in Figure 7. The allowable area of unfused weld for this location is 84.8 percent of the total area. This approach to the fusion zone with the carbon steel head is only approximate, but may provide a realistic estimate of the allowable. Note that even a complete lack of fusion in this region would not result in rod ejection, because the weld to the tube would prevent it.

The allowable lack of fusion for the weld fusion zone to the head may be somewhat in doubt, because of the different geometry, where one cannot ensure that the failure would be due to pure shear. To investigate this concern, additional finite element models were constructed with various degrees of lack of fusion discretely modelled, ranging from 30 to 65 percent. The stress intensities around the circumference of the penetration were calculated, to provide for the effects of all stresses, as opposed to the shear stress only, as used above. When the average stress intensity reaches the flow stress (53.7 ksi), failure is expected to occur. The code allowable stress intensity is 1.5 Sm, or 35 ksi, using the lower of the Alloy 600 and ferritic allowables at 320°C (610°F).

The results of this series of analyses are shown in Figure 8, where it is clear that large areas of lack of fusion are allowable. As the area of lack of fusion increases, the stresses redistribute themselves, and the stress intensity does not increase in proportion to the area lost. These results seem to confirm that the shear stress is the only important stress governing the critical flaw size for the head fusion zone as well.

SUMMARY AND CONCLUSIONS

The upper head penetrations have been extensively studied to characterize their integrity as a result of the inspection findings. The originally planned inspections of May 1993 were supplemented by a number of additional inspections, some of which involved the advancement of the state of the art.

The largest allowable area of lack of fusion was determined for each of the penetration welds, and the result was that over eighty percent of the fusion zone could be unfused, and the allowables of the ASME Code Section III would still be satisfied. There were no penetrations with areas of lack of fusion which even approached the allowable.

The boat sample excavation region of penetration 62 was carefully analyzed to determine its structural acceptability. The excavation introduces a structural discontinuity, but the analysis showed that its presence would not lead to the initiation of other cracks, and that the stresses in the vicinity continue to meet the design stress limits of the ASME Code Section III. The divot was sealed by installing a non-structural cover with a seal weld, to ensure that none of the areas of lack of fusion are exposed to the water reactor environment.

The Swedish regulatory authority, after extensive review, gave permission for the plant to restart, and the plant achieved full power on December 27, 1993.

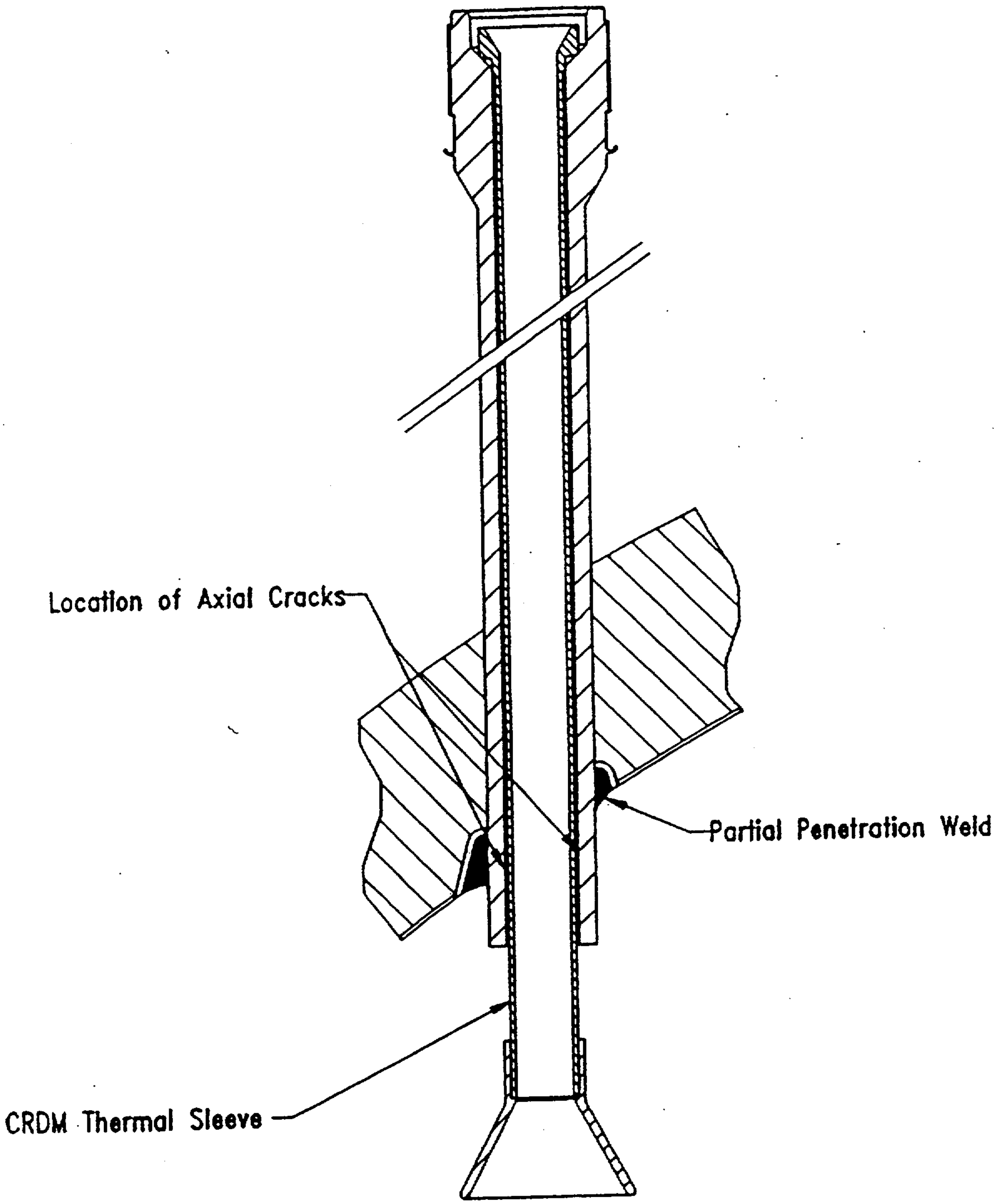


Figure 1. Typical Head Penetration

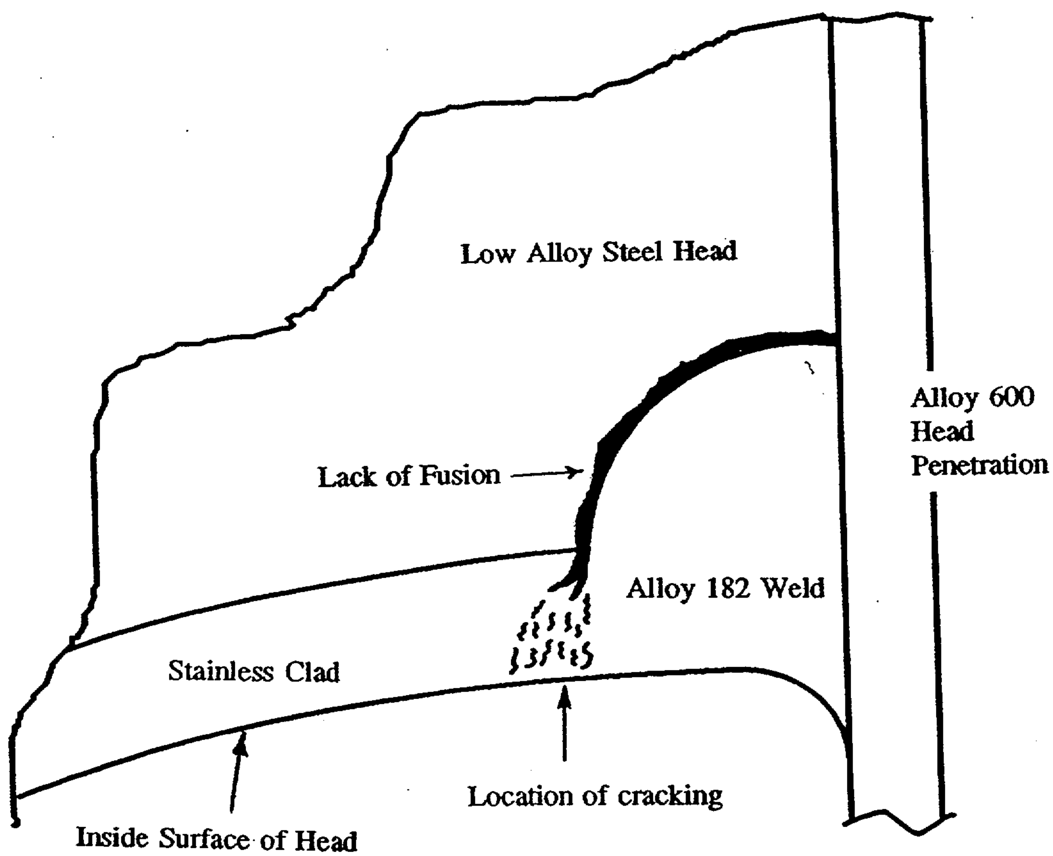
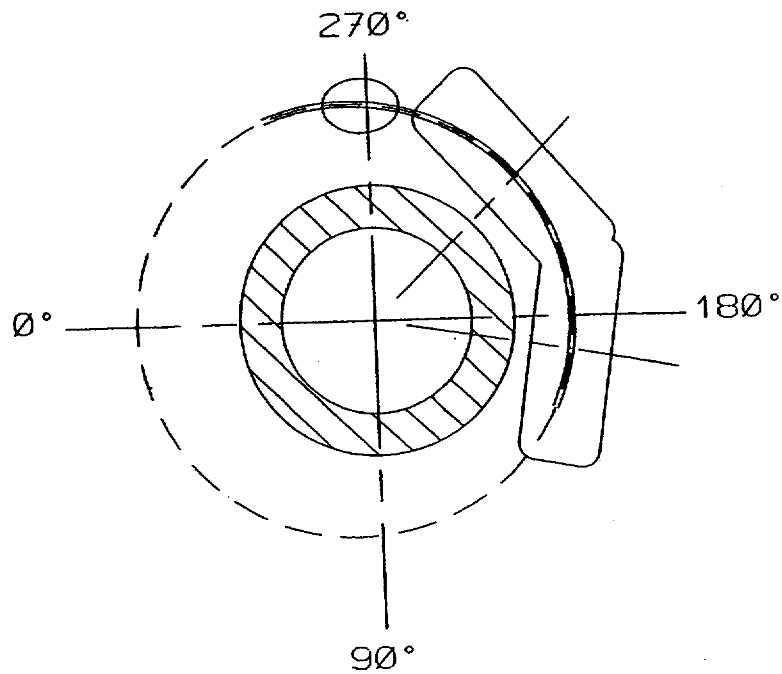


Figure 2. Location of Surface Indications at Penetration 62



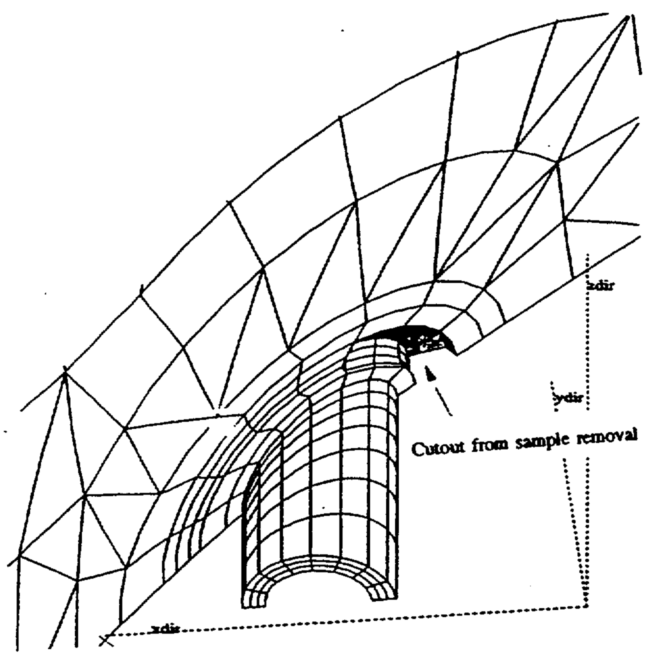


Figure 3. Schematic of the Boat Sample Excavation on Penetration 62, and the Finite Element Model.

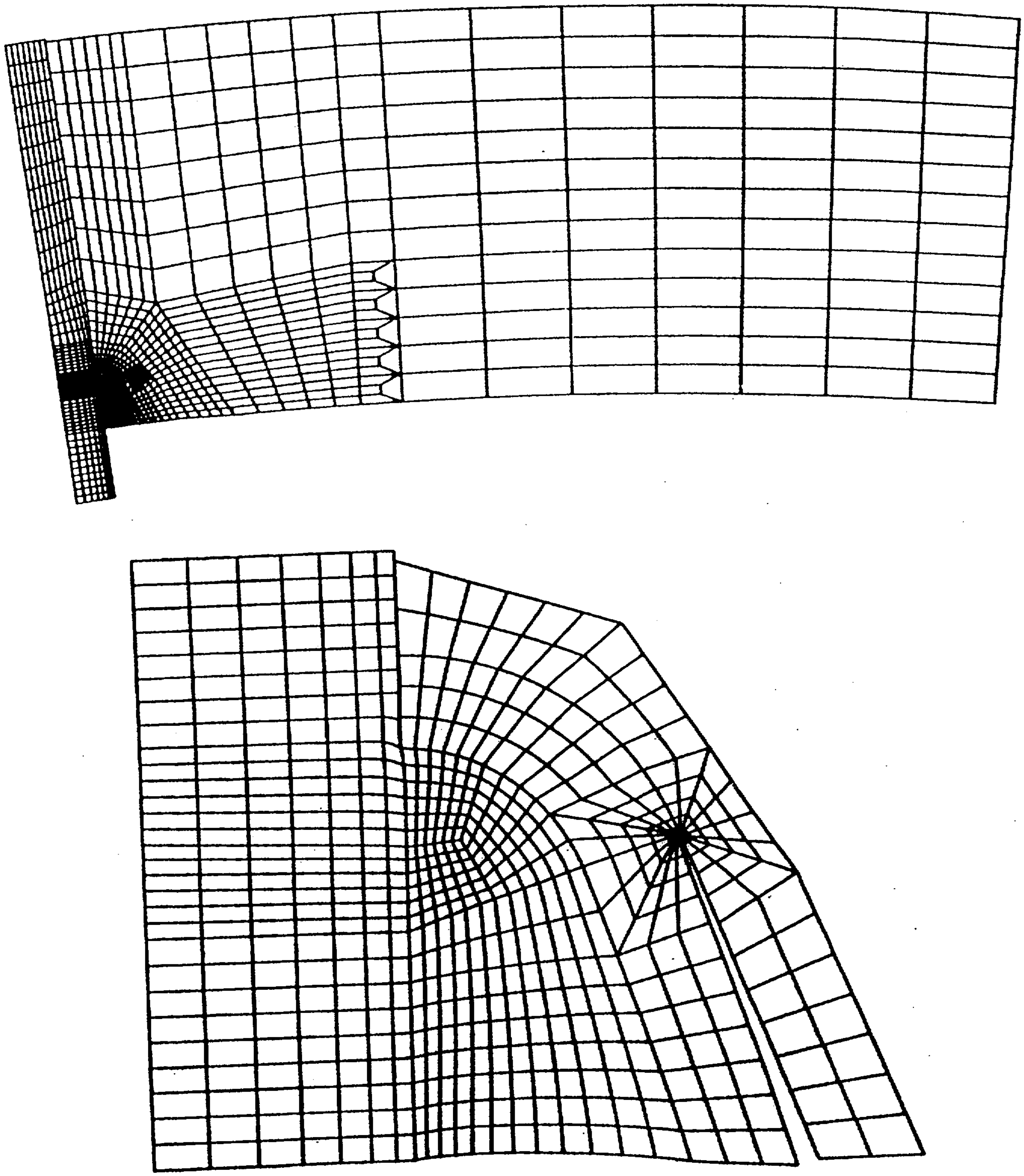


Figure 4. Finite Element Model of Lack of Fusion in the Weld to the Ferritic Head

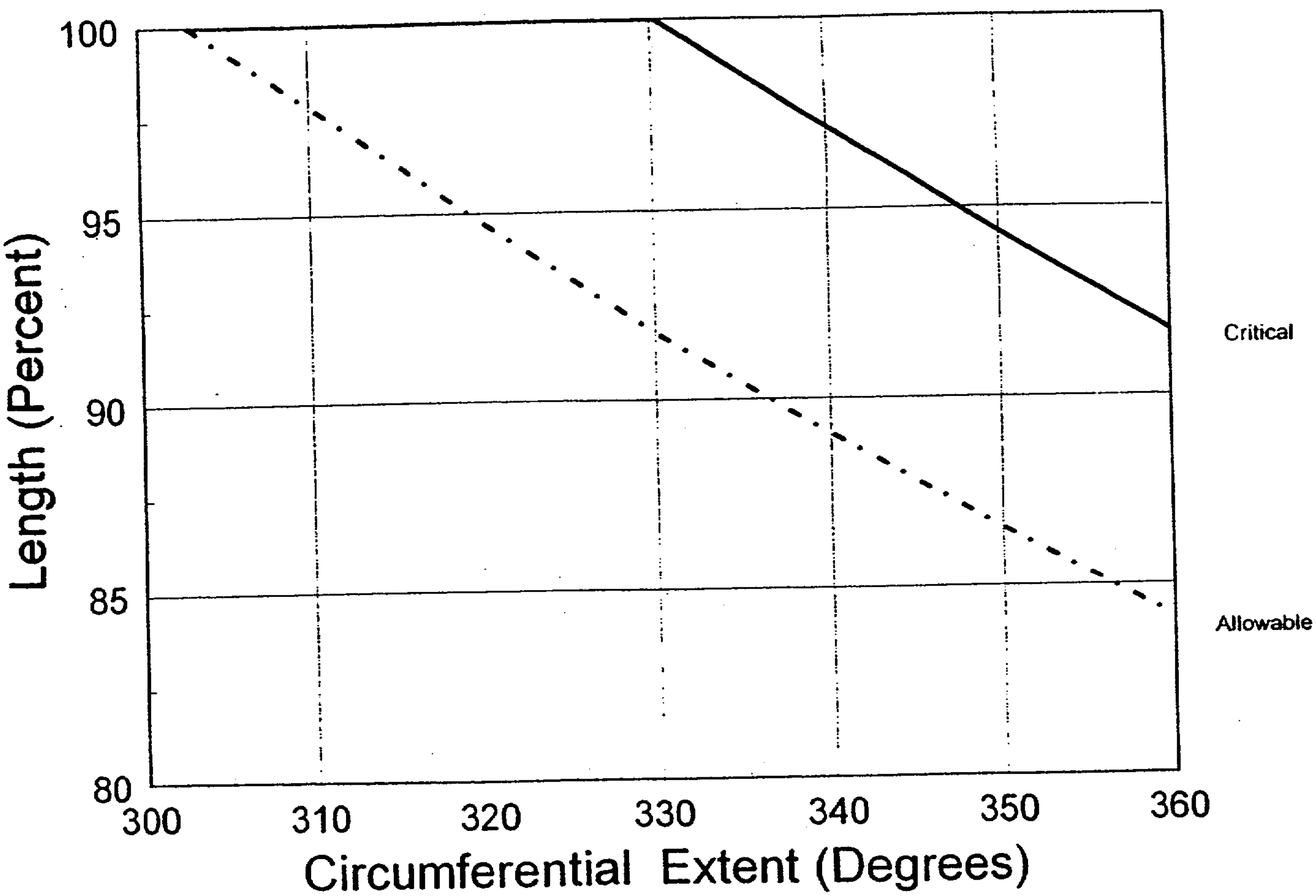


Figure 5. Allowable Regions of Lack of Fusion for the Outermost Penetration Tube to Weld Fusion Zone: Detailed View.

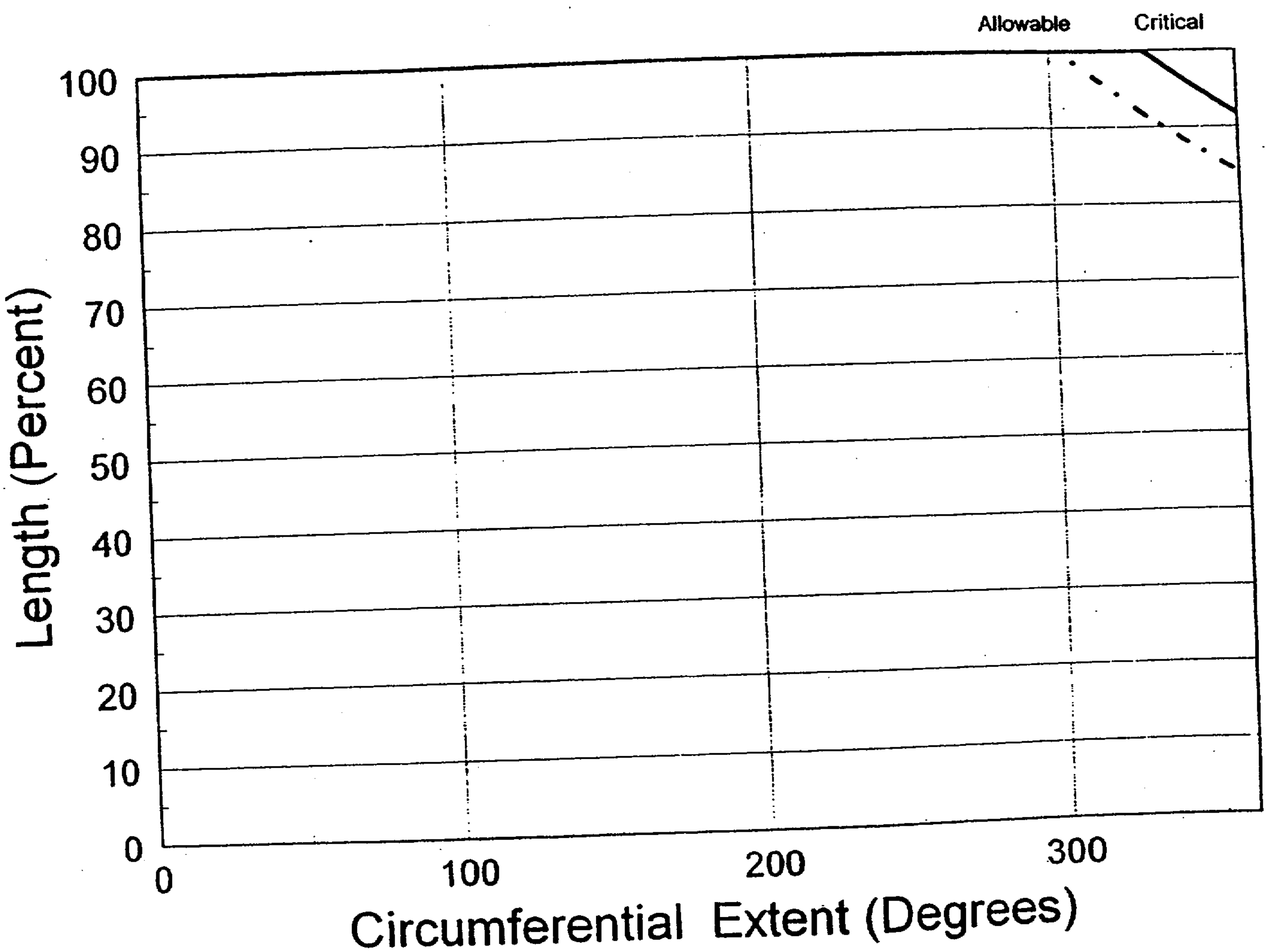


Figure 6. Allowable Regions of Lack of Fusion for the Outermost Penetration: Tube to Weld Fusion Zone.

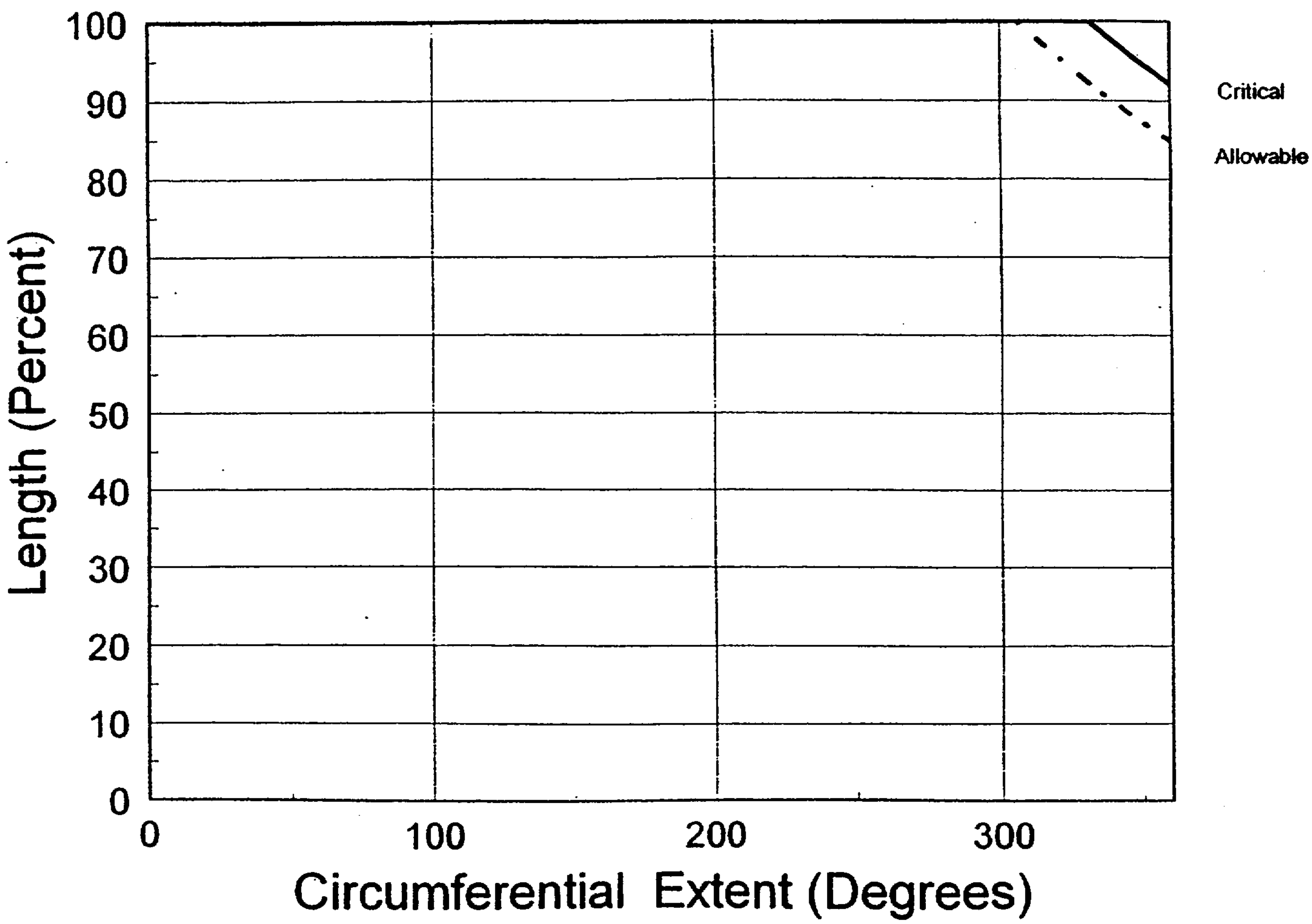


Figure 7. Allowable Regions of Lack of Fusion for All Penetrations: Weld to Vessel Fusion Zone.