BAW-1363
December 1970

Analysis and Resolution of Dye-Penetrant Indications in Submerged Arc Weld Cladding of Reactor Coolant System Straight Piping

Duke Power Company
Oconee Unit 1

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BABCOCK & WILCOX
Nuclear Power Generation Department
Components Engineering
Barberton, Ohio

Babcock & Wilcox

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I. INTRODUCTION

In the course of the piping system modifications incidental to the installation of a replacement coolant pump at Oconee Unit 1, Duke Power, the straight section of the B-67 clad piping assembly was returned to the Mt. Vernon Works of Babcock & Wilcox for rework. In the course of this rework a routine dye penetrant examination revealed some indications in the cladding. The affected cladding was removed by machine grinding and replaced by welding in Mt. Vernon.

In order to assure that the balance of the cladding in the Oconee Unit 1 piping system did not show a similar condition, a complete reinspection of all of the cladding in the Oconee Unit 1 cooling piping system was initiated.

This report is addressed specifically to the work done with relation to the cladding on the straight sections of the coolant piping system; the investigation and findings of the problem with respect to manufacturing and non-destructive testing; and the corrective actions taken with respect to the Oconee 1 coolant system straight pipe and manufacturing processes. An accompanying report, BAW-1364, addresses the work relating to cladding on the elbows of the coolant system piping.

II. DESCRIPTION OF STRAIGHT PIPING PROBLEM

Straight sections of the 28-in. and 36-in. main coolant piping for Duke Power Company's Oconee Unit 1 were fabricated by cladding carbon steel with austenitic stainless steel by a multiple electrode submerged arc process. Following complete installation of the B-67 assembly main coolant piping, a straight section of the B-67 28-in. return coolant piping was removed to permit installation of the Westinghouse replacement reactor coolant pump, and was returned to the shop for rework.

Micro-fissures, as defined in section III of this report, and frequently referred to as fissures, were found in the cladding of the B-67 assembly during the course of routine shop inspection. Complete dye-penetrant inspection of all other remaining arc-weld-clad piping in Unit 1, carried out as a result of the B-67 inspection findings, revealed a small amount of micro-fissuring in one other assembly, B-57. The remaining ten assemblies showed no evidence of fissures. As discussed in section III-D of this report, laboratory tests on excess material determined that the cladding was not embrittled, that it was completely satisfactory for its intended service and that all of the B-67 fissures were removed by grinding or replacement after identification by dye-penetrant examination.

A complete record of the results of the re-examination by dye-penetrant procedures of the Oconee Unit 1 weld metal cladding of the reactor coolant system piping is listed below.

Table I. Dye-Penetrant Examination of Reactor Coolant Pipe Cladding

Assembly*	Results	Inspection Completion Date
A-57	PT - OK	9/4/70
B-67	PT - Reject Linear Fissuring in Vertical Run	9/4/70
B-45	PT - OK	9/4/70
B-41	PT - OK	9/14/70
A-67	PT - OK	9/9/70
B-46	PT - OK	9/11/70
A-33	PT - OK	9/12/70
A-32	PT - OK	9/12/70
A-24-1 (A Loop)	PT - OK	9/14/70
A-24-2 (B Loop)	PT - OK	9/14/70
B-40	PT - OK	9/14/70
B-57	PT - Reject Linear Indications in Vertical Run	9/16/70

*All straight pipe

All the Liquid Penetrant Inspection performed at Duke Power Company was witnessed by Duke Power Inspectors. For the dye-penetrant inspection and weld repair procedures utilized in connection with shop and site work, see Appendixes I and II.

To summarize this report, the following assemblies required corrective action:

Assembly	Results
B-67	Removed and shipped to Mt. Vernon for repairs
B-57	1 area 12" × 18" linear indications blend ground and PT'd clear on 9/16/70 at the job site.

See Figure 3, Reactor Coolant Loop Isometric for further clarification of assemblies and location of individual components. Segments of A-57, B-67, A-67 and B-57 were cut out of the coolant system as typically shown on Figure 3 and returned to Mount Vernon for rework. The segments were shortened to permit the installation of a longer pump suction nozzle associated with the Westinghouse reactor coolant pump. In addition, assemblies B-40, B-41, B-45 and B-46 were modified at the job site as typically shown on Figure 3. The segments were modified to meet new system angular configuration of the pump discharge associated with the reactor coolant piping changeover.

III. INVESTIGATION AND FINDINGS

A. Investigation of Manufacturing Aspects

Straight run main coolant piping for the Duke Power Company's Unit 1 reactor coolant system at Oconee was fabricated by cladding carbon steel pipe with austenitic stainless steel weld metal. The base material for this pipe is in accordance with A106 Grade C, and was quenched and tempered to enhance its toughness prior to cladding.

Cladding was done with the submerged arc welding process which deposits a single layer of stainless steel overlay. The requirements for chemical analysis of the deposited cladding were 17% minimum chromium, 7% minimum nickel, and 0.08% maximum carbon. All cladding for Oconee Unit 1 was done at B&W's Barberton Works.

The first four assemblies (B-67, A-57, B-45, and B-41) were completed and shipped to the construction site from the Barberton Works. Pipe manufacturing operations were later moved to the Mount Vernon Works and the remaining eight piping assemblies, (A-67, B-57, B-40, B-46, A-32, A-33, A-24-1 and A-24-2), for Oconee Unit 1 were shipped from there.

The significant difference in fabrication methods between the two plants is that final dye-penetrant inspection of the submerged arc cladding on the Barberton-shipped assemblies was performed prior to post weld stress relief heat treatment rather than afterward. This was not in accordance with the requirements of the B&W internal specification which stated that final non-destructive testing should follow heat treatment of piping components. The stress relief heat treatment had been shifted to a later sequence in the manufacturing process and the dye-penetrant inspection sequence was not shifted in a parallel manner. Both Quality Control Engineering and Process Engineering personnel have since been instructed to assure in the future that all process sequences for cladding operations are carefully reviewed for conformance with specification in order to prevent a reoccurrence of this problem. Post-weld heat treatments greatly facilitate the detection of micro-fissures by dye-penetrant inspection.

It was recognized that stringent control standards had to be set up and maintained in order to assure uniform high quality in the clad deposit. The procedure employed for cladding this pipe had been successfully employed for cladding many reactor vessel shell courses made of A302 Grade B low alloy steel and was requalified for the A-106 Grade C material. The welding parameters were the same for the two applications. Standard quality control practices employed to assure production of satisfactory cladding include:

1. Use of a thoroughly developed and testing welding procedure which is identical for both base metals.

2. Qualification of the procedure and all operators in accordance with the ASME Code.

3. Qualification of each combination of heat of filler wire and lot of welding flux by making test plates using the production welding procedure and making chemical analyses of these to assure that the alloying material in the weld deposit complies with the specification.

4. Chemical analysis of chips removed from every fifth production weld bead. Chips are analyzed for carbon, chromium, and nickel to assure the procedure is under control and in accordance with specification. Since the routine chemical analysis check involves only carbon, chromium, and nickel, a meaningful calculation of the ferrite content is not possible. The Schaeffler calculations are used only where a complete analysis is available such as in the course of Procedure Qualification Developments and are not utilized as a Quality Control technique in production.

5. Periodic checks of the ferrite content of the weld metal during the cladding operation. This is done with a Severn Ferrite Detector which is considered to provide a general indication of clad quality, subject to confirmation by chemical analysis.

In view of the extensive non-destructive testing of the cladding in the course of fabrication, no additional testing by the liquid penetrant method was planned for the pipe cladding during installation at Oconee except for small areas adjacent to back cladding of circle seams used to join assemblies. No indications were reported from this examination.

B. Investigation of Oconee Unit 1 Problem and Definition of Problem

An eight foot long straight vertical run section of the 28-in. return coolant piping assembly was removed from each loop as discussed in section II of this report (A-57, B-67, B-57, A-67) at a location just below the main pumps and returned to B&W - Mount Vernon Plant for rework.

One of the requirements of the pipe modification program was to flame cut twenty inches of excess material from each pipe section (A-57, B-67, B-57, A-67) returned to Mount Vernon. During the course of preparing the remaining pipe of the B-67 assembly for welding to another section, dye-penetrant inspection of the internal cladding adjacent to the weld preparation revealed the presence of small randomly oriented linear indications defined as micro-fissures (see section III-D of this report). Further penetrant inspection revealed general surface fissuring throughout the B-67 vertical run, but similar 100% inspection showed that no fissures were present in the other three return coolant pipe sections, (A-57, B-57, A-67) returned to Mount Vernon for rework.

It was determined from the processing that only four assemblies (B-67, A-57, B-45, and B-41) had been shipped directly from Barberton to Oconee Unit 1 and none of these were liquid penetrant inspected after stress relief. At Mount Vernon the fabrication sequence required liquid penetrant inspection of the cladding after post weld stress relief heat treatment. This change was incorporated on all piping assemblies shipped from there.

On the basis of the fissures found on the B-67 assembly, shipped from Barberton, it was decided to perform a 100% liquid penetrant inspection on all the Barberton shipped straight main coolant pipe at Oconee Unit 1. The remaining portion of the B-67 return coolant pipe which was still attached to the return coolant elbow on the lower head of the steam generator contained the same type of fissures as were noted on the eight foot length which had been shipped to Mount Vernon for rework. No other fissures were found in any of the remaining assemblies shipped from Barberton.

In addition, 10% of the surface of each straight pipe assembly shipped to Oconee Unit 1 from Mount Vernon was subjected to liquid penetrant inspection. During the site inspection of the B-57 assembly, which is similar in configuration to the B-67 assembly but on the other steam generator, micro-fissures were found in a 12" x 18" area about a foot below the cut edge. Figure 3 shows the general location of the indications. These fissures were similar to those found in the B-67 pipe, but on a smaller scale. Since 10% inspection revealed a small area containing fissures, all Mount Vernon shipped piping, both 28- and 36-in. diameter pipe were also subjected to 100% inspection by the dye-penetrant method. No new indications were disclosed.

Thorough surface preparation and 100% liquid penetrant inspection of the straight main coolant piping on Oconee Unit 1 showed that ten of the twelve assemblies were free of indications. The B-67 assembly contained fissures through its entire length, the B-57 assembly was free of indications except for one 12-in. by 18-in. area.

As previously stated, the linear indications resulting from the dye-penetrant inspection were restricted to the surface of the cladding. The 1-1/2 ft^2 of defects in the B-57 pipe were removed at the site by grinding an average of 1/64 in. to 1/16 in. of material from the surface with the maximum depth of localized probing being 1/8 in. The depth of grinding was determined by actual measurement using a straight edge and rule and the cladding thickness remaining in the ground areas was confirmed with the Eddy Current Instrument as acceptable.

The fissures in the upper portion of the B-67 straight pipe run were repaired while the piece was still at Mount Vernon being modified as discussed in section II of this report and as described in detail in the Process Documents, Appendix II. These fissures were removed by machining 1/8 in. of material from the surface, leaving sound cladding. After performing a liquid penetrant inspection to verify removal of all indications, the inside surface was overlayed with stainless steel using the submerged arc process, and ground for surface requirements. The pipe section was then subjected to a post weld stress relief heat treatment. Inspection after heat treatment by the liquid penetrant and ultrasonic test methods showed clad to be free of fissures. It was returned to the Oconee site for re-installation.

The lower portion of the ... which remained attached to the steam generator lower head outlet elbow also contained fissures in the clad. Rather than attempt repair of this section in the field, this pipe section was removed and a sound duplicate section from another unit was substituted.

C. Investigation of Manufacturing History — Mount Vernon and Barberton

All processing has been reviewed to assure that fabrication and inspection is in accordance with the applicable specifications and codes. It is emphasized that Mount Vernon processing has always specified penetrant testing after stress relief heat treatment.

B&W has examined all records pertaining to the pipe fabrication, paying particular attention to heat treatment records. No omissions or temperature excursions beyond the specified range were found. Records indicate that all components have been examined by the appropriate non-destructive test after post-weld stress relief heat treatment at Mount Vernon.

Indications found in the submerged arc deposited cladding of two return coolant piping assemblies installed in Oconee Unit 1 are defined in section III-D of this report as inter-granular micro-fissures that were formed during solidification of the weld metal. Fissures in the B-57 assembly occurred in an area of less than 1-1/2 ft^2 and were removed by light grinding. More extensive microfissuring was detected in the B-67 assembly and a portion was repaired in the shop.

The microfissures occurred during weld metal solidification when the submerged arc welding flux was not uniformly enriched with chromium. The resulting cladding had patches with insufficient delta ferrite to resist fissuring during weld metal solidification. Similar indications had been infrequently noted during pipe fabrication and corrected at that time.

Corrective action at the flux manufacturer's plant was instituted as soon as the problem was noted in the shops. No further difficulties have been experienced.

The fissures in the B-67 piping covered a wide area. They were missed in the shop because they were very small and tight, and had not been subjected to a post weld heat treatment prior to the liquid penetrant inspection. Had the cladding been heat treated prior to liquid penetrant testing, the fissures would have been found. Fissures in piping shipped from Mt. Vernon were caught in the shop and corrected prior to shipment, since Mt. Vernon Engineering changed the processing to require penetrant inspection after heat treatment. The small area of minor fissuring in the B-57 assembly was not disclosed in the shop because of human error. Extensive retraining of dye-penetrant operators on actual samples removed from the scrapped pipe is being continued. Careful grinding and dye-penetrant inspection of all pipe in Oconee Unit 1 clad by the automatic submerged arc process has been completed.

The nominal cladding thickness is specified to be 1/4 in. and in order to assure that the cladding thickness in the areas that were ground in the course of corrective work would still meet minimum cladding thickness requirements, the entire clad surface was subjected to an Eddy Current testing program to clearly establish that the minimum cladding thickness of 1/8 in. was not violated. A special instrument had been designed and built by B&W for this type of analysis and was utilized for the work.

D Laboratory Examinations

After discovering and reporting the existence of small linear indications on the surface of the two straight runs of piping, B&W decided to confirm their opinion that the indications were micro-fissures formed during solidification of the submerged arc weld metal. Since the twenty inches of excess length that was removed from the B-67 assembly during modification at Mt. Vernon contained indications of the same type and severity as those that were present in the remainder of the pipe, portions of this excess material was used to provide test specimens for metallographic examination, side bend tests, ferrite checks, and chemical analysis. Samples were not removed from the B-57 piping at Oconee since the indications were similar in nature and it was not considered necessary to cause the major field repair that would result from removing a sample. Following are the details of these tests performed on the scrap portion of the B-67 pipe. The results obtained and their comparison with similar tests conducted on other piping are noted.

1. Ferrite Check:

Use of the Severn Ferrite Indicator showed that the stainless steel cladding in the 20 inches of excess pipe had a delta ferrite content 1-1/2 to 2-1/2%. Although the clad thickness on the sample tested was 1/4 inch, there was found to be some magnetic influence from the carbon steel backing material. When the steel backing was cut away, the ferrite reading on the cladding alone was less than 1-1/2%.

Similar ferrite checks on the B-67 pipe remaining at Oconee, which had scattered fissuring along the entire length, showed values ranging from 2-1/2% to 10%. The worst fissuring was in the areas showing 2-1/2% ferrite.

The ferrite content of the B-57 return coolant piping was checked in the field after this problem was discovered, and was found to be 5% in the 12 in. by 18 in. area that contained the fissures. The surrounding areas, which had no indications, showed a ferrite content of 10% to 15% based upon the Severn Indicator.

It should be noted that delta ferrite checks are random partial checks and were made periodically during cladding of the piping. Acceptance standards were 2-1/2% minimum if additional chemical analysis of production cladding were made; otherwise the acceptance standards were 5% minimum ferrite. As long as the welding flux has the proper homogeneity such spot checking constitutes a satisfactory Quality Control procedure. When the welding flux is not uniform as was the case here, a satisfactory weld metal cladding cannot be consistently achieved.

2. Side Bend Tests:

A portion of the 20 in. excess length section of the B-67 pipe was prepared for side bend tests in accordance with all of the requirements and dimensions of section IX of the ASME Boiler and Pressure Vessel Code. The samples were taken from the 20 in. excess length as shown in Figure 4. The area selected for bending contained indications representative of those present in the remainder of the B-67 piping. Fissures present on the face of the specimen were ground away to provide a meaningful test of the cladding ductility. Testing of the specimen in accordance with ASME Code requirements produced no tears or fissures, demonstrating adequate ductility of the production cladding in the area of indications.

3. Metallographic Examination:

Figure 1 shows photomicrographs of etched and unetched cross sections of typical fissures removed from the same piece of excess length previously discussed. The location of the sample for metallographic examination was immediately adjacent to the area where the ferrite was checked by Severn Indicator and found to be less than 1-1/2%. Metallographic examination, as shown in Figure 1, confirms the low ferrite content of the cladding in this area. It is clear that the indications are typical micro-fissuring caused by insufficient delta ferrite and are therefore defined as such. These photographs should be compared with those shown in Figure 2, the latter illustrating a normal submerged arc weld made by the same procedure, with sufficient delta ferrite. The uncorrected Severn Ferrite Indicator reading of the sample illustrated in Figure 2 shows it to contain 9% to 10% ferrite.

4. Chemical Analysis:

Chemical analyses of five representative areas in the 20 inches of excess length removed from the B-67 pipe are shown in Table II. This analysis confirms the results obtained from both the Severn ferrite check and the metallographic examination which had indicated that the ferrite content was less than 1-1/2% in the area of fissuring. The calculated level of ferrite in this area of the cladding, based upon the Schaeffler diagram, ranges from 0 to 2%.

The low ferrite content of this weld metal results in part from the unusually high carbon content of 0.089 to 0.097% in this portion of the cladding. Carbon will reduce the ferrite content of the weld metal very rapidly; for example, carbon is 30 times as effective as the same percentage of nickel. This effect is demonstrated both by the Severn gauge data as well as by the Schaeffler Calculations. It should be noted that the chrome and nickel contents of this portion of the cladding are on the high side in spite of the high carbon level. This occurs as a result of the previously discussed flux inhomogeneity which changed the weld penetration, thus resulting in greater dilution with the base metal while maintaining more than sufficient chromium and nickel in the weld. The adequate ferrite level (5%+) in the balance of the weld cladding provides assurance that this condition prevailed only in the pipe welded with the improperly made flux.

Preliminary samples taken from the cladding of the B-67 assembly indicated chromium values of 17.43%, 17.5%, 17.95% and 18.02%. The corresponding nickel contents were 8.58%, 8.64%, 8.71% and 8.68%. Carbon values were also out of specification (0.111%, 0.205%, 0.120% and 0.102%). Since the samples were removed with a carbide burr, the high carbon content can be attributed to sample contamination. The lack of homogeneity of the welding flux is directly responsible for the erratic chromium and nickel values obtained from these samples.

E. Discussion of Investigations

Two questions are raised by the disclosure of microfissures in the submerged arc cladding. The first, why did the fissures occur in a process that had been so thoroughly developed, qualified, and field tested? Second, why were the indications not detected during normal shop inspection?

B&W is certain that these fissures are not something new or unexplainable. B&W has known since the early forties that certain analyses of austenitic stainless steels may be subject to intergranular microfissuring during solidification from the liquid under restraint. This is corrected by adjusting the chemistry to provide a two phase structure of austenite plus a few percent by volume of delta ferrite. The delta ferrite breaks up the continuous grain boundary network found in the purely austenitic stainless steel, significantly increasing the grain boundary length and reducing its thickness. Grain boundary thickness reduction is beneficial because it reduces the weakening effect of low melting point constituents at the grain boundary that may cause intergranular microfissuring during solidification of the weld metal. The welding development and qualification program, the filler metal testing procedure, and the production quality control procedures were specifically designed to incorporate this technology and prevent weld microfissuring.

Some submerged arc cladding done early in 1968 employed flux which had not been manufactured in such a way as to insure homogeneous chromium enrichment. Techniques of blending and addition of sodium silicate binder were not in accordance with previous or subsequent practice. This led to small areas in the clad deposit which had sufficient chromium for corrosion resistance, but an insufficient amount to maintain the beneficial delta ferrite at the level required to preclude microfissuring. This infrequent lack of homogeneity was not disclosed in the flux qualification tests or in process tests.

Corrective action for this deficiency was instituted as soon as the problem was identified. By this time, the cladding for Oconee Unit 1 was essentially complete as far as the weld cladding was concerned.

Corrective action consisted of an elaborate blending schedule at the flux manufacturers plant and an improvement in their method of adding sodium silicate binder. B&W is maintaining a surveillance of the operation to preclude further difficulties.

Some minor indications were noted during normal shop inspection and were easily corrected. By coincidence, the only piping shipped to Oconee Unit 1 with a large number of undetected fissures in the straight lengths was the B-67 assembly. This was one of four assemblies fabricated and shipped from Barberton; these assemblies did not receive the originally scheduled post weld stress relief heat treatment prior to liquid penetrant inspection of the cladding. As can be seen by the typical photomicrographs shown at 100X and 500X magnification in Figure 1 and Figure 2, even after stress relief the microfissures remain exceedingly tight. Prior to stress relief, they could be too tight for meaningful interpretation by the dye-penetrant inspection. Thermal strains imposed by the differential expansion characteristics between the overlay and the steel base material would tend to open the fissures during subsequent heat treatment. The pipe, however, received no further dye-penetrant inspection until the rework operation and the disclosure of the indications at Mt. Vernon.

The above analysis does not explain the presence of a small patch of fissures in the B-57 piping which was shipped from the Mt. Vernon Plant. There, the manufacturing sequence was changed to require liquid penetrant inspection of cladding after the stress relief heat treatment. The fissures in this pipe were apparently even tighter and most were removed after grinding about 1/32 in. from the surface. These fissures were missed during liquid penetrant inspection because of operator error.

IV. CONCLUSION OF INVESTIGATION

A. Corrective Action to Reactor Coolant System

As pointed out in section II, straight pipe cladding in assemblies B-67 and B-57 required repairs. The action taken in each case is as follows:

1. B-67 Assembly — Replacement and Repair

a. An 8-ft section of pipe was removed by the following method:

(1) Made a cut 12 in. below the Bingham pump suction nozzle.

(2) Made second cut 8 ft below first cut.

b. This 8-ft section was shipped back to Mt. Vernon.

c. The section was then cut in Mt. Vernon to a length of 5 ft 2-3/8 in.

d. At that time, indications were found. One-eighth inch of cladding was machined out and nine remaining local indications were ground out. A layer of cladding was then deposited using the single-wire submerged-arc welding process. A preliminary dye-penetrant examination disclosed no indications.

e. The piece was stress-relieved after final assembly in Mt. Vernon and again examined by dye-penetrant procedures. No indications were found.

f. A type-316 alloy stainless steel transition 14 in. long and a type-316 alloy stainless steel safe end 17-1/4 in. long were welded to the 5-ft 2-3/8-in. carbon steel piece forming a piece approximately 7 ft 10 in. long.

g. Due to indications found in the remaining straight piping at Oconee in the B-67 assembly, it was determined that this piping should be removed. A 16-ft (approximately) section was removed and replaced with an acceptable substitute.

h. Accordingly, the new 16-ft section of clad carbon steel pipe was welded to the approximately 7-ft 10-in. piece in Mt. Vernon. This new 16-ft piece was made up of two pieces taken from spare material. Two carbon-steel-to-carbon-steel welds were made. This required re-stress-relieving the assembly.

i. Prior to stress-relieving, the 316 stainless steel transition piece and safe end were cut off.

j. After stress-relieving, this 316 stainless steel piece was rewelded forming a piece 23 ft 10-13/16 in. long. This piece was then shipped to Oconee.

k. This 23-ft 10-13/16-in. piece was welded into the piping system between the Westinghouse pump suction nozzle and the 90-degree elbow leading from the steam generator.

2. B-57 Assembly — Repair

This assembly had only one small area 12 by 18 in., which was ground clear at Oconee. The deepest penetration was 0.121 in. deep. Cladding thickness was checked, following grinding and determined to be 1/8 in. thick or greater.

B. Corrective Action to Manufacturing Processes and Quality Control Improvements

The occurrence of a manufacturing problem such as the one described here usually represents financial as well as schedular losses to the manufacturer and the customer, but it also provides a lesson that can prevent similar occurrences in the future if properly heeded. The effectiveness of the lesson is best evaluated by the quality and extent of the corrective action instituted to avoid repetition of the problem. The following corrective action has been taken by B&W:

1. B&W has instituted a program where the clad surface of the piping will be dye-checked after every major operation to ensure freedom from this type of indication in the end product and ensure detection and correction of the problem at the earliest possible time in the manufacturing process.

2. Mt. Vernon has effected a very intensive operator training program for using the dye-penetrant technique. The men see about 80 hours of classroom and practical demonstration work as part of the B&W training program, and, in addition to that, are qualified dye-

penetrant inspectors in strict accordance with the provisions of section I Appendix IX of the ASME Code. Qualification is in accordance with the provisions of SNT-TC1A, which is the standard upon which the ASME Code relies. This involves another 10-30 hours of intensive training. Actual samples of unacceptable production work, such as those discussed herein, are used as visual aids.

3. The flux manufacturing operation is being closely monitored to ensure homogeneous enrichment of the material with chromium and nickel. Corrective action in this area was initiated more than two years ago.

V. SUMMARY

B&W's actions towards the solution of this problem will succeed in completely eliminating the micro-fissure from the current Oconee Unit 1 straight pipe as well as from piping supplied for all future jobs. The very careful training of B&W operators, together with better control of the manufacturing processes, should guarantee sound cladding in future components, and certainly the thorough examination and corrective work conducted at the Oconee Unit 1 job site provides adequate assurance that the problem there has been solved. In this connection, it is important to recognize that the cladding of this straight pipe is not considered part of the structure in terms of the piping's ability to withstand operating stresses. From a design point of view, the carbon steel carries the entire load. Thus, the cladding does not contribute to the integrity of the pressure boundary but rather provides a surface protection for the carbon steel.

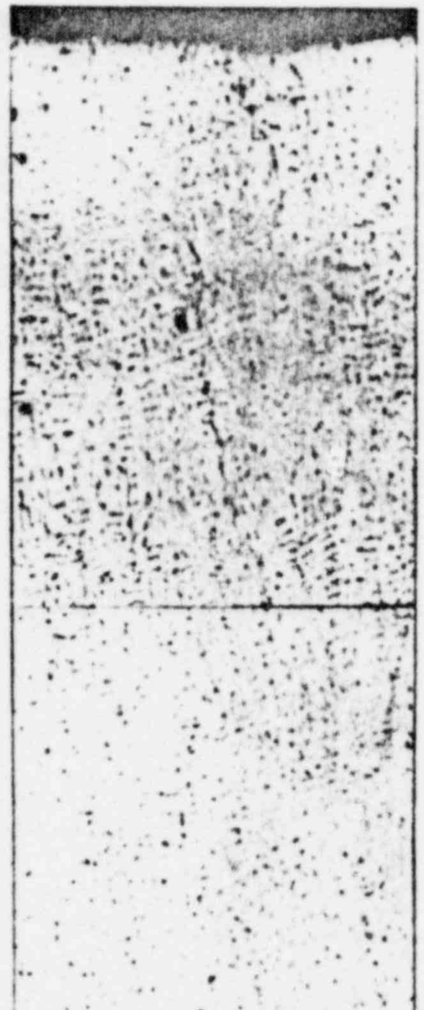
The extensive investigations, surface examinations, and field rework as discussed throughout this report make possible the final conclusions that the reactor coolant system integrity has not been jeopardized in any way and that the reactor coolant system is 100% sound for operation with respect to the investigations and repairs reported here.

Table II. Chemical Analysis of Five Representative Areas in the 20-Inch-Long Section of Excess Material Removed From the B-67 Straight Inlet Pipe at Mt. Vernon

	% by weight		
Area	Carbon[(a)]	Chromium	Nickel
1	0.093	18.45	8.99
2	.097	18.14	8.87
3	.092	18.07	8.92
4	.094	18.02	8.89
5	0.089	18.50	8.94

[(a)] The carbon content is in excess of the maximum of 0.08% carbon allowed by the specification. There is no logical explanation for this discrepancy. All QC records indicate that 0.08% carbon was not exceeded in the shop.

Unetched - 100X
Magnification

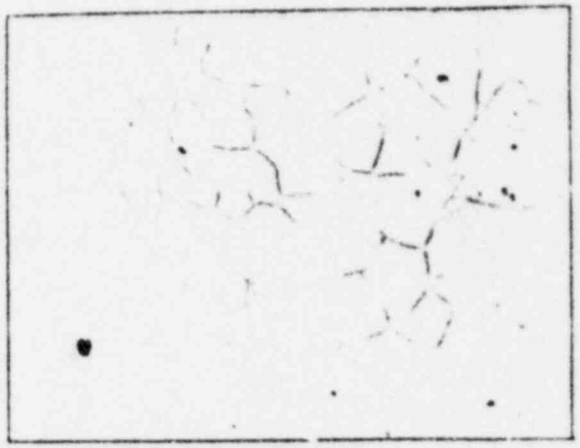


Kallings etch - 100X
Magnification

Kallings etch - 500X
Magnification

TRANSVERSE CROSS SECTION OF TYPICAL MICROFISSURES IN SUBMERGED ARC CLADDING ON B67 RETURN COOLANT PIPING - OCONEE No. 1. THE CENTER PHOTOGRAPH SHOWS A CAST DENDRITIC STRUCTURE. SOME DELTA FERRITE IS VISIBLE AT 500X MAGNIFICATION: THIS IS INSUFFICIENT TO PREVENT MICRO FISSURES DURING COOLING.

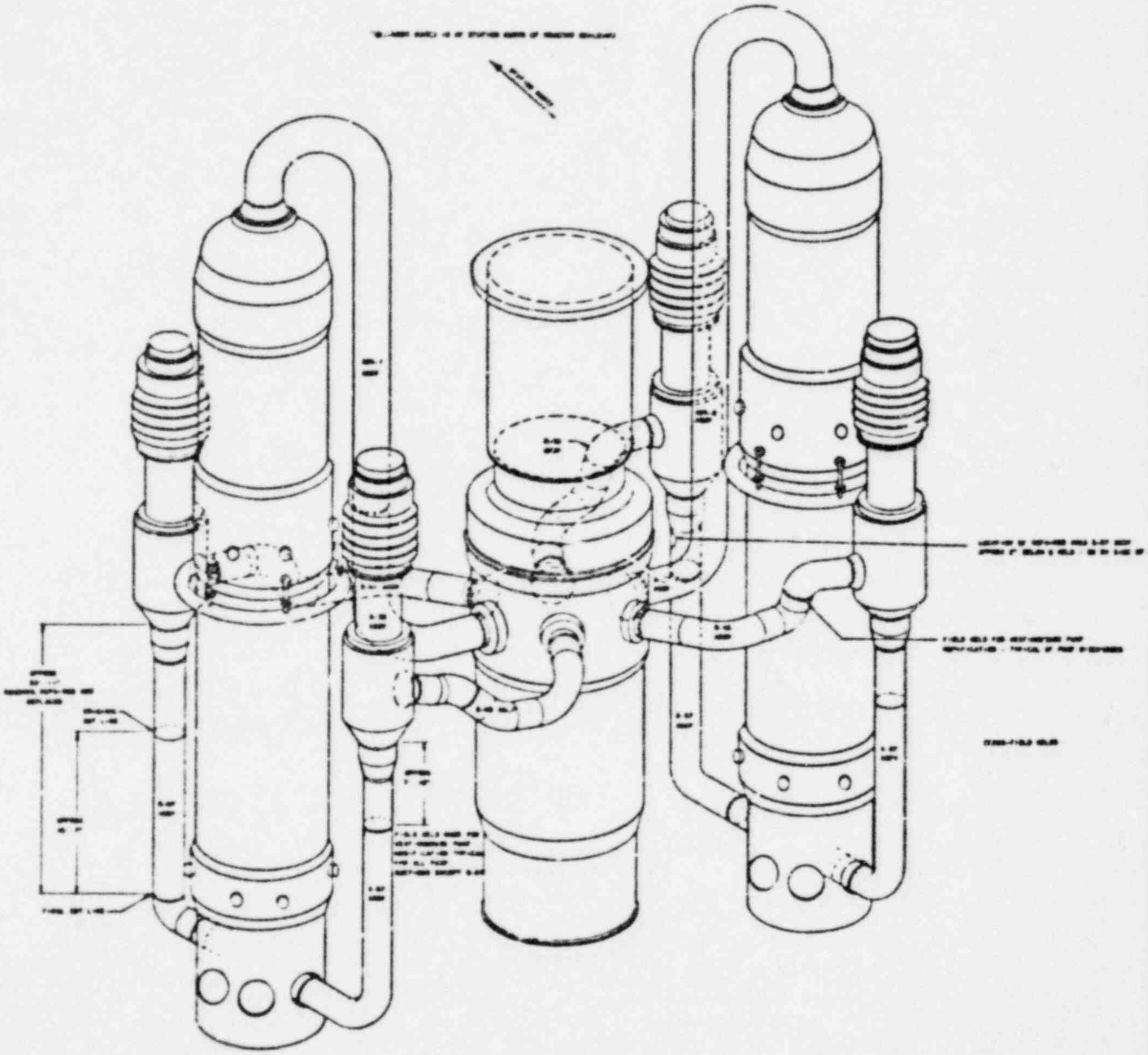
Kallings Etch - 100X



Kallings Etch - 500X

Transverse cross section of typical Stainless Steel Weld Deposit made by B&W multi-wire submerged arc process. This sample shows sufficient delta ferrite to prevent hot short micro-fissures during welding.

FIGURE #2



REACTOR COOLANT LOOP ISOMETRIC

Figure 3

ATTACHMENTS

APPENDIX I

NDT P· · for Dye-Penetrant Inspection
of the -posited Cladding in the Coolant
- ping System of Oconee Unit 1

PDS 9179

ISSUED	SUBJECT	SPEC. NO.
12-2-63	DYE PENETRANT INSPECTION AND ACCEPTANCE STANDARDS FOR WELDS	S-102C

1. SCOPE: This specification shall govern the dye penetrant method of inspection and acceptance standards for welds. The dye penetrant inspection described herein shall be used for the detection of surface flaws, such as cracks or porosity in welds made in accordance with the following codes and regulations:

   A. ASME Boiler and Pressure Vessel Code

   B. MIL-STD-278

   C. Coast Guard Regulation CG-115

   D. American Welding Society Codes

2. PREPARATION OF SURFACES:

   2.1 The weld surfaces to be tested and the adjacent surfaces within one inch shall be cleaned to insure they are free of loose film, slag, dirt, grease, embedded sand, etc. The surfaces may be inspected without surface preparation or conditioning except as noted above, but the surface finish shall permit proper interpretation of inspection results. Shot, sand, grit, and vapor blasting shall not be performed on surfaces prior to liquid penetrant inspection

   2.2 There shall be no extraneous matter that would obscure surface openings or otherwise interfere with the tests. In all cases, the surface to be examined shall be cleaned with acetone before application of the dye. The drying of the test surfaces shall be accomplished by normal evaporation; blotting with paper towels or clean, lint-free cloth; or using circulating air. The minimum drying time shall be five minutes. It is important in the drying operation that no contaminating materials such as oil from air nozzles or lint from cloths be introduced onto the surface, since they may cause irrelevant indications.

3. APPROVED DYES, CLEANERS, AND DEVELOPERS:

   3.1 The following penetrant, developers, and cleaners produced by the Magnaflux Corporation that are listed in Group I of Military specification MIL-I-25135 may be used in combination with one another, but shall not be used in conjunction with any other manufacturer's materials. Combination No. 1 is preferred and shall be used whenever possible.

	Combination No. 1	Combination No. 2
Penetrant	SKL-HF	SKL-HF
Developer	SKD-S	SKD-NF
Cleaner	SKC-S	SKC-NF

The SKD-S and SKC-S materials, though not on the Qualified Products List for Specification MIL-I-25135, have been approved for use by authorized Government agencies.

Materials made by other companies are acceptable provided they are qualified on approved test plates using the procedures of this specification.

3.2 All penetrant materials shall be qualified by demonstrating the adequacy of the materials to detect known defects in standard and approved test plates.

3.3 Each batch of materials shall have been tested for residual amounts of total halogen and total sulfur exclusive of carrying liquids or gases. The residual amount of each shall not exceed 1 percent by weight.

4. APPLICATION OF PENETRANT DYE:

4.1 All surfaces to be tested shall be thoroughly and uniformly coated with the penetrant dye. The dye shall be applied to the weld and to the base material for 1/2" on each side of the line of fusion whenever possible. The dye may be applied by brushing, swabbing, dipping, or spraying.

4.2 The surfaces shall remain wetted with the penetrant for a minimum of 15 minutes and a maximum of 20 minutes. On special applications, the maximum time limit may be increased when permitted by Quality Control and the customer. Any Complete drying of penetrant during the penetration time shall require recleaning of the surfaces and a repeat of the test. The work piece and the penetrant shall be at a temperature between 50F and 100F during the dye penetrant operation.

4.3 After the penetrant dye has been on the surface to be inspected for the prescribed amount of time, all excess dye shall be removed by the following steps:

A. Remove all possible penetrant dye with a clean, dry, lint-free cloth or absorbent paper.

B. Finish cleaning the surface with lint-free cloths that have been dampe with the approved cleaner. Flushing of the surface with a cleaning solution for the purpose of removing excess penetrant shall be prohibited.

4.4 The drying of surfaces after removal of the excess penetrant shall be accomplished by normal evaporation or by blotting with clean lint-free cloths or absorbent paper. Forced air circulation in excess of normal vnetilation shall be prohibited.

5. APPLICATION OF PENETRANT DYE DEVELOPER:

5.1 The penetrant dye developer shall be thoroughly agitated and shall be applied to the surface within 15 minutes after the preceding operations have been completed. Normally, the developer shall be applied by spraying. The developer may be applied by dipping, swabbing, or brushing when spraying is not possible. When applying the developer by swabbing or brushing, intentional swabbing out or brushing out of the developer shall be prohibited.

5.2 The developer shall dry for seven minutes before interpretation and the interpretation should be completed within 30 minutes. However, evaluation may continue after the 30 minute period has elapsed provided indications remain within applicable acceptance standards. Surfaces which are evaluated after 30 minutes and have indications exceeding the acceptance standards shall be cleaned and reinspected by the technique described in the preceding paragraphs except that interpretation shall be started after the developer has dried for seven minutes and shall be completed within 30 minutes.

6. INTERPRETATION OF RESULTS:

6.1 Precaution shall be taken to prevent any object from touching the dry developer film as it is very friable and easily damaged. When questionable results are obtained, the surfaces shall be reinspected.

6.2 Indications and defects in the surface shall be identified as red stains against the white developer. A thin red line may indicate a fine crack or a cold shut. Scattered red dots may indicate porosity in the material and a line of dots may indicate a tightly closed crack.

7. LIGHTING IN THE TEST AREA:

7.1 The area in which the inspection is performed shall be adequately illuminated for proper evaluation.

PDS 9179

ISSUED	SUBJECT	SPEC. NO.
12-2-63	DYE PENETRANT INSPECTION AND ACCEPTANCE STANDARDS FOR WELDS	S-102C

8. ACCEPTANCE STANDARDS: Welds, base materials, and weld edge preparations shall meet the minimum quality requirements of this specification.

8.1 All indications revealed by liquid penetrant inspections are not necessarily defects, and nonrelevant indications are sometimes encountered. However, all indications in the weld craters or in the line of fusion between base material and weld metal shall be treated as defects. All indications believed to be nonrelevant shall be explored by surface conditioning and reinspected or shall be reinspected by other non-destructive methods. If reinspection reveals any indications they shall be considered defects and shall be evaluated to the acceptance standards as specified in Para. 8.2.

8.1.1 Linear defects are those defects in which the length is greater than three times the width.

8.1.2 Rounded defects are those defects which are circular or elliptical with the length less than three times the width.

8.2 Weld metal including cladding and adjacent base materials, including 1/2" on each side of the weld, shall be free of the following indications:

8.2.1 All cracks and linear defects.

8.2.2 All rounded indications with dimensions greater than 3/16 inch.

8.2.3 Four or more rounded indications in line, regardless of size, separated by 1/16" or less, as measured from edge to edge.

8.2.4 Ten or more rounded indications, regardless of size, located in any six square inches of surface whose minor dimension is no less than one inch with these dimensions taken in the least favorable location relative to the indications being evaluated.

8.3 Weld Edge Preparation - Base Material (Cross-Section Inspection): Liquid penetrant inspection shall be used to evaluate cracks, laminations, and similar discontinuities.

8.3.1 The test surface shall be free of all cracks, and nonlaminar defects.

8.3.2 Discontinuities which are parallel to the surface, such as luminar type indications, shall be acceptable as specified below:

Base Material Thickness	Max. Total Indication Length in 3"	Max. Length of any Single Indication
1/4" or below	1/16"	1/16"
Above 1/4" to and incl. 1/2"	1/8"	1/8"
Above 1/2" to and incl. 1"	1/2"	1/4"
Above 1" to and incl. 2"	3/4"	1/2"
Above 2" to 4"	1-1/4"	1"
4" and over	1-1/2"	1"

8.3.3 Repairs on Weld Edge Preparation of Base Material: Only such indications need removal and repair as to render the base material acceptable to the limits specified in Paragraph 8.3.2. Indications which have been probed to a depth of 3/8" from the surface of the weld edge preparation and have not been removed, amy be sealed by welding.

9. FINAL CLEANING: When the inspection is concluded, the penetrant material shall be removed as soon as possible with acetone or other approved solvents.

10. SAFETY PRECAUTIONS:

10.1 Repeated or prolonged contact of penetrant dye or developer with the skin shall be avoided since these liquids are skin irritants.

10.2 The solutions used in dye penetrant inspections shall be used in well ventilated areas, since they are highly volatile.

10.3 Dye penetrant solutions have low flash points and shall not be heated or exposed to open flames and hot surfaces. It is recommended that "No Smoking" signs be posted in areas where penetrants are used.

APPENDIX II

Fabrication Procedure for the Modification of the B-67 Assembly in Mt. Vernon

Note: The following fabrication procedure applies only to one partial section of the vertical straight piping in the B-67 assembly that was reclad in Mt. Vernon; therefore, all dye-penetrant examination described in the following process is of a preliminary nature and an additional Quality Control measure. Final dye-penetrant examination was conducted after a stress-relieving heat treatment in the course of subsequent fabrication. The remainder of the modification work was done in accordance with standard manufacturing procedures and processes.

S. SHOP	SC ORD-CP-EXP	UNIT	GR	MARK	CONTROL NO.	ITEM	QTY REQ'D	PCS/UNIT	PCS/CONT.
	620-0003-50	1	21	C-215		Salvaged Pipe Assembly	1	1	1

MATERIAL SIZE	MATERIAL SPEC.	PROD-PC-LINE	UT REQ'D	STOCK OR P.O. NO.	DRAWING NUMBER
	SA-106-C				154647E-0

PROC BY	EST BY	PART NO. OF NEXT ASSY	MAIN LOCATION	DATE ISSUED	PAGE
Vogel	PLR	C-211		7-11-70	1 OF 7

HEAT NO.

SERIAL NO. C 215-203-50-1

NOTE: MATERIAL DEPARTMENT TO VERIFY CERTIFICATION OF MATERIALS.

LIST OF ALL REQUIRED PARTS BY MARK NUMBERS	LIST OF ALL DWG'S.	SPECIFICATIONS	TOOLS REQUIRED AND NUMBERS
(1) MK 215 Salvaged Pipe Assembly From Field	154647E	W-52 S-102B S-102C	
Estimated for one Pc.			

REV NO	DATE	BY	DESCRIPTION	REV NO	DATE	BY	DESCRIPTION

PROCESS SHEET - FIRST PAGE
FORM 31258-1

COPY 1

S. SHOP	SC-ORD-CP-EXP	UNIT	GR	PART NO. MARK	CONTROL NO.	ITEM	QTY REQ'D	PCS/UNIT	PCS/CONT.
	620-0003-50	1	21	C-215		Salvaged Pipe Assembly	1	1	1

MATERIAL SIZE	MATERIAL SPEC.	PMO-PC-LINE	LT. REQ'D	STOCK OR P.O. NO.	DRAWING NUMBER
	SA-106-C				See Pg. 1

START	FINISH	SEQ. NO.	CHG. SHOP	W.C.	OPER.	OPERATION DESCRIPTION - OUTLINE	STD. HRS.	ESTIMATED MANHOURS SET UP	RUN	TOTAL	INSP. PAPERS	CUST/NAVY
			219		00	Insp.				0.0	7	
		10	208	101	10	Mach.	S			5.8		
		20	219	008	06	Gr.				0.0		
			219		00	Insp.				0.0	7	

PROC. BY Vogel EST. BY: RLR PART NO. OF NEXT ASSY. C-211 MAT'L LOCATION ISSUED DATE 7-11-70 PAGE 2 OF 7

SEQ. NO.	OPERATION DESCRIPTION - DETAIL	SERIAL NO. C 215-203-50-1	HEAT NO.	SPECIFICATION NO.	FOREMAN'S INITIAL	INSP.
00	Receive and inspect, check for any damage that might have occurred during shipment.		(1.0)			
10	Set up on engine lathe, part off stainless steel safe end at 2' 3 3/4" from centerline of MK-58 nozzle. Face to 2' 3 1/2" from centerline of MK-58 nozzle and form weld prep per Detail "F" on Drawing 154647E. Reposition: Part off carbon end of pipe to an O.A. length of 5' 2 5/8". Face to an O.A. length of 5' 2 3/8" and form weld prep per Detail "H" on same drawing.					
20	Blend grind if required to remove tool marks.					
00	Inspect machining.		(0.6)			

* R IN THIS COLUMN INDICATES RE-ESTIMATE

REV NO.	DATE	BY	DESCRIPTION	REV NO.	DATE	BY	DESCRIPTION

PROCESS SHEET
POK 31260-1

COPY 1

S. SHOP	SC-ORD-CP-EXP	UNIT	PART NO. GR	PART NO. MARK	CONTROL NO.	ITEM	QTY. REQ'D	PCS/ UNIT	PCS/ COMP.
	620-0003-50	1	21	C-215		Salvaged Pipe Ass'y.	1	1	1

MATERIAL SIZE	MATERIAL SPEC.	PMO-PC-LINE	UT. REQ'D	STOCK OR P.O. NO.	DRAWING NUMBER
	SA-106-C				See Page 1

START	FINISH	SEQ. NO.	CHG. SHOP	W.C.	OPER.	OPERATION DESCRIPTION - OUTLINE	STD* HRS.	SET UP	RUN	TOTAL	INSP PAPERS	CUST/ NAVY
		30	203	161	02	M.T.	S			0.8	10	
		40	203	561	32	Pr. Gr.				0.0		
		50	203	561	02	M.T.				0.0	10	
			219		00	Insp.				0.0	7	
		60	219	413	10	Wld.				0.0		
		70	219	408	06	Gr.				0.0		

PROC. BY Vogel | EST. BY RLR | PART NO. OF NEXT ASSY. C-211 | MAT'L LOCATION | ISSUED DATE 7-11-70 | PAGE 3 OF 7

SEQ. NO.	OPERATION DESCRIPTION - DETAIL	SPECIFICATION NO.	FORE-MAN'S INITIAL	INSP.
	SERIAL NO. C 215-203-50-1 / HEAT NO.			
30	M.T. weld prep on carbon end of pipe.	S-102 B		
40	Remove defects.			
50	Reinspect as required.			
00	Inspect and chart cavities.			
60	Repair weld.	W-52		
70	Blend grind repairs.			

* R IN THIS COLUMN INDICATES RE-ESTIMATE

REV NO	DATE	BY	DESCRIPTION	REV NO	DATE	BY	DESCRIPTION

PROCESS SHEET
PDX 31260-1

COPY 1

S. SHOP	SC-ORD-CT-EXP	UNIT	GR	MARK (PART NO.)	CONTROL NO.	ITEM	QTY. REQ'D	PCS/UNIT	PCS/COMPL
	620-0003-50	1	21	C-215		Salvaged Pipe Assembly	1	1	1

MATERIAL SIZE	MATERIAL SPEC.	PMO-PC-LINE	UT REQ'D	STOCK OR P.O. NO.	DRAWING NUMBER
	SA-106-C				See Pg. 1

START	FINISH	SEQ. NO.	CHG. SHOP	W.C.	OPER.	OPERATION DESCRIPTION - OUTLINE	STD.* HRS.	SET UP	RUN	TOTAL	DISP PAPERS	CUST/NAVY
			219		00	Insp.				0.0	7	
		80	203	561	02	M.T.				0.0	10	
		90	203	161	06	P.T.	S			1.0	9	

PROC. BY Vogel EST. BY RLR PART NO. NEXT ASSY C-211 MATL LOCATION ISSUE DATE 7-11-70 PAGE 4 OF 7

SEQ. NO.	OPERATION DESCRIPTION - DETAIL	SERIAL NO. C 215-203-50-1	HEAT NO.	SPECIFICATION NO.	FOREMAN'S INITIAL	INSP.
00	Inspect grinding.					
80	M.T. repaired areas.			S-102 B		
90	P.T. edge of cladding at carbon end of pipe. P.T. weld prep on S.S. end of pipe. NOTE: P.E. action is required if any defects exist in edge of cladding.			S-102 J		

* R IN THIS COLUMN INDICATES RE-ESTIMATE

REV NO.	DATE	BY	DESCRIPTION	REV NO.	DATE	BY	DESCRIPTION

PROCESS SHEET
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COPY 1

S. SHOP	SC-ORD-CP-EXP	UNIT	GR	PART NO. MARK	CONTROL NO.	ITEM	QTY REQ'D	PCS/UNIT	PCS/CONT.
	620-0003-04	1	13	C-215		Salvaged Pipe Assy.	1	1	1

MATERIAL SIZE	MATERIAL SPEC.	PMO-PC-LINE	UT. REQ'D	STOCK OR P.O. NO.	DRAWING NUMBER
	SA-106 C				Sec Page #1

START	FINISH	SEQ. NO.	CHG. SHOP	W.C.	OPER.	OPERATION DESCRIPTION - OUTLINE	STD. HRS.	SET UP	RUN	TOTAL	INSP. PAPERS	CUST/ NAVY
		101	219	538	14	Gr.						
			219		00	Insp.						
		102	203	561	06	P.T.						
		103	219	403	08	L.O.						
			219		00	Insp.						

PROC. BY Vogel | EST. BY | PART NO. OF NEXT ASSY. C-211 | MAT. LOCATION | DATE 7-11-70 | PAGE 5 OF 7

SEQ. NO.	OPERATION DESCRIPTION - DETAIL	SERIAL NO. C215-203-50-1	HEAT NO.	SPECIFICATION NO.	FOREMAN'S INITIAL	INSP.
101	Set up on I.D. grinder and grind to remove all defective cladding.					
00	Inspect grinding.					
102	Reinspect I.D. surface with P.T. as required.					
103	Layout the following areas and indicate as inconel for easy identification. Layout 6" dia. circle around MK 11 nozzle. Layout 12" dia. circle around MK 58 nozzle. Layout 6" wide area measuring from stainless steel end of pipe, (360°). Identify these (3) areas as inconel.					
00	Inspect layouts.					

* R IN THIS COLUMN INDICATES RE-ESTIMATE

REV. NO.	DATE	BY	DESCRIPTION	REV. NO.	DATE	BY	DESCRIPTION

PROCESS SHEET
PDX 31260-1

COPY 1

S. SHOP	SC-ORD-CP-EXP	UNIT	PART NO. GR	PART NO. MARK	CONTROL NO	ITEM	QTY. REQ'D	PCS/UNIT	PCS/CONT.
	620-0003-04	1	13	C-215		Salvaged Pipe Assy.	1	1	1

MATERIAL SIZE	MATERIAL SPEC.	PMO-PC-LINE	UT REQ'D	STOCK OR P.O. NO.	DRAWING NUMBER
	SA-106 C				See Page #1

START	FINISH	SEQ. NO.	CHG. SHOP	W.C.	OPER.	OPERATION DESCRIPTION - OUTLINE	STD* HRS.	EST. MANHOURS SET UP	RUN	TOTAL	INSP. PAPERS	CUST/NAVY
		104	219	566	11	Auto. Clad						
			219		00	Insp.						
		105	219	413	10	Wld.						
			219		00	Insp.						
		106	219	408	06	Chip						

PROC. BY Vogel | EST. BY: | PART NO. OF NEXT ASSY. C-211 | MAT'L LOCATION | ISSUED DATE 7-11-70 | PAGE 6 OF 7

SEQ. NO.	OPERATION DESCRIPTION - DETAIL (SERIAL NO. C215-203-50-1; HEAT NO.)	SPECIFICATION NO.	FOREMAN'S INITIAL	INSP.
104	Set up and sub arc clad I.D. of pipe with (1) layer of S.S. clad. Use single wire deposit. DO NOT clad (3) areas marked inconel.	W-52-4		
00	Inspect cladding.			
105	M.M.A. clad (3) remaining areas with inconel. Tie in with stainless steel.	W-52-4		
00	Inspect for sufficient cladding.			
106	Take chip samples from S.S. cladding.			

* R IN THIS COLUMN INDICATES RE-ESTIMATE

REV. NO.	DATE	BY	DESCRIPTION	REV. NO.	DATE	BY	DESCRIPTION

PROCESS SHEET
POX 3:260-1

COPY 1

S. SHOP	SC-ORD-CP-EXP	UNIT	GR	MARK (PART NO.)	CONTROL NO.	ITEM	QTY. REQ'D	PCS/ UNIT	PCS/ CONT.
	620-0003-04	1	13	C-215		Salvaged Pipe Assy.	1	1	1

MATERIAL SIZE	MATERIAL SPEC.	PMO-PC-LINE	UT. REQ'D	STOCK OR P.O. NO.	DRAWING NUMBER
	SA-106 C				See Page #1

START	FINISH	SEQ. NO.	CHG. SHOP	W.C.	OPER.	OPERATION DESCRIPTION - OUTLINE	STD.* HRS.	ESTIMATED MANHOURS SET UP	RUN	TOTAL	INSP. PAPERS	CUST/ NAVY
		107	219	538	14	Auto. Gr.						
			219		00	Insp.						
		108	203	561	06	P.T.						
		109	203	561	04	U.T.						

PROC. BY Vogel | EST. BY: | PART NO. OF NEXT ASSY. C-211 | MAT'L LOCATION | ISSUED DATE 7-11-70 | PAGE 7 OF 7

SEQ. NO.	OPERATION DESCRIPTION - DETAIL	SERIAL NO. C215-203-50-1	HEAT NO.	SPECIFICATION NO.	FORE-MAN'S INITIAL	INSP.
107	Set up on I.D. grinder and grind I.D. to maintain 28" min. I.D.					
00	Inspect grinding, verify surface waviness.					
108	P.T. I.D. surface 100%.			S-102C-5		
109	U.T. I.D. surface 100%.			S-102S-3		

* R IN THIS COLUMN INDICATES RE-ESTIMATE

REV. NO.	DATE	BY	DESCRIPTION	REV. NO.	DATE	BY	DESCRIPTION

PROCESS SHEET
POX 31260-1

COPY 1