June 25, 1971
Dr. Stanley Weiss
4841 North Oakland
Milwaukee, Wisconsin 532

Mr. William C. Seidle
Senior Reactor Inspector
U. S. Atomic Energy Commission
Division of Compliance-Region II
230 Peachtree Street, N. W.
Suite 818
Atlanta, Georgia 30303

Dear Mr. Seidle:

In reference to Report No. DC 89, "Inspection of Leaks and Cracks in the (A) Steam Generator at H. B. Robinson II," June 23, 1971, I would like to offer the following opinions and recommendations:

(1) Westinghouse is primarily placing the blame for this leakage and cracking problem on the inadequacy and reliability problems associated with the explosion bonding cladding process. There is justification in placing high suspicion on this process. Experience has indicated that inconsistent bond integrity has been obtained on large, relatively complicated parts. For example, bond adhesion problems might be expected to localize in the central and outer edge portions of a component such as the steam generator. Although the basic principles and potential of this process have merit, the application of the process to various components often presents considerable practical difficulties.

The process dates back to the late 1950's and early 1960's and, is generally based on the Cowan, G. R., Douglass, J. J., and Holtzman, A. H., U. S. Patent No. 3,137,937 issued June 3, 1964 and assigned to E. I. du Pont de Nemours and Co. A typical cladding arrangement, as well as the basic operating principles are illustrated in Figure 1. After the explosive is detonated, the prime metal is accelerated very rapidly to a high velocity (V_p) by the detonation pressure. As the detonation front (D) moves across the plate, an angle is established between its undeflected and deflected portions. When the deflected portion of the prime metal collides with the backer plate, the region of high-pressure collision moves across the plates at high speed. This velocity (V_c) equals the detonation

velocity for the illustrated situation. Ahead of the collision region in each plate, high pressures cause surfaces of both metals to flow plastically into the space between the plates.

The jet which forms acts to remove surface films of oxides and of other materials normally detrimental to bonding. At the same time, the clean metal surfaces are subjected to high pressures in the collision region causing plastic deformation. The metals supposedly come into interatomic contact with each other, establishing a metallurgical bond.

Furthermore, difficulties have been experienced in the past in arriving at destructive testing techniques which result in obtaining reliable bond strength information.

Based on this failure and past experiences of manufacturers of large vessels, it is recommended that past and intended future application of this process be thoroughly reviewed.

(2) It is the writers opinion that the following factors contributed to this failure:

(a) Marginal clad bond integrity resulting from the explosive cladding process.
(b) High residual stresses resulting from welding of the divider plate to the clad tube sheet. These stresses probably further deteriorated the clad bonded interface and initiated separation.
(c) Operating and applied stresses then may have led to propagation of the clad bond separation resulting in failure and leakage.

(3) Undoubtedly boric acid solutions and residues have, by capillary action, penetrated up the sides of the tubing and along the propagating cladding cracks. At ordinary temperatures, 75°F, the boric acid solution is only slightly acidic, reflecting the weak ionization of the borate ion. The corrosivity of the solution at this temperature toward ordinary system materials, e.g., stainless steels, inconel is insignificant and can be disregarded. However, the existing condition can present problems because of the contact which has been made with the underlaying forged steel tube sheet and the potential of higher temperatures. Also, aerated boric acid solutions resulted in significantly higher rates

of corrosion as compared to deaereated boric acid solutions.

It is recommended that efforts be undertaken to analyze the potential hazards of this condition and the difficulties associated with eliminating the condition.

(4) It is recommended that the stress analysis currently being performed by Westinghouse be submitted, as soon as possible, for review by an independent, outside consultant (e. g., Parameter, Inc.).

(5) It is the opinion of the writer that generic aspects of this problem exist. Evidence of this has already occurred at the Robinson II site where two out of three steam generators already exhibit the problem. Furthermore, as a result of our conversations, it was indicated that the problem is imminent at other sites.

(6) The following observations opinions and recommendations are offered regarding the Westinghouse proposed repair procedure:

(a) The removal of defective areas should be performed in a careful and planned manner so as to enable a rigorous fracture analysis.
(b) Although the repair completion was estimated as one month, it is believed that this estimate is overly optimistic. The man hours required and working conditions imposed will probably result in a multiplication factor of 1 1/2 to 2 times the estimate.
(c) No mention was made in the procedure of methods or attempts for removing the trapped boric acid solutions.
(d) Detailed "in-process" and "final" inspection procedures were not described. Obviously far more than just the code requirements will be necessary for this repair. Mention was made of a secondary hydrotest as a check for leaks.
(e) Westinghouse is arranging to subcontract the localized stress relieving operation (Cooper Heat was mentioned). They will attempt to accomplish a localized heat treatment of the deposited repair cladding by designing and building equipment capable of heating the area of interest to 1000^{0}F. Westinghouse claims wide experience in accomplishing this type of weld stress relieve. This localized stress relief will result in high thermal gradients and stresses. Efforts

should be made to determine beforehand the effects this operation will have on the surrounding hardware (e. g., remaining explosion bonded interfaces, metallurgical effects in the thermal gradient region, etc.).

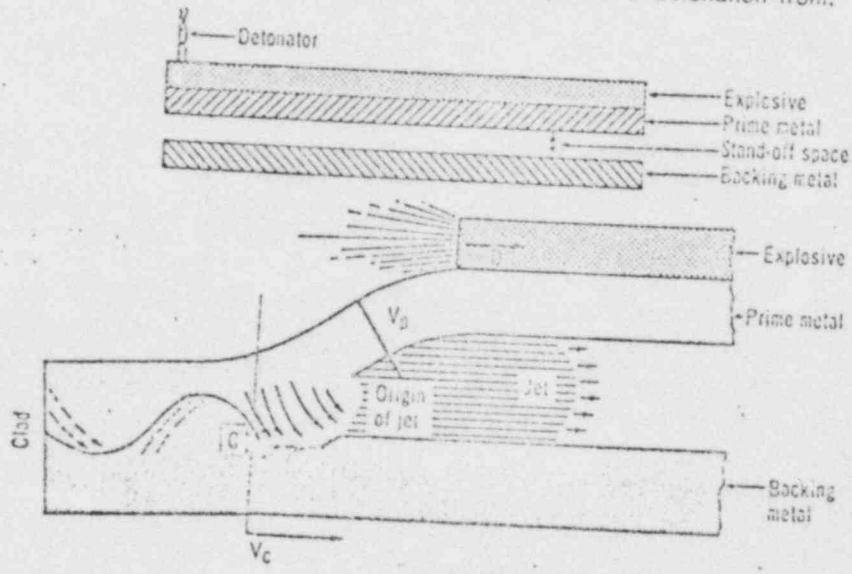
Very truly yours,

Stanley Weiss

Dr. Stanley Weiss

cc: DC-89 file
S. Weiss
Lett. Comm "A" file

Fig. 1—In bonding, the explosive and prime metal are placed together and spaced slightly away from the backing metal. When the explosive is detonated, the prime metal collides with the backer. Jetting, which takes place ahead of the collision, acts to clean the joint zone. V_p indicates prime metal velocity, V_c collision velocity, and D detonation front.



UNITED STATES
ATOMIC ENERGY COMMISSION
DIVISION OF COMPLIANCE
REGION II - SUITE 818
230 PEACHTREE STREET, NORTHWEST
ATLANTA, GEORGIA 30303

526-4503
TELEPHONE: XXXXXX

CO INQUIRY REPORT NO. 71-14

Carolina Power and Light Company
Docket No. 50-261
License No. DPR-23
H. B. Robinson No. 2

CLADDING SEPARATION IN STEAM GENERATOR NOS. 1 AND 3 (SUPPLEMENTAL INFORMATION TO INQUIRY REPORT NOS. 71-11, 71-12 AND 71-13)

Prepared By: D C Kirkpatrick 6/28/71
D. C. Kirkpatrick, Reactor Inspector Date

This report advances the highlights of a special inspection made to the subject facility on June 18, 1971, by D. C. Kirkpatrick and Dr. S. Weiss, AEC Consultant. A report of the visit also will be made by Dr. Weiss and will be attached to the forthcoming CO Report No. 50-261/71-08.

On May 27, shortly prior to the reactor shutdown due to turbine vibration, low level radioactivity was detected for the first time in water samples from the secondary side of the steam generators. The primary side domes of all three steam generators were entered and examinations were made which included visual observations, leak tests and ultrasonic tests. On June 18, the consultant and the inspector entered the No. 1 steam generator to make visual observations and to take photographs.

In both the No. 1 and No. 3 steam generators, the one-fourth-inch inconel tube sheet cladding has been pulled loose from its base metal in the area over the divider which separates the two halves of the lower dome. The separations extend laterally from both sides of the divider to the adjacent rows of seven-eighths-inch O.D. inconel tubes. A sectional view of the failure is shown in Exhibit A (provided by Westinghouse). The separation extends along the top of the divider to within six inches of each end of the divider. The separation area is shown in Exhibit B.

The cladding is cracked along the edge of the separation area. This crack extends to the bottom surface of the cladding in the cold leg sides of both steam generators. The cladding is also broken away from the tubes which are next to the divider so that the crack is continuous, proceeding across the web between two tubes, around the tube fillet weld, across the next web, around the next fillet and so on for 25 to 30 tubes. (See Exhibit B.) In

some cases the crack breaks through the wall of the tube rather than through the fillet weld. The crack tends to be small in the web between the tubes and wide in the fillet. One crack was measured to be about .025-inch wide. The crack is not visible on the hot leg side of either of the two damaged steam generators, probably because the tubes are farther from the divider on that side.

Two leaks emanate from the crack in the No. 1 steam generator cladding at the rate of about one drop per minute with 800 psi of water pressure on the secondary side. Small amounts of rust were observed at numerous locations along the No. 1 steam generator crack.

No damage was observed in the No. 2 steam generator.

A discussion on the problem was attended by representatives of Compliance, CP&L and Westinghouse on June 18.

Westinghouse attributed the failure to inadequate bonding strength between the cladding and the tube sheet. The cladding had been applied by the "explosive" method. Samples of explosively applied cladding, tested by Westinghouse, proved to be inhomogeneous in bond strength, varying from 30,000 psi to 60,000 psi. It was postulated that the failures started during the 3106 psi hydrostatic test and have spread since then due to expansion and contraction during thermal cycling. The calculated stress in the cladding to tube sheet bond was 20,000 psi over the divider during the hydrostatic test.

The divider to cladding fillet welds have not been stress relieved. It was stated that Westinghouse had stress relieved similar welds at their plant and thermal stresses had broken the cladding loose during the treatment.

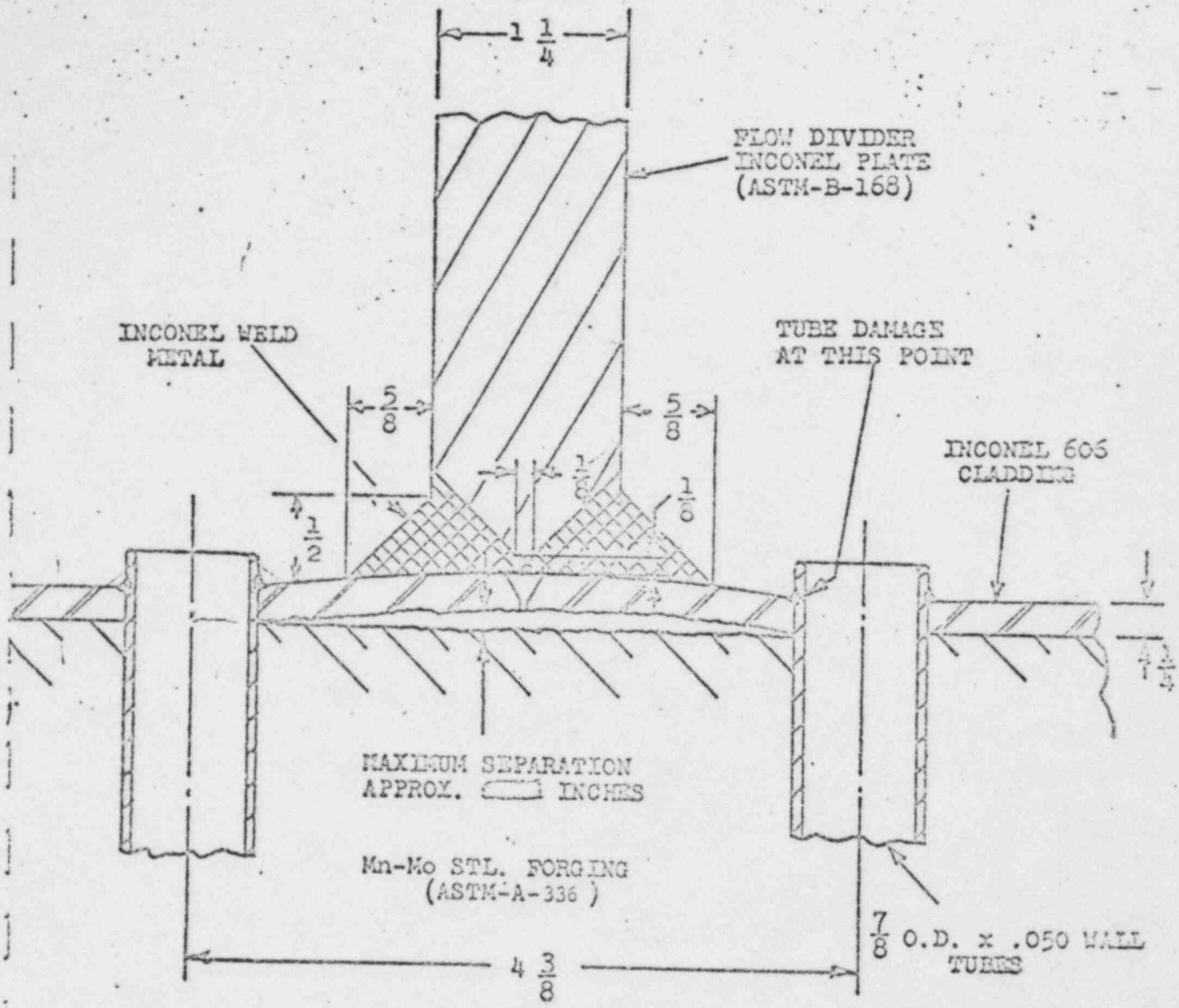
Since the steam generators are under warranty, Westinghouse is responsible for the repair effort, with CP&L providing radiation control. The main repair steps include:

1. Removing the cladding over the divider, out to a line between the first and second rows of tubes on either side of the divider. (See Exhibit B.)

2. Removing enough of the top of the divider to provide access to the space above the divider for rewelding the cladding.

3. Grinding off the first row of tubes on each side of the divider flush with the tube sheet and plugging these tubes.

4. Replacing the cladding by weld overlay which will also cover over the ends of the plugged tubes.



CP & L CLAD SEPARATION

FIG. 1

Exhibit A
Page 1 of 1

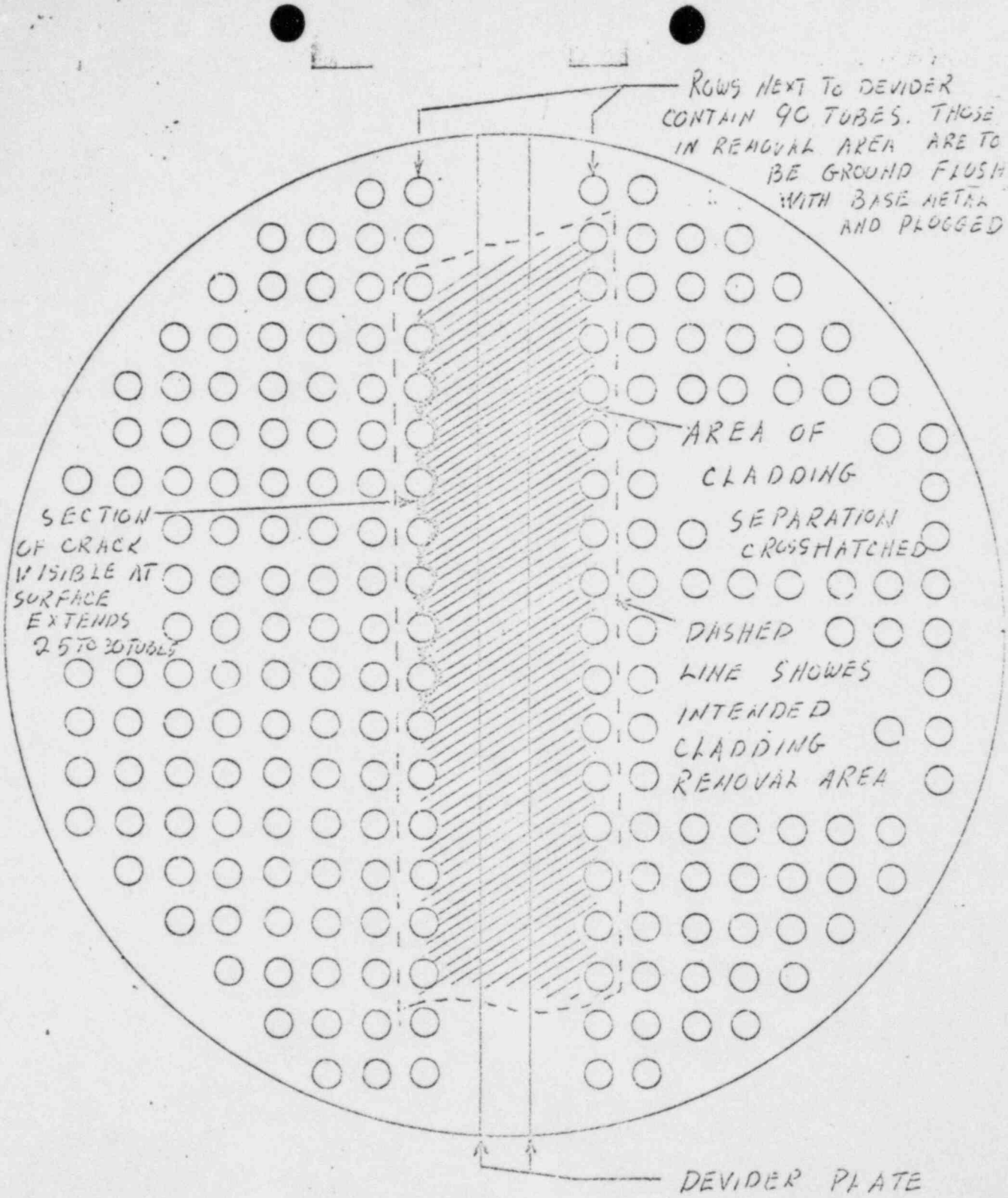


FIG 2.

DIAGRAM OF TUBE SHEET. TUBE HOLES ARE ENLARGED FOR CLARITY. STEAM GENERATOR ACTUALLY HAS 3260 U TUBES

6/19/71

MR JOHN DAVIS - DIRECTOR
A.E.C. REGION II COMPLIANCE OFFICE
SUITE 818
230 PEACHTREE ST, NORTH EAST
ATLANTA, GA 30303

DEAR MR DAVIS

DUE TO THE CURRENT WESTERN UNION STRIKE WE ARE UNABLE TO SEND A TELEGRAM TO COMPLY WITH DPR-23 TECHNICAL SPECIFICATION 6.6.1.C. WE HOPE YOU ACCEPT THIS HANDWRITTEN LETTER AS A SUBSTITUTE.

A LEAK HAS BEEN DETECTED IN A STEAM GENERATOR. THIS FALLS UNDER ABNORMAL OCCURRENCE DEFINITION 1.8.e. THE PROBLEM IS BEING INVESTIGATED BY OUR CONTRACTORS & IT HAS BEEN FOUND THAT THE LEAK IS DUE TO CRACKING OF THE TUBE SEAL WELDS AT THE TUBE SHEET DUE TO A SEPARATION OF THE INCONEL CLADDING FROM THE TUBE SHEET. THIS SEPARATION HAS BEEN FOUND IN TWO

STEAM GENERATORS. WE ARE PROCEEDING WITH REPAIRS.

MR. DON KIRKPATRICK OF YOUR STAFF HAS BEEN KEPT FULLY INFORMED FROM THE TIME WE FIRST SUSPECTED THE LEAK. A DETAILED REPORT WILL FOLLOW WHEN AVAILABLE.

YOURS TRULY

Guy P. Beatty

Supt. H. B. Robinson Plant

Report on
Inspection of Leaks and Cracks in the (A) Steam Generator at H. B. Robinson II

Report No. DC 89 June 23, 1971

Prepared for: U. S. Atomic Energy Commission
Division of Compliance
AEC Contract AT (11-1)-1658
Subcontract No. 10

by: Dr. Stanley Weiss
Materials Department
University of Wisconsin-Milwaukee

through: Parameter, Inc.
Consulting Engineers
Elm Grove, Wisconsin

NOTICE

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Dr. S. Weiss (1)

I. Discussions and Observations Prior to Inspection

A visit was made to the H. B. Robinson II site by Mr. Donald Kirkpatrick of Region II and the writer on June 18, 1971 to review and inspect the reported leaks and cracks occurring in the A steam generator.

Prior to the inspection, discussions were held with Messrs. G. P. Beatty and R. Bessac of Carolina Power and Light. We were informed that we would be allowed into the steam generator for only a limited time (approximately 12-15 minutes) because of existing conditions and their safety requirements. The following information was presented to us during these inital discussions:

(1) The inconel cladding overlay was bonded to the base plate by the explosion bonding process.

(2) Continuous leaks in the form of droplets were observed in the A generator in two locations, approximately in the region of the 40th and 44 tubes, as counted from the north direction towards the south, in the row of tubes adjacent to the divider plate in the cold leg of the generator.

The C steam generator was reported to exhibit dampness but no droplet formation, whereas, the B generator was reported as dry with no apparent leaks.

(3) Ultrasonic testing performed by Westinghouse indicated that separation had occurred at the bond interface between the cladding and the 22 inch thick tube sheet material between the rows of tubes immediately adjacent to the divider plate

in the hot and cold legs of the A generator. The bond separation is believed to be extensive so as to encompass at least 80 tubes along these first rows. Ultrasonic testing further indicates that bond separation between the cladding and base plate ceases approximately at the mid-point of each of the first rows of tubes adjacent to the divider plate.

(4) Cracks were reported in the fillet welds extending through the cladding between the tubes containing the cracked fillets in the cold leg of the A generator. Approximately 20 to 30 tube fillets were reported as visually cracked.

(5) It was reported that the C generator was dry boiled whereas the A and B generators were not.

(6) Preliminary reports indicate that Point Beach may be experiencing a similar problem although the intensity of the problem is not yet fully known.

II. Inspection of the Steam Generator

Mr. Kirkpatrick and the writer were "suited-up" and proceeded to enter individually and inspect the cold leg of the A steam generator. The inspection was performed visually using a low power magnifying lens. Mr. Kirkpatrick attempted to photograph the conditions we observed with a 35 mm. camera using a close-up lens. The following conditions were observed during this inspection: (See Figs. 1,2 &3

(1) Severe cracks were present in the fillet welds of approximately 30 tubes. The highest intensity of fillet cracking was apparent in the region included in and surrounding the 35th

to 45th tubes (a[illegible]counted from the north toward[illegible]he south). These cracks were opened approximately . 030 to . 050 inches and were approximately semi-circular on the side of the fillet welds facing the flow divider plate.

(2) Cracking in the 1/4 inch thick cladding was extensive in the region described above. These cracks were linear in the north-south direction (parallel to the divider plate) and were located approximately in line with the center of the first row of tubes. These cracks were tighter than those observed in the fillets and appeared to range in the vicinity of . 005 to . 010 inches wide and extended the entire length of the cladding between the cracked tubes.

(3) Rusting and corrosion products were observed in the immediate vicinity of the fillet weld cracks progressing into the cladding cracks. This evidence shows that galvanic action and electrochemical corrosion has already occurred between the tube sheet material and the austenitic materials involved, through the borated solution which acted as an electrolyte.

(4) The writer visually observed a contoured region of the cladding, adjacent to the divider plate and in the vicinity of the 40th to 50th tubes that showed definite signs of having been separated from the tube sheet.

(5) Linear crack indications in the fillet weld joining the flow divider plate to the tube sheet cladding were observed. These

cracks appeared to be very tight, were located in the toe of the weld adjacent to the cladding and, were aligned in the direction of the weld.

(6) The fillets of the tube welds appeared to be undersized in various locations. A throat size of 1.5 T is required for this joint where T is nominally .050 inches, the tube wall thickness.

(7) Inspection of the fillet weld joining the opposite end of the flow divider plate to the steam generator wall indicated no apparent defects.

(8) The divider plate is located significantly closer to the first row of tubes in the cold leg of the A generator than to the first row of tubes in the hot leg of this generator.

III. Post Inspection, Discussions, and Observations

In the late afternoon a meeting was held between Mr. Kirkpatrick, myself and personnel from CP and L, Westinghouse and Ebasco as indicated by the attached meeting list. The personnel shown on this list had participated during the morning and early afternoon of June 18 in a closed meeting to review the cause of the problem and proposed repair procedures. Pertinent facts brought out by our later discussions with them were as follows:

(1) During the initial manufacturing of these steam generators all processing was completed with the exception of the fillet weld joining the flow divider plate to the tube sheet. Prior to completing this joint, the unit was stress relieved to code requirement. The final weld joining the divider plate to the

tube sheet was then performed without any subsequent stress relief.

(2) Westinghouse has not arrived at final conclusions with regards to the cause of the overall problem. They will attempt to perform a failure analysis based on samples removed during the intended repair. At this time they believe the problem is primarily related to deficiencies in the bond strength associated with the explosive cladding process (commercial process generally used is "Detaclad"). They believe that stress relief, operating stress conditions, and stress vibration considerations were not primary factors in causing this failure.

(3) Westinghouse has eliminated the explosion cladding process based on numerous difficulties which they have experienced with obtaining consistent bond strengths. They have reverted back to conventional arc fusion cladding techniques.

(4) Westinghouse reported that the worst stress condition which they believe the A generator had been subjected to was a one-time hydrotest subjecting it to 3106 pounds on the chamber side. They believe this resulted in a 40,000 psi stress in the divider plate and consequently a 20,000 psi stress on the cladding. Although they have experienced widely varying bond strengths in the explosion clad tube sheet (reportedly ranging from 30,000 to 50,000 psi), they are not able at this time to determine

whether or not the hydr' :st performed initiated the failure.

(5) Westinghouse stated that no serious problems are anticipated related to boric acid attack resulting from the leakage which had occurred. They furthermore indicated that stress corrosion and hydrogen cracking problems will not arise.

(6) When asked about the adequacy of their stress analysis of this vessel Westinghouse replied that they are currently undertaking a thorough re-study of this subject.

(7) When questioned with regards to the anticipated life of a repaired vessel, Westinghouse replied that they believe the repair will eliminate the defective areas and perform in a service manner so that reoccurrence of the problem is precluded. It was admitted, however, that a more complete answer to this question would be forthcoming when the failure analysis and factual reasons for the cause of the problem have been determined.

(8) Westinghouse personnel stated they do not have sufficient information at this time to determine the generic nature of the problem; however, it is their belief at this time that it is not widespread. No data or information was presented at this time to substantiate this opinion.

(9) Ultrasonic inspection by Westinghouse of the hot leg of the A generator has confirmed that separation has occurred between the cladding and tube sheet. Although there is no visual confirmation of cracking in this location, it is suspected that a cracking condition does exist.

(10) A repair procedure proposed by Westinghouse was described to us. The following repair considerations were discussed:

(a) A minimum amount of material, including the fillet welds, be removed from the divider plate.

(b) Defectively bonded cladding will be removed by arc and grinding methods.

(c) Attempts will be made to utilize the removed material as the basis for a failure analysis study to implement a more thorough understanding of the cause of the basic problem.

(d) The tube sheet will be re-clad using shielded metal arc (coated electrodes) techniques and the cracked tubes will be ground back and permanently blocked off by seal-welding.

(e) The repaired region will be locally stress relieved at 1000°F prior to accomplishing the final weld between the flow divider plate and the tube sheet.

(f) The final divider plate to tube sheet weld would then be performed without any subsequent stress relieving.

(g) Inspection procedures planned were to perform penetrant testing to the code requirements. When asked if that was the only non-destructive testing to be performed, it was stated that supplementary ultrasonic testing will be used

at their discretion to assure adequacy of the repair.

Stanley Weiss

Dr. Stanley Weiss
Wisconsin P. E. 11316

CP&L STEAM GENERATOR

REPAIR MEETING

June 16, 1971

N. B. Bessac	CP&L
W. W. Lowe	CP&L
B. H. Webster	CP&L
C. M. Clark	CP&L
G. P. Beatty, Jr.	CP&L
W. J. Fretague	Ebasco Services, Inc.
R. E. Cantrell	Westinghouse, Tampa
F. K. Shealy	Westinghouse, Atlanta
A. Lohmeier	Westinghouse, Tampa
R. F. Lehr	Westinghouse, PWRSD
W. Beers	Westinghouse, Tampa
S. Wismer	Westinghouse, Tampa
C. J. "Clete" Weber	Westinghouse, Tampa
W. M. Byerley	Westinghouse, Tampa
G. V. Burleson	Westinghouse, Raleigh
F. X. Brown	Westinghouse, Tampa

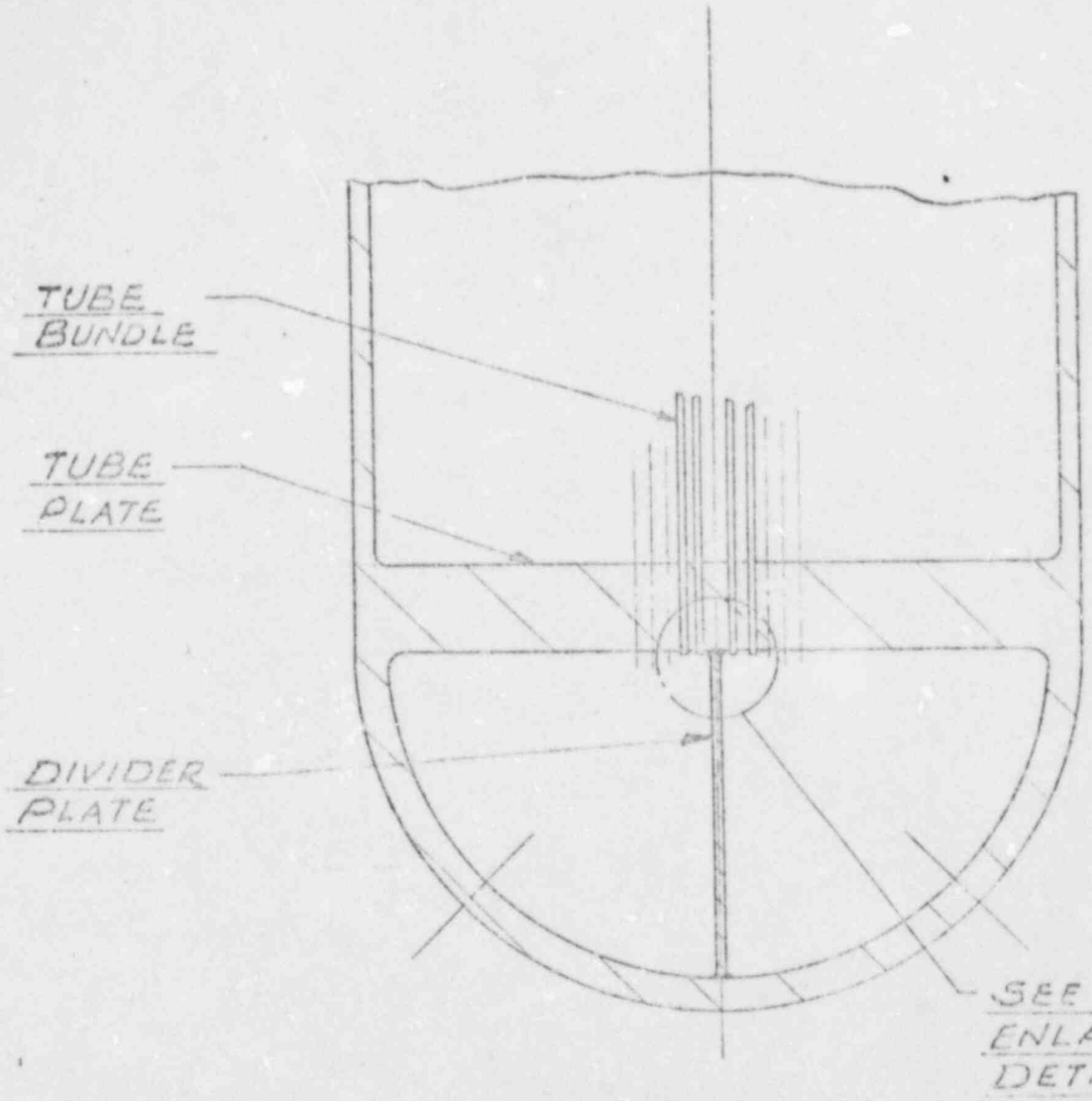

FIG. 1
"A" STEAM GENERATOR

REPORT DC-89
CONT. - AT(11-1)-1658, TASK
LEAKS & CRACKS IN
"A" STEAM GENERATOR
H.B. ROBINSON II
BY: D.S. 6/25/71

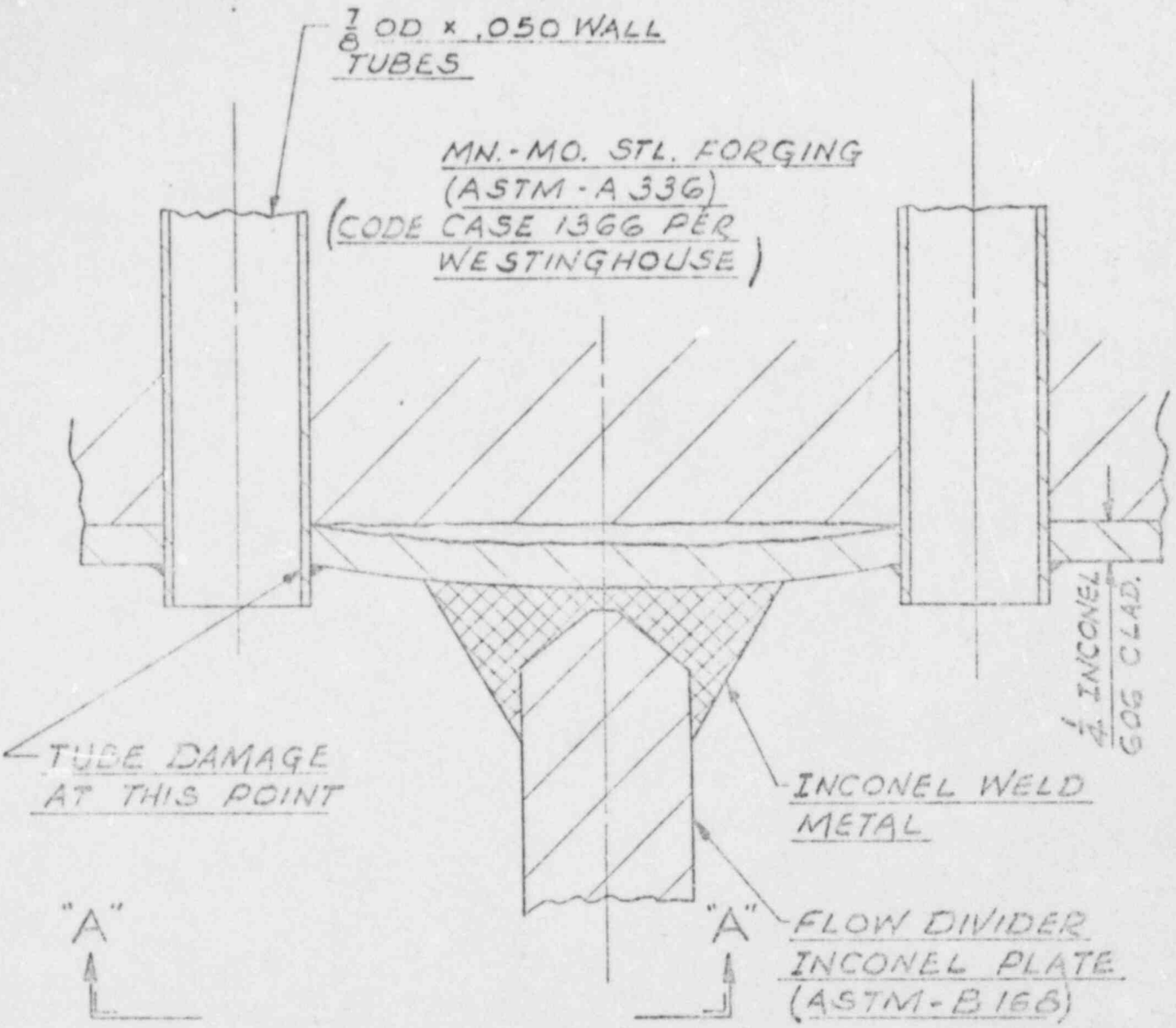

FIG. 2
ENLARGED VIEW OF CLAD SEPARATION

REPORT DC-89
CONT. AT(11-1)-1658 TASK A
LEAKS & CRACKS IN "A" STEAM GENERATOR
H. B. ROBINSON II
BY: D.S. 6/25/71

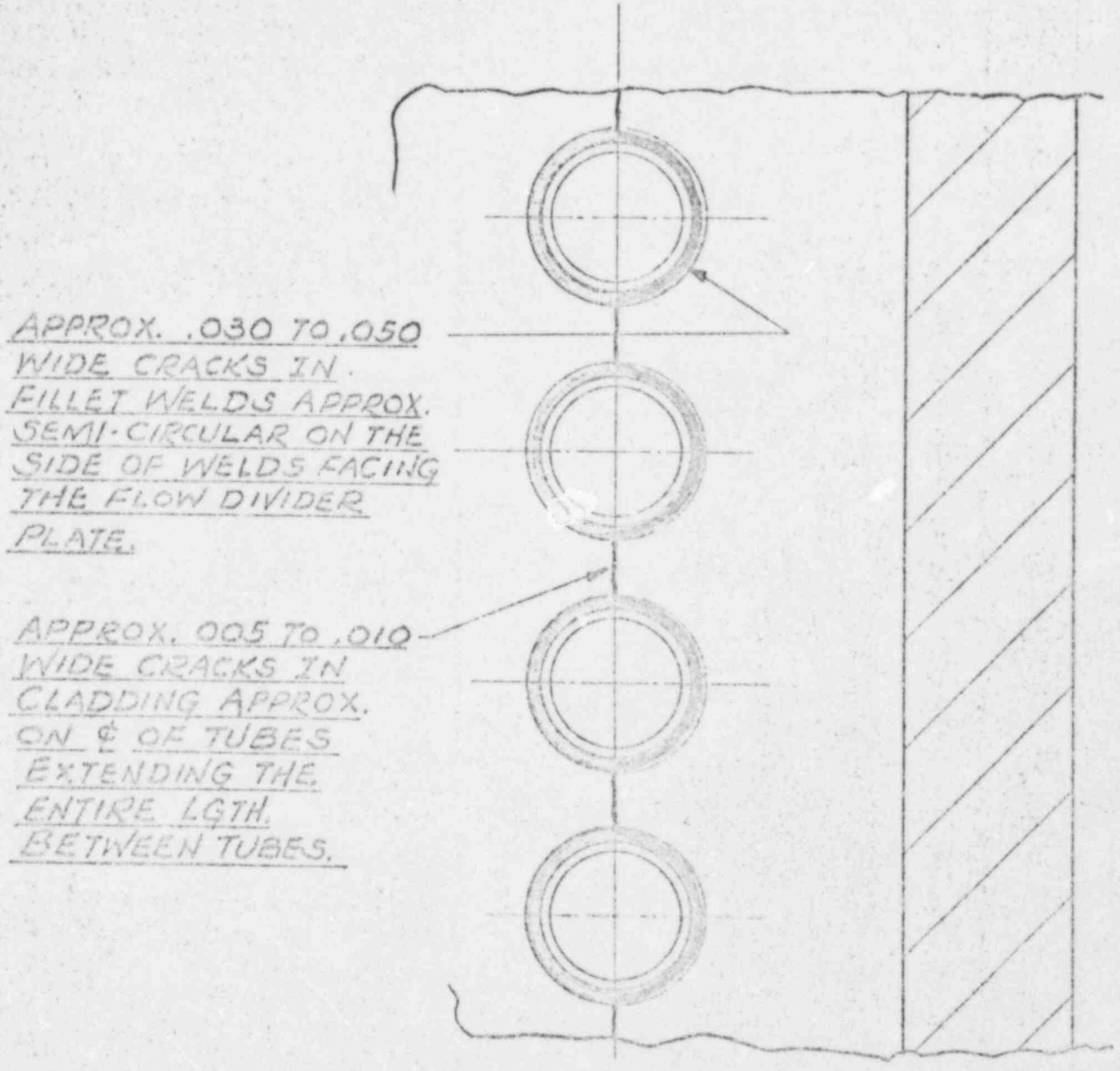

FIG. 3
VIEW "A-A"
FROM FIG. 2

REPORT DC-89
CONT-AT(11-1)-1658 TASK A
LEAKS & CRACKS IN
"A" STEAM GENERATOR
H. B. ROBINSON II
BY: D.S. 6/25/71

ENCLOSURE 3

WESTINGHOUSE STEAM GENERATOR PROBLEM
OTHER APPLICABLE REACTOR FACILITIES

Reactors	No. of Units
Ginna	2
Turkey Point 3	3
Turkey Point 4	3
Indian Point 2	4
Indian Point 3	4
Robinson 2	3
Point Beach 1	2
Point Beach 2	2
Surry 1	3
Salem 1	1
Diablo 1	1

ENCLOSURE 4

WESTINGHOUSE STEAM GENERATOR PROBLEM
INFORMATION RELATED TO OTHER PWR FACILITIES

1. Ginna - No inspections of the steam generators have been performed. There has been no indication of primary to secondary steam generator leakage to date.

2. Point Beach 1 - No inspections of the steam generators have been performed. A primary to secondary steam generator leak rate of 80 gallons per day has been experienced. The cause of the leakage has not yet been determined.

3. Point Beach 2 - Westinghouse personnel have performed visual and ultrasonic inspections of the cladding on both steam generators. No defects were detected. The preoperational hydrostatic test has been performed.

4. Indian Point 2 - Westinghouse personnel have performed visual and ultrasonic inspections of the cladding on all four steam generators. Cladding failures, similar to that experienced at Robinson, have been experienced on each of the four steam generators.

5. Turkey Point 3 - Westinghouse personnel have performed visual and ultrasonic inspections of the cladding on all three steam generators. Cladding failures, similar to that experienced at Robinson, have been detected on two of the three steam generators.

6. Turkey Point 4 - Westinghouse personnel have performed visual and ultrasonic inspections of the cladding on all three steam generators. No defects were detected. The preoperational hydrostatic test has not been performed.