VIRGINIA ELECTRIC AND POWER COMPANY

RICHMOND, VIRGINIA 23261

November 22, 1995

U.S. Nuclear Regulatory Commission
Attention: Document Control Desk
Washington, D.C. 20555

Serial No. 95-605
NES/ISI/PJN/EJW
Docket No. 50-338
License No. NPF-4

Gentlemen:

VIRGINIA ELECTRIC AND POWER COMPANY
NORTH ANNA POWER STATION UNIT 1
REACTOR VESSEL HEAD PENETRATIONS
USE OF AN ALTERNATIVE REPAIR TECHNIQUE

Inspections at pressurized water reactors have shown the presence of cracking in some reactor vessel head penetration tubes. This phenomenon has been followed closely by the Nuclear Energy Institute (NEI) and the owners groups. Based on a reassessment of the phenomenon by the Westinghouse Owners Group (WOG), it appears that Virginia Electric and Power Company's (Virginia Power's) North Anna and Surry Power Stations may be more susceptible to the cracking mechanism than previously believed.

Because of the slow rate of crack growth and relative ease of detection, the issue appears to have a low safety significance but potential economic risk. As a precautionary measure, it is our intent to perform a limited inspection at this time. The results of those inspections will be used to refine the WOG guidelines for reactor vessel head penetration tube cracking and to determine the necessity for similar inspection activities in the future at North Anna and Surry.

Virginia Power currently plans to inspect North Anna Unit 1 during the February 1996 refueling outage. In the unlikely event that repairs are required as a result of the inspection, we request, pursuant to 10 CFR 50.55(a)(3), the use of the attached Alternative to Code Requirements. We also request that the NRC's review and approval of this alternate repair technique occur prior to mid-January 1996 in order to facilitate the upcoming North Anna Unit 1 outage, currently scheduled to begin February 9, 1996.

Change: NRC PDR 1 INP
Ltr Encl

A001 1/1 Prop 1 INP

The following documents are referenced in the attached Alternative to Code Requirements and are enclosed:

1. WCAP-13998, Rev. 1, "RV Closure Head Penetration Tube ID Weld Overlay Repair" (Proprietary) (5 copies)

2. WCAP-14519, "RV Closure Head Penetration Tube ID Weld Overlay Repair" (Non-Proprietary) (5 copies)

3. USNRC Letter, W.T. Russell to Raisin, NUMARC, "Safety Evaluation for Potential Reactor Vessel Head Adapter Tube Cracking," November 19, 1993.

4. USNRC Letter, A.G. Hansen to R.E. Link, "Acceptance Criteria for Control Rod Drive Mechanism Penetrations at Point Beach Nuclear Plant, Unit 1," March 9, 1994.

Also enclosed are a Westinghouse authorization letter, CAW-95-906, accompanying affidavit, Proprietary Information Notice, and Copyright Notice.

As Item 1 contains information proprietary to Westinghouse Electric Corporation, it is supported by an affidavit signed by Westinghouse, the owner of the information. The affidavit establishes the basis on which the information may be withheld from public disclosure by the Commission and addresses with specificity the considerations listed in paragraph (b)(4) of Section 2.790 of the Commission's regulations. Accordingly, the information which is proprietary to Westinghouse should be withheld from public disclosure in accordance with 10 CFR Section 2.790 of the Commission's regulations

Correspondence with respect to the copyright or proprietary aspects of the items listed above or the supporting Westinghouse Affidavit should reference CAW-95-906 and should be addressed to N. J. Liparulo, Manager of Nuclear Safety Regulatory & Licensing Activities, Westinghouse Electric Corporation, P.O. Box 355, Pittsburgh, Pennsylvania 15230-0355.

The attached relief request has been approved by the Station Nuclear Safety and Operating Committee. If you have any questions concerning this request, please contact us.

Very truly yours,

ML Bowling

for James P. O'Hanlon
Senior Vice President - Nuclear

Attachment

cc: U.S. Nuclear Regulatory Commission
Region II
101 Marietta Street, N.W.
Suite 2900
Atlanta, Georgia 30323

Mr. R. D. McWhorter
NRC Senior Resident Inspector
North Anna Power Station

ALTERNATIVE TO CODE REQUIREMENTS

I. IDENTIFICATION OF COMPONENTS

Drawing - 11715-WMKS-RC-R-1.2 Class 1

Ring[1]	Penetration #	Description
Initial Sample Group		
13	62 - 69	4" control rod drive tube (sleeved)
12	58 - 61	4" control rod drive tube (sleeved)
11	51, 53, 54, 57	4" thermocouple tube (not sleeved)
	50, 52, 55, 56	4" control rod drive tube, spare (not sleeved)
Expansion Groups[2]		
10	46 -49	4" control rod drive tube (sleeved)
9	38 - 45	4" control rod drive tube (sleeved)
8	30 - 37	4" control rod drive tube (sleeved)
7	26 - 29	4" control rod drive tube (sleeved)
6	22, 23, 24, 25	4" control rod drive tube, rods removed (not sleeved)
5	15, 17, 19, 21	4" control rod drive tube, spare (not sleeved)
4	10 - 13	4" control rod drive tube (sleeved)
3	6 - 9	4" control rod drive tube (sleeved)
2	2 - 5	4" control rod drive tube (sleeved)
1	1	4" control rod drive tube, rods removed (not sleeved)

[1] Ring number identifies the distance from the center of the reactor vessel head. The higher the ring number the greater the distance from center and a higher probability of finding a flaw.

[2] Expansion scope - If an unacceptable flaw is found in the initial sample group, then the next ring will be examined. Expansion will continue until all the penetration tubes in a ring are found to be acceptable.

II. IMPRACTICAL CODE REQUIREMENTS

The North Anna Unit 1 reactor vessel closure head penetrations are scheduled to be examined during the 1996 refueling outage, as shown above. The initial inspection scope will include the twenty penetrations in the outer three rings. The closure head penetration tube base material in the region of the attachment weld will be examined volumetrically using eddy current. Any identified flaws will be characterized by ultrasonics. There are no inservice acceptance standards established for this area since this examination is not required by ASME Section XI, 1983 Edition, Summer 1983 addenda. As allowed by subparagraph IWA-3100(b) "If acceptance standards for a particular component, Examination Category, or examination method are not specified in this Division, indications that exceed the acceptance standards for materials and welds specified in the Section III edition applicable to the construction of the component shall be evaluated to determine disposition. Such disposition shall be subject to review by the enforcement authority having jurisdiction at the plant site."

Acceptance criteria have been established by Westinghouse and reported in WCAP 14024, "Inspection Plan Guidelines for Industry/Plant Inspection of Reactor Vessel Closure Head Penetration Tubes." The acceptance criteria have been reviewed and accepted by the NRC[1,2], with comments. The NRC comments have been incorporated in WCAP 14024. Virginia Power and Westinghouse are developing repair techniques in the event repairs are required. The Code requires flaws exceeding the acceptance criteria to be removed or reduced to an acceptable size, as stated in subparagraph IWB-3112(c) "Components whose examination (IWB-2200) reveals flaw indications, other than the indications of (b) above, that exceed the standards of Table IWB-3410-1 shall be unacceptable for service unless such flaws are removed or repaired to the extent necessary to meet the allowable flaw indication standards prior to placement of the component in service."

Thermal sleeves are installed in 48 of the 65 reactor vessel head penetration tubes. Due to the penetration configuration and the available tooling, complete removal of flaws greater than 0.25 inches deep requires the removal of the thermal sleeve. Removal and reinstallation of the thermal sleeve is a very difficult process. Any removal and reinstallation method involves special tooling, a significant amount of remote machining/welding, radiation exposure, and uncertainty.

III. BASIS FOR ALTERNATIVE TO CODE REQUIREMENTS

An alternative to removing the thermal sleeve and totally removing the flaw is to partially remove the flaw and weld overlay to the original wall thickness. This technique is referred to as an "embedded flaw repair." This repair technique is described in the Westinghouse Annotated Letter and WCAP 13998 (attached), entitled "RV Closure Head Penetration Tube ID Weld Overlay Repair."

The weld overlay eliminates the exposure of the flaw to the reactor coolant environment, which stops further flaw growth and results in a subsurface flaw as defined by ASME Section XI, IWA-3320. Acceptance standards for flaws will be based on the NEI/NUMARC guidelines. The penetration tube is sufficiently stiff, and constrained by the vessel head, so the integrity of the tube will be maintained by the weld overlay regardless of the extent of the flaw.

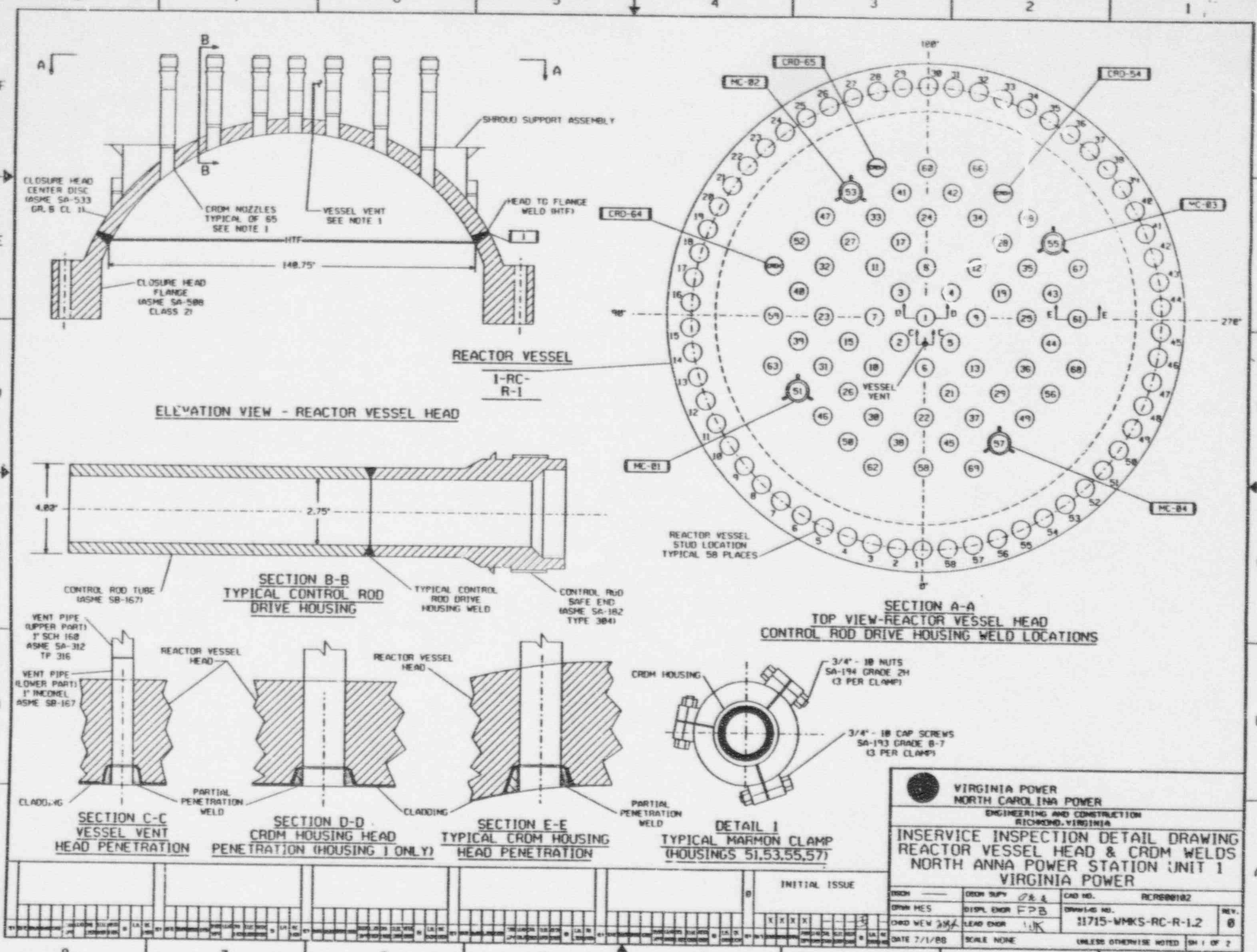
The other advantages to this type of repair verses a Code repair is that this technique results in lower residual stress than a complete excavation with a full weld build up and a better surface for reinspection than a complete excavation and a partial weld build up. Therefore, it is also advantageous to use this technique for unsleeved penetrations. Additionally the development of analysis and tooling for a single versatile repair technique is preferred.

[1]USNRC Letter, W.T. Russell to Raisin, NUMARC, "Safety Evaluation for Potential Reactor Vessel Head Adapter Tube Cracking," November 19, 1993.

[2]USNRC Letter, A.G. Hansen to R.E. Link, "Acceptance Criteria for Control Rod Drive Mechanism Penetrations at Point Beach Nuclear Plant, Unit 1," March 9, 1994.

IV. ALTERNATIVE TO CODE REQUIREMENTS

The embedded flaw repair method, proposed and supported by the stated Westinghouse documentation, will be used as an alternative to the Code requirements if repairs are required, for axial flaws up to 75% through-wall in reactor vessel head penetration tubes. The flaw will be partially removed using electric discharge machining (EDM). The excavation will be based on the depth of the measured flaw and will range from 0.090 to 0.125 inches. A weld overlay will be performed to restore the tube wall thickness. The final weld will be examined volumetrically using eddy current and ultrasonics and surface examined using liquid penetrant. The reactor vessel head will be VT-2 examined without removing the insulation during startup at nominal operating pressure.


SHROUD SUPPORT ASSEMBLY
CLOSURE HEAD CENTER DISC (ASME SA-533 GR. B CL 1)
CRDM NOZZLES TYPICAL OF 65 SEE NOTE 1
VESSEL VENT SEE NOTE 1
HEAD TO FLANGE WELD (HTF)
HTF
140.75"
CLOSURE HEAD FLANGE (ASME SA-508 CLASS 2)
REACTOR VESSEL
1-RC-R-1
ELEVATION VIEW - REACTOR VESSEL HEAD
CRD-65
MC-02
CRD-54
MC-03
CRD-64
MC-01
MC-04
VESSEL VENT
REACTOR VESSEL STUD LOCATION TYPICAL 58 PLACES
SECTION A-A
TOP VIEW-REACTOR VESSEL HEAD
CONTROL ROD DRIVE HOUSING WELD LOCATIONS
4.02"
2.75"
CONTROL ROD TUBE (ASME SB-167)
SECTION B-B
TYPICAL CONTROL ROD DRIVE HOUSING
TYPICAL CONTROL ROD DRIVE HOUSING WELD
CONTROL ROD SAFE END (ASME SA-182 TYPE 304)
VENT PIPE (UPPER PART) 1" SCH 160 ASME SA-312 TP 316
VENT PIPE (LOWER PART) 1" INCONEL ASME SB-167
REACTOR VESSEL HEAD
CLADDING
PARTIAL PENETRATION WELD
SECTION C-C
VESSEL VENT
HEAD PENETRATION
SECTION D-D
CRDM HOUSING HEAD
PENETRATION (HOUSING 1 ONLY)
SECTION E-E
TYPICAL CRDM HOUSING
HEAD PENETRATION
CRDM HOUSING
3/4" - 10 NUTS SA-194 GRADE 2H (3 PER CLAMP)
3/4" - 10 CAP SCREWS SA-193 GRADE B-7 (3 PER CLAMP)
DETAIL 1
TYPICAL MARMON CLAMP
(HOUSINGS 51,53,55,57)
INITIAL ISSUE
VIRGINIA POWER
NORTH CAROLINA POWER
ENGINEERING AND CONSTRUCTION
RICHMOND, VIRGINIA
INSERVICE INSPECTION DETAIL DRAWING
REACTOR VESSEL HEAD & CRDM WELDS
NORTH ANNA POWER STATION UNIT 1
VIRGINIA POWER
DRWN MES
DATE 7/1/88
SCALE NONE
CAD NO. RCR000102
11715-WMKS-RC-R-1.2
REV. 0
UNLESS OTHERWISE NOTED
SH 1 OF 2

Westinghouse
Electric Corporation

Energy Systems

Nuclear Technology Division

Box 355
Pittsburgh Pennsylvania 15230-0355

November 20, 1995
CAW-95-906

Document Control Desk
US Nuclear Regulatory Commission
Washington, DC 20555

Attention: Mr. William Russell

APPLICATION FOR WITHHOLDING PROPRIETARY
INFORMATION FROM PUBLIC DISCLOSURE

Subject: "RV Closure Head Penetration Tube ID Weld Overlay Repair," WCAP-13998, Rev. 1 (Proprietary)

Dear Mr. Russell:

The proprietary information for which withholding is being requested is further identified in Affidavit CAW-95-906 signed by the owner of the proprietary information, Westinghouse Electric Corporation. The affidavit, which accompanies this letter, sets forth the basis on which the information may be withheld from public disclosure by the Commission and addresses with specificity the considerations listed in paragraph (b)(4) of 10 CFR Section 2.790 of the Commission's regulations.

Accordingly, this letter authorizes the utilization of the accompanying Affidavit by Virginia Power Company.

Correspondence with respect to the proprietary aspects of the application for withholding or the Westinghouse affidavit should reference this letter, CAW-95-906, and should be addressed to the undersigned.

Very truly yours,

JM Brennan For

N. J. Liparulo, Manager
Nuclear Safety Regulatory & Licensing Activities

RSL/bbp

Enclosures

cc: Kevin Bohrer/NRC (12H5)

CAW906/NSRLA554L

AFFIDAVIT

COMMONWEALTH OF PENNSYLVANIA:

ss

COUNTY OF ALLEGHENY:

Before me, the undersigned authority, personally appeared James M. Brennan, who, being by me duly sworn according to law, deposes and says that he is authorized to execute this Affidavit on behalf of Westinghouse Electric Corporation ("Westinghouse") and that the averments of fact set forth in this Affidavit are true and correct to the best of his knowledge, information, and belief:

James M. Brennan

James M. Brennan, Manager
Operating Plant Licensing

Sworn to and subscribed
before me this 20th day
of November, 1995

Loraine M. Piplica
Notary Public

Notarial Seal
Lorraine M. Piplica, Notary Public
Monroeville Boro, Allegheny County
My Commission Expires Dec. 14, 1995
Member, Pennsylvania Association of Notaries

(1) I am Manager, Operating Plant Licensing, in the Nuclear Technology Division, of the Westinghouse Electric Corporation and as such, I have been specifically delegated the function of reviewing the proprietary information sought to be withheld from public disclosure in connection with nuclear power plant licensing and rulemaking proceedings, and am authorized to apply for its withholding on behalf of the Westinghouse Energy Systems Business Unit.

(2) I am making this Affidavit in conformance with the provisions of 10CFR Section 2.790 of the Commission's regulations and in conjunction with the Westinghouse application for withholding accompanying this Affidavit.

(3) I have personal knowledge of the criteria and procedures utilized by the Westinghouse Energy Systems Business Unit in designating information as a trade secret, privileged or as confidential commercial or financial information.

(4) Pursuant to the provisions of paragraph (b)(4) of Section 2.790 of the Commission's regulations, the following is furnished for consideration by the Commission in determining whether the information sought to be withheld from public disclosure should be withheld.

(i) The information sought to be withheld from public disclosure is owned and has been held in confidence by Westinghouse.

(ii) The information is of a type customarily held in confidence by Westinghouse and not customarily disclosed to the public. Westinghouse has a rational basis for determining the types of information customarily held in confidence by it and, in that connection, utilizes a system to determine when and whether to hold certain types of information in confidence. The application of that system and the substance of that system constitutes Westinghouse policy and provides the rational basis required.

Under that system, information is held in confidence if it falls in one or more of several types, the release of which might result in the loss of an existing or potential competitive advantage, as follows:

(a) The information reveals the distinguishing aspects of a process (or component, structure, tool, method, etc.) where prevention of its use by any of Westinghouse's competitors without license from Westinghouse constitutes a competitive economic advantage over other companies.

(b) It consists of supporting data, including test data, relative to a process (or component, structure, tool, method, etc.), the application of which data secures a competitive economic advantage, e.g., by optimization or improved marketability.

(c) Its use by a competitor would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing a similar product.

(d) It reveals cost or price information, production capacities, budget levels, or commercial strategies of Westinghouse, its customers or suppliers.

(e) It reveals aspects of past, present, or future Westinghouse or customer funded development plans and programs of potential commercial value to Westinghouse.

(f) It contains patentable ideas, for which patent protection may be desirable.

(g) It is not the property of Westinghouse, but must be treated as proprietary by Westinghouse according to agreements with the owner.

There are sound policy reasons behind the Westinghouse system which include the following:

(a) The use of such information by Westinghouse gives Westinghouse a competitive advantage over its competitors. It is, therefore, withheld from disclosure to protect the Westinghouse competitive position.

(b) It is information which is marketable in many ways. The extent to which such information is available to competitors diminishes the Westinghouse ability to sell products and services involving the use of the information.

(c) Use by our competitor would put Westinghouse at a competitive disadvantage by reducing his expenditure of resources at our expense.

(d) Each component of proprietary information pertinent to a particular competitive advantage is potentially as valuable as the total competitive advantage. If competitors acquire components of proprietary information, any one component may be the key to the entire puzzle, thereby depriving Westinghouse of a competitive advantage.

(e) Unrestricted disclosure would jeopardize the position of prominence of Westinghouse in the world market, and thereby give a market advantage to the competition of those countries.

(f) The Westinghouse capacity to invest corporate assets in research and development depends upon the success in obtaining and maintaining a competitive advantage.

(iii) The information is being transmitted to the Commission in confidence and, under the provisions of 10CFR Section 2.790, it is to be received in confidence by the Commission.

(iv) The information sought to be protected is not available in public sources or available information has not been previously employed in the same original manner or method to the best of our knowledge and belief.

(v) The proprietary information sought to be withheld in this submittal is that which is appropriately marked in "RV Closure Head Penetration Tube ID Weld Overlay Repair", WCAP-13998 Rev. 1 (Proprietary), November, 1995 for North Anna Power Station Units 1 and 2, being transmitted by the Virginia Power Company letter and Application for Withholding Proprietary Information from Public Disclosure, to the

Document Control Desk, Attention Mr. William T. Russell. The proprietary information as submitted for use by Virginia Power Company for North Anna Power Station Units 1 and 2 is expected to be applicable in other licensee submittals in response to certain NRC requirements for potential reactor vessel head penetration repairs.

This information is part of that which will enable Westinghouse to:

(a) Provide data supporting the acceptability of repairing reactor vessel head penetrations utilizing the "embedded flaw" technique.

(b) Define the concept and benefits of the reactor vessel head penetration "embedded flaw" weld repair approach.

(c) Assist the customer to obtain NRC approval.

Further this information has substantial commercial value as follows:

(a) Westinghouse plans to sell the use of similar information to its customers for purposes of meeting NRC requirements for licensing documentation.

(b) Westinghouse can sell support and defense of the technology to its customers in the licensing process.

Public disclosure of this proprietary information is likely to cause substantial harm to the competitive position of Westinghouse because it would enhance the ability of competitors to provide similar methodologies and licensing defense services for commercial power reactors without commensurate expenses. Also, public disclosure of the information would enable others to use the information to meet NRC requirements for licensing documentation without purchasing the right to use the information.

The development of the technology described in part by the information is the result of applying the results of many years of experience in an intensive Westinghouse effort and the expenditure of a considerable sum of money.

In order for competitors of Westinghouse to duplicate this information, similar technical programs would have to be performed and a significant manpower effort, having the requisite talent and experience, would have to be expended for developing testing and analytical methods and performing tests.

Further the deponent sayeth not.

Copyright Notice

Proprietary Information Notice

Transmitted herewith is a proprietary document furnished to the NRC in connection with requests for generic and/or plant-specific review and approval.

In order to conform to the requirements of 10 CFR 2.790 of the Commission's regulations concerning the protection of proprietary information so submitted to the NRC, the information which is proprietary in the proprietary versions is contained within brackets, and where the proprietary information has been deleted in the non-proprietary versions, only the brackets remain (the information that was contained within the brackets in the proprietary versions having been deleted). The justification for claiming the information so designated as proprietary is indicated in both versions by means of lower case letters (a) through (f) contained within parentheses located as a superscript immediately following the brackets enclosing each item of information being identified as proprietary or in the margin opposite such information. These lower case letters refer to the types of information Westinghouse customarily holds in confidence identified in Sections (4)(ii)(a) through (4)(ii)(f) of the affidavit accompanying this transmittal pursuant to 10 CFR 2.790(b)(1).

VRA-95-121

Westinghouse Electric Corporation
Energy Systems

Box 355
Pittsburgh Pennsylvania 15230-0355

November 20, 1995

Mr. R. W. Calder
Supervisor - Materials Engineering
Virginia Power
Innsbrook Technical Center
5000 Dominion Boulevard
Glen Allen, VA 23060

Ref: RM07-1599
Ref: RM06-1602
Ref: RM30571
Ref: BKI'14411
Ref: VRA-95-122

VIRGINIA POWER
NORTH ANNA POWER STATION UNITS 1 AND 2
ANNOTATED LETTER ON REACTOR VESSEL HEAD PENETRATION
EMBEDDED FLAW REPAIR

Dear Mr. Calder:

See the eight (8) page attachment which provides a discussion, summary and conclusions for the reactor vessel head penetration embedded flaw repair.

If you have any questions or require anything further, please call me at (412) 374-3370.

Very truly yours,

WESTINGHOUSE ELECTRIC CORPORATION

C. D. Webb for,

D. R. Beynon, Jr., Project Manager
Chesapeake/Pittsburgh Area
Operating Plant Programs

Attachment

ATTACHMENT TO WESTINGHOUSE LETTER VRA-95-121

A. Background

Inspections have shown the presence of cracking in reactor vessel head penetration tubes in a number of pressurized water reactors. The cause of this cracking has been attributed to primary water stress corrosion cracking (PWSCC). Several methods are available for performing repairs to the penetration tubes should cracking be significant enough to warrant repairs. These methods include excavation of the penetration tube to remove shallow flaws and, for deeper flaws, excavation and weld repair. With respect to excavation and weld repair, two methods are available. These methods would be to 1) completely remove the crack by excavation followed by a full or partial weld buildup, and 2) partial removal of the flaw by excavation followed by a weld overlay ("embedded flaw" repair).

B. Introduction

1. Weld Build-up Repair Technique

Several issues are associated with the case of complete removal of the flaw followed by a weld buildup that have an undesirable affect on site schedule, personnel exposure, and component adequacy for continued operation. These are discussed in the following paragraphs.

a. Thermal Sleeve Removal

Due to the spacial constraints associated with the design of the vessel penetration and thermal sleeve, thermal sleeve removal is necessary to completely remove a flaw that is deeper than 0.25 inches for those penetrations which contain thermal sleeves. Removal of the thermal sleeve can be achieved by two methods.

The first method removes a portion of the thermal sleeve through the bottom of the penetration. To accomplish this, first the thermal sleeve is cut at an elevation above the crack in the penetration. However, the distortion and ovality of the penetration produced by the original attachment weld may not permit removal of the thermal sleeve. The thermal sleeve contains an alignment collar that has a small clearance to the penetration ID and may not pass through the bottom end without cutting the thermal sleeve into segments. Following this cutting and removal, the repair is made to the penetration and the thermal sleeve subsequently reinstalled. This reinstallation requires remote welding of the thermal sleeve followed by inspection to verify an acceptable weld as well as correct alignment.

Although the technique for cutting and rewelding of the thermal sleeves has been developed in Europe, additional development and qualification of this process by Westinghouse would be required prior to its use at North Anna.

For those penetrations with ovality and distortion that will not permit thermal sleeve removal through the bottom end, the second method is to remove the thermal sleeve through the top of the penetration. This method requires removal of the CRDM rod travel housing by cutting the canopy seal weld and threading the rod travel housing out of the CRDM latch housing, cutting the thermal sleeve above the thermal sleeve guide, and removal of the remaining thermal sleeve out of the top of the penetration. Following the repair, it is necessary to reinstall the thermal sleeve through the top of the penetration, threading the guide to the bottom of the thermal sleeve and welding it to the thermal sleeve, reinstalling the rod travel housing and reweld the canopy seal weld.

Both of these methods involve a significant amount of remote machining/welding and radiation exposure associated with the removal and installation of the thermal sleeve.

b. Penetration Residual Stress/Inspection Following Repair

One method for application of the weld buildup is to completely fill the excavation and restore the ID of the penetration. While this method provides a surface that can be readily inspected following repair, it will require the application of a significant amount of weld material which results in a significant increase in penetration residual stress which could adversely affect the susceptibility of the penetration to PWSCC. An alternate method for repair is to apply a smaller amount of weld material and thereby minimize the amount of additional penetration residual stress and deformation. However, this method has the drawback of not restoring the penetration ID and would result in a much more difficult surface for post repair inspection by UT (manual method only currently developed) and Eddy Current (development of method is required).

While both of these repair techniques are in accordance with the ASME Code, the embedded flaw repair technique avoids the above mentioned drawbacks.

2. Embedded Flaw Repair

The embedded flaw repair technique involves an excavation at the inside surface of the penetration. This excavation would be sufficient to remove the portion of the crack which is exposed to the reactor coolant at the inside surface of the penetration. The depth of the excavation, 0.125 inch or smaller, would be set such that following application of a weld overlay, the remaining portion of the flaw will qualify as a subsurface flaw according to the rules of ASME Section XI paragraph IWA 3310 (b). The depth of the excavation is controlled by utilizing "hard stops" which are incorporated into the tooling to limit travel of the EDM electrode. Following excavation and prior to welding, a dye penetrant test will be performed to verify that the excavation has covered the full length of the flaw. The weld is applied and examined with dye penetrant, eddy current and ultrasonics to verify an acceptable weld. This approach eliminates exposure of the flaw to the reactor coolant environment, which stops further flaw growth due to PWSCC. See the attached figure entitled "Head Penetration Embedded Flaw Repair" for a schematic of the proposed repair configuration.

3. North Anna Proposed Embedded Flaw Repair

The North Anna 1 and 2 reactor vessel head penetrations are typical of those in Westinghouse designed plants. These penetrations are nominally 4.0 inch OD with a 2.75 inch ID. Installed into the majority of the North Anna Unit 1 head penetrations are thermal sleeves. While these thermal sleeves are generally similar to the standard Westinghouse design, they have a continuous collar located approximately at the elevation of the high side of the penetration attachment weld (see attached figure entitled "Standard Thermal Sleeve Guides"). This collar is machined such that there is a very small clearance between the collar and the head penetration inside diameter to align the thermal sleeve to the penetrations. This close clearance makes removal of the thermal sleeve through the bottom of the penetration uncertain. The potential for interference between the collar and the lower portion of the penetration due to the ovalization of the penetration resulting from the original welding of the penetration into the head is the concern. To eliminate the necessity for thermal sleeve removal, an excavation and weld overlay repair of the penetration is performed through a "window" which will be cut into the thermal sleeve. A local weld overlay (as opposed to 360° coverage) over the cracked area will be used to minimize penetration deformation and residual stresses. This repair process will be equally useful for unsleeved penetrations, but it has particular advantages for

sleeved geometries. Although this repair technique is considered to be practical for axial flaws with a depth up to through wall, it is currently being considered only for flaws which have a depth of up to 75% of the wall thickness. If application of this technique is considered for axial flaws greater than 75% wall thickness or for circumferential flaws, a separate submittal to the NRC will be required. The flaw extent will determine the extent of the repair, and the flaw depth will determine the thickness of the repair weld. The penetration tube is sufficiently stiff, and constrained by the vessel head, so the integrity of the tube will be maintained by the weld overlay regardless of the extent of the flaw. When the repair process is complete the ID surface of the penetration has been restored and is readily re-inspected.

The "embedded flaw" repair methodology has been developed using technology which has been demonstrated in WCAP 13998 (attached), entitled "RV Closure Head Penetration Tube ID Weld Overlay Repair". Although this report contains a number of approaches to penetration tube repair, only some of these are used in the embedded flaw repair technique. Section C, below, will highlight the key portions of the report that are used as the technical basis for the proposed repair.

C. Summary of key relevant topics of WCAP 13998

The technical basis for the embedded flaw repair methodology is developed as shown in report WCAP 13998. The following paragraphs provide a summary of the key relevant topics of the report.

The report contains all the elements of a repair design package, and an outline of the package is contained in Chapter 2. The potential repairs were performed on a full scale mockup of a head penetration along with several mock penetration tubes. The preparation of these mockups is described in Chapter 4.

The welding process uses Alloy 52 filler metal, to maximize the corrosion resistance of the weld. The development of the welding process and its qualification are shown in Chapter 5, which also contains pictorial examples of overlay welds performed over flaws machined into the penetration using electrical discharge machining (EDM). Test results showed no cracks in the weld or cracking of the surrounding area. The welding specification is contained in Appendix A.

A range of weld overlay thicknesses were investigated. It was found that the thickest overlays produced measurable deformation of the tubes, as shown in Chapter 6. Smaller deformations occur with a smaller amount of weld metal thickness. One of the

benefits of the embedded flaw overlay is that with a smaller amount of weld deposit the deformation is minimized.

To verify the adequacy of the weld repair process, a series of residual stress measurements were also performed on excavated and repaired tubes, and these results are discussed in Chapter 7. As expected, the residual stresses are increased as more weld metal is deposited. The residual stresses produced by local weld overlays were comparable to the unrepaired configuration for excavation and weld deposit up to 0.25 inches in depth. The measured residual stresses also compare favorably to those of a three-dimensional finite element analysis for residual stress. These comparisons are shown in Chapter 7, Figures 7.4-1 through 7.4-4.

To complete the weld repair design package, a generic safety evaluation according to 10CFR50.59 was performed, and was provided as a separate document from the WCAP.

D. Comparison of the embedded flaw approach and WCAP 13988

To produce an embedded flaw configuration, a weld overlay thickness of 0.090 to 0.125 inch is needed. The embedded flaw repair will apply the weld in an axial direction. The welding process which was utilized in the WCAP applied the weld in a circumferential direction relative to the longitudinal axis of the penetration.

It is judged that welding axially in this range of thicknesses will maintain the penetration ID surface residual stresses comparable to the unrepaired tube. This judgement is based on the results listed in the WCAP that showed this comparable condition for weld thickness up to 0.25 inch.

Further, the residual stress measurement results and their favorable comparison to previous analyses (refer to Chapter 7 Figures 7.4-1 through 7.4-4 of WCAP 13998) is sufficient to provide confidence that the penetration stresses after weld repair have been fully described such that additional testing for corrosion behavior is not necessary.

In the early days of the Westinghouse program to evaluate small amounts zinc additives to the RCS coolant, measurements were taken of the electrode potentials of the various primary side materials. No difference was found between them, including 600 and 690 materials. This is in agreement with the investigations by others in the high temperature electrochemistry area. At high temperatures the potentials of all of these alloys tend towards the potential of the hydrogen electrode; i.e., there are no differences to promote any galvanic coupling effects.

In addition, Westinghouse has many years experience in laboratory tests and field exposures with alloys 600 and 690 intimately connected either mechanically or by welding in steam generator applications. Exposures of approximately 15 years on hybrid expansion joints have not produced any evidence of galvanic coupling. Sleeving and plugging exposures have not revealed any evidence of galvanic interaction over years (5 at least) of operation.

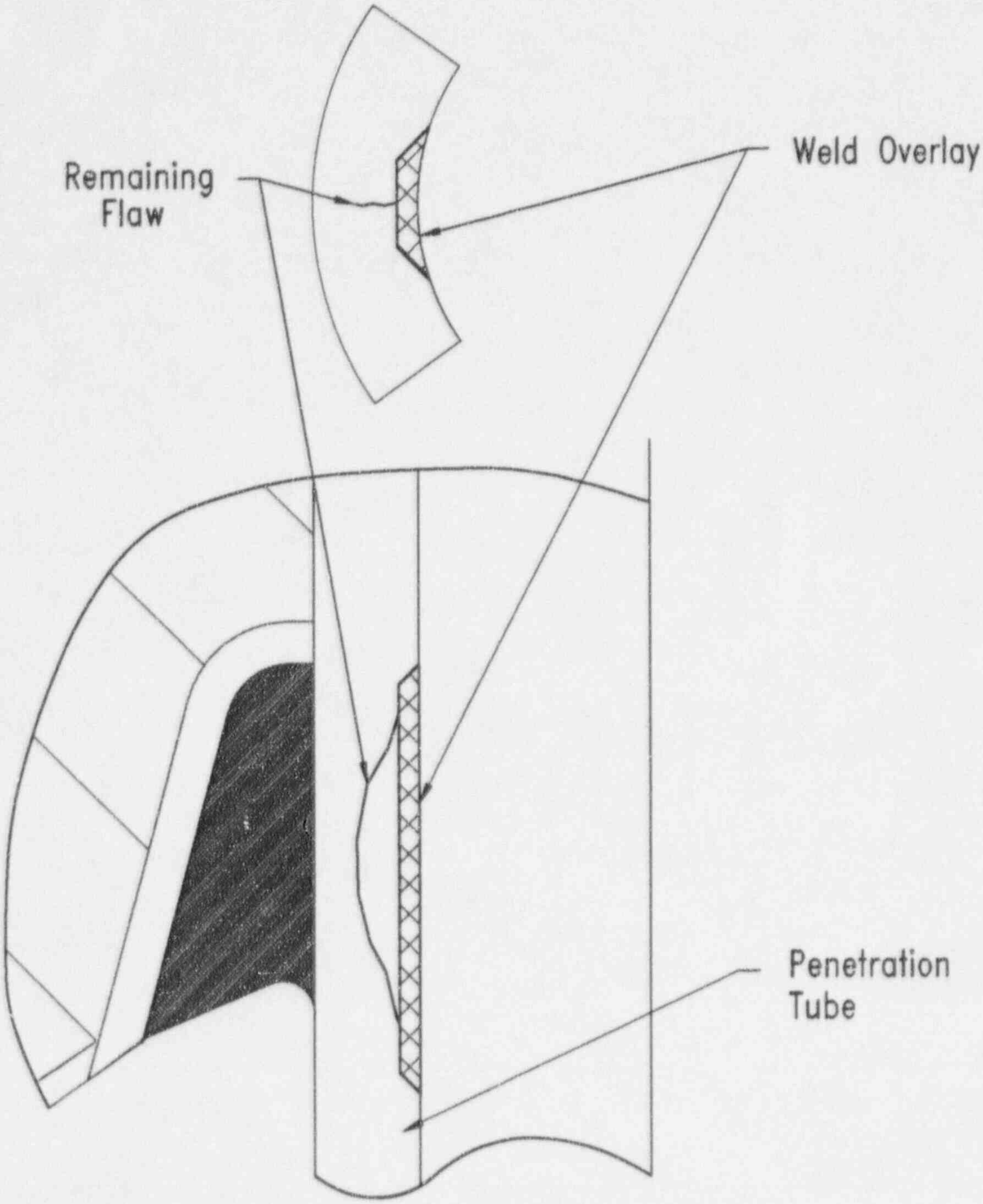
E. Flaw Acceptability

Although the flaw characterization rules of Section XI paragraph IWA 1300 are being used to establish sufficient weld overlay thickness to classify the repaired flaw configuration as subsurface, determinations about flaw acceptability will be based on the NEI/NUMARC guidelines. These guidelines were accepted in a Safety Evaluation Report issued to Wisconsin Electric Power Co. on March 9, 1994 (Docket No. 50-226), and in a previous Safety Evaluation Report issued November 19, 1993 to W. Raison of NEI/NUMARC.

F. Summary and Conclusions

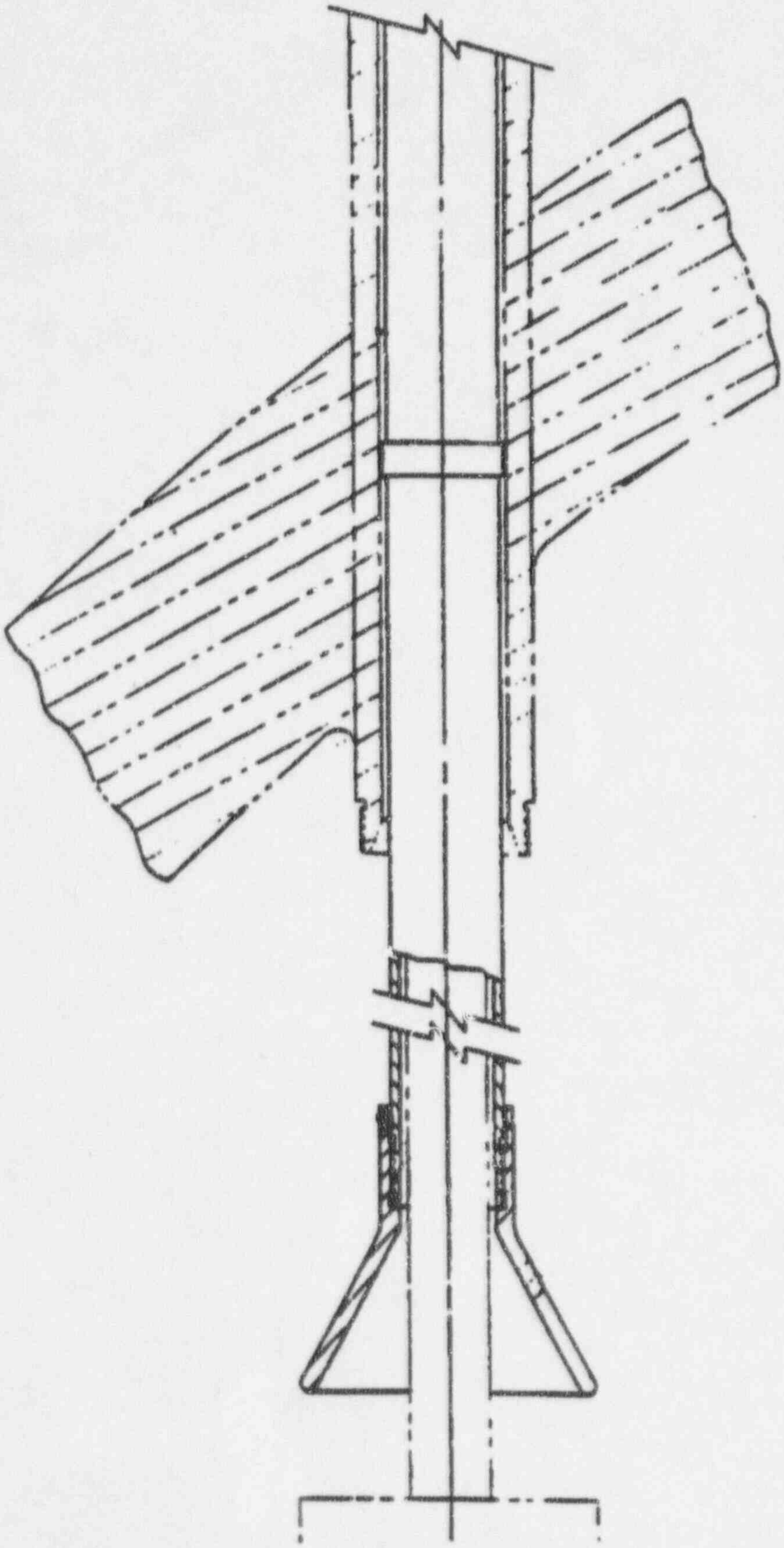
The embedded flaw approach has been developed as a variation on the repair techniques documented in WCAP 13998. The technique is versatile, in that it can be applied to the penetration tubes with or without thermal sleeves, and does not require the removal of the thermal sleeve.

There are a number of advantages to the technique. It results in a permanent repair that seals the flaw from the water environment, and thus stops PWSCC. There is no other mechanism of growth for cracks in these tubes because fatigue fluctuations are very small. The small thickness of the weld minimizes deformation of the tube, as well as residual stresses in the surrounding region.



Head Penetration
Embedded Flaw
Repair

Standard Thermal Sleeve Guides



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

March 9, 1994

Docket No. 50-266

Mr. Robert E. Link, Vice President
Nuclear Power Department
Wisconsin Electric Power Company
231 West Michigan Street, Room P379
Milwaukee, Wisconsin 53201

Dear Mr. Link:

SUBJECT: ACCEPTANCE CRITERIA FOR CONTROL ROD DRIVE MECHANISM PENETRATION INSPECTIONS AT POINT BEACH NUCLEAR PLANT, UNIT 1

On July 30, 1993, the Nuclear Management and Resources Council (NUMARC) submitted proposed acceptance criteria for flaws detected during control rod drive mechanism (CRDM) penetration inspections to the NRC staff for review and concurrence. These proposed acceptance criteria were based on extensive safety assessments conducted by the Babcock & Wilcox Owners Group (B&WOG), the Combustion Engineering Owners Group (CEOG), and the Westinghouse Owners Group (WOG). The proposed acceptance criteria were separated into criteria for axial flaws and for circumferential flaws by location (above or below the J-Groove weld on the CRDM penetration). The proposal for axial flaws was to allow through-wall axial flaws of any length below the J-Groove weld and axial flaws 75 percent through-wall of any length at or above the J-Groove weld. These criteria conform to the American Society of Mechanical Engineers (ASME) Section XI criteria for flaws in piping. Therefore, the staff has found them acceptable.

The NUMARC proposal for circumferential flaws was through-wall and 75 percent around the circumference below the J-Groove weld, and 75 percent through-wall and 50 percent around the circumference at or above the J-Groove weld. Based on the information submitted by the owners groups that circumferential flaws should not initiate and grow, and the more serious consequences of circumferential flaws, the staff has not accepted the proposed criteria for circumferential flaws. The staff has further stated that acceptance criteria for circumferential flaws would not be pre-approved and that any circumferential flaws would be reviewed on a case-by-case basis.

On January 31, 1994, NUMARC submitted supplemental safety assessments developed by the owners groups. These supplemental assessments provided a more detailed evaluation of the stress states in the nozzles and discussed the circumferential flaws observed at Ringhals and Bugey 3. The Ringhals circumferential flaws were attributed to fabrication flaws and were not related to primary water stress corrosion cracking (PWSCC). The Bugey 3 circumferential flaw initiated at the external surface of the CRDM penetration above the J-Groove weld, and propagated at an angle 30° from horizontal. All three owners groups submitted assessments that included finite element

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analyses that indicated that short, circumferential cracks are possible, although these flaws would not be expected to propagate through-wall due to compressive stresses below the flaws.

Based on its review of the owners groups supplemental evaluations, the staff has concluded that short, partial through-wall circumferential flaws are possible in the CRDM penetrations. Based on the stress analyses presented in the owners groups reports and the length of time that the Point Beach plant has been in operation, a shallow circumferential flaw 10 percent of the circumference of the penetration could exist. Therefore, the staff has concluded that circumferential flaws whose length, including postulated crack growth during the next operating cycle, does not exceed 10 percent of the circumference, are less than 75 percent through-wall, and are in a location consistent with the finite element analysis (outside diameter flaws), are acceptable. These flaws would have to be reinspected in subsequent examinations consistent with the reinspection approach of IWB-2420 of ASME Section XI.

You will not be required to obtain NRC approval to continue operation if short circumferential flaws are identified. However, you will be required to report to the NRC the location, length, and depth of these flaws and any other flaws identified during the inspection. If the depths of the flaws are not determined, you may assume that the depth is one half of the length of the flaw.

Any flaws found during the inspections that are not resulting from PWSCC should be evaluated in a manner consistent with the approach for flaw evaluation in ASME Section XI using the assumptions in the proposed acceptance criteria submitted by NUMARC to NRC on July 30, 1993. Examples of these flaws would be short, shallow fabrication defects or manufacturing defects in locations not predicted by the finite element stress analyses. Should you choose to disposition any flaws (which exceed ASME Section XI criteria) by analysis, the staff will require that your evaluations be reviewed and approved prior to unit startup.

If you have any questions regarding this issue, please contact me at (301) 504-1390.

Sincerely,

Allen G. Hansen

Allen G. Hansen, Project Manager
Project Directorate III-3
Division of Reactor Projects III/IV/V
Office of Nuclear Reactor Regulation

cc:
See next page

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

November 19, 1993

William Rasin, Vice President
Director of the Technical Division
Nuclear Management and Resources Council
1776 Eye Street, N.W.
Suite 300
Washington, D.C. 20006-3706

Dear Mr. Rasin:

The attached safety evaluation was prepared by the Materials and Chemical Engineering Branch, Division of Engineering, Office of Nuclear Reactor Regulation, on the NUMARC submittal of June 16, 1993, addressing the Alloy 600 Control Rod Drive Mechanism (CRDM)/Control Element Drive Mechanism (CEDM) pressurized water reactor vessel head penetration cracking issue. This submittal addressed stress analyses, crack growth analyses, leakage assessments, and wastage assessments for potential cracking of the inside diameter of CRDM/CEDM nozzles. Based on the overseas inspection findings and the review of your analyses, the staff has concluded that there is no immediate safety concern for cracking of the CRDM/CEDM penetrations. This finding is predicated on the performance of the visual inspection activities requested in Generic Letter 88-05. Also, special nondestructive examinations are scheduled to commence in the Spring of 1994 to confirm your safety analyses for each PWR owners group.

Your submittals for each PWR type did not address the Bugey-3 flaw that was oriented approximately 30° off the vertical axis nor a circumferential, J-groove flaw discovered at Ringhals. Preliminary information supplied to the staff by Swedish authorities indicates that the J-groove flaw may be associated with a fabrication defect. We are continuing to work with the Swedish authorities to confirm this. From the information available to us today, neither of these flaws would pose a threat to the integrity of the CRDM penetrations. It is our understanding that you are also reviewing these flaws and you will provide your assessment as to their significance and origin. NRC will issue a supplemental safety evaluation after reviewing your supplemental assessment.

The staff agrees that there are no unreviewed safety questions associated with CRDM/CEDM penetration cracking. The staff agrees that the flaw predictions based upon penetration stress analyses are in qualitative agreement with inspection findings. However, the stress analyses do not address stresses from possible straightening of CRDM penetration tubes during fabrication. These stresses, if large, could result in circumferential flaw orientations. The staff requests that you also address this issue in your supplemental assessment. Based upon information received from overseas regulatory authorities, your analyses, and staff reviews, the staff believes that catastrophic failure of a penetration is extremely unlikely. Rather, a flaw would leak before it reached the critical flaw size and would be detected during periodic surveillance walkdowns for boric acid leakage pursuant to Generic Letter 88-05. However, the staff recommends that you consider

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enhanced leakage detection by visually examining the reactor vessel head until either inspections have been completed showing absence of cracking or on-line leakage detection is installed in the head area. The staff requests that you also address the issue of enhanced leakage detection in your supplemental assessment.

The NRC staff has reviewed your July 30, 1993 submittal, which proposed flaw acceptance criteria to be used in dispositioning any flaws found during CRDM/CEDM inspections. The staff finds the proposed flaw acceptance criteria acceptable for axial cracks because the criteria conform to the American Society of Mechanical Engineers (ASME) Section XI criteria. The staff determined that flaws that are primarily axial (less than 45° from the axial direction) should be treated as axial cracks as indicated in Figure 1(b), (d), and (f) of your July 30, 1993 letter. Flaws more than 45° from the axial direction should be treated as circumferential flaws. However, based upon information submitted to date and the more serious safety consequences of circumferential flaws, the staff does not agree with your proposed criteria for circumferential flaws. Circumferential flaws which a licensee proposes to leave in service without repair, should be reviewed by the staff on a case-by-case basis.

Sincerely,

Original signed by

William T. Russell, Associate Director
for Inspection & Technical Assessment
Office of Nuclear Reactor Regulation

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SAFETY EVALUATION
FOR
POTENTIAL REACTOR VESSEL HEAD ADAPTOR TUBE CRACKING

1.0 INTRODUCTION

Primary water stress corrosion cracking (PWSCC) of Alloy 600 was identified as an emerging issue by the NRC staff to the NRC Commission following a 1989 leakage from an Alloy 600 pressurizer heater sleeve penetration at Calvert Cliffs Unit 2, a Combustion Engineering designed pressurized water reactor (PWR). Several instances of PWSCC of Alloy 600 pressurizer instrument nozzles had been reported to the NRC between the time period of 1986 to the present on domestic and foreign pressurized water reactors (PWR). The licensee at Arkansas Nuclear Operations, Unit 1, a Babcock & Wilcox (B&W) designed PWR, reported a leaking pressurizer instrument nozzle in 1990, after 16 years of operation. Westinghouse PWR's do not use Alloy 600 for penetrations or nozzles in the pressurizers.

According to the information provided to the staff by NUMARC at a public meeting held on July 5, 1993, a leak was discovered in an Alloy 600 control rod drive mechanism (CRDM) adaptor tube penetration during a hydrostatic test at the Bugey 3 plant in France in 1991 after 12 years of operation. A visual examination of the CRDM adaptor tube penetration indicated the presence of axial flaws in the inside diameter (ID) of the CRDM adaptor tube penetration. The remaining 65 CRDM adaptor tube penetrations were examined at Bugey 3 and 2 additional CRDM adaptor tube penetrations contained axial cracks on the ID of the CRDM adaptor tube penetrations. An examination of 24 CRDM adaptor tube penetrations at Bugey 4 revealed axial ID cracks in 8 CRDM adaptor tube penetrations. CRDM adaptor tube penetrations have been examined at 37 nuclear power plants in France, Sweden, Switzerland, Japan, and Belgium and 59 of the 1,850 penetrations have revealed short, axial crack indications.

The primary safety concern associated with stress corrosion cracking in Alloy 600 in CRDM penetrations is the potential for circumferential cracks. Extensive circumferential cracking could lead to the ejection of a CRDM resulting in an unisolable rupture in the primary coolant system. As indicated above, the inspections to date have identified short axial cracks. However, two other inspection findings are of particular interest. First, the CRDM penetration that leaked during hydrostatic testing at Bugey-3 was removed and examined metallurgically during December 1992. A secondary crack that was 0.120 inches long and 0.090 inches deep at about 30 degrees to the axial direction was observed on this CRDM. Second, in early in 1993, a J-groove weld at the Ringhals plant in Sweden was discovered to contain a circumferential crack. Preliminary indications are that this flaw is a fabrication defect. Additional work is in progress by the staff at the Swedish Nuclear Power Inspectorate to confirm this.

The Westinghouse CRDM adaptor tube penetrations are similar in design to the European PWR's and use Alloy 600 for the penetrations. The NRC staff met with the WOG on January 7, 1992 to discuss the experience at

the Bugey 3 plant and the relationship of the French design of the CRDM adaptor tube penetrations to the design of domestic Westinghouse plants. The WOG informed the NRC staff that a program had been initiated in December 1991 to: (1) determine the root cause of the CRDM penetration cracking; (2) analyze the stress distributions in the CRDM penetrations of a typical domestic plant; (3) compare the design and operational characteristics of domestic and French plants to determine the likelihood for cracking; and (4) identify the need for additional efforts. The NRC staff also met with the Combustion Engineering Owners Group (CEOG) and the Babcock & Wilcox Owners Group (B&WOG) to discuss the PWSCC of CRDM adaptor tube penetrations. The Nuclear Management and Resources Council (NUMARC) coordinated the PWR Owners' Group efforts on this subject.

On June 16, 1993, NUMARC submitted safety assessments to the NRC from WOG, CEOG, and B&WOG for review by the NRC staff. These safety assessments present stress analyses, crack growth analyses, leakage analyses, and wastage assessments for flaws initiating on the ID of CRDM adaptor tube penetrations. NRC requested additional information on the safety assessments by letter dated September 2, 1993. NUMARC submitted the response to NRC on September 22, 1993. The safety assessments submitted to the NRC did not address the secondary flaw observed at the Bugey-3 plant that was oriented approximately 30° from the longitudinal axis of the penetration nor the apparent fabrication flaw at the Ringhals plant. Neither of these flaws posed a threat to the integrity of the CRDM penetrations. However, NUMARC has committed to submit a safety assessment relevant to this type of cracking. After this safety assessment has been reviewed by NRC, a supplement to this SER will be issued.

2.0 STAFF EVALUATION

2.1 WOG WCAP-13565, ALLOY 600 REACTOR VESSEL HEAD ADAPTOR TUBE CRACKING SAFETY EVALUATION

The WOG submitted the, "Alloy 600 Reactor Vessel Head Adaptor Tube Safety Evaluation," through NUMARC on June 16, 1993. The safety evaluation addresses the following elements:

1. A summary of the stress analysis focusing on the type (orientation) of cracking that may be expected in the Alloy 600 material, and the stresses necessary for flaw propagation;

2. A summary of the flaw propagation analysis along with the background of the flaw prediction method;

3. An assessment of the WOG plants with respect to penetration flaw indication data from plant inspections at Ringhals, Beznau, and various Electricite de France plants, in which the key parameters for cracking are compared to WOG plants;

4. A leakage assessment summarizing leak rate vs. flaw size, and postulating leaks for WOG plants for which leakage considerations may apply; and,

5. A vessel head wastage assessment including the process that leads to wastage and an estimate of the allowable wastage.

2.1.1 REGULATORY BASIS AND DETERMINATION OF UNREVIEWED SAFETY QUESTIONS

The WOG prepared safety evaluation addresses the potential for cracking and the ramifications of such cracking of the reactor vessel head adaptor tubes at Westinghouse designed NSSS plants. The WOG compared the results of this safety evaluation to the criteria in the Title 10, Code of Federal Regulations, Section 50.59 (10 CFR 50.59). The WOG concluded that an unreviewed safety question did not exist. Its evaluation considered the following:

1. Continued plant operation will not increase the probability of an accident previously evaluated in the FSAR.

2. The consequences of an accident previously evaluated in the FSAR are not increased due to continued plant operation.

3. Continued plant operation will not create the possibility of an accident which is different than any already evaluated in the FSAR.

4. Continued plant operation will not increase the probability of a malfunction of equipment important to safety.

5. Continued plant operation will not increase the consequences of a malfunction of equipment important to safety previously evaluated in the FSAR.

6. Continued plant operation will not create the possibility of a malfunction of equipment important to safety different than any already evaluated in the FSAR.

7. The evaluation for the effects of continued plant operation with potentially cracked reactor vessel head adapters has taken into account the applicable technical specifications.

2.1.2 STAFF'S EVALUATION OF THE REGULATORY BASIS AND DETERMINATION OF UNREVIEWED SAFETY QUESTIONS

The staff agrees that no unreviewed safety question exists, provided only axial flaws are found. Those axial flaws would be expected to be short, and they would most probably leak noticeably prior to the flaw size reaching unstable dimensions. The existence of any unexpected leaks would not adversely affect plant operation, or accident/transient response. No significant equipment degradation would be expected. Details of the staff's evaluation that led to the above conclusions is discussed in the following sections.

2.1.3 PENETRATION STRESS ANALYSIS

The WOG conducted an elastic-plastic, finite element analysis of a 4-loop WOG plant vessel head penetrations. The WOG concluded that the 4-loop WOG plant is bounding since prior analyses showed that the operating and residual stresses are higher on a 4-loop plant than on 2 or 3-loop plants on the outermost penetrations. Three penetration locations were modeled, the center location, the outermost location, and the location next to the outermost location. The stress history was simulated by using a load sequence of the thermal load from the first welding pass, the thermal load from the second weld pass, the fabrication shop cold hydrotest, the field cold hydrotest, and the steady state operational loading.

The highest stresses are found in the zone around the weld and are the highest in the penetration farthest from the center of the vessel (peripheral penetrations). The highest stresses on that penetration are on the side of the penetration nearest to the center of the vessel (centerside) and on the side of the penetration farthest from the center of the vessel (hillside). Also, the stresses are the highest below the weld and decrease significantly above the weld. The ratio of peak hoop stress to axial stress at the same location at the outermost penetrations was about 1.4 compared to a value of about 1.6 estimated based on the degree of ovaling measured on actual penetrations. The ratio of hoop stress to axial stress was about the same for center penetrations as for peripheral penetrations (1.6 for center penetrations compared to 1.4 for peripheral penetrations); however, the magnitude of the stresses at the peripheral penetrations was higher. The analysis indicates that axial flaws would be more likely than circumferential flaws, flaws are more likely below the weld than above the weld, and that axial flaws would appear at locations in the penetrations where they have been found in service.

2.1.4 STAFF EVALUATION OF THE PENETRATION STRESS ANALYSIS

The staff is in agreement with the results of the WOG stress analysis that predicts that the cracking will be predominately axial. These results are in qualitative agreement with field inspection findings. However, the WOG did not address the effects of possible straightening of the CRDM penetration tubes during fabrication. Such straightening operations could significantly alter the residual stress fields within the penetration tubes. Results of inspections to date have not identified any problems directly related to this process; however, the staff requests that NUMARC address this issue for all three owners groups' plants.

2.1.5 CRACK GROWTH ANALYSIS: FLAW TOLERANCE

The WOG crack growth analysis was based on the assumptions that the flaw would be caused by primary water stress corrosion cracking, and that the crack growth is controlled by the hoop stress. The maximum principal stress will be oriented at a slight angle to the hoop stress and flaws

would be expected to be perpendicular to the maximum principal stress. However, all of the flaws found in service with two exceptions have been axially located. Hence, the WOG used the hoop stress as an approximation of the maximum principal stress. The outer- most penetration for a 4-loop Westinghouse plant was selected for analysis since this location experiences the highest stresses. The highest stress was located along the inner surface just below the center side of the weld. The calculated hoop stress through the wall of the penetration was used for flaw growth calculations. The flaw growth data were obtained from steam generator field experience and laboratory data.

Based on the stress fields that exist in the CRDM penetrations, any flaw growth that occurs is expected to be predominately axial in nature. Furthermore, the growth of any flaws inclined from the vertical would be limited in length due to the nature of the existing stresses. These conclusions are consistent with the inspection results described above. Accordingly, there is no significant potential for failure of a penetration by ejection of the CRDM sleeve. With regard to axial cracking, WOG has concluded that the critical flaw length for an axial flaw for Alloy 600 is sufficiently long that leakage would occur and be detected during surveillance walkdowns as required by GL 88-05. Therefore, the consequences of cracking in the penetration sleeve are limited to the affects of leakage as discussed below.

The flaw growth analysis showed that under the most severe conditions of metallurgical microstructure, peak hoop stress, and operating temperature, it would take about five years for a flaw to grow through wall. Under the same conditions, it would take an additional 10 years for a through-wall flaw to grow 1 ½ inches above the weld on the lower hillside of the outermost head penetrations (Figure 3.2-2) and about the same time to grow two inches above the J-groove weld on the center side of the outermost penetrations (Figure 3.2-3). The flaw growth analysis indicates that through wall flaws would essentially arrest before growing a maximum of two inches above the weld. These flaws would be constrained within the head and could not significantly open thus limiting the amount of leakage that could occur.

2.1.6 <u>STAFF EVALUATION OF THE CRACK GROWTH ANALYSIS</u>

The WOG stated that the crack growth analysis is in general agreement with the inspection findings. The crack growth rate data used in this analysis was limited, but the results predicted using these flaw growth data bound the results of the inspections. Crack growth rates are difficult to determine precisely; however, the assumed growth rates compare well with inspection data available to date and the large margins that exist in the analyses will account for any possibly higher growth rates. There are large margins of safety in the analyses and the CRDM penetrations are constructed of inherently tough material with a critical flaw size of approximately 13 inches in the free span above the reactor vessel shell. Therefore, the staff concludes that catastrophic failure of a penetration is extremely unlikely because a flaw would be

detected during boric acid leakage surveillance walkdowns before it reached the critical flaw size.

2.1.7 ASSESSMENT OF WOG PLANTS

The WOG compared the Ringhals and Beznau plants to the domestic Westinghouse plants and developed a model for the relative susceptibility to PWSCC. The WOG considered residual and operating stresses in the penetrations, the environment, material condition, operating temperature, and time-of-operation at temperature, and pressure. Based on this evaluation, the WOG has evaluated domestic WOG PWR's with regard to their degree of susceptibility. Based on what WOG considers to be conservative assumptions, the Ringhals plants envelope 45 domestic plants. None of these plants are expected to have any flaws other than some short, shallow, axial flaws. Nine additional WOG plants are not enveloped by the Ringhals plants. Based on the stresses, operating temperatures, hours of operation, and the flaw growth curves provided in the WOG safety assessment, the WOG does not expect any CRDM penetration axial flaws to reach a length in excess of 1 inch before about the middle of 1995.

2.1.8 STAFF EVALUATION OF THE WOG ASSESSMENT

The susceptibility model developed by the WOG considers the appropriate parameters affecting IGSCC and should provide a reasonable ranking of plant susceptibilities. In addition, this evaluation indicates that it is unlikely that U.S. plants should exhibit any cracking significantly worse than that found in European plants.

2.1.9 LEAK RATE CALCULATIONS

The leak rates were calculated based on the assumption that the leak rate will be controlled by the flow rate through the flaw in the head penetration or by the flow through the penetration annulus, whichever is smaller. WOG estimates the maximum leak rate would be 0.7 gpm for a 2 inch long flaw and an annular clearance of 0.003 inches. Leakage above 1.0 gpm is detectable in domestic WOG plants according to WOG. Growth of an axial flaw outside of the part contained within the reactor head will result in leakage greater than 1.0 gpm prior to reaching the critical flaw size. The WOG stated that an axial flaw would remain stable for growth up to 13 inches above the reactor vessel head.

2.1.10 STAFFS EVALUATION OF THE WOG LEAK RATE CALCULATIONS

The staff agrees with the WOG assumptions about leakage and concludes, that based on existing leakage monitoring requirements, there is reasonable assurance that leakage in excess of the 1.0 gpm technical specification limit would be detected prior to any unstable extension of the flaw.

2.1.11 REACTOR VESSEL HEAD WASTAGE ASSESSMENTS

This section assesses the potential wastage of the reactor vessel head due to leakage of primary coolant through the CRDM penetrations. This assessment is based on wastage data from previous Westinghouse experiments and from the results of a penetration mockup test conducted by the Combustion Engineering Owners Group (CEOG).

This analysis assumed that coolant escaping from the penetration would flash to steam leaving boric acid crystals behind. WOG assumed that crystals would accumulate on the vessel head but would cause minimal corrosion while the reactor was operating. The head temperature would be about 600°F during operation and significant wastage of the reactor head by the boric acid crystals would not be expected. Dry boric acid crystals do not cause corrosion. Wastage would only occur during outages when the head temperature is below 212°F.

The CEOG provided all of the PWR owners groups with the results of pressurizer penetration mockup test results. The WOG examination of the CEOG mockup test results showed that the maximum penetration rate at the deepest pit was 2.15 inches/year while the average penetration rate was 0.0835 inches/year. The maximum total metal loss rate or wastage volume was 1.07 in^3/year, and the greatest damage occurred where the leakage left the annulus. The WOG considered the maximum wastage would be 6.4 in^3 of vessel head material. The assumptions made were that any leakage over 1.0 gpm can be detected so only leak rates between 0.0 and 1.0 gpm were considered. The WOG analyzed the situation using finite element analyses for a 2 loop, 3 loop, and 4 loop reactor vessel head where a 1.0 gpm leak went undetected for 6 years and concluded that the ASME code minimum wall thickness requirement would be satisfied and that the stresses remain within the ASME code allowable stresses.

2.1.12 THE STAFF'S EVALUATION OF THE REACTOR VESSEL HEAD WASTAGE ASSESSMENTS

The assumption used in the WOG corrosion assessment are based on experimental data and should provide a reasonable estimate of potential wastage of the reactor vessel head. Based on these evaluations, there would be significant time between initiating a leak and experiencing wastage that would reduce the structural integrity margins of the reactor vessel head to below acceptable levels. Considering the length of time involved, there is reasonable assurance that leakage, manifested by the accumulation of moderate amounts of boric acid crystals would be detected during a surveillance walkdown in accordance with GL 88-05.

3.0 CEOG SAFETY EVALUATION

The CEOG safety evaluation is essentially the same as the WOG safety evaluation. The CEOG plants run at a slightly higher temperature than the European plants that have experienced cracking, have greater hillside angles, and have been in operation longer than many of the European plants. The CEOG indicated that all of these factors would

increase the probability of cracking for the CEOG plants. However, the CEOG plants have significantly less weld metal in the J-groove welds and the CEOG stated that this would significantly reduce the residual welding-induced stresses and would reduce the probability of PWSCC. CEOG concluded that any PWSCC that formed would be short, axial flaws.

The CEOG states that they can detect a 0.12 gpm leak in the primary coolant system. CEOG also states that the boric acid accumulation as a result of a 0.12 gpm leak would not result in wall thinning below the code allowables in less than 8.8 years compared to 6 years for WOG plants and that surveillance walkdowns would detect boric acid crystals long before the 8.8 years.

3.1 STAFF EVALUATION OF THE CEOG SAFETY EVALUATION

The staff has concluded that the potential for PWSCC of CRDM/CEDM for CEOG plants does not create an immediate safety issue as long as the surveillance walkdowns required by GL 88-05 continue and corrective action is instituted when leaks are discovered. The CEOG analyses indicating that the stresses would favor development of axial rather than circumferential cracks and that significant time would be required to reduce the wall thickness of the vessel head to below the ASME code allowables demonstrates that an immediate safety concern does not exist.

4.0 B&WOG SAFETY EVALUATION

The B&WOG safety evaluation was essentially the same as the WOG and CEOG safety evaluations. The B&WOG analysis indicates that B&WOG plants have essentially the same susceptibility to PWSCC as the European plants based on operating temperature, residual stresses, and operational life. The B&WOG predicts short, axial flaws on the peripheral locations based on the results of finite element analyses. The B&EOG estimates that it would take 10 years from the time a flaw initiates on the inside diameter of a CRDM penetration until a leak appears. Once a leak starts, B&WOG concluded that it would take 6 years before enough corrosion would occur to reduce the wall thickness of the reactor vessel head to below ASME code minimums, and that this amount of leakage would be detected during surveillance walkdowns.

4.1 STAFF EVALUATION OF THE B&WOG SAFETY EVALUATION

The staff has concluded that the potential for PWSCC of CRDM for B&WOG plants does not create an immediate safety issue as long as the surveillance walkdowns required continue and as long as any leakage is corrected. The B&WOG analyses, indicating that the stresses would favor development of axial rather than circumferential cracks and that significant time would be required to reduce the wall thickness of the vessel head to below the ASME code allowables, demonstrates that an immediate safety concern does not exist.

5.0 PROPOSED FLAW ACCEPTANCE CRITERIA

On July 30, 1993, NUMARC submitted the proposed flaw acceptance criteria for flaws identified during inservice inspection of reactor vessel upper head penetrations to the NRC for review. These criteria were developed by utility technical staffs and the domestic PWR vendors. NUMARC proposes that axial flaws are permitted through-wall below the J-groove weld and 75 percent through-wall above the weld. There is no limit on the length of the flaws. NUMARC proposes that circumferential flaws through-wall and 75 percent around the penetration be allowed below the J-groove weld and that circumferential flaws above the weld could be 75 percent through-wall and 50 percent around the penetration. Proximity rules found in ASME Section XI, Figure IWA 3400-1 are proposed for determining the effective length of multiple flaws in one location. NUMARC proposes that the flaws be characterized by length and preferably depth. NUMARC proposes that if only the length is characterized, that the depth be assumed to be one half of the length based on inspection findings to date.

5.1 STAFF EVALUATION OF THE PROPOSED FLAW ACCEPTANCE CRITERIA

The staff finds the proposed flaw acceptance criteria acceptable for axial flaws because the criteria conform to the American Society of Mechanical Engineers (ASME) Section XI criteria. The assumption that flaw depth is one half the flaw length for flaws whose depth cannot be determined will limit the flaw length to 1.5 times the thickness of the penetration sleeve. However, it is expected that reasonable attempts will be made to determine flaw depths. Flaws found through inservice inspection (ISI) that are primarily axial (less than 45° from the axial direction) will be treated as axial flaws as indicated in Figure 1(b), (d), and (f) of NUMARC'S July 30, 1993 letter. Flaws more than 45° from the axial direction are considered to be circumferential flaws. Based upon information submitted to date and the more serious safety consequences of circumferential flaws, the staff has concluded that criteria for circumferential flaws should not be pre-approved. Detection of such flaws would be contrary to inspection results to date and to the conclusion of the Owners Groups evaluations. The curcumstances associated with such a flaw would have to be well understood. Therefore, any circumferential flaws found through ISI, which a licensee proposes to leave in service without repair, will be reviewed on a case-by-case basis by the staff.

6.0 LEAKAGE MONITORING

NUMARC, through the owners groups' reports, determined that any leakage in excess of 1 gpm would be detected prior to any unstable extension of axial flaws. Also, leakage at less than 1 gpm would be detectable over time based on boric acid buildup as noted during periodic surveillance walkdowns. Although NUMARC has proposed, and the staff agrees, that low level leakage will not cause a significant safety issue to result, the staff determined that NUMARC should consider methods for detecting smaller leaks to provide defense-in-depth to account for any potential

uncertainty in its analyses. The reported leak rate at Bugey 3 was about 0.003 gpm and was detected using acoustic monitoring techniques during the performance of a hydrostatic test. The staff does not think that it is necessary to detect a 0.003 gpm leak, but does think that permitting leakage just below 1.0 gpm as currently proposed may be undesirable. Leakage of this magnitude would produce significant deposits (thousands of pounds/year) of boric acid on the reactor vessel head. Further, most facilities' technical specifications state that no pressure boundary leakage is permitted. The staff notes that small leaks resulting from flaws which progressed through-wall just prior to a refueling outage would be difficult to detect while the thermal insulation is installed. Although running for an additional cycle with that undetected leak would not result in a significant safety issue, the NUMARC should consider proposing a method for detecting leaks that are significantly less than 1.0 gpm, such as the installation of on-line monitoring equipment.

7 0 CONCLUSIONS

Based on review of the NUMARC submittal and the overseas inspection results, the staff concludes that the CRDM/CEDM cracking at the reactor vessel heads is not a significant safety issue at this time as long as the surveillance walkdowns in accordance with GL 88-05 continue. The staff agrees with the NUMARC's determination that there are no unreviewed safety questions associated with stress corrosion cracking of CRDM penetrations. However, new information and events may require a reassessment of the safety significance. Furthermore, there is a need to verify the conclusions of the NUMARC's safety evaluations. Therefore, nondestructive examinations should be performed to ensure there is no unexpected cracking in domestic PWRs. These examinations do not have to be conducted immediately since only short, shallow, axial flaws are likely to be present in the CRDM penetrations. The industry has committed to conduct inspections at three units in 1994. They are:

(a) Point Beach Unit 1 in the Spring of 1994,
(b) D.C. Cook Unit 2 in the third quarter of 1994,
(c) Oconee Unit 2 in September 1994.

As the surveillance walkdowns proposed by NUMARC are not intended for detecting small leaks, it is conceivable that some affected PWRs could potentially operate with small undetected leakage at CRDM/CEDM penetrations. In this regard, the staff believes it is prudent for NUMARC to consider the implementation of an enhanced leakage detection method for detecting small leaks during plant operation.

The staff found NUMARC's flaw acceptance criteria acceptable for axial flaws but NRC review and approval of the disposition of any circumferential flaws will be required.

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WCAP-14519

RV Closure Head Penetration Tube
ID Weld Overlay Repair

A Westinghouse Owners Group Program Report

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EXECUTIVE SUMMARY

A technical approach to address the issue of primary water stress corrosion cracking (PWSCC) on the ID surface of reactor vessel closure head penetration tubes has been outlined by the Westinghouse Owners Group (WOG). In addition, the WOG has supported NUMARC at the industry level in taking a proactive role in resolution of this issue. In structuring an approach the WOG has supported root cause evaluations, investigated how WOG plants are impacted, submitted a generic safety evaluation, developed plant inspection criteria, and solicited volunteers to perform plant inspections. Also, via the weld overlay program authorization (MUHP-5017), the subject of this report, the WOG is providing generic guidelines applicable for penetration tube repair and potentially a methodology to mitigate PWSCC in the penetration tube ID.

This part of the program provides a weld design package which can be applied to repair reactor vessel closure head penetration tube ID initiated PWSCC. The weld design package provides the criteria for the repair of the penetration tube ID either through the application a local weld repair or via the application of a 360° weld overlay. The local weld repair process is targeted at restoring the minimum required design thickness of the penetration tube wall. The 360° weld overlay is intended to provide a remedial measure to mitigate PWSCC in the Alloy 600 penetration tube ID by eliminating exposure of the highly stressed regions of the tube wall to the primary water environment.

If an individual utility decides to perform volumetric inspections of vessel head penetrations indications could possibly be encountered which would require disposition in order to permit plant start-up. Indications detected via penetration tube volumetric inspections need not necessarily immediately be repaired. Each penetration tube indication needs to be evaluated against the established industry acceptance criteria. Dependent on indication position, depth, and orientation it is quite possible no immediate corrective action is required. In fact no corrective measure may be required for the remaining design life of the plant. If however corrective action is required the first course of action would require removal of the defect by excavation. Excavation by itself is an acceptable corrective measure as long as the minimum required design thickness of the penetration tube wall is not violated, approximately 0.3 inch. If the minimum required design thickness is violated the integrity of the penetration tube wall needs to be re-established, i.e. via the local weld repair.

In support of the weld repair processes the following has been investigated; 1) Excavation geometries and various depths as related to flaw geometry, 2) Limitation of the weld repair with respect to crack length, 3) The definition of welding process parameters, 4) The definition of allowable weld filler metals, 5) Weld surface finish, 6) Requirements relative to the surface profile of the penetration inside diameter, 7) Industry suggested parameters for shot peening, and 8) Weld inspection requirements. Shot peening was examined as a post weld surface treatment to mitigate the residual stresses induced by welding. In addition to support the repair process, Westinghouse performed a generic 50.59 Safety Evaluation such that a utility could license such a repair on an as needed basis. The definition of the above items along with the safety evaluation provides a comprehensive package such that the utilities can independently implement and or contract such services, i.e. local weld repair or 360° weld overlay.

Conclusions of the program are:

- An acceptable weld overlay process has been developed and qualified to Section IX of the ASME Code.

- The welding process specification developed as a result of the qualification is applicable for both local weld repairs and 360° weld overlays in the reactor vessel closure head penetration tubes.

- Multiple repair geometries exist, each repair required should be individually specified. An individual utility needs to specify repair requirements based on the technical merits and economic impacts of each repair situation.

  - An excavation only repair is suggested up to a depth of [ ]^{a,c,e}.

  - It is suggested that if excavation to a depth of [ ]^{a,c,e} does not remove the entire defect, excavation should continue until the defect is removed or until [ ]^{a,c,e} inch of the penetration tube wall remains.

  - A weld overlay repair needs to restore the minimum required penetration tube wall design thickness.

- Repair welding provides an overall increase in the surface principle stresses in the penetration tube. Dependent on weld thickness and circumferential extent the principle stresses will vary. These residual principle stresses for any of the geometries considered are comparable in magnitude to the residual plus operating stresses estimated via the elastic/plastic analysis for the outermost penetration tubes.

- Areas of the penetration tube adjacent to the weld may be more susceptible to PWSCC than the alloy 600 base material not impacted by the welding process. However the susceptibility of adjacent material quickly dissipates due to the drop off of residual stresses as you move away from the weld.

- The extent to which a utility wishes to pursue post weld surface treatment(s), such as shot peening needs to be an individual utility decision based on the technical merits and economic impacts. The Westinghouse owner's group may consider such a program in the future.

- The final geometry and surface finish of the repaired area needs to be such to facilitate baseline and potential future volumetric inspections.

- Weld design depths, geometry, location, and circumferential extent can be varied in an attempt to minimize the impacts of the associated welding residual stresses. These variations are outlined on the associated design drawings provided in Appendix B. The WCAP report which follows is intended to provide the in depth information required to understand these impacts.

1.0 INTRODUCTION

Previously, leakage has been reported from an Alloy 600 reactor vessel closure head penetration tube in a French plant during hydro testing at elevated pressure. Subsequent inspections of the leaking penetration indicate the presence of axial cracks on the inside diameter of the penetration tube. Cracks extend above and below the penetration tube to reactor vessel head attachment weld. The leakage has been determined to result from an axially oriented through-wall crack in the penetration tube wall. The cause of the axially oriented cracks has been attributed to primary water stress corrosion cracking (PWSCC), driven by both steady state operating and residual stress. The residual stresses have been attributed to the ovality in the penetration tube which is a direct result of bending introduced in the penetration tube due to the offset geometry of the attachment weld. Reported data from inspections of head penetrations at additional plants (Both French plants and plants of Westinghouse design) has established the presence of axially oriented cracking in additional penetrations.

The plants of Westinghouse design with reported reactor vessel head penetration tube inside diameter PWSCC are [ ]^{a,c,e}. A review of available inspection data would indicate that flaws have been detected in approximately 2% to 3% of the penetrations inspected. A review of the reported inspection results also indicates that the majority of flaws were detected in penetration tubes located at the periphery of the reactor vessel closure head. This finding is consistent with estimate that residual stresses are greatest in the peripheral penetrations because the offset in the (or angle of) attachment weld is greatest at these locations.

Reactor vessel closure head penetrations on all Westinghouse supplied plants are of similar construction as that of the French plants and Westinghouse designed plants that have experienced cracking. Thus, based on the character of the cracking and the known potential of the Alloy 600 material for susceptibility to PWSCC this phenomenon may be possible on all Westinghouse plants.

Currently the WOG has undertaken an extensive program to examine and manage the phenomena of PWSCC initiated from the inside diameter of the reactor vessel Alloy 600 penetration tubes. The WOG's position has been that U.S. industry should take a proactive but logical approach to addressing the issue. Thus the WOG has initiated various project authorizations, outlined below, which are intended to address the various aspects of this issue such that the issue can be technically and economically managed to a successful resolution.

- Understand the cause and extent of cracking experienced by the French in their plants. From this phase of the work the WOG concluded that the issue could impact selected US plants, however the extent and/or time frame could not be immediately quantified.

- Assess the safety impacts of the issue. Detailed engineering analyses were conducted to understand the extent and safety impacts of cracking. A generic safety evaluation was performed and presented to the NRC. The conclusions were that the issue does not represent an immediate safety issue. The significance of cracking is that it can result in leakage which could result in wastage of the carbon steel vessel head. The WOG estimated wastage corrosion rates based on analysis performed by Westinghouse and experimental data provided by the Combustion Engineering Owners Group. The conclusion was that wastage could alter the reactor vessel head however the ASME Code Allowable stresses would be maintained for a minimum of 6 years.

- The experimental data used to estimate crack propagation for the thick-walled Alloy 600 penetration tubes, which was used in the flaw tolerance evaluation portion of the safety evaluation, was based on thin-walled Alloy 600 tubing. The WOG chose to investigate crack propagation rates in thick-walled Alloy 600 tubing to verify that the crack propagation model for thin-walled tubing was valid for use. Thus the WOG initiated a crack propagation testing program to investigate this phenomenon. This work is scheduled to be completed in the fourth quarter of 1994.

- The WOG had the opportunity to confirm the mechanism of cracking in the penetration tubes. The [ ]^{a,c,e} plant, a Westinghouse supplied plant, has also experienced cracking and has undertaken a program to investigate the cracking. As part of the Ringhals program boat samples were removed from the ID of a penetration which has experienced cracking. The WOG was offered the opportunity to perform a failure evaluation on one of these boat samples. Westinghouse performed this work under authorization [ ]^{a,c,e}. This work further confirmed the French findings that the cause of cracking was PWSCC.

- The WOG has authorized a report outlining a Flaw Evaluation Procedure which is intended to identify the techniques required to estimate the propagation of any flaws detected by an inspection.

- The WOG has supported an industry initiative coordinated by NUMARC to develop acceptance criteria for flaws detected along the inside diameter of reactor vessel closure head penetration tubes. These acceptance standards have been provided as the standard for acceptance of any flaws detected during an in-plant inspection. Additionally, EPRI has applied these acceptance standards in developing a qualification program and standards for utilities to use in the qualification of vendors offering inspection services.

- The WOG has also solicited utility volunteers to perform pilot volumetric inspections of their reactor vessel closure head penetrations. The WOG intends to evaluate inspection results and assess the impact on the pilot and other W plants.

Through these programs the WOG has attempted to determine cause, address the safety significance of this issue, develop inspection and acceptance criteria, provide a mechanism to qualify vendors offering inspection services such that interpretation of results across the industry is consistent, and make available pilot inspection results such that the future actions/requirements with respect to this issue relative to the U.S. nuclear industry can be formulated. Lastly, the WOG authorized a program to develop a weld repair methodology for penetrations which have experienced cracking. The following document outlines the program and reports on the results of the weld repair program.

2.0 PROGRAM DESCRIPTION

2.1 Objectives

The objective of the program was to provide a weld design package which can be applied to repair reactor vessel closure head penetration tube ID initiated PWSCC. The weld design study has investigated repair of partial through-wall and full through-wall cracks. The objective was to investigate a local weld repair process and a 360° weld overlay process as part of the weld design package. In addition to the weld repair process, information regarding excavation geometries and post weld surface treatment was investigated. Excavation serves two purposes; 1) It provides access for application of the weld, and 2) It serves to remove any existing defects. For the purposes of this project authorization the post weld surface treatment investigated was shot peening. The objective of a post weld surface treatment such as shot peening is to negate/mitigate residual stresses induced by welding.

In support of the weld repair processes Westinghouse investigated; 1) Excavation geometries and various depths as related to flaw geometry, 2) Limitation of the weld repair with respect to crack length, 3) The definition of welding process parameters, 4) The definition of allowable weld filler metals, 5) Identification of the weld surface finish, 6) Requirements relative to the surface profile of the penetration inside diameter, 7) Industry suggested parameters for shot peening, and 8) Weld inspection requirements. The definition of these items provides a comprehensive definition of the process such that the utilities can independently implement such a repair.

In support of the repair process, Westinghouse performed a generic 50.59 Safety Evaluation such that a utility could license such a repair on an as needed basis. Also, this program provided engineering justification of the process through the preparation of a full size penetration mock-up to provide engineering data to enable evaluation of effects on penetration residual stress and deformation due to the weld overlay. The change in stress was measured using a Hole Drilling Strain Gage Method in accordance with ASTM E837. Mock-up testing was also used to investigate the extent of weld shrinkage associated with the weld overlay process and the extent that the weld overlay process impacts the shrink fit between the penetration tube and reactor vessel head.

2.2 Weld Repair Program Outline

The development of a weld repair design package was structured to investigate specific weld process parameters and provide engineering justification for the various associated technical issues. In order to investigate the weld process parameters and technical issues several major program tasks were defined. Each of these tasks along with a brief description follows:

Task 1 Development of Weld Overlay Repair Process Specification:

The Westinghouse weld repair process specification defines: A weld thickness of [ ]^{a,c,e} to [ ]^{a,c,e} inches, defines critical welding process parameters, defines allowable weld filler metals [ ]^{a,c,e} and identifies weld surface finish requirements and inspection requirements.

Also, shot peening as a post weld surface treatment available for mitigation of post weld residual stresses will be discussed. The documentation also defines target shot peening process parameters. Target shot peen process parameters were provided as a result of recommendations solicited from a commercial shot peen vendor and work performed by Westinghouse, independent of this program authorization.

Task 2 Define Penetration Excavation Geometry:

A drawing is supplied to compliment the penetration repair process to define such items as: the excavation geometry and depths for both an excavation only repair and excavation followed by a weld repair, the required ID profile of the penetration ID after the application of the weld overlay, and any limitations with respect to positioning the weld overlay relative to projected stress profiles in the penetrations.

In addressing excavation of the penetration two aspects were addressed: 1) It was imperative that the structural adequacy of the penetration was not compromised, this was investigated via a review of available ASME code stress reports on the reactor vessel closure head, and 2) The excavation geometry was defined such that adequate

penetration material was removed such that, application of the weld does not restrict the flow area in the penetration or thermal sleeve movement is not impacted.

Task 3 Provide Evaluation of Applying Weld Overlay Over Existing Cracks:

The effect of applying weld material over existing partial through-wall and full through-wall cracks was investigated. The applicable ASME Code paragraphs were investigated which discuss leaving cracks in the pressure boundary were reviewed. Also EDM notches were placed in mock-ups to assess impacts on the welding process.

Task 4 Penetration Mock-up Tests:

A full size penetration mock-up was fabricated. The mock-up was fabricated using an alloy 600 penetration tube welded in a plate of low alloy carbon steel using the partial "J"-groove geometry for the attachment weld. The mock penetration tube was skewed to the surface of the plate to simulate the weld offset of actual penetration tube assembled in the reactor vessel closure head. The mock-up was used to investigate the application of weld material in a similar geometry to the penetration tube, and to quantify the addition of any residual stresses on the ID adjacent to the weld repair.

Several mock penetration tubes were also fabricated to investigate the application of various weld thicknesses and geometries. The various weld thicknesses were evaluated for cladding integrity via a cross-section taken through the weld thickness.

Task 5 Generic Safety Evaluation:

A generic 50.59 safety evaluation was performed to aid WOG members in implementing a weld overlay repair at their specific plant sites. The Safety Evaluation is provided as a stand alone document.

In completing the above tasks the stated goal was to identify engineering justification and appropriate specifications for implementation of a local weld repair and a 360° weld overlay. Both weld repairs involve an appropriate amount of excavation from the penetration inside diameter followed by

application of filler metal in the excavated area. In the case of the local weld repair the repair is targeted at restoring the minimum required penetration tube wall to maintain the pressure boundary. For the 360° weld overlay the intent is to provide a remedial measure for mitigation of PWSCC. The 360° weld overlay would cover the entire inside surface of the penetration tube most susceptible to PWSCC over some given length.

3.0 APPROACH FOR DEVELOPMENT OF PENETRATION TUBE WELD REPAIR AND OVERLAY DESIGNS

In developing the weld application options for the reactor vessel closure head penetration tubes, two basic designs were targeted; 1) A local weld repair process and 2) A 360° weld overlay process. The local weld repair process is targeted to restore the minimum required design thickness of the penetration tube wall. The 360° weld overlay repair is intended to provide a remedial measure to mitigate PWSCC in the Alloy 600 penetration tube ID. Refer to Figure 3.0-1 for an overview of the reactor vessel closure head to penetration tube geometry.

3.1 Local Weld Repair

In designing a local weld repair several considerations were taken into account:

- The weld repair has to restore the minimum required design thickness. The governing design requirement with respect to the penetration tube is design pressure. An examination of a typical 4-loop vessel head indicates that the required penetration tube thickness to meet design pressure requirements is approximately 0.29 inch.

- Slots were examined in [ ]^{a,c,e} Reference 6, as a potential repair for the reduction of residual surface stresses in the penetration tube ID. The maximum slot depth examined was [ ]^{a,c,e} inch.

- The industry flaw acceptance criteria developed for penetration tubes identifies the depth of an allowable flaw to be 75% of the tube wall thickness or [ ]^{a,c,e} = [ ]^{a,c,e} inch. Thus a weld overlay repair in a penetration excavated to a depth of [ ]^{a,c,e} inch may be required.

- In specifying the circumferential extent of the local weld repair designs, the stress analysis results reported in WCAP-13525, Reference 5, were taken into account as well as the slot widths examined in [ ]^{a,c,e} Reference 6. For the purpose of the local weld repair the intent was to position the toe of the weld in an area of the penetration tube ID having relatively low hoop stresses. Thus circumferential extents of 45° and 90° were selected, such

that the toe of the weld could be approximately located on the 45° axis of the penetration tubes where the hoop stresses were estimated to be low.

- Additionally, lengths of 4 and 6 inches were selected to investigate the variations which might occur due to changing the overall weld length.

Based on the above considerations local weld repair design geometries with varying weld thicknesses of [ ]^{a,c,e} inch, overall lengths of 4 to 6 inches, and having circumferential extents of 45° through 90° were considered for investigation.

3.2 360° Weld Overlay

In performing a 360° weld overlay repair the two items taken into consideration were; 1) The weld overlay depth should be thick enough to provide a boundary which prohibits exposure of the Alloy 600 base material to the primary water over the applied length of the repair, and 2) The depth should be minimized such that any associated weld shrinkage minimizes the residual stress in the base material and does not negatively impact the interference fit on the OD of the penetration tube between the reactor vessel closure head and penetration tube.

Based on the above a [ ]^{a,c,e} inch weld thickness was judged as appropriate to meet the above two criteria. A thickness of [ ]^{a,c,e} inch is approximately [ ]^{a,c,e} weld passes. However, an overlay need not be limited to [ ]^{a,c,e} inch. Weld overlay thickness of [ ]^{a,c,e} inch were investigated for lengths varying from 4 to 6 inches.

The perceived advantages of the weld overlay are; 1) Application of the weld overlay can be a continuous process using a spiraling application, and 2) both ends of the weld overlay can be readily positioned in lower stress regions of the penetration tube ID.

3.3 General Program Goal

In order to evaluate the above defined design geometries a series of tests and measurements were identified for investigation of a weld process which could be qualified to the ASME Section IX Code requirements, Reference 2. Additionally, these test and measurements were used to assess technical

impacts such that the specification of weld repair would not negatively impact the penetration tube geometry. These tests and measurements involved the fabrication of penetration tube samples and a full size reactor vessel closure head/penetration tube mock-up as well as the investigation of methodologies for performing weld overlay repairs. The following sections provide the details and results of these investigations.

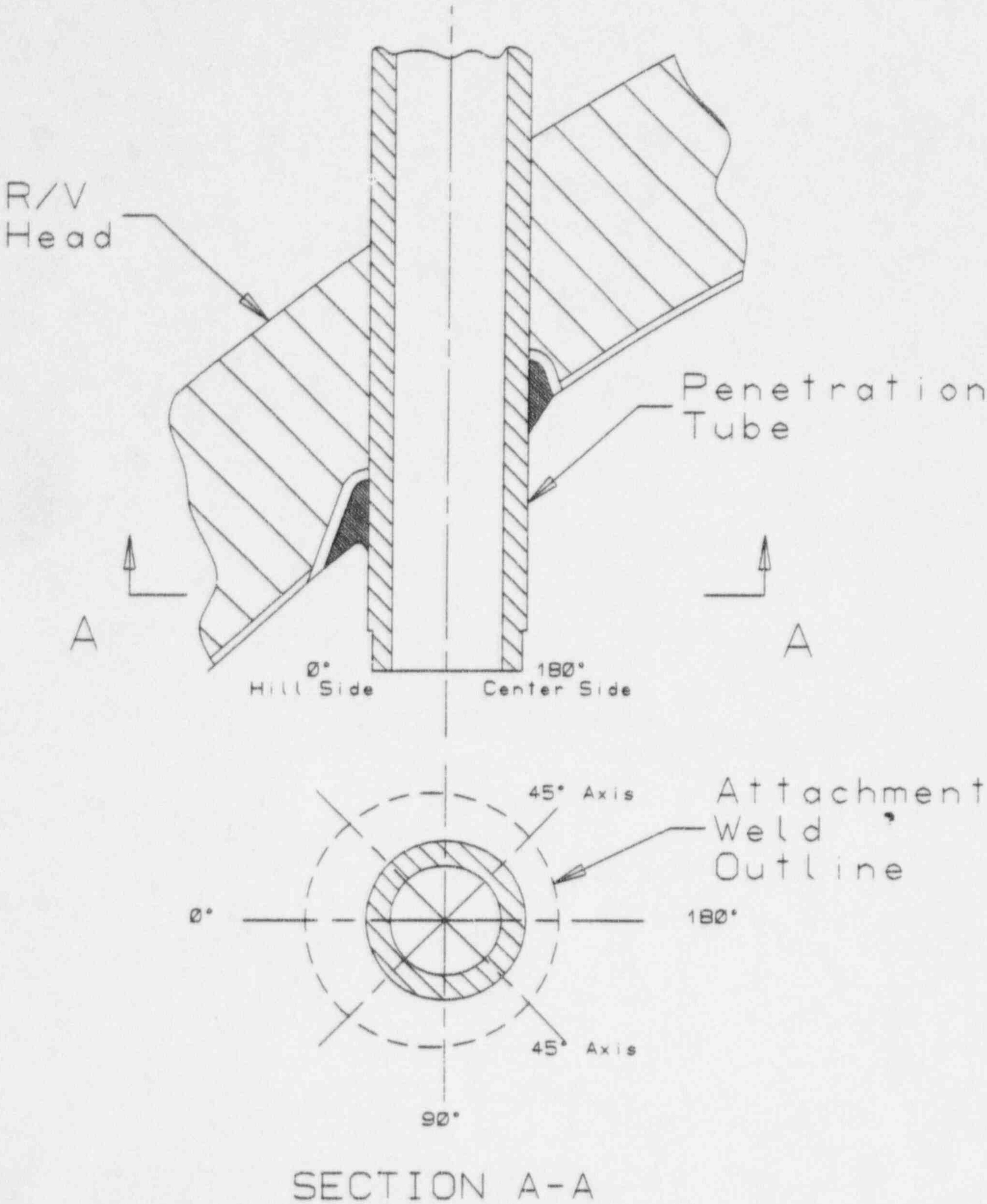

Figure 3.0-1 Reactor Vessel Closure Head to Penetration Tube Geometry

4.0 PENETRATION TUBE SAMPLE & REACTOR VESSEL HEAD/PENETRATION TUBE MOCK-UP FABRICATION

4.1 Preparation of Penetration Tube Samples

Figure 4.1-1 depicts the geometry of the grooves machined in the 10 inch penetration tube samples. The grooves were machined using electric discharge machining (EDM). As shown in Figure 4.1-1 the tube wall was machined to the defined depth and made use of a [ ]^{a,c,e} taper to blend the excavation depth into the original tube inside diameter (2.75 inch). The [ ]^{a,c,e} taper was applied both circumferentially and axially. For the groove depths of [ ]^{a,c,e} inch and [ ]^{a,c,e} inch the [ ]^{a,c,e} taper resulted in an acceptable geometry. However, for those samples with a groove depth of [ ]^{a,c,e} inch the taper was reduced to a ratio of [ ]^{a,c,e}. The taper was reduced because the [ ]^{a,c,e} taper was impractical from the standpoint that it extended two far around the penetration circumference, requiring too much weld filler metal to fill in the taper transition area. After performing weld repairs on the [ ]^{a,c,e} taper geometry process time was still too long and too much weld filler metal was still required, thus an alternative transition design was identified for blending from the excavation depth to the inside surface of the penetration tube. The alternative transition is a typical weld "J" preparation applied in the industry and is depicted in Figure 4.1-2.

4.2 Fabrication of Reactor Vessel Closure Head/Penetration Tube Mock-Up

A full scale mock-up of the reactor vessel closure head and penetration tube was fabricated to depict the most peripheral penetration in a 4-loop reactor vessel head, thus indicative of a penetration tube with the greatest offset in the attachment weld, i.e. therefore the maximum residual stress. Fabrication sketches of the mockup are provided in Appendix C, Fabrication Data Package for the Penetration Mock-Up & Penetration Mock-Up Sketches. The fabrication data package includes as-built dimensional data.

To validate the applicability of the mock-up, measurements were taken of the penetration tube inside diameter to measure the ovality which occurred as a result of performing the mock-up attachment weld. As in the actual reactor vessel head geometry, a "J" groove weld prep was used for the attachment weld between the penetration tube and low carbon steel plate. The maximum ovality

(major diameter less minor diameter) which occurred in the mock-up was [ ]^{a,c,e} mils ([ ]^{a,c,e} inch) as compared to the maximum approximated ovality of [ ]^{a,c,e} mils ([ ]^{a,c,e} inch) estimated from the linear regression equation for ovality which was developed based on actual plant ovality measurements, Reference 1.

a,c,e

Figure 4.1-1 [ ]a,c,e

a,c,e

Figure 4.1-2 Full Size Mock-up Sketch Depicting "J" Preparation Excavation Geometry

5.0 WELD PROCESS SPECIFICATION

A welding process specification, which can be used for either the local repair or application of the 360° weld overlay in the reactor vessel closure head penetration tubes was generated and is attached in Appendix A of this WCAP report. The welding process specification is written to provide guidance for the qualification of welding procedures to be used for the performance of welding in Westinghouse PWR reactor vessel closure head penetration tubes. The parameters recommended in the specification were based on the welding operations performed for this feasibility study. Therefore, the parameters were qualified for the intended applications to the extent as discussed in the following paragraphs.

5.1 Selection of Welding Equipment

An automated pulsed gas tungsten arc welding (GTAW) system designed and manufactured by The [ ][a,c,e] (power supply model 215, Figure 5.1-1, and model 94 ID cladding and welding head, Figure 5.1-2), was selected for this program. The model 94 weld head is designed for spiral cladding and groove welding inside diameters as small as 2 inches. The model 94 provides arc rotation, axial(linear) travel, filler wire feed and arc voltage control (AVC) for arc gap control. The combination of axial travel and arc rotation provides a spiralling effect directly applicable for use in a 360 degree weld metal overlay process.

To demonstrate the capabilities of the selected automated welding system and identify target welding parameters a pipe ID weld overlay was performed on a 2 inch nickel base alloy pipe with inconel 82 filler metal. The current design of the model 94 weld head feeds a 0.030 inch diameter weld wire. The filler metal of choice for this program, [ ][a,c,e] was not available in 0.030 inch diameter at the time of the demonstration. A 20 lb. spool of 0.035 in. diameter [ ][a,c,e] filler metal was obtained and reduced to the required 0.030 inch diameter.

5.2 Qualification of the Welding Parameters

The intent of qualifying the parameters at the beginning of the program was to ensure that the starting parameters were appropriate for use with the [ ][a,c,e] filler metal. The starting parameters were based on the parameters used with the [ ][a,c,e] filler metal during the demonstration of the welding system. This approach was taken due to the limited supply of the [ ][a,c,e] filler

wire at the beginning of the program, and the long lead time required to reduce the diameter of the available weld wire to 0.030 inch. The weld wire situation prevented any practice welding to establish welding parameters in advance with the [ ]a,c,e.

Two alloy 600 pipe assemblies were welded using [ ]a,c,e filler metal to qualify the parameters to the ASME Section IX mechanical test requirements. Four 5-inch long pipe samples were machined with 37.5° grooves as shown in Figure 5.2-1. The 37.5° groove was machined starting from the ID of the pipe and finishing the groove at the OD of the pipe so that the groove could be welded from the pipe ID.

Starting process parameters for welding the pipe assemblies with the [ ]a,c,e filler metal were those process parameters used in the demonstration with [ ]a,c,e. The parameters were adjusted as welding progressed. Some difficulties were experienced in welding the first assembly, during the initial two layers burn-through and stuck wire in the weld puddle occurred. Once the parameters were adjusted based on the difficulties, there was no problem with the subsequent layers of the first assembly or the second assembly. Upon completion of welding the two pipe assemblies, mechanical test coupons, i.e., tensile and bend (face and root) specimens, were machined from each assembly in accordance with ASME Section IX requirements. All bend specimens were free of cracks with the exception of the root bend specimen of the first assembly. The failure of the root bend was attributed to the difficulties experienced as explained above.

During welding of the qualification pipe assemblies it was observed that inconel 52 filler metal has a very sluggish characteristic, even worse than [ ]a,c,e. This may be due to higher contents of Cr, Fe and deoxidizers such as Al and Ti in [ ]a,c,e compared to [ ]a,c,e. The [ ]a,c,e filler metal mixed well with the alloy 600 penetration tube producing a relatively smooth surface, as was observed in the first layers of the pipe assemblies. The subsequent layers, however, started showing the sluggish characteristics which produced a relatively rough surface in comparison.

In general the surface condition of a weld is controlled by grinding or machining operations after welding. However, considering the actual field applications of this process it was desirable to improve the surface condition through weld process controls such that no grinding operation would be required after repair welding. As an attempt to improve the surface finish a [ ]a,c,e

mixture of shielding gas was tried during the welding of the second pipe assembly. The [ ]^{a,c,e} mixture gas was tried because it was readily available for a similar application on a nickel base alloy. The change in the shielding gas did not improve the surface finish of the as-welded condition. Thus the shielding gas was changed back to [ ]^{a,c,e} gas. Welding process parameters were adjusted during welding of the subsequent test tube samples to maximize the quality of the final surface finish.

5.3 Welding of Penetration Tube Samples

Table 5.3-1 shows the matrix of the eight [ ]^{a,c,e} penetration tube samples and their respective geometries. Repair welding of the tube samples started with sample number 4, which had a 360 degree groove of [ ]^{a,c,e} inches deep. Although the welding system was capable of welding the groove in one spiral operation the operation was stopped every one (1) inch or so to maintain the interpass temperature below [ ]^{a,c,e} maximum. The [ ]^{a,c,e} interpass temperature was selected because this is typical industry practice for minimizing distortion in stainless and nickel base alloys. Those samples with a partial groove, [ ]^{a,c,e}, required a similar interpass temperature control. It should be pointed out that the samples with a partial groove took a much longer time to weld due to the setup required for every pass. Each weld pass was performed circumferentially for this program. The necessity of a setup for every pass could impose some difficulties on actual field applications for repair welding and special attention should be given in development of field tooling to minimize this impact.

As explained in the previous section during welding of the [ ]^{a,c,e} tube samples the parameters were adjusted to improve the weld surface finish, such that the surface smoothness could be maximized. Although surface finish appeared to be adequate, more improvement would appear to be possible. Welding of additional samples for further adjustment of parameters would be beneficial as well as investigating the use of other shielding gases. Another possible shielding gas would be a helium/argon mixture. Other options, such as a combination of [ ]^{a,c,e} with [ ]^{a,c,e} and/or [ ]^{a,c,e} on the last layer should be considered.

As indicated in the Table 5.3-1 tube sample number 7 and 8 included EDM notches in the repair area. This was to study repair welding over [ ]^{a,c,e}. Figures 5.3-1 through 5.3-3 depict the cross sections of repair welds over the EDM notches. The notches were

approximately [ ]^{a,c,e} inches deep and [ ]^{a,c,e} inch wide. The metallography samples of the notches showed no cracks or indications generated in the surrounding area due to the welding. Considering [

]^{a,c,e}.

5.4 Welding Reactor Vessel Closure Head/Penetration Tube Mock-Up

Two EDM grooves, Figure 4.1-2, were machined in the penetration mockup to simulate weld repairs in the plant. It was learned from the [ ]^{a,c,e} penetration tube samples that a 360° groove would be much easier to weld repair as opposed to the partial groove with the welding system available. Thus, partial grooves were selected for the mockup to investigate the potential difficulties which might be experienced in a field application. The [ ]^{a,c,e} inch groove depth was selected for the partial grooves as the most probable thickness of weld overlay to be used in a field application.

Repair welding the excavation areas in the mockup were performed very much the same as in the penetration tube samples. Since the mockup, Figure 5.4-1, had more mass to transfer the heat during welding it was not necessary to stop the welding operation as often as in the [ ]^{a,c,e} inch penetration tube samples, to meet the [ ]^{a,c,e} interpass temperature requirement. It is estimated that the interpass temperature control may not be a concern with the field application due to the mass of the penetration tube and surrounding reactor vessel closure head.

a,c,e

ARC MACHINES, INC.

Figure 5.1-1 Weld Head Used for Weld Repair Program

a,c,e

ARC MACHINES, INC.

Figure 5.1-2 Weld Power Supply/Controller Used for Weld Repair Program

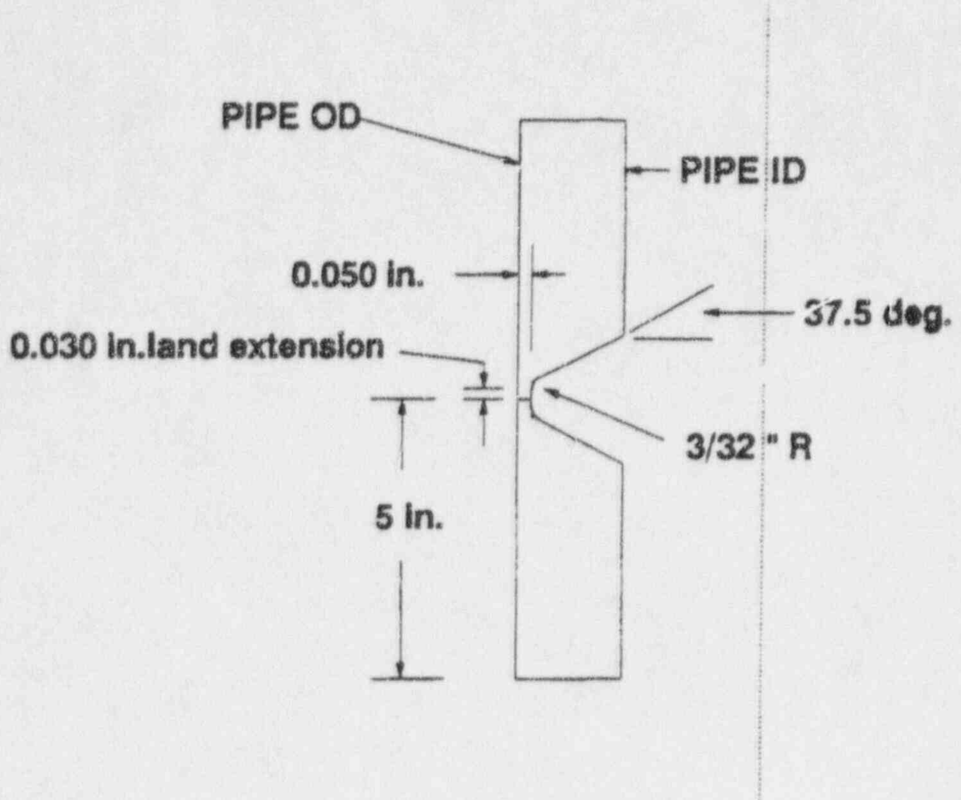

Figure 5.2-1 Joint Geometry for Qualification Samples

Table 5.3-1

TEST MATRIX FOR [ ]a,c,e PENETRATION TUBE SAMPLES

a,c,e

a,c,e

Figure 5.3-1 Penetration Tube Sample No. 8 Cross-Section Showing Weld Repair [ ]a,c,e

a,c,e

Figure 5.3-2 Penetration Tube Sample No. 8 Cross-Section Showing [ ]^{a,c,e}

a,c,e

Figure 5.3-3 Penetration Tube Sample No. 7 Cross-Section [

]^{a,c,e}.

a,c,e

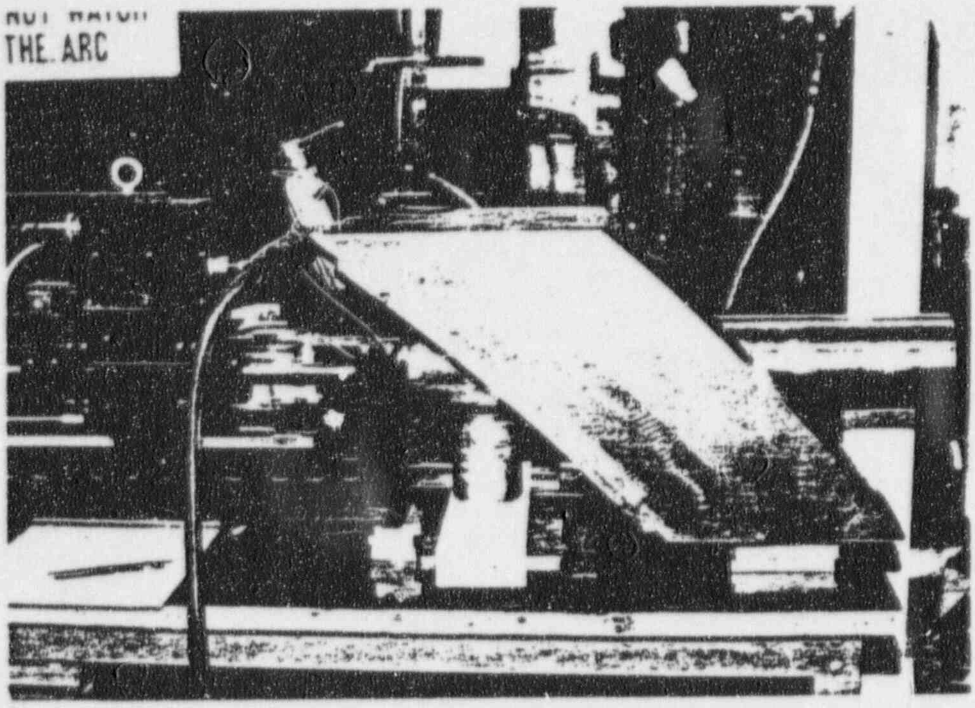

Figure 5.4-1 Photograph Depicting Weld Tooling Set-Up In Full Size Penetration Tube Mock-Up

6.0 EVALUATION OF WELDED PENETRATION TUBE SAMPLES

The penetration tube samples were used to evaluate the feasibility of welding within the 2.75 inch diameter of the penetration tube and to evaluate the impacts of the various selected geometries. As defined in Table 5.3-1, eight penetration tube samples were selected to explore the various weld repair geometries. The overall weld length, circumferential extent and depth were varied.

6.1 Discussion of Diametral Measurements

To evaluate the penetration tube samples each sample had pre and post weld dimensional data taken. The measurements were taken across both the inside and outside diameter in 0.5 inch increments over the entire length. The outside diameter measurements were used as the primary mechanism for comparison as opposed to inside diameter measurements in order to avoid variations resulting from the weld surface finish and the weld applied thickness. Figures 6.1-1 through 6.1-8 provide plots of the dimensional data. The dimensional data as-measured pre and post welding is provided in Appendix D, Penetration Tube Dimensional Data.

The penetration tubes were scribed to retain the orientation of the axis, i.e. 0°, 45°, 90°, and 135°. The outside diameter measurements taken across each of these axis were very consistent and on the average were 4.000 +/- 0.001 inch. The pre-weld diametral measurements were averaged and plotted as a single line on Figures 6.1-1 through 6.1-8. Post weld measurements were taken across the same axis and are plotted individually on each of their respective figures.

Based upon a review of Figures 6.1-1 through 6.1-8 the following observations were made:

- Regardless of the weld length (4 or 6 inches) the diametral dimensions are impacted over a length approximately 1 inch greater than the weld repair length. Recall the weld repair lengths do not include the taper length which is also filled with weld material. This would indicate that an approximately 0.5 inch transition zone exists from the end of the repair depth where weld shrinkage impacts the diametral measurements. This transition zone appears to independent of weld depth or taper length.

- A 360° weld repair results in deformation across each axis. The deformation is approximately uniform for each axis, Refer to Figures 6.1-2, 6.1-4, and 6.1-8.

- The deformation associated with a 90° weld repair also impacts each axis, particularly those axis 45° from the weld centerline (i.e. primary axis). The 45° axis experiences deformation approximately 30% to 40% of the primary axis. The axis 90° from the primary axis appears to be the least impacted. See Figure 6.1-3 and 6.1-5.

- In all penetration tube samples the deformation, resulting from weld shrinkage, appeared to result in a decrease of the outside diameter except over a very few number of local positions, See Figures 6.1-1, 6.1-5, and 6.1-7.

- On the average the deformations resulting from the various weld depths are:

Weld Depth (inch)	Average Deformation (inch)	Maximum Deformation (inch)
[ ]a,c,e	[ ]a,c,e	[ ]a,c,e
[ ]a,c,e	[ ]a,c,e	[ ]a,c,e
[ ]a,c,e	[ ]a,c,e	[ ]a,c,e

These deformations are based on the measurements taken in the [ ]a,c,e penetration tube samples. It is judged that deformation in the actual plant penetration tubes would be less because of the available mass to dissipate the welding heat input.

a,c,e

Figure 6.1-1 Deformation in Penetration Tube Sample #1 [ ]^{a,c,e}

a,c,e

Figure 6.1-2 Deformation in Penetration Tube Sample #2 [ ]^{a,c,e}

a,c,e

Figure 6.1-3 Deformation in Penetration Tube Sample #3 [ ]^{a,c,e}

a,c,e

Figure 6.1-4 Deformation in Penetration Tube Sample #4 [ ]a,c,e

a,c,e

Figure 6.1-5 Deformation in Penetration Tube Sample #5 [ ]^{a,c,e}

a,c,e

Figure 6.1-6 Deformation in Penetration Tube Sample #6 [ ]a,c,e

a,c,e

Figure 6.1-7 Deformation in Penetration Tube Sample #7 [ ]^{a,c,e}

a,c,e

Figure 6.1-8 Deformation in Penetration Tube Sample #8 [ ]^{a,c,e}

7.0 RESIDUAL STRESS MEASUREMENTS ON REACTOR VESSEL HEAD/ PENETRATION TUBE MOCK-UP

7.1 Approach to Residual Stress Measurement

To determine the residual stresses buildup from welding the reactor vessel closure head and penetration tube full scale mock-up fabricated for this program was used. The fabrication of the mockup was described in a previous section of this report. The hole drilling method of residual stress measurement was used for these measurements. A sketch of the head penetration model and test fixture is shown in Figure 7.1-1. All of the residual stress measurements were made on the ID of the tube.

The residual stress measurement program was divided into three steps:

[

]a,c,e

7.2 Hole Drilling Method

This method involves mounting a three strain gage rosette at the location the measurement is required. A small hole is drilled at the center of the rosette and the relieved strain is measured by the three gages on the rosette. The relieved strain and elastic constants of the material and constants for the rosette are used to calculate the residual stress. The rosette constants are obtained by calibration, either by the rosette manufacturer, or using the ASTM standard practices. The rosettes used were procured from Micro Measurements, gage model [ ]a,c,e. This is a special three element 45° rosette in a circular pattern. The hole drilling method measures a near surface residual stress and is described in ASTM standard E-837-92. Stress is assumed to be uniform, or at worst, varying uniformly through the thickness of the object measured. For a uniform stress field the accuracy is estimated within [ ]a,c,e.

7.2.1 Installation of Strain Gage Rosettes

Rosette locations for each step are shown in Figures 7.2-1, 7.2-2, and 7.2-3. These figures depict maps of the inside surface of the penetration tube and show the angular position and distance from the inside end of the penetration tube. The rosette locations are also tabulated in Table 7.2-1. Rosettes were oriented with the number one gage in the axial direction of the tube.

The ID surface of the tube was prepared for installation of the strain gages by first cleaning with a chlorothen degreaser. The surface over which the strain gage rosettes were installed was dusted with micro sand blasters to give a mat finish for better adhesion of the strain gages. For mounting strain gage rosettes in the EDM machined areas, in Step 2, the surface was first smoothed [ ]^{a,c,e}. The welds in the weld repair area, in step 3, were ground to a flat surface suitable for strain gage installation. [ ]^{a,c,e} adhesive was used to bond the gages.

7.2.2 Drilling Holes

The setup for the residual stress measurements on the model is shown in Figures 7.2-4 and 7.2-5. Air abrasive machining was used to machine the holes. A special fixture (shown in Figure 7.1-1) was made to position the drill to target the center of the rosette. The rosettes are masked before drilling to protect them from the abrasive. Strain readings are taken before and after drilling. Hole depth is determined by air pressure, abrasive size, nozzle diameter and time. [ ]^{a,c,e}

7.3 Test Results

The principal stresses and directions were calculated using the relieved strains and equations in ASTM E 837. [ ]^{a,c,e} The relieved strains were corrected for transverse sensitivity and gage factor variations. These factors are provided by the strain gage manufacturer (see Figure 7.3-1). The equations for the calculation of residual stresses are:

[ ]a,c,e

The equation for calculating the angle C from gage 1 of the rosette to the nearer principal stress is:

[ ]a,c,e

The relationship of principal stress directions to the rosette is shown in Figure 7.3-2.

The results of the residual stress measurements are given in Table 7.3-1. Residual stress versus distance from the end of the tube is shown in Figures 7.3-3 and 7.3-4.

7.4 Comparison of Test Results to Analysis

Elastic/Plastic analysis of the reactor vessel closure head/penetration tube geometry has been performed and documented in WCAP-13525, Reference 5, also several repair geometries have been analyzed and documented in [ ]a,c,e, Reference 6. The elastic/plastic analysis are of particular interest for comparison with residual stress measurements taken in the reactor vessel closure head/penetration tube mock-up, because the measurements serve to validate both the analysis and measurements. Also, the repair geometries examined local grooves (i.e. slots) as measures to reduce penetration tube residual stresses.

While the hole drilling technique is a fairly accurate means for the measurement of residual stresses it should be noted that the measured values represent an average stress over the depth of the hole, [ ]^{a,c,e} inch in this case. Thus the measured stress value is slightly below the actual surface stress on the order of magnitude of 10%. The finite element analysis provides a calculation of the surface stress. Figures 7.4-1 through 7.4-4 provide plots of the penetration tube residual stress as calculated after welding (as-opposed to the residual + operating stress) as compared with the measured stress values. Figures 7.4-1 and 7.4-2 plot hoop stresses while Figures 7.4-3 and 7.4-4 provide plots of the axial stresses. Also, the plots distinguish between the penetration tube center side (180° orientation on Figures 7.2-1, 7.2-2, and 7.2-3) and hill side (0°/360° orientation). The plots depict in general the same trends (peaks and valleys) between the measurements and the finite element calculations, also fairly good quantitative agreement exists, particularly for the hoop stress values.

Several other observations/comparisons were drawn from the hole drilling residual stress measurements and finite element calculations (It should be noted that the residual stress measurement locations in Table 7.3-1 identified with the same numerical value are approximately positioned with the same coordinates):

- The machining of the grooves generally appeared to lower stresses at the location measured. Hoop stresses were decreased at locations 4a, 8a, 9a, 12a, 14a and increased only at locations 3a. Axial stresses were decreased at locations 3a, 8a, 9a, 12a, 14 and increased only at location 4a. This generally supports the conclusions made in the analytical study of repair configurations, Reference 6.

- Weld repair areas have fairly high residual stresses, the greatest measured value being a principal stress of [ ]^{a,c,e} ksi, see location 11b on Figure 7.2-3. Although fairly high this value is comparable with the calculated surface stresses.

- Tensile stresses adjacent to the weld as indicated are fairly high but dissipate rather quickly, see locations 11b and 16b on Figure 7.2-3. Adjacent to the weld the axial/hoop stresses are [ ]^{a,c,e} ksi respectively, but drop to [ ]^{a,c,e} ksi less that 1 inch away.

- The penetration tube stresses approaching the 45° axis are expected by analysis to be low approaching compression. A review of these stresses after welding, see location 12B and 14b, in fact have compressive axial stresses of [ ]^{a,c,e} and [ ]^{a,c,e} ksi with low hoop stresses of [ ]^{a,c,e} and [ ]^{a,c,e} ksi.

- Axial and hoop stresses in the alloy 690 weld repair are higher than their corresponding values before welding, hoop stresses increasing by approximately [ ]^{a,c,e} ksi with the largest increase being in the axial stress components [ ]^{a,c,e} ksi to [ ]^{a,c,e} ksi and [ ]^{a,c,e} ksi to [ ]^{a,c,e} ksi, see locations 3/3b and 9/9b.

- A review of measured principal stress in the penetration tube weld region prior to and after welding indicate an overall increase in surface stresses.

- Although the individual measured stress components (axial and hoop) prior to and after welding indicate an overall increase in surface stresses the after welding values are comparable to calculated values. Again, Figures 7.4.1 through 7.4.4 provide the calculated and measured stress component values prior to welding.

a,c,e

Figure 7.1-1 Overall Dimensions of Head Penetration Model and Air Abrasive Drill Positioning Fixture

Table 7.2-1

ROSETTE LOCATIONS ON THE ID OF THE TUBE

a,c,e

a,c,e

Figure 7.2-1 Location Map of Residual Stress Measurements for Step 1 [ ]a,c,e

a,c,e

Figure 7.2-2 Location Map of Residual Stress Measurements for Step 2 [ ]^{a,c,e}

a,c,e

Figure 7.2-3 Location Map of Residual Stress Measurements for Step 3 [ ]a,c,e

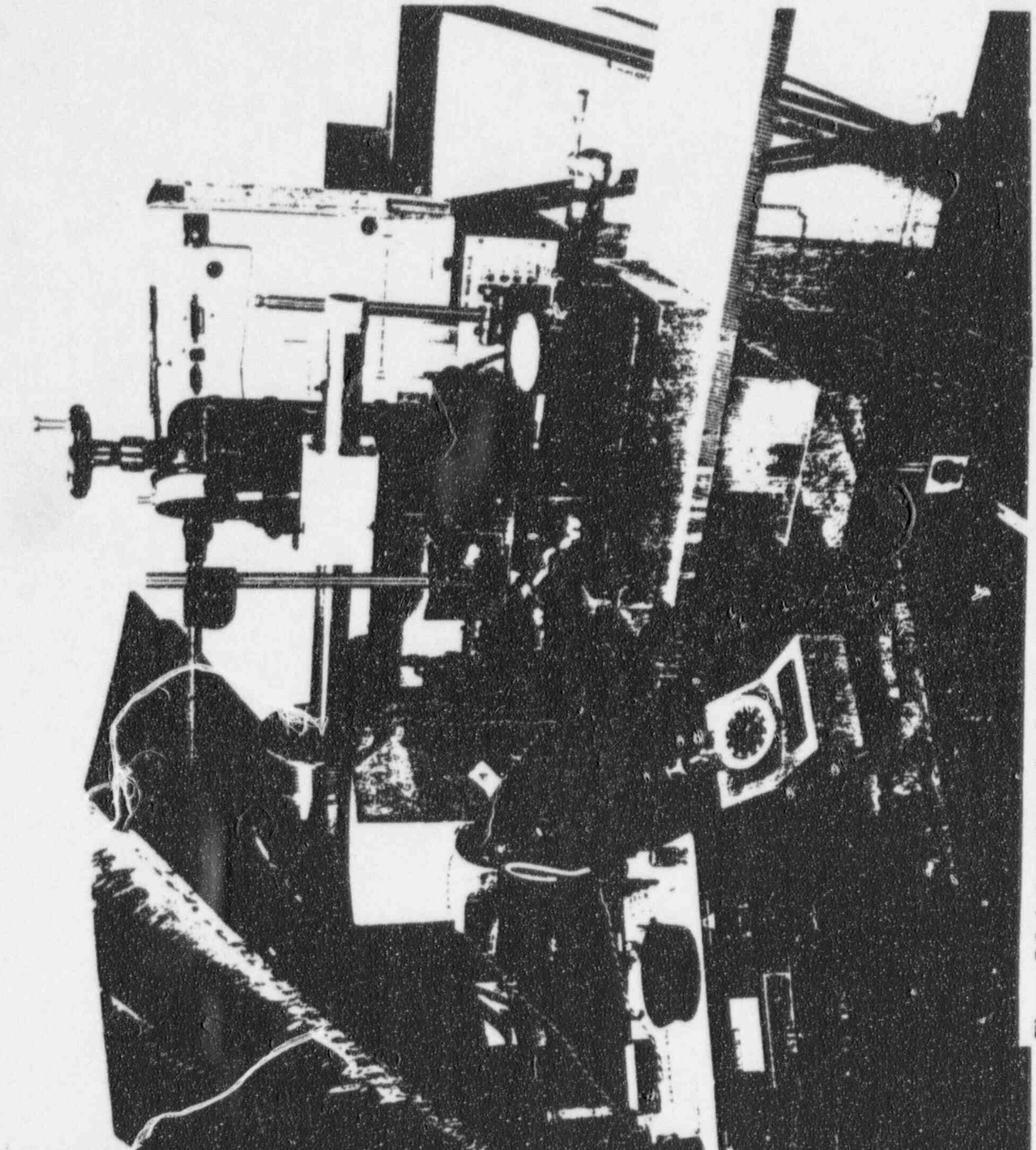

Figure 7.2-4 Test Setup for Residual Stress Measurements

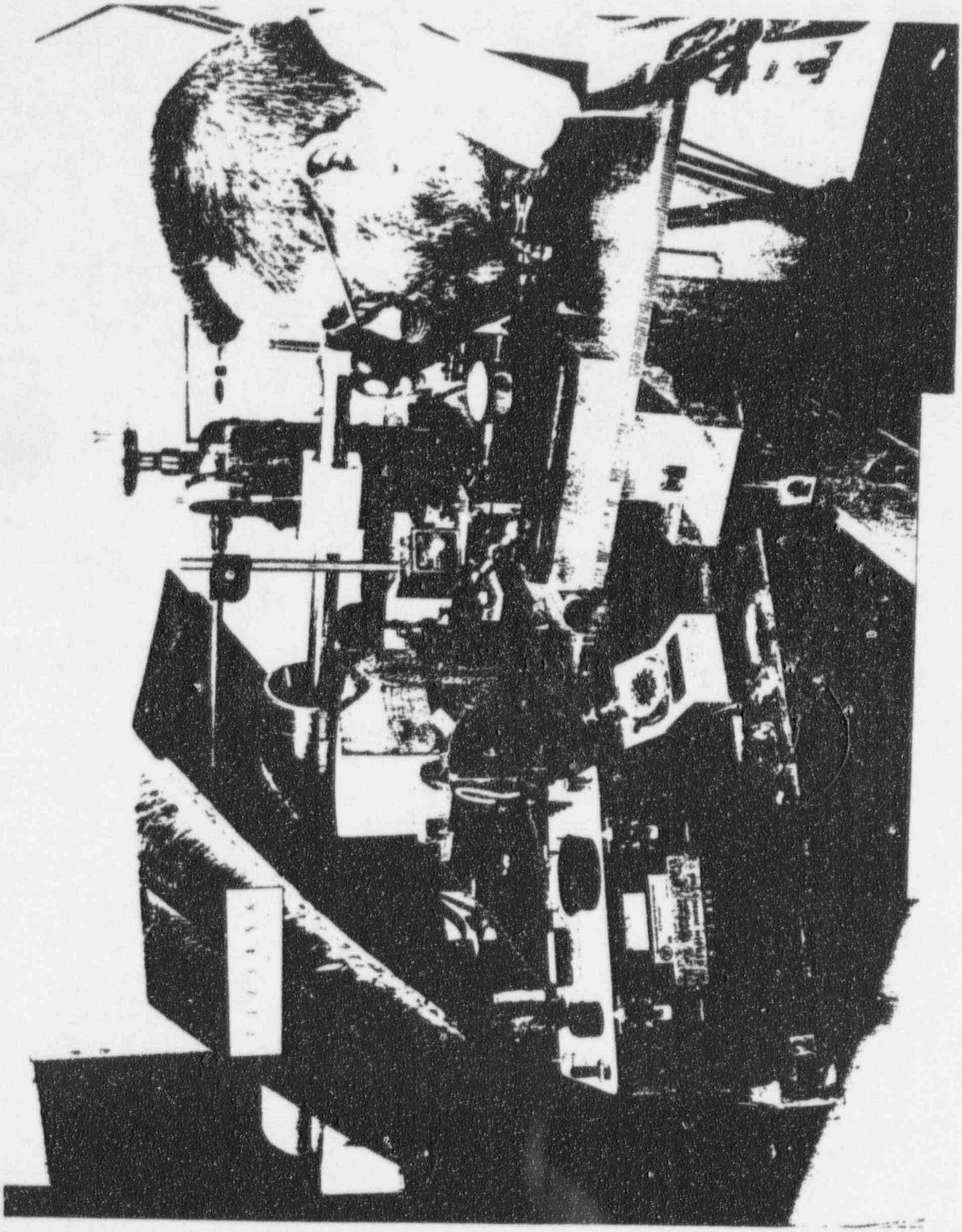

Figure 7.2-5 Adjusting Hole Drilling Fixture

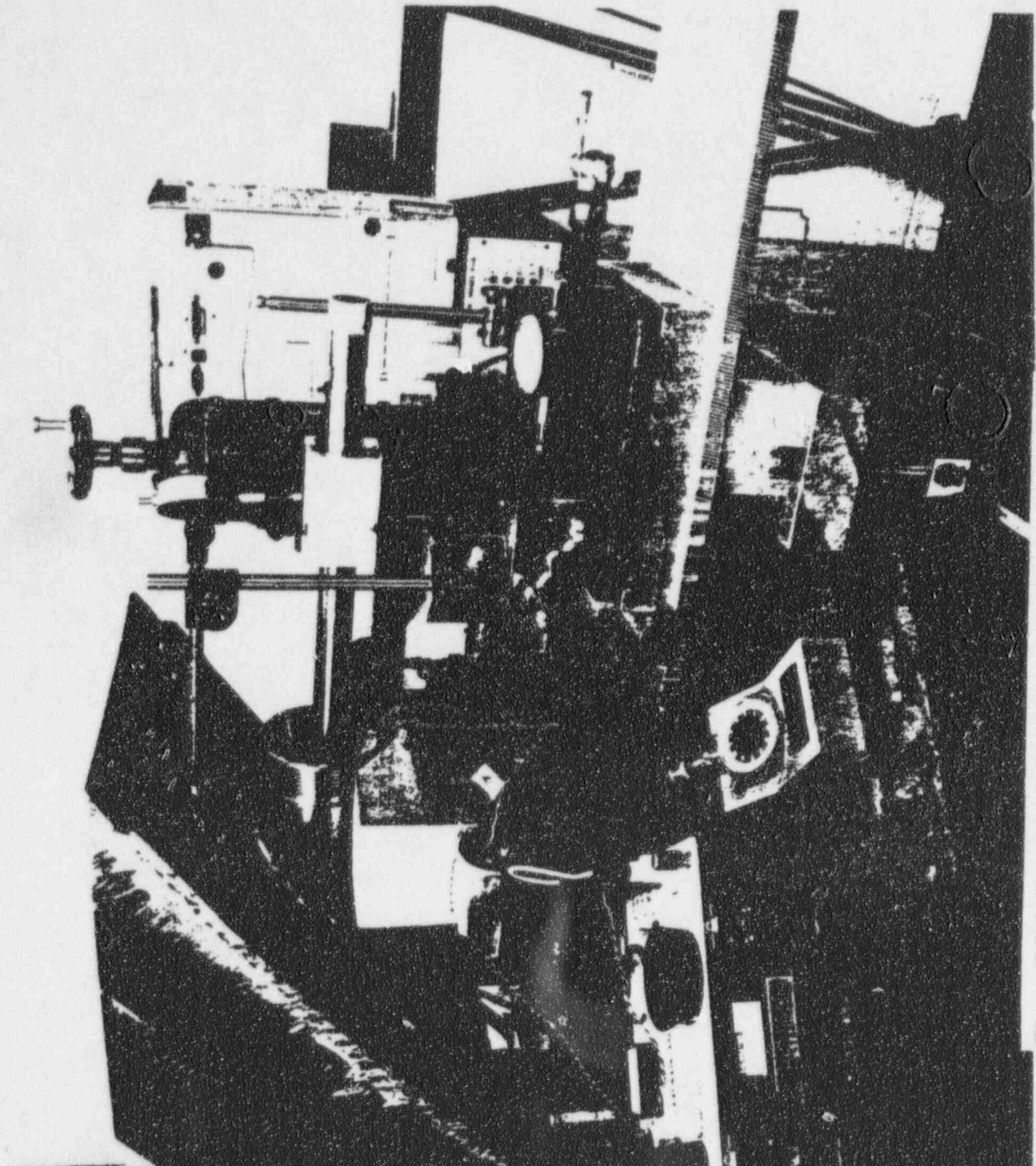

Figure 7.2-4 Test Setup for Residual Stress Measurements

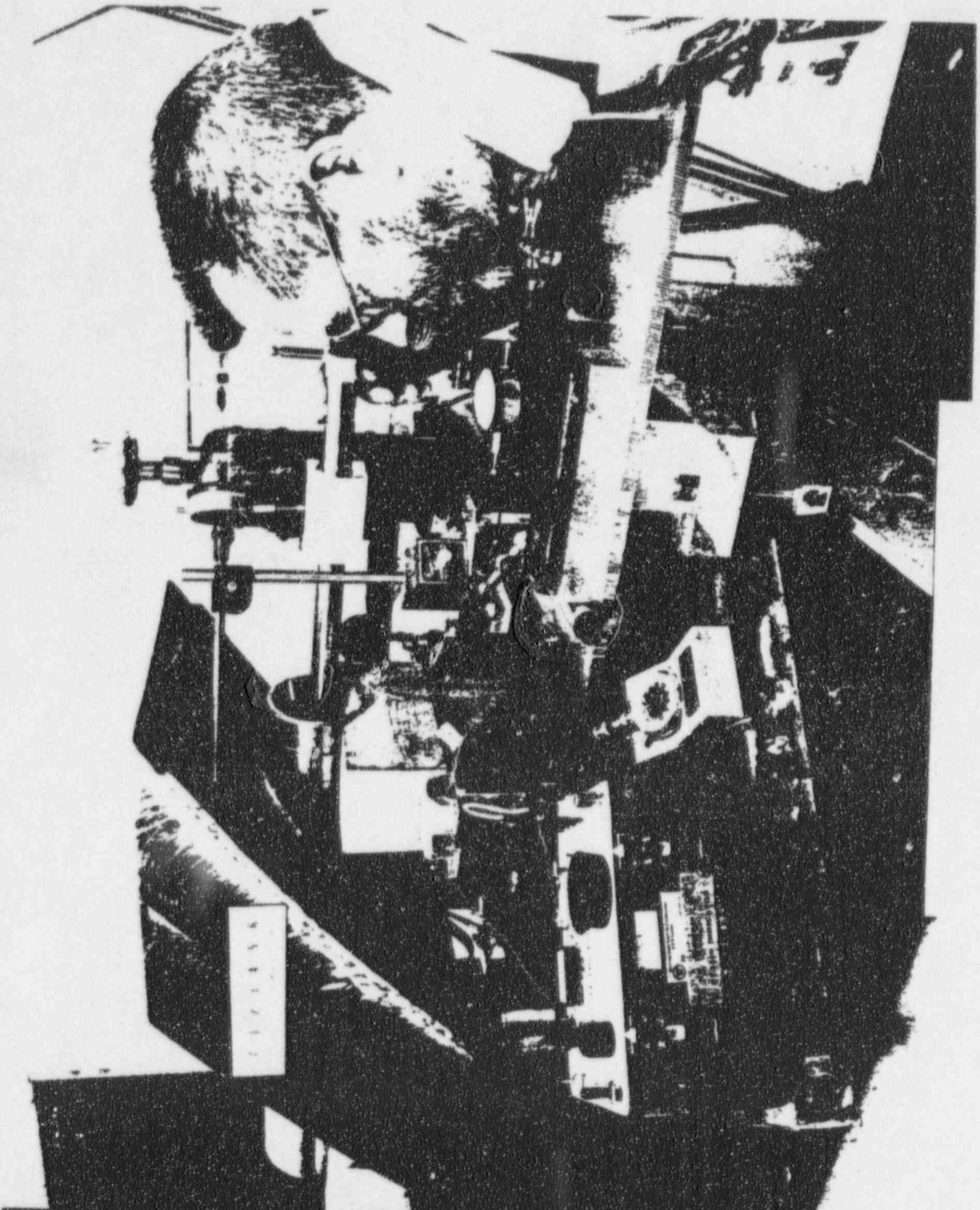

Figure 7.2-5   Adjusting Hole Drilling Fixture

Table 7.3-1
RESIDUAL STRESS MEASUREMENTS IN REACTOR VESSEL HEAD/ PENETRATION TUBE MOCK-UP

a,c,e

a,c,e

Figure 7.3-1 Hole Drilling Rosette Strain Gage Data

a,c,e

Figure 7.3-2 Relationship of Principal Stress Directions to Rosette Gages

a,c,e

Figure 7.3-3 Residual Stress Versus Distance From End of Tube for Step 1 at 180° Location

a,c,e

Figure 7.3-4 Residual Stress Versus Distance From End of Tube for Step 1 at 0° Location

a,c,
e

Figure 7.4-1 Residual Hoop Stress As-Measured Compared to Analytical Estimates of Hoop Stress for Center Side of Penetration

a,c,
e

Figure 7.4-2 Residual Hoop Stress As-Measured Compared to Analytical Estimates of Hoop Stress for Hill Side of Penetration

a,c,
e

Figure 7.4-3 Residual Axial Stress As-Measured Compared to Analytical Estimates of Hoop Stress for Center Side of

a,c,
e

Figure 7.4-4 Residual Axial Stress As-Measured Compared to Analytical Estimates of Hoop Stress for Hill Side of Penetration

8.0 DISCUSSION OF POST WELD SURFACE TREATMENT

Post weld surface treatment of welds is typically performed to serve one or all of the following functions:

1) Improve the surface finish such that an acceptable surface is provided for performing post-weld inspections and/or future penetration tube inspections.

2) Provide an acceptable geometry such that the function of the component is not negatively impacted. In the case of the penetration tube inside diameter, the inside diameter can not be reduced such that it impacts the thermal sleeve or reduces the flow path in the penetration tube ID to thermal sleeve OD annulus [ ]^{a,c,e}.

3) Mitigate the residual stresses in the weld metal and adjacent base material which occur as a result of the welding process.

In developing process requirements for welding, regardless if it is to be used as a mitigative measure for PWSCC (360° overlay) or a repair to restore the penetration tube pressure boundary (local repair), items (1) and (2) above are intended to be addressed via process controls. The post weld surface finish, item 1, and the post weld geometry, item 2, are intended to be controlled via weld process and inspections requirements. In order to address item 3 the WOG requested via the program authorization that shot peening be examined as the remedial measure for the mitigation of residual stresses induced by welding.

8.1 General Discussion of Shot Peening

Shot peening is a cold working process in which the surface of the material is bombarded with small spherical media called shot. Each piece of shot striking the material acts as a tiny peening hammer, imparting to the surface a small indentation or dimple. In order for the dimple to be created, the surface fibers of the material must be yielded. The cold working process results in the application of beneficial compressive stresses being applied at or just below the material surface. Compressive stresses are beneficial in increasing resistance to fatigue failures and stress corrosion cracking. Benefits obtained due to cold working include hardening, intergrannular corrosion resistance and

surface texturing. Westinghouse has investigated shot peening as a mitigative technique for application to the Alloy 600 penetration tube to increase the materials margin against primary water stress corrosion cracking (PWSCC).

The maximum value of the residual compressive stress is often called the magnitude of the residual stress induced. Variations in the shot peening process have little effect on the magnitude of the compressive stress induced as long as the shot used is at least as hard as or harder than the material being peened. The magnitude of the compressive stress is primarily a function of the base material mechanical properties. As a general rule the magnitude of compressive stress induced has a value of at least one half the yield strength to a maximum of approximately 60% of the ultimate tensile strength. For the minimum allowable mechanical properties listed for alloy 600 SB-166 & 167 this relates to a compressive stress range of [ ]^{a,c,e}.

The energy of the shot is a function of the media size, material, hardness, velocity and impingement angle. In order to specify, measure and calibrate peening energy a method utilizing SAE1070 spring steel specimens, called Almen strips, was developed. There are three standard Almen scales currently in use, each based on a different Almen strip thickness. The three scales are the "N", "A", and "C" scale in increasing order of intensity. The depth of the compressive layer is proportional to the Almen intensity. It should be noted that the magnitude of the compressive stress induced is independent of the compressive layer depth. Peening depth needs to be examined from two aspects; 1) The greater the depth the larger the impact on surface or subsurface material imperfections, and 2) The stress distribution through the component has to be balanced, thus for the case of the penetration tube wall an increase of compressive stress on the ID results in an increase in tensile stress on the OD.

The maximum benefit of shot peening is realized when the surface is uniformly peened to a saturation energy level. Saturation is defined as the earliest point where doubling the exposure time produces no more than a 10% increase in Almen intensity.

8.2 Shot Peen Parameters

Westinghouse performed a feasibility study to investigated shot peening for the reactor vessel closure head penetration geometry. The two primary objectives of the feasibility were:

- Show that tensile stresses on the inside diameter of the test chamber (penetration tube mock-up) before shot peening were [ ]^{a,c,e}.

- Confirm that shot peening reduces these inside diameter tensile stresses to [ ]^{a,c,e}.

The intent of these two objectives were to produce stresses in the penetration tube above the estimated threshold to PWSCC such that the penetration tube test chambers were susceptible to PWSCC. The shot peen process investigated did successfully reduce the susceptibility of the test chamber sample material to stress corrosion cracking in a series of laboratory tests.

Through the specification of process control parameters an Almen intensities of [ ]^{a,c,e} on the "N" scale were developed in the test chambers resulting in a compression layer depth of approximately [ ]^{a,c,e}. It was estimated that the magnitude of compressive stress induced was [ ]^{a,c,e}, approximately [ ]^{a,c,e} of the ultimate tensile strength of the material used in the test.

Subsequent discussions with commercial shot peen vendors have indicated that it should be feasible to develop Almen intensities of approximately 8 on the "C" scale resulting in approximate compressive depth layers of [ ]^{a,c,e}. Although the Almen intensity scales can not be directly related the approximate relationship between the two scales is: N = 0.1C or 10N = C.

8.3 Conclusions Regarding Post Weld Surface Treatment

A properly controlled shot peening process should a reliable remedial measure for the mitigation of residual tensile stresses associated with a weld overlay repair. It appears feasible that a shot peen process can be developed which would apply a compressive stress to the surface of the base material on the order of [ ]^{a,c,e} ksi or greater dependent on the base material properties to a depth [ ]^{a,c,e}. Such a process should increase the margin against PWSCC in the alloy 600 base material both in the heat affected zone adjacent to the weld and generally throughout the penetration tube ID.

Much investigation has been given to the development of approaches to provide margin against cracking in the weld toe profile. One common methodology is to grind the weld toe profile such that

the geometric discontinuities are removed from this area. This practice could also prove beneficial to the penetration tube ID, either performed by itself or in combination with shot peening. The extent to which a utility wishes to pursue post weld surface treatment needs to be an individual utility decision based on the technical merits and economic impacts. Clearly all post weld surface treatments add margin to weld life, each having its individual implementation costs and radiological impacts.

9.0 DISCUSSION OF WELD OVERLAY REPAIRS

9.1 Penetration Tube Repair Parameters

Generally, prior to the implementation of a weld overlay repair, any detected flaws will be evaluated against the industry acceptance standard using flaw evaluation techniques to determine if the flaws can be accepted as-is or need to be repaired. If repair is required or the utility chooses to implement a repair, the next appropriate repair would be the removal of the defect. If it is either determined by volumetric inspection or during the course of defect removal that the minimum required penetration tube wall thickness is violated a repair of that penetration location would be required. As investigated via this WCAP report a weld overlay repair is viable option for that repair.

9.1.1 Excavation Depths and Weld Thickness

As defined, the minimum required penetration tube wall thickness is approximately 0.3 inch. Excavation depths which leave a remaining wall ligament of less than the required design thickness, ~0.3 inch, would require a build up of the penetration tube wall. Additionally, another factor should be consider in specifying excavation depths. Excavation of the penetration tube wall and subsequent repair welding could result in a heat affected zone in the reactor vessel closure head base material. To avoid having to perform a post weld heat treatment of the weld repaired area and adjacent reactor vessel closure head base material it is suggested that some minimum ligament be maintained in the penetration tube wall. [ ]^{a,c,e} It is judged that this thickness could be directly applied for use in repair of the penetration tube wall. Thus during excavation it is suggested that a minimum penetration tube wall thickness (ligament) of [ ]^{a,c,e} inch be maintained. Based on the above discussion the following criteria are suggested for repair of reactor vessel closure head penetration tubes:

- Any defects detected in the penetration tube wall surface should first be repaired by excavation. No additional repair is required if the excavation depth does not violate the minimum required design basis thickness, approximately 0.3 inch.

- If excavation to a depth of [ ]^{a,c,e} inch does not remove the entire defect, excavation should continue until the defect is removed or until [ ]^{a,c,e} inch of the penetration tube wall remains.

- A weld repair to restore the minimum required design thickness needs to take into consideration the remaining acceptable penetration tube wall thickness such that the acceptable tube wall after repair welding is 0.3 inch or greater. For example;

  If the flaw were through wall, no remaining acceptable penetration tube wall thickness would exist and the minimum required weld overlay thickness would be 0.3 inch.

  Conversely, If the remaining acceptable tube wall thickness were [ ]^{a,c,e} inch, the minimum required weld overlay thickness would be [ ]^{a,c,e} inch, such that the total thickness was 0.3 inch.

9.1.2 Repair Geometry

As reported welding does provide an overall increase in the surface principle stresses of the penetration tube. These residual stresses are comparable in magnitude to the maximum residual plus operating stresses estimated via the elastic/plastic analysis for the outermost penetration tubes. It is difficult to quantify the impacts this increase in stress would have on the susceptibility of the alloy 600 base material to PWSCC. However, it would seem appropriate to estimate that the areas of the penetration tube adjacent to the weld would be more susceptible to PWSCC than the alloy 600 base material not impacted by the welding process. Of course, the alloy 690 weld filler metal should not be susceptible to PWSCC as compared with the base material.

As discussed previously, the toe of the weld could potentially be positioned, by design, in areas of the penetration tube estimated to initially have relatively low stresses by comparison. The intent being that the increase in stress due to welding will result in final stresses of lower magnitude than if the toe of the weld were positioned in a high stress region initially.

These considerations directly impact the selection of weld repair circumferential extent.

As investigated in this WCAP, if it is desirable to locate the toe of the weld outside the comparably high stress zones in the penetration tube ID, the circumferential extent of the weld should be selected such that it falls along the [ ].[a,c,e] Or as discussed in Section 8.0, post weld surface treatment(s) could be used as a means to possibly mitigate the residual stresses induced by welding.

The specific local weld repair geometry a utility wishes to pursue needs to be an individual utility decision based on the technical merits and economic impacts. Westinghouse drawing [ ],[a,c,e] attached in Appendix B, depicts the various weld repair geometry requirements and suggested repair profiles.

Drawing [ ][a,c,e] also depicts the geometries associated with a 360° weld overlay. As stated earlier a 360° weld overlay repair was investigated to offer a remedial repair which could generally be implemented to mitigate PWSCC in the highly susceptible region of the penetration tube ID.

9.1.3 Weld Surface Finish

The surface finish achieved in the application of a local weld repair or 360° weld overlay in the reactor vessel closure head penetration tubes is important from two aspects; 1) An acceptable weld surface finish is desirable to permit inspection of the weld and penetration tube base material, and 2) The smoother the weld surface finish the less susceptible the weld filler metal is to the initiation of surface cracks.

The intent as discussed in development of the weld process parameters was to refine the parameters such that the best possible surface finish could be achieved. The goal was to achieve a surface finish that would permit the volumetric inspection (ECT and/or UT) of the weld filler metal and base metal without having to rework the weld surface finish by some post weld machining operation. While rework of the surface is permissible the intent was to avoid the time and cost associated with rework of the surface. A realistic target surface finish judged to be achievable via the weld process and yet permissible for volumetric inspection was [ ].[a,c,e] In the development work performed a [ ][a,c,e] was achieved over limited lengths of applied weld, but over the full 6 inch length weld applied in the penetration tube samples the [ ][a,c,e] surface finish was not maintained.

It is suggested that the final check/qualification of the applied welding process should be verification that the final weld geometry/surface finish could be volumetrically inspected, using ECT as a minimum.

9.1.4 ASME Code Approach to Weld Repair

Repair welding is intended to be performed to the guidelines established in Section XI of the ASME Code. However, Section XI does not specifically define guidelines for what depth of flaws must be repaired in the reactor vessel closure head penetration tube ID. In applying weld repair to re-establish the minimum required design thickness of the penetration tube wall no code ambiguities seem to exist for the case where the defects have been totally removed. [

]a,c,e

[ ]a,c,e

9.1.5 Post Weld Inspection Requirements

ASME Code Section XI Subsection IWA-4500 outlines the guidelines for inspections of repair welds made to pressure boundary components. The code requires that a baseline volumetric inspection be performed of the weld repair for future reference, this is also consistent with the general guidelines

outlined for repair welds made to base metal by the component fabricator, ASME Section III Subsection NB-4130.

9.2 Conclusions

In summary the following conclusions are made:

[ ] a,c,e

a,c,e

10.0 REFERENCES

[ ]a,c,e

2. ASME Boiler and Pressure Vessel Code, Section IX, "Welding and Brazing Qualifications," 1989 Edition, ASME, New York, New York, July 1, 1989

3. ASME Boiler and Pressure Vessel Code, Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components," 1989 Edition, ASME, New York, New York, July 1, 1989

[ ]a,c,e

APPENDIX A

WELDING PROCESS SPECIFICATION

REPAIR WELDING OF REACTOR VESSEL CLOSURE HEAD PENETRATIONS

[ ]a,c,e

SAFETY REQUIREMENTS: Personnel responsible for welding application shall have a safety and industrial hygiene program for handling hazardous materials and arc welding equipment (ANSI B7.1, Z43 and Z49.1)

1.0 SCOPE

[ ] a,c,e

1.2 This process specification is applicable to the Safety related ASME Code items. The applicable code issue and/or other requirements will be specified in the equipment specification or procurement document.

1.3 This process specification is intended as a guide for the qualification of welding procedures and for the performance of welding on Westinghouse Nuclear Steam Supply System Components. Any exceptions to or deviations from the requirements of this specification must be documented in writing and submitted to WNTD (Westinghouse Nuclear Technology Division), Materials and Engineering Mechanics, at the time the welding procedure is submitted for approval.

2.0 REFERENCE DOCUMENTS

2.1 ASME Boiler and Pressure Vessel Code Section IX "Welding and Brazing Qualifications".

2.2 ASME Code Case 2142.

[ ]a,c,e

2.4 Additional documents that may be referenced in design specification, drawings and/or procurement documents.

3.0 MATERIALS

3.1 Base Materials

3.1.1 Nickel-Chromium-Iron Alloy base material in the solution annealed condition, ASME Section IX classification P-43.

3.2 Filler Materials

[ ]a,c,e

3.3 Electrode

[ ]a,c,e

3.4 Shielding Gas

3.4.1 The shielding gas shall be welding grade [ ]a,c,e.

4.0 PROCEDURE REQUIREMENTS

4.1 Qualification

All weld procedure specifications and welding personnel shall be qualified to the requirements of Section XI of the ASME Code. Exceptions to this requirement will only be permitted by written approval of W NTD, prior to any welding being performed on components.

4.2 Equipment

[ ]a,c,e

4.3 Joint Geometry & Preparation

4.3.1 Weld joint geometry shall be in accordance with the drawing number [ ]a,c,e attached in Appendix C.

4.3.2 The joint geometry shall be prepared by [ ]a,c,e.

[ ]a,c,e

4.4 Electrical Characteristics

[ ]a,c,e

4.5 Welding Position

All welding shall be done in the horizontal (2G) position where possible.

4.6 Preheat and Interpass Temperature

[ ]a,c,e

4.7 Postweld Heat Treatment

Postweld Heat Treatment (PWHT) is not required, nor permitted, unless specified in design specification, design drawings or other contractual documents.

4.8 Technique

4.8.1 Filler metal diameter shall be suitable for the base material thickness and weld joint configuration used in the component. [ ]a,c,e diameter is required for the parameters in table 1.

[ ]a,c,e

4.8.2 Deposition Method

4.8.2.1 All welds must be deposited with stringer beads.

4.8.3 Interpass Cleaning

a,c,e

a,c,e

4.9 Tooling & Fixturing

4.9.1 Discretion shall be used in the selection of material for tooling and fixturing for parts being welded such that there will be no detrimental effects to the weldment due to contamination as a result of heating, rubbing, smearing or excessive clamping pressure.

a,c,e

5.0 QUALITY ASSURANCE

5.1 Fabricators Quality System, Quality Release Requirements, Data Packages, and witness and notification points, when required, shall be as specified in the procurement documents.

5.1.1 Weld procedures shall be submitted to W NTD, or its designee, for review and approval. Any deviation from the requirements of this specification shall be

resolved by W NTD, Materials and Engineering Mechanics, as specified in Paragraph 1.3 of this specification.

5.1.2 All nondestructive examination procedures shall be submitted to W NTD, or its designee, for review and approval. Any procedure requirements not in compliance with Code or procurement document requirements shall be resolved by W NTD, as specified in paragraph 1.3 of this specification.

5.2 All welding inspections shall be in accordance with applicable code requirements and/or design specifications and drawings.

Table 1

MACHINE WELDING PARAMETERS

Function

Ti.ne--

a,c,e

APPENDIX B

WELD REPAIR DRAWING

a,c,e

a,c,e

APPENDIX C

DATA PACKAGE FOR THE PENETRATION MOCK-UP
&
PENETRATION MOCK-UP SKETCHES

All of this section is proprietary [a,c,f]

This Appendix C, pages C-1 thru C-31, contains detail dimensional data on the penetration mock-up test piece and material certifications that apply to the components within the mock-ups. Also contained are proprietary Westinghouse sub vendor information.

APPENDIX D

PENETRATION TUBE DIMENSIONAL DATA

All of this section is proprietary [a,b,c,g]

This Appendix D, pages D-1 thru D-33, contains detail diametrical measurement data on the penetration mock-up tube samples before and after weld repair. Also contained are proprietary Westinghouse sub vendor information