REPORT ON INVESTIGATION OF REACTOR COOLANT PIPE WELD THICKNESS AT DIABLO CANYON

July 1, 1983

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I. INTRODUCTON

In December 1982, members of the Inservice Inspection/Nondestructive Examination (ISI/NDE) section of the plant staff Quality Control group performed, using an ultrasonic technique, a series of measurements across the weld and adjacent base metal for 31 of the 56 girth welds on the reactor coolant system piping of Diablo Canyon Unit 1. The objective of this effort was to generate a plot of the contour of the weld root counterbore surface. These axial thickness "profiles" were made at several locations around each weld.

These measurements were taken when the ISI/NDE group was completing a general review of the plant's ASME B&PV Code, Section XI preservice inspection (PSI) program. Profile information is not required for PSI data, but does provide additional information useful in evaluating ultrasonic indications that might be observed in future inservice inspections. The examiners were primarily interested in locating irregularities on the inside surface of the pipe which could act as geometric reflectors and produce anomalous shear wave ultrasonic indications. While the inside surface can be directly observed during PSI work, post-operational access to these surfaces is not feasible due to high radiation levels. While it is possible to obtain this profile information post-operationally on an as-need basis, this work would also involve additional personnel radiation exposure. These factors provided the incentive to identify geometric reflectors before the plant started up.

Review of the profile data revealed that four locations on weld WIB - RC-2-17 on the cold leg of Loop-2 might be below the specified minimum thickness. During the next several months various efforts were made to resolve this matter. On May 9, 1983, after these subsequent investigations failed to resolve the concern, a verbal notification was made to the NRC. A written Licensee Event Report (LER) was submitted on May 23, 1983. This LER was considered to be an interim report, with a final report to be submitted following completion of further investigation.

During the course of the ensuing UT investigation, it was discovered that there might be below minimum thickness areas on nine other welds in addition to 2-17. As a result of this development and its broader implications and in response to questions raised by the NRC, the ongoing investigation was intensified to resolve the problem. This investigation included a review of all quality records and controls related to these welds, mechanical measurements of pipe ID and OD using micrometers, visual inspection of a number of welds, a comprehensive UT measurement and evaluation program, and a review of the significance of apparent below minimum measurements on the adequacy of the welds.

This report summarizes the results and conclusions of the investigations which were performed. In addition, it includes a detailed chronology of the events.

II. SUMMARY OF CONCLUSIONS

The principle conclusions of the investigation are summarized below.

- Review of the construction quality records and controls showed:
  - A rigorous quality assurance program was followed in the manufacture and installation of the reactor coolant piping.
  - Inspections and tests verified that the pipe was made in compliance with the technical requirements.
  - Documentation of required inspections and tests are available in the quality records. The records show that the pipe and welds meets specified requirements including the minimum wall thickness requirements.
  - Records show that metal removal during grinding was controlled and met specification.
  - No evidence of failure to perform required checks or to complete required documents was found.
- Reinspections conducted during this investigation have confirmed and coroborated the original records.
- Micrometer measurements of the inside diameter of the weld corroborated records of original diameter measurements and control of inside surface grinding.
- Micrometer measurements of the outside diameter, coupled with those made of the inside diameter, corroborate records of original pipe wall thickness and show that minimum wall thickness specifications are met in all cases.

- Analysis of ultrasonic (UT) thickness measurement capabilities and UT data and records show that UT measurements lack the precision required to verify the original micrometer wall thickness measurements on reactor coolant piping.

The overall conclusions gained from this investigation are that (1) the reactor coolant loop piping and other design Class I piping in the plant meet minimum wall requirements, and (2) the associated concerns raised by the misleading UT readings have been completely resolved.

III. SUMMARY OF CONSTRUCTION QUALITY RECORDS AND CONTROLS

When preliminary UT data indicated that as many as 10 reactor coolant loop piping girth welds might potentially have areas less than minimum specified thickness, an extensive investigation was made of the quality assurance records and controls for these welds. The purpose of this investigation was to:

1. Verify that a complete quality package was available,
2. Identify and review the adequacy of the quality controls on activities such as field grinding which may have caused the concern, and
3. Obtain any supplemental information which might substantiate, refute, or explain the preliminary ultrasonic results which had been obtained.

In this section, the results of this quality investigation are described.

A. Background Information on Welds

1. Location and Type

The welds being examined are girth welds located in the reactor coolant system (RCS) loop piping which is comprised of 4 reactor coolant loops attached to the reactor vessel, as shown on Figures III-1, III-2, III-3 and III-4. Each loop is made up of a hot leg, a crossover leg, and a cold leg. The hot leg connects the reactor vessel to the steam generator, the crossover leg connects the steam generator to the reactor coolant pump, and the cold leg connects the reactor coolant pump to the reactor vessel.

As shown on the figures, each loop contains 14 girth welds, for a total of 56. Of the 14 girth welds on each loop, 4 are located on the hot leg (2.335 inch specified minimum wall thickness) of which 2 are shop and 2 are field welds; 6 are located on the crossover leg

(2.495 inch specified minimum wall thickness) of which 2 are shop and 4 are field welds; and 4 are located on the cold leg (2.215 inch specified minimum wall thickness) of which 2 are shop and 2 are field welds.

2. <u>Design, Fabrication and Installation</u>

The RCS loop piping was designed to the USAS B31.1 Code, 1955 edition, with the addition of Code Cases N-7 and N-10 and Westinghouse (<u>W</u>) equipment specification G-676343. The piping was fabricated and examined by Southwest Fabricating and Welding Company (Southwest) in accordance with <u>W</u> specification G-676343 and ASME Section I, 1968 edition and was documented on a Form P-4A. The shop welds were made by Southwest in 1969 and 1970 for the hot and cold legs. The shop welds on the crossover legs were made by Southwest in 1973 and 1974. The hot and cold leg piping was received by PG&E in June of 1970. The crossover piping was received in the time period between September 1973 and February 1974.

After design was complete and fabrication started, ASME Section III was expanded in scope to cover piping for nuclear power plants. PG&E Specification 8752, issued for installation of the nuclear steam supply systems, was revised in March 1974 to incorporate requirements of ASME Section III, 1971 edition.

The RCS loop piping installation was performed by Wismer and Becker (W&B) and documented on a modified Form N-5. Although W&B was an ASME Section III "NA" stamp certified installer, the installation was not stamped because the design and fabrication had been done to different and earlier codes. The field welds were made by W&B during the period from May of 1973 to April of 1974. The W&B welds were performed to ASME Section I, 1968 edition and ASME Section III, 1971 edition with Summer 73 addendum, W specification G-676496, PG&E Specification 8752, and under W&B's quality assurance program. RCS was released to the PG&E operations by PG&E General Construction on May 2, 1977.

B. Quality Records on RCS Loop Piping Welds

One of the main purposes of the investigation was to review the quality package on each weld for completeness. The reviewers found the records to be comprehensive and complete. The factual basis for much of the discussion which follows is contained in these records.

C. History and Controls on Grinding

If a less than minimum wall condition were proven to be true, it was postulated that the most likely cause was grinding on the welds to prepare surfaces for PSI and/or to remove indications found during PSI. As a result, a thorough review was made of the history and controls placed upon grinding operations on these welds. In this section, the results of this investigation are discussed.

1. Shop Fabrication

Shop welds were ground on the inside and outside by Southwest for surface preparation for liquid penetrant and radiographic examination and to remove penetrant indications. Southwest had procedures and inspection controls to measure pipe wall thickness at the weld bevel end prior to welding to insure minimum thickness specifications were met. This provided benchmark references for subsequent welding. Control of thickness during welding was by control of counterbore and outside diameter dimensions together with use of alignment jigs to maintain concentricity. Dimensional checks using micrometers were made prior to shipment.

In 1970, PG&E General Construction Department inspected the as-received hot and cold legs and identified depressions in the pipe surface and "punch mark" identification markings. This was documented on PG&E Deviation Report Serial No. 39. This report addressed wall thickness and resulted in extensive optical, mechanical and ultrasonic thickness measurements being made. These measurements confirmed prior determinations that minimum wall thickness specifications were met. They also showed that ultrasonic thickness measurements were not always consistent on this pipe material, and were not of adequate precision for measuring to the specified tolerances.

2. Field Welding

The weld preparations and fit-up were checked prior to welding and the depth to the top of the root pass was measured as documented in the W&B Documentation Checklist-Traveler Packet. These measurements further verify that adequate wall thickness existed prior to field weld out.

PG&E Specification 8752 and W&B weld procedure specification 3500-1 required "The inside surface of the weld shall be clean, smooth, and free from the presence of sharp irregularities, lumps, and oxidation. Surface shall also be free of undercut." These criteria were included on the W&B visual weld examination checklist as item #18. The inside surfaces were polished clean and smooth. Metal removal was kept to a minimum under surveillance of W&B QC, PG&E inspectors and Westinghouse. Visual and liquid penetrant inspections of the inside surface are documented in the W&B Documentation Checklist - Traveler Packet. When grinding was done to remove penetrant indications, the depth of grinding was measured and weld metal added (if required) as documented in the Documentation Checklist - Traveler Packet to assure that minimum wall thickness was maintained. No direct wall thickness measurements were made after field weld completion.

3. Preparation for UT Inspection

Shop and field welds were ground on the weld crown in 1974 and 1975 by W&B at the direction of PG&E to facilitate ultrasonic inspection required by ASME Section XI for PSI/ISI. On several shop welds, indications required grinding and weld buildup. The weld buildup was performed by Southwest in the field in 1975.

Requirements for weld crown grinding to prepare for ultrasonic examination were specified by PG&E instructions. Confirmation was obtained from the pipe supplier and designer (Westinghouse) that weld reinforcement was not required to meet minimum wall thickness requirements. Welds were ground approximately flush (+1/16, -0) with immediately adjacent base material. A special grinding crew was selected and trained by W&B to do the work. PG&E General Construction inspectors provided continuous surveillance of the grinding to assure that grinding did not go below the immediately adjacent pipe or fitting surface, and that grinding was confined to the weld metal. This process assured that minimum wall thickness requirements were maintained. Special short straight edges were fabricated to gage flushness (+1/16,-0) and flatness across the welds. PG&E UT examiners inspected final surface finish for adequate smoothness for ultrasonic examinations. Liquid penetrant examination of the final weld outside surface was also performed by W&B.

4. Preservice Inspection

The PSI liquid penetrant examinations of the outside weld surfaces have not required further grinding. No inside weld surface liquid penetrant examinations were made for preservice inspection in 1975. Ultrasonic inspection conducted for preservice inspection in 1979 disclosed indications at the inside diameter of some of the reactor coolant loop girth welds. The indications were investigated by liquid penetrant inspection of the weld inside surfaces. These indications were removed by superficial spot grinding and by buffing and polishing under controlled conditions. This work was performed by Pullman Power Products (PPP) and PG&E in 1979.

The depth of grinding was measured and evaluated for impact on wall thickness by comparison with the depth of the weld counterbore. This check verifies that wall thickness requirements were met. In some cases ultrasonic thickness measurements were made of the adjacent pipe wall and the depth of grinding was measured with a machinist level and depth gage. This work and these inspections, measurements and evaluations are documented in the PSI data packages for the reactor coolant piping girth welds.

D. Grinding on Girth Welds on Other Design Class I Piping Systems

An evaluation was also performed of grinding on girth welds in other design Class I piping systems to evaluate its impact, if any, on maintenance of minimum wall thickness.

Grinding on welds can be separated into inside and outside surface grinding. Reactor coolant pipe welds are accessible for inside grinding due to the pipe's large diameter and availability of access through the reactor vessel nozzles and steam generator manways. The inside surface of most other welds cannot be ground because there is no way to gain physical access. Special access provisions such as cutting the pipe to allow one to reach in would be required.

The inside surfaces of the four feedwater pipe to steam generator nozzle welds were inspected in 1977 and work performed as needed. Access for work on the inside surface of the welds was provided by cutting out a short section of pipe. The inside surfaces of the four main steam pipe to steam generator nozzle welds were inspected in 1977 and work was performed as needed. Access was provided by entering through the steam generator manway, removing internal parts and building scaffold on top of the moisture separator section. In addition, two branch line connections off the reactor coolant pipe had some minor inside surface grinding. These were the 14 inch surge line and the 14 inch residual heat removal branch connection welds.

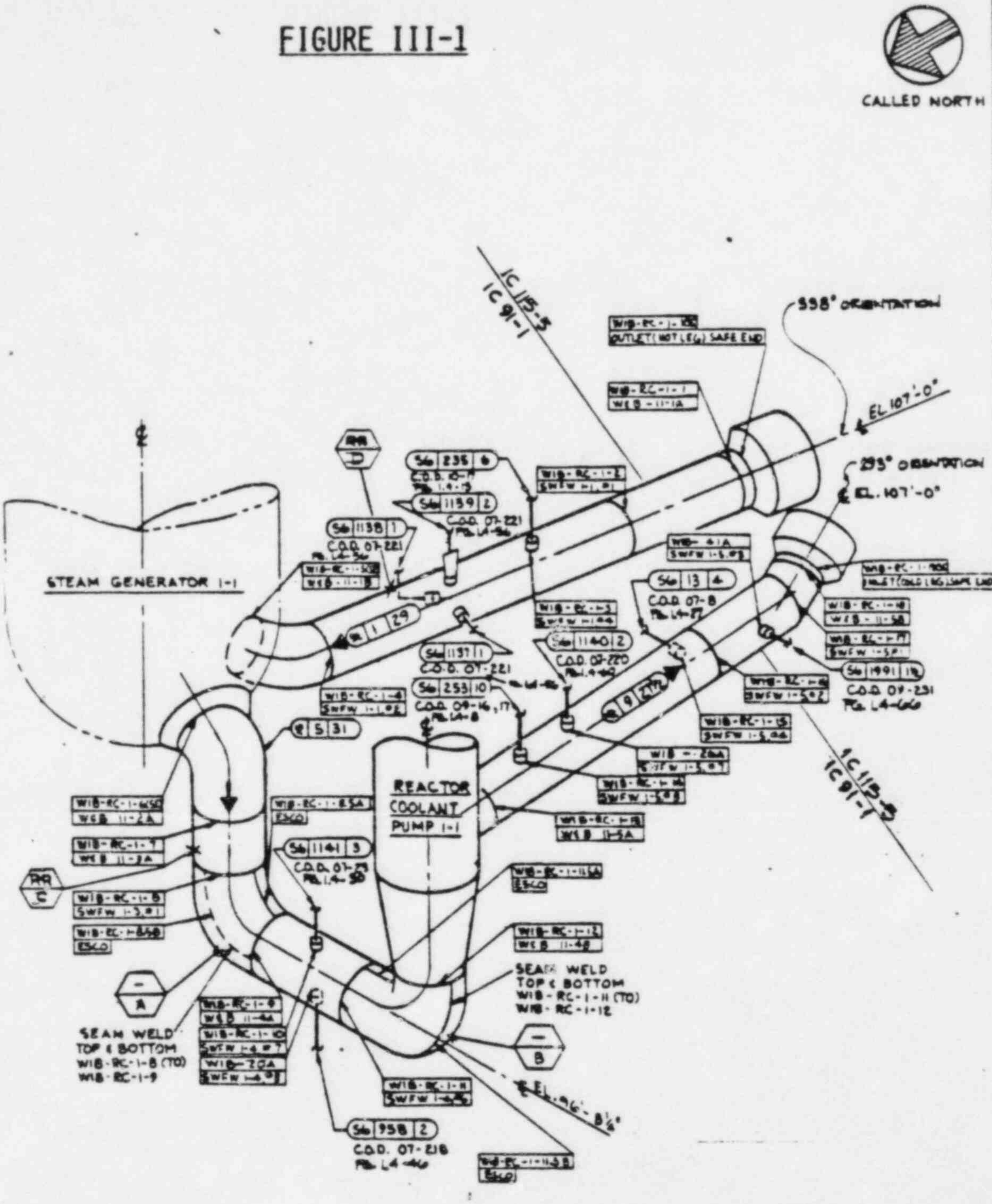
In all cases, work on the inside surface of welds was closely monitored and inspected to assure compliance with Code and design requirements.

The depth of any grinding was measured and, if necessary, a weld buildup added to assure maintenance of minimum wall thickness. Wall thickness verification was also made using ultrasonic methods. Work and inspections are documented in the PPP records. The outside crown of welds in other than the reactor coolant pipe were originally prepared for visual, surface and volumetric (liquid penetrant and radiography) examination and acceptance as required by the applicable fabrication and installation Codes. Some of these welds were selected for inservice inspection and had further outside surface grinding performed to facilitate PSI/ISI ultrasonic examinations. The outside surface preparation requirements for these welds did not require the weld to be ground flush with the pipe surface as the requirements for the reactor coolant pipe preparation did. These weld crowns could be "flat topped" and left higher than the adjacent pipe surface. It was not necessary to grind the weld crown to as smooth a blend or transition from the pipe surface to the weld surface. The weld crown preparation requirements for PSI/ISI were defined by PG&E and in PPP's procedures.

E. CONCLUSIONS

As the foregoing review demonstrates the shop fabrication, field installation and inservice inspection preparation work was all performed in accordance with appropriate quality procedures, was technically appropriate, and assured that minimum wall thickness requirements were met.

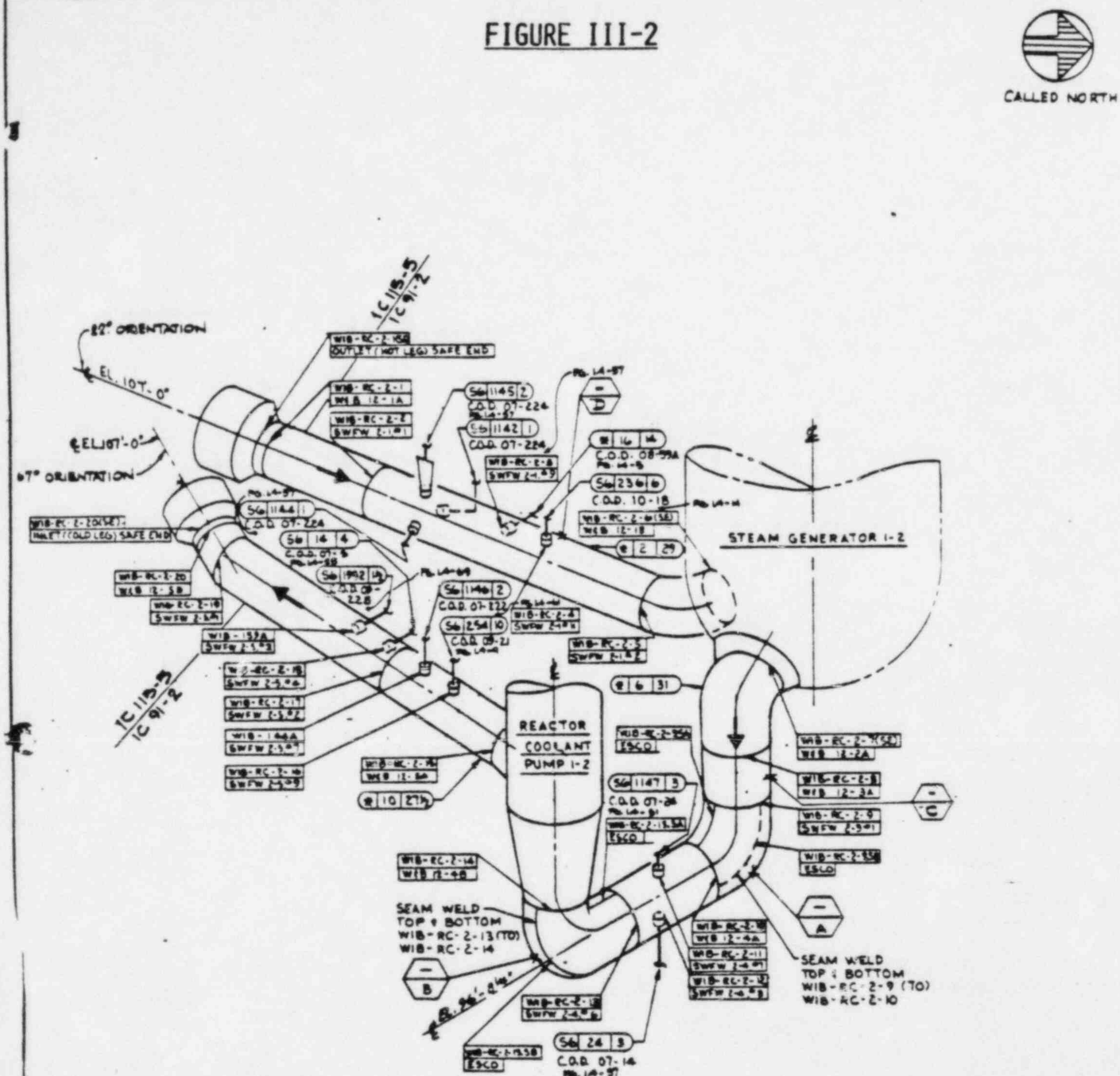
FIGURE III-1



	DIABLO CANYON UNIT I INSERVICE EXAMINATION ISOMETRIC PACIFIC GAS AND ELECTRIC COMPANY			
	AREA: F&G	ISO: 07-30	P&ID COORD: 07-10381	SYSTEM: RCS
	REF. DWG. RC 1-1	REPL'S. 001	LINE NO. 8-1-29, 6-5-31, 8-9-27½	DRAWN: B. GATTISON
				CHK'D.
				APPR'D:
			PAGE: 1.4-1	DATE:

LINE NO	DESCRIPTION
8-9-27½ SPL	REACTOR COOLANT PP DISCH LOOP 1
6-5-31 SPL	REACTOR COOLANT PP SUCT LOOP 1
8-1-29 SPL	REACTOR COOLANT OUT LOOP 1

FIGURE III-2



DIABLO CANYON UNIT I

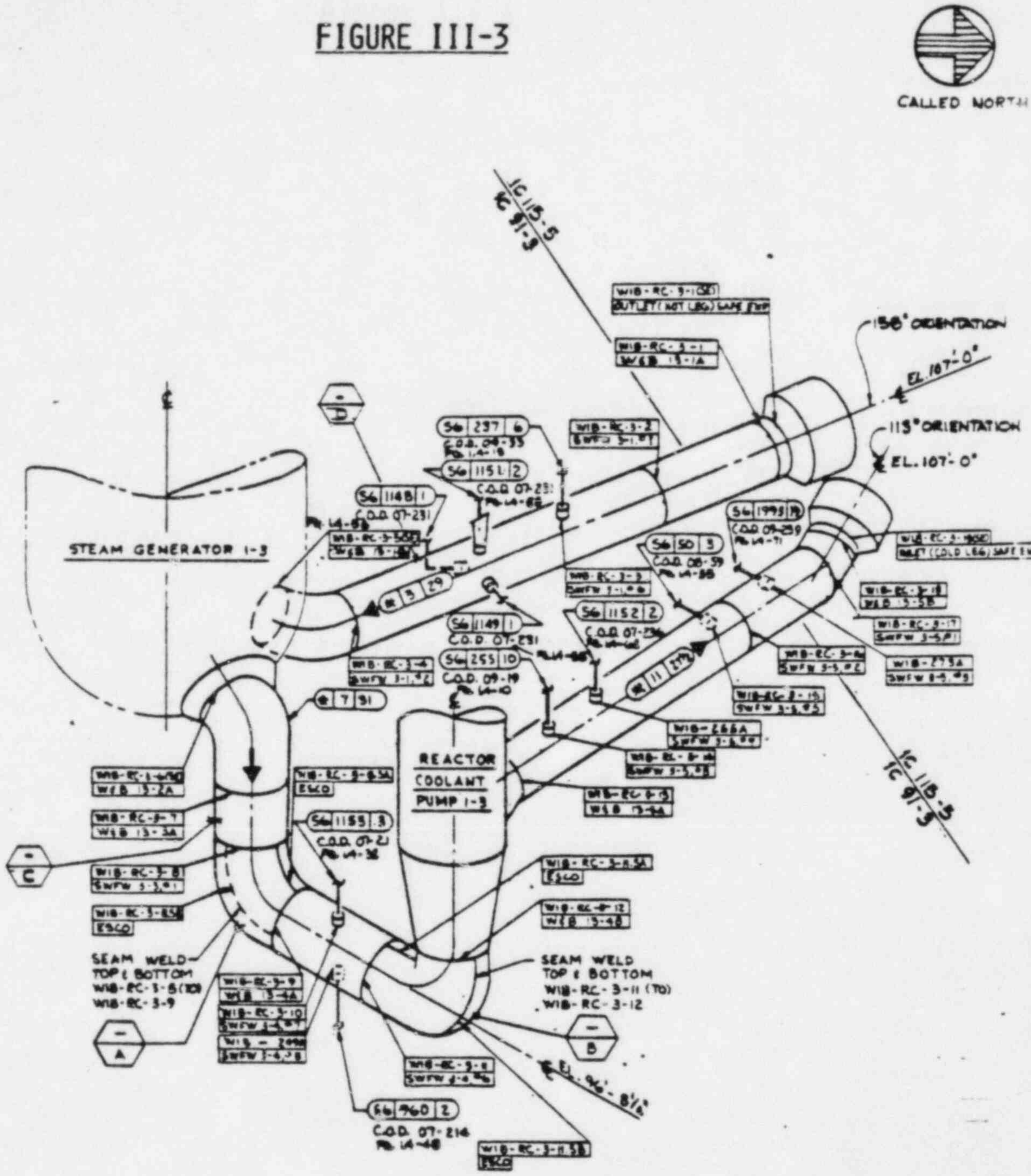
INSERVICE EXAMINATION ISOMETRIC

PACIFIC GAS AND ELECTRIC COMPANY

AREA: F&B	ISO: 07-31	P&ID COORD:	SYSTEM: RCS
REF. DWG. RC 1-2	REPL'S. 014	LINE NO. 2-2-29, 8-6-31, 4-10-27½	DRAWN: B. GATTISON
			CHK'D:
			APPR'D:
		PAGE: 1.4-2	DATE:

LINE NO.	DESCRIPTION
2-2-29 SPL.	REACTOR COOLANT OUT LOOP 2
8-6-31 SPL.	REACTOR COOLANT PP SUCT LOOP 2
4-10-27½ SPL.	REACTOR COOLANT PP DISCH LOOP 2

FIGURE III-3



DIABLO CANYON UNIT I

INSERVICE EXAMINATION ISOMETRIC

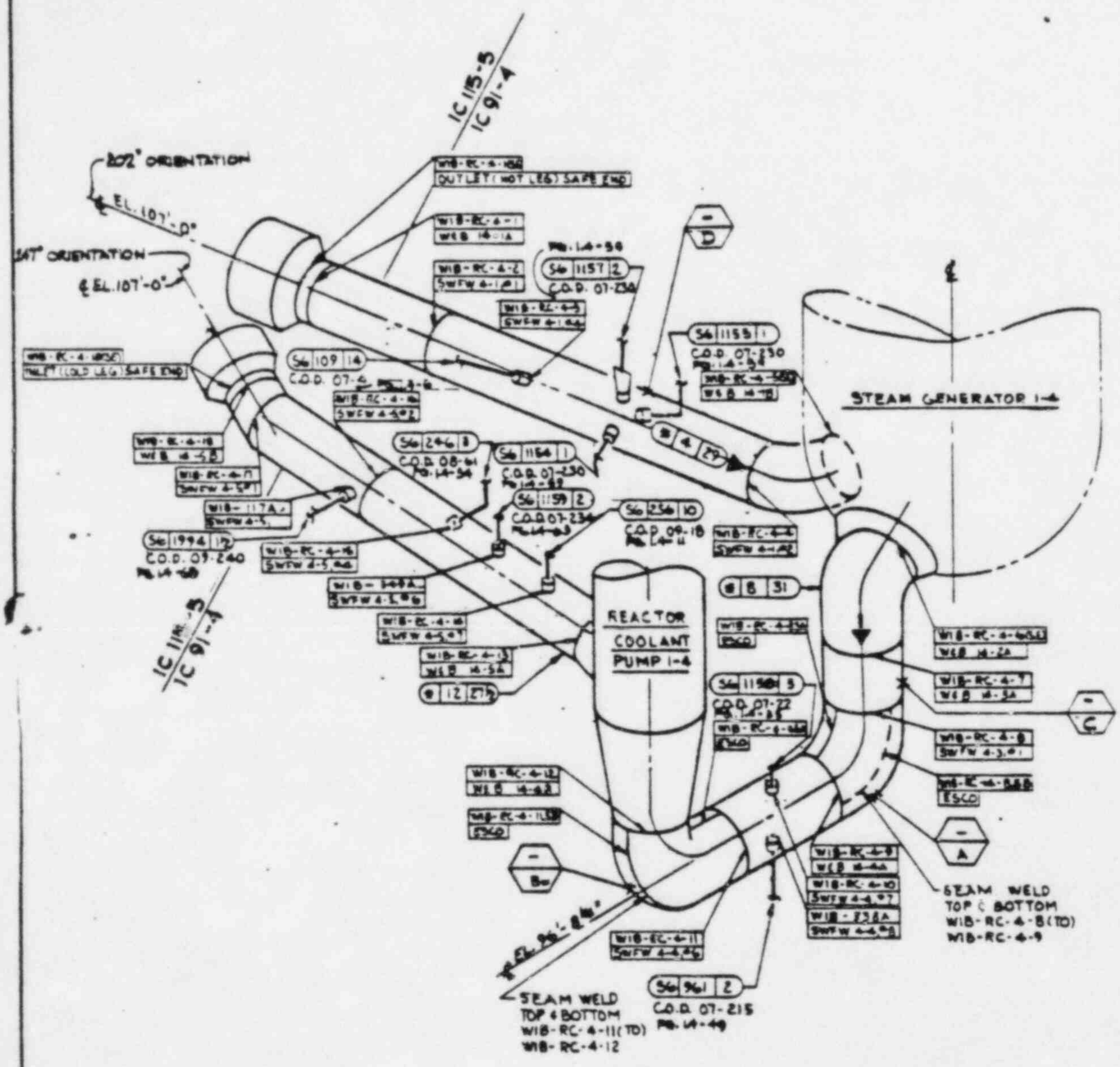
PACIFIC GAS AND ELECTRIC COMPANY

R-3-29 SP.	REACTOR COOLANT OUT LOOP 3
R-7-31 SP.	REACTOR COOLANT PP SUCT LOOP 3
R-11-27½ SP.	REACTOR COOLANT PP DISCH LOOP 3
LINE NO.	DESCRIPTION

AREA: FIG	ISO 07-[illegible]A	P&ID COORD:	SYSTEM: RCS
REF. DWG. RC 1-3	REPLS. 029	LINE NO. R-3-29, 6-7-31, R-11-27½	DRAWN: B. GATTISON
			CHK'D:
			APPR'D:
		PAGE: 1.4-3	DATE:

FIGURE III-4

CALLED NORTH



DIABLO CANYON UNIT I

INSERVICE EXAMINATION ISOMETRIC

PACIFIC GAS AND ELECTRIC COMPANY

AREA: S/G	ISO: 07-30A	P&ID COORD: 07-...	SYSTEM: RCS
REF. DWG. RC 1-4	REPLYS. 042	LINE NO. 0-4-29, 0-8-31, 0-12-27½	DRAWN: B.GATTISON
			CHK'D:
			APPR'D:
		PAGE: 1.4-4	DATE:

LINE NO.	DESCRIPTION
0-4-29 SPL	REACTOR COOLANT OUT LOOP 4
0-8-31 SPL	REACTOR COOLANT PP SUCT LOOP 4
0-12-27½ SPL	REACTOR COOLANT PP DISCH LOOP 4

IV. VISUAL INSPECTION AND RADIOGRAPH REVIEW

In order to further corroborate information contained in the quality records, a visual inspection was conducted on the suspect welds, and the acceptance radiographs for selected reactor coolant pipe welds were reviewed. The results of these investigations are discussed in this section.

A. Visual Inspection

On June 28 and 29, 1983, Mr. Jim Miller, Lead Welding Engineer for the Diablo Canyon Project Team, performed a visual inspection of nine (WIB-RC-1-1, 1-2, 1-8, 1-11, 1-16, 2-1, 2-17, 3-9 and 4-16) of the girth welds under investigation in the reactor coolant system on Diablo Canyon, Unit 1. Both the outside and inside surfaces of the welds were inspected. As a result of this inspection, Mr. Miller concluded that:

> "The inspected welds are visually acceptable to the specification and codes governing weld quality visual acceptance standards, workmanship is considered good and meets industry standards."

A copy of his report is included as Attachment IV-1. This report confirms the constructon visual inspection records for the welds.

B. Radiograph Review

The film quality of radiographs used for acceptance of the Unit-1 reactor coolant pipe welds was reviewed by D. R. Cady, Bechtel NDE Level III, and witnessed by PG&E. Radiograph film from four shop welds and five field welds, chosen at random, and weld WIB-RC-2-17 were reviewed. The completed checklist from the review is included as Attachment IV-2. All film reviewed was in compliance with the originally specified requirements.

ATTACHMENT IV-I

INTEROFFICE MEMORANDUM

Diablo Canyon Project

PACIFIC GAS AND ELECTRIC COMPANY
BECHTEL POWER CORPORATION

To J. D. Shiffer - NPO

From J. A. Miller

Of General Construction

At Diablo Canyon Project Extension

Date June 30, 1983

File No.

Subject Visual Inspection Report Reactor Cooling Loop Piping Welds

On June 28 and 29, 1983, I performed the requested visual inspection of selected code Class I welds on the Reactor Coolant Piping in Unit #1 at Diablo Canyon. I am presently assigned as Lead Welding Engineer for construction at Diablo Canyon.

On June 28, 1983, I was accompanied by:

Jim Shiffer - Manager, Nuclear Plant Operations - PG&E
Frank Dodd - Senior Metallurgical Engineer - PG&E
Rick Cahoon - Site Mechanical Engineer - Westinghouse
Pete Broadnick - Nuclear Plant Operations Maintenance Foreman - PG&E
Bob Hindmarsh - Senior Construction Engineer - PG&E

On June 29, 1983, I was accompanied by Mr. Hindmarsh.

The attached is my report on the subject welds.

J. A. Miller
Lead Welding Engineer
Project Team
Diablo Canyon

JAMiller:fgm

cc: H. Friend w/o attachments w/report
J. Shryock " "
L. Rossetta " "
D. Rockwell " "
R. Etzler " "
R. Manley (M&QS) " "
J. Manning " "
R. Bain " "

June 30, 1983

VISUAL INSPECTION REPORT

SUBJECT: Unit 1 Reactor Cooling Loop Piping Visual Inspection of Specific Welds.

SCOPE: Visual inspection both inside and outside of weld deposit and related exposed joint preparation condition. Weld joints to be inspected were numbers: 1-1, 1-2, 1-8, 1-11, 1-16, 2-1, 2-17, 3-9 and 4-16.

PROCEDURE: An overlay was prepared for both outside and inside circumferences. The inside overlay was adjusted to reflect the variation in the circumference and correlated to the master outside overlay.

The specific location of the welds to be inspected and identification was determined from general location drawings which physically located all welds on the Reactor Coolant Piping System by number. Free and open access was provided to all welds.

BASIC EQUIPMENT (TOOLS ETC.): Dial indicator, parallel bar, straight edge rule, cloth measure tape, adjustable profile, spirit level and supplementary hand flash lights.

GENERAL OBSERVATIONS (FOR ALL WELDS INSPECTED): All welds subject to visual inspection were identified by the associated weld number stamped into the base metal adjacent to the O.D. of the weld. Top dead center was indicated by a "V" stamp pointing in the direction the overlay was laid out.

The visual inspection of the internal weld joint, (i.e., the Weld Root Pass), revealed no areas of metal removal that visually impinged on existing wall thickness.

The back side of the root bead area was either flat or slightly convex in physical shape, with no visual evidence of base metal or weld metal removal other than that required to provide a smooth acceptable surface for non-destructive examination (NDE). The internal back bevel face of bevel is present with visual evidence of light grinding or buffing to blend in the parent base metal with the root bead reinforcement. This interface area is either flat or slightly contoured and uniform in shape throughout. At various locations the shop machining tool marks are present indicating the start and stop, width and plane of the internal bevel. Machining of the bevel planes are smooth and follow the general shape of the pipe. The internal shape of the weld joint is either totally flush with the base metal across the root weld area, flat between the beveled pipe ends or slightly contoured. All areas are acceptable to NDE preparation requirements.

External weld deposit area visual examination shows generally polished surface blended into the base metal at the toes of the weld. The deposited weld metal is flat or slightly convex above the base metal. Slight variances do exist in some areas at the toe of the weld, however, these variations are common and are basically the result of "flapper wheel" use to blend in the feather effect of the weld at the toe of the weld to the base metal. This blending is done to facilitate required NDE. Superficial areas of grinding were noted in the base metal area. These areas do not indicate a reduction in the basic pipe wall thickness.

ATTACHMENT IV-2

FILM QUALITY REVIEW CHECKLIST

Check Point	Weld No. 1-1B	1-1A	4-1A	3-5A	7524F 9 W-1	7524F 6 W-1	7524F 13 W-2	7524F 9 W-2	7524F 4 W-1
Reader Sheet Complete	X	X	X	X	X	X	X	X	X
Penetrameter No.	X	X	X	X	X	X	X	X	X
Sensitivity	X	X	X	X	X	X	X	X	X
Pen. Location	Note 1	Note 3	X	X	X	X	X	X	X
Weld Indent.	X	X	X	X	X	X	X	X	X
Density*	X	X	X	X	X	X	X	X	X
Processing Quality	Note 2	X	X	X	X	X	X	X	X

NOTES:

1. 1-1B at 0-1 penetrameter is partly off edge of film but all T-holes are readable. There are 3 other penetrameters that are completely on the film. (Three penetrameters required for panoramic exposures.)

2. Artifacts identified on reader sheet and did not mask the interpretation for indications.

3. 0-1-2 Pen. ok @ 0.
   2-3-4 Pen. in overlap @ 2 ok.
   4-5-6 Pen. in overlap @ 4 but 2 T hole at lap. <u>Not</u> ok.
   6-7-8 Pen. @ 8 partially off film but holes are readable.
   8-9-10 Pen. @ 10 partially off film but holes are readable.
   10-11-12 Pen. @ 10 in overlap area, same pen. as 8-9-10.
   12-13-14 Pen. @ 14 partly off film but holes are readable.
   14-15-0 Pen. @ 14 and 0 in overlap areas.

4. Yellowing from age is beginning to appear on some film.

5. 7524F, 9, W-2 is WIB-RC-2-17.

Reviewed by,

D.R. Cady

Witnessed by: F.J. Dodd

*Densitometer not available for density measurements.

CONCLUSIONS: The inspected welds are visually acceptable to the specifications and codes governing weld quality visual acceptance standards, workmanship is considered good and meets industry standards.

ATTACHMENT #1 - Weld Locations

ATTACHMENT #2 - Resume - J. A. Miller

ATTACHMENT #3 - Field Inspection Notes

J. A. Miller
Lead Welding Engineer
Diablo Canyon Project Team

V. SUMMARY AND ANALYSIS OF MEASUREMENTS AND INSPECTIONS

A. Reactor Coolant Loop Piping Weld Thickness Program

After an assessment of alternative methods of measurement it was concluded that the direct mechanical method using micrometers was the most accurate and valid method of measuring piping of this size and material. This conclusion was consistent with information developed in 1970, when measurements on the piping in question showed that the UT thickness measurements — when compared to mechanical measurements made at that time — were not consistent or of adaquate precision.

1. Mechanical Measurements

The outside (OD) and inside (ID) diameters of the pipe were measured. The two micrometers were aligned at the same circumferential locations on the weld centerline using an ultrasonic reference point. Because of the complexity and time consuming nature of these measurements, only welds with low ultrasonic readings were mechanically measured. The method consisted of measuring the OD and ID at the vertical and horizontal axis and one additional measurement at the thinnest point indicated by the previous ultrasonic examination.

Mechanical measurement results are listed in Table V-I for each weld identified by UT as possibly having wall thickness less than specified. In each case, the mechanical measurement indicates that the wall thickness is in fact above minimum requirements.

Table V-2 contains a comparison of measured diameters to specified values for "Max ID" and "Min OD" for unwelded pipe which was made to verify that pipe wall thickness was maintained in the weld area.

The measured ID values confirm that inside grinding was well controlled and did not reduce the wall thickness below specified requirements. Comparing the measured OD and ID values at each location corroborates the records of original pipe wall thickness measurements and shows that minimum wall thickness specifications are met in all cases.

2. Ultrasonic Measurements:

All RCS ultrasonic data collected prior to the June 22, 1983 NRC notification was first reviewed and compared with the appropriate minimum wall thickness criteria. If the data indicated that a measurement was below the specified requirement, two teams of ultrasonic examiners independently performed a second and third set of independent thickness measurements.

Each weld's thickness was measured at points located on the weld centerline at 3 inch intervals around the entire circumference of the weld. The base metal thickness was also measured at both sides of the weld at these locations. The readings recorded were the lowest obtainable at each location. Any weld areas which appeared to be less than the minimum specified wall thickness were mapped. These areas were mapped along with those points immediately adjacent to them which met minimum wall thickness requirements. Also, similar thickness measurements were made for those welds that previously had only profile data measured.

Forty-four reactor coolant loop welds were ultrasonically measured. Seven had UT measurements below minimum requirements in the weld material. Three additional welds had low UT measurements in the base metal adjacent to the weld. Because weld number 1-8 had only one low reading which was not supported by additional measurements it was disregarded.

For each weld where ultrasonic data indicated that a below minimum wall condition may have existed, extensive ultrasonic wall thickness measurements were obtained. Table V-1 also summarizes the pertinent data for each of these investigated welds.

B. Investigation of Other Design Class I Welds

The second part of the investigation consisted of a review of Design Class I piping welds not in the reactor coolant loop piping systems. In addition to the reactor coolant loop piping, other piping is required to have volumetric examinations of selective welds. Therefore only those selected welds would have had any exterior weld grinding for PSI/ISI preparation.

1. Visual Inspection

With the exception of the main steam and feedwater piping inside the containment isolation valves, the balance of the Code Class 2 piping is too small in diameter for internal grinding of welds. If external grinding complied with the applicable specifications and procedures, the welds would be flush with or higher than the adjacent pipe surface and adequate weld thickness would be maintained.

Sixteen Code welds were inspected by placing a straight-edge across the weld axially with the pipe to determine if the original grinding requirements were met.

Of the (16) welds inspected, 14 had exterior weld preparation (grinding). Four of the 14 welds were ground flush with the pipe base metal. There was no indication of weld grinding below the base metal. The other 10 had visible weld crowns (weld above base metal). The remaining two welds had not been ground for ISI. Visual examination results corroborate the construction quality records assuring that the wall thickness of other Design Class I welds meets thickness specifications.

Visual examination results corroborate the construction quality records assuring that the wall thickness of other Design Class I welds meets thickness specifications.

2. Ultrasonic Thickness Measurements

Because it was known that some interior examination and grinding was done on main steam pipe to steam generator nozzle welds and on main feedwater pipe to steam generator nozzle welds, three of these welds were ultrasonically examined. These welds were: WICG 105-2 (F/W to SG 1-2), WICG 101-A1-4 (F/W to SG 1-4), and WICG 27-4 S/G to M/S 1-4). Two reactor coolant loop nozzle to branch pip welds were UT examined. These welds were Residual Heat Removal (RHR) pipe weld WIB - 227 and Pressurizer Surge Line Weld WIB - 65. All measurements were well above the minimum required thickness.

TABLE V-1
SUMMARY OF MEASUREMENT RESULTS FOR INVESTIGATED WELDS

WELD NUMBER	(a) CODE ALLOWABLE MIN WALL	(b) UT MEAN WALL	(c) LOWEST UT MEAN MIN WALL	(d) MIN WALL BY MECH MEASURE
1-1	2.335	2.414	2.310	2.413
1-2	2.335	2.375	2.315	2.355
1-16	2.215	2.259	2.185	2.236
2-1	2.335	2.406	2.323	2.433
2-2	2.335	2.397	2.295	2.341
2-17	2.215	2.224	2.150	2.223
4-16	2.215	2.234	2.180	2.239
Minimum Base Metal by UT				
1-11	2.495	2.564	2.470	2.660
3-9	2.495	2.638	2.465	2.560

Column Definitions:

(a) The minimum wall specified thickness.

(b) The mean wall thickness of the entire length of the weld, measured by ultrasonic techniques.

(c) The minimum average wall thickness of the three sets of measurments at the thinnest point. The readings recorded were the lowest recorded at each location.

(d) Wall thickness by mechanical measurement obtained at the minimum wall location.

Note: December 1982 and May 1983 UT data which showed low measurements on welds 2-9, 2-10, 2-13, 2-19, 4-1 and 4-17 could not be repeated in the most recent series of measurements.

TABLE V-2
"MAX ID" - "MIN OD" COMPARISON REACTOR COOLANT PIPING

Reference: Westinghouse Spec. G676341
SW Fabrication Sheet Q89.7524

WELD	SPECIFICATION MAX** ID / MIN OD	MEASURED MAX. ID	MEASURED MIN. OD	MINIMUM WALL (2X) SPECIFICATION	MEASURED 2X MIN WALL
1-16	27.710/32.140	27.683	32.155	4.430	4.472
2-17	27.710/32.140	27.710	32.183*	4.430	4.473
		27.694*	32.140	4.430	4.446
4-16	27.710/32.140	27.691	32.168*	4.430	4.477
		27.660*	32.143	4.430	4.483
1-1	29.210/33.880	29.161	34.014*	4.670	4.853
		29.145*	33.970	4.670	4.825
1-2	29.210/33.880	29.175	33.885	4.670	4.710
2-1	29.210/33.880	29.173	34.030*	4.670	4.857
		29.147*	34.012	4.670	4.865
2-2	29.210/33.880	29.209	33.890	4.670	4.681
1-11	31.210/36.200	31.196	36.727*	4.990	5.531
		31.157*	36.477	4.990	5.320
3-9	31.210/36.200	31.098	36.533*	4.990	5.435
		31.030*	36.150	4.990	5.120

Notes

* - Value corresponding to Min. or Max. value.

** - Includes allowed 0.010 inches machining tolerance for ID.

C. MICROMETER MEASUREMENT METHODOLOGY

1. Method

The method developed and used to determine pipe wall thickness using micrometer measurements supplemented by ultrasonic measurements is described below.

a. The outside and inside diameters (OD and ID) were measured with micrometers calibrated with standards traceable to NBS. To assure that the ID and OD measurements were obtained at the same location, plastic wedge UT damping location techniques were utilized.

b. Care was exercised by personnel making the measurements to assure that the maximum ID and minimum OD were obtained in the plane of measurement.

c. Measurements were made at the minimal wall location previously identified for each weld by ultrasonic means, in addition to a horizontal measurement and a vertical measurement at each weld.

d. The wall thickness was then determined as follows:

$$t = \frac{OD-ID}{2}$$

2. Justification

This method of measurement for piping welds of this size is justified as the most accurate and valid for the following reasons:

a. Care was exercised during pipe fabrication, fitup and assembly to assure that the pipe was concentric, not overbored, and that proper outside diameters were maintained. This was assured by the following:

- o The shop machining practices required the pipe to be counterbored within limits which assured minimum wall.
- o Strict tolerances were applied during both shop and field weld fit-up.

b. All grinding performed on the exterior weld crowns (in preparation for inservice inspection) was controlled to assure that the crown was not removed to a depth below the adjacent piping OD.

c. Grinding on the weld ID was performed only to remove superficial blemishes. This is substantiated by the fact that the recent ID measurements show a reduction in ID from before the pipe was welded.

An alternative way to establish the wall thickness would be to utilize relative values of ultrasonically measured thickness. However, the accuracy of UT thickness measurement for piping welds of this type is considered less than the variation in wall thickness around the pipe measured at the spool ends prior to welding. Further, the scatter in the current UT measurements is larger than this variation. Reliable estimates of UT measurement accuracy are of the order of ± 5%, including the effects of both equipment accuracy and how personnel use it. Therefore, use of UT measurements to furthur adjust the micrometer measurement results cannot be supported.

D. <u>CONCLUSIONS</u>

Micrometer measurements are the most accurate and valid means to obtain minimum wall thickness for piping welds of this size and material. The micrometer measurements shown in Table V-1 and Table V-2 confirm previous data (prior to December 1982) that minimum wall thickness requirements were met.

APPENDIX A-1

CHRONOLOGY OF MAJOR EVENTS RELATED TO DISCOVERY AND RESOLUTION OF MINIMUM WALL CONCERN

Date	Discussion
December 1982	NPO ISI/NDE group decided to make a series of thickness "profiles" axially across the reactor coolant loop piping girth welds to generate contour plots of the weld root counterbore surface. Thirty-one of the 56 RCS piping loop girth welds were profiled using an ultrasonic technique: WIB-RC-1-2, 1-4, 1-7, 1-8, 1-9, 1-11, 1-13, 1-16, 2-2, 2-5, 2-8, 2-9, 2-10, 2-13, 2-15, 2-17, 3-4, 3-7, 3-8, 3-9, 3-11, 3-13, 3-16, 4-2, 4-4, 4-7, 4-8, 4-9, 4-11, 4-13, and 4-16.
December 13, 1982	A review of the data revealed a point on the centerline of weld WIB-RC-2-17 and four points in the pipe downstream of weld WIB-RC-3-13 where the indicated thickness was suspiciously low. The recommendation of the ISI/NDE group was that the welds be reexamined after the RCS loops were drained[1] so that internal access could be provided.
December 17, 1982	Nuclear Plant Problem Reports were prepared for both welds to document the problem pending resolution.
January 7, 1983	An additional set of readings was made using both the original ultrasonic instrument and a newly acquired ultrasonic instrument which could be read to one more decimal place than the original instrument. The

(1) The reactor vessel was flooded from October 20, 1982 to January 15, 1983 for other work.

Date	Discussion
	latter turned out to be effective on parent metal, but was unable to penetrate the weld material. On the retest, the suspect area adjacent to weld WIB-RC-3-13 measured thicker by both instruments. The retest of weld WIB-RC-2-17 continued to show a low reading at the weld centerline. The new instrument showed a previously unidentified area of concern 3" downstream.
February 16, 1983 (approximate)	An attempt was made to confirm the UT measurements on weld WIB-RC-2-17 by mechanical methods. The UT data was assumed accurate on the pipe metal, and a straight edge and depth gauge were used to measure the counterbore depth. The results were judged to be inconclusive.
March 28, 1983	Using another new ultrasonic instrument and a 1" diameter, 2.25 MHz dual transducer, ISI/NDE personnel made another series of measurements on weld WIB-RC-2-17in the area of interest. A minimum thickness of 2.15" was indicated on the weld centerline.
May 5, 1983	NPO initiated a Nonconformance Report on weld WIB-RC-2-17.
May 6, 1983	The Plant Manager requested data on the entire circumference of weld WIB-RC-2-17, and to use a different team of examiners in order to obtain independent measurements.

Date	Discussion
May 9, 1983	Data obtained on May 9 appeared to support previous data and a verbal notification was made to NRC Region V. A verbal commitment was made to examine the remaining welds to the extent feasible.
May 11, 1983	A Technical Review Group was convened to discuss the situation and lay out an investigation and corrective action program. This TRG included members from the plant staff, on-site QA, and on-site Westinghouse. This initial meeting was primarily to orient the TRG members to the issue.
May 13, 1983	A second meeting was convened including off-site personnel. At this meeting the TRG hypothesized that the cause was grinding preparation of the OD and ID weld surfaces to improve the finish for radiography.
May 20, 1983	Additional measurements were performed on UT thickness for weld WIB-RC-2-17 which supported earlier UT measurements.
May 23, 1983	LER 83-006 was submitted to the NRC discussing the findings on WIB-RC-2-17.
May 25, 1983	Beginning on May 25 and continuing on to June 2, plant staff ISI/NDE personnel took thickness measurements on welds located within the biological shield, which had not previously been examined.

Date	Discussion
	Twelve additional welds were examined: WIB-RC-1-1, 1-17, 1-18, 2-1, 2-19, 2-20, 3-1, 3-17, 3-18, 4-1, 4-17, and 4-18.
June 3, 1983	Review of the previous data indicated that two cold leg welds, WIB-RC-2-19 and 4-17, each showed one small spot on the weld centerline which may have been below minimum wall, although the descrepancies were very small (_ 0.015"). The cause was assumed to be related to grinding.
June 22, 1983	It was determined that the crossover pipe and hot legs had higher minimum wall specifications than the cold leg (2.215" for the cold leg, 2.335" for the hot leg, and 2.495" for the crossover pipe). Prior to this time, the cold leg value had been used in identifying whether minimum wall specifications had been violated. This called into question seven additional welds: WIB-RC-RC-1-1, 2-1, 2-9, 2-10, 2-13, 3-9 and 4-1. An immediate telephone notification was made to the Manager, NPO. Although the results were recognized to be preliminary and unverified, the Manager, NPO instructed site personnel to inform the NRC site resident inspectors of this development to keep them appraised and to discuss reporting implications.

Date	Discussion
June 23, 1983	Representatives of Region V arrive at Diablo Canyon to review the latest information regarding the reactor coolant piping welds.
June 24, 1983	At the routine weekly NRC exit interview the Plant Staff agreed to provide a written report regarding the reactor coolant piping welds to region V.
June 24, 1983	From the evening of June 24, 1983 thru July 1, 1983 an investigation team including project personnel and specialists from Bechtel and Westinghouse began a comprehensive investigation into the minimum wall concern. During this investigation the use of UT as a precise measurement technique was discarded due to its unreliability with regard to the piping in question. The investigation also confirmed that minimum wall thickness requirements had been met. The results of that investigation have been included in a written report to be submitted NRC Region V.

APPENDIX - B

ENGINEERING EVALUATION

A. Scope of Evaluation

This appendix provides additional perspective on the significance of minor variations in piping wall thickness. This evaluation is not intended to depart from existing applicable code requirements, although certain later code concepts are used to describe conservative margins inherent in the existing design.

Minimum wall thickness is a code criterion used prior to fabrication to size pipe and pressure vessel wall thickness. The objective is to have a single number criterion which provides assurance that subsequent required calculations of operational stresses will show acceptable results. The concept includes inherent margins in material thickness to cover variations in manufacturing techniques, material properties, etc. The application of the concept for RCS loop pipe included additional margins.

An evaluation was done considering several aspects of design margin to assess the significance of potential minimum wall deviations of the size in question. The aspects considered included margin in the original piping stress analysis, and the margin inherent in the use of code, minimum allowable stress based on material properties rather than those measured for the actual pipe material. Also included was a parallel consideration of the recognized increases in recent years in published allowable stresses. Finally, consideration was given to the margin which could be shown by more explicit treatment of local geometry by current code techniques.

B. Margin in Piping Stress Analysis

Along with the equations for minimum wall thickness, the USAS B31.1 code (B31.1) requires that additional evaluations be performed on a piping system to quantify the stress resulting from operating loads such as internal pressure, dead load, and seismic loads. The RCS loop piping was qualified for all of these loadings, and as summarized in Section 5 of the FSAR, the piping, met the applicable allowable limits in all cases. Meeting the stress allowables in the B31.1 code provides specific indication of the design adequacy of the reactor coolant piping; whereas the minimum wall thickness equations are used to size non-standard pipe and vessel products with some margin.

To demonstrate this design margin, an evaluation of the RCS loop piping was performed assuming a 10% reduction in the pipe wall thickness below the minimum defined by B31.1. For the evaluation, stresses of all of the highly loaded points in each of the RCS loop piping were re-calculated. The stresses resulting from the various conditions were combined in the same manner as the original evaluations and the results were compared with the allowable stresses.

The results of this evaluation are summarized in Table B-1. It demonstrates that for all loading conditions, the stresses calculated with an assumed reduction in wall thickness of 10% still meet the

B 31.1 code allowables. In all cases there is sufficient additional margin to take a further reduction in the wall thickness without violating the code limits on calculated stress. This demonstrates the amount of extra material that the code minimum wall equation builds into the design. It also shows that the piping has sufficient wall thickness to operate safely with a significant reduction of material.

TABLE B-1
Summary of Piping Stress Analysis

Combined Stresses (FSAR)	FSAR Results (PSI)	Evaluation With 10% Wall Reduction (PSI)	Code Allowable Limit (PSI)
Normal Condition	6,771	8,001	17,050
Upset Condition	15,300	19,068	20,460
Faulted Condition	45,700	54,383	61,380

C. Margin in Allowable Stress Limits

1. Effect of Measured Material Properties

The reactor coolant loop piping is seamless extruded ASTM A376 Type 316 stainless steel. Transverse tensile tests were performed by Cameron Iron Works on both ends of each spool piece at ambient temperature and an additional tensile test was performed at 650° F on the pipe end exhibiting the lowest yield stress. Notarized test reports from Cameron Iron Works were examined and the results are reported in Table B - 2 below.

TABLE B-2
Summary of Tensile Tests on Pipe Material

Test Temperature	Cameron Yield Test Results Average	Minimum
Ambient	40.9 ksi	32.5 ksi
650° F	23.5 ksi	20.5 ksi

The fittings were statically cast of ASTM-A351 CF8M by ESCO Inc. Tensile tests were performed at ambient temperature for each casting heat and the results are reported in Table B-3. There was also one certified test result at 650° F for one of the casting heats for a Diablo Canyon fitting which is reported below.

TABLE B-3
Summary of Tensile Tests on Fitting Material

Test Temperature	ESCO Yield Test Results Average	Minimum
Ambient	45.9 ksi	37.5 ksi
650° F	N/A	21.9 ksi

The pipe was designed to the requirements of USAS B31.1, 1955. The minimum wall requirements were set using the alternate formula from B31.1 which is based on the inside diameter of the pipe. The stress allowable used in the formula was obtained from Code Case N-7 using a design temperature of 650° F. For austenitic stainless steel such as that used in the reactor coolant loop piping, the stress allowable value for elevated temperature was set at 0.9 times the yield strength of the material at that temperature. Using the 0.9 factor and the actual yield data obtained for the A376 Type 316 pipe at 650° F, an "actual material" allowable stress of 18.45 ksi can be recalculated using the same B31.1 equation. If this "actual material" allowable is used in the alternate equation for minimum wall thickness, it results in approximately a 7% reduction in the Code minimum wall thickness. For the cold leg this would mean a reduction of the Code minimum wall thickness from 2.215 in. to 2.058 in. Similar reductions would be obtained for the other legs. Thus without any change in method, one can show a significant margin in the design of the RCS pipe . The reductions also show that if any areas of the pipe or weld were to be slightly smaller than the minimum original design they could be shown acceptable to the same Code requirements and they clearly would not have an adverse affect on the safe operation of the plant.

2. Evolution of Published Allowable Stress

In addition to the above information on actual material properties for the RCS loop piping, it should be noted that there has been a general increase in the published stress allowables for the stainless steels used in pipe and fittings over the last 20 years. When the A376 material was first included in B31.1, the allowable stress was set at 14.2 ksi. In later years it was increased to 15.9 ksi and by the time the piping was manufactured, a code case had raised it to 17.05 ksi, the value that was used to set the pipe thickness. The ASME code allowable for this material is currently 18.2 ksi. Use of this value requires that the material be nitrogen enriched. Discussion with W indicates that the pipe manufacturing included nitrogen enrichment. If the ASME Section III allowable stress value was used to calculate minimum wall requirements, it would result in close to a 7% reduction in requirements. This would be similar to the reduction obtained by using actual material properties. The forgoing indicates the conservatism in the B31.1 design basis for the RCS loop pipe.

C. Local Stress Effects

The ASME Boiler and Pressure Vessel Code Section III has long recognized that because of design considerations or manufacturing or fabrication processes, some localized areas of a pressure vessel may have thickness variations that produce stresses greater than the basic design limit on primary membrane stress. The ASME Section III addresses these areas with the local primary membrane stress limits defined in NB 1213.10. This paragraph allows for a 50% increase in the basic allowable stress limit of Sm. The increase is justified based on the fact that the stress is of a localized nature and does not effect the overall pressure boundary integrity. However, there are restrictions on the extent of the local area in the axial direction as well as restrictions on axial proximity of adjacent areas of the same type. Applying the local membrane limits of ASME Section III NB 3213.10 to the reactor coolant loop piping and using the Sm allowable for this material given in ASME Section III, a reduction in the wall thickness of greater than 10% can be justified. The reduction would be limited to small areas but could extend completely around the inside surface or outside surface of the pipe. Areas such as this would not violate the intent of the code to limit the general primary membrane stress and protect the pressure boundary.

The localized areas originally in question in this evaluation (based upon UT measurements) do not extend around the pipe and none of the suspect readings indicate anything close to a 10% reduction in thickness. All the areas identified meet the restrictions of ASME Section III for application of local limits. Thus, use of the latest availabe Code analysis would permit local "thin spots" both deeper and more extensive than any originally suspected with UT measurements.