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SUPERHEATER EVALUATION STUDIES FOR DD931/DD945 CLASS  
BABCOCK & WILCOX BOILERS

NSL PROJECT B-494  
May 1962  
by

W. A. FRITZ, JR.  
T. P. TORSI, JR.

**NAVAL BOILER AND TURBINE LABORATORY**  
**PHILADELPHIA NAVAL SHIPYARD**  
**PHILADELPHIA 12, PENNA.**



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ABSTRACT

Three ships of the DD931 Class experienced tube failures in the superheater third pass. All failures occurred in the same tube row and all boilers inspected revealed similar patterns of fireside corrosion, wall thinning and overheating. Tubes of the USS BARRY (DD933) were inspected and found to have experienced wall thinning up to 54% in certain areas, although no failures. The Naval Boiler and Turbine Laboratory was assigned the responsibility of planning and directing an investigation aboard the USS BARRY in order to evaluate boiler conditions and determine the cause of wall thinning and tube failures. Metal temperatures as high as 1390°F were observed. Various superheater modifications including gas baffling and superheater tube removal were made; appreciable reductions in metal temperatures were observed. Calculations based on the investigation data determined the optimum class modification required to reduce tube metal temperatures.

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ADMINISTRATIVE INFORMATION

This project was authorized by BUSHIPS ltr DD931 C1/9510; DD945 C1/9510; Ser 651A-947 of 29 June 1961. Approval for the superheater investigation to be conducted aboard the USS BARRY (DD933) was given by the Commander, Destroyer Force, United States Atlantic Fleet by COMDESLANT dispatch 031946Z of July 1961. Boston Naval Shipyard Request for Performance of Work WR2-0202 of 7 July 1961 provided funds to the Naval Boiler and Turbine Laboratory for the instrumentation of one boiler on the USS BARRY and consultant services for conducting the evaluation. BUSHIPS ltr DD933; Ser 651A-1007 of 27 July 1961 directed that a representative from the Naval Boiler and Turbine Laboratory head the personnel conducting these evaluations.



BACKGROUND

Superheater tube failures by bursting have occurred in superheaters of DD931 Class Babcock & Wilcox boilers. Table 1 gives pertinent facts on failures.

Table 1DD931 Class Superheater Failures

Ship	Boiler	SH* Tube	Steaming Hours @ Failure
USS FOREST SHERMAN (DD931)	1A	19B	11,892
	1B	19A	11,819
	2B	19B	12,200
USS JOHN PAUL JONES (DD932)	1B	19B	—
USS MANLEY (DD940)	—	19A	—

\*NOTE: Tubes numbered 1 through 45 bottom to top, end A through H from furnace side to generating bank side of superheater.

All superheater tube failures had the following similarities:

- a. Location of all failures was in tubes of the 19th row from the bottom on the furnace side leg. This 19th row is the top tube row of the lower furnace side header section and has a 2-1/2" space between it and the bottom tube row (20) of the upper header section. The 19th row is in the third pass; the 20th row in the second pass.
- b. All tube failures occurred on the outer loop or in the second loop in (the A or B leg).
- c. All ruptures occurred on the tube side facing the furnace.
- d. All ruptures occurred approximately 30" from the superheater header.

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e. All ruptures were thick lipped but varied in size from slits with little bulging to rather large ruptures (4" long x 1-3/4" across the opening) with much bulging.

f. Tube walls in the area of the ruptures had thinned from the gas side on that portion of the tubes facing the furnace. This was especially so in the outer loop tubes, and thinned tubes included tubes from at least the 8th tube from the bottom to the 19th tube from the bottom.

g. All failed tubes were 18 Cr - 8 Ni alloy with nominal wall thickness of 0.156". All tubes in the 3rd and 4th pass are of this material.

During examination of boilers 2A and 2B on FORREST SHERMAN on 5 May 1961, it was noted that there was quite a difference in appearance between the superheater tubes of the top two passes and those of the bottom two. It was noted that the bottom two passes showed signs of corrosion and overheating toward the rear that were not nearly as evident toward the front, and that these signs were non-existent in the upper two passes.

Observations similar to the above were repeated on boiler 13 of JOHN PAUL JONES on 16 May 1961 and were verified by special inspection of FORREST SHERMAN on 31 May 1961 when it was also determined that the 19th, 18th, 17th, 16th and 15th tubes from the bottom showed very definite signs of corrosion as compared to the tubes below them.

Inspection of the USS BARRY (DD933) superheaters from furnace and cavity in early July 1961 showed a similar pattern from the firesides,

but not nearly as accentuated as on FORREST SHERMAN and JOHN PAUL JONES. The difference was undoubtedly due to the fact that BARRY boilers had fewer steaming hours than the boilers of the other two ships.

It was fairly well established that failure of the superheater tubes could be attributed to wall thinning caused by fuel - ash corrosion and high tube metal temperatures. Materials Laboratory, Boston Naval Shipyard (refer to Report No. 1534 of 29 June 1961) estimated that a fractured tube from the FORREST SHERMAN had reached a temperature in the vicinity of 1300°F during boiler operation. This was verified by separate Boiler and Turbine Laboratory data wherein it was determined that the failed tube from JOHN PAUL JONES had operated in the region of 1400°F (refer to Plate 1). Materials Laboratory, Boston Naval Shipyard also determined that superheater tubes from the BARRY experienced up to 54% wall thinning in the A row and up to 48% in the B row, with maximum thinning occurring at tube 19A. It was concluded that this thinning was due to external corrosive attack by fuel oil ash.

It is known that high tube metal temperatures, especially above 1250°F are a prime factor to be considered as concerns the amount and extent of corrosion from residual fuel oil ash. The amount of erosion-corrosion which takes place in a particular boiler will also depend upon gas temperatures and gas velocities entering the various sections of the superheater and the amount and condition of the ash carried along with the gases of combustion. It has been considered that perhaps both gas flow and steam flow maldistribution have increased the corrosion

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rate on the superheaters in boilers of the FORREST SHERMAN type. To somewhat improve gas flow distribution and to provide some initial improvement in the superheaters of the DD931 and DD945 Class, a gas baffle for installation in the space between the 2nd and 3rd passes on the superheater furnace side was recommended by NSTL and was authorized by Bureau of Ships dispatch 022038Z of 1 June 1961.

The superheaters of the DD931 Class Babcock & Wilcox boilers have four passes containing a total of 180 U-type tubes. Each tube row consists of four separate U-loops so arranged that the space between legs of the innermost loop provides sufficient room for a person to enter the superheater cavity. Both inlet and outlet headers are on the generating bank side of the superheater with the inlet header being at the top. Two rows of staggered two-inch screen tubes are located between the furnace and the superheater bank. Superheater tubes of the first two passes are 1-1/4" OD by 0.156" thick and are to Military Specification MIL-T-16286B, Class e which is 2-1/4% Cr, 1% Mo. Tubes of the last two passes are 1-1/4" OD by 0.156" thick and are to the same specification, but are class f which is 18% Cr, 8% Ni, austenitic. The working pressure of the superheater is 1250 psig and the steam temperature at the superheater outlet is a minimum of 921°F at cruising and full power not to exceed 970°F at any rev.

Bureau of Ships ltr DD931 C1/9510, DD945 C1/9510; Ser 651A-947 of 29 June 1961 and Boston Naval Shipyard Request for Performance of Work WR2-0202 of 7 July 1961 requested that Babcock & Wilcox DD931/DD945 Class boilers be evaluated to determine the conditions in the superheaters

which led to tube thinning and failure. These evaluations were conducted on Boiler 2B of the USS BARRY (DD933) in accordance with the Agenda, Appendix I. Some portions of the Agenda such as excess air and high speed lighting off runs were not conducted since high superheater tube temperatures were observed and evaluated during normal boiler operations.

Knowledge gained from this evaluation resulted in a class modification (Condition D - see "Purpose of Test") which was installed on all boilers of the USS JOSEPH PAUL JONES by direction of Bureau of Ships dispatch 252026Z of October 1961.

#### REPORT OF INVESTIGATION

##### PURPOSE OF TESTS

The primary consideration of this evaluation was to make an analysis of a superheater in a DD931 Class Babcock & Wilcox steaming boiler to determine (1) conditions under which tube corrosion is taking place, (2) what measures can be taken to extend superheater life, and (3) methods that can be used to predict superheater tube life. These objectives were obtained by instrumenting one superheater to primarily determine the following: (1) tube metal temperatures in the second, third, and fourth pass superheater tubes, (2) steam temperatures at various locations in the superheater steam passes; (3) combustion gas temperatures in the superheater cavity; and (4) supplementary information to assist in making a complete analysis of the problem. Pertinent plan drawings are shown in Plate 2, sheet 1 through 4.

This evaluation was conducted on Boiler 2B of the USS BARRY (DD933) with the following boiler conditions (refer to Plate 3) existing for

each phase of testing:

a. Condition A - Original configuration of USS BARRY Boiler 2B. This configuration is the same as the final configuration of the Laboratory's DD931 Class test boiler as reported under NBTL Report B-168.

b. Condition B - Same as Condition A except that a refractory brick baffle was added in the lane between the second and third superheater passes (Tube 19 and 20) extending over the entire furnace depth.

c. Condition C - Same as Condition A except that superheater tube row 19 (plan pieces 805, 806, 807 and 808) and third pass inner loop tubes 14 through 18 (plan piece 808) were removed. A refractory brick baffle was placed between superheater tube rows 18 and 20, which extended over the entire furnace depth.

d. Condition D - Class modification arrived at by evaluation of data obtained during conditions A, B, and C testing aboard the USS BARRY. This boiler condition is the same as condition A except that tube row 19 (plan pieces 805, 806, 807 and 808) and the entire third pass inner loop tubes (plan piece 808) are removed. In order to maintain the support structure of the superheater, cast slugs are installed in the spaces left by the removed tubes as shown in Plate 4.

#### METHOD OF TEST

##### General

These evaluations were conducted on Boiler 2B of the USS BARRY (DD933) in conjunction with Post Repair Trials out of Boston Naval Shipyard during September and October 1961, in accordance with the

Agenda, Appendix I. Installation and initial checkout of all instrumentation was completed on 28 September 1961. The complete shipboard testing program ran from 29 September to 9 October 1961; of this time, four days were required to complete the evaluation of the shipboard boiler Conditions A, B, and C, while the intermediate working days were consumed in completing boiler modifications to Conditions B and C.

The Laboratory was assigned the responsibility of planning, coordinating, conducting, evaluating and reporting on the test with assistance from the Boston Naval Shipyard and ship's complement.

#### Instrumentation

The arrangement and details of instrumentation for the superheater evaluation was as shown in Plate 5, and is summarized as follows:

a. Tube Metal Temperatures - A total of eleven thermocouples were installed on the outer skin of the superheater tubes with all hot junctions in the gas path 30" from the centerline of the superheater headers. Starting to count superheater tubes from the bottom, last pass, and labeling tube legs A to H beginning with the furnace side leg, the following tube locations had thermocouples: 1A, 1E, 6A, 6E, 8H, 9A, 13A, 18A, 19A, 19B, and 20A.

b. Steam Temperatures - Thermocouples were installed to indicate steam temperature in the various superheater circuits. These were installed in the superheater tubes adjacent to the superheater headers in the header vestibule. Using the same numbering procedure as in subparagraph A above, these steam temperature thermocouples were located as follows:

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(1) Boiler Conditions A and B - Total of 32 thermocouples located at: 1A, 1D, 1E, 1H, 8A, 8D, 8E, 8H, 9A, 9D, 9E, 9H, 13A, 13H, 16A, 18A, 18H, 19A, 19D, 19E, 19H, 20A, 20D, 20E, 20H, 27A, 27H, 31A, 31H, 32A, 32H, and 42A.

(2) Boiler Condition C - Total of 36 thermocouples located at: 1A, 1D, 1E, 1H, 3A, 3H, 5A, 5D, 5E, 5H, 8A, 8D, 8E, 8H, 9A, 9D, 9E, 9H, 13A, 13H, 16A, 18A, 18C, 18F, 18H, 20A, 20D, 20E, 20H, 27A, 27H, 31A, 31H, 32A, 32H, and 42A.

c. Two multi-shielded high velocity thermocouple probes were installed in the superheater cavity to obtain gas temperatures. One was located in the gas path between the third and fourth passes and the other between the second and third passes. These probes could be traversed through the furnace depth.

d. Five thermocouples were installed in the gas path before, and five after the economizer.

e. A pencil type thermocouple was installed at the superheater outlet to measure final steam temperature.

f. Pencil type thermocouples were installed at both forced draft blower discharges to measure combustion air temperature to the boiler.

g. Economizer water inlet and outlet temperatures were measured by peened thermocouples.

h. CO<sub>2</sub>, CO, and O<sub>2</sub> percentages in the stack gas were measured using a cone primary element and an Orsat apparatus for analysis and readout.

i. Ship's instrumentation was used to obtain fuel oil supply



pressure and the following steam pressures: steam drum, superheater outlet, desuperheater inlet, and desuperheater outlet during Conditions A and B testing. For condition C testing, two 16" Laboratory test gages were installed for measurement of drum and superheater outlet pressures in order to permit more accurate evaluation of pressure drop.

j. Fuel oil rate to the test boiler was obtained from the ship's fuel oil meter and verified by sprayer plate capacity curves using fuel pressure obtained from ship's fuel supply pressure gage.

k. Air pressure at the windbox was obtained using ship's manometer.

l. Fuel oil samples were obtained during test and later analyzed. Samples were taken twice during each day's testing from a line tapped directly off the burner fuel supply manifold.

#### Procedure

Boiler Condition A - Shipboard evaluation of the USS BARRY Boiler 2B under this condition was conducted on 29 and 30 September 1961. Data was observed during boiler light-off and shut-down, ship's maneuvering into and out of port, steady ship's speeds at boiler rates of 10, 15, 20, and 25 knots and boiler full power. Boiler data was also observed during 10 to 25 knot, and 25 to 10 knot maneuvers, as well as during soot blowing of tubes at the 25 knot boiler condition. The burner combinations and sprayer plates used during all operations were essentially in agreement with the recommendations of NBTL Report B-168, except when burner changes were made at the request of the test engineer in order to observe the effects of varying burner combinations on superheater tube metal and final steam temperatures.

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Boiler Condition B - The shipboard evaluation of the USS BARRY Boiler 2B under this condition was conducted on 3 October 1961. Boiler data was observed for essentially the same operational conditions as for Condition A described above.

Boiler Condition C - Test instrumentation for this Condition C was slightly modified as noted in the instrumentation section above. Shipboard evaluation of the USS BARRY Boiler 2B under this condition was conducted on 9 October 1961. Boiler data was observed for essentially the same operational conditions as for Conditions A and B described above.

#### RESULTS OF TESTS

Superheater tube metal temperatures were observed to be extremely high (refer to Plate 6) during Condition A steady state runs. Tube 19A was 1200°F at the 15 knots condition, and reached a maximum of 1390°F at the 25 knots condition. Condition B resulted in an appreciable reduction in tube 19A metal temperatures, yielding 1100°F at 15 knots and 1300°F at 25 knots. This condition, however, had negligible effect on tube 19A at full power where a maximum of 1350°F occurred. Tubes 13A, 18A and 19B remained from 50 to 75°F below tube 19A during Condition A, and reduced proportionally during Condition B.

During Condition C operation, tubes 13A and 18A dropped to 1180°F at 25 knots, but reached 1265°F at full power. Plate 7 gives comparison of tube 19A metal temperatures for A and B Conditions, and Plate 8 compares tube 18A metal temperatures for all Conditions A, B, and C.

Final steam temperatures for shipboard Conditions A, B, and C are presented in Plate 9. The Condition A curve steadily rises from low

rate to full power with no apparent peak value at any rate. For Condition B the final steam temperature dropped slightly at rates below cruising, but remained essentially unchanged at rates above cruising. Condition C caused final steam temperature to drop approximately 25°F to 40°F at all rates.

#### CLASS MODIFICATION

Data from this superheater evaluation was independently evaluated by the Bureau of Ships, Babcock & Wilcox Company, and the Naval Boiler and Turbine Laboratory. A conference was held at the Bureau of Ships on 20 October 1961 to discuss the results of these tests and to evaluate an optimum class modification. The class superheater configuration resulting from this meeting is as previously described under boiler Condition D and involves the removal of 14 tubes from the superheater third pass and the addition of a refractory gas baffle in the lane between the second and third superheater passes. These alterations are schematically presented in Plate 3. Cast slugs are installed in place of the removed inner loop tubes in order to maintain the superheater support structure as shown in Plate 4.

#### CALCULATIONS

Calculations were made (refer to Appendix II for procedure) based on Conditions A, B, and C operation in order to evaluate heat transfer coefficients, and to permit prediction of the effects of further superheater modifications on final steam temperature and superheater tube metal temperatures. Results indicate that removal of additional tubes from the third pass (above that number removed in Condition C)

will result in acceptable tube metal temperatures, with neither excessive reduction of final steam temperature nor excessive increase in steam pressure drop through the superheater. This modification is to be accomplished by boiler Condition D previously described.

Calculations indicate that boiler Condition D will result in an appreciable reduction of metal temperature in the remaining upper tubes of the third pass. Tube 18A is indicative of this condition in that it experienced temperatures above 1300°F during Condition A, and a maximum of 1200°F is calculated for it during Condition D. The lower tubes of the third pass were improved greatly by Condition C, but would be relatively unaffected by Condition D. These calculations indicate that maximum metal temperatures within the third pass will be in the vicinity of 1175 to 1250°F at 75% to 100% of boiler full power, with lesser temperatures at other boiler rates. Metal temperatures obtained for Conditions A, B, and C as compared with calculated values for Condition D for selected tubes in the superheater third pass are presented in Plate 10.

Calculations further indicate that the mean gas flow through the third pass for Condition D will be 85% greater than Condition A and 32% greater than Condition C at the full power boiler rate.

The estimated final steam temperature for boiler Condition D is presented in Plate 9, and was obtained by linear extrapolation of the A, B, and C Condition curves. This temperature is 925°F at full power and 880°F at cruising which falls below the originally specified minimum of 925°F at cruising.

Tabulated data for Conditions A, B, C and D are presented in Plate 11.

#### SUMMARY AND DISCUSSION

The superheater evaluations conducted on Boiler 2B of the USS BARRY (DD933) yielded information on superheater tube metal and final steam temperatures for three boiler conditions: A - original shipboard configuration, B - gas baffle added in lane between second and third superheater passes, and C - nine tubes removed from superheater third pass and gas baffle added in lane between second and third superheater passes.

Condition A resulted in tube metal temperatures as high as 1390°F in tube 19A and 1340°F in tube 18A. Condition B reduced these temperatures appreciably at all boiler rates except full power, where the temperature reduction was negligible. Condition C further reduced metal temperatures for the intermediate and full power boiler rates and resulted in a maximum of 1265°F for tube 18A at full power. Tube 19A was among those removed.

Superheater outlet temperatures for Condition C were reduced approximately 35°F over the entire range of boiler rates resulting in temperatures of 890°F at cruising and 945°F at full power.

Based on information gained in this evaluation, it was mutually agreed by the Bureau of Ships, Babcock & Wilcox Company, and the Naval Boiler and Turbine Laboratory that a class modification (Condition D) should include the removal of 14 tubes from the superheater third pass and the addition of a gas baffle in the lane between the second and the third superheater passes. This modification required the addition of

cast slugs in place of the removed tubes to maintain the superheater support structure.

Calculations predicting superheater metal temperatures for this class modification indicate that maximum metal temperatures will be in the vicinity of 1175 to 1250°F at boiler rates of 75% to 100% of full power. It also appears that gas flow through the third pass will be 85% greater than Condition A and 32% greater than Condition C at the full power boiler rate. Even with this increased gas flow it is fairly certain that superheater tube wall thinning will be appreciably reduced since the resultant metal temperatures are below the range where serious fuel oil ash corrosion takes place. Fuel oil ash products contributing mostly to corrosion are vanadium pentoxide and sodium sulphate which have melting points at 1274°F and 1625°F respectively. These products have the most corrosive effect in the molten state and therefore at temperatures above their melting points. Plate 12 shows there is a definite relation between maximum tube metal temperature and amount of wall thinning experienced by the tubes. Tube 19A which experienced temperatures as high as 1390°F during Condition A operation, reduced 54% in wall thickness, whereas tube 9A which experienced 1260°F lost only 31% of wall thickness.

Calculations for Condition D indicate that temperatures for third pass tubes will be 1175°F to 1250°F. Wall thinning at worst will be equal to that experienced by tubes 8A and 9A during Condition A operation, or about 30% in 10,000 to 11,000 hours. FORREST SHERMAN Boiler 2B superheater tube 19B had reduced 66% at time of failure; tube 19A also reduced 66% but had not failed. This indicates that

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Condition D can operate for at least 20,000 hours before tube walls are reduced to the range required for failure.

RECOMMENDATIONS

It is recommended that superheaters of the DD931/DD945 Class ships be modified to the boiler Condition D previously described.

Work on this project indicates two areas which should be considered for further study: One is to investigate possible superheater configurations and locations which will result in lower tube metal temperatures. The second is a quantitative evaluation of the effects of gas velocity on the wall thinning of tubes by the dual process of erosion and corrosion in order to allow more accuracy in predicting tube life.

ACKNOWLEDGEMENTS

The cooperation of the ship's Commanding Officer, his officers and men during these evaluations is sincerely appreciated. Special appreciation is given to LT. R. C. Trossbach, Engineering Officer, for his expeditious handling of requests.

The assistance of Mr. Allyn Lee of the Bureau of Ships in planning, coordinating and conducting these superheater evaluations is greatly appreciated.

The services of Mr. H. Teitelman and Mr. A. Somerville of the Boston Naval Shipyard in rapidly completing boiler modifications is appreciated.

Mr. Leonard Cohen, Laboratory Technical Specialist, gave valuable assistance in a consulting capacity.



DD 931 SUPERHEATER STUDIES

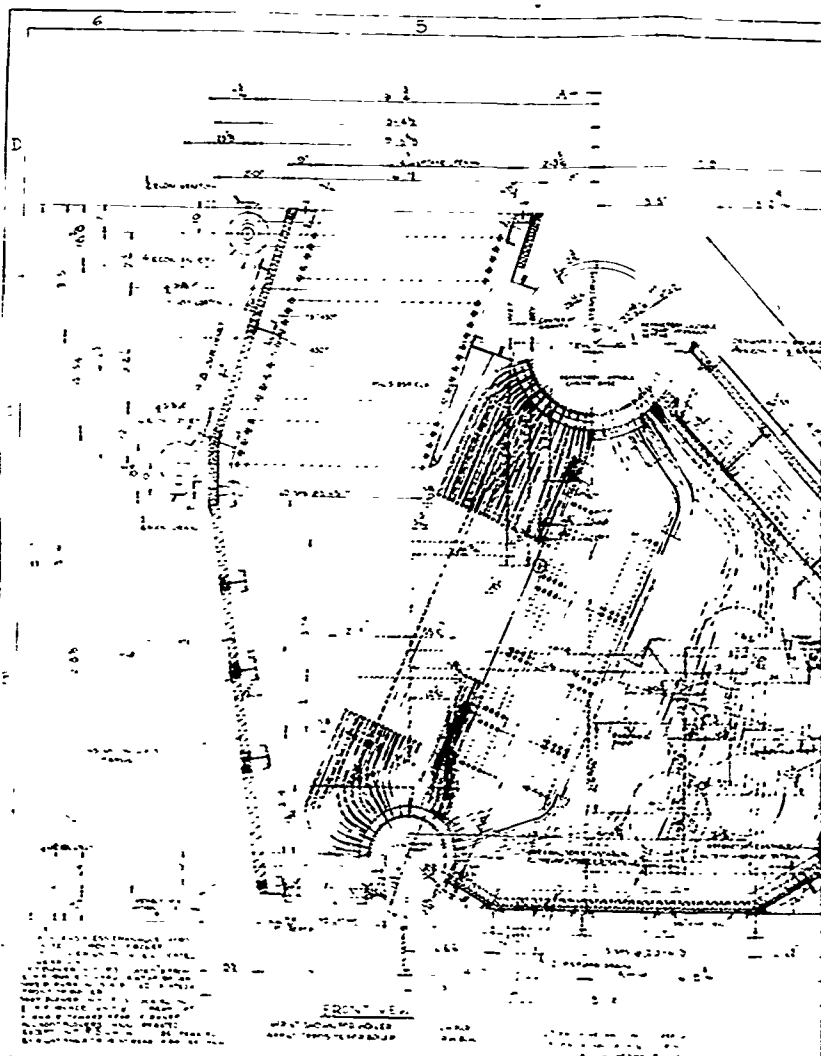
USS JOHN PAUL JONES (DD 932) BOILER 1B

EXAMINATION OF FAILED SUPERHEATER TUBE

DISTANCE FROM E OF S.H. HEADER	TUBE 19 A OUTER			TUBE 19 B INNER		
	TUBE WALL TEMP	TUBE WALL THICK	TUBE HARD- NESS	TUBE WALL TEMP	TUBE WALL THICK	TUBE HARD- NESS
	IN.	IN.	Rock B	°F	IN.	Rock B
14	1425	.118	82	1350	.109	82
16	-	.103	84	1375	-	94
17.5	-	-	-	-	.082	94
18	-	.105	81	1400	.072	74
20	-	.119	86	-	.099	85
23	1400	.123	84.5	1375	.115	93
26	-	-	-	-	.121	88
32	1375	.135	88	1375	.119	88
38	-	-	-	-	.130	96
41	1375	.147	88	1350	.138	91
49	1350	.159	92	1350	.153	95
55	-	-	-	-	.160	93
58	1300	.160	92	-	-	-
61	-	-	-	1350	.157	92
68	1325	.159	93	-	-	-
70	-	-	-	1325	.155	92

Note: Failed Section Boxed

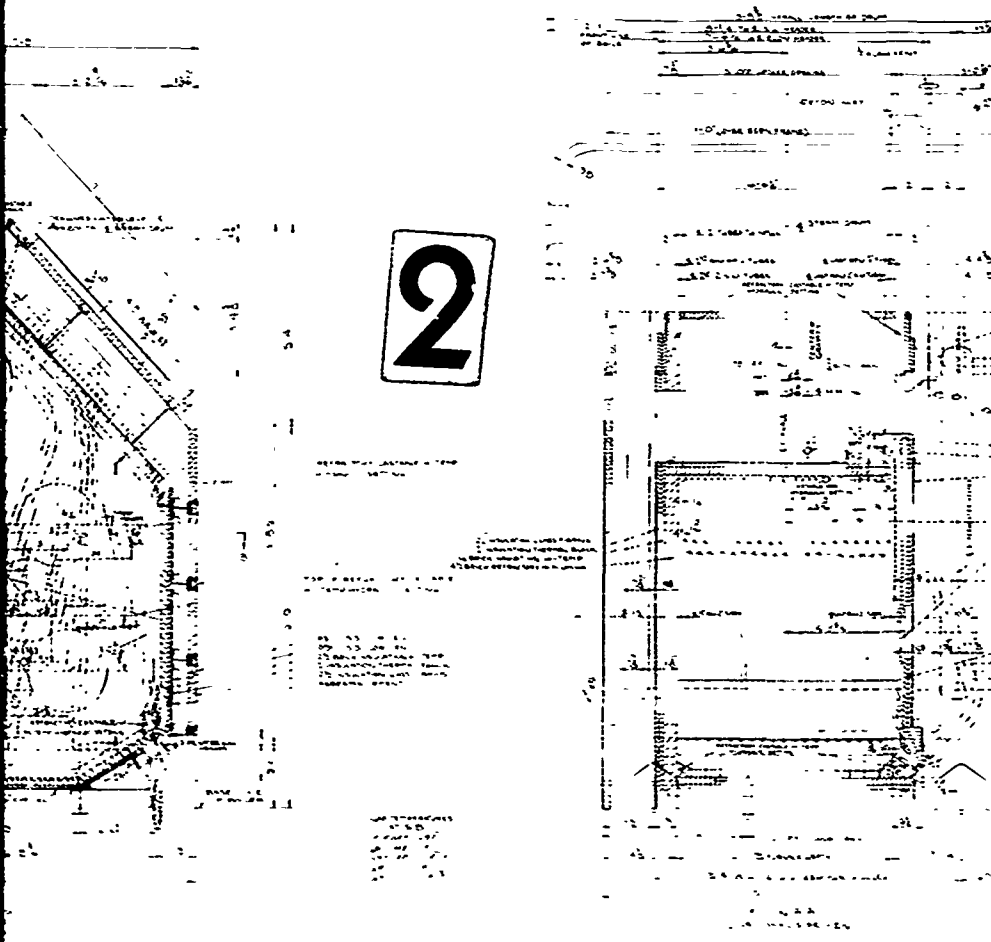
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QTY	DESCRIPTION	UNIT	PRICE	TOTAL
5	500 1/2" x 1/2" x 1/2"	PC	1.50	7.50
6	500 1/2" x 1/2" x 1/2"	PC	1.50	9.00
7	500 1/2" x 1/2" x 1/2"	PC	1.50	10.50
8	500 1/2" x 1/2" x 1/2"	PC	1.50	12.00
9	500 1/2" x 1/2" x 1/2"	PC	1.50	13.50
10	500 1/2" x 1/2" x 1/2"	PC	1.50	15.00
11	500 1/2" x 1/2" x 1/2"	PC	1.50	16.50
12	500 1/2" x 1/2" x 1/2"	PC	1.50	18.00
13	500 1/2" x 1/2" x 1/2"	PC	1.50	19.50
14	500 1/2" x 1/2" x 1/2"	PC	1.50	21.00
15	500 1/2" x 1/2" x 1/2"	PC	1.50	22.50
16	500 1/2" x 1/2" x 1/2"	PC	1.50	24.00
17	500 1/2" x 1/2" x 1/2"	PC	1.50	25.50
18	500 1/2" x 1/2" x 1/2"	PC	1.50	27.00
19	500 1/2" x 1/2" x 1/2"	PC	1.50	28.50
20	500 1/2" x 1/2" x 1/2"	PC	1.50	30.00
21	500 1/2" x 1/2" x 1/2"	PC	1.50	31.50
22	500 1/2" x 1/2" x 1/2"	PC	1.50	33.00
23	500 1/2" x 1/2" x 1/2"	PC	1.50	34.50
24	500 1/2" x 1/2" x 1/2"	PC	1.50	36.00
25	500 1/2" x 1/2" x 1/2"	PC	1.50	37.50
26	500 1/2" x 1/2" x 1/2"	PC	1.50	39.00
27	500 1/2" x 1/2" x 1/2"	PC	1.50	40.50
28	500 1/2" x 1/2" x 1/2"	PC	1.50	42.00
29	500 1/2" x 1/2" x 1/2"	PC	1.50	43.50
30	500 1/2" x 1/2" x 1/2"	PC	1.50	45.00
31	500 1/2" x 1/2" x 1/2"	PC	1.50	46.50
32	500 1/2" x 1/2" x 1/2"	PC	1.50	48.00
33	500 1/2" x 1/2" x 1/2"	PC	1.50	49.50
34	500 1/2" x 1/2" x 1/2"	PC	1.50	51.00
35	500 1/2" x 1/2" x 1/2"	PC	1.50	52.50
36	500 1/2" x 1/2" x 1/2"	PC	1.50	54.00
37	500 1/2" x 1/2" x 1/2"	PC	1.50	55.50
38	500 1/2" x 1/2" x 1/2"	PC	1.50	57.00
39	500 1/2" x 1/2" x 1/2"	PC	1.50	58.50
40	500 1/2" x 1/2" x 1/2"	PC	1.50	60.00
41	500 1/2" x 1/2" x 1/2"	PC	1.50	61.50
42	500 1/2" x 1/2" x 1/2"	PC	1.50	63.00
43	500 1/2" x 1/2" x 1/2"	PC	1.50	64.50
44	500 1/2" x 1/2" x 1/2"	PC	1.50	66.00
45	500 1/2" x 1/2" x 1/2"	PC	1.50	67.50
46	500 1/2" x 1/2" x 1/2"	PC	1.50	69.00
47	500 1/2" x 1/2" x 1/2"	PC	1.50	70.50
48	500 1/2" x 1/2" x 1/2"	PC	1.50	72.00
49	500 1/2" x 1/2" x 1/2"	PC	1.50	73.50
50	500 1/2" x 1/2" x 1/2"	PC	1.50	75.00
51	500 1/2" x 1/2" x 1/2"	PC	1.50	76.50
52	500 1/2" x 1/2" x 1/2"	PC	1.50	78.00
53	500 1/2" x 1/2" x 1/2"	PC	1.50	79.50
54	500 1/2" x 1/2" x 1/2"	PC	1.50	81.00
55	500 1/2" x 1/2" x 1/2"	PC	1.50	82.50
56	500 1/2" x 1/2" x 1/2"	PC	1.50	84.00
57	500 1/2" x 1/2" x 1/2"	PC	1.50	85.50
58	500 1/2" x 1/2" x 1/2"	PC	1.50	87.00
59	500 1/2" x 1/2" x 1/2"	PC	1.50	88.50
60	500 1/2" x 1/2" x 1/2"	PC	1.50	90.00
61	500 1/2" x 1/2" x 1/2"	PC	1.50	91.50
62	500 1/2" x 1/2" x 1/2"	PC	1.50	93.00
63	500 1/2" x 1/2" x 1/2"	PC	1.50	94.50
64	500 1/2" x 1/2" x 1/2"	PC	1.50	96.00

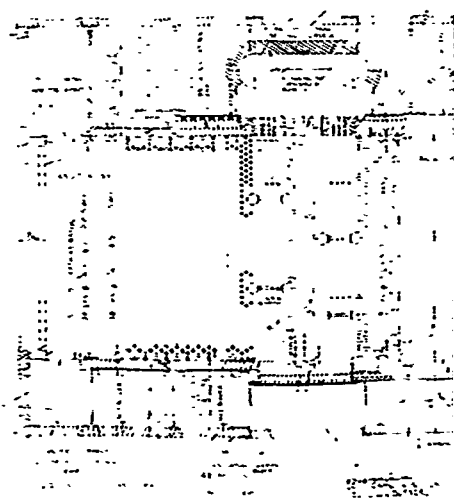
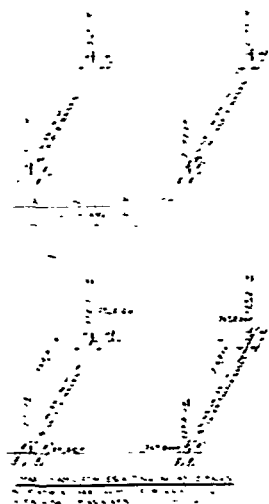
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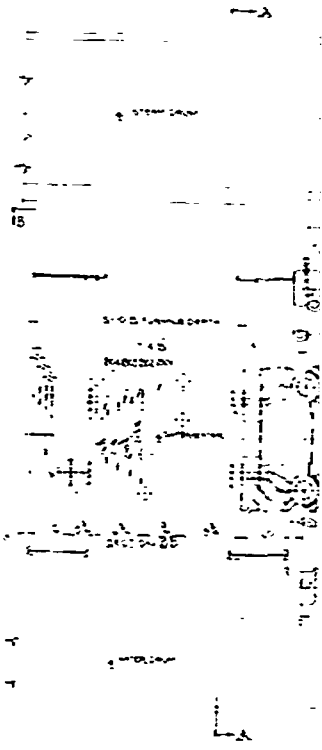
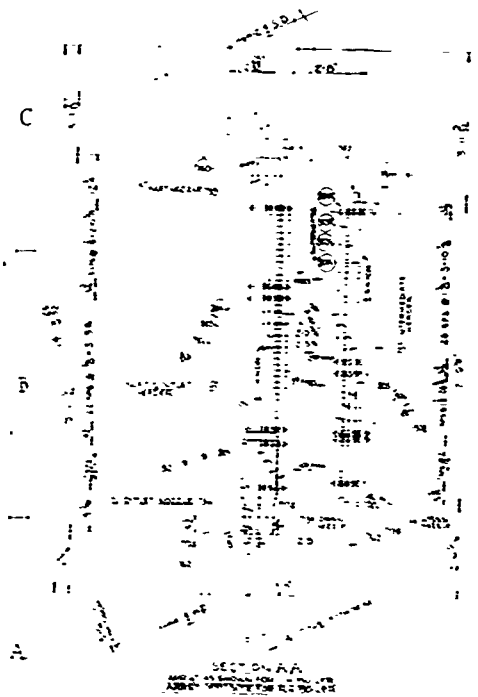




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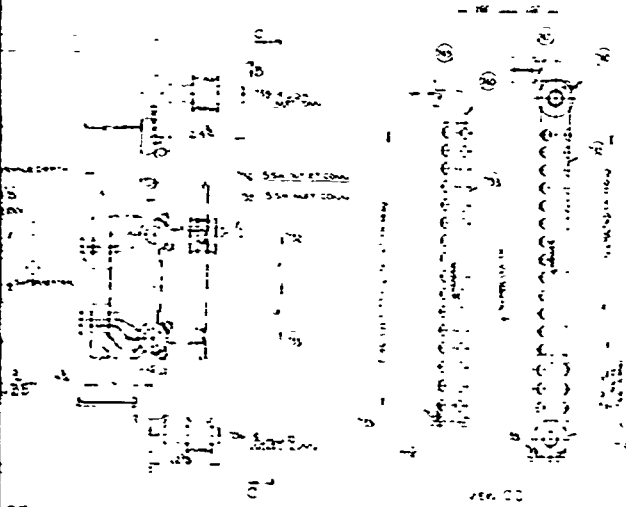
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REV 5025

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FORM 8-72						U.S. MATERIAL FOR ONE BULLET			
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NAME	MATERIAL	SPECS	SIZE	DEN CO	DWG NO	STOCK NO	STOCK LT	REMARKS	
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2	100% COTTON	100% COTTON	100% COTTON	100% COTTON	100% COTTON	100% COTTON	100% COTTON	100% COTTON	
3	100% COTTON	100% COTTON	100% COTTON	100% COTTON	100% COTTON	100% COTTON	100% COTTON	100% COTTON	
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79	100% COTTON	100% COTTON	100% COTTON	100% COTTON	100% COTTON	100% COTTON	100% COTTON	100% COTTON	
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81	100% COTTON	100% COTTON	100% COTTON	100% COTTON	100% COTTON	100% COTTON	100% COTTON	100% COTTON	
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100	100% COTTON	100% COTTON	100% COTTON	100% COTTON	100% COTTON	100% COTTON	100% COTTON	100% COTTON	

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### GENERAL NOTES

### MATERIAL NOTES

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1. The first step in the process is to identify the problem or issue that needs to be addressed. This involves gathering information and understanding the context of the problem.

*[Handwritten notes in German]*

1980

[illegible]

ARRANGEMENT OF SUPERHEATER

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[illegible]

GENERAL NOTES

### MATERIAL NOTES

[illegible]

4

## SYNOPSIS

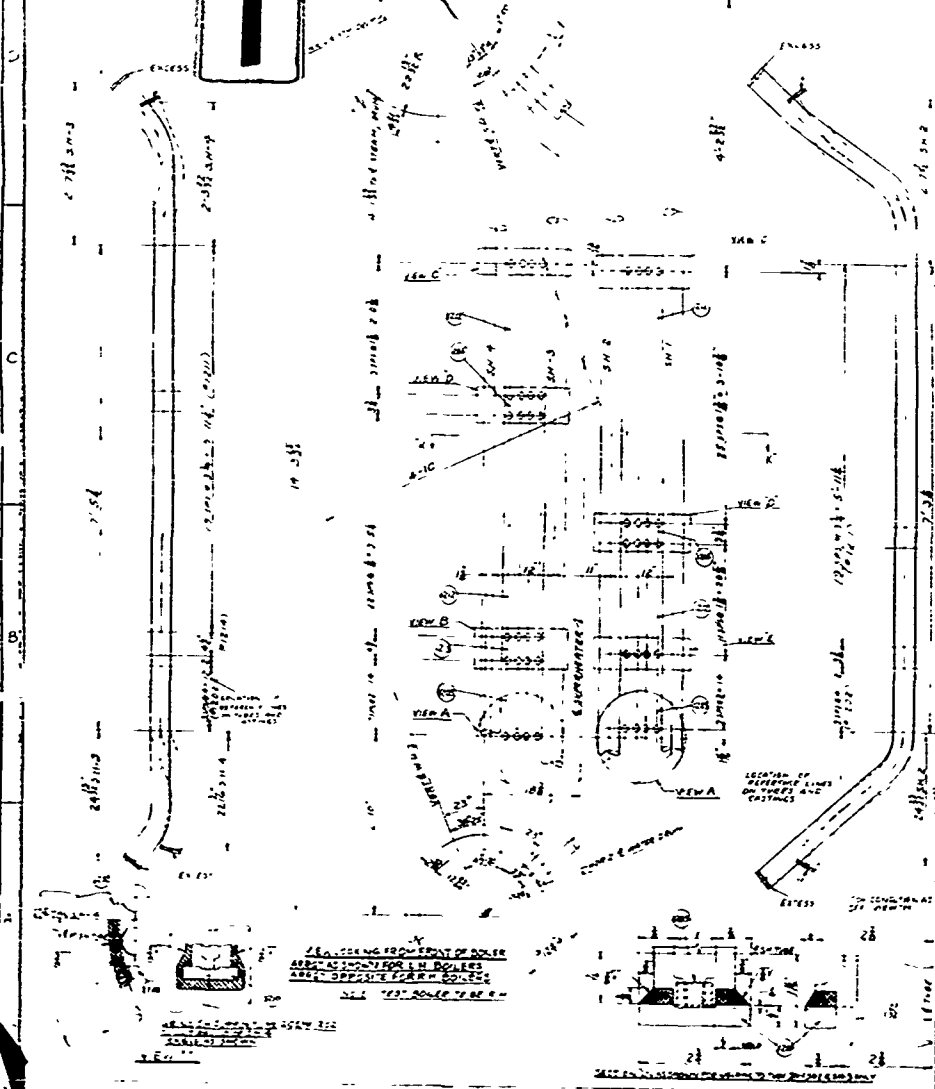
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ARRANGEMENT OF  
SUPERHEATER

PAGE 2  
SERIAL 3 OF 4

# 1

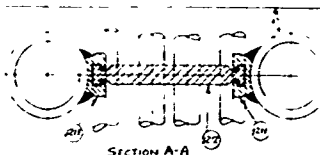


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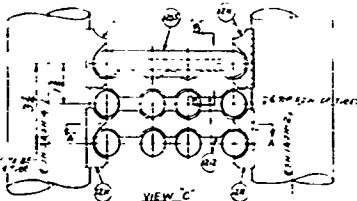
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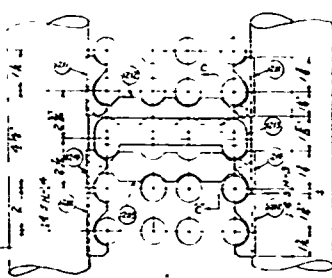
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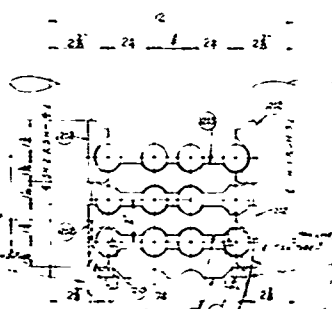
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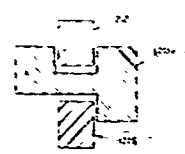
VIEW C



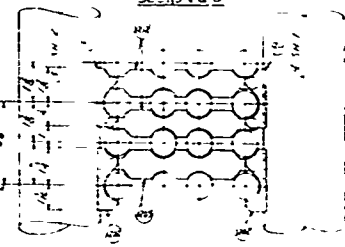
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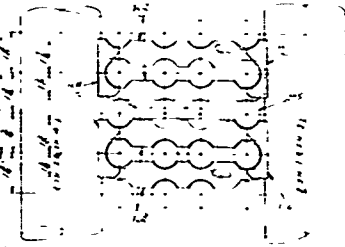
VIEW A



SECTION C-C



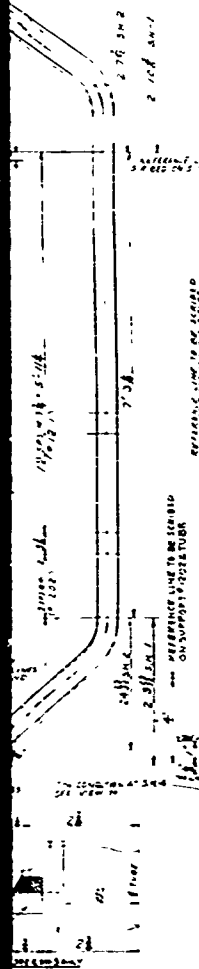
VIEW E



VIEW D



VIEW S-B





NBTL PROJECT B-494

4

GENERAL

1. THE SITE IS A 100' X 100' AREA OF LAND, 10' FROM THE NORTH LINE OF THE ROAD, 10' FROM THE WEST LINE OF THE ROAD, 10' FROM THE SOUTH LINE OF THE ROAD, 10' FROM THE EAST LINE OF THE ROAD.
2. THE SITE IS A 100' X 100' AREA OF LAND, 10' FROM THE NORTH LINE OF THE ROAD, 10' FROM THE WEST LINE OF THE ROAD, 10' FROM THE SOUTH LINE OF THE ROAD, 10' FROM THE EAST LINE OF THE ROAD.
3. THE SITE IS A 100' X 100' AREA OF LAND, 10' FROM THE NORTH LINE OF THE ROAD, 10' FROM THE WEST LINE OF THE ROAD, 10' FROM THE SOUTH LINE OF THE ROAD, 10' FROM THE EAST LINE OF THE ROAD.
4. THE SITE IS A 100' X 100' AREA OF LAND, 10' FROM THE NORTH LINE OF THE ROAD, 10' FROM THE WEST LINE OF THE ROAD, 10' FROM THE SOUTH LINE OF THE ROAD, 10' FROM THE EAST LINE OF THE ROAD.
5. THE SITE IS A 100' X 100' AREA OF LAND, 10' FROM THE NORTH LINE OF THE ROAD, 10' FROM THE WEST LINE OF THE ROAD, 10' FROM THE SOUTH LINE OF THE ROAD, 10' FROM THE EAST LINE OF THE ROAD.
6. THE SITE IS A 100' X 100' AREA OF LAND, 10' FROM THE NORTH LINE OF THE ROAD, 10' FROM THE WEST LINE OF THE ROAD, 10' FROM THE SOUTH LINE OF THE ROAD, 10' FROM THE EAST LINE OF THE ROAD.
7. THE SITE IS A 100' X 100' AREA OF LAND, 10' FROM THE NORTH LINE OF THE ROAD, 10' FROM THE WEST LINE OF THE ROAD, 10' FROM THE SOUTH LINE OF THE ROAD, 10' FROM THE EAST LINE OF THE ROAD.
8. THE SITE IS A 100' X 100' AREA OF LAND, 10' FROM THE NORTH LINE OF THE ROAD, 10' FROM THE WEST LINE OF THE ROAD, 10' FROM THE SOUTH LINE OF THE ROAD, 10' FROM THE EAST LINE OF THE ROAD.
9. THE SITE IS A 100' X 100' AREA OF LAND, 10' FROM THE NORTH LINE OF THE ROAD, 10' FROM THE WEST LINE OF THE ROAD, 10' FROM THE SOUTH LINE OF THE ROAD, 10' FROM THE EAST LINE OF THE ROAD.
10. THE SITE IS A 100' X 100' AREA OF LAND, 10' FROM THE NORTH LINE OF THE ROAD, 10' FROM THE WEST LINE OF THE ROAD, 10' FROM THE SOUTH LINE OF THE ROAD, 10' FROM THE EAST LINE OF THE ROAD.

REMARKS

THE SITE IS A 100' X 100' AREA OF LAND, 10' FROM THE NORTH LINE OF THE ROAD, 10' FROM THE WEST LINE OF THE ROAD, 10' FROM THE SOUTH LINE OF THE ROAD, 10' FROM THE EAST LINE OF THE ROAD.

PLATE 2  
SHEET 4 OF 4

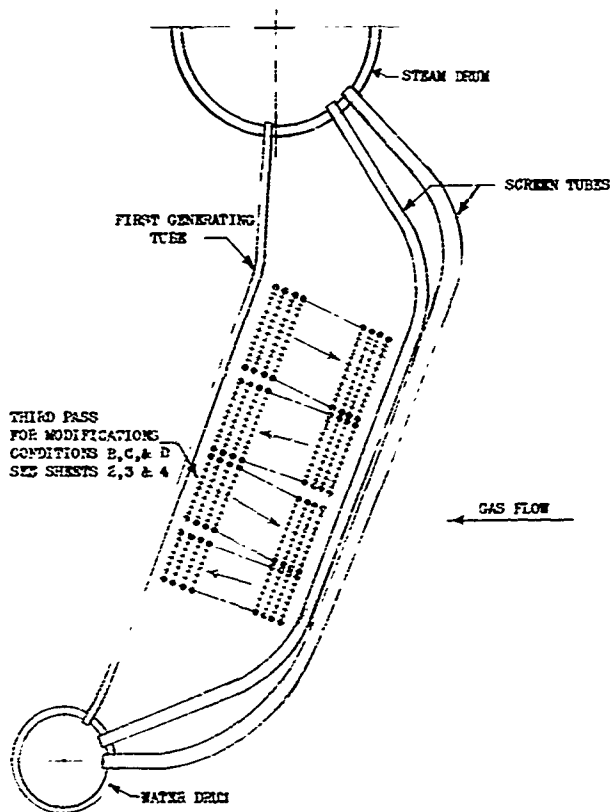
THE SITE IS A 100' X 100' AREA OF LAND, 10' FROM THE NORTH LINE OF THE ROAD, 10' FROM THE WEST LINE OF THE ROAD, 10' FROM THE SOUTH LINE OF THE ROAD, 10' FROM THE EAST LINE OF THE ROAD.



DD 931 SUPERHEATER STUDIES  
USS BARRY (DD 933) BOILER 2B

SUPERHEATER MODIFICATIONS

CONDITION A (ORIGINAL SHIPBOARD)



CONDITION B (BAPFILE ADDR:))

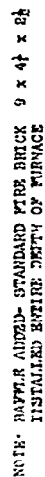
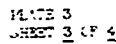


PLATE 3  
SHEET 2 OF 4

## SUPPLEMENTARY MODIFICATIONS

SECOND PASS

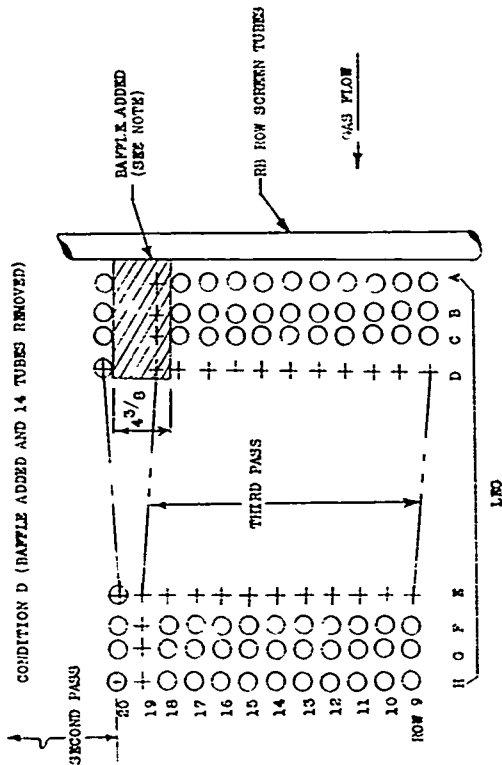


NOTE: BATTLE, "WIND-STANDARD WYRK BRICK 0 x 4 1/2 x 2 1/2 "ROUND" " " x 4 3/8 x 2 1/2 " , and INSTALLED ENTIRE DEPTH OF MURNACE

DD 931 SUPERHEATER STUDIES  
USN BARRY (DD 933) BOILER EB

SUPERHEATER MODIFICATIONS

CONDITION D (BAFFLE ADDED AND 14 TUBES REMOVED)



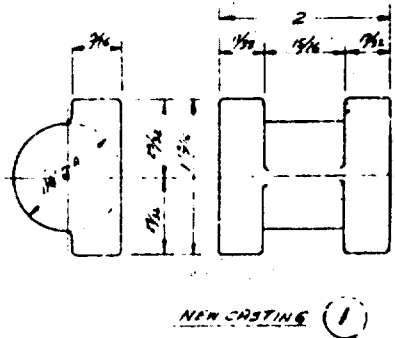
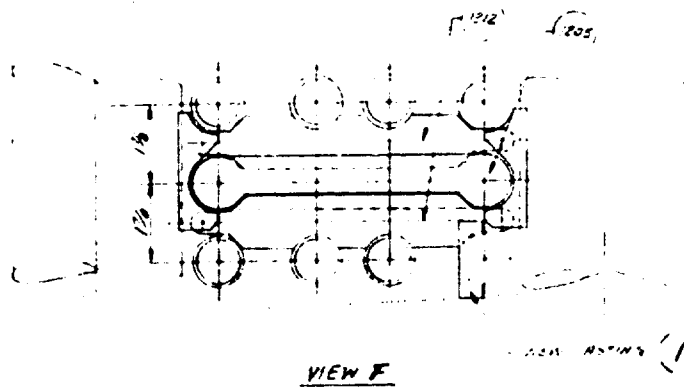
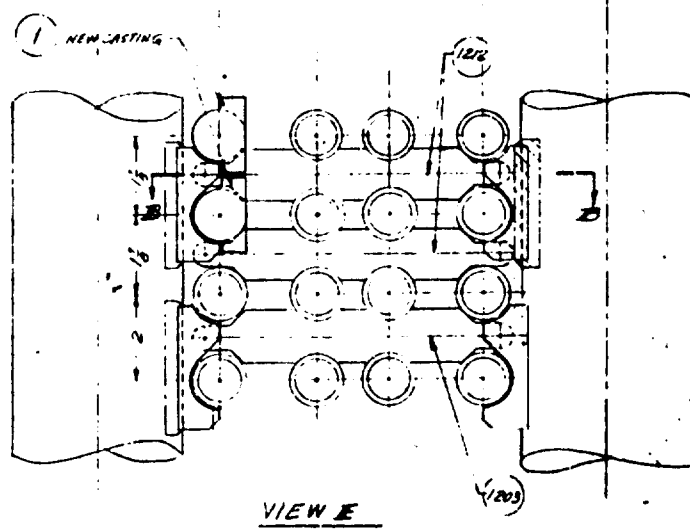
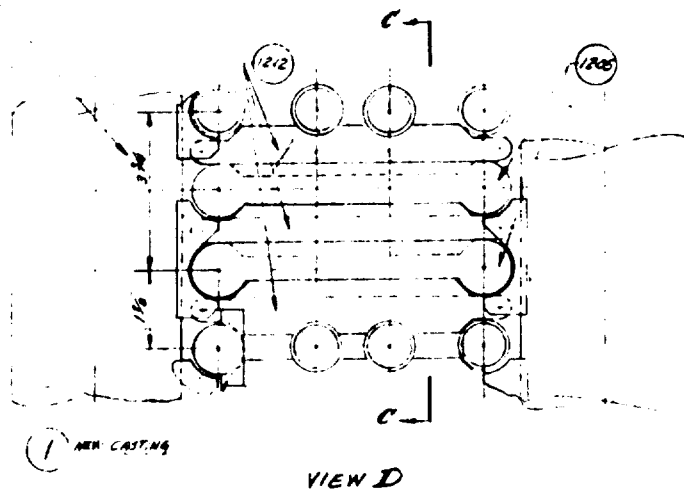
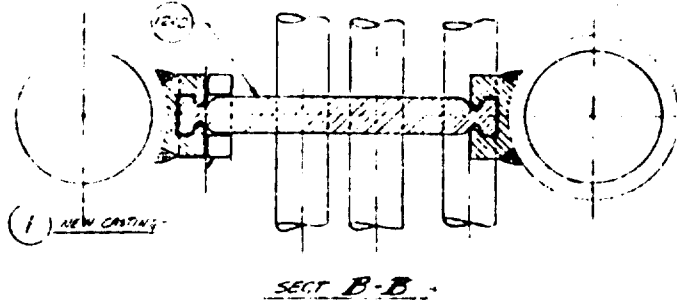
NOTE: BAFFLE ADDED- STANDARD FIRE BRICK  $9 \times 4\frac{1}{2} \times 2\frac{1}{2}$   
GROUND TO  $9 \times 4\frac{3}{8} \times 2\frac{1}{2}$  AND INSTALLED  
ENTIRE DEPTH OF FURACE

Best Available Copy

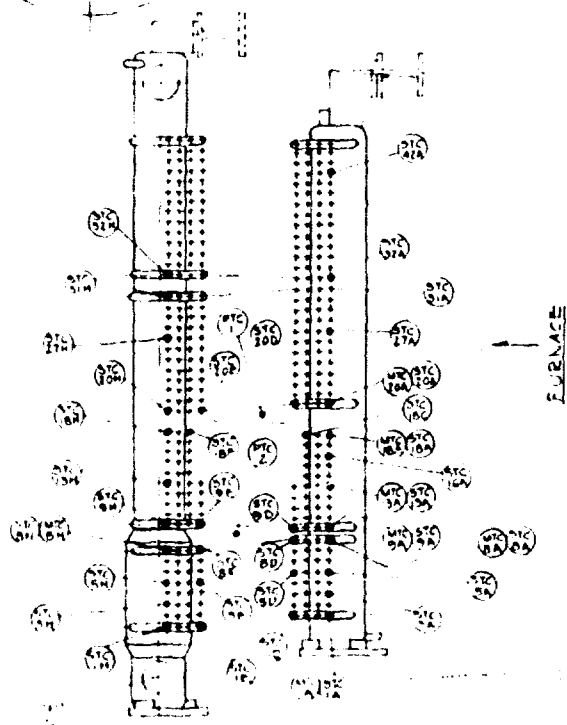
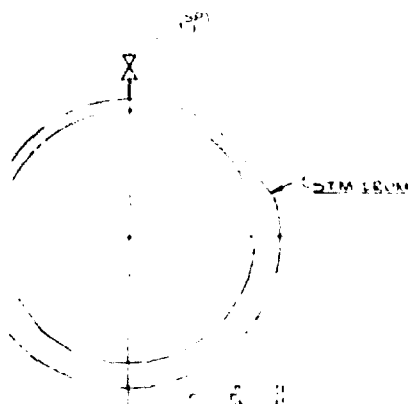
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1212	46	538 F.B.

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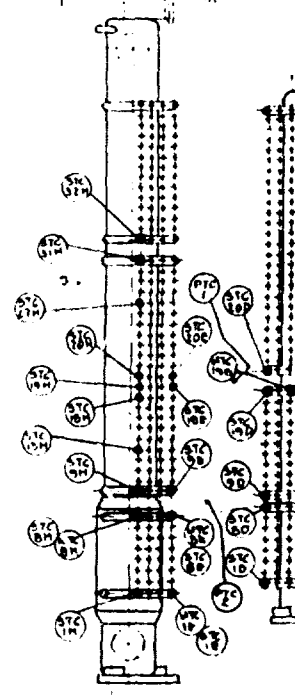


PROPOSED TO	THE DRAWING IS THE PROPERTY OF THE BABCOCK & WILCOX COMPANY	<p>NOTES FOR REFERENCE SEE S.D. IN 5 1500 (PART 2 SHEET 4)</p> <p>PROPOSED ALTERATION TO S.H. SUPPORT CASTINGS - 3RD PASS</p> <p>PLATE 4</p> <p>PII404-A -29M0</p>
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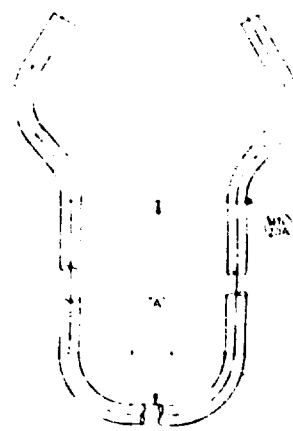
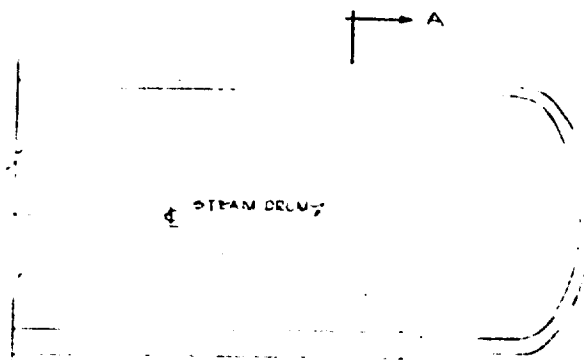
SECTION-AA  
PHASE II  
(SEE NOTE 4)

1

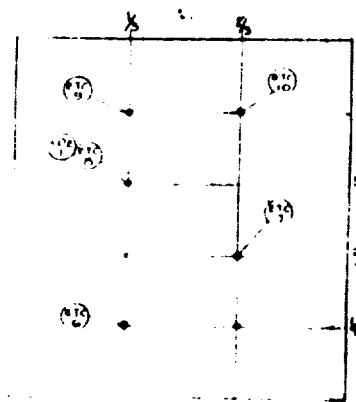
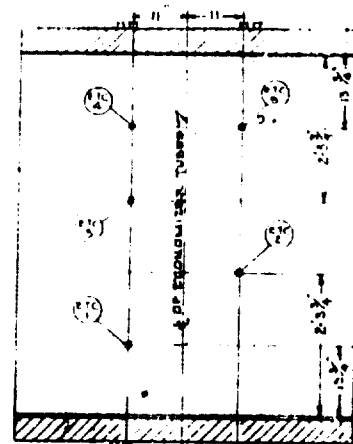
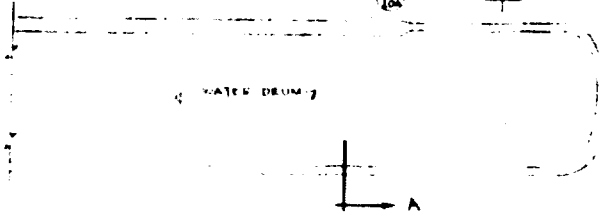
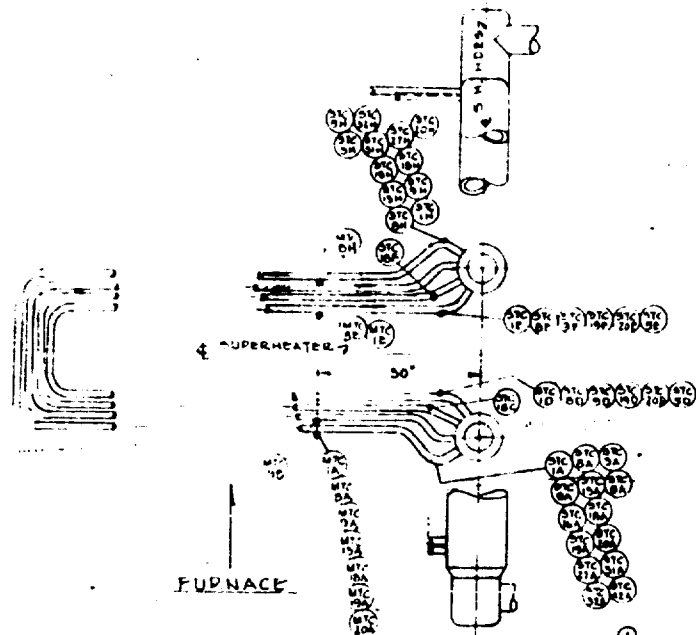
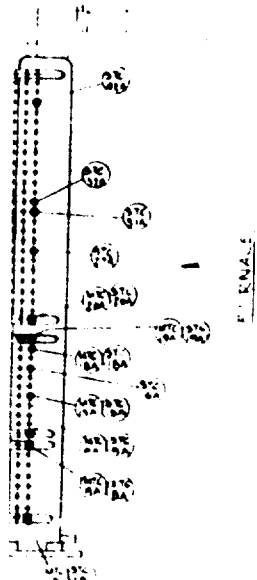


SECTION-AA  
PHASE I  
(SEE NOTE 4)

M. D. 211



201-5-2

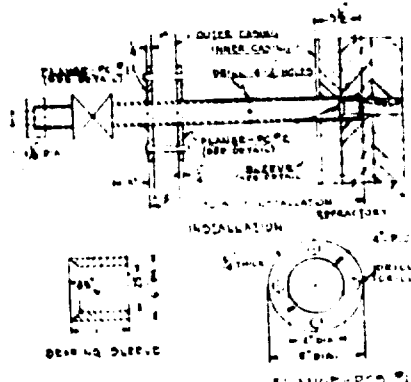




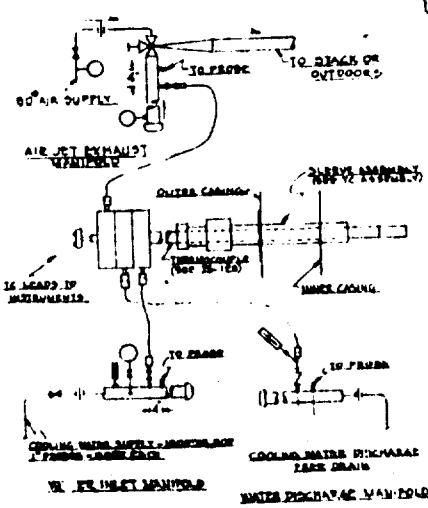
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MTC-1B	4	1/2" DIA. BOLTS
MTC-1C	4	1/2" DIA. BOLTS
MTC-1D	4	1/2" DIA. BOLTS
MTC-1E	4	1/2" DIA. BOLTS
MTC-1F	4	1/2" DIA. BOLTS
MTC-1G	4	1/2" DIA. BOLTS
MTC-1H	4	1/2" DIA. BOLTS
MTC-1I	4	1/2" DIA. BOLTS
MTC-1J	4	1/2" DIA. BOLTS
MTC-1K	4	1/2" DIA. BOLTS
MTC-1L	4	1/2" DIA. BOLTS
MTC-1M	4	1/2" DIA. BOLTS
MTC-1N	4	1/2" DIA. BOLTS
MTC-1O	4	1/2" DIA. BOLTS
MTC-1P	4	1/2" DIA. BOLTS
MTC-1Q	4	1/2" DIA. BOLTS
MTC-1R	4	1/2" DIA. BOLTS
MTC-1S	4	1/2" DIA. BOLTS
MTC-1T	4	1/2" DIA. BOLTS
MTC-1U	4	1/2" DIA. BOLTS
MTC-1V	4	1/2" DIA. BOLTS
MTC-1W	4	1/2" DIA. BOLTS
MTC-1X	4	1/2" DIA. BOLTS
MTC-1Y	4	1/2" DIA. BOLTS
MTC-1Z	4	1/2" DIA. BOLTS

ALL BOLTS

FITTING FOR SHOT (SEE NOTE 2)



THERMOCOUPLE ASSEMBLY



THERMOCOUPLE ASSEMBLY  
SERVICE PIPING  
ADAPTED TO SUIT IN FIELD

PHASE	ITEM NO.	QTY	DESCRIPTION
PHASE I	MTC-1A	4	1/2" DIA. BOLTS
	MTC-1B	4	1/2" DIA. BOLTS
	MTC-1C	4	1/2" DIA. BOLTS
	MTC-1D	4	1/2" DIA. BOLTS
	MTC-1E	4	1/2" DIA. BOLTS
	MTC-1F	4	1/2" DIA. BOLTS
	MTC-1G	4	1/2" DIA. BOLTS
	MTC-1H	4	1/2" DIA. BOLTS
	MTC-1I	4	1/2" DIA. BOLTS
	MTC-1J	4	1/2" DIA. BOLTS
PHASE II	MTC-1K	4	1/2" DIA. BOLTS
	MTC-1L	4	1/2" DIA. BOLTS
	MTC-1M	4	1/2" DIA. BOLTS
	MTC-1N	4	1/2" DIA. BOLTS
	MTC-1O	4	1/2" DIA. BOLTS
	MTC-1P	4	1/2" DIA. BOLTS
	MTC-1Q	4	1/2" DIA. BOLTS
	MTC-1R	4	1/2" DIA. BOLTS
	MTC-1S	4	1/2" DIA. BOLTS
	MTC-1T	4	1/2" DIA. BOLTS
PHASE III	MTC-1U	4	1/2" DIA. BOLTS
	MTC-1V	4	1/2" DIA. BOLTS
	MTC-1W	4	1/2" DIA. BOLTS
	MTC-1X	4	1/2" DIA. BOLTS
	MTC-1Y	4	1/2" DIA. BOLTS
	MTC-1Z	4	1/2" DIA. BOLTS
	MTC-2A	4	1/2" DIA. BOLTS
	MTC-2B	4	1/2" DIA. BOLTS
	MTC-2C	4	1/2" DIA. BOLTS
	MTC-2D	4	1/2" DIA. BOLTS
PHASE IV	MTC-2E	4	1/2" DIA. BOLTS
	MTC-2F	4	1/2" DIA. BOLTS
	MTC-2G	4	1/2" DIA. BOLTS
	MTC-2H	4	1/2" DIA. BOLTS
	MTC-2I	4	1/2" DIA. BOLTS
	MTC-2J	4	1/2" DIA. BOLTS
	MTC-2K	4	1/2" DIA. BOLTS
	MTC-2L	4	1/2" DIA. BOLTS
	MTC-2M	4	1/2" DIA. BOLTS
	MTC-2N	4	1/2" DIA. BOLTS

SUPERHEATED

WATER GAS

GAS TEMPI

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NOTE-5:-

1. CONTACT FACE OF FLANGES TO HAVE A PHOTOGRAPHIC FINISH TO .0005 DEVIATIONS PER INCH, .002" TO .0005 DEEP.
2. SEE 15-112 FOR MATERIAL SPECIFICATIONS
3. THE GAGES USED TO MEASURE PRESSURE AT THE FOLLOWING LOCATIONS ARE TO BE CALIBRATED BY SHIPS FORCE & TO AGENDA OPERATION:
- A- DRUM
  - B- SUPERHEATER OUTLET
  - C- DESUPERHEATER INLET
  - D- DESUPERHEATER OUTLET
  - E- FUEL OIL SUPPLY

14. PHASE 3: SUPERHEATER AS ORIGINALLY INSTALLED  
PHASE 2 SUPERHEATER WITH FOLLOWING TUBES REMOV

14	INNER TUBE	
15		
16		
17		
18		
19	ALL	

CONNECTIONS  
NOT SHOWN  
FIELD INSTAL  
LATION

4

PLATE 5

PROJECT NUMBER AND ELEMENT NAME		NAVAL BOILER AND TURBINE LAB	
PROJECT DESCRIPTION		N.D.T.L. PROJECT	
SUBJECT		INSTRUMENTATION TO DETERMINE SUPERHEATER PERFORMANCE	
DATE		DD-931 (11-5)	
AUTHORITY		MAFSA	
APPROVED BY		H-3	

THERMOCOUPLES & THERMOMETERS														
PRIMARY CONNECTION			ELEMENT DATA					RECORDING INSTRUMENT						
MEASUREMENT	TYPE	TEMP. TUBE	TYPE	NO.	NO.	NO.	NO.	NO.	NO.	LOCATION	TYPE	RANGE	REMARKS	
OF METAL TEMP	1	1	1	1	1	1	1	1	1	SHIFBOARD	SPEEDOMETER	0-2400	C SHIELDED	
6TH														
5TH														
15TH														
19TH														
20TH														
1ST														
6TH														
9TH														
15TH														
16TH														
18TH														
19TH														
20TH														
27TH														
31ST														
32ND														
42ND														
SUPERHEATER OUTLET														
WTR GAS TEMP BETWEEN 2ND & 3RD PASS														
3RD & 4TH														
TEMPERATURE TUBE (CONDUIT)														
AFTER														
TO BOILER - BLONDER DISCHARGE														
WTR ECONOMIZER INLET														
OUTLET														
WTR INLET														
WTR OUTLET														
10TH														

# NOTES:

- CONTACT FACE OF PLANGED TO HAVE A PHONOGRAPHIC FINISH 60 TO 80 SEERATIONS PER INCH, .002" TO .0005 DEEP.
- SEE 15-112 FOR MATERIAL SPECIFICATIONS.
- THE GAGES USED TO MEASURE PRESSURE AT THE FOLLOWING LOCATIONS ARE TO BE CALIBRATED BY SHIPS FORCE PRIOR TO AGENDA OPERATION:
  - DRUM
  - SUPERHEATER OUTLET
  - DESUPERHEATER INLET
  - DESUPERHEATER OUTLET
  - FUEL OIL SUPPLY
- PHASE 3 - SUPERHEATER AS ORIGINALLY INSTALLED  
PHASE 2 - SUPERHEATER WITH FOLLOWING TUBES REMOVED

14 INNER TUBE  
15  
16  
17  
18  
19 ALL

5

PRESSURE MEASUREMENTS														
PRIMARY CONNECTION			ELEMENT DATA					RECORDING INSTRUMENT						
MEASUREMENT	TYPE	TEMP. TUBE	TYPE	NO.	NO.	NO.	NO.	NO.	NO.	LOCATION	TYPE	RANGE	REMARKS	
DRUM OUTLET														
SUPERHEATER OUTLET														

PRESSURE MEASUREMENTS														
PRIMARY CONNECTION			ELEMENT DATA					RECORDING INSTRUMENT						
MEASUREMENT	TYPE	TEMP. TUBE	TYPE	NO.	NO.	NO.	NO.	NO.	NO.	LOCATION	TYPE	RANGE	REMARKS	
DRUM OUTLET														
SUPERHEATER OUTLET														

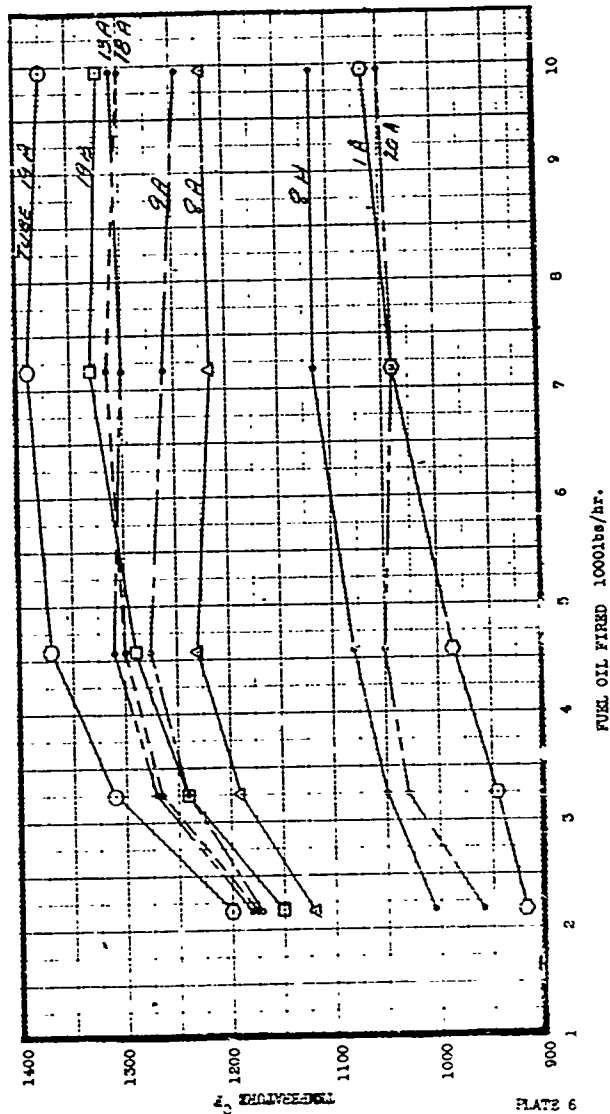
PLATE 5

NAVAL BASE PUEBLO 12, PA	
NAVAL BOLLER AND TURBINE LABORATORY	
N.B.T.L. PROJECT D-494	
INSTRUMENT DETERMINED	
SUPERHEATER PERFORMANCE AND BOLLER	
DD-931 CLASS	
H-3603	

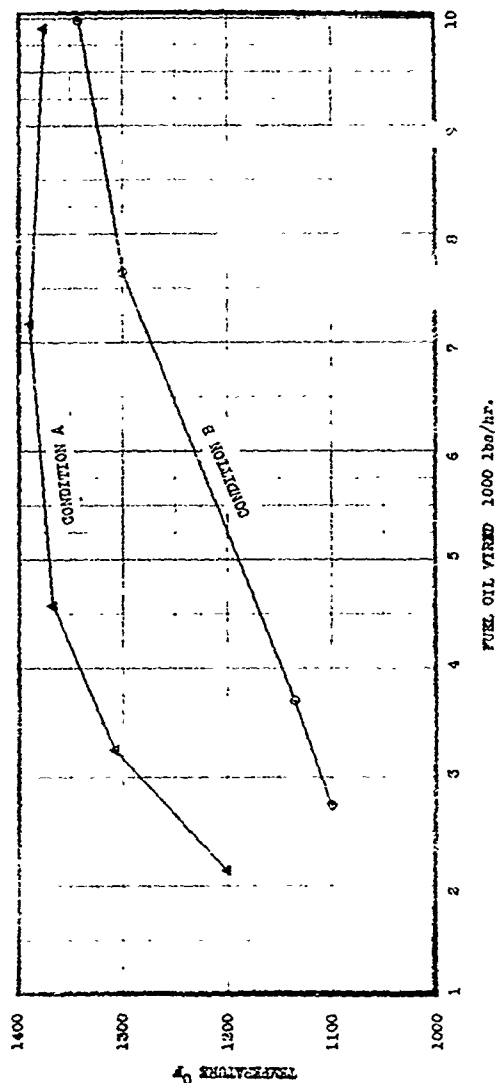
NO 931 SUPERHEATER STUDIES  
 USS HARRY (DD 933) BOILER 2B

SUPERHEATER METAL TEMPERATURES

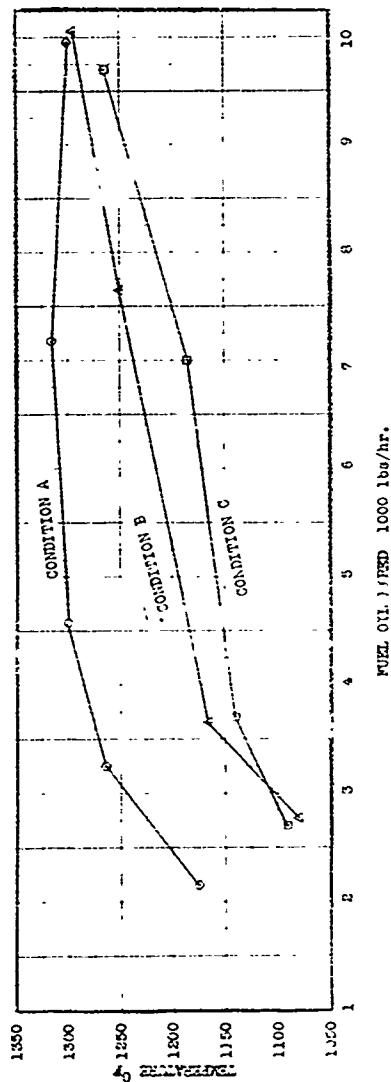
CONDITION A (ORIGINAL SHIPBOARD SUPERHEATER CONFIGURATION)



DD 931 SUPERHEATER STUDIES  
 USS BARRY (DD 933) BOILER EB  
 SUPERHEATER METAL TEMPERATURES (TUBE 19A)  
 CONDITIONS A & B



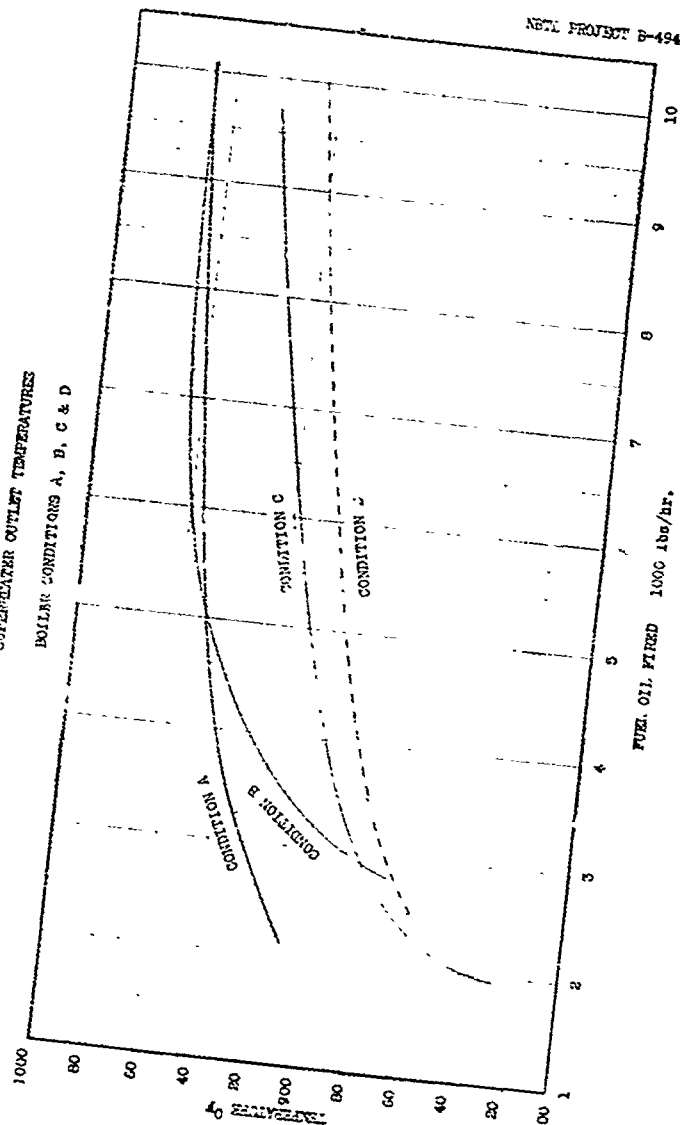
NO. 921 SUPERHEATER STUDIES  
 U-S BARRY (DD 933) BOILER 2B  
 SUPERHEATER METAL TEMPERATURES (TUBE 18A)  
 BOILER CONDITIONS A, B and C



ED 931 CLASS SUPERHEATER STUDIES  
 USS BARRY (DD 933) BOILER #2

SUPERHEATER OUTLET TEMPERATURES

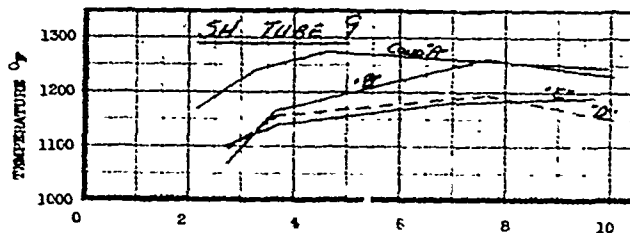
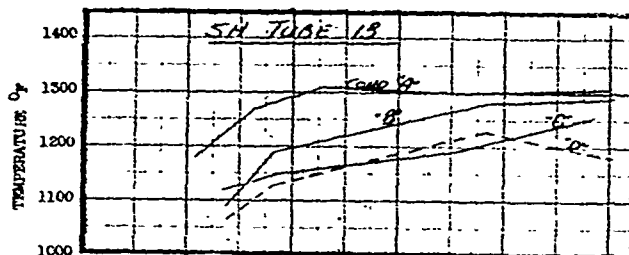
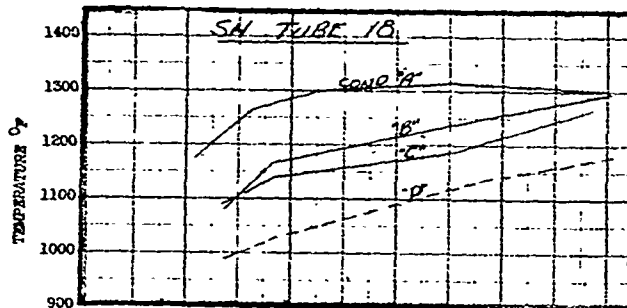
BOILER CONDITIONS A, B, C & D



DD 931 SUPERHEATER STUDIES  
USS BARRY (DD 933) BOILER 23

SUPERHEATER TUBE METAL TEMPERATURES

(OBSERVED FOR BOILER CONDITIONS A, B & C AND CALCULATED FOR CONDITION D)



FUEL OIL FIRED 1000 lbs/hr.



NO. 43 SUPERHEATER

TEST NO. 271

RUN	TIME	CONDITION A				CONDITION B				CONDITION C			
		5	6	9	8	12	16	17	18	21	22	23	24
% FULL POWER	%	95.5	100.0	100.0	100.0	95.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0
OIL RATE	1/4 IN	21	32	49	96	21	35	74	97	21	37	66	96
Total Steam Rate	1/4 IN	2170	3255	7773	9740	2167	3245	7621	9749	2138	3232	7621	9749
Desup. Steam Rate	1/4 IN	3145	4624	7475	13125	3145	4624	7475	13125	3145	4624	7475	13125
% CO <sub>2</sub>	%	60.7	65.6	76.7	15.5	62.1	68.2	74.2	15.7	63.2	69.2	75.2	15.9
H.M.V. of Fuel	1/4 IN	10.8	12.4	13.0	14.2	10.8	12.4	13.0	14.2	10.8	12.4	13.0	14.2
Total Sensible Heat	1/4 IN	15.24	15.873	16.282	16.68	15.24	15.873	16.282	16.68	15.24	15.873	16.282	16.68
Efficiency %	%	85.5	87.3	88.8	85.5	85.5	87.3	88.8	85.5	85.5	87.3	88.8	85.5
Steam Drum Press	PSI	1210	1225	1210	1250	1190	1250	1155	1240	1225	1210	1250	1240
Superheater Cut Back	PSI	1210	1216	1196	1186	1206	1254	1134	1166	1216	1226	1196	1186
Desup. Cut Press	PSI	1185	1195	1195	1185	1195	1165	1110	1185	1175	1160	1195	1185
Windbox Press	1040	6.5	11.2	30.5	37.5	5.0	15.0	27.5	34.0	11.0	15.5	34.0	37.5
GAS TEMPERATURES													
2 & 3 Pass (1st 1000)	F	1565	1704	2436	2692	1546	1610	2258	2327	1788	1509	1927	2692
2 & 3 Pass (2nd 1000)	F	1325	1375	2376	2506	1325	1479	2352	2461	1325	1375	2352	2506
3 & 4 Pass (1st 1000)	F	1655	1781	2395	2613	1655	1791	2254	2461	1655	1781	2395	2613
3 & 4 Pass (2nd 1000)	F	1636	1734	2254	2555	1636	1734	2254	2465	1636	1734	2254	2555
Gas Temp. Before Econ	F	654	715	860	997	670	700	860	960	651	708	858	997
Gas Temp. After Econ	F	317	341	426	465	345	350	440	451	320	350	440	465
Econ. Inlet Water Temp	F	261	262	440	255	261	262	440	255	255	260	255	255
Econ. Outlet Water Temp	F	375	400	432	445	416	416	416	425	400	420	440	445
Superheater Cut Temp	F	910	930	955	970	870	874	945	945	880	895	920	970
SUPERHEATER TUBE METAL TEMPS													
Tube 20 A	F	740	1030	1040	1050	1025	745	1040	1070	720	735	980	1050
19 A	F	1200	1300	1370	1370	1100	1100	1300	1370	1100	1100	1300	1370
18 A	F	1150	1240	1330	1320	1140	1230	1320	1360	1140	1230	1320	1360
17 A	F	1170	1265	1310	1310	1160	1140	1310	1370	1090	1140	1190	1370
16 A	F	1180	1270	1300	1310	1150	1150	1300	1370	1120	1150	1260	1370
15 A	F	1170	1260	1300	1300	1140	1140	1300	1370	1100	1140	1190	1370
14 A	F	1140	1190	1210	1220	1140	1140	1210	1220	1080	1110	1160	1220
13 A	F	1050	1050	1115	1115	740	760	1090	1100	780	1010	1060	1115
12 A	F	720	750	1040	1045	685	740	1015	1045	720	740	1015	1045
SUPERHEATER STEAM TEMP													
Tube 20 A	F	650	655	650	655	640	645	650	660	645	645	660	660
20 H	F	760	775	785	800	720	745	765	790	745	750	790	800
19 A	F	845	870	900	940	785	810	890	915	810	810	915	940
18 A	F	—	—	—	—	—	—	—	—	—	—	—	—
17 A	F	730	750	755	770	705	725	760	765	705	725	760	765
16 A	F	810	815	870	900	770	800	870	890	815	820	890	900
15 A	F	725	745	750	760	730	725	755	760	730	740	755	760
14 A	F	840	875	875	910	805	825	890	900	825	830	890	900
13 A	F	720	750	750	770	700	720	745	760	700	700	745	760
12 A	F	835	875	880	895	800	830	880	885	820	820	885	895
11 A	F	730	750	750	770	700	720	740	750	690	695	750	770
10 A	F	835	860	860	895	780	815	870	885	810	820	885	895
9 A	F	895	915	940	965	830	870	950	960	770	775	960	965
8 A	F	810	835	865	880	765	790	850	860	790	770	860	880
7 A	F	860	875	915	935	815	855	920	930	830	835	930	935

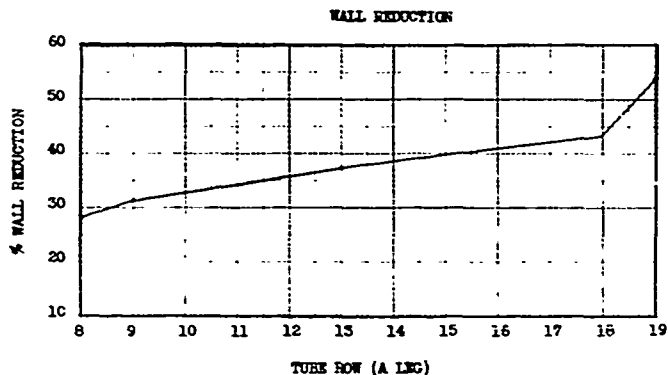
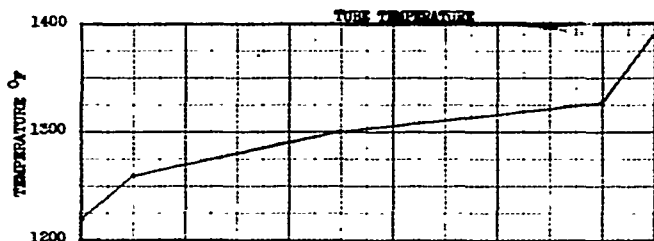
1

	CONDITION A				CONDITION B				CONDITION C				CONDITION D			
	5	6	9	8	12	16	17	18	21	22	24	25	CALCULATED			
1000	1055	1055	1060	1130	1055	1065	1065	1110	1005	1015	1150	1225	21	35	74	91
1000	1055	1055	1110	1110	1055	1055	1110	1110	1015	1055	1055	1155	21	37	68	94
1000	21	32	69	96	27	35	74	97	21	37	68	94	21	35	74	91
1000	2170	2255	2775	2940	2167	2455	2651	2699	2158	2330	2610	2620	2167	2455	2651	2699
1000	3445	3620	3651	3651	3429	3447	3651	3651	3429	3447	3651	3651	3429	3447	3651	3651
1000	607	6565	6775	7352	6417	6527	6775	7352	6327	6527	6775	7352	6217	6527	6775	7352
1000	106	124	130	142	10	9.5	14.4	14.7	9.5	9.5	12.5	14.1	7.5	9.5	14.4	14.7
1000	16.24				13.64				13.64				6.86			
1000	15.27	15.27	15.27	15.27	15.27	15.27	15.27	15.27	15.27	15.27	15.27	15.27	15.27	15.27	15.27	15.27
1000	15.27	15.27	15.27	15.27	15.27	15.27	15.27	15.27	15.27	15.27	15.27	15.27	15.27	15.27	15.27	15.27
1000	1216	1225	1210	1250	1190	1250	1155	1240	1225	1240	1232	1255	1190	1230	1155	1240
1000	1216	1216	1194	1184	1206	1254	1154	1184	1216	1224	1194	1194	1206	1251	1184	1184
1000	1185	1195	1195	1185	1195	1185	1110	1145	1175	1180	1155	1145	1175	1185	1110	1145
1000	6.5	11.2	30.5	37.5	150	150	27.5	34.0	110	13.5	34.0	35.5	15.0	15.0	27.5	34.0
1000	1565	174	2435	2692	1348	1410	2258	2507	1768	1529	1959	2134	846	882	913	925
1000	1537	—	2376	2544	1323	1479	1950	2063	—	—	—	—	—	—	—	—
1000	1655	1181	2515	2643	1473	1791	2352	2481	1564	1565	2019	2178	—	—	—	—
1000	1434	—	2234	2555	1456	1791	2254	2485	—	—	—	—	—	—	—	—
1000	654	715	855	899	670	700	860	960	651	708	854	959	651	708	854	959
1000	317	341	924	465	345	350	415	451	320	350	430	465	320	350	430	465
1000	217	232	440	255	265	265	240	240	258	260	258	255	258	260	258	255
1000	355	400	432	445	416	416	416	425	400	420	440	425	400	420	440	425
1000	910	920	925	970	870	874	945	965	880	895	925	942	846	882	913	925
1000	940	1030	1040	1050	1024	945	1040	1070	720	755	985	1040	—	—	—	—
1000	1200	1300	1370	1370	1100	1105	1240	1345	—	—	—	—	—	—	—	—
1000	1150	1240	1330	1330	1140	1140	1230	1240	—	—	—	—	—	—	—	—
1000	1170	1265	1310	1310	1160	1140	1250	1290	1090	1140	1190	1265	959	1025	1154	1180
1000	1180	1270	1340	1340	1190	1180	1260	1340	1120	1150	1205	1255	1065	1129	1232	1179
1000	1170	1240	1240	1255	1170	1160	1240	1250	1100	1140	1190	1190	1097	1155	1194	1151
1000	1140	1170	1210	1240	1140	1140	1210	1215	1080	1110	1180	1190	—	—	—	—
1000	1055	1050	1115	1115	940	960	1075	1100	780	1010	1080	1075	—	—	—	—
1000	920	950	1040	1045	825	945	1015	1045	720	940	1000	1040	—	—	—	—
1000	650	655	650	655	640	645	650	660	665	665	660	670	—	—	—	—
1000	760	775	775	800	720	745	765	790	745	750	785	805	—	—	—	—
1000	845	870	900	940	785	830	890	915	—	—	—	—	—	—	—	—
1000	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1000	720	750	755	770	705	725	760	765	—	—	—	—	—	—	—	—
1000	840	845	870	900	770	800	870	890	815	820	850	885	784	804	850	865
1000	725	745	750	760	705	725	755	760	730	740	750	770	—	—	—	—
1000	850	875	875	910	805	825	890	900	825	830	865	885	845	864	908	915
1000	730	750	750	770	700	720	745	760	690	700	710	730	—	—	—	—
1000	755	875	880	895	800	830	880	885	820	820	835	870	826	858	874	880
1000	730	750	750	770	700	720	740	750	690	695	720	735	—	—	—	—
1000	835	860	860	895	780	815	870	885	810	820	850	870	—	—	—	—
1000	775	915	940	965	830	870	950	960	770	775	835	870	—	—	—	—
1000	810	835	865	880	745	790	850	860	790	790	820	850	—	—	—	—
1000	860	875	915	935	815	855	920	930	830	835	870	890	—	—	—	—



NO 931 SUPERHEATER STUDIES  
 USS BARRY (DD 933) BOILER 2B

SUPERHEATER TUBE TEMPERATURES AND WALL REDUCTION  
 (TEMPERATURES OBSERVED FOR 25 KNOTS, CONDITION A)



NSIL PROJECT B-494

APPENDIX I

AGENDA

AGENDA FOR NBTIL PROJECT B-43.

AGENDA FOR SUPERHEATER ANALYSIS TESTS  
TO BE CONDUCTED ON USS BARRY (DD933)

18 September 1961

Authority:

1. Tests to determine conditions in the superheaters of Babcock & Wilcox DD931 Class boilers that have lead to tube thinning and failure were requested by Bureau of Ships letter DD931 C1/9510; DD945 C1/9510; Ser 651A-947 of 29 June 1961. The approval for superheater tests, to be conducted on USS BARRY (DD933), was given in Commander Destroyer Force, United States Atlantic Fleet dispatch 0319867 of July 1961. By Boston Naval Shipyard Request for Performance of Work WR2-0202 of 7 July 1961 the Boiler and Turbine Laboratory was furnished funds in the amount of \$10,000.00 to instrument one boiler on USS BARRY and to provide consultant services for the test. Bureau of Ships letter DD933; Ser 651A-1007 of 17 July 1961 outlined the purpose and procedures for conducting superheater tests in more detail than in the Bureau of Ships letter of 29 June 1961. On 19 June 1961, a conference was held at Naval Shipyard, Boston with representatives of the Shipyard, USS BARRY, Boiler and Turbine Laboratory, and Babcock & Wilcox present. At this conference procedures and responsibilities for test preparation and conducting of tests were discussed. This agenda is a final procedure for the complete test, its preparation, performance, and evaluation.

Purpose of Tests:

2. The primary consideration of these tests is to make an analysis of a superheater in a DD931 Class Babcock & Wilcox steaming boiler to determine (1) conditions under which tube corrosion is taking place, (2) what measures can be taken to extend superheater life, and (3) methods

AGENDA FOR NBTL PROJECT B-494

that can be used to predict superheater tube life. These objectives will be obtained by instrumenting one superheater to primarily determine the following: (1) tube metal temperatures in the second, third, and fourth pass superheater tubes; (2) steam temperatures at various locations in the superheater steam passes; (3) combustion gas temperatures in the superheater cavity; and (4) supplementary information to assist in making a complete analysis of the problem. Data is to be obtained both before and after installation of a gas baffle in a lane between second and third pass superheater tubes on the furnace side of the superheater. It is in the area below this lane wherein serious superheater tube corrosion is being experienced.

Background:

3. Superheater tube failures by bursting have occurred in superheaters of DD931 Class Babcock & Wilcox boilers. The first two of these failures occurred on USS FORREST SHERMAN and were located as follows:

Boiler 1B - 19th tube up - A or outer loop  
Boiler 1A - 19th tube up - B or 2nd loop in

These failures occurred immediately prior to 5 May at which time boilers had the following steaming hours:

1A	1B	2A	2B
11892	11819	12102	12187

Approximately 12 May, FORREST SHERMAN had another superheater tube failure as follows:

Boiler 2B - 19th tube up - B or 2nd loop in

At approximately the same time as the FORREST SHERMAN failures, JOHN PAUL JONES (DD932) had a superheater tube failure as follows.

Boiler 1B - 19th tube up - B or 2nd loop in

AGENDA FOR NHTL PROJECT B-494

USS MANLEY (DD940) also had a ruptured superheater tube failure in the 19th tube from the bottom in the A or outer loop.

5. All superheater tube failures had the following similarities:

a. Location of all failures was in the 19th row from the bottom on the furnace side leg. This 19th row is the top tube row of the lower furnace side header section and has a 2-1/2" space between it and the bottom tube row of the upper header section. The 19th row is in the third pass; the 20th row in the second pass.

b. All tube failures occurred on the outer loop or in the second loop in.

c. All ruptures occurred on the tube side facing the furnace.

d. All ruptures occurred approximately 30" from the superheater header.

e. All ruptures were thick lipped but varied in size from slits with little bulging to rather large ruptures (4" long x 1-3/4" across the opening) with much bulging.

f. Tube walls of tubes in the area of the ruptures had thinned on the gas side on the side of the tubes facing the furnace. This was especially so in the outer loop tubes and thinned tubes included tubes from at least 13th tube from the bottom to 19th tube from the bottom.

g. All failed tubes were 18 Cr - 8 Ni alloy with nominal wall thickness of 0.156". All tubes in the 3rd and 4th pass are of this material.

6. During examination of boilers 2A and 2B on FORREST SHEPHERD on 5 May 1961, it was noted that there was quite a difference in appearance between the superheater tubes of the top two passes and those of the

AGENDA FOR NBTL PROJECT B-494

bottom two. It was noted that the bottom two passes showed signs of corrosion and overheating toward the rear that were not nearly as evident toward the front and that these signs were non-existent in the upper two passes.

7. Observations similar to the above were repeated on boiler 1B of JOHN PAUL JONES on 16 May 1961 and were verified by special inspection of FORREST SHERMAN on 31 May 1961 when it was also determined that the 19th, 18th, 17th, 16th, and 15th tubes from the bottom showed very definite signs of corrosion as compared to the tubes below them.

8. Inspection of the BARRY superheaters from furnace and cavity in early July 1961 showed a similar pattern from the firesides, but not nearly as accentuated as on FORREST SHERMAN and JOHN PAUL JONES. Perhaps the difference was due to the fact that BARRY boilers had fewer steaming hours than the boilers of the other two ships.

9. It has been fairly well established that failure of the superheater tubes may be attributed to wall thinning caused by vanadium ash from the fuel oil attacking the superheater in areas where tubes have had a high metal temperature. Materials Laboratory, Boston Naval Shipyard estimated that a fractured tube from the FORREST SHERMAN had reached a temperature in the vicinity of 1300°F during boiler operation. This was verified by separate Boiler and Turbine Laboratory data wherein it was determined that the failed tube from JOHN PAUL JONES had operated in the region of 1300°F. It is known that high tube metal temperatures, especially above 1150°F to 1200°F are a prime factor to be considered as concerns the amount and extent of corrosion from residual fuel oil



AGENDA FOR NETL PROJECT B-494

ash. The amount of corrosion which takes place in a particular boiler will also depend upon gas temperatures and gas velocities entering the various sections of the superheater and the amount and condition of the ash carried along with the gases of combustion. It has been considered that perhaps both gas flow and steam flow maldistribution have increased the corrosion rate on the superheaters in boilers of the FORREST SHERMAN type. To somewhat improve gas flow distribution and to provide some initial improvement in the superheaters, a gas baffle for installation in the space between the 2nd and 3rd passes on the superheater furnace side was authorized by Bureau of Ships dispatch 022038Z of 1 June 1961.

10. The superheaters of the DD931 Class Babcock & Wilcox boilers have four passes containing a total of 180 U-type tubes. Each tube row consists of four separate U-loops so arranged that the space between legs of the innermost loop provides sufficient room for a person to enter the superheater cavity. Both inlet and outlet headers are on the generating bank side of the superheater bank with the inlet header being at the top. Two rows of staggered two-inch screen tubes are located between the furnace and the superheater bank. Superheater tubes of the first two passes are 1-1/4" OD by 0.165" thick and are to Military Specification MIL-T-16286B, Class E; tubes of the last two passes are 1-1/4" OD by 0.156" thick and are to the same specification, but are Class C. The working pressure of the superheater is 1250 psig and the steam temperature at the superheater outlet is a minimum of 925°F at cruising and full power not to exceed 970°F at any rate.

AGENDA FOR NBTL PROJECT B-424

General Considerations and Responsibilities

11. Tests are to be conducted on Boiler 2B of the USS BARRY (DD-933) in conjunction with Post Repair Trials out of Boston Naval Shipyard in September 1961. It is expected that tests will be conducted during dock trials and during two days at sea; the first day of sea tests will be conducted with the brick gas baffle between the second and third passes removed; and the second day of tests will be conducted with the gas baffle installed and will follow the first sea tests by about four days.
12. The fact that these tests are being conducted or these tests are desired shall in no way interfere with operation and safety of the ship under its Commanding Officer. An engineer (or officer) from the Philadelphia Naval Shipyard (Naval Boiler and Turbine Laboratory) shall be designated to head the personnel under the Bureau of Ships and Boston Naval Shipyard assigned to assist in taking data and observing these tests. All requests for information, suggestions, etc. will be made through the designated head engineer to Engineering Officer or an officer to be designated by the Commanding Officer of the USS BARRY.
13. It is requested that after each day's runs the USS BARRY furnish the Naval Boiler and Turbine Laboratory with copies of the fireroom, engine room operating records and the bell logs, and fuel oil sample. It would be appreciated that during runs announcement of changes in operating conditions be announced prior to actual commands to assist data takers in properly marking records.
14. Boston Naval Shipyard is requested to install the instrumentation furnished by Philadelphia Naval Shipyard (Naval Boiler and Turbine

AGENDA FOR NBTL PROJECT B-494

Laboratory) remove instrumentation after tests, and furnish assistance as may be required during these tests.

15. Philadelphia Naval Shipyard (NBTL) is assigned the responsibility for coordinating conduct of tests, assuring proper calibration and operation of instruments, preparing all data taking forms, collecting data, observing the behavior of the boiler and preparing a report of the results of the test. Data taken shall be such that a reasonable heat balance be made of the boiler so that an estimate can be made of gas temperatures entering the superheater and superheater cavity.

16. In accordance with the request of Bureau of Ship's letter DD933, Ser 651-1007 of 17 July 1961 that the Boiler and Turbine Laboratory inform interested activities of assistance required for the tests, Boston Naval Shipyard was requested during meeting of 17 August 1961 and by telephone conversation of 14 September 1961 to provide the following assistance:

(a) Install economizer thermocouples and stack gas sampling cone.

(b) Manufacture and install MHTV gas temperature probe sleeves.

Install all required connecting piping.

(c) Manufacture and install panel boards for Leeds and Northrup recorders, including electrical outlets and wiring. Install the instruments.

(d) Assist NBTL in installation of instrumentation and calibration of instruments as required.

(e) Provide an orsat apparatus and operator during dock and sea trials.

(f) Provide two data takers during dock and sea trials.

AGENDA FOR NBTIL PROJECT B-494

Test Instrumentation:

.7. An arrangement and detail of instrumentation for the superheater evaluation is shown in NBTIL drawing H-3603-0 of 8 August 1961. In summary the following is the instrumentation set-up for the tests:

(a) A total of eleven thermocouples will be installed on the outer skin of the superheater tubes with all hot junctions in the gas path 30" from the centerline of the superheater headers. Starting to count superheater tubes from the bottom, last pass, and labeling tube legs A to H beginning with the furnace side leg, the following tube locations will have thermocouples: 1A, 1E, 2A, 2E, 9A, 13A, 18A, 19A, 19B, and 20A.

(b) A total of 32 thermocouples will be attached to the superheater tubes adjacent to the superheater headers in the header vestibule. These thermocouples will indicate steam temperature in the various circuits. Counting tube rows from the bottom and assigning A to H designations for the tube legs beginning at the furnace side leg, the following locations will be instrumented:

1A, 1D, 1E, 1H, 8A, 8D, 8E, 8H, 9A, 9D, 9E, 9H, 13A, 13H, 16A, 16A, 18H, 19A, 19D, 19E, 19H, 20A, 20D, 20E, 20H, 27A, 27H, 31A, 31H, 32A, 32H, and 42A.

(c) Two multi-shielded high velocity thermocouple probes will be installed in the superheater cavity to obtain gas temperatures. One will be located in the gas path between the third and fourth passes and the other between the second and third passes.

(d) Five thermocouples will be installed in the gas path before and after the economizer.

AGENDA FOR ABTL PROJECT B-14

(e) A pencil type thermocouple will be installed at the superheater outlet to measure final steam temperature.

(f) Pencil type thermocouples will be installed at both forced draft blower discharges to measure combustion air temperature to the boiler.

(g) Economizer water inlet and outlet temperatures will be measured by peened thermocouples.

(h)  $CO_2$  percentage in the stack gas will be measured using a cone primary element and an orsat apparatus for analysis and readout.

(i) Ship's instrumentation will be used to obtain fuel oil supply pressure and the following steam pressures: steam drum, superheater outlet, desuperheater inlet, and desuperheater outlet.

(j) Ship's fuel oil meter will be used to obtain fuel oil rate.

(k) Air pressure at the windbox will be obtained using ship's manometers.

(l) Fuel oil samples will be obtained and analyzed. Samples will be taken as close to the supply burner manifold as possible during the test runs.

Test Evaluation:

18. During dock trials all instrumentation will be checked-out; final calibrations will be made as required including calibration of the high velocity thermocouple probes, and preliminary data will be obtained.

19. Tests conducted during the first and second day of sea trials will be the same except that the first day the brick gas baffle between the second and third superheater pass will not be installed and on the second day this gas baffle will be installed.

AGENDA FOR NSTL PROJECT B-494

20. All test runs will be made with two boilers operating in the ship under split plant conditions.

21. Steady state runs will be made holding the boiler rate constant for a period of 15 minutes or until superheater tube temperature data becomes steady. Normal fuel oil burner combinations and settings used by the ship will be employed for the test runs. The steady state runs will be conducted at the boiler ratings equivalent to the ship conditions shown in the following table and at boiler full power rating:

Ship Condition Knots	Lbs. Oil/Blr/Hr	Final Steam Temp. °F	Air Press. at Wind- box "H <sub>2</sub> O
10	-	-	-
15	2150	880	4
20	3600	950	8
25	7090	970	23
Boiler Full Power	10260	945	42

During the steady state runs, at least two rounds of data will be recorded, and more when runs are longer than fifteen minutes. Data will be recorded on data sheets made-up and arranged in advance by the Boiler and Turbine Laboratory.

22. At completion of the 15K and 25K steady state tests, normal ship-board soot blowing operations should be conducted. At least two rounds of data will be recorded during soot blower operations at each rate.

23. At completion of the boiler full power steady state run, ship's speed should be brought to 25K and held there until all superheater

AGENDA FOR NBTL PROJECT B-494

temperatures steady-out so as to prepare for the maneuvering run. Maneuvering operations should consist of rapidly reducing the ship's speed from 25K to 10K in the normally practiced procedure. After holding a speed of 10K for 10 minutes, increase ship's speed to 25K. This maneuvering may be repeated to verify data obtained. (Note: The 25K condition is the approximate speed where superheater outlet temperature is expected to reach maximum under steady steaming conditions; a lower speed may be selected by Commanding Officer, USS BARRY if so desired for operating convenience.) Data will be recorded during maneuvering operations.

24. During the time that the boiler is being brought on the line superheater tube metal temperatures, interpass steam temperatures, and data usually recorded in the standard fireroom operating record will be taken every 10 minutes after boiler light-off. Similarly, when the boiler is being secured the same data should be obtained at the same interval until steam generation ceases and for approximately 10 minutes after the bleeder test to the auxiliary exhaust valve is closed.

25. During the period that the ship is getting in and out of port, the instruments recording superheater tube metal and steam temperatures will be cut-in to obtain useful data concerning effects of maneuvers. If any unusual conditions occur, procedures under which they happened will be logged and additional data will be obtained. Copies of the engineer's bell book log only will be required for these periods. Data will be recorded as required during these periods.

26. As time permits, additional steady state runs as follows will be conducted:

AGENDA FOR NSTL PROJECT B-494

(a) At boiler rates below full power, operations will be conducted with various burner combinations in use to determine the effect of burner location upon superheater metal and steam temperatures.

(b) At boiler rates to full power, runs will be conducted with various windbox pressures to determine the effect of various amounts of excess air upon superheater metal and steam temperatures.

27. If conditions permit at anytime during the test period and danger of burning-out superheater thermocouples is not involved or is no longer important, superheater temperature data will be obtained during an emergency high speed lighting-off operation.

28. The possibility exists that data from the first day's sea trials may indicate the necessity of removing superheater tubes in the upper part of the third pass to increase steam velocity in that pass. If this becomes necessary arrangements may be made to remove those tubes before the second day's trials.

29. At completion of all testing, the Boiler and Turbine Laboratory representatives with the assistance of Boston Naval Shipyard will remove all instrumentation. Instrumented superheater tubes will not be removed and renewed.

A. LEE  
Head Engineer  
Boiler and Heat Exchanger  
Branch  
Code 651 BUSHIPS

W. A. FRITZ, JR.  
Head, Steam Generating  
Branch  
Naval Boiler and Turbine  
Laboratory

15 September 1961



RGTL PROJECT B-494

APPENDIX II  
CALCULATIONAL PROCEDURE

DE931 SUPERHEATER STUDIES

APPENDIX II

Calculational Procedure used in evaluating Heat Transfer Characteristics for boiler Conditions A, B and C and for predictions of Condition D.

SYMBOLS

- A Outside surface area of tube; square feet.
- D Tube diameter;  $D_i$  = inside;  $D_o$  = outside, feet.
- G Combustion gas flow; pounds per hour
- H Steam enthalpy;  $\Delta H$  = total steam enthalpy change per tube per unit time or per superheater pass per unit time; BTU per hour.
- $h_s$  Steam enthalpy per pound of steam;  $\Delta h$  = steam enthalpy change per pound of steam; BTU per pound
- $h_i$  Steam film coefficient of heat transfer;  $\text{Btu}/(\text{hr})(\text{ft}^2)(^\circ\text{F})$
- $h_o$  Gas film coefficient of heat transfer;  $\text{Btu}/(\text{hr})(\text{ft}^2)(^\circ\text{F})$
- Q Heat transfer rate; BTU per hour
- Q/A Mean heat transfer rate to steam per square foot of tube surface area based on enthalpy rise of steam;  $\text{Btu}/(\text{hr})(\text{ft}^2)$
- R Combined resistance to heat flow through tube wall and steam film where  $R = 1/h_i + 1/U_c$ ;  $(\text{hr})(\text{ft}^2)(^\circ\text{F})/\text{Btu}$ .
- t Temperature, deg F;  $t_s$  = steam temperature;  $t_{so}$  = outside metal surface temperature of tube;  $t_g$  = average gas temperature in vicinity of a tube;  $\Delta t_s$  = temperature drop through steam film;  $\Delta t_w$  = temperature drop through tube wall.
- $U_c$  Thermal conductivity through a tube wall;  $U_c = k/l$ , where  $l' = 1/2 D_o \ln(D_o/D_i)$ ;  $\text{Btu}/(\text{hr})(\text{ft}^2)(^\circ\text{F})$ .
- $\dot{W}_s$  Total steam flow through superheater; pounds per hour
- $\dot{w}_s$  Average steam flow per superheater tube;  $\dot{w}'_s$  is other than average value of steam flow per tube; pounds per hour per tube.

### Tube Temperature Evaluation

This method involves the evaluation of film coefficients and  $h$  at transfer rates using data collected during boiler operation under Conditions A, B, and C, and extrapolating the trends of these items for application to Condition D. These boiler conditions are shown schematically in Plate 3 of the report. All calculations used the outer loop superheater tubes (plan piece 805 for third pass and 809 for fourth pass).

Initial attempts at evaluation used tube 8AH, figure 1, as the basis for evaluation since this tube had both metal and steam thermocouples at each end. Using these temperatures to obtain a logarithmic mean temperature difference and a steam enthalpy rise in the tube, a combined average heat transfer coefficient was obtained by the relation:

$$R = \frac{h_{avg}}{Q/A} = \frac{1}{h_i} + \frac{1}{U_c}$$

This value of  $R$  was used along with known data from tube 9AH as indicated in figure 2 to calculate the heat transfer rate at location 2:

$$\frac{Q_2}{A} = \frac{t_{bo2} - t_{s2}}{R}$$

The ratio:

$$X = \frac{Q_2/A}{Q/A}$$

is a factor which relates the heat transfer rate at location 2 to mean heat transfer rate obtained by enthalpy. Assuming that steam flow distribution and gas temperature and flow distribution are constant over the third pass, this factor should hold relatively constant for the pass at a particular boiler steam rate. These  $R$  and  $X$  values

were then used to calculate outside metal temperatures at location 2 for the remaining tubes in the pass as follows:

$$t_{m0} = (Q/A)(X)(R) + t_s$$

where  $t_{m0}$ ,  $t_s$  and  $Q/A$  are for the particular tube being evaluated. This method yielded excellent correlation between calculated and observed metal temperatures for tubes 13 and 18 during Condition A full power run 8. Tube 19 calculated temperature was 50°F higher than observed, and this is probably due to the steam flow through tube 19 being much less than the assumed average. The reduced flow through tube 19 was calculated:

$$w'_s = \frac{A}{RX} \left[ \frac{t_{m0} - t_s}{\Delta h} \right] \text{ observed}$$

For run 8, tube 19,  $w'_s$  was evaluated at 89% of the average  $w_s$  for the pass.

The identical procedure was employed for evaluation of Condition B, full power run 18, and resulted in fairly good correlation between calculated and observed metal temperatures. Tube 18 resulted in the poorest correlation with the calculated metal temperature being 30°F below observed. The calculated value for tube 19 agreed within 4°F of observed. This was unexpected and is probably due to the fact that tube 19 effective surface area was reduced by addition of a baffle which countered the effects of reduced steam flow in the calculations.

The foregoing results indicated that the inside (steam) film coefficient varies appreciably with boiler Conditions A, B, and C. It was therefore necessary to evaluate the trend of this coefficient in order to predict its value for boiler Condition D. This was accomplished

by evaluating the inside film coefficient as follows:

$$\frac{1}{h_i} = \frac{(t_{w2} - t_s)}{Q/A} - \frac{1}{U_c}$$

for selected boiler rates from 20% to 100% full power, and plotting these values against total steam flow as shown in figure 3. These curves are extrapolated to Condition D by taking 14/9 of the numerical difference between the B and C Condition curves. Similarly, the total heat transferred to the steam for each tube is plotted in figure 4 and extrapolated to the D Condition. Constants predicted in this manner were used in conjunction with information from Condition B test runs in order to predict metal temperatures for boiler Condition D, as follows:

Known (from Condition B test runs; same as in Fig. 2)

$\bar{w}_s$

$t_{s1}$  (entering particular tube)

$h_{s1}$  (at  $t_{s1}$  and 1200 psia)

$\Delta$

Assumed (boiler Condition D)

12 tubes removed (remaining = 44-12 = 30)

Baffle added between 2 & 3 passes

Procedure

Evaluate  $\Delta H$  at  $\bar{w}_s$  (Fig. 4)

Evaluate  $h_i$  at  $\bar{w}_s$  (Fig. 3)

$$\bar{w}_s = \frac{\bar{w}_B}{30} \quad \text{LB/HR/tube}$$

$$Q/A = \frac{\Delta H}{\Delta} \quad \text{BTU/HR/FT}^2$$

$$\Delta t = \frac{\Delta H}{h_i} \quad \text{BTU/LB}$$

Steam Enthalpy at Location 2.

$$h_{s2} = h_{s1} + \Delta t$$

Find  $t_{s2}$  at  $h_{s2}$  and 1200 psia from steam tables.

Temperature drop through:

$$\text{Steam film} = \Delta t_{s2} = \frac{Q/A}{h_i}$$

$$\text{Tube wall} = \Delta t_{w2} = \frac{Q/A}{U_c}$$

Outside tube metal temperature at location 2:

$$t_{m2} = t_{s2} + \Delta t_{s2} + \Delta t_{w2}$$

#### Comment

The  $Q/A$  value used in these calculations is a mean heat transfer rate for the particular tube based on enthalpy rise. The steam film coefficient is based on observed steam and metal temperatures at location 2 and the mean heat transfer rate. This coefficient is therefore valid only when used with the mean heat transfer rate for evaluation of temperature at location 2.

#### Results

Resultant tube metal temperatures as calculated by the foregoing method are shown in Plate 10 of the report for tubes 9, 13 and 18. These calculations predict an appreciable reduction in temperature from the C to D boiler condition for tube 18, but practically no change for tubes 9 and 13. This condition may be explained by the fact that steam enthalpy rise per tube (Btu/hr/tube) is not the same for all boiler conditions. That is, for tube 18, the enthalpy rise increases in the order C, B, A; whereas for tubes 9 and 13 the enthalpy rise increases in the order B, A, C. This indicates that Condition C shifted a

greater portion of the work from the top of the third pass to the lower tubes in the third pass. This greater transfer of heat in tubes 9 and 13 probably overcomes the effects of the increased steam film coefficient due to increased flow per tube during boiler Condition C. This effect is naturally carried through to the extrapolation from Condition C to D.

#### Gas Flow Distribution

Vertical distribution of gas flow through the third pass was evaluated by determining the gas side film coefficient of heat transfer for tubes 9, 13, 18 and 19 during Conditions A, B, and C by the following approximation:

$$h_o = \frac{Q/A}{t_g - t_{mo}}$$

Since this film coefficient is proportional to  $G^n$  for a particular configuration, we may write:

$$\frac{G'}{G} = \left[ \frac{h_o'}{h_o} \right]^{\frac{1}{n}}$$

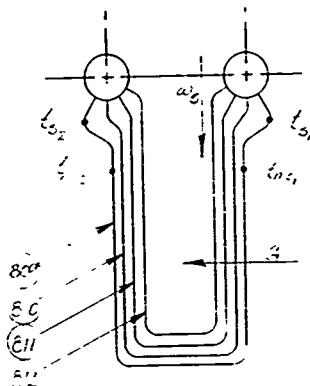
This relation may then be used to compare gas flows to a common base. This was done by relating film coefficients of all tubes under consideration to that for tube 9, Condition A. This procedure resulted in a flow pattern as shown in figure 5 for Conditions A, B, and C. The mean gas flow through the pass increased approximately 5% from Condition A to B full power runs, and increased an additional 48% during the Condition C full power run. This is probably due to the fact that the removal of tubes reduced the resistance to gas flow through the pass. A similar evaluation shows the flow through the third pass will increase.

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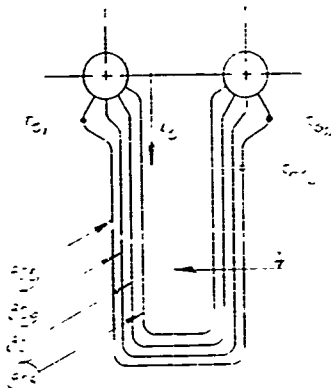
an additional 32% for Condition D. Gas flow through the third pass for Condition D is therefore 85% greater than for Condition A at the full power rate. A similar procedure used the variation in gas side film coefficient to evaluate the horizontal distribution of gas flow for the Condition B full power run. Results indicated that the gas flow through the third pass, at the rear of the furnace was approximately 65% greater than the mean flow through the third pass.



**INSTRUMENTATION: TUBE ROWS 8 & 9**



**TUBE 8 AH**  
**INSTRUMENT LOCATIONS**



TUE 9 AM  
INSTRUMENT LOCATIONS

DO 931 SUBTHERMAL STUDIES  
USS BARRY (DD 933) BOILER 28  
STEAM FILM COEFFICIENT OF HEAT TRANSFER  
BOILER CONDITIONS A, B, C & D

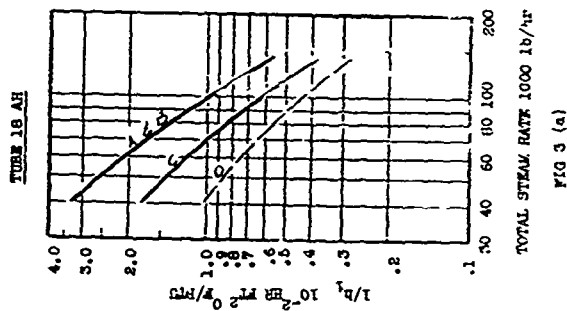


FIG 3 (a)

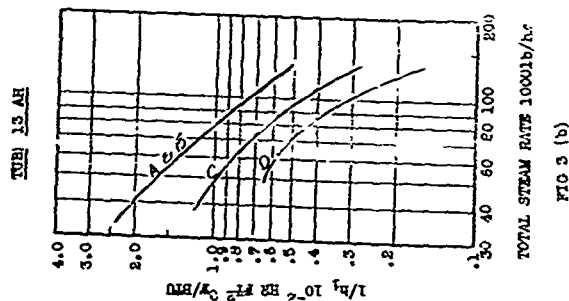


FIG 3 (b)

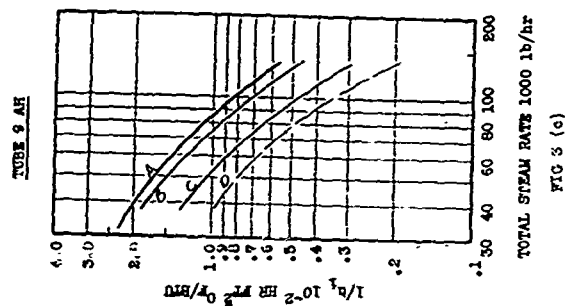
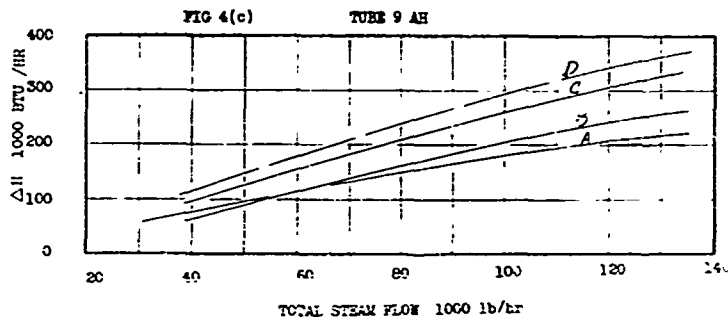
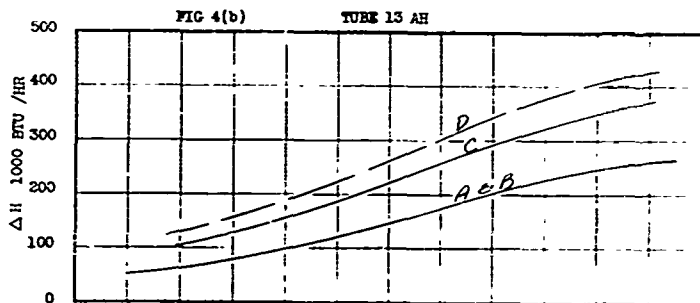
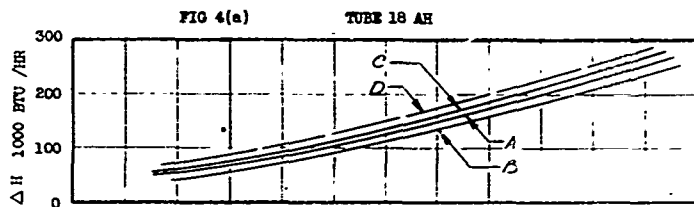


FIG 3 (c)

DD 931 SUPERHEATER STUDIES  
 USS BARRY (DD 933) BOILER 2B

 STEAM ENTHALPY RISE PER TUBE  
 BOILER CONDITIONS A, B, C & D


TOTAL STEAM FLOW 1000 lb/hr

10 of 11

APPENDIX II

DD 931 SUPERHEATER STUDIES  
USS BARRY (DD 933) BOILER 2B

GAS FLOW DISTRIBUTION THROUGH THIRD PASS

BOILER CONDITIONS A, B, C & D

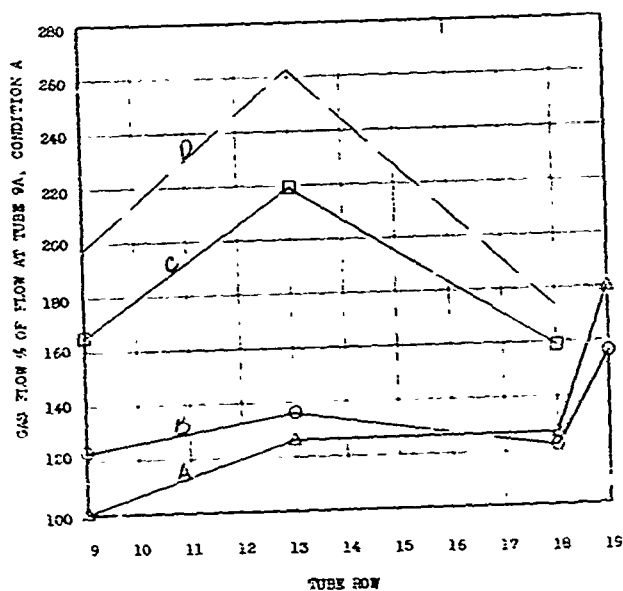


FIG 5

<p>Naval Boiler and Turbine Laboratory Project No. B-494 SUPERHEATER EVALUATION STUDIES FOR DD931/DD945 CLASS BABCOCK &amp; WILCOX BOILERS, EVALUATION REPORT, by W. A. Fritz, Jr. T. P. Tursi, Jr. May 1962</p> <p>16 p., 12 encl., 2 append. UNCLASSIFIED</p> <p>Three ships of the DD931 Class experienced tube failures in the superheater third pass. All failures occurred in the same tube row and all (over)</p>	<p>1. Heat Transfer Studies Fuel Ash Corrosion I. Fritz, W.A., Jr. Tursi, T.P., Jr. II. Babcock &amp; Wilcox Company</p>
<p>Naval Boiler and Turbine Laboratory Project No. B-494 SUPERHEATER EVALUATION STUDIES FOR DD931/DD945 CLASS BABCOCK &amp; WILCOX BOILERS, EVALUATION REPORT, by W. A. Fritz, Jr. T. P. Tursi, Jr. May 1962</p> <p>16 p., 12 encl., 2 append. UNCLASSIFIED</p> <p>Three ships of the DD931 Class experienced tube failures in the superheater third pass. All failures occurred in the same tube row and all (over)</p>	<p>1. Heat Transfer Studies Fuel Ash Corrosion I. Fritz, W.A., Jr. Tursi, T.P., Jr. II. Babcock &amp; Wilcox Company</p>
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