Incident Investigation Report

1. Location & Date of Incident: [redacted] – January 16, 2017

2. Personnel involved: [Hotwork Technician #1], [Hotwork Technician #2]

3. Incident as reported: A Hotwork burner was firing into the bottom of a large metal vessel (approximately 96’ high x 26’ dia.) during a Weld Pre-Heat. A thermocouple (60’ of zap wire) had been extended thru the exhaust, into the vessel, and down from the top of the vessel about 45’ to monitor the vessel atmosphere temperature in the gas stream from the burner. The client objective was to achieve specific external metal skin temperatures and this TC was “for reference” to anticipate what the metal would achieve after soaking. Due to its widely separated proximately to the burner (about 45’), the readings from the TC were not indicative of the flame temperature, but rather, the internal vessel temperature. The plant gas pressure of 90 PSI was being controlled through a Hotwork regulator with a maximum capable output pressure of 50 PSI, followed by a flow meter and by a Tee to supply two burners/vessels. Gas supply diagram attached.

   At around 11:30 pm, the plant gas supply dropped and was observed at 48 PSI on the client header (below the regulator set point of 50) over the course of roughly 10-15 minutes. [Tech #1] reported this unexpected drop in pressure to plant personnel, but after various people performed various checks, no progress was made in determining the cause of this drop in pressure. The pressure gauge on the Hotwork flow meter showed a reading of around 28 PSI at the time of logging the values (3 hour interval). In an attempt to maintain the temperatures required by the preheat schedule, [Tech #1] and [Tech #2] adjusted the Hotwork regulator to allow for maximum output to the Hotwork A/C box, as well as opening up the valves inside the A/C box in order to try to maintain temperature. The [A] and [C] vessels were at desired temperature at the onset of the pressure event. The [B] vessel was ramping from ambient to target temperature so the burner output was significantly higher on [B].

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   Attempts were made to get [B] onto the desired schedule by opening control valves and adjusting the regulator. These measures were an attempt to get more gas to the [B] burner to stem the loss of temperature that was occurring. Small amounts of gas were also taken off the already low firing burners in vessels [A] and [C] in an attempt to direct the available gas to [B]. In spite of these actions, the temperatures continued to decline on [B].

   After operating at a low plant supply gas pressure for approximately four hours, the plant supply gas pressure suddenly surged back to 100 PSI (according to plant gauge). Since the regulator had been opened 100% and the A/C box valves had been opened to accommodate the reduced gas pressure, this surge in supply pressure caused an increase in gas volume to flow to the Hotwork burner. This resulted in the vessel temperature spiking approximately 200° upward, and we suspect simultaneously releasing excess gas that the burner was incapable of burning due to the ratio of air to gas being insufficient to accommodate complete combustion. Although there was a significant spike in this thermocouple, the highest value (about 500°F) was well below the point at which the burner would be expected to go reducing (approximately 2600°F flame temperature).

With the burner firing at an alarming rate and the temperature spiking dramatically upwards, [Tech #1] spent 5-10 minutes making adjustments to the Hotwork regulator and A/C box valves in an attempt to get the temperature back under control by lowering the gas pressure and throttling the control valves. After 10 minutes, the flow had been successfully lowered, but it is suspected that an amount of unburned gas had entered the vessel in the minutes leading up to this. When the gas being introduced was lowered to the point that the combustion air being forced into the unit created the correct gas to air ratio for combustion, a flash occurred when the mix of unburned gas and air ignited inside the vessel, away from the burner. This flash was forceful enough to blow the TC hanging 45' down into the vessel back up to, and out of, the top exhaust stack. At that point, the TC ceased to provide values to the recorder. It also caused hot gas blowback into the Hotwork burner, melting the internals. No flame was observed coming out of the vessel by the plant fire watch, only a "whoosh" sound was heard.

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4. Injuries: None

5. Property damaged: Damage to internals of one Hotwork burner.

6. Analysis of the Event: The Hotwork burner typically produces a burner discharge (flame) temperature as shown in the table below:

Temp F	BTU/Hr	SCFH
200	268,691	256
300	449,607	428
400	634,461	604
500	828,619	789
600	1,034,410	985
700	1,250,400	1,191
800	1,474,980	1,405
900	1,705,107	1,624
1000	1,941,408	1,849
1100	2,170,194	2,067
1200	2,413,921	2,299
1300	2,661,854	2,535

1400	2,908,623	2,770
1500	3,155,214	3,005
1600	3,426,728	3,264
1700	3,750,938	3,572
1800	4,117,871	3,922
1900	4,544,710	4,328
2000	5,053,162	4,813
2100	5,669,950	5,400
2200	6,427,315	6,121
2300	7,363,503	7,013
2400	8,523,265	8,117

The typical Hotwork setup has a thermocouple positioned in proximity to the burner nozzle in order to monitor the performance of the burner. In this case, the vessel air thermocouple was useful for predicting metal skin temperatures but there was significant time lag and temperature dampening that occurred between the burner nozzle and the TC. The magnitude of the vessel size, the conductive nature of the metal (versus refractory), air ingress around the burner (and/or thru the coke dropout) due to negative internal vessel pressure, and flow “channeling” between the burner nozzle and the exhaust point, all created a very attenuated temperature reading at the air thermocouple versus the burner discharge nozzle. This situation was greatest during temperature ramping situations and was somewhat reduced during temperature holds.

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The turbine flow meter used in the Hotwork system is intended for cumulative gas consumption reporting under the SCAQMD environmental permits. These meters have never been used for control purposes. These turbine meters in effect count revolutions caused by gas flowing through the meter. There is a known volume for each revolution. The standard condition volume of gas that is passed for each rotation is a function of the gas pressure. When a higher pressure occurs, gas compresses, and more gas is contained in each turbine rotation. Therefore a pressure factor is used to adjust the flow meter readings and convert it to standard gas volumes. Meter readings and pressures are taken at a certain time, and gas volume is calculated for the time interval. As long as gas pressures are relatively constant in the time interval, the flow measurements are relatively accurate. In periods of changing gas pressure, it is possible to create large errors if the pressure that occurs at the time of the reading is not representative of the average pressure that occurred during the time interval.

Attached is a chart depicting the air thermocouple measurements on all three vessels that were under fire in the time period of the incident. Vessel [A] was in an extended hold at the time of the pressure loss. Technicians reported low burner output (barely on main) in order to sustain the hold temperature. Vessel [C] was also in an extended hold at the time of the pressure loss and Technicians reported that it was also on low fire (pilot only). Vessel [B] was attempting to ramp from ambient to skin temperatures of 300°F. In order to do this temperature ramping of the large volume of air in the vessel and the large mass of metal, this burner was firing at a much higher rate (burner on boost). At the time of the pressure loss, although air thermocouples in all three vessels were in a similar range, the firing condition of the three burners were quite different. With low flow conditions on two vessels, the loss of pressure had minimal impact on the air TCs. The metal in those vessels was at close to the same temperature as the air in the vessel. On [B], while ramping, the burner flame temperature was significantly hotter than the air TC and the metal was lagging behind the air. When loss of pressure caused a reduction in flow to this burner, the flame temperature diminished and the colder metal pulled the air temperature down to a greater degree than in the other two vessels. Attempts were made to offset the temperature declines by opening [B] gas valves and by taking gas off [A] and [C] in order to direct gas to [B]. It is apparent from the air TC reading that the flame temperature of the burner diminished significantly and the colder metal temperatures contributed to the air temperature declining.

The log of the flow meter readings during the low pressure event provide some information about what may have been going on at the burner. On 1/16, between 1am and 4:00am (during low pressure event), the meter shows a usage of 29,738 scfh for the three hour period (9,913 per hour). As configured at this time, the meter was monitoring the combined consumption of the burners in [A] and [B]. Assuming that [A] was slightly on main, it is likely that burner was consuming about 2,000 scfh of gas leaving about 7,913 scfh for [B]. This amount of gas is within normal operating range for the Hotwork burner but it would likely create a flame temperature approaching 2400°F. The behavior of the air TC does not indicate anywhere near that amount of energy release. These two pieces of information appear to be inconsistent – low and declining air temperature and high gas flow to the burner. Possible explanations for this problematic observation are evaluated below:

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a.) Burner was reducing for this entire period. The quantity of gas measured during this period is within the Hotwork burner normal operating range. It is highly unlikely to be reducing at these values. In addition, when actions were taken to direct more gas to [B], the rate of temperature decline was affected indicating that the additional gas was burned. Also, at the time of the pressure restore, there was a dramatic increase in the air temperature. If the burner had been reducing for the previous four hours, when gas pressure was restored, the air temperature in the vessel would have declined due to a greater reducing condition. It is highly unlikely that the burner was over fueled for this four hour period but the air temperature measurements do not support a flame temperature implied by that rate of gas flow. Air temperature measurements indicate that the energy released was only enough to keep the air temperature slightly above the metal temperature.

b.) Consumption reading from meter was inaccurate. There are several possible ways that errors could have been introduced in the three hour gas flow measurement. One possibility is that the accumulating meter readings were not taken in a timely manner and they do not actually represent a three hour period. If the start of period reading was taken 15 minutes early and the end of period reading was taken 15 minutes late, it could have been a 3.5 hour time period represented as 3 hours. Since this was not a control device, and since total consumption for the entire project is the only requirement for permit reporting, it is entirely possible to have that type of timing variability in the reading. But even that magnitude of time interval deviation does not explain the magnitude of the differential between measured temperature and calculated gas flow. Another possibility is that the 28psi reading taken at the time of the flow meter recording was not representative of the entire three hour period. If the gas pressure was significantly lower than this value during the three hour interval, the gas pressure correction factor used would overstate the consumption and it could be by a significant amount. The logged pressure at 1:00 and 4:00 both showed 28psi which would tend to argue for a consistent lower pressure but it is during a pressure upset condition and there was not continuous monitoring.

c.) BTU content of gas was not constant. Hotwork has experienced events where the BTU content of the fuel supplied was variable. These events have typically been when a process byproduct is used for fuel. In some cases there have been gas mixing stations that attempt to "sweeten" process gas with natural gas in order to maintain constant BTU value. Hotwork has no information on the cause of the low pressure event that occurred but is it possible that there was an associated low BTU event? If the gas BTU declined when the pressure declined, it could easily explain the high gas flow measurement during in the four hour period when the temperature declined in the vessels.

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Hotwork does not have enough information to factually reconcile the measured temperatures with the pressure adjusted gas flow reading during the four hour low pressure event. We see no reason to doubt the temperature measurements and the direction of air and metal temperatures appear logical. We do not believe that the energy input during the low pressure event is anywhere near the value indicated by the flow meter reading

Hotwork believes that a low gas pressure event initiated at about 23:26 on 1/15. This event happened during a temperature ramp on vessel [B] and the burner control was already set for a fairly high flame temperature. When pressure was lost, the crew attempted to compensate by adjusting the regulator and the gas control valves to get more flow to the burner. The gas supply situation was inadequate to achieve target temperatures and both gas and metal temperatures declined. Attempts to direct more flow to vessel [B] resulted in temporary halt in the temperature decline but after 10 minutes, the decline continued. The low pressure event continued for over four hours. At about 4:30 on 1/16 a pressure restore event happened. This caused a rapid rise in the air TC in vessel [B] as both the regulator and the gas control valves had been adjusted for maximum flow at the lower pressure. In less than 15 minutes, the air TC in vessel [B] climbed 181°F which indicates a significantly higher flame temperature at the burner. Hotwork suspects that the burner went reducing during this period. Adjustments were made to the regulator and control valves in order to reduce the flame temperature. It appears that these adjustments were accomplished at about 4:43. The flame was then burning in an excess air mode and combustion air was reintroduced to the vessel along with products of combustion. At 4:52, the air thermocouple in vessel [B] was destroyed and ceased to report to the recorder.

7. Remedial Action: Gas and burners shut down and project suspended until client facility completed incident investigation.

8. Procedural Change:
   a. In concert with [redacted] and [redacted], additional flow and pressure monitoring has been implemented for each individual burner. Procedures were established in the event of excursions on any of the monitored values.
   b. Hotwork Technicians were instructed to maintain last adjustments in the event of a pressure loss and to work with the client to achieve pressure restore.

   Information about burner discharge temperature is important to understanding the combustion condition. Physical limitations have made it difficult to place a burner control thermocouple to measure the conditions at the nozzle discharge. Several attempts have been made to position a thermocouple for more accurate and immediate indication of flame condition. These attempts have proven unsatisfactory. For future work, this thermocouple placement must be incorporated into the initial job plan.

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9. Reported by:

Hotwork Management Incident Investigation Team

Compiled by: Kari Evely – Safety Coordinator

10. Reviewed By:

Thomas C. Graham Jr. – President / CEO

Irwin C. Cobane – Vice President

Lawrence Drake – Operations Manager

Daniel Devera – HPI Industry Manager

Incident Investigation Report

11. Attachments: (Facility Report/Photographs/Medical report)

a. [redacted] Coke Drum Incident (Open Air Thermocouples)
b. Vessel [B] Incident
c. Coke Drum Schematic
d. Hotwork Equipment Layout Sketch
e. Burner Damage Photos (1 & 2)

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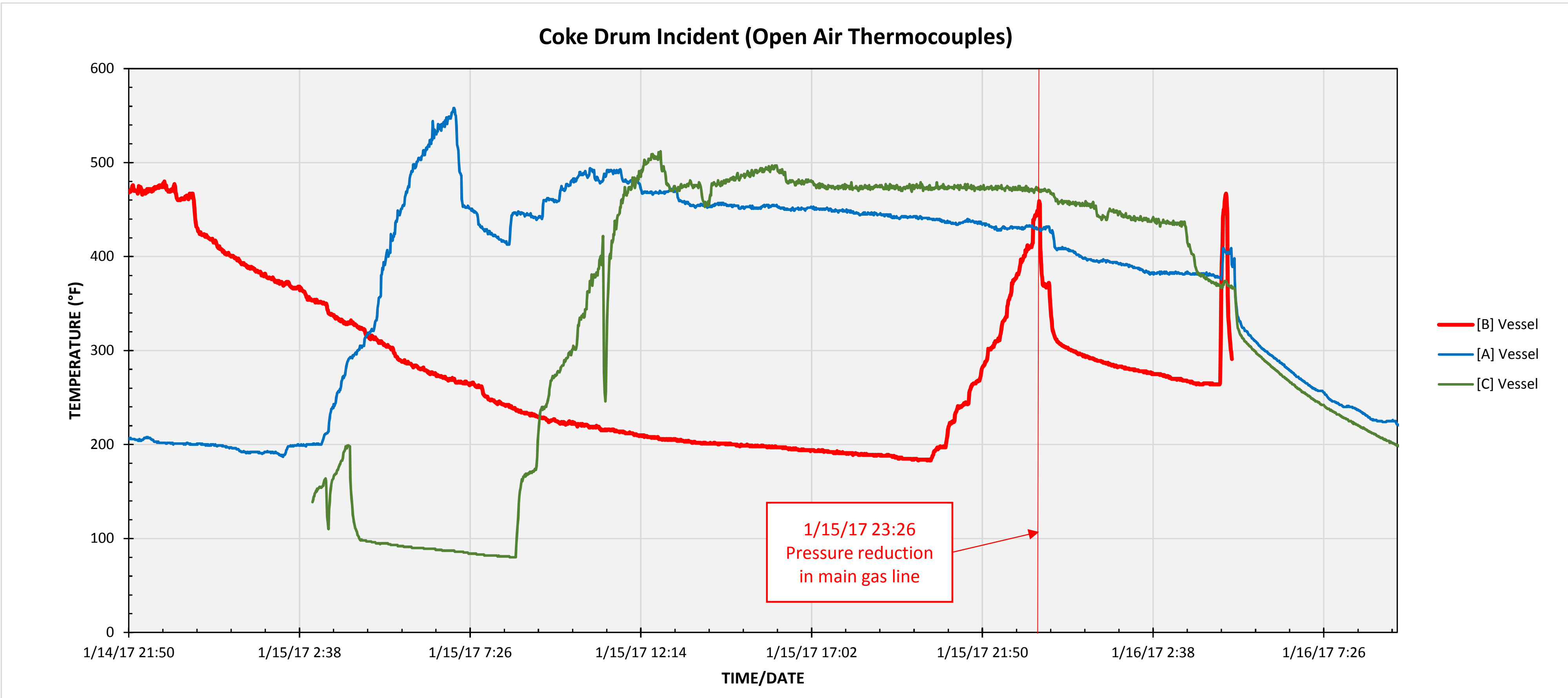
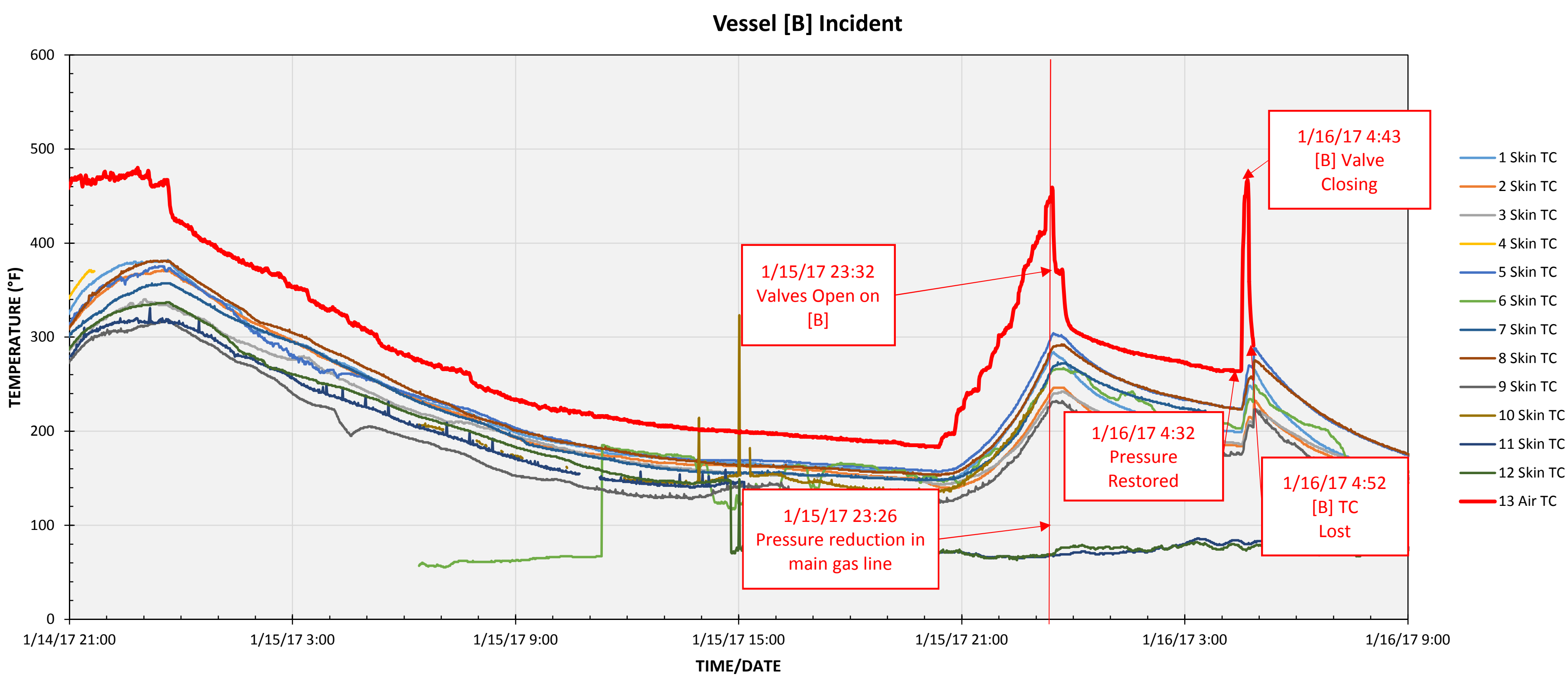
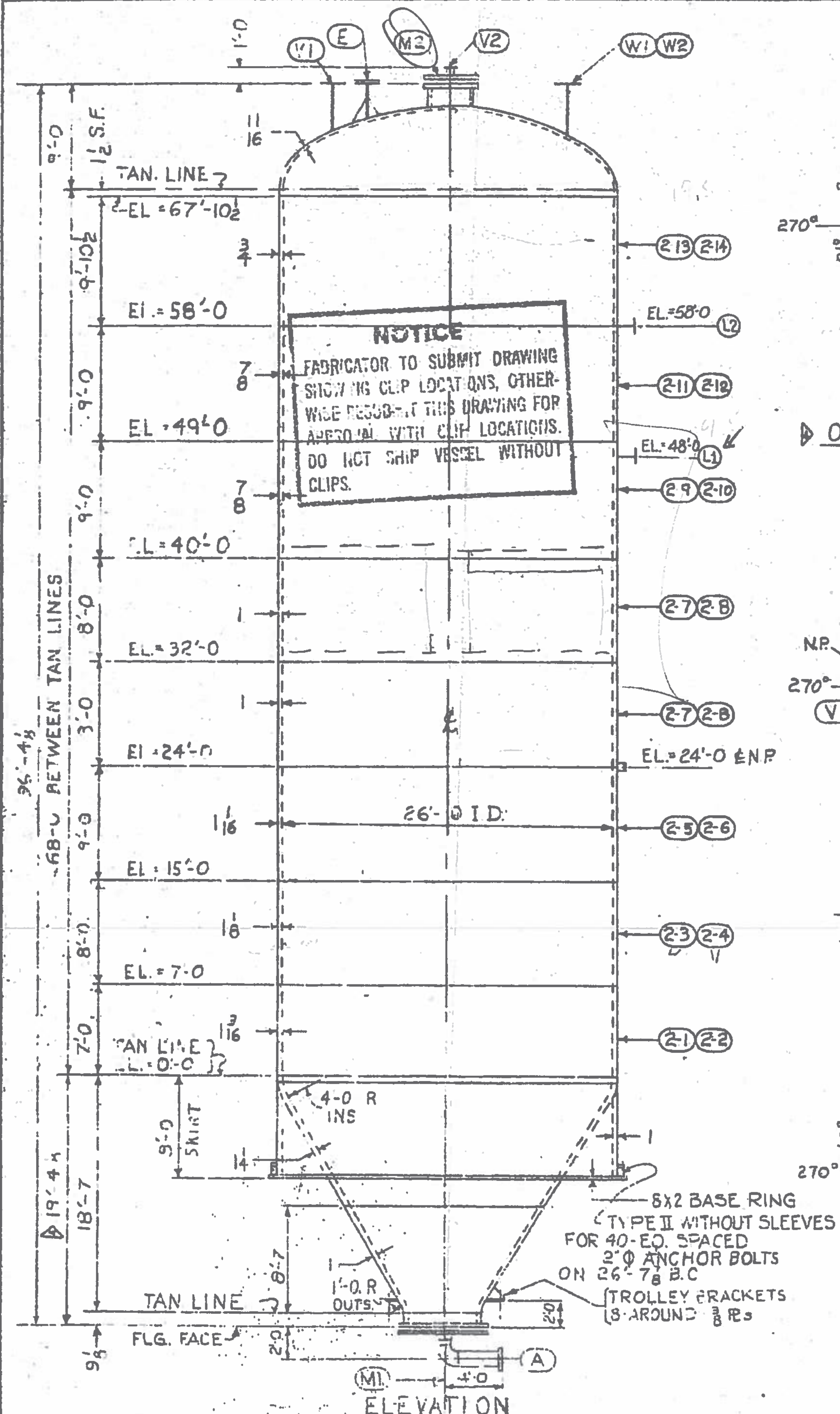
Attachment A

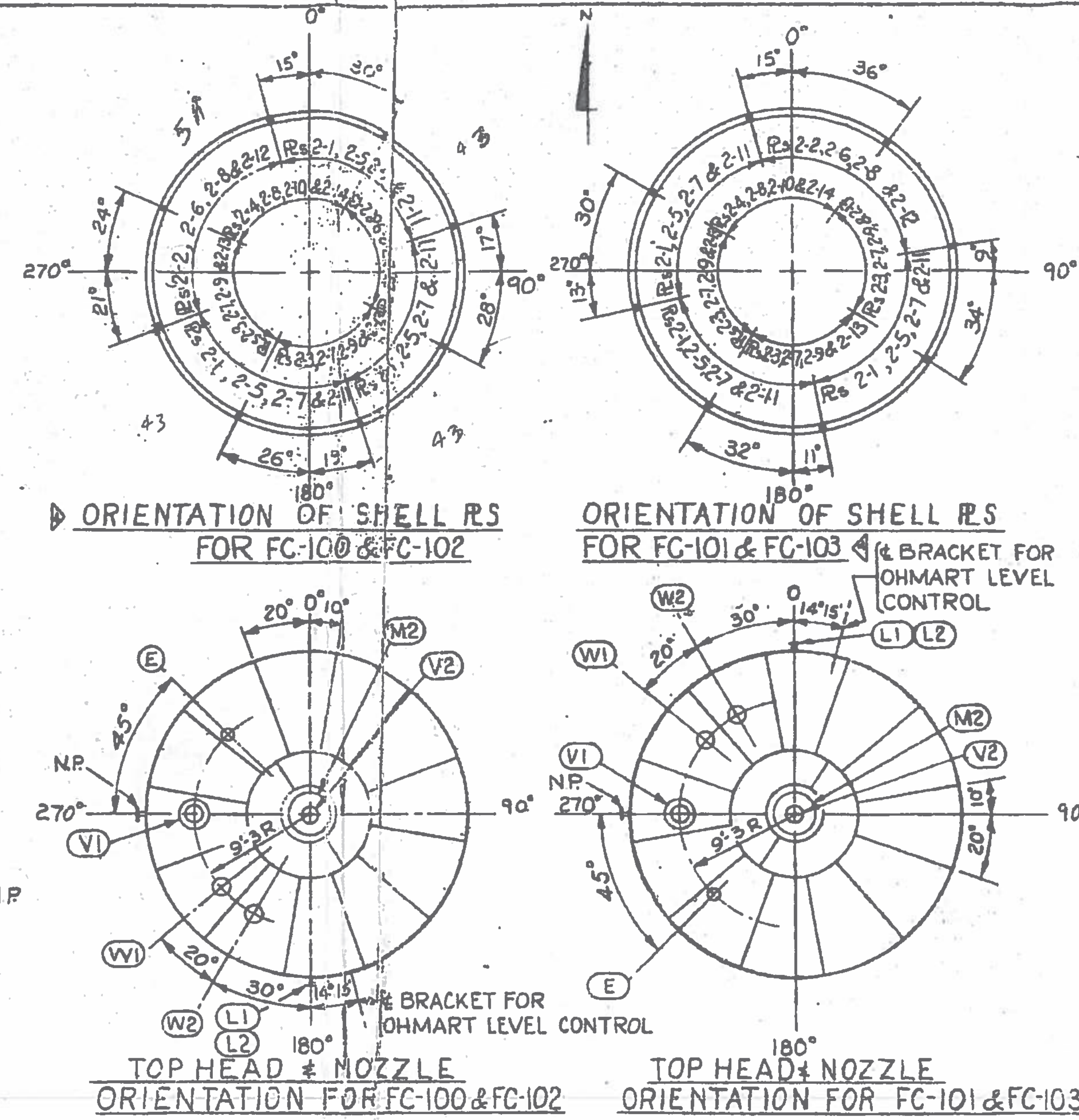


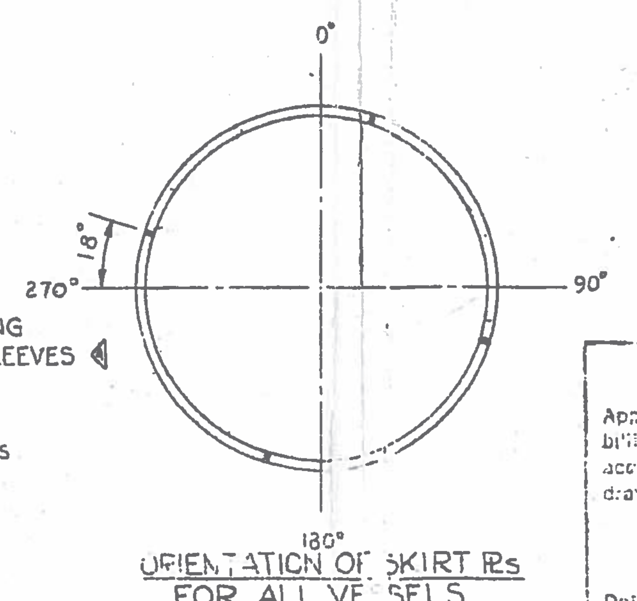
Attachment B



Attachment C







LIST OF FITTINGS (PER VESSEL)

MARK	NO REQD	DESCRIPTION	MATERIAL FLANGE	MATERIAL NECK
M1	1	72" I.D. MANHOLE & COKE OUT (TAYLOR FORGE CLASS 350) M&F	SA-182-F12	
M2	1	42" I.D. MANHOLE (TAYLOR FORGE CLASS 175) SPECIAL M&F	DO	*
A	1	10" 300# R.F. INLET	SA-182-F12	*
E	1	2" 300# R.F. ANTIFOAM	SA-182-F9	SA-335-P9
L1, L2	2	4" 300# R.F. LEVEL CONNS.	DO	
V1	1	18" 300# R.F. VAPOR OUTLET	SA-182-F12	*
V2	1	4" 300# R.F. VENT	SA-182-F9	
W1, W2	2	6" 300# R.F. RELIEF VALVES	SA-182-F12	*

* SAME AS SHELL R

GENERAL NOTES

SPECIFICATIONS: CUSTOMER AND A.S.M.E. CODE
DESIGN PRESSURE: (a) 30 PSIG @ 850°F. @ TOP TANGENT LINE 0.36 PSI/FT STATIC HEAD BELOW TANGENT LINE.

CORROSION ALLOWANCE: SHELL, HEADS, AND NOZZLE NECKS - 0.109 CLAD

VESSEL THICKNESS SHOWN INCLUDE 0.109" CLADDING
MATERIAL: SHELL AND HEADS - SA-263 CLAD W/SA-387-B FBX ANNEALED, 7/64" (MIN.) TYPE 410S CLAD
SKIRT - SA-387-B
BASE PLATE & ASSM. - SA-283-C
GASKETS - SPIRAL TYPE 304 STAINLESS W/ASBESTOS 1/8" THK & C.S. CTR.RING
BOLTS & NUTS - EXTERNAL - A193-B7 & A194-2H

VIII

WELD ROD - AUTOMATIC - 1¼CR., ½% Mo. W/LINDE 80 FLUX
- MANUAL - E8018 B2
- OVERLAY - INCO "A" AND/OR INCO 92

used Inco 182 overlay when required

PICKLE AND PAINT: NONE REQUIRED
JOINT EFFICIENCY: HEADS AND SHELL - 100%
PWHT: YES
RADIOGRAPHING: 100% - BACKING MATERIAL
SPOT - SEAM OVERLAY
INSPECTION: MILL - CERTIFIED TEST REPORTS
SHOP - A.S.M.E. AND CUSTOMER
FIELD - A.S.M.E. AND CUSTOMER
CODE STAMPED: YES
HYDROSTATIC TEST PRESSURE: 93 PSIG @ TOP HEAD NEW & COLD

TABLE OF ARCS

ELEV.	ANGLE	ARC ON OUTS.
0'-0	15°	3'-5⅝
49'-0	14° 15'	3'-3
68'-0	10°	2'-3⅜
	30°	6'-10 1/16
	45°	10'-3 1/16

APPROVED:

Approval does not relieve the fabricator of responsibility for compliance to the Codes, Specifications, accuracy of shop dimensions and fluor engineering drawings which are part of the Purchase Order.

THE FLUOR CORPORATION, LTD.
Los Angeles, California

Date SEP 2 1966 By [signature]

THE FLUOR CORP., LTD.
4224-4-101-1-4
ITEM FC-100 - 103
SEP 30 1966
V-895, V-896, V-897, V-898
ALL MATL BILLED FOR 1 - 4 REQD.

5	3-23-67	RCI	TEST PRESSURE
4	6-21-66	JHJ	CORRECT DIM. & NOTATION
3	5-20-66	JHJ	NOZZ. ORIEN. TROLLEY BASE R
2	[illegible]	LCM	LIST OF FITTINGS DESIGN PRESS.
1	[illegible]	LCM	[illegible]
NO.	DATE	BY	REMARKS

CHICAGO BRIDGE & IRON COMPANY
CHICAGO, ILL

GENERAL PLAN
4-COKE DRUMS (FC-100, 101, 102, 103)
26'-0 I.D. × 68'-0 T.L.
THE FLUOR CORP. LTD. TEXACO INC
WILMINGTON, CALIFORNIA
PURCHASER'S NO. 4224-4-101
DRAWN BY RG DATE 2-2-66
CHECKED BY ESL DATE 2-3-66
E. S. [illegible]NSKI
ENGINEERING SUPERVISOR
9-2554

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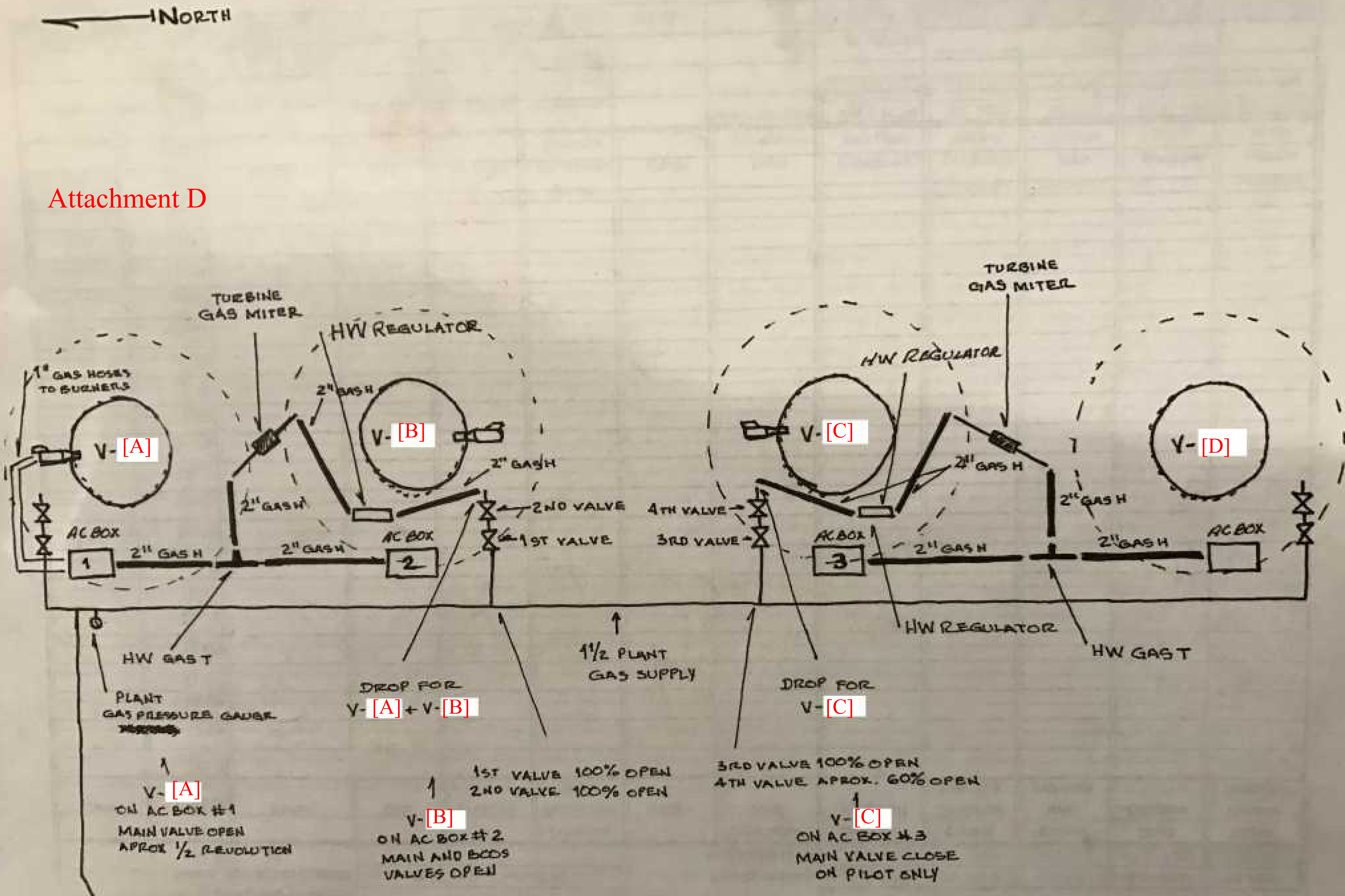
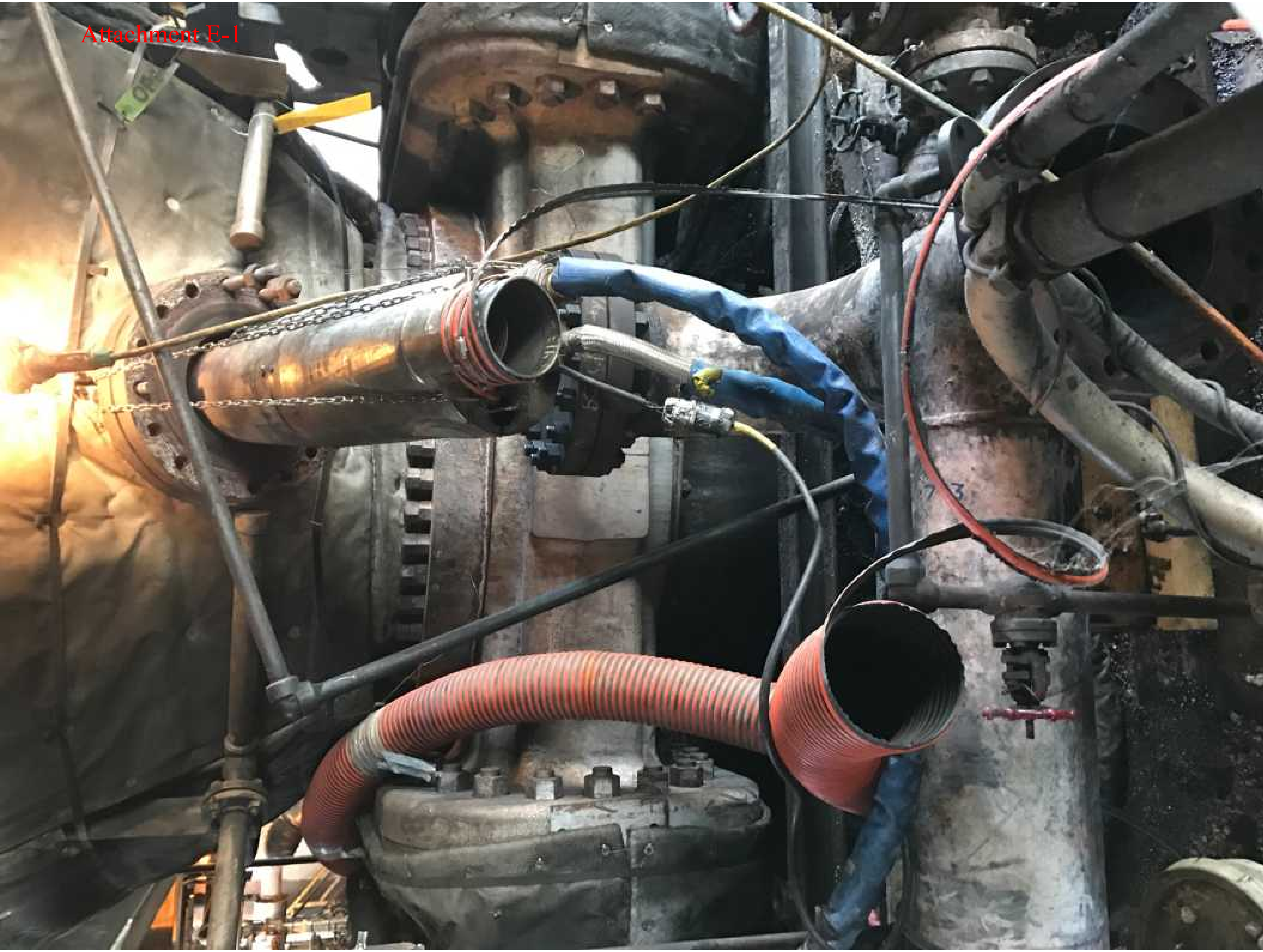
Attachment D



Attachment E-1



Attachment E-2