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

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION RELATIVE TO INSPECTION AND REPAIRS OF THE REACTOR COOLANT SYSTEM PIPING

PILGRIM NUCLEAR POWER STATION
BOSTON EDISON COMPANY
DOCKET NO. 50-293

1.0 INTRODUCTION

The Pilgrim station was shut down on December 10, 1983 in accordance with the NRC confirmatory order issued on August 26, 1983 to inspect ASME Class 1 austenitic stainless steel piping that is susceptible to intergranular stress corrosion cracking (IGSCC). When IGSCC was reported in various piping systems during the early stage of the inspection, the licensee, Boston Edison Company (BECO), elected to discontinue inspections and to replace most of the ASME Class 1 austenitic stainless steel piping.

During the replacement of the recirculation system piping, cracks were found in the Inconel alloy 182 weld butter of three recirculation nozzles (one outlet nozzle and two inlet nozzles) and in the outer thermal sleeves of nine inlet nozzles as a result of performing the Code required liquid penetrant tests (PT) prior to joining the new piping. The cracked Inconel 182 weld butter locations in the three recirculation nozzles was repaired. Although the licensee did not repair the cracked thermal sleeves, this was justified by a crack growth calculation showing that the amount of crack growth in the thermal sleeves during the next fuel cycle (18 months) will not impact the structural integrity of the thermal sleeves. Cracks were also found by UT on the furnace sensitized 304 stainless steel safe-end on jet pump instrumentation penetration nozzle N9A. The cracked safe-end was weld overlay repaired with Inconel alloy 82 materials. The details of the cracking and repairs in the above mentioned components are provided in later sections. Region I has concluded that the inspections and repairs were performed properly and that all applicable staff and Code requirements are met.

1.1 Piping Replacement

The following portions of the piping systems including all the cracked welds were replaced with nuclear grade 316 stainless steel materials:

(1) all recirculation system piping;

(2) all Class 1 stainless steel residual heat removal (RHR) system piping inside the containment;

(3) the stainless steel portion of the core spray system piping inside the containment and the portion of the piping outside the containment which included weld #14-B-21; and

(4) the suction piping of the reactor water clean-up (RWCU) system inside the containment.

The licensee indicated that the piping replacement activities were conducted in accordance with the procedural guidance provided in Generic Letter 84-07. Further, the licensee stated that (1) the original design basis was used when the piping replacement involved only materials changes and (2) for small diameter piping (2 inches and less), more recent NRC-approved Codes and Standards were used when the piping replacement involved major changes in configuration.

The last-pass-heat-sink welding was used on five welds, which connect the new 316 NG piping to existing 304 piping at the containment penetrations inside the drywell. In addition to piping replacement, the inside surfaces of the RHR penetrations and the penetration welds were cladded with 308L stainless steel.

1.2 Ultrasonic Examination

Magnaflux Quality Services (MQS) performed ultrasonic examinations for the licensee. NRC Region I has determined that the UT examinations were performed in accordance with the qualified procedures and methods. All UT personnel who performed the examinations were properly trained and all Level II and Level III UT operators were qualified in accordance with IEB 83-02.

Except for six piping welds, all of the IGSCC susceptible Class 1 piping not replaced was ultrasonically examined. No crack indications were found in those welds. Of the six piping welds not ultrasonically examined, four welds (two core spray penetration welds and two RWCU welds) are not accessible because of component configurations and two welds (one core spray piping weld and one RWCU piping weld) are tri-metallic welds. These tri-metallic welds were examined by radiography (RT) because ultrasonic examination of these welds is not meaningful. No defects were found in these tri-metallic welds.

1.3 Cracking and Repair of Inconel 182 Weld Butter in Recirculation Nozzles

During the replacement of the recirculation safe-ends, liquid PT of the weld preparation surfaces revealed axial crack indications in Inconel 182 weld metal at several locations. The PT examinations are required by ASME Code Section III, Subsection NB-5130.

The 304 stainless steel safe-end to low alloy steel nozzle is a complex bi-metallic joint. The configuration at the start of recirculation piping replacement was as follows:

(1) The interior surface of the alloy steel nozzle in contact with reactor coolant was cladded with 308 weld deposited metal.

(2) The weld face of the nozzle was surfaced with Inconel 182 weld metal to join 304 stainless steel safe-ends to the steel nozzles during original fabrication. These safe-ends were subsequently sensitized during post-weld heat treatment. After problems with sensitized safe-ends were identified, the safe-ends were removed, leaving some of the Inconel 182 as a "butter" on the face of the weld. Additional Inconel 182 weld metal was deposited on the inner lip of the joint to allow for machining a weld land on the inner diameter of the joint. Inconel 182 weld metal is deposited by the shielded metal arc process, because it has higher deposition rates than the tungsten inert gas (TIG) process used to deposit Inconel 82 weld metal.

(3) The replacement 304 stainless steel safe-end was surfaced with Inconel 182 weld metal and then solution annealed and water quenched to eliminate the sensitized heat-affected-zone (HAZ) created by the Inconel 182 weld surfacing.

(4) The field weld root between the 182 weld surfaced steel nozzle and the Inconcel 182 weld surfaced solution annealed 304 stainless steel safe-end was made using the gas tungsten arc process with Inconel 82 weld metal. The gas tungsten arc process is used to weld the root of pipe joints because its ease of control produces higher quality in the difficult weld roots of these joints.

(5) The rest of the weld was made using the shielded metal arc process with Inconel 182 weld metal (See Figure 1).

The Inconel 182 had crack indications in one of two outlet nozzles and in three of the ten inlet nozzles. These indications were confirmed to be cracks by subsequent metallographic examinations and were further characterized as interdendritic stress corrosion cracks.

The cracks in the inlet nozzle's Inconel 182 weld butter were found to be a maximum of 70% of the wall thickness in depth. The cracks were confined to the Inconel 182 weld butter except for slight crack extensions into the stainless steel safe-end HAZ in a few instances. No cracking was found in the low alloy steel nozzle base material or in the Inconel 82 weld root pass of the field weld. The Inconel 182 weld metal deposit was found to have cracks in both the low alloy nozzle steel and the 304 stainless steel safe-end sides of the joint.

Cracks at the inlet nozzles were reported only in the low alloy steel nozzle 182 weld deposits, probably because the 182 weld deposits on the 304 stainless steel safe-ends had been machined away during weld preparation.

The practicalities of weld repair with associated post-weld heat treatment determined that the half-bead weld technique without post-weld heat treatment be used on the inlet nozzle 182 weld metal repairs. The attached 304 stainless steel thermal sleeves on the inlet nozzles would become sensitized if a local post weld heat treatment were attempted and this was a factor for deciding to avoid post-weld heat treatment after weld repair. Local post-weld heat treatment was used after weld repairs of the 182 weld metal surfacing of the outlet nozzle.

The stress analysis performed showed that the highest stresses in the area of cracking were the weld residual hoop stresses. These stresses were a primary cause of the stress corrosion cracking and controlled the cracking orientation.

The magnitude of the weld residual hoop stress in a full penetration butt weld will overwhelm the previous stress history produced by the relatively small half-bead weld repairs.

The inlet nozzle half-bead weld repair of the Inconel 182 weld surfacing without post-weld heat treament was qualified in accordance with ASME Code, Section XI, Subsection IWB-4340. The reason for this is that the Inconel 182 weld surfacing being repaired had less than 1/8 in. thickness over the low alloy steel nozzle.

The outlet nozzle Inconel 182 weld surfacing was removed by machining. The nozzle end was resurfaced with Inconel 82 applied by an automatic gas tungsten arc welding process. Local post-weld heat treatment of the nozzle end was then performed.

The new 316 nuclear grade stainless steel safe-ends which were to be welded to the nozzles were weld buttered with Inconel 82. The safe-ends were then welded to their respective nozzles with Inconel 82 weld metal using an automatic gas tungsten arc welding process. All weld procedures were qualified in accordance with Section IX of the Code.

1.4 Jet Pump Instrumentation Nozzle Safe-end Cracking and Repair

IGSCC of the welds in the jet pump instrumentation penetration nozzle assemblies was recently reported in several operating boiling water reactor (BWR) plants. Regarding these components in the Pilgrim plant, the licensee indicated that only one short piece of safe-end on nozzle N9A was nonconforming. This piece of safe-end, which was made of 304 stainless steel and was in a furnace sensitized condition, was inadvertently left over during the replacement of furnace sensitized safe-ends in 1969. This safe-end was welded to the low alloy steel nozzle at one end and at the other end was welded to the alloy 182 buttered 304 stainless steel penetration seal. These two welds were made of alloy 82 weld materials. Ultrasonic examination was performed on the safe-end with procedures qualified for this particular safe-end/weld configuration The results of the examination identified two crack-like indications in the circumferential orientation in the furnace sensitized safe-end adjacent to the nozzle weld. The total length of the two circumferential cracks was approximately one inch. No crack depth was determined because of ALARA considerations. The cracked safe-end was weld overlay repaired.

General Electric (GE) performed the weld overlay design for the licensee. The overlay was made of Inconel alloy 82 material and was designed to have a minimum thickness of 0.135 inch, not including the first layer of approximately 0.09 inch in thickness, and a minimum length of 1.3 inches. The overlay was conservatively designed, assuming the presence of a 360 degree through wall crack, and met the ASME Code Section XI IWB-3640 limits. The overlay was located at least 0.1875 inch away from the nozzle to avoid heat-treating the low alloy steel nozzle materials. The licensee indicated that the overlay was deposited by using a high quality gas tungsten arc welding technique (GTAW) with water inside the pipe, which will produce a high quality, high toughness weld material resistant to IGSCC.

1.5 Recirculation Inlet Nozzle Thermal Sleeves Cracking

Again during the replacement of the recirculation system piping, nondestructive examinations (PT and RT) were performed on the accessible areas of the inlet nozzle thermal sleeves prior to connecting the new piping to the safe-ends. The type 304 stainless steel thermal sleeve consists of inner and outer sleeves, which are attached to each other at the end by a fillet weld. Four shop welded pads equally spaced around the circumference were applied on the outside surface of the outer thermal sleeve to facilitate alignment with the safe-end. Cracks were found on nine of the ten outer thermal sleeves. No cracks were found on the inner thermal sleeves by means of radiographic examinations.

All cracks were located on the outer surface of the outer thermal sleeves in the areas near the weld pads. Because of access limitations, ultrasonic examinations could not be performed to determine the depth of the cracks. All cracks were relatively short; the longest one was reported to be about 1.9 inches. The thermal sleeve in nozzle N2-E was reported to be the most extensively cracked. The cracking in nozzle N2-E thermal sleeve consisted of 13 cracks with a total crack length about 10.2 inches.

GE performed two crack growth calculations for the licensee based on an initial crack depth of 20% of wall thickness and a total crack length of six inches. One calculation was based on assuming the presence of one single crack six inch long and the other calculation was based on assuming the presence of four cracks, each 1.5 inch long, separated by equal distance around the sleeve. An axisymmetric finite element model was employed to analytically calculate the residual stresses in the outer thermal sleeve which result from applying one layer of the end fillet weld in joining the inner and outer thermal sleeves. The residual hoop stresses were calculated to be mostly compressive. The maximum tensile residual stresses were calculated to be 40 ksi in the axial orientation on the outside surface of the outer thermal sleeve. These tensile residual stresses were considered the main driving force in initiating and propagating the cracks. The regions where the calculated tensile residual stresses prevailed were in the general locations around the weld pads where circumferential cracks were found. However, because of GE's use of a simplified finite element model of the thermal sleeves, the location of the calculated maximum tensile residual stresses did not quite agree with the general crack locations. The crack growth rate used in the calculations was based on the upper bound data for sensitized material in 0.2 ppm oxygenated water at 550° F. The results of GE's calculations indicated that in both cases the cracks at the end of an 18-month period will grow to a through wall crack with a total length about 32% of the circumference. GE stated that this final crack size does not exceed two-thirds of the Code allowable limits in IWB-3640 tables. GE also indicated that, even though the initial crack size was assumed to be through wall, the final crack size at the end of an 18-month period is still within two-thirds of the Code allowable limits in IWB-3640 tables. Based on the above crack growth calculations, the licensee did not repair the cracked thermal sleeves because the Code required safety margins for structural integrity of the thermal sleeves would be maintained during the next 18-month fuel cycle. The licensee plans to implement the hydrogen water chemistry during the next refueling outage and the crack growth in the thermal sleeves is expected to be arrested in such an environment. As discussed later, the beneficial effect of the hydrogen water chemistry may be relatively small when the cracking mechanism is not IGSCC.

The licensee further indicated that even assuming the thermal sleeves were separated from the jet pump riser piping as cracking continues during the next fuel cycle, there would be no safety concerns because there is no threat to the reactor coolant pressure boundary (RCPB). Any significant loss of the coolant would be detected by the jet pump instrumentation and appropriate operator action would be taken if the technical specification safety limits were exceeded.

1.6 Hydrogen Water Chemistry (HWC)

The licensee indicated that HWC will be implemented during the next refueling outage. Based on the laboratory test data and the field experience in Dresden Unit 2, HWC is expected to arrest IGSCC and to supress crack initiation in components susceptible to IGSCC.

2.0 EVALUATION

Following are our evaluation of the licensee's submittals including GE's repair program of Inconel 182 weld butter in the recirculation nozzles, the weld overlay design of the jet pump instrumentation nozzle safe-end, and the calculations of the crack growth in the recirculation nozzle thermal sleeves to support the continuing service of Pilgrim plant for an 18-month fuel cycle at the present configuration:

2.1 Piping Replacement

The new piping was made of nuclear grade 316 stainless steel materials. The nuclear grade 316 stainless steel materials are considered to be highly resistant to IGSCC under normal BWR operating environment and are recommended by the NRC Pipe Crack Task Group in the draft NUREG-1061 as the most desirable piping replacement materials. The licensee performed the piping replacement in accordance with the guidelines in Generic Letter 84-7, which states, in accordance with 10 CFR 50.59, that prior NRC approval is not necessary unless the licensee determines that the proposed changes to the facility involves an unreviewed safety question or a change in the Technical Specification. However, the analyses supporting this determination must be maintained by the licensee to permit the staff to audit such evaluation, as appropriate.

2.2 Cracking of the Recirculation Nozzle Thermal Sleeves

The licensee assumed the reported cracking on the recirculation nozzle outer thermal sleeves to be IGSCC. This is based on the consideration that the heat input from the application of a fillet weld in joining the outer and inner thermal sleeves sensitized the neighboring thermal sleeve materials. We have some reservations with this assumption because many cracks as shown in Figure J-b were located outside the

HAZ of both the fillet weld and the pad welds. Therefore, other potential cracking mechanisms such as crevice corrosion and fatigue due to flow induced vibration should have also been considered. These mechanisms can initiate cracking at non-sensitized materials. If we consider these cracking mechanisms, the beneficial effect of hydrogen water chemistry will probably be very limited and the cracking of the outer thermal sleeves will most likely continue even if HWC is implemented.

Consequently, during the life of the plant, the cracked thermal sleeves may disintegrate into many pieces of various sizes. This scenario raises a concern regarding the potential impact of loose parts on the safe operation of the plant in the long term. We do not expect the loose parts concern to become a safety problem during the next fuel cycle. However, we believe this potential problem should be reviewed promptly to allow timely implementation of an appropriate mitigation. We recommend that the licensee be required to continue to study the cracking mechanism in the thermal sleeves and develop plans for mitigation or repairs of the cracks. A report including these plans and a schedule for implementation should be submitted to NRC for review at least one month before the next scheduled refueling outage.

2.3 Repair of Inconel 182 Butter in Recirculation Nozzles

We have reviewed the licensee's program for repair of the Inconel 182 butter in the recirculation nozzles. The procedures and techniques used in the repair are consistent with the Code and staff requirements.

However, we noted that the cracked Inconel 182 weld butter on the three recirculation nozzles was repaired with the same materials, which will continue to be susceptible to IGSCC. Our acceptance of the repair program is based on the following considerations:

(1) The cracks found on Inconel 182 weld butter are predominantly in the axial orientation and their lengths are limited within the region of the weld butter. The width of the repaired Inconel 182 weld butter is reported to be less than one half of an inch. Axial cracks of such a short length are not expected to have significant impact on the structural integrity of the nozzles.

(2) In accordance with the available laboratory test data, Inconel 182 is at least as resistant to IGSCC as normal grade 304 stainless steel Therefore, we do not expect cracks to be initiated immediately and grow to significant size in the repaired Inconel 182 weld butter during the next 18-month fuel cycle. Furthermore, we are not aware of any reported IGSCC in any operating BWR plants after an operation of one fuel cycle.

(3) The licensee indicated that HWC will be implemented during the next refueling outage. Based on the laboratory test data and the on-going field experience in Dresden Unit 2, HWC has been

shown to be very effective in prohibiting the initiation of the IGSCC. Therefore, the initiation of the IGSCC is not expected in Inconel 182 butter after the implementation of the HWC.

(4) Region I has determined that the repairs of the Inconel 182 weld butter in recirculation nozzles were performed satisfactorily and met the Code and staff requirements.

So far, the cracking of the Inconel 182 weld butter was found only in the Pilgrim plant recirculation nozzles. Inspection of Inconel 182 weld buttered nozzles was performed on Monticello and Hatch Unit 1 plants during their replacement of the recirculation system piping, but no crack indications were found. Therefore, it appears that the cracking in Inconel 182 butter is unique to Pilgrim plant. To assure that this is not a generic problem, the BWR Owner's Group (BWROG) has recommended that each affected licensee inspect at each plant at least one outlet recirculation nozzle and two inlet recirculation nozzles for potential cracking in the Inconel 182 weld butter.

2.4 Repair of Jet Pump Instrumentation Nozzle Safe-End

We have determined that the alloy 82 weld overlay repair of the jet pump instrumentation nozzle safe-end is acceptable. This is based on the following considerations:

(1) The reported cracks in the safe-end are very short, less than one inch in total length. Even if these cracks are assumed through wall, they would not have significant impact on the structural integrity of the nozzle.

(2) The thickness of the overlay was conservatively designed by assuming the crack to be a fully circumferential, through wall crack. This provides a large safety margin in the design because the reported crack length is only one inch long. In weld depositing alloy 82 over 304 stainless steel, there is no dilution concern in the first layer of the alloy 82 overlay and the first layer can always be considered as IGSCC resistant. In GE's overlay design, credit for the thickness of the first layer (0.09 inch) was not taken. This first layer will provide additional safety margin for the designed overlay.

(3) The overlay was deposited by using a high quality GTAW technique with water inside the pipe. The GTAW technique will produce high toughness weld metal and the last-pass-heat-sink welding technique will produce compressive residual stresses on the inside surface of the safe-end to prohibit further crack initiation and propagation.

2.5 Inspection Program

We have reviewed the licensee's inspection program and have determined that the inspections have fully met the confirmatory order requirements. The licensee indicated that because of limited access and tri-metallic weld design, six welds (three RWCU welds, two core spray welds and one head spray weld) could not be ultrasonically examined. These welds are of small diameter pipe welds ($\leq$ 10 inches in diameter) and leakage from these welds is within the primary coolant make-up capacity. The normal operating temperature in the two uninspected core spray piping penetration welds (10" in diameter) is less than 200°F and extensive IGSCC is not expected in these welds. Based on a discussion with the licensee, we also noted that the six uninspected welds are all isolable. Therefore, we conclude that even if these welds were cracked through the pipe wall, it will not have a significant impact on the safe operation of the plant.

2.6 Augmented Leak Detection and Leakage Limits

The licensee in its response to Generic Letter 84-11 indicated that a technical specification amendment will be submitted to incorporate the augmented leak detection and leakage limits requirements in accordance with those in the confirmatory order. This amendment will provide added assurance that possible through-wall cracks in pipes will be detected before they grow to a size that could compromise the safety of the plant.

3.0 CONCLUSION

We conclude that the inspection performed at the Pilgrim Station during this outage fully met the confirmatory order requirements. The repairs performed on jet pump instrumentation nozzle safe-end and the recirculation Inconel 182 buttered nozzles are acceptable. The unrepaired recirculation nozzle thermal sleeves are also acceptable because the crack growth in the thermal sleeves during the next fuel cycle will not compromise the safe operation of the plant. Therefore, we conclude that Pilgrim plant can be safely returned to operation in its present configuration for at least one 18-month fuel cycle.

As discussed ea[illegible] we have a residual concern relative to the cracking o[illegible]ation nozzle thermal sleeves because we are not certain [illegible]king was predominantly due to IGSCC. To resolve thi[illegible] request that the licensee continue to study the crackin[illegible]velop plans for mitigation or repair of the cracks. [illegible]ding these plans and a schedule for their implementation, sh[illegible] submitted for our review at least one month before the start of the next refueling outage.

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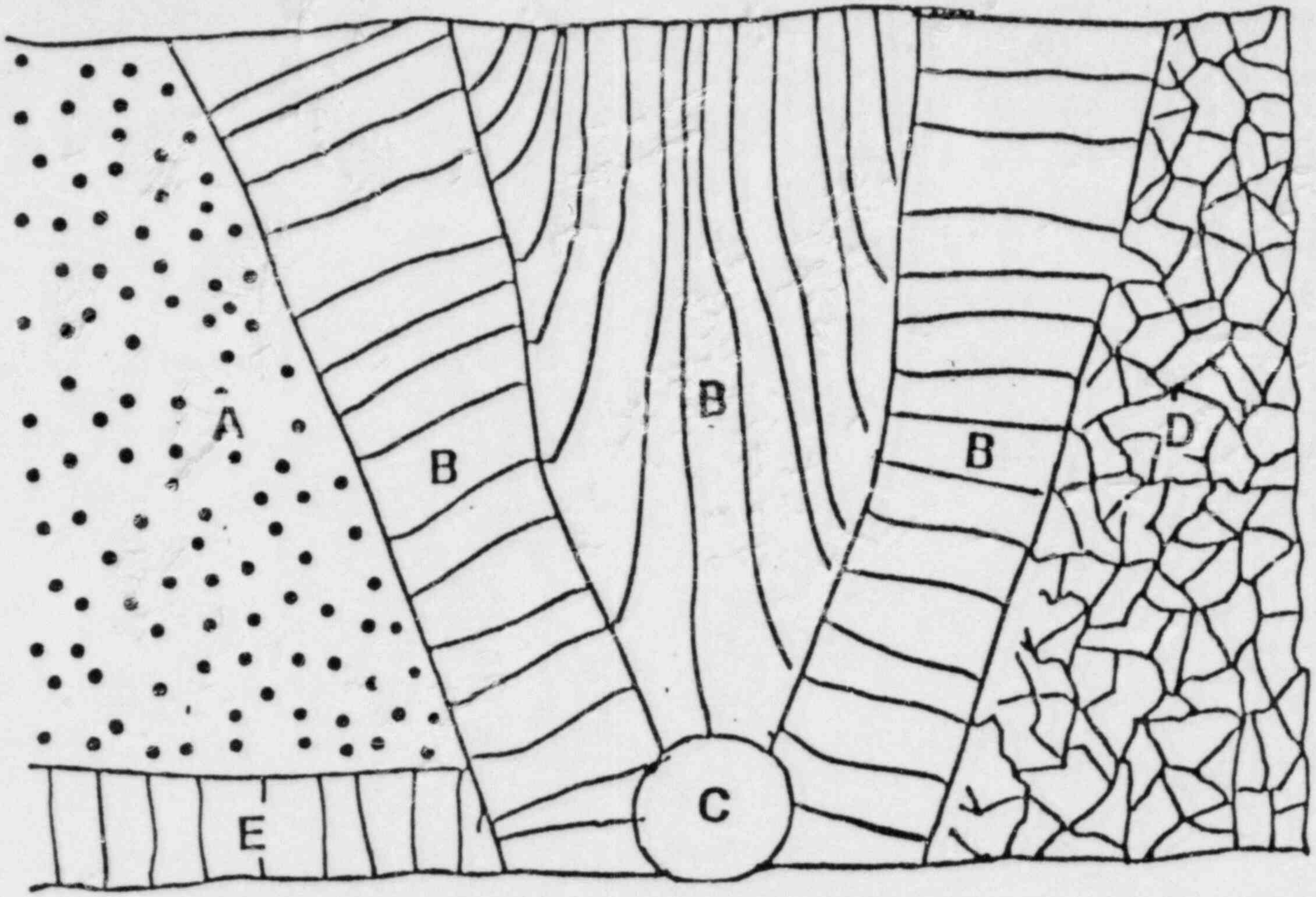
FIGURE 1 - Complex Metallurgical Condition of Safe End to Nozzle Attachment



A) LOW ALLOY STEEL NOZZLE
B) ALLOY 182 WELD BUTTER/FILLER
C) WELD METAL ROOT PASS
D) STAINLESS SAFE END
E) STAINLESS STEEL CLADDING