DPE-2178

HEAVY WATER COMPONENTS TEST REACTOR

Savannah River Plant
Project S8-1086

CONDITION OF REACTOR VESSEL
FINAL REPORT

E. I. DU PONT DE NEMOURS & CO., (INC.)
Engineering Department
Wilmington, Delaware

6662267

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FINAL REPORT

Issued October, 1961
Design Division

E. I. DU PONT DE NEMOURS & CO., (INC.)
Engineering Department
Wilmington, Delaware

CONTRACT AT(07-2)-1 WITH THE
UNITED STATES ATOMIC ENERGY COMMISSION

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I. SUMMARY

A. INTRODUCTION

The HWCTR reactor is a 1,500 p.s.i. pressure vessel approximately 30 ft. long with diameter ranging from about 5 ft. to 7 ft. This vessel was delivered to the Savannah River Plant on June 29, 1961. A detailed examination of the vessel was made at that time by Construction and SRP forces to check its condition before installation in Bldg. 770-U. During the past several months, the apparent defects noted during that examination, plus any deficiencies reported before shipment, have been studied and evaluated. The only item of any consequence is concerned with the omission of a normalizing heat treatment on 21 vessel nozzles, and the effect of this omission on the impact strength of the nozzles. Another item was the damage to a welding lip during shipment of the reactor from the PACECO plant in Alameda, California to SRP. This lip permits seal welding of the vessel head to the body.

This report covers a discussion of the above items as outlined under "Objectives" and presents our final conclusions and recommendations regarding the condition of the reactor vessel. Certain of the conclusions and recommendations have been modified somewhat from those contained in a preliminary report on this subject issued in August, 1961.

B. OBJECTIVES

1. Record the important items covered in the examination and investigation of the HWCTR reactor and assessment of its condition as received at SRP.

2. Investigate the effect of omitting the normalizing heat treatment step on small nozzles.

3. Establish procedures for satisfactory reactor operation in view of any limitation due to impact strength of the small nozzles.

C. CONCLUSIONS AND RECOMMENDATIONS

Responsibility for damage to the vessel during shipment appears to rest with the railroad. It is our opinion that the damage to the welding lip will have no adverse effect on the sealing capabilities of the gasketed joint. Although a method of repair has been developed, it is our recommendation that this repair work not be done at this time.

Omission of the normalizing heat treatment on the small nozzles has resulted in increasing the Nil-Ductility-Transition temperature of these parts. This means that a temperature-pressure relationship limitation must be applied to the operation of the reactor at low temperature levels. It does not appear practical to mitigate the brittle condition of the nozzles.

Miscellaneous observations on reactor vessel quality, other than the above two items, were investigated and judged not to be infractions of the specifications. These items are listed in Section II-C of this report.

The quality standards established in the detailed specifications for this vessel were of a high order and entirely appropriate for its proposed service. We believe that the close inspection of all phases of the fabrication of the vessel assures that it was built in accordance with those specifications with one exception noted. This exception involves a fabrication procedure for nozzle lining requested as an alternate by the vendor. It was not a part of the original specifications. Consequently, it is our opinion that the HWCTR reactor is basically a sound, high quality vessel.

II. DISCUSSION

A. SHIPPING DAMAGE - BROKEN FLANGE LIP

The reactor vessel was shipped from the vendor's shop f.o.b. Alameda, California with freight allowed to SRP. Railroad representatives inspected the vessel bracing on the car at the vendor's plant and accepted it for shipment. The vessel was received at SRP in a damaged condition as described in Exhibit 23. Exhibits 1 through 9 show details of the damage, method of bracing and indications of bracing slippage.

Design analysis indicates that the sealing capabilities of the gasketed joint will not be impaired by the damage to the welding lip. Metallurgical examination confirms the fact that the portion broken off is all stainless steel and that no carbon steel of the main flange has been exposed.

A design has been developed for repairing the broken portion of the lip, as indicated in Exhibits 10, 11 and 12. No stress relief after welding would be required, as there would be no welding directly on the carbon steel flange section, and the copper chill bar would serve to maintain the temperature of the carbon steel section at a moderate level.

It is our recommendation that the repair work not be done at this time. The welding lip was provided to allow for the eventuality when it might be necessary to revert to a seal weld because of the inability of the gasketed joint to provide a leak-tight closure. We believe that it will not be necessary to use this method of sealing the vessel. However, in the event that this eventuality does materialize, the welding lip could be repaired at that time.

The following steps were taken to assure that the damaged lip has not impaired the gasket groove:

1. All burrs were removed from the edge of the outer gasket groove along the line where the lip separated from the groove.

2. The flange was checked for flatness in the vicinity of the broken lip and found to be within acceptable tolerances.

3. The flange was examined for cracks with dye penetrant and none were found.

A hydrostatic test will be applied to the gasketed closure as part of the normal test procedure prior to start-up. The section between the two concentric gaskets will also be pressurized through the leak-off connection. This will test the integrity of each gasket separately.

B. LIMITATIONS - NIL-DUCTILITY TEMPERATURE OF 2" AND 4" NOZZLES

Origin of Investigation

After fabrication was completed on the HWCTR reactor vessel and two successful hydrostatic tests made at 1.5 times design pressure to prove integrity, PACECO discovered and reported that the 2" and 4" nozzles had not been normalized after the "brazing-in" of their stainless steel liners. Omission of this important heat treatment was of considerable concern because it was felt the nozzles were left with a coarse grain structure which would adversely affect the minimum safe temperature for pressurizing the vessel. The investigation reported here was immediately initiated to determine the minimum safe temperature for vessel pressurization. A careful review of the fabrication records revealed no other discrepancies, but did show that the major portion of the vessel had been stress relieved eight times for a total accumulated time above 1100°F. of 53 hours (Exhibit 24). It was felt the repeated stress relieving treatments and prolonged time above 1100°F. may have had an adverse effect on the minimum safe pressurization temperature. Determination of this temperature was of prime importance in establishing safe pressurizing procedures so as to avoid brittle fracture of the vessel.

Conclusions and Recommendations

The HWCTR reactor vessel is free of harmful defects detectable by non-destructive test techniques and the fabrication workmanship is of high quality.

The reactor vessel should not be pressurized above 300 p.s.i.g. (20% of design pressure) at a temperature less than 140°F. (the minimum safe pressurization temperature to avoid brittle failure).

Hydrostatic testing at 1.5 times design pressure should be done no more frequently than absolutely necessary to reduce the possibility of low cycle fatigue failure. Basis of design is 2,000 cycles at design pressure. Hydrostatic testing above 1.5 times design pressure should be avoided altogether.

Impact testing of samples cut from an actual nozzle would not result in a practical or significant change in the 140°F. minimum safe pressurization temperature. Since little or no operating advantage would be obtained, sacrifice of a nozzle, and the effort to remove a nozzle and install a replacement closure is considered not justified.

Data and Test Results

Composition and physical properties of the carbon steel of the stainless steel clad shell plates supplied by Lukens Steel Co. and of the forgings supplied by Isaacon Iron Works and Moore Drydock Co. for the nozzles are reported in Exhibit 13.

The first series of impact testing by PACECO was carried out on a sample forging (No. 1) selected and heat treated to duplicate as nearly as possible the condition of the 2" and 4" nozzles. The result of this work is reported in Exhibit 14. A second series of impact testing (Exhibit 15) by PACECO was carried out on a second sample forging (No. 2) which was selected and heat treated to duplicate the condition of the 2" and 4" nozzles. In addition, impact tests were made on samples cut from a piece of the reactor shell plate, and from re-heat treated pieces of the No. 1 sample forging. The results of this series of testing are reported in Exhibits 16, 17 and 18. An explanation and definition of terms associated with brittle fracture are given in Exhibit 19. Paragraphs of the Bureau of Ships' requirements for hydrostatic testing of reactor pressure vessels are reproduced in Exhibit 20.

Discussion

Because of the importance of establishing the minimum safe pressurizing temperature of the reactor vessel, and because the heat treatment cooling rates of the sample forgings could not exactly duplicate those of the nozzle forgings, it was concluded it would be highly desirable to have the unbiased opinions of two reputable and recognized specialists regarding the condition of the vessel, and to have their help in setting its minimum safe pressurizing temperature. Consequently, contact was made with W. S. Pellini, Superintendent, Metallurgy Division, U. S. Naval Research Laboratory, Washington, D. C., and Professor Maxwell Gensamer, D.Sc., School of Mines, Columbia University, New York, N. Y. Gensamer and Pellini over the years have done a tremendous amount of research and test work on the fracture characteristics of metals, particularly steels. For the past several years Pellini has been intimately concerned with establishing safe materials, design, fabrication and operating specifications for reactor pressure vessels.

Gensamer and Pellini concurred in their analyses and opinions regarding the condition of the vessel and its minimum safe operating temperature. Their conclusions and recommendations are reported in Exhibit 21.

Although the sample forging No. 1 procured by PACECO and 2" and 4" nozzle forgings had essentially identical chemical compositions, and tensile properties of the same order of magnitude, in their normalized and stress relieved condition their impact properties were quite different. At +10°F. the nozzle forgings had a Charpy "V" notch impact strength of 16-24-25 ft.-lb. The sample forging on the other hand had a Charpy "V" notch impact strength of 50-55-66 and 70-96-100 ft.-lb. The reason for this difference is not apparent, but could result from any one or a combination of such variables as actual aluminum, aluminum oxide, nitrogen and oxygen contents, carbon-manganese ratio, cleanliness, microstructure, austenitic grain size and heat treatment. It was felt, even with this difference, that the response of the nozzle forgings, insofar as impact strength and NDT temperature were concerned, would parallel the response of the sample forging to the brazing thermal cycle.

PACECO found that the NDT temperature of the sample forging in the normalized and stress relieved condition was -45°F., and in normalized and stress relieved, plus the brazing thermal cycle and stress relieving,* was +50°F. This 95° rise in the NDT temperature is attributed to the enlarged grain size and grain structure of the steel which developed during the simulated brazing heat treatment. The initial impact testing of the nozzle forging showed a Charpy "V" notch impact strength of 16-24-25 ft.-lb. at +10°F., and the NDT temperature is estimated to be in the 0°F. to 10°F. range.

Inasmuch as the steel of the nozzles and the sample forging is A105, Grade II, made to fine grain practice, both steels should have approximately the same grain coarsening temperature and should develop the same coarse grain size and structure with the same impact properties when this temperature is exceeded. This coarsening temperature should be something over 1750°F., but less than the 2050°F. brazing temperature. When heated to the brazing temperature, both steels would develop the same coarse grain size.

If the grain size of the sample forging in the normalized and stress relieved condition was smaller than the grain size of the normalized and stress relieved nozzle forgings, then the total grain growth of the sample forging would be greater than the nozzle forging because both developed the same final coarse grain size and structure during brazing. If this is the actual situation, then one may conclude

*8 stress relieving heat treatments with a total accumulated time of 53 hours above 1100°F.

because of the relationship between impact strength and grain size and structure that the NDT temperature of the nozzle forging would not have been raised quite as much as the NDT temperature of the sample forging (Exhibit 21, Page 4, Paragraph 2).

Because the impact strengths of the sample forging No. 1 (Exhibit 14, Tables II and III) were so exceptionally good, Gensamer and Pellini felt that this forging was not typical and did not reliably represent the nozzle forgings. They, therefore, recommended (Exhibit 21, Page 4, Paragraph 3) that another sample forging (No. 2 of this investigation) be procured, heat treated to duplicate the nozzle forging, and that a second series of impact tests be carried out. This test program is recorded in Exhibit 15, and the results in Exhibits 16, 17 and 18. These results were discussed and analyzed in detail with W. S. Pellini (Exhibit 22) and forwarded to Maxwell Gensamer for comment and confirmation of concurrence. The conclusions resulting from this second series of tests are:

1. Sample forging No. 2 is typical of an ASME SA-105, Grade II, forging made to fine grain practice, and reliably represents the 2" and 4" nozzles of the reactor vessel.

2. The NDT temperature of the 2" and 4" nozzles is 75-80°F.

3. Sample forging No. 1 does not represent the vessel nozzles, and the initial test results and conclusions based on sample forging No. 1 should be disregarded.

4. The NDT temperature of the steel portion of the stainless steel clad plate in the reactor vessel wall is 30-35°F. Therefore, the limiting or controlling NDT for the reactor vessel is that of the 2" and 4" nozzles.

5. The minimum safe pressurizing temperature for pressures over 300 p.s.i.g. (20% of design pressure) is 140°F. (Based on Bureau of Ships' Requirements for Hydrostatic Testing of Reactor Pressure Vessels, Exhibit 20.)

C. MISCELLANEOUS OBSERVATIONS ON VESSEL QUALITY

During the course of the detailed examination of the reactor vessel after its delivery to the Savannah River Plant, questions were raised on several items in regard to possible nonadherence to the specifications and code which served as a basis for vessel fabrication. These items, which are listed below, have been investigated and judged to be in accordance with the specifications and code and should have no adverse effect on the integrity of the vessel.

1. Local Stress Relief of Center Nozzle in Head
2. Non-Bond in Brazed Nozzle Liner
3. Stress Relief of SRP Lining Repair
4. Undercuts in Welds at Brackets
5. Slag Inclusions in Overlay Welding

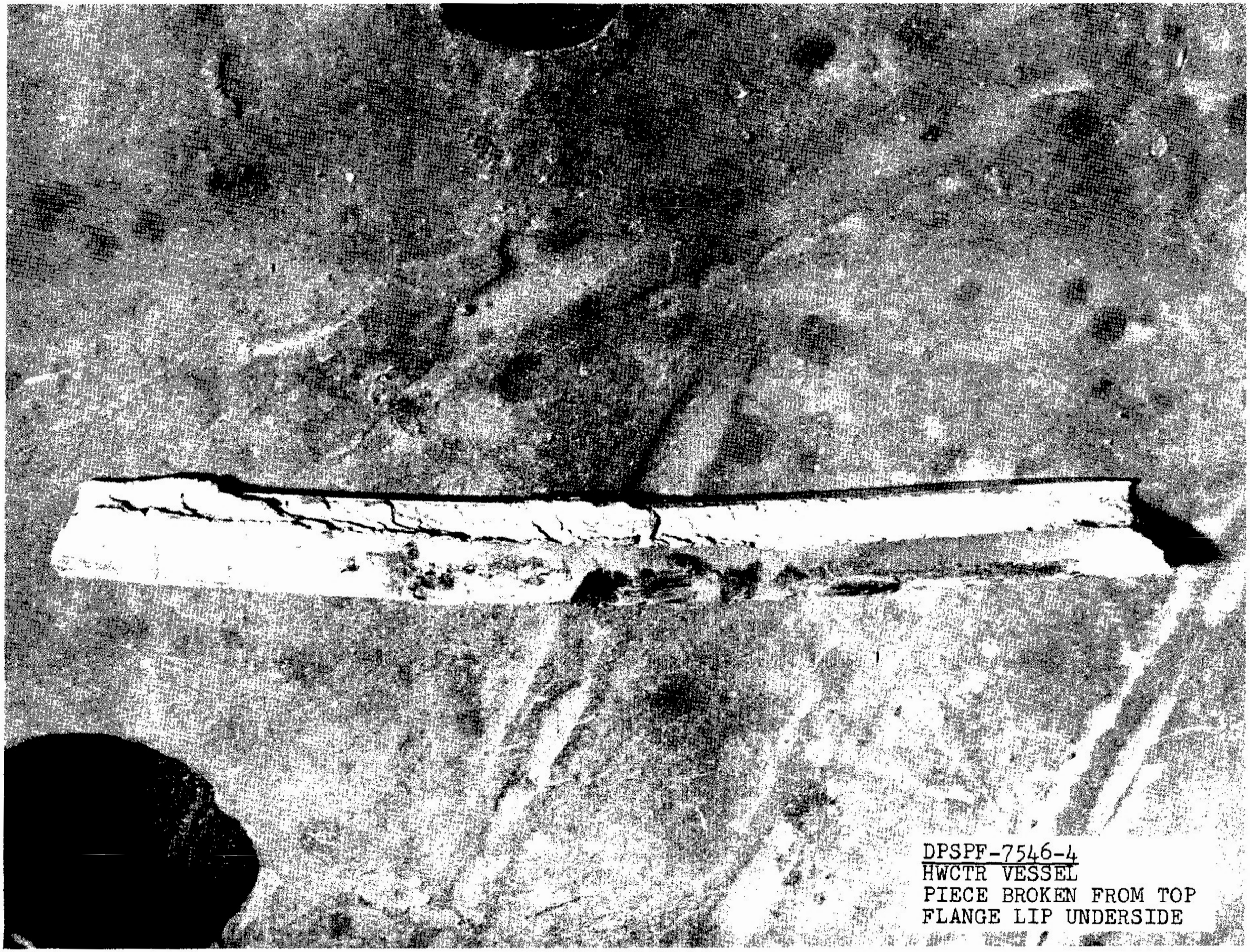
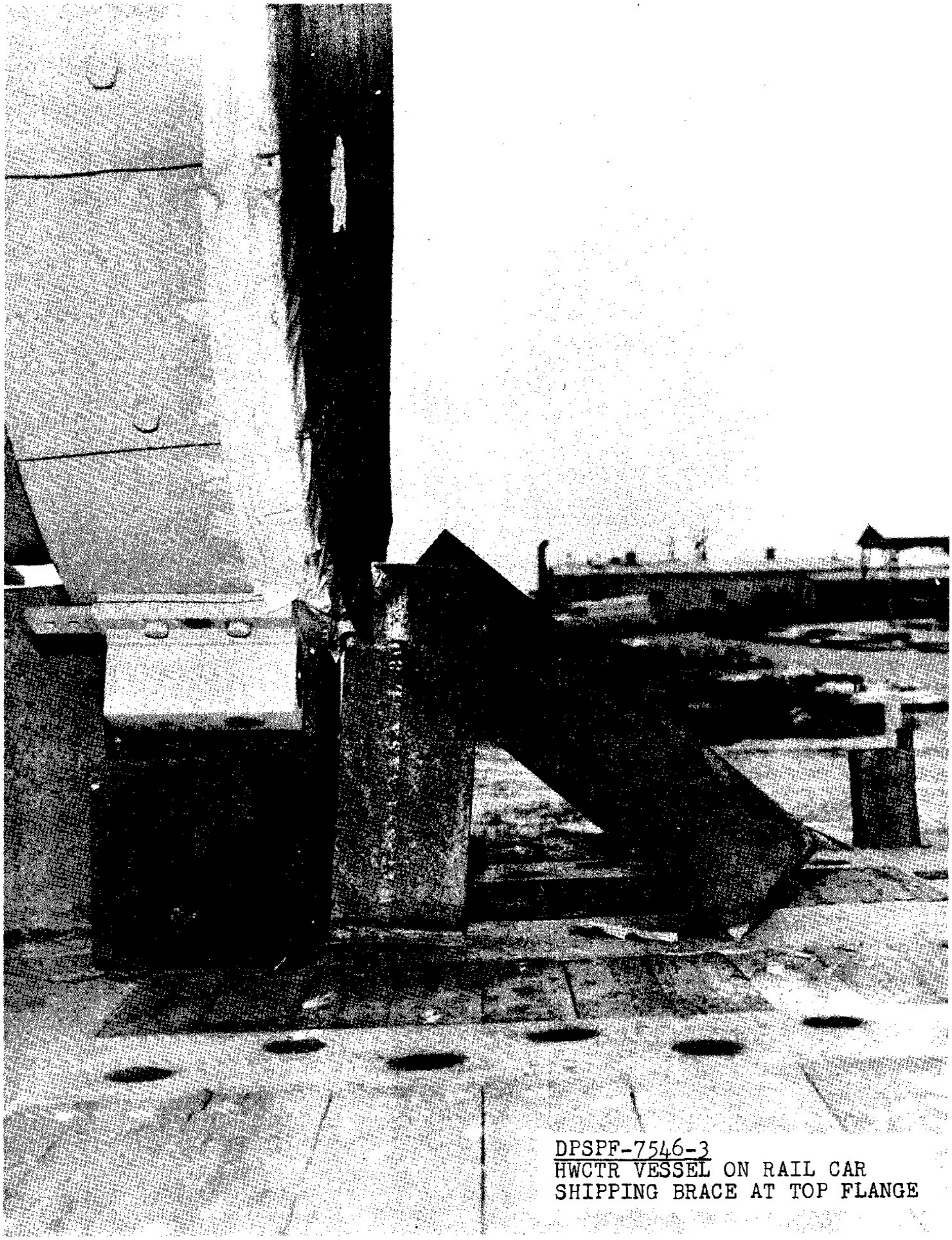

DPSPF-7546-4
HWCTR VESSEL
PIECE BROKEN FROM TOP
FLANGE LIP UNDERSIDE

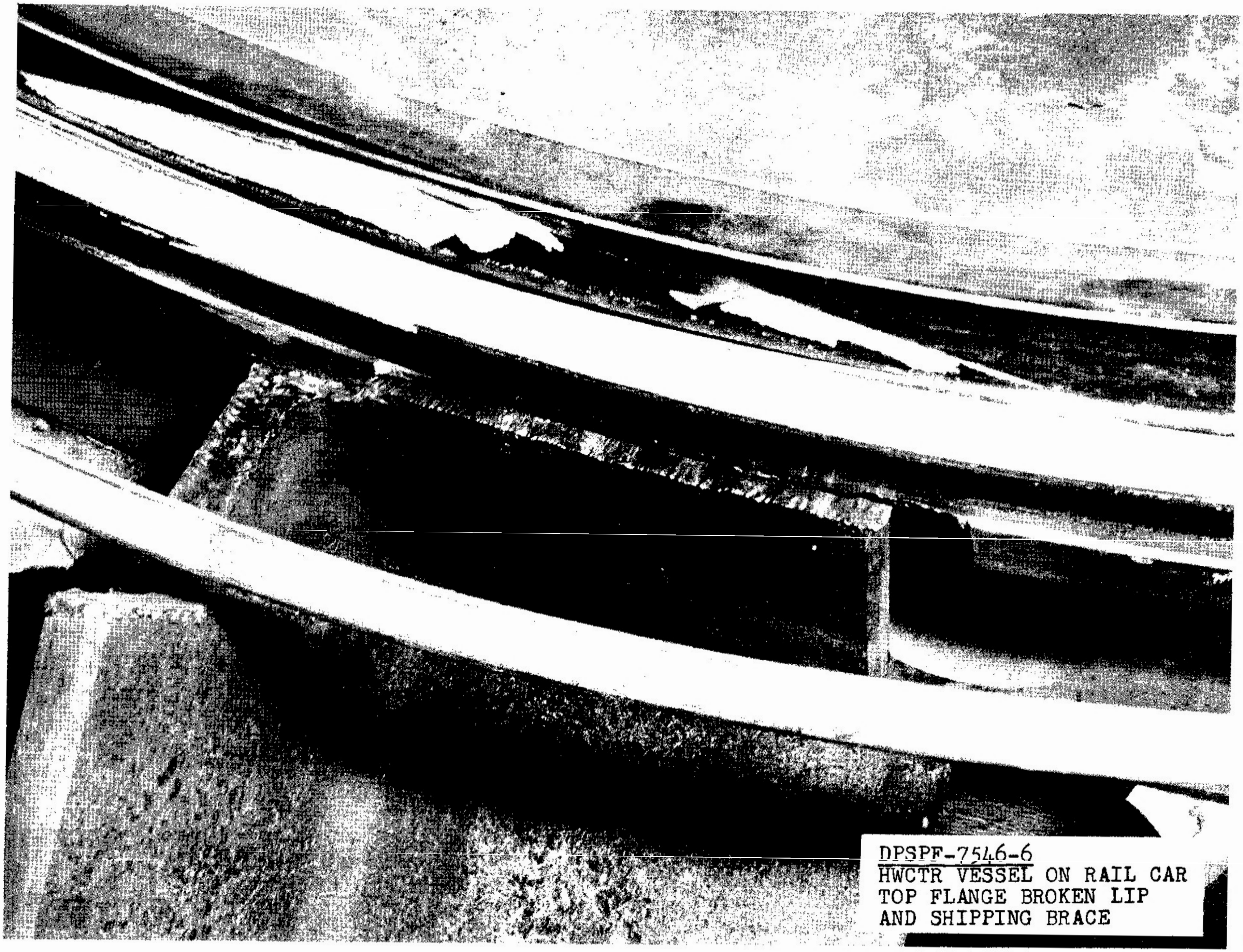
EXHIBIT 1

EXHIBIT 2

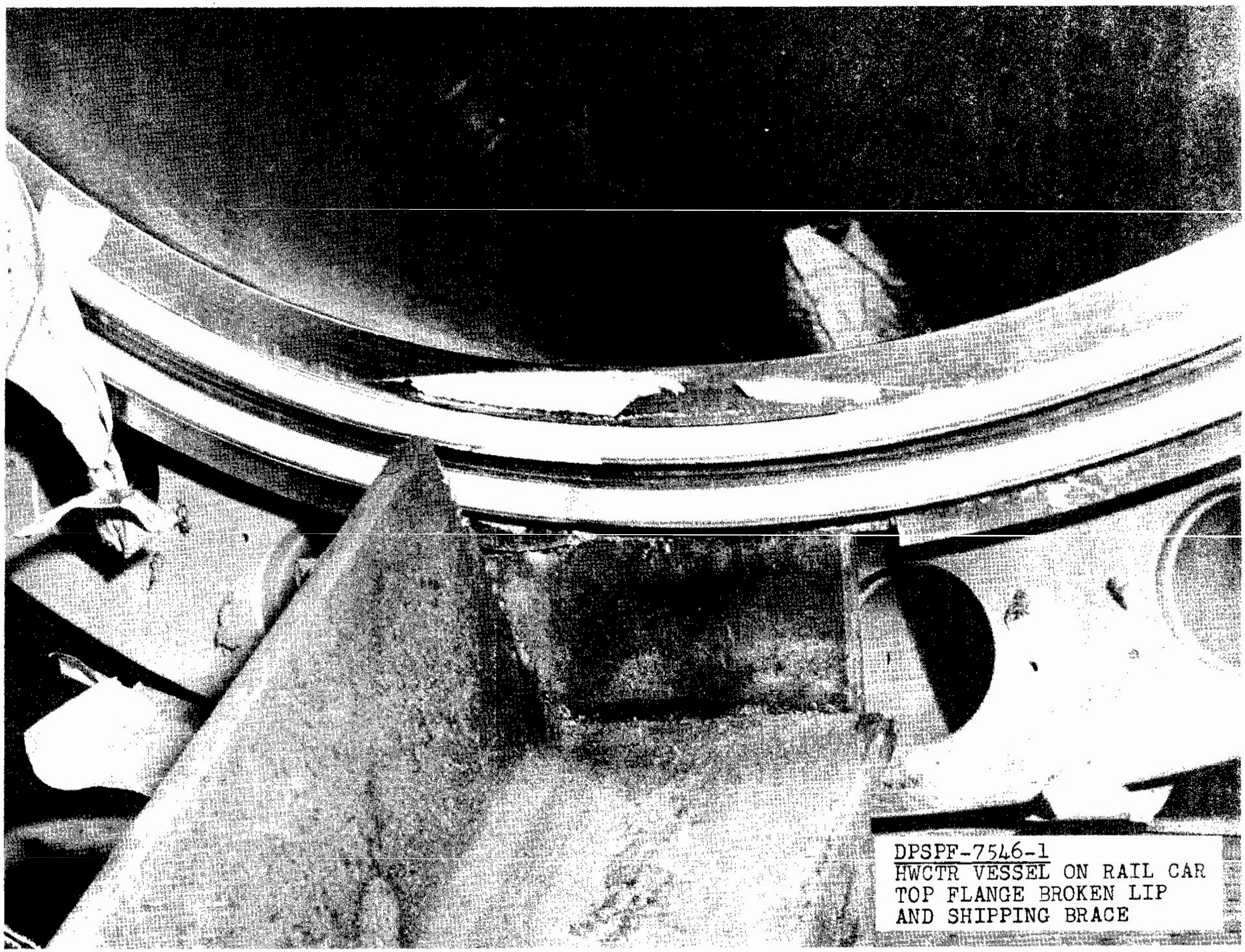


DPSPF-7546-3
HWCTR VESSEL ON RAIL CAR
SHIPPING BRACE AT TOP FLANGE

EXHIBIT 3

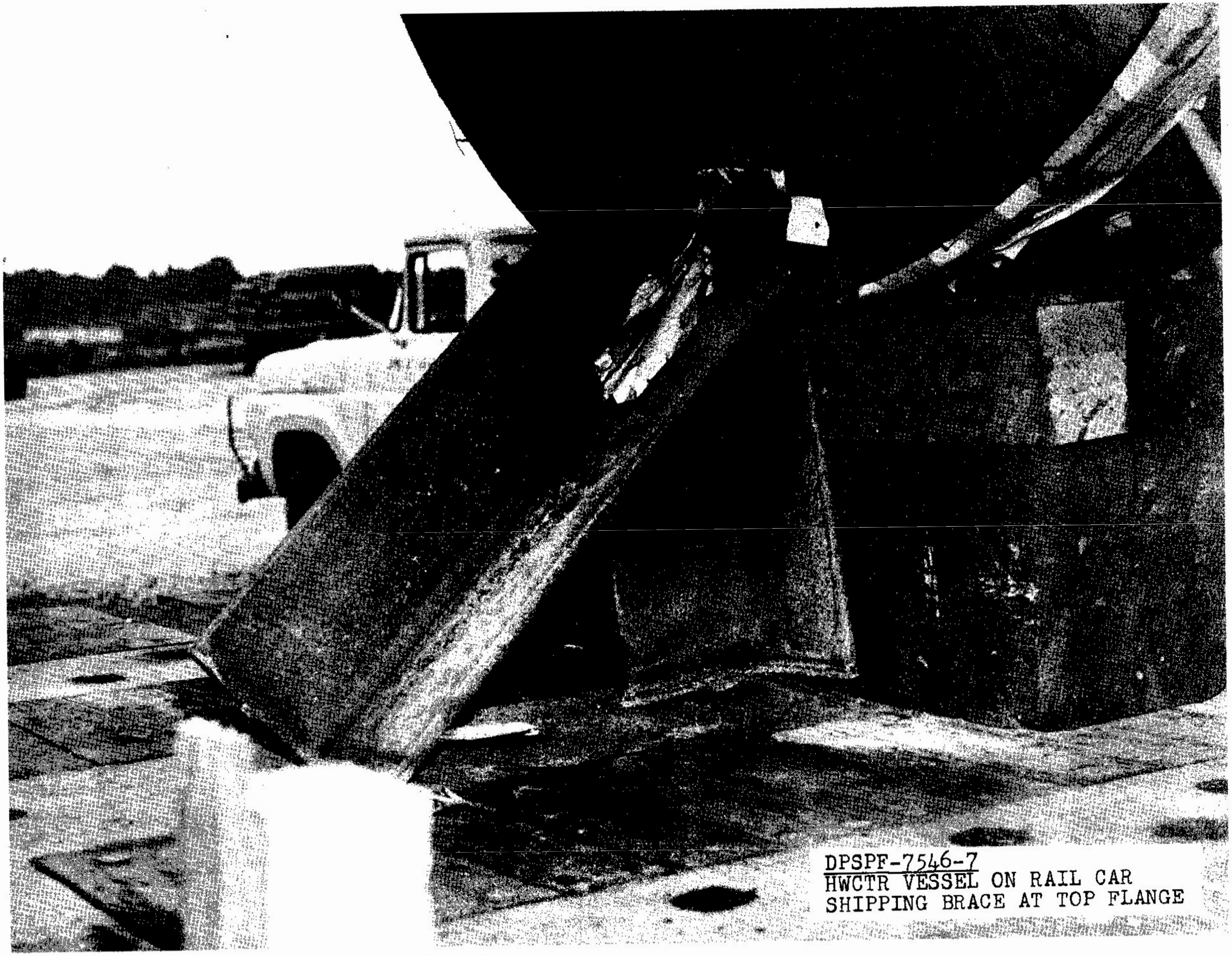


DPSPF-7546-6
HWCTR VESSEL ON RAIL CAR
TOP FLANGE BROKEN LIP
AND SHIPPING BRACE



DPSPF-7546-1
HWCTR VESSEL ON RAIL CAR
TOP FLANGE BROKEN LIP
AND SHIPPING BRACE

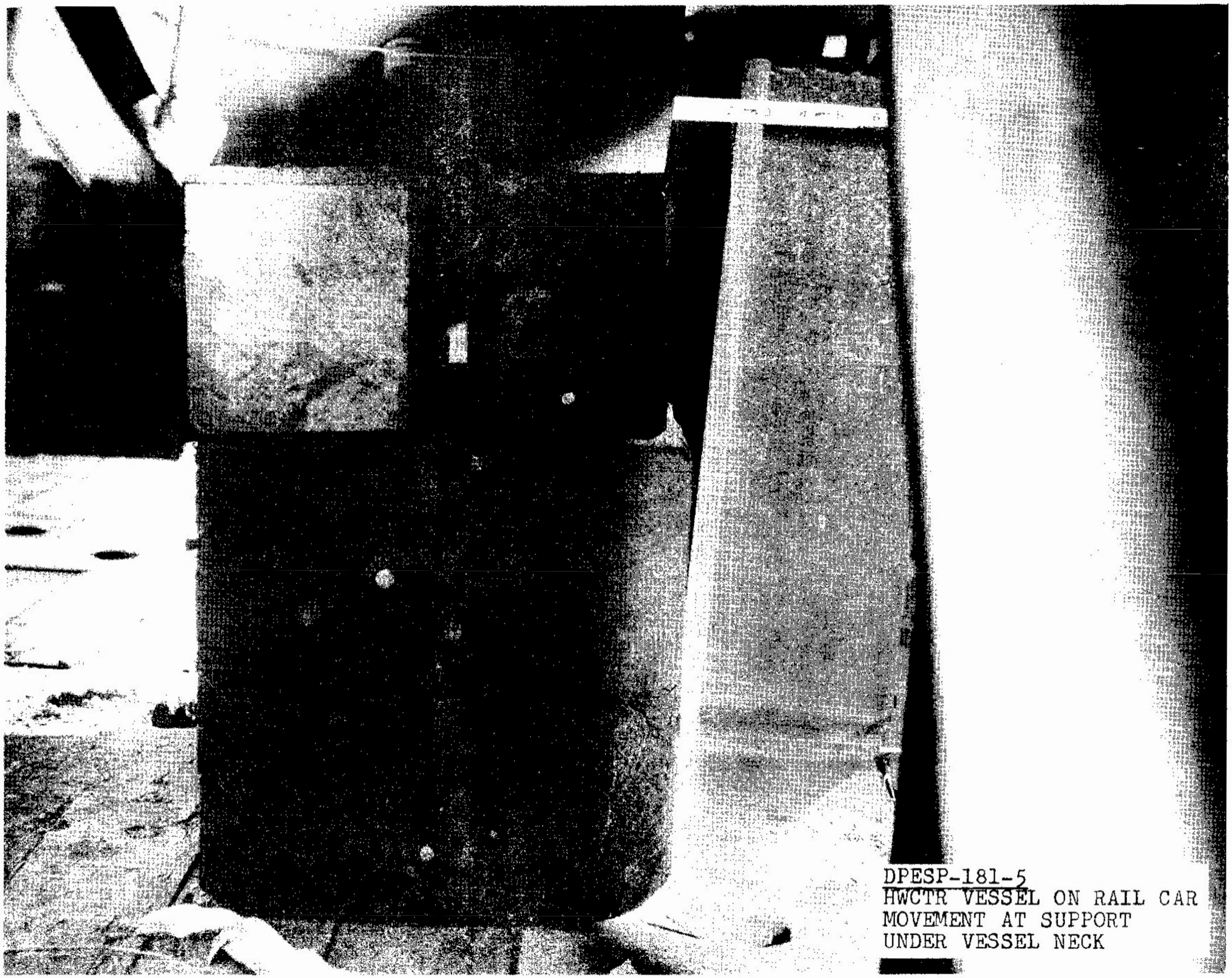
EXHIBIT 4



DPSPF-7546-7
HWCTR VESSEL ON RAIL CAR
SHIPPING BRACE AT TOP FLANGE

EXHIBIT 5

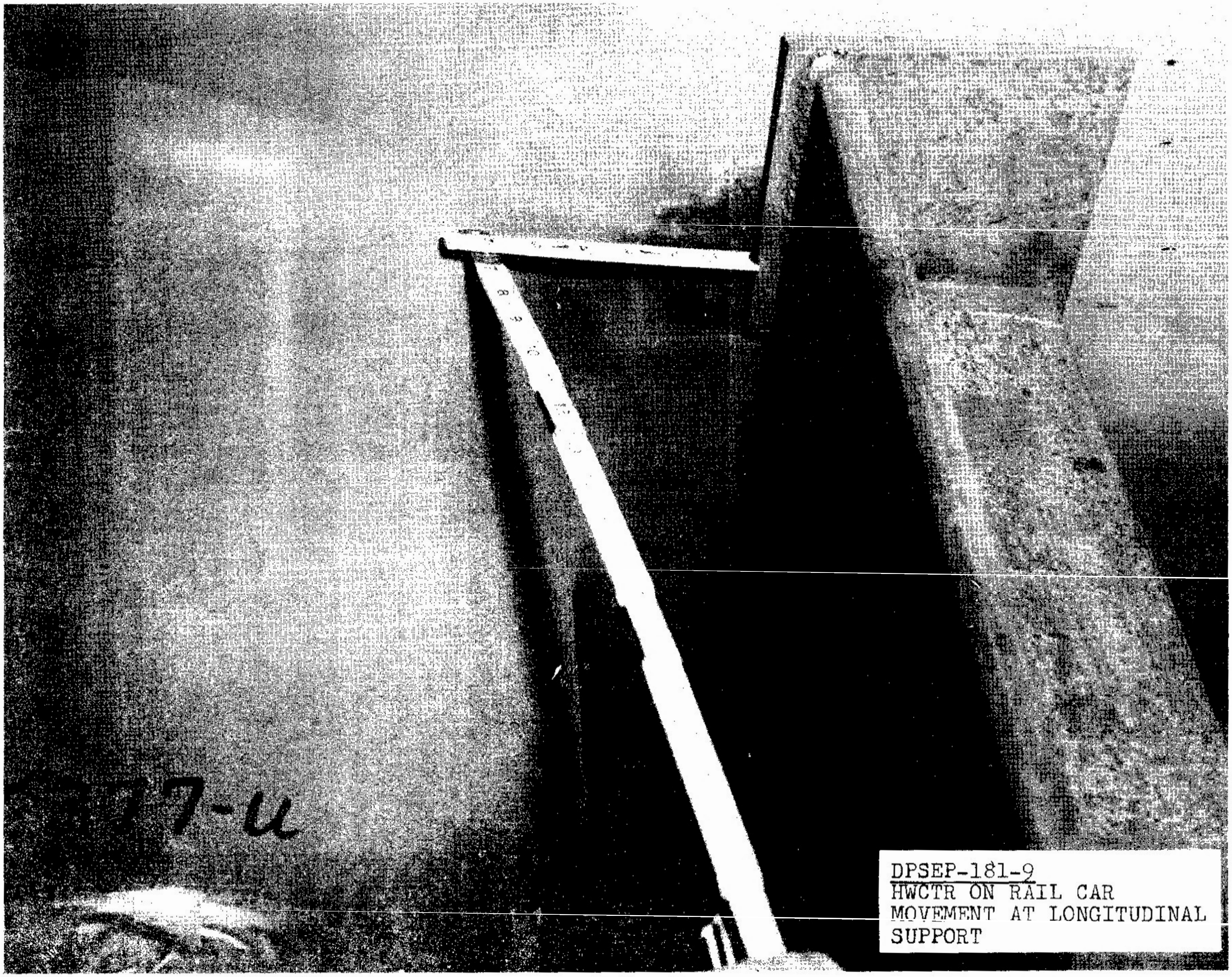
EXHIBIT #6



DPESP-181-5
HWCTR VESSEL ON RAIL CAR
MOVEMENT AT SUPPORT
UNDER VESSEL NECK

EXHIBIT 6

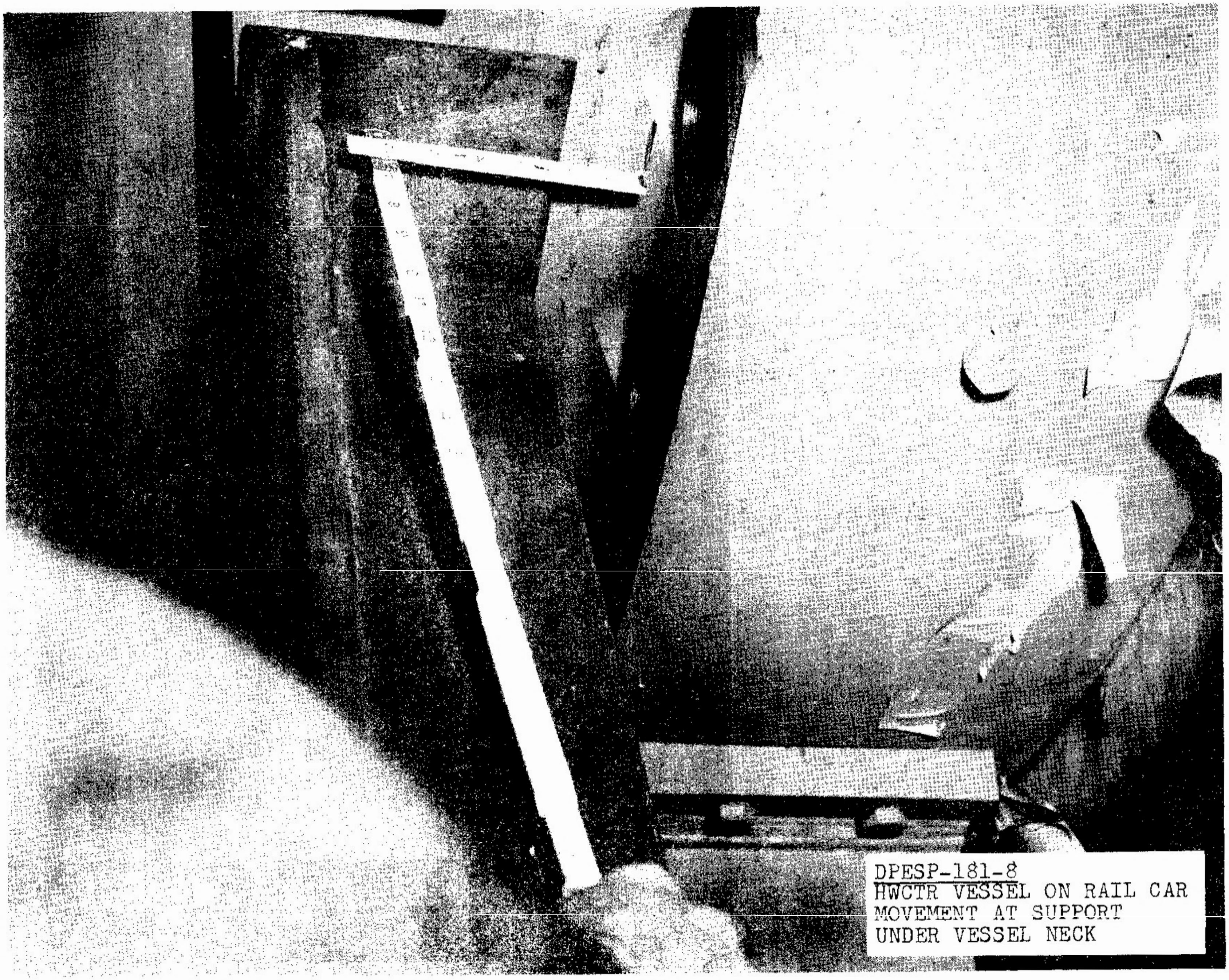
EXHIBIT #7



DPSEP-181-9
HWCTR ON RAIL CAR
MOVEMENT AT LONGITUDINAL
SUPPORT

EXHIBIT 7

EXHIBIT #8



DPESP-181-8
HWCTR VESSEL ON RAIL CAR
MOVEMENT AT SUPPORT
UNDER VESSEL NECK

EXHIBIT 8

OSR 6-23 (Rev. 6-57)

EXHIBIT #9

E. I. DU PONT DE NEMOURS & COMPANY
INCORPORATED
SAVANNAH RIVER PLANT
AIKEN, SOUTH CAROLINA

DAMAGE REPORT

REPORT NO. [illegible]

DATE 6-2[illegible]-61

1	DATE SHIPPED	[illegible]-61
1	POINT OF ORIGIN	Oakland Calif.
1	DESTINATION	[illegible] S.C.
2	SHIPPER	Pacific Coast Engr. Co.
2	CONSIGNEE	E.I. DuPont De Nemours Co Inc.
3	ORDER NO.	[illegible]97 1/2
3	COMMODITY	Reactor [illegible]
3	FREIGHT BILL NO.	[illegible]-2377 Thru 80
4	CAR INITIALS AND NUMBER	[illegible]
4	CONDITION OF CAR	Good
5	DATE OF ARRIVAL	6-2[illegible]-61
5	DATE SPOTTED FOR UNLOADING	6-2[illegible]-61
6	SEAL RECORD, RIGHT	Flat Car
6	LEFT	
7	UNLOADING COMMENCED (DATE) (HOUR)	6-2[illegible]-61 10:00 A.M.
7	UNLOADING FINISHED (DATE) (HOUR)	6-2[illegible]-61 12:00 Noon
8	IF RECEIVED BY TRUCK, WHOSE TRUCK?	
9	WHEN WAS DAMAGE DISCOVERED?	Unloading
9	BY WHOM?	[illegible] Muir & Others
10	DATE AND HOUR CARRIER NOTIFIED OF DAMAGE	Immediately
11	IF PROPERTY RECEIVED DID NOT FILL CONTAINER, WHAT MATERIAL OCCUPIED THE REMAINING SPACE?	
12	IF WOODEN BOX, WAS IT NEW?	
12	WAS IT CORDED OR STRAPPED?	
13	IF FIBREBOARD, WERE FLAPS SEALED, GLUED, CLEATED OR STAPLED?	
14	WAS DAMAGE OF SUCH A NATURE THAT IT COULD HAVE BEEN NOTICED AT TIME OF DELIVERY?	Yes
14	IS THERE ANY SALVAGE?	Yes
15	DESCRIBE FULLY THE NATURE AND EXTENT OF DAMAGE AND WHAT INDICATED DAMAGE OCCURRED WHILE IN THE CARRIER'S POSSESSION?	Outer Edge Of Top Flange Broken
16	WHERE ARE THE DAMAGED GOODS NOW LOCATED?	770-[illegible] Bldg.
17	DID CARRIER'S REPRESENTATIVE MAKE AN INSPECTION; IF SO, WHEN AND BY WHOM?	Yes [illegible]
18	IF NO INSPECTION OR REPORT WAS MADE, STATE WHY	

INSPECTOR	CARRIER'S REPRESENTATIVE	NAME OF CARRIER
[illegible] Muir [signature]	[signature]	[illegible]

______________________, AGENT DATE ______________________

______________________ R.R. OR TRUCK COMPANY

____

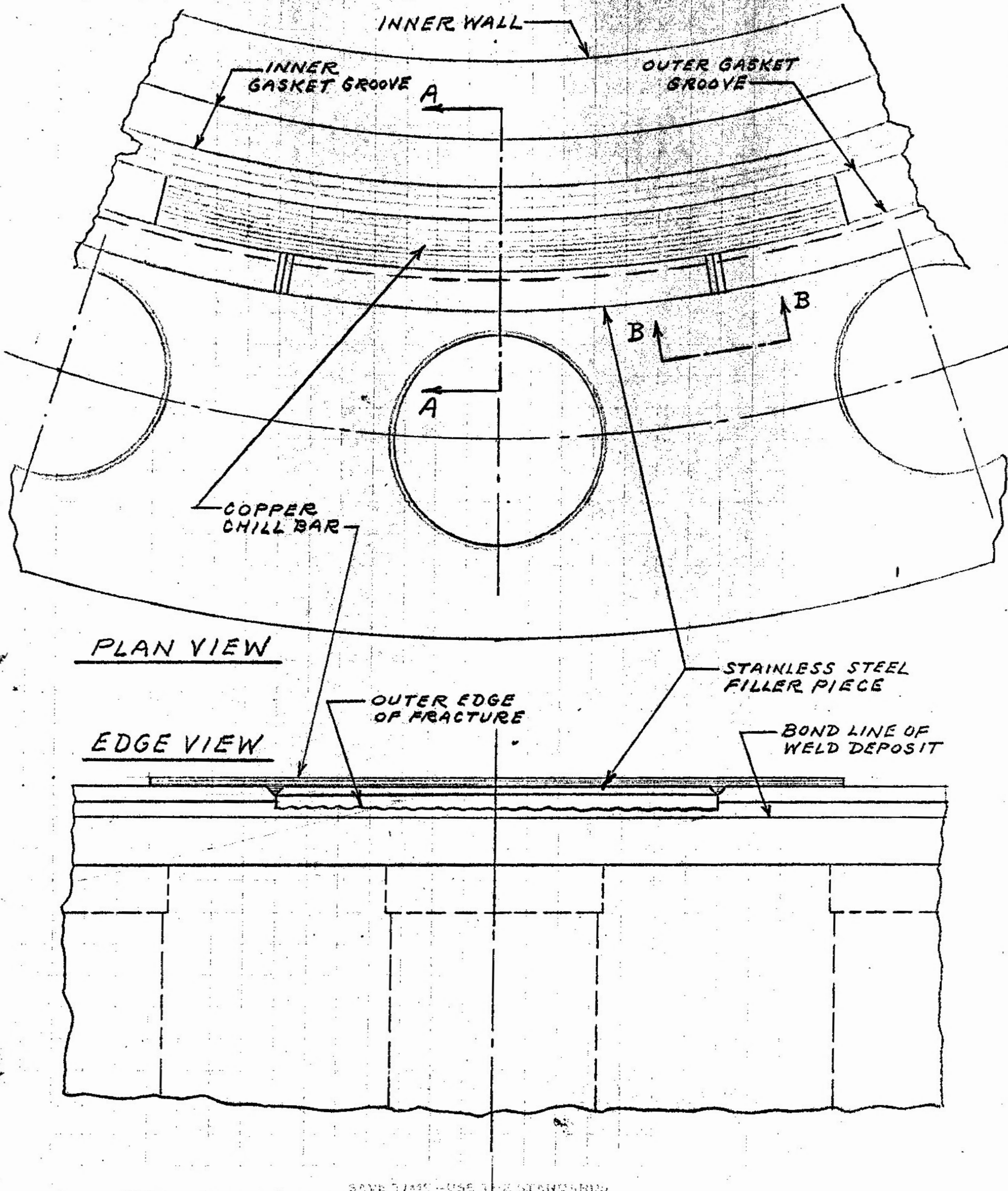
You are hereby notified that the above damage (or loss) was noted as per this inspection report. We herewith file preliminary claim in the amount of $100.00 more or less, for the damage (or loss) incurred as soon as the exact value involved is determined, final claim with necessary supporting documents will be filed with you or the initial carrier who issued the bill of lading.

TRAFFIC & TRANSPORTATION DEPARTMENT

By ______________________
TRAFFIC SUPERVISOR

HWCTR
REPAIR OF SEAL-WELDING LIP
ARRANGEMENT

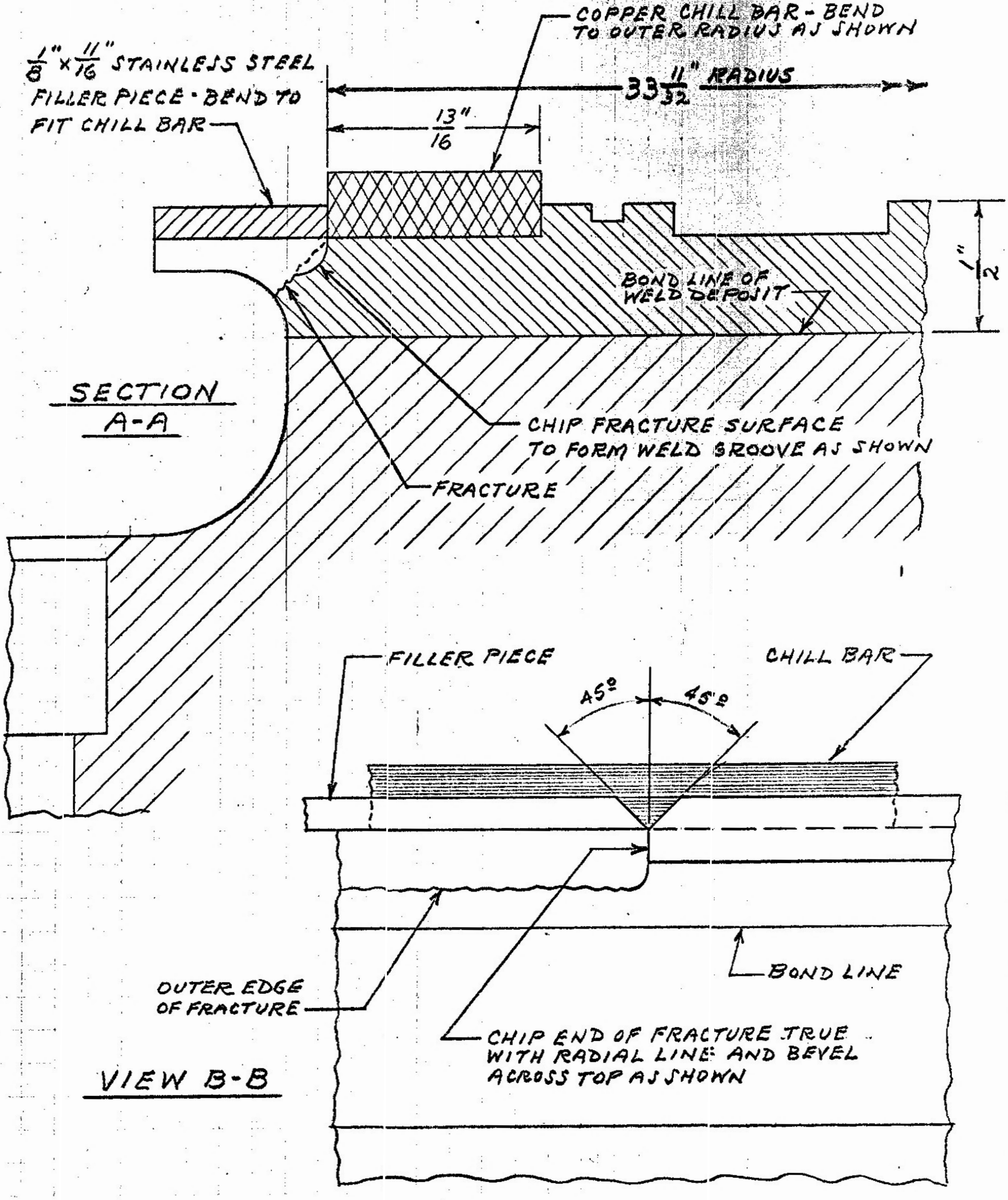
981086-20
S.R.P.
7-7-61



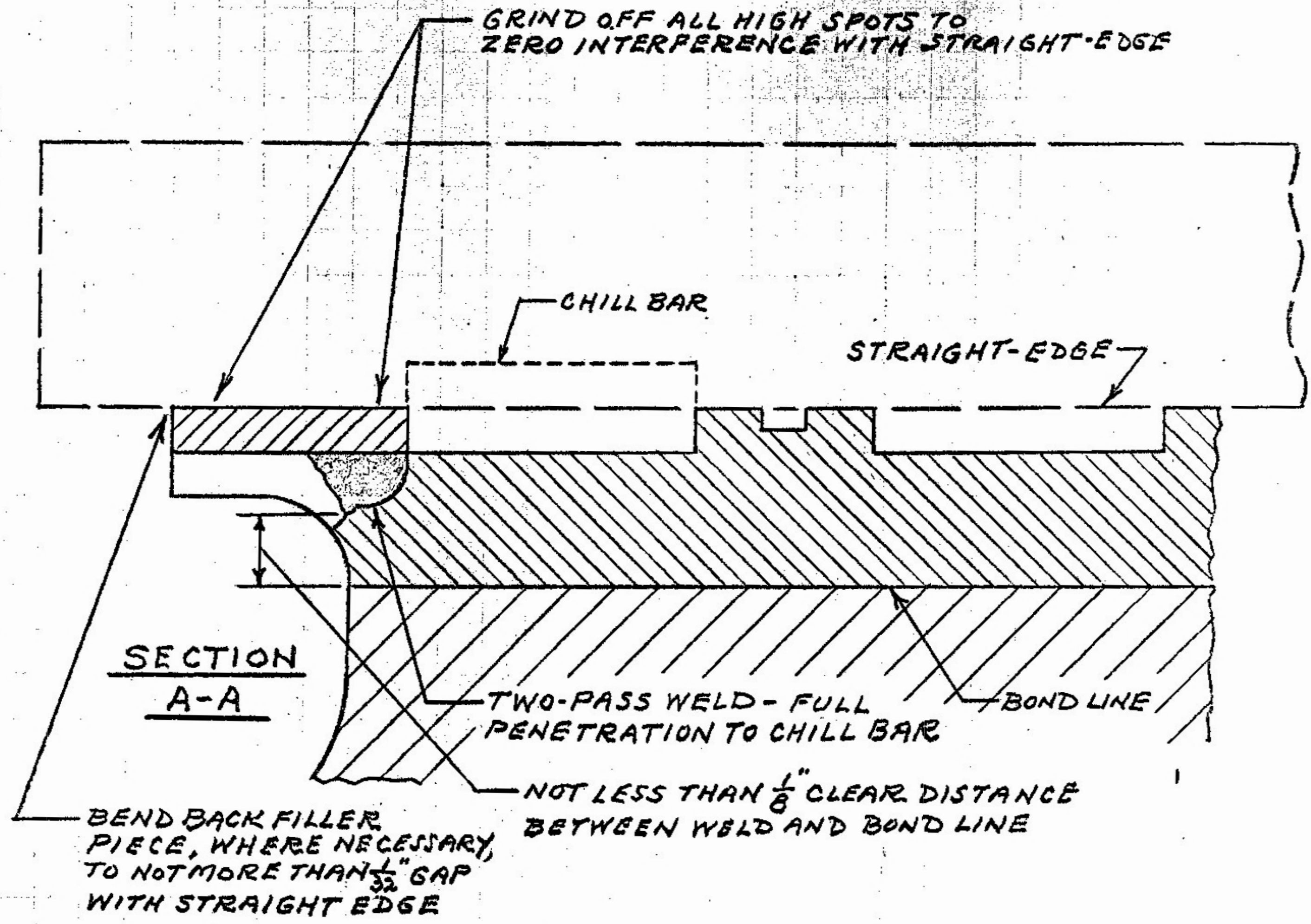
981086-20

HWCTR
REPAIR OF SEAL-WELDING LIP
PREPARATION

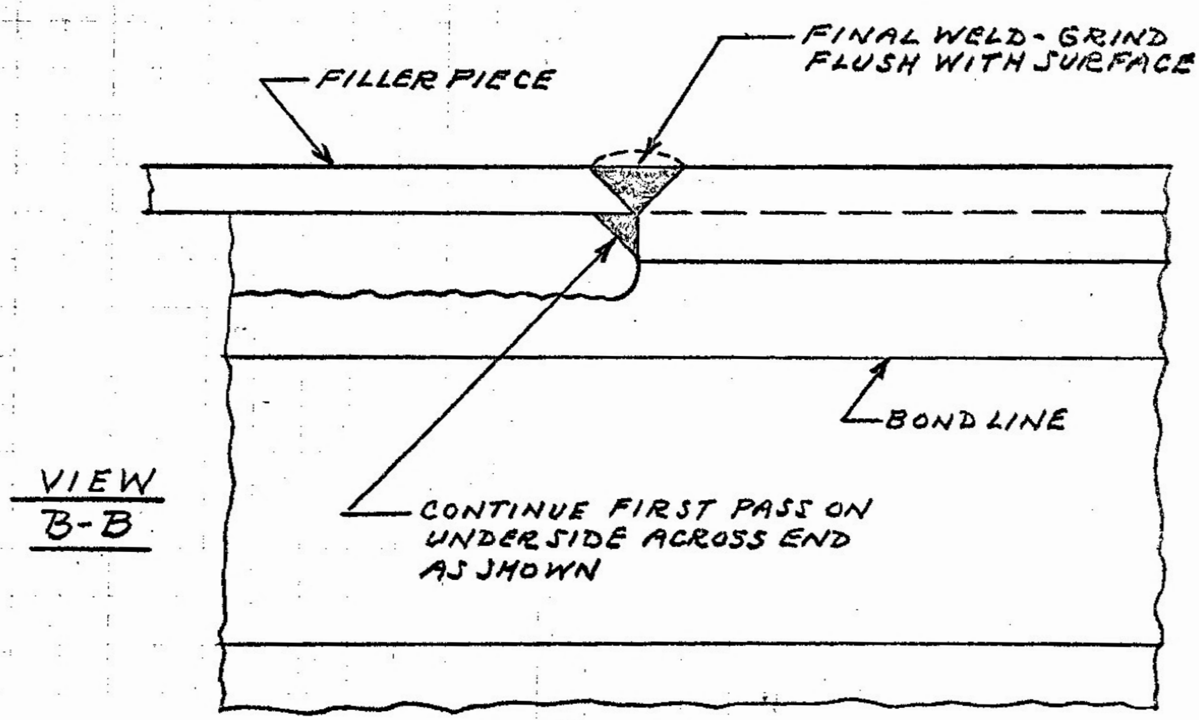
S.R.P.
7-7-61



HWCTR 981086-20
REPAIR OF SEAL-WELDING LIP S.R.P.
WELD DETAILS ΔβW 7-7-61



SECTION A-A



VIEW B-B

COMPOSITION AND PROPERTIES OF CARBON STEEL

ITEMS USED IN HWCTR PRESSURE VESSEL

1. Clad Plate Supplied by Lukens Steel Company

ASME - SA212 Grade B made to Fine Grain Practice (1)

Heat No.	Tensile Strength PSI	Yield Point PSI	% Elong.	Composition C	Mn	Si	10°F. Charpy V Notch Impact Strength Ft.-Lb.
1138-4	72500	49000	32	.27	.75	.20	31-38-34
20444	77400	45800	35	.27	.81	.24	28-34-30
A0894	74900	45000	31	.27	.70	.22	28-30-23
A1126	76500	42900	30	.28	.75	.21	21-20-20
A0960 (1)	74200	46500	34	.27	.84	.25	41-31-33
A0960 (2)	77300	48200	30	.27	.84	.25	33-33-33
21674	76900	46900	32	.27	.75	.20	19-15-15

Heat No.	Thickness	Location
1138-4	5"	Bottom Shell
20444	5"	Bottom Shell
A0894	5-1/2"	Cone
A1126	4-1/4"	Bottom Head
A0960 (1)	5"	Lower Portion of Top Shell
A0960 (2)	3-3/4"	Top Shell Plate
21674	5-3/4"	Top Head

2. Forgings

ASME - SA105 Grade II made to Fine Grain Practice (2)

Heat No.	Tensile Strength PSI	Yield Point PSI	% Elong.	Composition C	Mn	Si	10°F. Charpy V Notch Impact Strength Ft.-Lb.
1079	76750	48750	31	.29	.73	.29	25 Avg. (3 Tests) 28 Avg. (3 Tests)
8578	74800	49300	33	.27	.75	.22	16-24-25
8977	74800	44800	30.5	.27	.74	.20	27-18-22
F96950	7900	48800	36	.27	.71	.24	48-101-86

Heat No.	Supplier	Location
1079	Isaacson Iron Works	Plug support ring, shield plug, head flange, shell flange
8578	Moore Drydock	2" and 4" Nozzles
8977	Moore Drydock	16" Nozzles
F96950	Taylor Forge	10" Nozzles

(1) The carbon steel base material shall be ASME SA212 Grade B mfg. to ASME SA300, class practice and tested in accordance with SA300 class 1, with the exceptions that a Charpy "V" notch impact test specimen (ASTM A370 Fig. 14) shall be used and the test temperature shall be +10°F.

(2) Carbon steel base material shall be ASME SA105 Grade II mfg. to ASME SA350 Grade LF1 practice and tested in accordance with ASME SA350 with the exceptions that a Charpy "V" notch impact specimen (ASTM E23, Fig. 3, Type A) shall be used and the test temperature shall be +10°F.

IMPACT TEST PROGRAM CONDUCTED BY PACECO

1. Material

Comparison of compositions of test forging and 2" and 4" nozzles.

	Sample Forging No. 1	Nozzles (Ht. #8578)
C	.28	.27
Mn	.76	.75
Si	.23	.22
P	.019	.019
S	.021	.022
Ni	.05	.06
Cr	.10	.04
Mo	.02	.03
Cu	.16	.16
Sn	.017	.016

2. Heating and Cooling Cycle for Copper Brazing Operation

Hold at 1900°F. for 30 min.
Hold at 2050°F. for 10 min.
Cool to 1900°F. in 40 min.
Cool to 1000°F. in 110 min.
Air cooled to 300°F. in 3 hrs., 30 min.

3. First Impact Test Program

The test forging was chosen to duplicate the composition of the 2" and 4" nozzles. The object of the test was to subject the test forging to heating cycles simulating the brazing and stress relieving operations and to determine the effect on Charpy "V" notch impact properties at +10°F. It was felt that impact properties in the normalized and stress relieved condition would be approximately the same as those for the actual nozzles. This was not the case, however.

Table I

Test Forging

Heat Treatment	Tensile	Yield	% Elong.	+10°F. Charpy V Notch Impact Values, Ft.-Lb.
Normalized	71000	46000	33	44-42-40
Norm. + Stress Relieve 2-1/2 hr. at 1150°F.	64800 65000	43000 45000	36.5 35.5	50-55-66 70-96-100
Brazing Cycle + Norm. + Stress Relieve 2-1/2 hrs. at 1150°F.	64000	42200	38	60-64-95-70
Brazing Cycle Only	68700	38000	29	23-13-12
Brazing Cycle + Stress Relieve 2-1/2 hrs. at 1150°F.	64600	33800	34	29-21-10
Brazing Cycle + Stress Relieve 8 hrs. at 1150°F.	62200	31000	37	10-10-16 10-15-17
2" & 4" Nozzle Forgings				
Norm. + Stress Relieve 2-1/2 hrs. at 1150°F.	74800	49300	33	16-24-25

4. Second Impact Test Program

The second test program was designed to determine how much the NDT temperature of the test forging had been raised as the result of the heating cycle in the brazing cycle followed by stress relieving for 30 hours at 1150°F. Two pieces remaining from the forging used in the first test were normalized and stress relieved for 2-1/2 hrs. at 1150°F. One of the pieces was then subjected to the brazing temperature cycle followed by stress relieving for 30 hrs. at 1150°F.

Table II

(a) Portion of Forging Normalized and Stress Relieved Only

Temp., °F.	Charpy V Notch Impact Value, Ft.-Lb.
0	74
-10	54
-30	31.5
-40	19.5
-45 (Approx. NDT Temp.)	16.4
-50	12.9

Table III

(b) Portion of Forging Norm. + S.R. + Brazing Cycle + 30 Hr. S.R.

Temp.	Charpy - Ft.-Lb.
-10	4.5
0	5.5
20	7.0
40	10.5
49	12.0
50	12.5
50 (Approx. NDT Temp.)	14.0
51	17.0
70	24.0

Tensile 62,100 and 63,400
Yield 34,000 and 36,500
% Elongation 39

Fig. 1

EXHIBIT 14
Page 4

G-45-A

ENGINEERING DUPONT COMPUTATION SHEET

SHEET NO.

TITLE OF PROJ. OR STUDY HWCTR

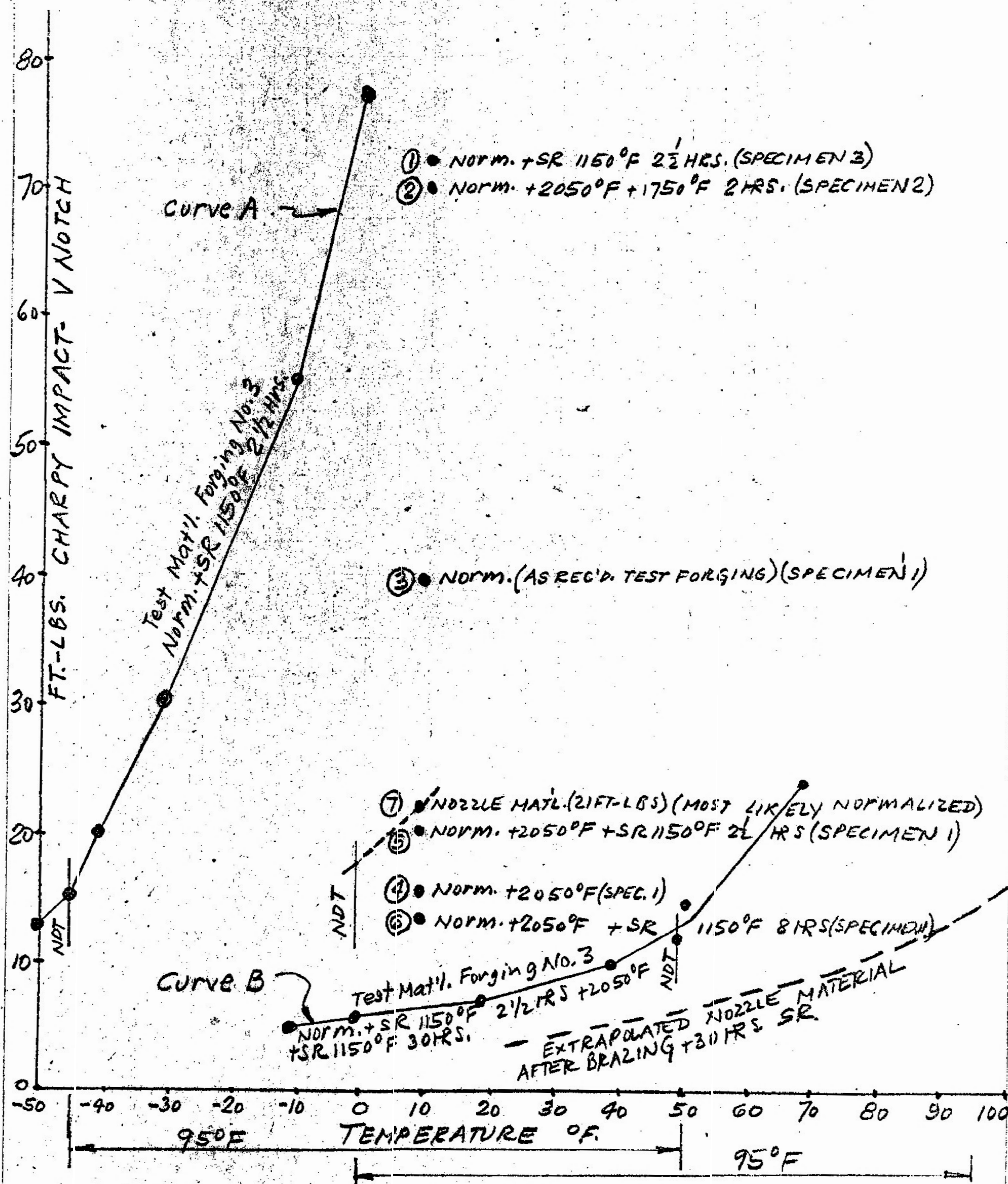
PROJ. OR STUDY NO. 981086

SUBJECT IMPACT PROPERTIES

WORKS S.R.P.

COMPUTER mas

DATE 10.10 1961



PROJECT 981086 - HWCTR - SAVANNAH RIVER PLANT

NDT TEMPERATURE DETERMINATIONS
SECOND SERIES

The following metallurgical tests shall be conducted to determine nil-ductility-transition temperatures of material in the HWCTR vessel:

1. Plate specimens to be obtained from test plates available at vendor's plant. Test plates are Lukens stainless steel clad plates, with weld overlay on other side. Base material ASTM A-212, Grade B, made to A-350 fine grain practice.

   1.1 First plate is 8" x 5" x 3-1/4" thick (carbon steel) and is to be labeled 1P.

   Second plate is 8-1/2" x 8" x 3-1/4" thick (carbon steel) and is to be labeled 2P.

   Plate 1P is to be held for further instructions.

   1.2 Determination of Rolling Direction:

   From 2P saw cut a strip, NDT-2, 8" x 1/4" x 3-1/4". Machine or grind one 8" x 3-1/4" face and both 1/4" x 3-1/4" ends flat and finished with a No. 80 grit abrasive belt. Forward by Air Mail to:

   James A. Collins
   E. I. du Pont de Nemours & Co., Inc.
   Engineering Department
   Louviers Building
   Wilmington 98, Delaware

   (This strip will be macroetched to establish the grain structure and thereby the rolling direction of the two plates 1P and 2P.) Du Pont will advise vendor regarding plate rolling direction. No cutting of samples is to be made until this advice is received by vendor.

   1.3 Heat treat plate 2P as follows:

   1.3.1 Heat to 1150°F., hold at temperature 4 hrs., cool to 300°F.

   1.3.2 Reheat to 1150°F., hold at temperature 7 hrs., cool to 300°F.

   1.3.3 Repeat 1.3.2 for a total of seven times. (This will result in eight stress relief anneals, a total time at 1150°F. of 53 hrs.)

   1.3.4 Cooling from 1150°F. to 300°F. shall conform to ASME Unfired Pressure Vessel Code requirements (Par. UCS-56) for stress relief anneals.

1.4 Cut the following Charpy "V" notch impact specimens from the plate 2P after completion of heat treatments of Par. 1.3 (See Par. 4).

1.4.1 Longitudinal: Cut 18 specimens, mark on both ends before cutting the notch 2PL1, 2PL2, 2PL3 - - - 2PL18.

1.4.2 Transverse: Cut 9 specimens, mark on both ends before cutting the notch 2PT1, 2PT2, 2PT3 - - - 2PT9.

1.5 Determination NDT Temperatures

1.5.1 For the purpose of this determination, the temperature at which the Charpy "V" notch impact strength is 15 ft.-lb. shall be considered the NDT temperature.

1.5.2 Each set of impact tests shall consist of three specimens. The test specimens, as well as the handling tongs, shall be cooled (or heated) for the sufficient time to reach the test temperature. The test temperature shall be maintained within ± 3°F. The specimen shall be transferred to the anvil of the test machine and broken as quickly as possible, but within a time lapse of not more than six seconds.

1.5.3 Tests shall be carried out with longitudinal specimens at + 10°F., + 70°F., and + 120°F. The resulting data shall be plotted with ft.-lb. as ordinate vs. temperature as abscissa and a smooth curve drawn through the three points. If the curve includes the 15 ft.-lb. impact strength location, the remaining three sets of specimens shall be tested in this temperature range to determine the temperature for 15 ft.-lb. as accurately as possible. If the 15 ft.-lb. impact strength is located beyond the curve defined by the first three tests, the curve shall be extrapolated to this temperature and the three remaining sets of specimens tested to determine as accurately as possible the temperature corresponding to 15 ft.-lb.

1.5.4 The NDT temperature of the plate determined in 1.5.3 shall be used as a reference point for the testing of the three sets of transverse specimens. The first test should be made at the longitudinal NDT temperature. If the impact strength is less than 15 ft.-lb., the second test should be made at an appropriately higher temperature. The third set of specimens should be used to establish as closely as possible the temperature corresponding to 15 ft.-lb.

2. Forging specimens to be obtained from 4" x 4" x 8" sample forging No. 2 available at vendor's plant. Sample forging is second sample and is A-105, Grade II, made to A-300 fine grade practice.

   2.1 Saw cut forging in half so that each piece is 2" x 4" x 8". Mark one cut piece 1F and the other 2F.

   2.2 Heat 1F and 2F to 1675-1725°F. and hold at temperature for three hrs. Withdraw 1F from the furnace and cool in air. Allow for free circulation of air for good air cooling. Leave 2F in furnace and allow it to cool with furnace.

   2.3 Cut 18 longitudinal Charpy "V" notch impact specimens from 1F and 18 from 2F. Mark both ends of each specimen before cutting notch -

   1F1, 1F2, 1F3 - - - 1F18
   2F1, 2F2, 2F3 - - - 2F18

   2.4 Determine longitudinal NDT temperature using specimens in 2.3 following same procedure as used for plate 1.5.1, 1.5.2 and 1.5.3.

   2.5 Balance of forgings 1F and 2F shall be heat treated as follows:

   2.5.1 Heat to 1900°F., hold at temperature 30 minutes.

   2.5.2 Heat to 2050°F., hold at temperature 10 minutes.

   2.5.3 Cool to 1900°F. in 40 minutes.

   2.5.4 Cool to 1000°F. in 110 minutes.

   2.5.5 Air cool to 300°F. in 3 hrs. 30 minutes.

   2.5.6 Heat to 1150°F., hold at temperature 4 hrs., cool to 300°F.

   2.5.7 Reheat to 1150°F., hold at temperature 7 hrs., cool to 300°F.

   2.5.8 Repeat 2.5.7 for a total of seven times. (This will result in a total time at 1150°F. of 53 hrs.)

   (Note: 2.5.6 and 2.5.8 can be done simultaneously with 1.3.1, 1.3.2 and 1.3.3)

2.6 Cut 18 longitudinal Charpy "V" notch impact specimens from 1F and 2F after completion of heat treatment in 2.5. Mark specimens on both ends before cutting notch:

Specimens from 1F - 1FB1, 1FB2, 1FB3 - - - 1FB18
Specimens from 2F - 2FB1, 2FB2, 2FB3 - - - 2FB18

2.7 Determine longitudinal NDT temperature using two specimens in 2.6 following same procedures used for plate 1.5.1, 1.5.2 and 1.5.3.

2.8 Balance of forging samples 1F and 2F shall be re-normalized by heating to 1675-1725°F., holding at temperature for two hrs. and air cooling.

2.9 Cut three longitudinal Charpy "V" notch impact specimens from re-normalized 1F and 2F. Mark specimens on both ends before cutting notch:

Specimens from 1F - 1FBN1, 1FBN2, 1FBN3
Specimens from 2F - 2FBN1, 2FBN2, 2FBN3

Determine impact strength at + 10°F.

3. Sample Forging No. 1 (Originally a Round with Hole in Center)

If any pieces of this forging are on hand, mark appropriately and heat treat and test per Pars. 2.2 to 2.7 with the exception that 18 impact specimens will not be required. If possible, nine impact specimens longitudinal should be sufficient to establish NDT temperature.

4. Impact Test Specimens and Procedure

4.1 The impact test shall be made on Charpy "V" notch specimens per ASTM Spec. E23-56T.

4.2 Longitudinal impact specimens shall be saw cut from the plate and/or forging and machined so that the long axis is parallel to the rolling direction of the plate, and/or to the long axis of the forging. The bottom of the notch shall be perpendicular to the surface of the plate or the forging.

4.3 Transverse impact specimens shall be saw cut from the plate and/or forging and machined so that the long axis is transverse to the rolling direction of the plate and to the long axis of the forging. The bottom of the notch shall be perpendicular to the surface of the plate or the forging.

4.4 The impact specimens shall be located 1/2" below the interface between the overlay weld and the carbon steel of the clad plate, and at least 1/4" below the surface of the forging, Figures 2 and 3. In addition, samples shall be no closer than 1/16" to any cut surface.

4.5 Vendor to report all test data results to Du Pont in writing.

4.6 All tested impact specimens shall be returned to James A. Collins (address in Par. 1.2).

G-46-A REV. 10-59

EXHIBIT 15
Page 6

ENGINEERING DU PONT COMPUTATION SHEET

SHEET NO. NDT-1

TITLE OF PROJ. OR STUDY HWCTR

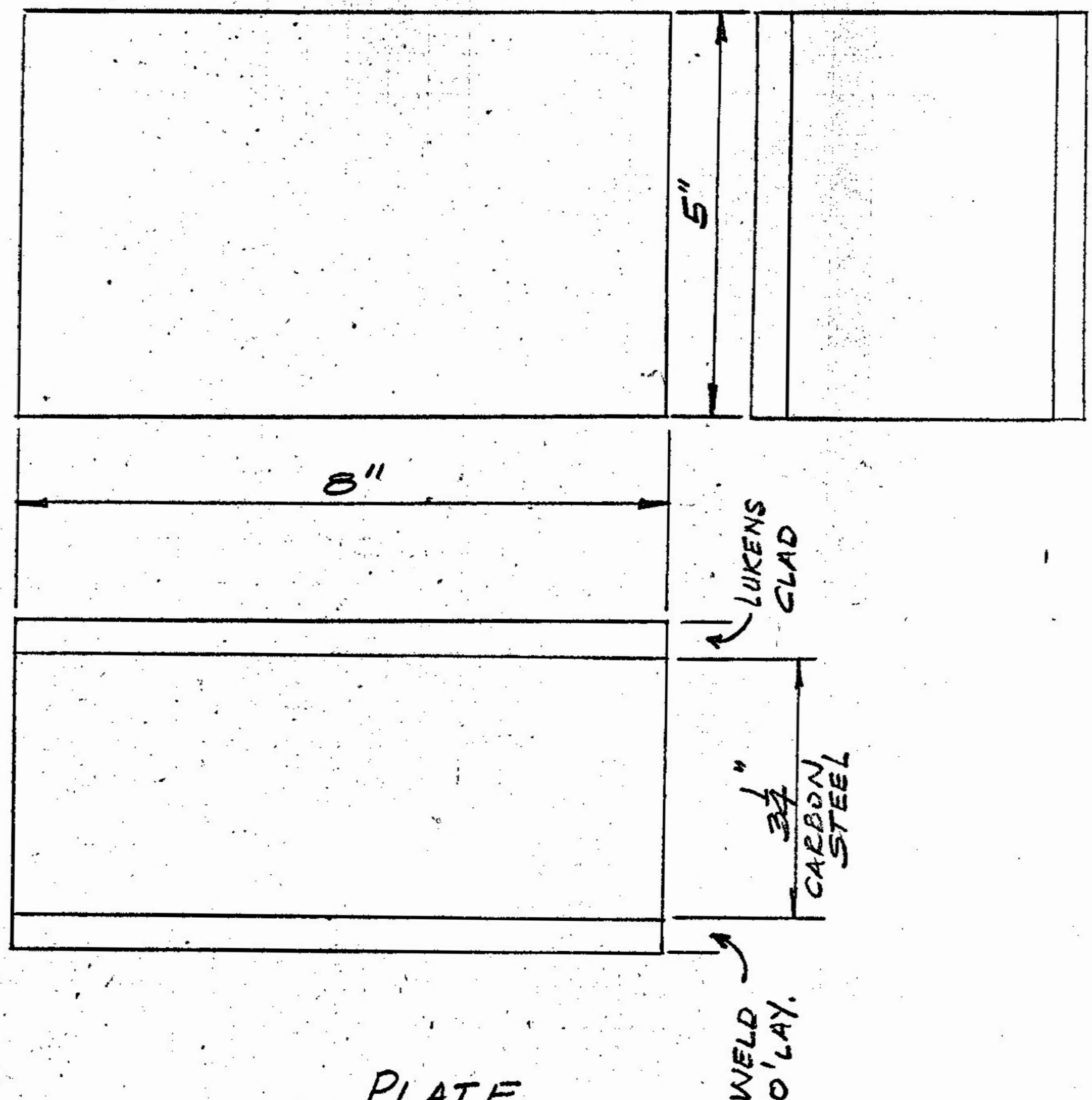
PROJ. OR STUDY NO. 98086

SUBJECT NDT TEMPERATURE DETERMINATION

WORKS S.R.P.

COMPUTER MAS.

DATE 8-24 1961



PLATE

Mark 1P

HOLD TILL FURTHER NOTICE

EXHIBIT 15
Page 7 SHEET No. NDT-2

ENGINEERING DU PONT COMPUTATION SHEET

TITLE OF PROJ. OR STUDY HWCTR PROJ. OR STUDY No. 981086

SUBJECT NDT TEMPERATURE DETERMINATION WORKS S.R.P

COMPUTER [signature] DATE 8·24 1961

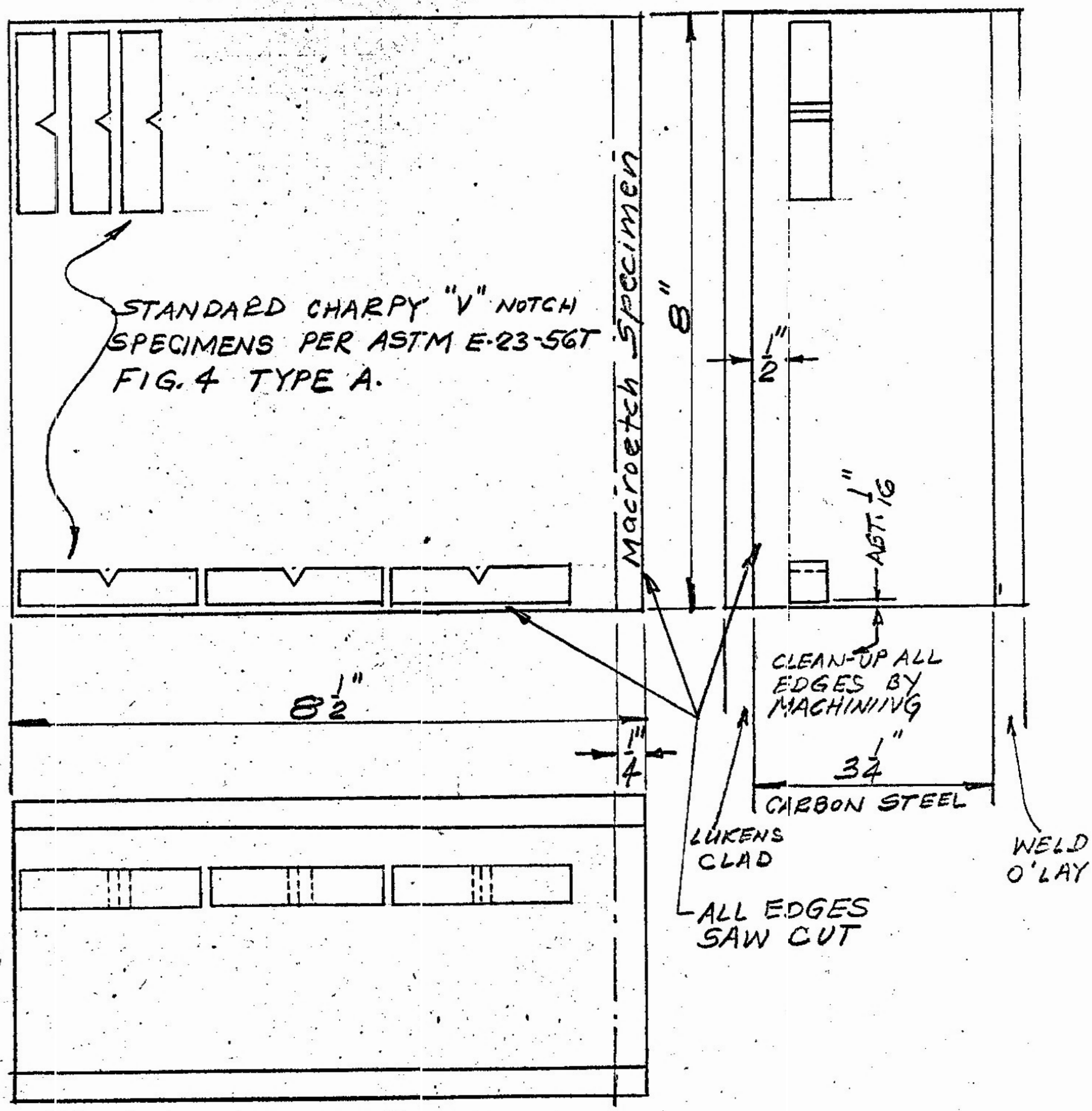


PLATE
Mark 2P

EXHIBIT 15
Page 8 SHEET NO. NDT-3

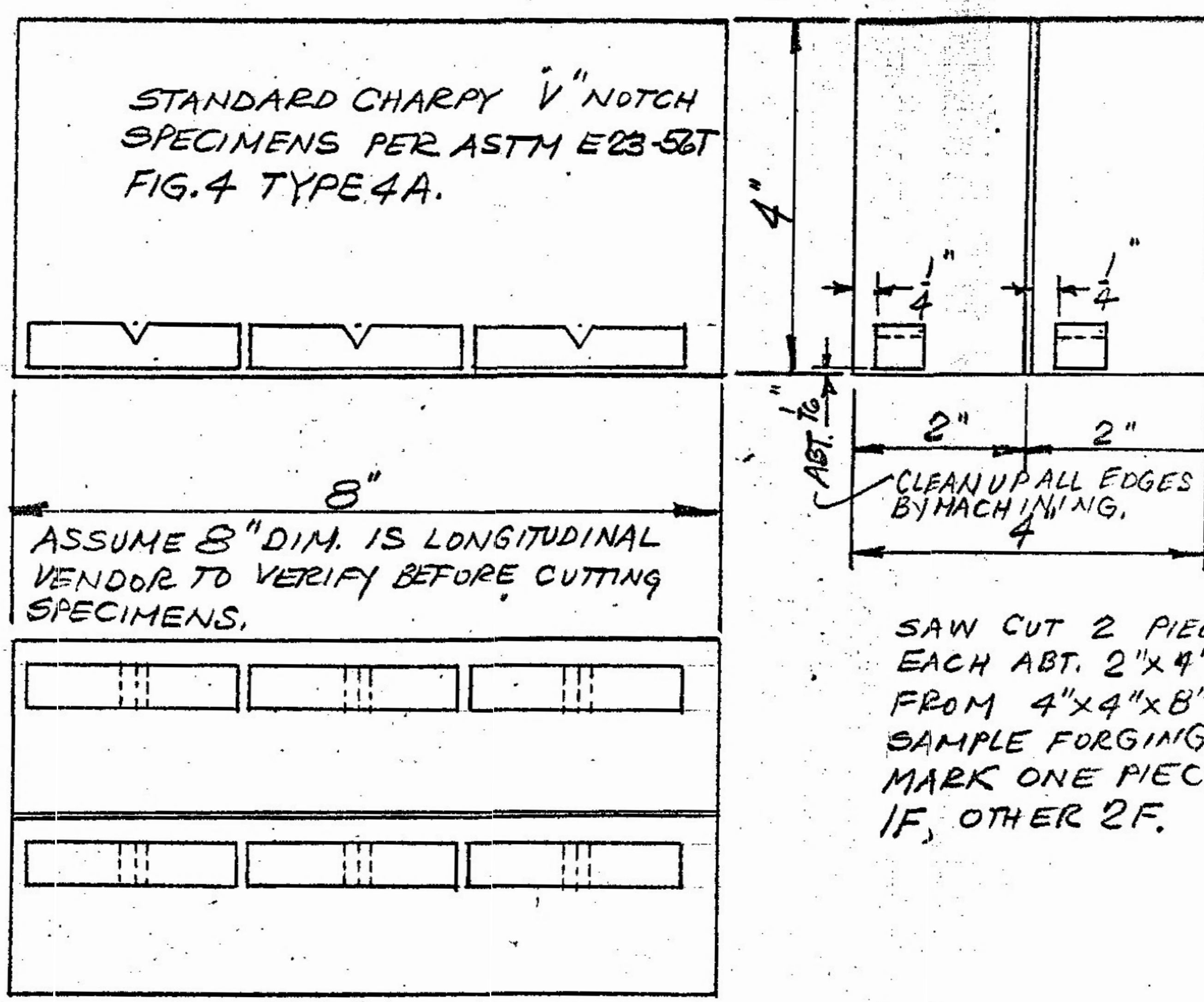
G-66-A REV. 10-59

ENGINEERING DUPONT COMPUTATION SHEET

TITLE OF PROJ. OR STUDY HWCTR PROJ. OR STUDY NO. 981086

SUBJECT NDT TEMPERATURE DETERMINATION WORKS S.R.P.

COMPUTER M.A.S. DATE 8-24-1961



SAW CUT 2 PIECES EACH ABT. 2"x4"x8" FROM 4"x4"x8" SAMPLE FORGING #2. MARK ONE PIECE 1F, OTHER 2F.

SAMPLE FORGING #2
Cut in two &
Mark 1F & 2F

Sample Forging No. 2

Composition & Mechanical Properties

ASME SA105 Grade II Fine Grain Practice

Composition

Carbon	0.27%
Manganese	0.76
Phosphorous	0.01
Sulfur	0.014
Silicon	0.24
Nickel	0.08
Chromium	0.08
Molybdenum	0.04
Copper	0.10
Tin	0.015

Mechanical Properties

Tensile Strength	76,000 lbs./sq. in.
Yield Strength	53,500 lbs./sq. in.
Elongation % in 2"	31.0
Reduction in Area %	56.1

Charpy "V" Notch

+ 10°F.	41.6 ft.-lb.

TABLE 3

NDT TEMPERATURE DETERMINATIONS

Sample Forging No. 2

1F Series Normalize Air Cool

No.	Temp. °F.	Charpy V-Notch
1	10	15.5
2	10	12.0
3	10	13.0
4	70	64.0 (N.G.)
5	70	41.0
6	70	26.0
7	120	44.0
8	120	46.0
9	120	58.0
10	25	12.5
11	20	12.0
12	25	16.0
13	25	14.0
14	25	15.0
15	25	16.0
16	25	19.0
17	25	20.0
18	25	13.5

NDT Temp. 24°F.

2F Series Normalize Furnace Cool

No.	Temp. °F.	Charpy V-Notch
1	10	6.5
2	10	7.0
3	10	6.0
4	70	23.0
5	70	22.0
6	70	23.0
7	120	46.0
8	120	48.0
9	120	47.0
10	40	10.5
11	45	21.5
12	45	14.5
13	45	14.0
14	45	13.25
15	50	14.5
16	50	16.0
17	50	16.25
18	50	16.0

NDT Temp. 49°F.

1FB Series Normalize Air Cool + Braze Cycle + Multiple Stress Relievings

No.	Temp. °F.	Charpy V-Notch
1	10	4.5
2	10	4.5
3	10	5.0
4	73	12.0
5	73	12.0
6	73	17.25
7	120	31.0
8	120	32.25
9	120	27.5
10	78	13.0
11	78	16.0
12	78	14.25
13	80	14.0
14	80	17.0
15	80	14.75
16	80	15.5
17	80	12.5
18	80	17.5

NDT Temp. 80°F.

2FB Series Normalize Furnace Cool + Braze Cycle + Multiple Stress Relievings

No.	Temp. °F.	Charpy V-Notch
1	10	4.5
2	10	4.0
3	10	5.0
4	73	16.5
5	73	14.25
6	73	16.0
7	120	37.25
8	120	32.5
9	120	36.25
10	77	15.0
11	77	17.5
12	77	16.75
13	77	17.0
14	75	14.5
15	75	14.5
16	75	15.0
17	75	16.25
18	75	14.5

NDT Temp. 75°F.

1FBN Series / 2FBN Series
Normalize + Braze Cycle + Multiple Stress Relievings + Renormalize

1FBN Series

No.	Temp. °F.	Charpy V-Notch
1	10	11.75
2	10	7.5 N.G.
3	10	13.5

2FBN Series

No.	Temp. °F.	Charpy V-Notch
1	10	12.5
2	10	14.25
3	10	14.5

TABLE 4

NDT TEMPERATURE DETERMINATION

HWCTR Clad Plate - Carbon Steel Portion

Plate Sample Stress Relieved to Duplicate Vessel Condition

2 PL Series Longitudinal

No.	Temp. °F.	Charpy V-Notch
1	10	12.25
2	10	10.5
3	10	8.25
4	73	44.0
5	73	35.5
6	73	30.5
7	120	65.0
8	120	60.0 N.G.
9	120	64.0
10	25	13.0
11	25	11.0
12	25	14.0
13	30	15.75
14	30	14.0
15	30	15.0
16	30	17.0
17	30	15.75
18	30	14.5

NDT Temp. 30°F.

2 PT Series Transverse

No.	Temp. °F.	Charpy V-Notch
1	30	13.5
2	30	13.0
3	25	11.0
4	35	12.5
5	35	15.0
6	35	14.75
7	35	14.0
8	35	16.5
9	35	16.0

NDT Temp. 35°F.

TABLE 5

NDT TEMPERATURE DETERMINATION

Sample Forging No. 1

Normalize + Braze Cycle + Multiple Stress Relieving

No.	Temp. °F.	Charpy V-Notch
1	50	15.0
2	50	14.5
3	50	13.75
4	50	12.75
5	50	12.0
6	53	13.0
7	50	14.0
8	55	15.5
9	55	13.0

NDT Temp. 55°F.   Compare With Table 2, Curve B, Data

Normalize + Braze Cycle + Multiple Stress Relievings + Renormalize

No.	Temp. °F.	Charpy V-Notch
1	10	60 N.G.
2	10	30
3	10	43

Compare With Table 2, Curve A

Fig. 2 EXHIBIT 17

G-40-A REV. 10-59

ENGINEERING DU PONT COMPUTATION SHEET

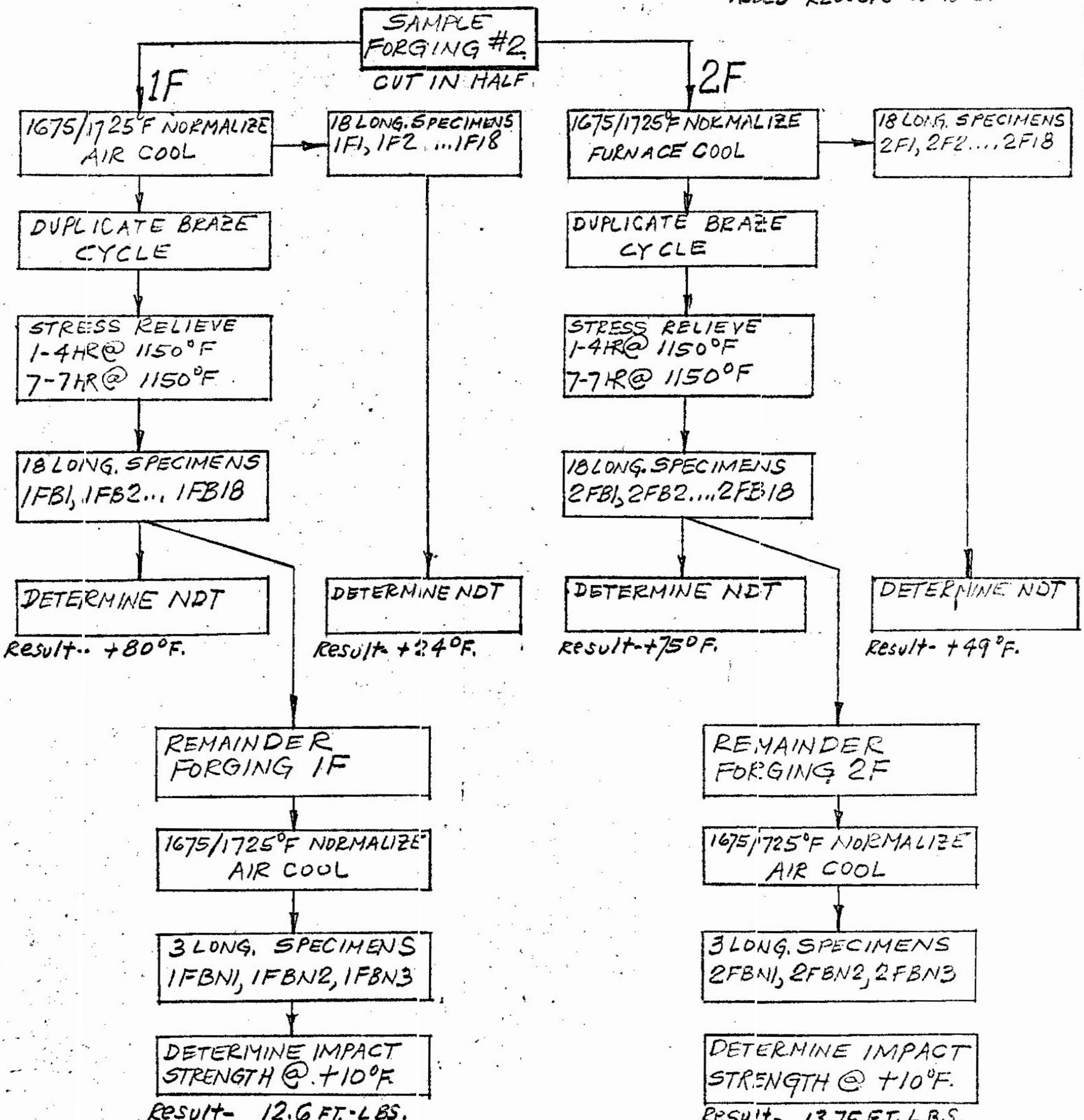
Sheet No. NDT-5

Title of Proj. or Study: HWCTR — Proj. or Study No. 981086

Subject: NDT TEMPERATURE DETERMINATION — Works: S.R.P.

Computer: [illegible] — Date: 8·24 1961

ADDED RESULTS 10·10·61



FLOW CHART FOR SAMPLE FORGING #2

G-40-A REV. 10-59

Fig. 3

EXHIBIT 18

ENGINEERING (DUPONT) **COMPUTATION SHEET**

SHEET NO. NDT-4

TITLE OF PROJ. OR STUDY HWCTR

PROJ. OR STUDY NO. 981086

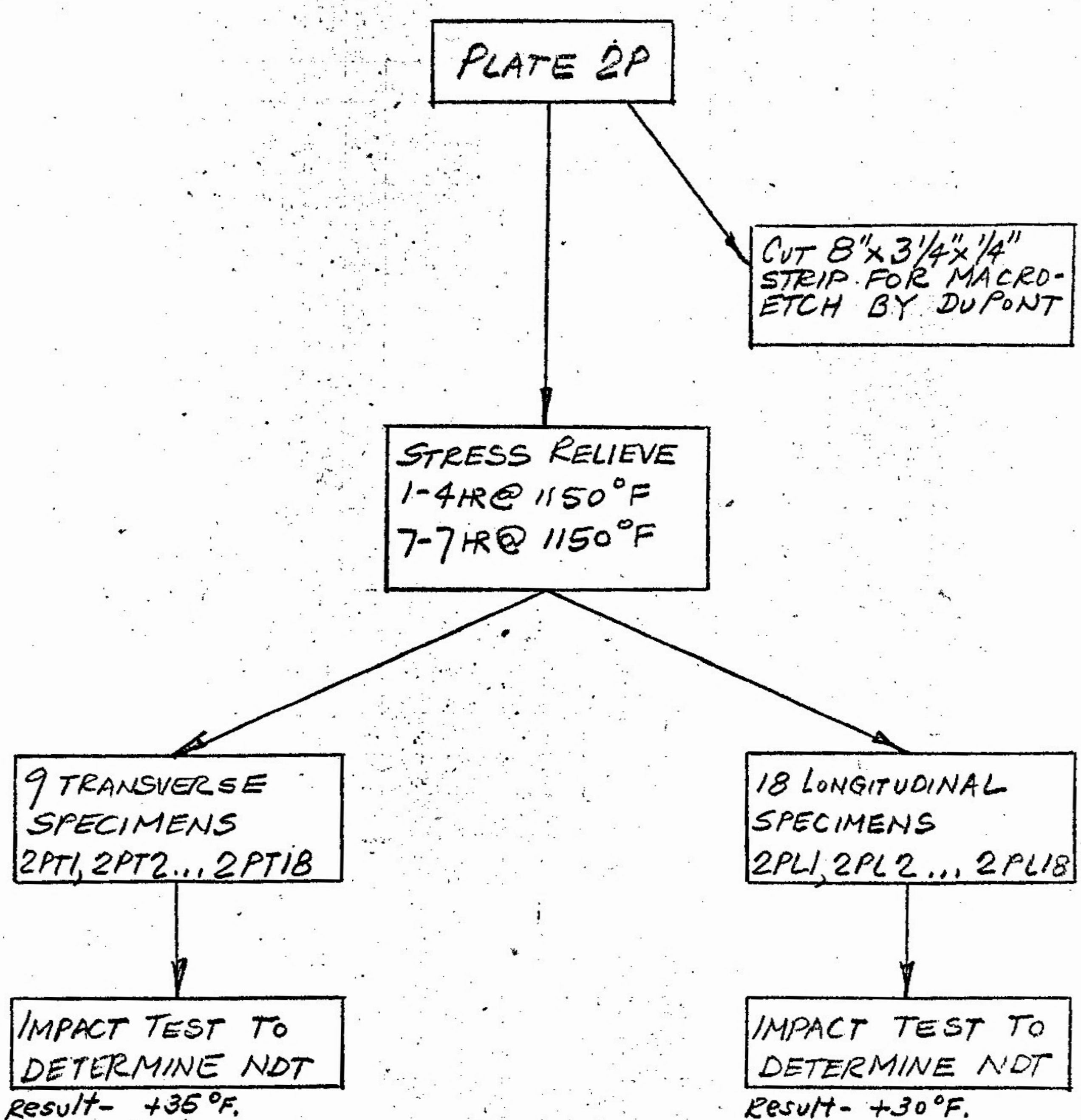
SUBJECT NDT TEMPERATURE DETERMINATION

WORKS S.R.P.

COMPUTER [illegible]

DATE 8.24 19 61

ADDED RESULTS 10.10.61



FLOW CHART
FOR
PLATE 2P

EXPLANATION OF TERMS ASSOCIATED WITH BRITTLE FRACTURE

1. Three Conditions Necessary for Brittle Fracture

   a. A stress-raiser, resulting from design or fabrication.

   b. A stress sufficiently great to cause localized yielding in the vicinity of the stress-raiser.

   c. A service temperature below the ductile-to-brittle transition temperature (nil-ductility-transition temperature) of the material with the given stress-raiser.

2. Nil-Ductility-Transition (NDT) Temperature

   The nil-ductility-transition temperature is that temperature below which very little prefracture deformation takes place and above which considerable plastic deformation precedes fracture.

3. Determination of NDT Temperature

   a. Drop Weight Test

   W. S. Pellini, P. P. Puzak and associates at the U. S. Naval Research Laboratory, in their investigations of the brittle fracture of ships, developed a test to measure susceptibility to initiation of brittle fracture (the drop weight test). The drop weight test specimen is a flat bar of steel 3-1/2 in. wide x 14 in. long. The crack inducer is a weld bead of hard-facing metal, 3 in. long, deposited longitudinally at the center of one 3-1/2 x 14 side of the specimen. The specimen is placed, weld down, on rounded end supports and struck by a 60 lb. falling weight with sufficient energy to bend the specimen about 5°. A cleavage crack forms in the bead of weld metal as soon as incipient yield occurs - at about 3° deflection - thus forming the sharpest possible notch in the test specimen. A series of specimens are tested over a range of temperatures to find the nil-ductility-transition; that is, the temperature below which steel, in the presence of a cleavage crack, does not deform plastically prior to fracturing, which is to say that fracture occurs immediately on yielding of the steel. This is a "go, no-go" test since the specimen either breaks or it doesn't.

   b. Charpy V Notch Impact Test

   The Charpy V notch test is used as a convenient method of determining, in a reasonably accurate manner, the NDT temperature. When tests are made with this method on steels at a series of temperatures, the energy absorbed at low temperatures is low and at high temperatures is high. Sometimes the transition is fairly abrupt, but often it is gradual. The appearance of the fracture is of importance in determining when the NDT temperature is reached, but visual observation is good only for an approximation. The best method for the use of this method is first to determine for a given steel, a correlation between the Charpy V notch test and the drop weight test. The NDT temperature is first determined by the more accurate drop weight test. Then, Charpy V notch tests are conducted on the same steel at the predetermined NDT temperature. In this manner, the Charpy value in ft.-lb. corresponding to the NDT temperature is established. This varies from steel to steel, so the Charpy method is only useful after such a correlation has been made for a given steel. It has been found for ASTM A212 steel that the temperature associated with the 15 ft.-lb. Charpy V notch value is an approximation of the NDT temperature. For semi-killed ASTM A285, the NDT temperature would correspond to the 10 ft.-lb. Charpy value, and for ASTM A302 the value would be 30 ft.-lb.

4. Fracture Transition Temperature

The fracture transition temperature is that temperature below which fracture occurs entirely by cleavage and above which some shearing occurs. This temperature is normally established by the explosion bulge test. In this test a specimen 14 in. square by 1 in. thick, containing a crack starter weld as in the drop weight test, is placed over a hollow die with the crack starter weld on the lower side and is loaded by the force of a controlled explosion with the weld bead on the tension side at temperatures lower than the nil-ductility-transition temperature (as determined by the drop weight test), the steel does not deform prior to fracturing and the specimens break flat under explosive impact because fracture initiation is easy. Just above the NDT temperature, considerable plastic deformation (bulging) precedes fracture; this means that it is now more difficult to initiate a fracture, but propagation is still very easy since fractures run to the edges of the test plate. As the testing temperature is increased to where fracture is partly by shear, propagation becomes more difficult and fractures are confined to the area of bulging. The fracture transition temperature is the minimum temperature at which cracks are confined to the bulged area and do not propagate to the edges of the specimen.

BUREAU OF SHIPS' REQUIREMENTS FOR HYDROSTATIC TESTING OF REACTOR PRESSURE VESSELS

Source: "Tentative Structural Design Basis for Reactor Pressure Vessels and Directly Associated Components". (No identifying number on this publication.)

Par. 7 Inspection and Tests

Par. 7.1.2 Hydrostatic Tests

(3) In order to decrease the probability of brittle fracture of ferritic steels, the following load restrictions shall be used in relation to the nil-ductility-transition (NDT) temperature (as defined below). When the metal temperature is less than 60°F. above the NDT temperature, the maximum applied load, including internal pressure, shall be restricted to 20% of the design value. When the metal temperature is more than 60°F. above the NDT temperature, there is no restriction upon the load from the aspect of brittle fracture prevention. However, under no circumstance shall a hydrostatic test be conducted at a temperature exceeding 200°F. There is no restriction on low temperature loading of materials other than ferritic steels.

(4) The nil-ductility-transition (NDT) temperature is that temperature below which the metal fails in a brittle manner in a drop weight test*. Correlation with Charpy V notch test is a satisfactory means of determining the NDT temperature. The following correlations may be used:

Material	Charpy V Notch Energy Absorption (Ft.-Lb.) Corresponding to NDT Temp.
ASTM A212	15
AISI Type 410	20
ASTM A302	30
SAE 4340	35

Correlation data for other ferritic steels listed in par. 4.1 are not available and should be obtained if they are to be loaded at temperatures which may fall below NDT +60°F. The following correlation between yield strength and Charpy V notch energy absorption is believed to be conservative and may be used as a guide in the absence of better data:

*"The Evaluation of the Significance of Charpy Tests for Quenched and Tempered Steels", by P. P. Puzak and W. S. Pellini, Welding Journal, June, 1956.

Material Class by Yield Strength	Charpy V Notch Energy Absorption (Ft.-Lb.)
45,000 p.s.i.	20
45,000 - 75,000 p.s.i.	30
75,000 p.s.i.	40

It may be found in some cases, especially for high strength steels, that the Charpy V notch energy absorption is at all times below the tabulated value. In such cases, the Charpy V notch correlation shall be determined experimentally.

EN-1026

E. I. DU PONT DE NEMOURS & COMPANY
INCORPORATED
WILMINGTON 98, DELAWARE

ENGINEERING DEPARTMENT

EXHIBIT 21
PAGE 1

August 16, 1961

Dr. Maxwell Gensamer
3 Florence Drive
South Chatham, Cape Cod
Massachusetts

Dear Max:

Attached are two copies of the report of our discussion at the Naval Research Laboratory on August 9 which incorporate the changes and additions we discussed yesterday. If you are in agreement with the report, please sign one copy and return it to me as soon as possible. A return envelope is included for your convenience. Retain the second copy for your file. If you take exception to any part, please contact me by 'phone if you desire any corrections, additions or deletions. I have sent two copies of the report to Pellini and requested the same action. In addition, I forwarded to him a Verifax copy of your initial report.

The reason for this urgency in arriving at agreement on the report lies in the fact that it will be included in a larger report being prepared for the Atomic Energy Commission, which has been requested on August 21.

I want to take this opportunity to again thank you for your cooperation and the excellent help you have given us in this matter.

Yours truly,

ENGINEERING SERVICE DIVISION

James A. Collins
Materials Engineering

('Phone - Wilmington, Delaware ENdicott 6-2211)

CC: W. S. Pellini
Naval Research Laboratory
Washington, D. C.

E-1828

DU PONT

ESTABLISHED 1802

E. I. du Pont de Nemours & Company

INCORPORATED

WILMINGTON 98, DELAWARE

EXHIBIT 21
PAGE 2

ENGINEERING DEPARTMENT

August 16, 1961

Mr. W. S. Pellini, Supt.,
Metallurgy Division, Code 6300
U. S. Navel Research Laboratory
Washington 25, D. C.

Dear Bill:

Attached is a Verifax copy of the initial report of our discussion at the Naval Research Laboratory on August 9. This was prepared by Gensamer. As you will note, no mention was made of low cycle fatigue, hydrostatic testing at a temperature less than the NDT temperature + 60°F., and of the conclusions re vessel quality based on the two successful hydrostatic tests at 1.5 times design pressure and approximately 55°F. This was discussed in detail with Gensamer and he asked me to prepare paragraphs on these points and include them in the final report.

Attached are two copies of the report with these changes and additions. If you are in agreement with the report, please sign one copy and return it to me as soon as possible. A return envelope is included for your convenience. Retain the second copy for your file. If you take exception to any parts, please contact me by 'phone of your desires for corrections, additions or deletions. I have sent two copies of the report to Gensamer and requested the same action by him.

The reason for this urgency in arriving at agreement on the report lies in the fact that it will be included in a larger report being prepared for the Atomic Energy Commission regarding the reactor vessel, which has been requested on August 21.

In my 'phone discussion with Gensamer, I pointed out that insofar as the minimum safe temperature for pressurizing to design pressure is concerned, there is no practical difference between 170°F. and 120°F.

I want to take this opportunity to again thank you for your cooperation and the excellent help you have given us in this matter.

Yours truly,

ENGINEERING SERVICE DIVISION

James A. Collins
Materials Engineering

('Phone - Wilmington, Delaware - ENdicott 6-2211)
JAC/emn

CC: Dr. Maxwell Gensamer
3 Florence Drive
South Chatham, Cape Cod
Mass.

3 Florence Drive
South Chatham, Mass.
Cape Cod
August 16, 1961

E. I. du Pont de Nemours & Co.
Engineering Department
Louviers Building
Wilmington 98, Delaware

Atten: Dr. James A. Collins

Gentlemen:

Based on the information provided at our meeting at the Naval Research Laboratory on Wednesday, August 9, the following comments and recommendations are made concerning the pressure vessel with the nozzles that were not normalized as specified.

The only datum point particularly applicable to the nozzles in this vessel is that provided by the tests conducted on the spare forging (prepared for that purpose simultaneously with the nozzles), and that is somewhat in doubt because there is some uncertainty about its heat-treatment. But the datum obtained is close to what would be expected of such forgings in the normalized condition, and is in agreement with data presented by Mr. Pellini for similar material, so it may be taken to represent reasonably nearly what the normalized forgings should yield. The transition temperature of the normalized forgings is probably quite near 0°F., perhaps 10 F. (This is the nil ductility transition temperature, which indicates the temperature above which the stress required to propogate a crack rises rapidly, perhaps within 30 or 40 F., to the yield strength, and below which a running crack may be propogated at a stress level below customary design stress levels). Because the shell material has about the same transition temperature, the safe operating temperature should be somewhere between 40 and 70 F., conservatively the latter temperature 70 F., with normalized forgings.

With forgings brazed at 2050 F., unnormalized, the transition temperature is certainly higher, but this does not affect the transition temperature of the shell materials, so the integrity of the shell itself is assured at 70 F. But there is the possibility of a brittle fracture within a nozzle forging that could encircle the opening and completely sever the vessel from the connecting tubing. The temperature below which this might occur at the design stress level depends on the amount by which the forging's transition temperature has been raised by the brazing.

The estimate made by Du Pont personnel, based on the amount by which the transition temperature of a normalized test forging was raised by a brazing heat-treatment is very conservative. The increase was 95 F., and it was assumed that the nozzle would suffer the same increase, bringing its transition temperature to about 95 F. Taking Mr. Pellini's recommendation that the minimum operating temperature be 60 F. above the transition temperature, and taking that to be plus 10 F., the temperature should be held above 165 F. when the vessel is subjected to the design pressure. Pressurization of the vessel at temperatures below 170 F. should not exceed 300 p.s.i.g. This is in accordance with the Bureau of Ships, "Tentative Structural Design Basis for Reactor Pressure Vessels and Directly Related Components," that when the metal temperature is less than 60 F. above the transition temperature the maximum applied load including internal pressure shall not exceed 20% of the design value.

I doubt that the brazing treatment will have raised the transition temperature of the nozzle material so high. It seems likely that the test forging was normalized in small pieces, for it has unusually high impact properties. It is more likely that whether or not the forgings are normalized in large or small pieces they will have the same transition temperature after brazing. The austenitic grain size produced by the brazing should be little affected by prior structure, and depend largely on the brazing temperature. So, I would expect the transition temperature to be about 60 F. in both the brazed test forging and the brazed nozzle forging. On this basis the safe operating temperature might be as low as 90 F., but more conservatively 120 F., which is barely warm.

I recommend another test forging be procured and that it be normalized by heating to the specified temperature and cooling <u>at the same rate</u> as the nozzle cooling rate, taking tests from not too near the surface of the billet so as to be within the columnar zone of the ingot in freezing. This ought to produce a transition temperature of about 10 F. Then, I would give this the brazing treatment to see if the transition temperature would be raised to about 60 F. instead of the 95 to 105 F. estimated by Du Pont. If so, the minimum operating temperature at stress could be lowered to, say, 120 F.

If it be desired to operate with a minimum temperature of 70 F., I see no recourse but to normalize the nozzle forgings, either by removing them - which will be costly and further increase the number of stress-relief annealings (already questionably many), or by normalizing the whole vessel - which is almost surely impractical considering the stringent dimensional tolerances.

On the subject of the effect of stress-relief annealing, the bad effect observed with the test forgings after the brazing cycle may not be as bad as the few test results make it appear, considering the statistics of this kind of testing; the reported results would not be considered very significant after a statistical analysis. However, I

EXHIBIT 21
PAGE 5

concur that it would be well to test a sample for the effects of repeated stress-relief annealings after a brazing cycle, for the coarse grained structure produced by 2050 F. may be more susceptible to tempering embrittlement than a normally fine austenitic grain size. I suspect that 1150 F. may be above the temperature of maximum rate of embrittlement, in which event slow cooling of the vessel from this temperature should be repeated no oftener than necessary. The testing should involve as many cycles of stress-relief annealing as may be required of the actual vessel, and the cooling from the annealing temperature should be as slow as that experienced by the vessel.

I see little reason for removing a nozzle, plugging the hole, and testing the removed nozzle. The test nozzle is surely from the same heat, and can be put back into the original normalized condition nearly enough to start from this point, as I have recommended above.

The use of a hydrostatic pressurization of the vessel at 1.5 plus times the design pressure at a minimum temperature of 170 F. to accomplish a mechanical stress relief or notch nullification is not recommended. Because of the vessel's complicated design, such a pressurization could be harmful to the bolted head closure, and could contribute to the occurrence of a low cycle fatigue failure.

The fact that two hydrostatic tests were conducted successfully on the vessel at 1.5 times the design pressure at 55 F. indicates a good vessel of high integrity, and no harmful defects as long as the operating pressure does not exceed design pressure.

It is understood that a final hydrostatic test at 1.5 times design pressure will be made on the vessel after erection and installation is completed. This should be done, of course, at a temperature not less than 170 F. Such pressurizations, even when conducted at a safe temperature above the transition temperature should be done as little as possible to avoid possibility of contributing to a low cycle fatigue failure.

Yours truly,

[redacted]

Maxwell Gensamer 8/17/61 Date

[redacted]

W. S. Pellini 8-18-61 Date

MG-WSP/

E. I. DU PONT DE NEMOURS & COMPANY
INCORPORATED
WILMINGTON, DELAWARE

ENGINEERING DEPARTMENT

October 10, 1961

Mr. W. S. Pellini, Superintendent (2)
Metallurgical Division
Naval Research Laboratory
Washington 25,
District of Columbia

Dear Mr. Pellini:

PROJECT S8-1086 - SAVANNAH RIVER PLANT - HWCTR
CONDITION OF REACTOR VESSEL

This will confirm our discussion and analysis in your office on Oct. 6, 1961, of impact test data developed from sample forgings selected and heat treated to duplicate as nearly as possible the condition of the 2" and 4" nozzles of the subject reactor vessel.

The impact test data developed from sample forging No. 1 and discussed with you and Maxwell Gensamer are tabulated in Tables 1 and 2, and graphically presented in Figure I (Exhibit 14). From these data, it was concluded (see letter-report of you and Gensamer dated August 16, 1961) the brazing heat treat cycle and multiple stress relieving heat treatments could have raised the NDT temperature of the 2" and 4" nozzles as high as 105°F., and that 165°F. is the minimum safe temperature for pressurization of the vessel. (See Heavy Water Components Test Reactor - Project S8-1086 - Savannah River Plant - Condition of Reactor Vessel - Preliminary Report, page 6.) However, you and Gensamer felt this was conservative and concurred in the opinion that the brazing and multiple stress relievings actually raise the NDT temperature of the nozzles to about 60°F.

> "I doubt that the brazing treatment will have raised the transition temperature of the nozzle material so high. It seems likely that the test forging was normalized in small pieces, for it has unusually high impact properties. It is more likely that whether or not the forgings are normalized in large or small pieces they will have the same transition temperature after brazing. The austenitic grain size produced by the brazing should be little affected by prior structure, and depend largely on the brazing temperature. So, I would expect the transition temperature to be about 60°F. in both the brazed test forging and the brazed nozzle forging. On this basis the safe operating temperature might be as low as 90°F., but more conservatively 120°F., which is barely warm."

On the basis of this opinion, and your recommendation, a second test forging was procured, heat treated and tested (Exhibit 15). The results of this second series of impact tests are tabulated in Tables 3, 4 and 5, and the NDT temperatures presented in Figure II (Exhibits 16 and 17).

From a careful analysis of the data developed in this second test program on sample forging No. 2, you concluded the measured impact strengths (1) were what you would expect of an ASME SA105, Grade II, forging made to fine grain practice, (2) were in line with impact strengths you had determined on similar steel forgings, and (3) of the 1FB and 2FB series (see Table 4) reliably represent the condition of the 2" and 4" nozzles, and that the NDT temperature of the 2" and 4" nozzles can be reliably taken to be 75-80°F. These results confirm the opinion expressed by you and Gensamer in your letter-report of August 16, 1961, quoted above.

It was also concluded that the NDT temperature determined on the sample forging No. 1 and reported in Table 2 (Exhibit 14) in the normalized and stress-relieved condition is so exceptionally good and so low that it is not typical of an ASME SA105, Grade II, steel forging made to fine grain practice. This could result from unusual characteristics of the forging, but more likely resulted from the sample sizes and method of heat treatment preparatory for testing. Because these data (Curve A, Figure I) are so far out of line, it is concluded they do not represent the 2" and 4" nozzles and should be disregarded.

The NDT temperature for the steel portion of the stainless steel clad plate used for the vessel wall was determined to be 30-35°F. (see Table 4, Exhibit 15). The limiting and controlling NDT temperature of the subject vessel, therefore, is that of the 2" and 4" nozzles; namely, 75-80°F. Adding 60°F. to the nozzle NDT temperature gives 140°F. for the minimum safe temperature for pressurizing of the vessel above 300 p.s.i.g.

If you concur with the above statements and conclusions, please sign the second copy of this letter and return it to me.*

Your assistance in analyzing the condition of the vessel and establishing safe operating and testing procedures has been most significant and beneficial.

Very truly yours,

ENGINEERING SERVICE DIVISION

James A. Collins, Group Supervisor
Materials Engineering

JAC/emp
Attach.

CC: Dr. Maxwell Gensamer (2)
Columbia University
New York, N. Y.

*Copies of this letter signed by W. S. Pellini & Maxwell Gensamer are available in Engg. Dept. Files.

EXHIBIT 23

EN-1030

DU PONT

E. I. DU PONT DE NEMOURS & COMPANY
INCORPORATED
P. O. BOX 117 – AUGUSTA, GA.

ENGINEERING DEPARTMENT

In reply please use subject listed below.

Date: August 2, 1961

C.C.:

To: R. K. MASON
DISTRICT SUPERINTENDENT
CONSTRUCTION DIVISION
WILMINGTON

From: H. J. FEINEN [redacted]

Subject: Construction - Savannah River Plant - IN-TRANSIT DAMAGE TO TOP FLANGE OF REACTOR VESSEL FOR HWCTR

The Reactor for HWCTR was received in Central Shops June 29, 1961. Prior to unloading, the Reactor Vessel was inspected, and a 6" x 1/2" piece was found to be sheared from the outer portion of the top flange. (Exhibit #1) The damage was caused by a steel brace welded to the floor of the railroad car (Exhibit #2). Apparently, the Reactor shifted forward against the brace with sufficient force to shear the cantilevered portion of the top flange (Exhibits #3 and #4).

The brace, made from 3/4" x 6" angle, was bent toward the front of the car, the car floor was depressed at the junction of the knee portion of the brace, and part of the weld at the joint of the vertical portion of the brace with the car was sheared (Exhibit #5).

The second brace on the back of the top flange was also bent slightly indicating the Reactor had been free to move back and forth approximately 2" during part of the trip (Exhibit #6). Side braces from the railroad car to the Reactor also indicated movement of approximately 2" (Exhibits #7 and #8).

Mr. George Muir of Construction Receiving notified Mr. Weatherly of Operations Traffic of the damage. Mr. Weatherly notified Mr. Sexton, representative for Vickers Agency of the Atlantic Coastline Railroad in Barnwell, South Carolina. Mr. Sexton gave permission by phone to unload the Reactor and then visited the unloading site the afternoon of June 29, 1961. Damage Report No. 1429 (Exhibit #9) was filled in and signed by Mr. Muir of Construction and Mr. Sexton, representing Vickers Agency of the Atlantic Coastline Railroad.

The original thinking was to make no repairs to the top flange; however, since a feasible method of repair has been developed by Design, the final decision has not been made.

HJF-MWH:cnb
Attachments: 9

EXHIBIT 24

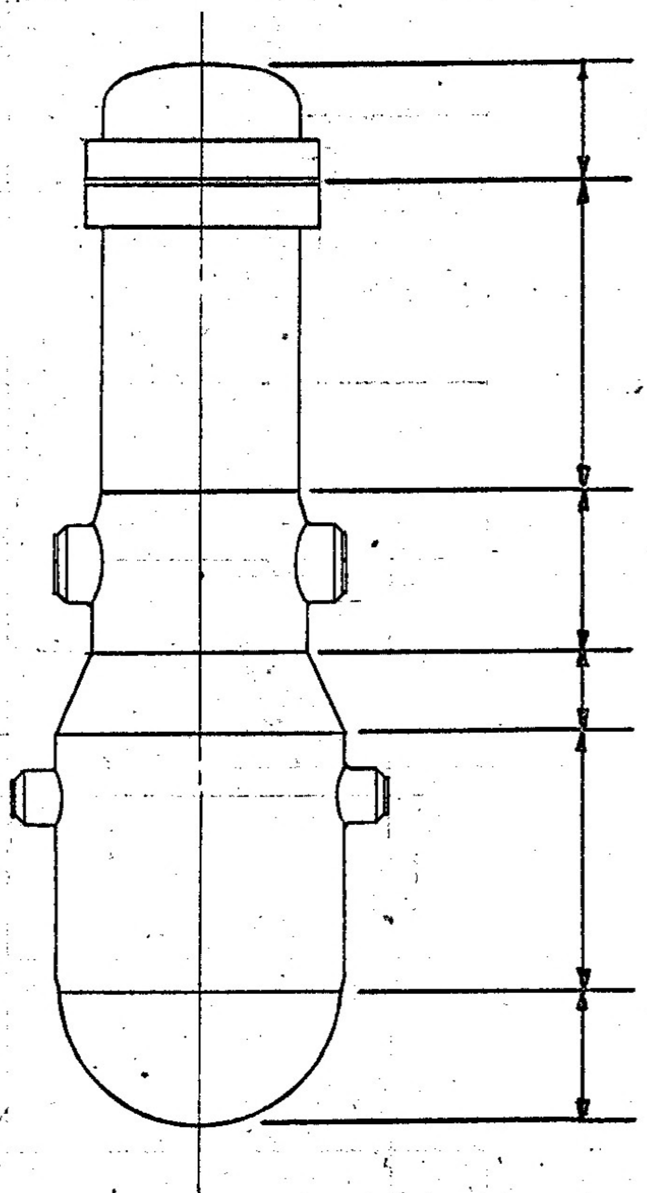
ENGINEERING DEPARTMENT SKETCH SHEET SHEET NO.

PROJ. NO. PLANT TITLE

BLDG. OR AREA FUNCTION SUBJECT

NAME DATE

EXHIBIT 18



Total Number Stress Relieving Treatments at 1150°F.	Total Hours at 1150°F.
3	21
8	53
4	28
5	35
7	49
5	35