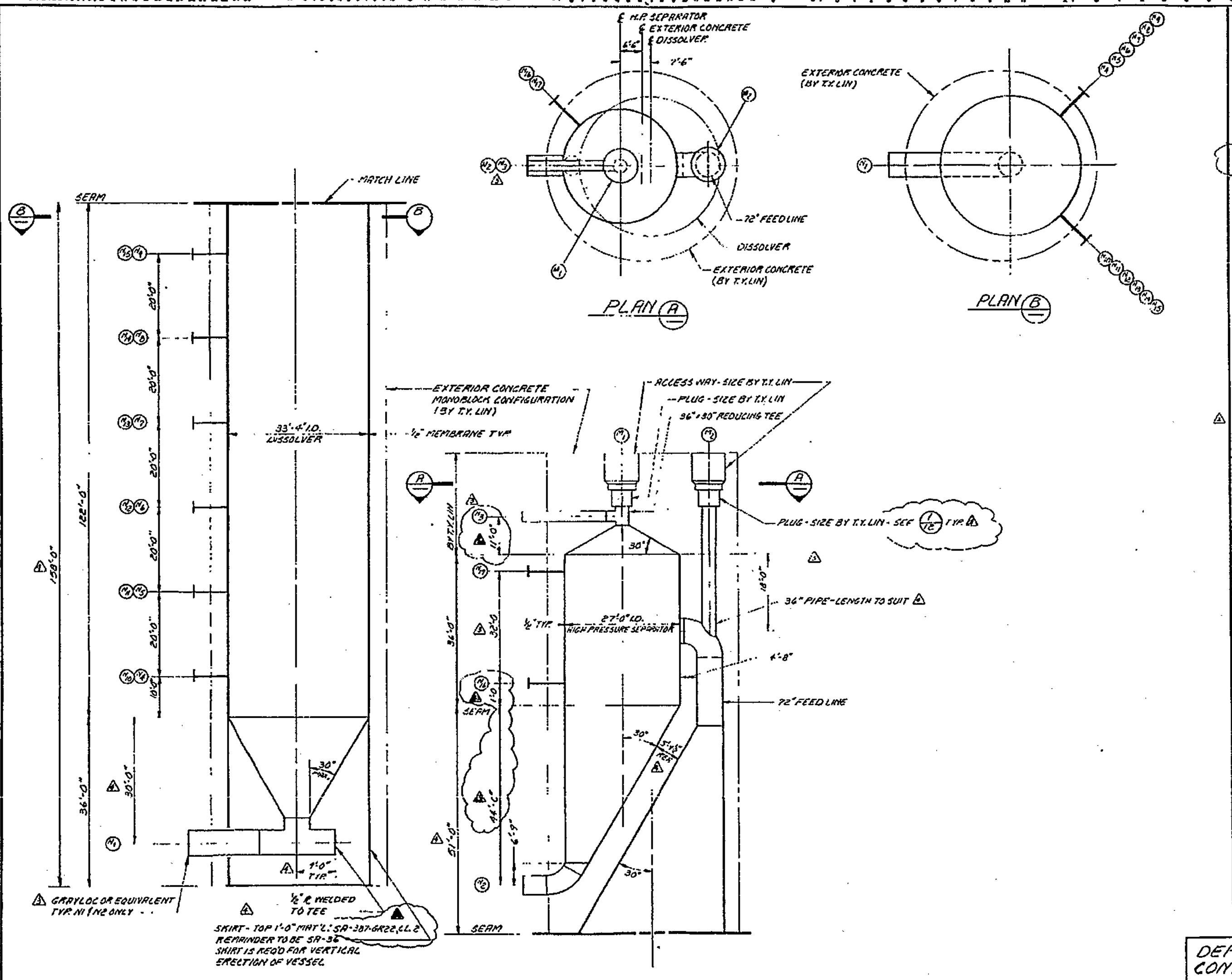
Allowable confined state local compressive stress	= 3,500 psi
Allowable confined state local tensile stress (adequately reinforced)	= 3,000 psi

These stresses are to be based on elastic analyses of the uncracked section. An elastic stress of 3000 psi will actually be much lower if cracking is considered. These values are believed to be conservative and may be modified upward after further studies. The design stress criteria for the PCPV can therefore be grossly different from values currently used for other pressure structures, but the basic considerations of safety and proper behavior will remain unchanged.

6.4.3 FAILURE CHARACTERISTICS OF A PCPV

One of the advantages of using prestressed concrete in the construction of a high pressure vessel is its benign failure characteristics, in that it will not rupture in an explosive manner when subjected to excessive internal pressure. Long before the circumferential prestressing tendons reach their breaking point, the concrete shell will crack and permit the escape and relief of the excessive inside pressure. To some extent, this advantage may be inhibited by the steel liner around the inner surface of the PCPV. For the excessive pressure to be relieved, it is also necessary for the steel liner to fail before the circumferential prestressing tendons do.



NOTES

1. REFER TO THE OAK RIDGE NATIONAL LABORATORY REPORT BY W. L. SHELLSTREET ET AL., "FEASIBILITY STUDY ON PRESTRESSED CONCRETE PRESSURE VESSELS FOR COAL GASIFIERS", FEBRUARY 1977, FOR GENERAL ACCESSWAY AND PLUG DESIGN GUIDE LINES.

2. PROVIDE ELEVATOR TO TOP OF DISSOLVER-SEPARATOR FOR INSPECTION AND DAVITS AROUND THE CIRCUMFERENCE FOR MAINTENANCE.

3. MATERIALS:
SHELL MEMBRANE, HEAD MEMBRANE, FLANGES, NOZZLE NECKS 24" AND LARGER TO BE SA-387 GR22 CLASS 2 (2 1/4 CR 1 MO) W/ .109" SB-409-800H (INCOLOY 800) CLADDING. PIPING AND FLANGES LESS THAN 24" SHALL BE SOLID SB-409-800H (INCOLOY 800).

Figure 6-1

ITEM	NO. REQ'D	SIZE	RATING	FACING	SERVICE
COOLING WATER	[illegible]		1500#	RF	
N6-N7	2	3"	1500#	RJ	LEVEL INDICATORS
N10-N15	6	3"	2500#	RJ	THERMOCOUPLES
N4-N9	6	3"	2500#	RJ	PRESSURE INDICATOR
N3	1	30"	WELD STUB		VAPOR OUTLET
N2	1	24"	SPECIAL		SLURRY OUTLET
N1	1	72"	SPECIAL		FEED INLET
M1, M2	2	36"	SPECIAL DESIGN		MANHOLE

NOZZLES AND COUPLINGS

~~RADIAL NOZZLE AND MANHOLE PROJECTIONS FROM O.D. OF VESSEL TO EXTREME FACE OF FLANGE:~~

SIZE	PROJECTION	SIZE	PROJECTION
~~THRU 4"~~	~~6"~~	~~6", 8" AND 10"~~	~~8"~~
~~12", 14", 16", 18" AND 20"~~	~~10"~~	~~24"~~	~~12"~~

~~EXCEPT FOR INTEGRAL-REINFORCED NOZZLES, OR AS NOTED.~~

DESIGN DATA

1. OPERATING PRESSURE AT 850 °F 2025 PSIG
2. DESIGN PRESSURE AT 875 °F 2228 PSIG
3. PRESSURE NEW CLD. BY ___ AT ___ °F ___ PSIG
4. CORROSION ALLOWANCE MEMBRANE 1/16" HEADS 1/16"
5. CODE DESIGN & CONSTRUCTION PER CERTAIN PROVISIONS OF ASME SECTION III, DIV. 2 & DESIGN CRITERIA
6. CODE CERTIFICATES REQ'D NO CODE STAMP NO
7. PWHT NONE X-RAYED NO
8. ALL STRESS AT DESIGN TEMP. JT. EFF. SHELL ___
9. HYDROTEST AT 3342 PSIG HEADS ___
10. MATERIALS:
    - SHELL MEMBRANE SEE NOTE 3
    - HEAD MEMBRANE SEE NOTE 3
    - SUPPORT CONCRETE
    - CONCRETE LATER
    - BOLTS (EXTERNAL) SA-193-B7 NUTS SA-194-2H
    - FLANGES SEE NOTE 3 CPLGS. —
    - NOZZLE NECKS SEE NOTE 3
    - GASKETS 304 S.S. - RING JOINT
11. CAPACITY
12. FABRICATION WEIGHT (EXCLUDING TRAYS)
13. TRAYS, CAPS, AND RISERS, WEIGHT
14. EMPTY WEIGHT
15. OPERATING WEIGHT
16. TEST WEIGHT
17. PAINT NOT APPLICABLE (N.A.)
18. INSULATION N.A.
19. FIREPROOFING N.A.
20. ACCESSORIES SUPPLIED & INSTALLED BY FABRICATOR:
    - VESSEL DAVIT N.A. MARK NO. —
    - LADDER AND PLATFORM CLIPS N.A.
    - PIPE SUPPORT AND PIPE GUIDE CLIPS N.A.
    - INSULATION SUPPORTS N.A.
    - FIREPROOFING SUPPORTS N.A.
21. [redacted]
22. ALL DIMENSIONS ARE FROM BOTTOM HEAD TANGENT LINE EXCEPT AS SHOWN.
23. BOLT HOLES SHALL STRADDLE CENTER LINES EXCEPT AS NOTED.
24. NOZZLES, MANHOLES AND TRAYS SHALL HAVE THE SAME DESIGNATION AS SHOWN ON THIS DRAWING.
25. VESSEL SHALL BE THOROUGHLY CLEANED INSIDE AND OUTSIDE, AND FREE FROM RUST, SLAG, SCALE, WELD SPATTER AND FOREIGN MATTER.

DEPARTMENT OF ENERGY
CONTRACT NO. EX-76-C-01-1775

REFERENCES DRAWING NO.	DESCRIPTION
D-01-VS-12	C.C.D.-S.V. PLUG DET.
D-01-VS-11	C.C.D.-S.V. DETAILS

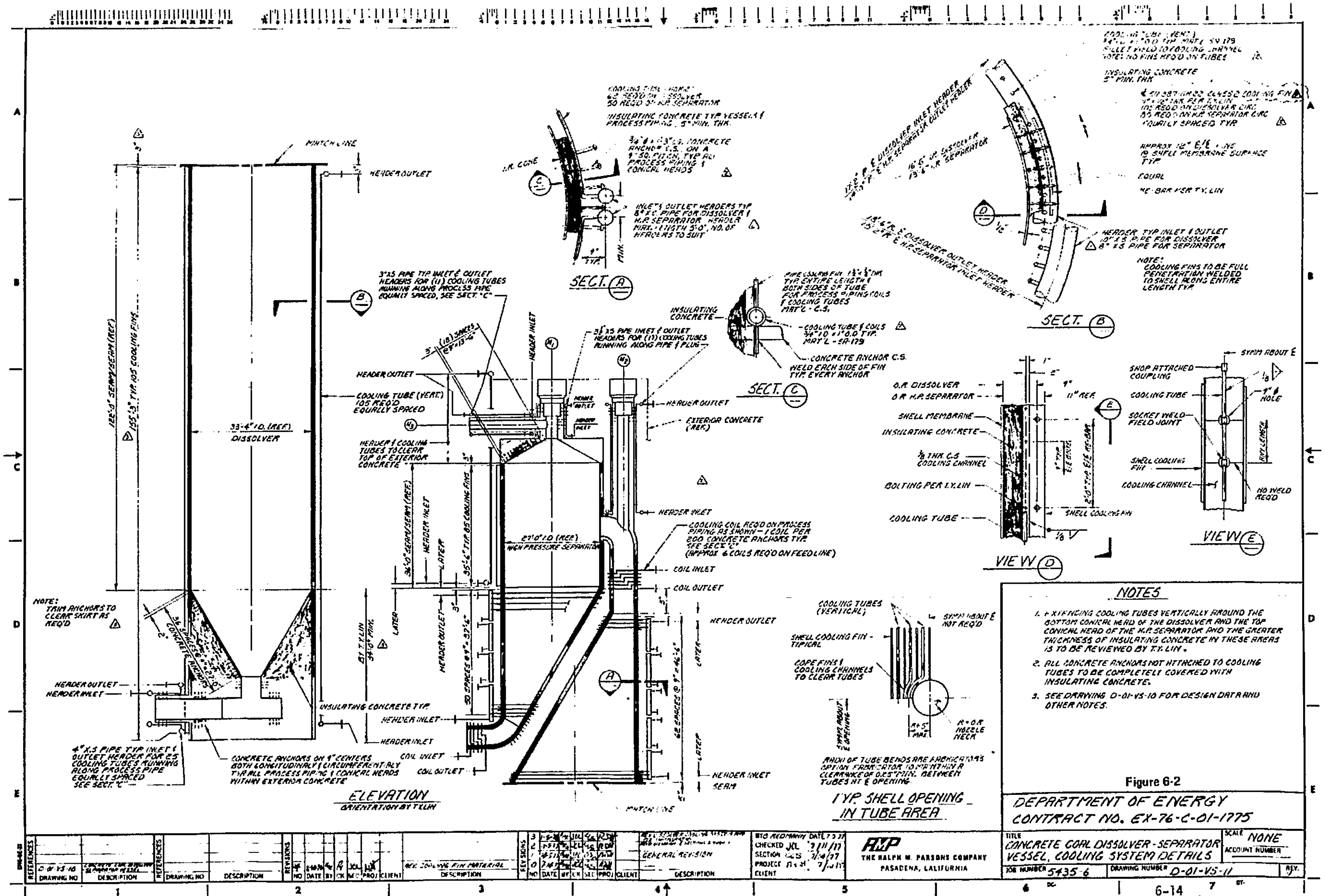
NO.	DATE	BY	CK.	SEC.	PROJ.	CLIENT	DESCRIPTION
5	3-14-78	[illegible]	[illegible]	[illegible]	[illegible]		ADD. N16 & 3 PLCS., REV. N1, N2, N3, N7, REV. & MATERIAL
4	1-6-78	[illegible]	[illegible]	CCS	1200	5-98	ADD. SKIRT, NOTE 2, REV. EL. & N2
3	11-3-77	[illegible]	[illegible]	CCS	[illegible]		[illegible] DELETED [illegible] ADD. NOTE 1
2	8-5-77	[illegible]	[illegible]	CCS	[illegible]		GENERAL REVISION
1	7-14-77	[illegible]	[illegible]	CCS	[illegible]		GEN. REV.; COMPLETELY REDRAWN
0		[illegible]	[illegible]	CCS	[illegible]		

BY B. REDMANN	DATE 7/4/77
CHECKED [illegible]	7-14-77
SECTION CS	7-14-77
PROJECT [illegible]	7/14/77
CLIENT	

RMP
THE RALPH M. PARSONS COMPANY
PASADENA CALIFORNIA

TITLE CONCRETE COAL DISSOLVER-SEPARATOR VESSEL (ELEVATION & PLAN)
SCALE NONE
ACCOUNT NUMBER
JOB NUMBER 5435-6
DRAWING NUMBER D-01-VS-10
REV. 5

ENG-VS-106



NOTES

1. EXTENDING COOLING TUBES VERTICALLY AROUND THE BOTTOM CONICAL HEAD OF THE DISSOLVER AND THE TOP CONICAL HEAD OF THE H.P. SEPARATOR AND THE GREATER THICKNESS OF INSULATING CONCRETE IN THESE AREAS IS TO BE REVIEWED BY T.Y. LIN.
2. ALL CONCRETE ANCHORS NOT ATTACHED TO COOLING TUBES TO BE COMPLETELY COVERED WITH INSULATING CONCRETE.
3. SEE DRAWING D-01-VS-10 FOR DESIGN DATA AND OTHER NOTES.

Figure 6-2

DEPARTMENT OF ENERGY
CONTRACT NO. EX-76-C-01-1775

REFERENCES	
DRAWING NO	DESCRIPTION
D-01-VS-10	CONCRETE COAL DISSOLVER SEPARATOR VESSEL

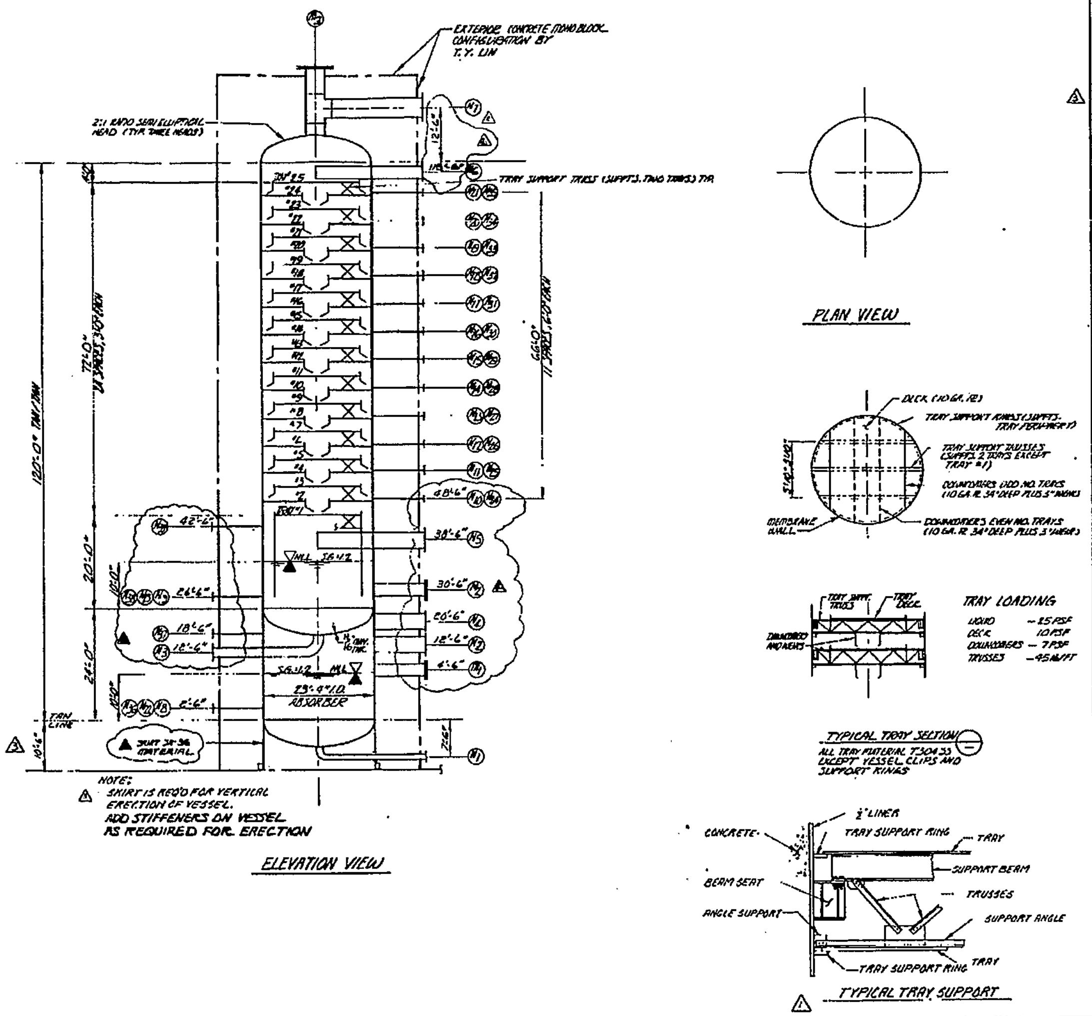
REVISIONS							
NO	DATE	BY	CK	SEC	PROJ	CLIENT	DESCRIPTION
3	[illegible]						[illegible]
2	[illegible]						[illegible]
1	[illegible]						GENERAL REVISION
0	[illegible]						REV. COOLING FIN MATERIAL

DRAWN	REDMANN	DATE 7-7-77
CHECKED	JCL	7/11/77
SECTION	CGS	7/14/77
PROJECT	[illegible]	7/14/77
CLIENT		

RMP
THE RALPH M. PARSONS COMPANY
PASADENA, CALIFORNIA

TITLE CONCRETE COAL DISSOLVER - SEPARATOR VESSEL, COOLING SYSTEM DETAILS
SCALE NONE
ACCOUNT NUMBER
JOB NUMBER 5435-6
DRAWING NUMBER D-01-VS-11
REV.

6-14



NOTES

1. VESSEL STEEL MEMBRANE & MIL 1/2" THICK MINIMUM
2. APPLY INSULATING CONCRETE, 1/2" MIN., 1" MAX. THK., TO THE EXTERIOR OF THE VESSEL MEMBRANE AND ALL PROCESS PIPING CONTAINED BY THE MONOBLOCK.
3. PROVIDE ELEVATOR TO TOP OF ABSORBER FOR INSPECTION AND DAVITS AROUND THE CIRCUMFERENCE FOR MAINTENANCE.

Figure 6-3

ITEM	NO. REQ'D	SIZE	RATING	FACING	SERVICE
M3	1	42"	SPECIAL	RJ	MANHOLE
M1, M2	2	24"	600#	RJ	MANHOLES
[illegible]	4	1"	600#	RJ	LEVEL INDICATORS
[illegible]	16	1"			PRESSURE INDICATORS
[illegible]	14	1"			TEMPERATURE CONN.
N7	1	[illegible]			GAS OUT
N6	1	[illegible]			LIQUID IN
N5	1	[illegible]			GAS IN
N4	1	[illegible]			GAS OUT
N3	1	[illegible]			LIQUID IN
N2	1	32"			GAS IN
N1	1	10"	600#	RJ	DRAIN OUT

NOZZLES AND COUPLINGS

~~RADIAL NOZZLE AND MANHOLE PROJECTIONS FROM O.D. OF VESSEL TO EXTREME FACE OF FLANGE~~

SIZE	PROJECTION	SIZE	PROJECTION
~~THRU. 4"~~	~~6"~~	~~6", 8" AND 10"~~	~~8"~~
~~12", 14", 16", 18" AND 20"~~	~~10"~~	~~24"~~	~~12"~~

~~EXCEPT FOR INTEGRAL-REINFORCED NOZZLES, OR AS NOTED.~~

DESIGN DATA

1. OPERATING PRESSURE AT 150 °F. 1075 PSIG
2. DESIGN PRESSURE AT 175 °F. 1183 PSIG
   DESIGN INTERMEDIATE HEAD FOR 50 PSIG ΔP
3. PRESSURE NEW LTD. BY — AT — °F — PSIG
4. CORROSION ALLOWANCE: SHELL 1/8" HEADS 1/8"
5. CODE DESIGN AND CONSTRUCTION TO CERTAIN PROVISIONS OF ASME SECTION III, DIV 2, AND DESIGN CRITERIA
6. CODE CERTIFICATES REQ'D NO CODE STAMP NO
7. PWHT YES X-RAYED NO
8. ALL STRESS AT DESIGN TEMP. — JT. EFF. SHELL —
9. HYDROTEST AT 1775 PSIG ([redacted] HEADS —
10. MATERIALS: CONCRETE
    MEMBRANE SHELL SA-516-70
    MEMBRANE HEAD SA-516-70
    SUPPORT CONCRETE
    TRAYS AND TRUSSES SA-240-304 SS
    BOLTS (EXTERNAL) SA-193-B7 NUTS SA-194-2H
    FLANGES SA-105-1 CPLGS. —
    NOZZLE NECKS SA-53-B OR SA-106-B
    GASKETS 304 S.S. RING JOINT
11. CAPACITY —
12. FABRICATION WEIGHT (EXCLUDING TRAYS) —
13. TRAYS, CAPS, AND RISERS, WEIGHT —
14. EMPTY WEIGHT —
15. OPERATING WEIGHT —
16. TEST WEIGHT —
17. PAINT NOT APPLICABLE (NA)
18. INSULATION N.A.
19. FIREPROOFING N.A.
20. ACCESSORIES SUPPLIED & INSTALLED BY FABRICATOR:
    VESSEL DAVIT N.A. MARK NO. —
    LADDER AND PLATFORM CLIPS N.A.
    PIPE SUPPORT AND PIPE GUIDE CLIPS N.A.
    INSULATION SUPPORTS N.A.
    FIREPROOFING SUPPORTS N.A.
21. ALL TRAY ELEVATIONS ARE TO TOP OF TRAY SUPPORT RING.
22. ALL DIMENSIONS ARE FROM BOTTOM HEAD TANGENT LINE EXCEPT AS SHOWN.
23. BOLT HOLES SHALL STRADDLE CENTER LINES EXCEPT AS NOTED.
24. NOZZLES, MANHOLES AND TRAYS SHALL HAVE THE SAME DESIGNATION AS SHOWN ON THIS DRAWING.
25. VESSEL SHALL BE THOROUGHLY CLEANED INSIDE AND OUTSIDE, AND FREE FROM RUST, SLAG, SCALE, WELD SPATTER AND FOREIGN MATTER.

DEPARTMENT OF ENERGY
CONTRACT NO. EX-76-C-01-1775

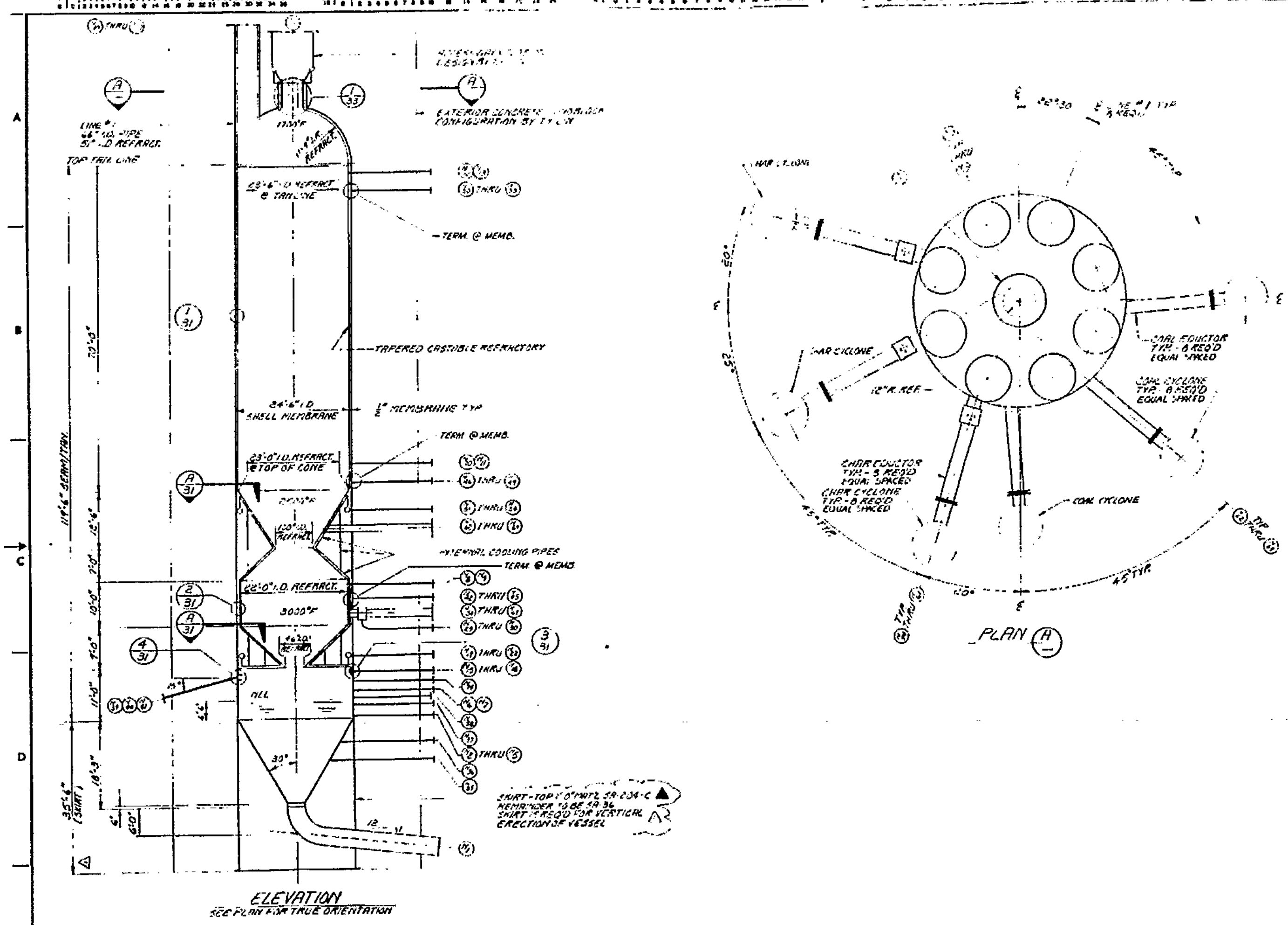
BY	JFL	DATE 7/7/77
CHECKED	CLS	7/7/77
SECTION	CLS	7/7/77
PROJECT	LFL	[illegible]
CLIENT		

RMP
THE RALPH M. PARSONS COMPANY
PASADENA, CALIFORNIA

TITLE CONCRETE COAL ABSORBER
SCALE NONE
ACCOUNT NUMBER
JOB NUMBER 5435-G
DRAWING NUMBER D-01-VS-20
REV. 4

NO.	DATE	BY	CK	SEC	PROJ	CLIENT	DESCRIPTION
4	[illegible]						[illegible]
3	[illegible]						[illegible]
2	[illegible]						[illegible]
1	[illegible]						ADD TRAY SUPPT DETAIL
0	[illegible]						[illegible]

ENG-VS-205



SCHEDULE OF CONNECTIONS

ITEM	NO.	SIZE	SERVICE	REFERENCE
N2-N?	1	[illegible]	GAS OUTLET	STUB END
N62-N69	8	4"	COAL CYCLONE CONN	
N54-N61	8	20"	CHAR CYCLONE CONN	
N42-N53	2	2"	THERMOWELLS	
N41	1	4"	OIL BURNER	
N40	1	6"	VIDEO SCANNER	
N39	1	6"	OPTICAL PYROMETER	
N35-N38	4	2"	LEVEL CONN	
N31-N34	4	10"	COOLING WATER OUTLET	
N23-N30	8	16"	OXYGEN INLET	CHAR EDUCTOR
N19-N22	4	10"	COOLING WATER INLET	
N15-N18	4	4"	CASCADE WATER INLET	
N14	1	6"	PURGE GAS INLET	
N6-N13	8	2"	PRESSURE TAP	
N2-N5	4	8"	QUENCH WATER INLET	
N1	1	48"	SLAG SLURRY OUTLET	STUB END

FLANGE RATING AND FACING
900# RING JOINT

DESIGN DATA

1. OPERATING PRESSURE AT (STEEL) 475 °F 1091 PSIG
2. DESIGN PRESSURE AT (STEEL) 500 °F 1200 PSIG
3. PRESSURE NEW LTD. BY — AT — °F PSIG
4. CORROSION ALLOWANCE: SHELL 1/16" HEADS 1/16"
5. CODE DES. & CONSTRUCTION TO CERTAIN PROVISIONS OF ASME SECT III, DIV 2 & DESIGN CRITERIA
6. CODE CERTIFICATES REQ'D NO CODE STAMP NO
7. PWHT NONE X-RAYED NO
8. ALL STRESS AT DESIGN TEMP JT. EFF SHELL
9. PRESSURE TEST AT 1500 PSIG HEADS
10. MATERIALS
    - SHELL MEMBRANE SA-204-C
    - HEAD MEMBRANE SA-204-C
    - SUPPORT CONCRETE
    - TRAYS
    - BOLTS (EXTERNAL) SA-193-B16 NUTS SA-194-CH
    - FLANGES SA-336-CL-F1 CPLGS —
    - NOZZLE-NECKS SA-335-P1 EXCEPT AS NOTED
    - GASKETS 304 SS RING JOINT

NOTES

1. SEE DRAWING D-01-VS-31 FOR DETAILS AND NOTES REGARDING INTERNAL COOLING, REFRACTORY LININGS AND REFRACTORY ANCHORS.
2. SEE DRAWINGS D-01-VS-32 & D-01-VS-33 FOR DETAILS AND NOTES REGARDING GASIFIER'S EXTERNAL COOLING SYSTEM AND GENERAL PLUG CONFIGURATION.
3. ALL MEMBRANE AND INTERNAL THICKNESSES TO BE 1/2" MINIMUM EXCEPT AS NOTED.
4. PROVIDE ELEVATOR TO TOP OF GASIFIER FOR INSPECTION AND DAVITS AROUND THE CIRCUMFERENCE FOR MAINTENANCE.

REFERENCES DRAWING NO	DESCRIPTION
D-01-VS-33	[illegible]
D-01-VS-32	[illegible]
D-01-VS-31	[illegible]

BY J. [illegible] DATE 12/1/77
CHECKED JCL 12/12/77
SECTION CLG 12/12/77
PROJECT EDW 12/12/77
CLIENT

RMP
THE RALPH M. PARSONS COMPANY
PASADENA, CALIFORNIA

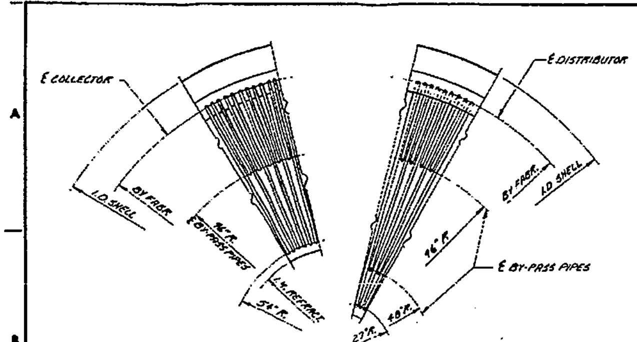
Figure 6-4

DEPARTMENT OF ENERGY
CONTRACT NO. EX-76-C-01-1775

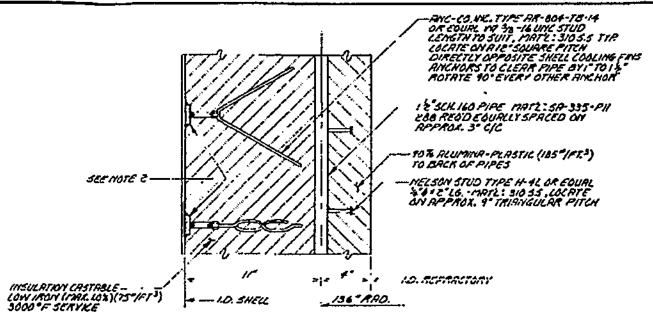
TITLE CONCRETE COAL GASIFIER ELEVATION & ORIENTATION
SCALE NONE
ACCOUNT NUMBER
JOB NUMBER 5435-6
DRAWING NUMBER D-01-VS-30
REV. 3

6-16 (A)

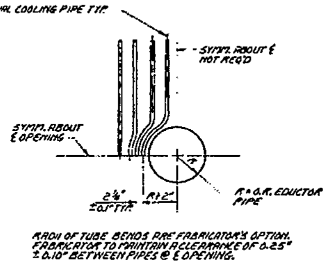
6-16



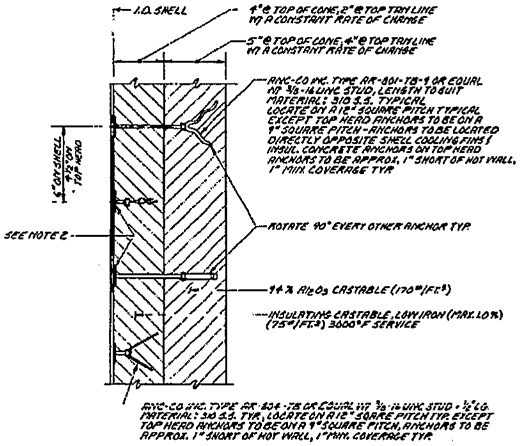
SECTION (A/31) REF. 30



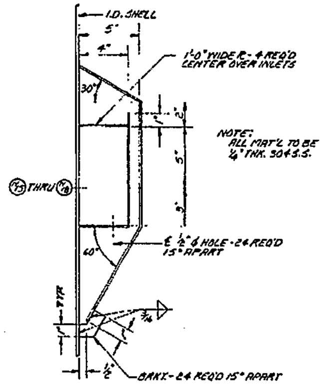
DETAIL (2/31) REF. 30



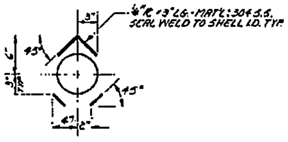
TYP. OPENING IN INTERNAL COOLING PIPE AREA



DETAIL (1/31) REF. 30



DETAIL (3/31) REF. 30



DETAIL (4/31) REF. 30
TYP. N39, N40 & N41

NOTES

1. REFRACTORY ANCHORS ON LINE NO. 1 AND MANHOLE "M1" TO BE ANC-CO. INC. TYPE AR-801-TB OR EQUAL WITH 3/8-16 UNC STUDS (LENGTH TO SUIT) AND ANCHOR BASES (SEE NOTE 2). MATERIAL - 310 STAINLESS STEEL. LOCATE ON A 9" SQUARE PITCH DIRECTLY OPPOSITE INSULATING CONCRETE ANCHORS FOR LINE NO. 1 AND 12" SQUARE PITCH DIRECTLY OPPOSITE SHELL COOLING FINS FOR "M1". REFRACTORY ANCHORS APPROX. 1" SHORT OF HOT WALL. 1" MIN. COVER.
2. REFRACTORY ANCHOR BASES: 1 1/2" O.D. X 3/8" PLATE. MATERIAL - 310 STAINLESS STEEL. WITH A 3/16" FILLET WELD ALL AROUND, DRILL AND TAP FOR ANCHOR STUDS TYPICAL.
3. REFRACTORY MATERIAL: H-W CASTOLAST G, EXCEPT WHERE NOTED.

Figure 6-5

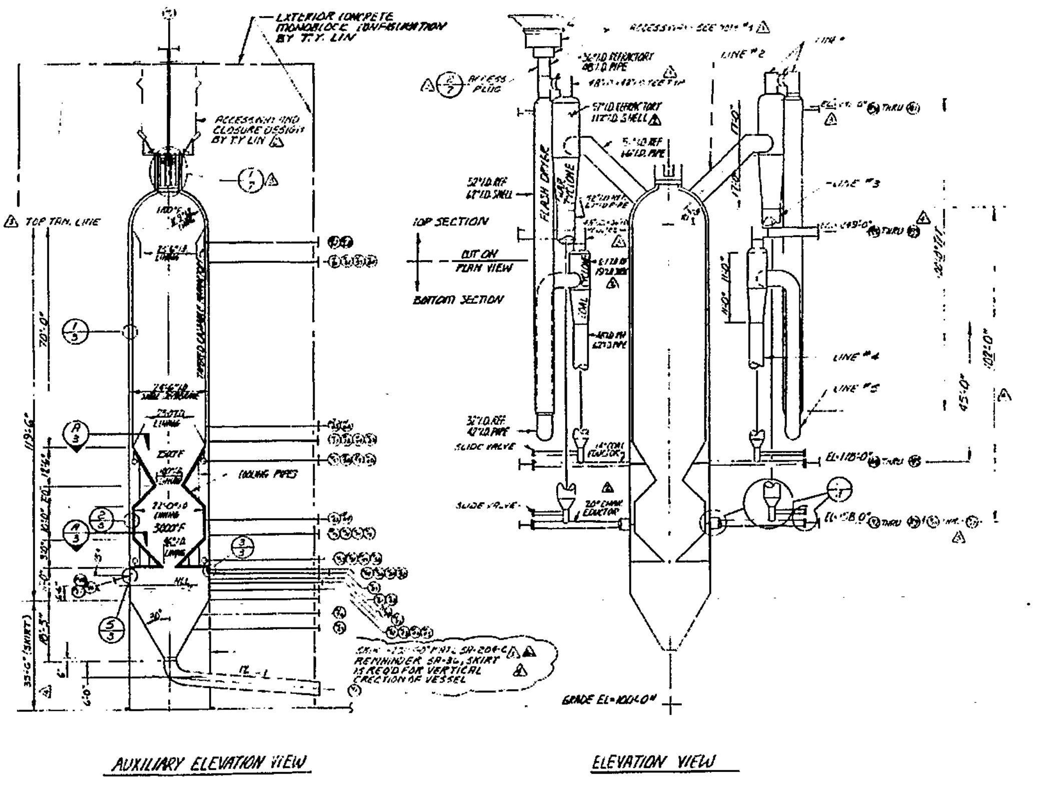
DEPARTMENT OF ENERGY
CONTRACT NO. EX-76-C-01-1775

REFERENCES DRAWING NO.	DESCRIPTION
D-01-VS-33	C.C.G. COOL'G SYS. DET.
D-01-VS-32	C.C.G. COOL'G SYSTEM
D-01-VS-30	C.C.G. ELEV. & ARRGMT.

BY G. REDMANN	DATE 12-9-77	
CHECKED JEL	12/12/77	
SECTION CLS	12/12/77	
PROJECT RDM	12/12/77	
CLIENT		

THE RALPH M. PARSONS COMPANY
PASADENA, CALIFORNIA

TITLE CONCRETE COAL GASIFIER
INTERNAL COOLING & REFRACTORY DET.
SCALE NONE
ACCOUNT NUMBER
JOB NUMBER 5435-6
DRAWING NUMBER D-01-VS-31
REV. 0



AUXILIARY ELEVATION VIEW

ELEVATION VIEW

SCHEDULE OF CONNECTIONS

ITEM	NO	SIZE	SERVICE	REFERENCE
M1		[illegible]	MANHOLE	
EXT. COOLING WATER PIPING [illegible]				D-01-VS-5
N85	1	6"	PURGE GAS INLET	
N73-N84	12	2"	THERMOWELLS	
N69-N72	4	2"	LEVEL CONN	
N61-N68	8	2"	PRESSURE TAP	
N57-N60	4	[illegible]	COOLING WATER OUTLET	
N53-N56	4	3"	COOLING WATER INLET	
N49-N52	4	4"	CASCADE WATER INLET	
N48	1	4"	OIL BURNER	
N47	1	6"	VIDEO SCANNER	
N46	1	6"	OPTICAL PYROMETER	
N42-N45	4	16"	QUENCH WATER INLET	
N34-N41	8	[illegible]	COAL SLURRY INLET	
N26-N33	8	36"I.D.	COAL GAS OUTLET	
N18-N25	8	6"	STEAM INLET	CHAR EDUCTOR
N10-17	8	6"	OXYGEN INLET	
N2-N9	8	8"	STEAM INLET	COAL EDUCTOR
N1	1	48"	SLAG SLURRY OUTLET	STUB END

FOR ORIENTATION SEE DWG

FLANGE RATING AND FACING
900# RING JOINT

DESIGN DATA

1. OPERATING PRESSURE AT (WALL) 475 °F 1091 PSIG
2. DESIGN PRESSURE AT (STEEL) 500 °F 1200 PSIG
3. PRESSURE NEW LTD BY — AT — °F — PSIG
4. CORROSION ALLOWANCE SHELL — HEADS —
5. CODE DESIGN AND CONSTRUCTION TO PERTINENT PROVISIONS OF ASME SECTION III, DIV.2 AND DESIGN CRITERIA
6. CODE CERTIFICATES REQ'D NO CODE STAMP NO
7. PWHT NONE XRAYED [illegible]
8. ALL STRESS AT DESIGN TEMP — JT EFF SHELL — HEADS —
9. PRESSURE TEST @ 1400 PSIG
10. MATERIALS:
MEMBRANE SHELL SA 204-C
MEMBRANE HEAD SA-204-C
SUPPORT CONCRETE
CASTABLE SEE DWG D-01-VS-3
BOLTS (EXTERNAL) SA-193-B16 NUTS SA-194-GH
FLANGES SA-336-CL-F1 CPLGS —
NOZZLE-NECKS SA-335-P11 (EXCEPT AS NOTED)
GASKETS 304 S.S. RING JOINT

NOTES

1. SEE DRAWING D-01-VS-3 FOR DETAILS AND NOTES REGARDING THE REFRACTORY LININGS AND ANCHORS.
2. SEE DRAWINGS D-01-VS-4,5 & 6 FOR DETAILS AND NOTES REGARDING THE EXTERNAL COOLING SYSTEM OF THE CONCRETE COAL GASIFICATION SYSTEM.
3. PROVIDE ONE [illegible] I.D. VERTICAL [illegible] FOR VERTICAL CENTERLINE FOR EACH CHAR CYCLONE, COAL CYCLONE AND FLASH DRYER, (8 TOTAL). ACCESS DESIGN BY T.Y. LIN.
4. INTERNAL GAS TEMPERATURES
A. 1600°F FOR FLASH DRYER AND CHAR CYCLONES
B. 600°F FOR COAL CYCLONES
5. ALL MEMBRANE AND INTERNAL THICKNESSES TO BE 1/2" MINIMUM
6. PROVIDE ELEVATOR TO TOP OF GASIFIER FOR INSPECTION AND DAVITS AROUND THE CIRCUMFERENCE FOR MAINTENANCE

Figure 6-6

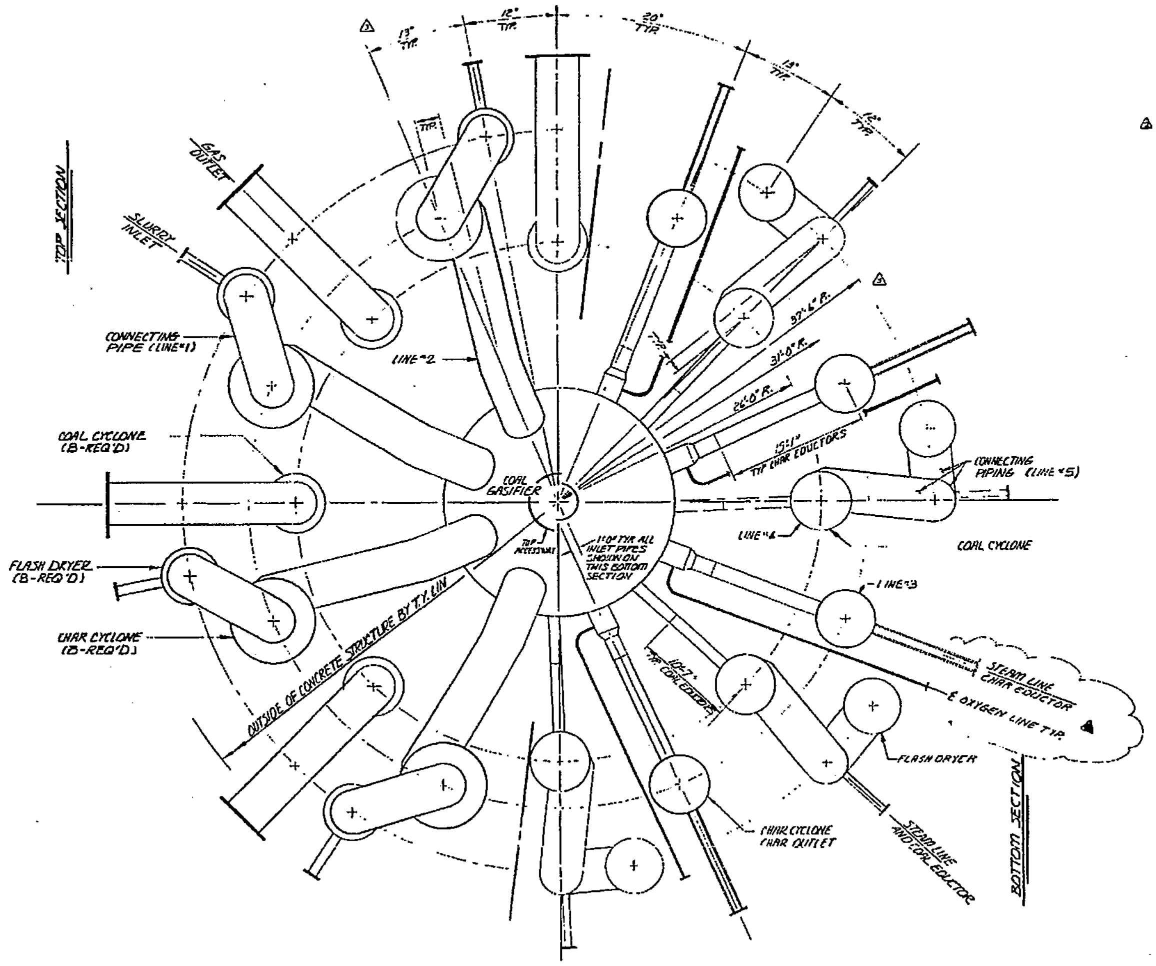
DEPARTMENT OF ENERGY
CONTRACT NO. EX-76-C-01-1775

TITLE CONCRETE COAL GASIFIER VESSEL
ELEVATION VIEW

SCALE NONE
ACCOUNT NUMBER
JOB NUMBER 5455-6
DRAWING NUMBER D-01-VS-1

RPP
THE RALPH M. PARSONS COMPANY
PASADENA, CALIFORNIA

REFERENCES	
DRAWING NO	DESCRIPTION
D-01-VS-3	CCG REFRACTORY
D-01-VS-4/6	CCG DETAIL
D-01-VS-2	CCG DETAILS
D-01-VS-2	CCG PLAN VIEW



△ PLAN VIEW

NOTES

1. THIS DRAWING SHOWS A TYPICAL TOP AND BOTTOM SECTION OF THE GASIFIER MONO BLOCK. THE TOP AND BOTTOM SECTIONS ARE DIVIDED JUST ABOVE THE HORIZONTAL INLET TO THE COAL CYCLONE.
2. PIPING FOR WATER, ACCESS, SLAG OUT, ACCESSORY, AND INSTRUMENTATION IS NOT SHOWN FOR CLARITY.
3. △ COAL SLURRY INLET ORIENTATION BY T.Y. LIN

Figure 6-7

DEPARTMENT OF ENERGY
CONTRACT NO. EX-76-C-01-1775

REFERENCES DRAWING NO.	DESCRIPTION
D-01-VS-1	CLEV. ELEV. VIEW

REVISIONS NO.	DATE	DESCRIPTION
4	2-10-78	REORIENT. ALL OXYGEN LINES
3	12-5-77	REV. ORIENT. & LOCATION
2	8-24-77	ADD NOTE 3. REV. TOP ACCESSWAY
1	7-11-77	DELETED EDUCTOR FLANGES
0		

BY KL
CHECKED CLS 6/3/77
SECTION CLS 6/3/77
PROJECT 6/3/77
CLIENT

RMP
THE RALPH M. PARSONS COMPANY
PASADENA, CALIFORNIA

TITLE CONCRETE COAL GASIFIER VESSEL
PLAN VIEW

SCALE NONE
ACCOUNT NUMBER
JOB NUMBER 5435-6
DRAWING NUMBER D-01-VS-2
REV. 4

6-19 (A)

6-19

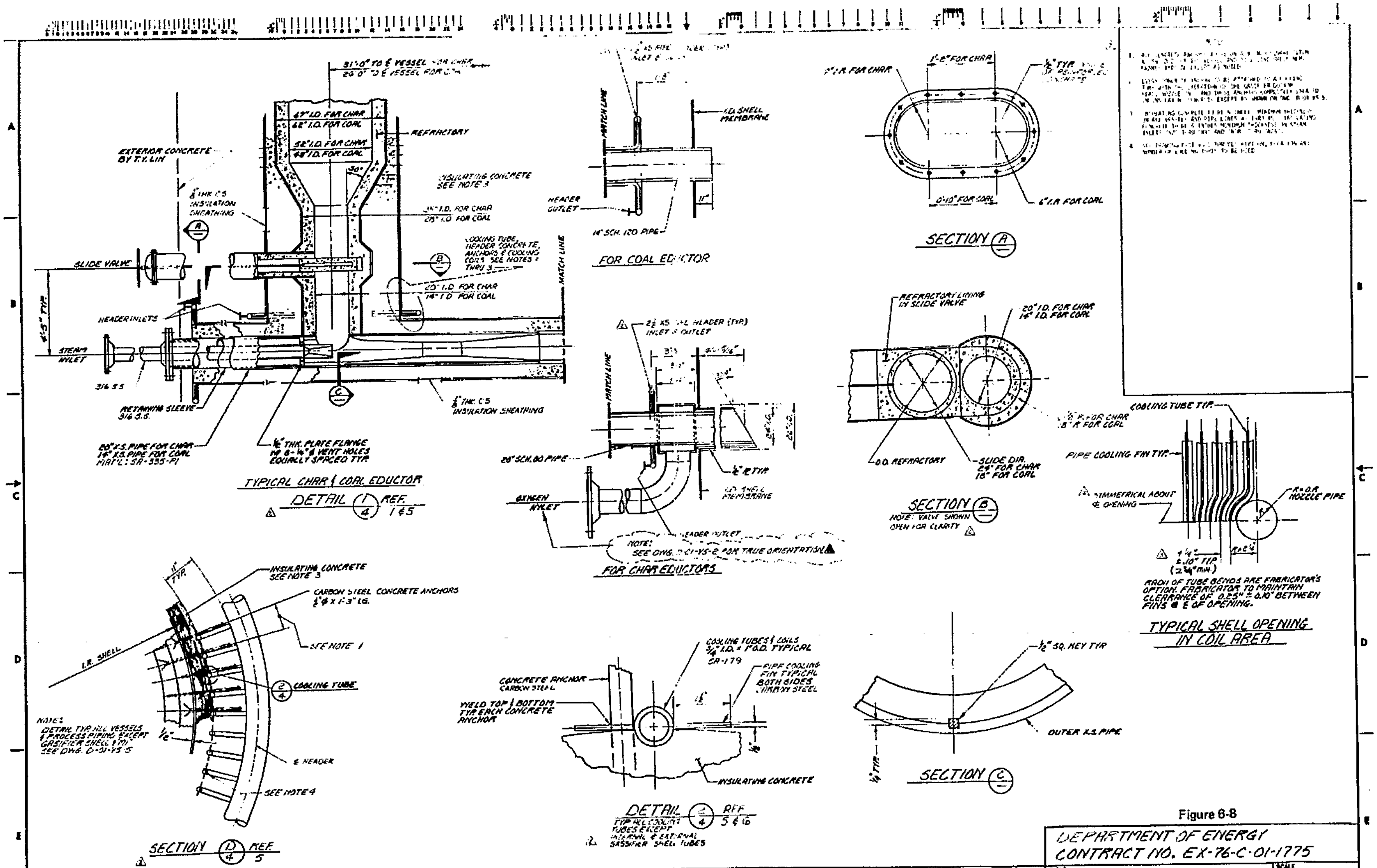


Figure 6-8

DEPARTMENT OF ENERGY
CONTRACT NO. EX-76-C-01-1775

REFERENCES		REVISIONS							
DRAWING NO	DESCRIPTION	NO	DATE	BY	CK	SEC	PROJ	CLIENT	DESCRIPTION
D-01-VS-5	CONC. DETAILS	1	1-5-78						REV. TYP. SHELL
D-01-VS-1	CONC. ELEVATION	2							GENERAL REVISION
		3							[illegible]

RMP
THE RALPH M. PARSONS COMPANY
PASADENA, CALIFORNIA

TITLE CONCRETE COAL GASIFIER VESSEL ADDITIONAL DETAILS
SCALE NONE
JOB NUMBER 5435-6
DRAWING NUMBER D-01-VS-4

6-20 (4)

6-20

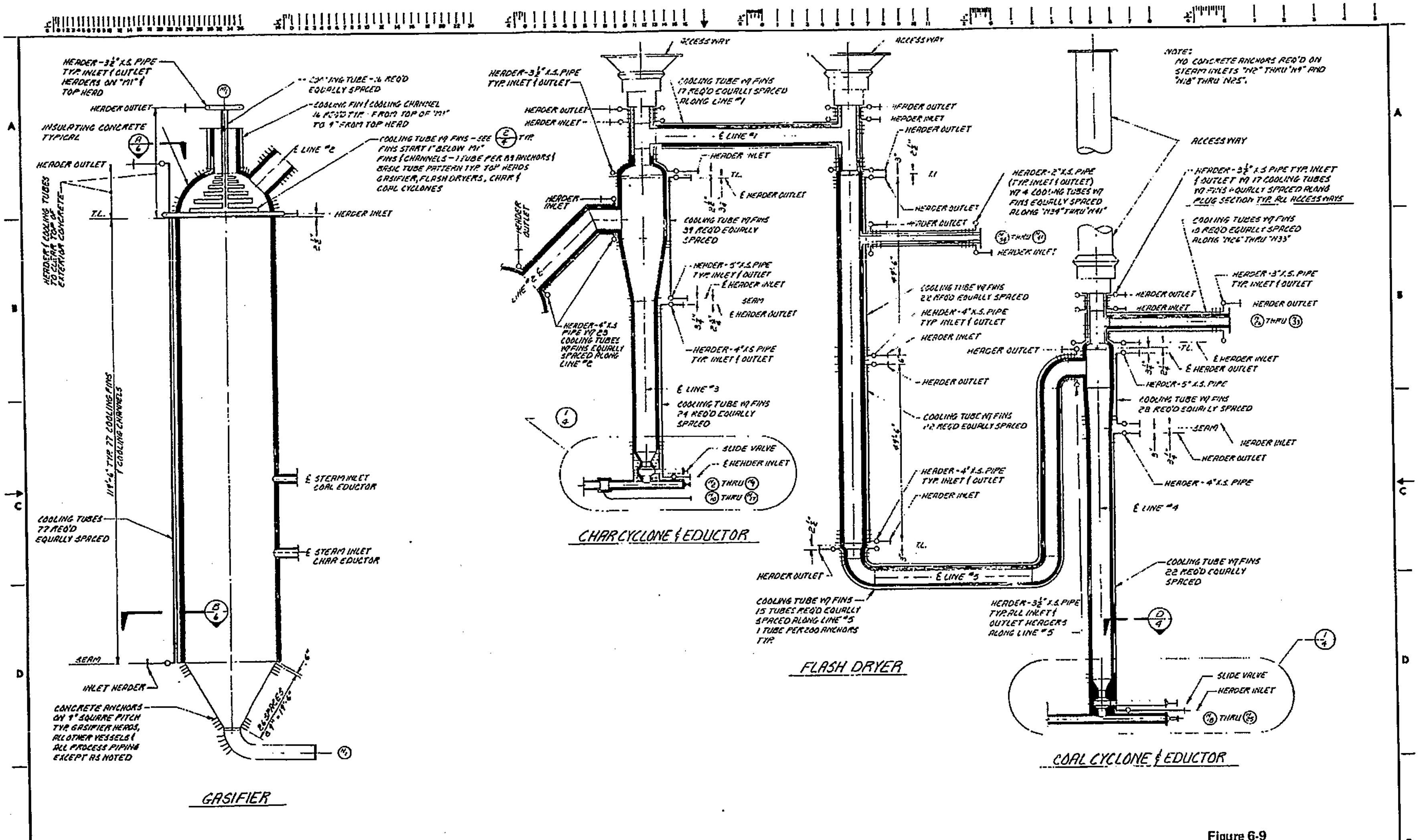


Figure 6-9

DEPARTMENT OF ENERGY
CONTRACT NO. EX-76-C-01-1775

REFERENCES DRAWING NO.	DESCRIPTION
D-01-VS-3,4,6	C.C.G.V. DETAILS
D-01-VS-1	C.C.G.V. ELEVATION

BY B. REDMANN DATE 11-4-77
CHECKED 12-5-77
SECTION CCS 12/5/77
PROJECT
CLIENT

RMP
THE RALPH M. PARSONS COMPANY
PASADENA, CALIFORNIA

TITLE CONCRETE COAL GASIFIER VESSEL COOLING SYSTEM SCHEMATIC
SCALE NONE
ACCOUNT NUMBER
JOB NUMBER 5435-6
DRAWING NUMBER D-01-VS-5
REV. 0

6-21 (A)

6-21

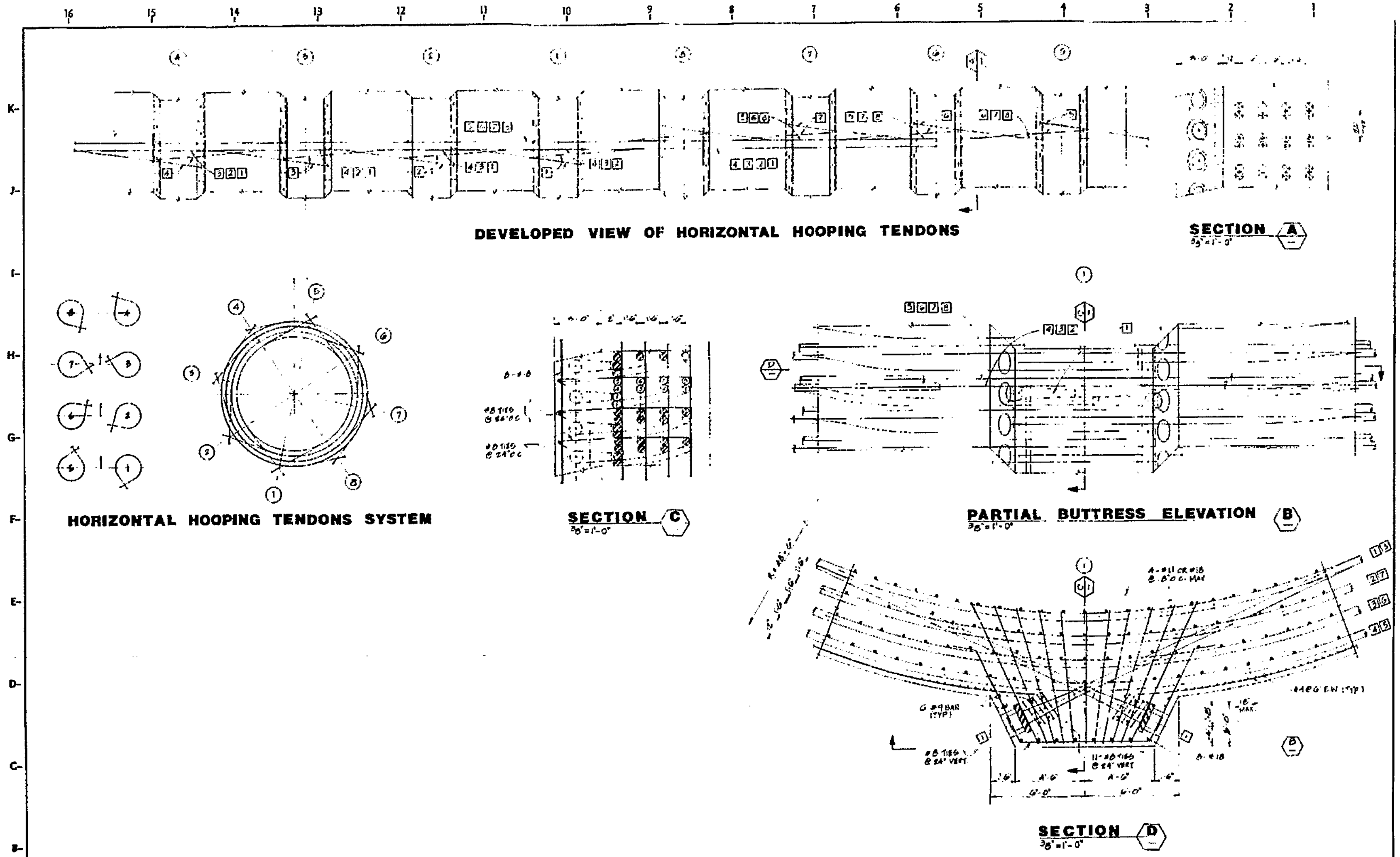


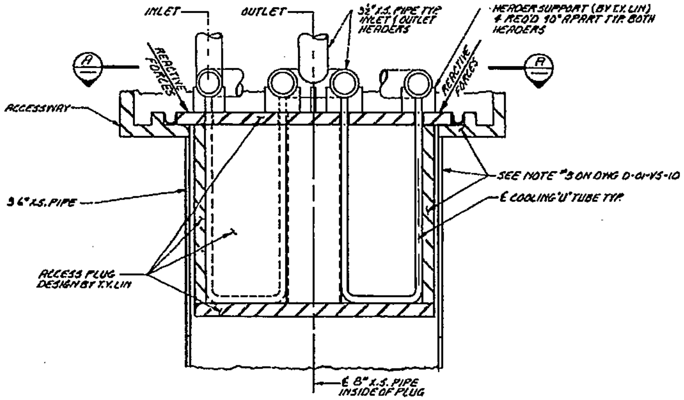
Figure 6-10

T. Y. LIN INTERNATIONAL
STRUCTURAL ENGINEERING

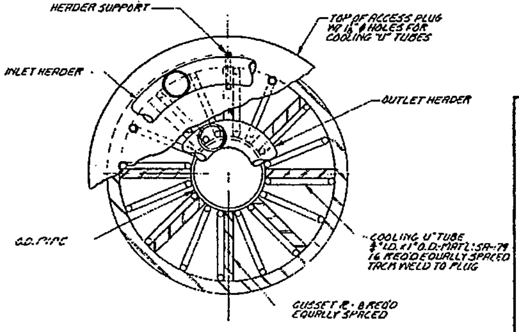
	99190
	M. K.
	F. H.
	P. G.
	3.21.78

INTEGRATED GASIFIER VESSEL
COAL CONVERSION PCPV
RMP / DOE

I-10



DETAIL (1/12) REF. 10
2 REQ'D



VIEW (A)

NOTES

1. THIS DRAWING IS INTENDED TO ILLUSTRATE GENERAL PLUG CONFIGURATION ONLY. DIMENSIONS, SIZES AND THICKNESSES BY T.Y. LIN EXCEPT AS SHOWN.
2. REFER TO THE OAK RIDGE NATIONAL LABORATORY REPORT BY W. L. GREENSTREET ET AL., "FEASIBILITY STUDY ON PRESTRESSED CONCRETE PRESSURE VESSELS FOR COAL GASIFIERS", FEBRUARY 1977, FOR GENERAL DESIGN GUIDE LINES.

Figure 6-11

DEPARTMENT OF ENERGY
CONTRACT NO. EX-76-C-01-1775

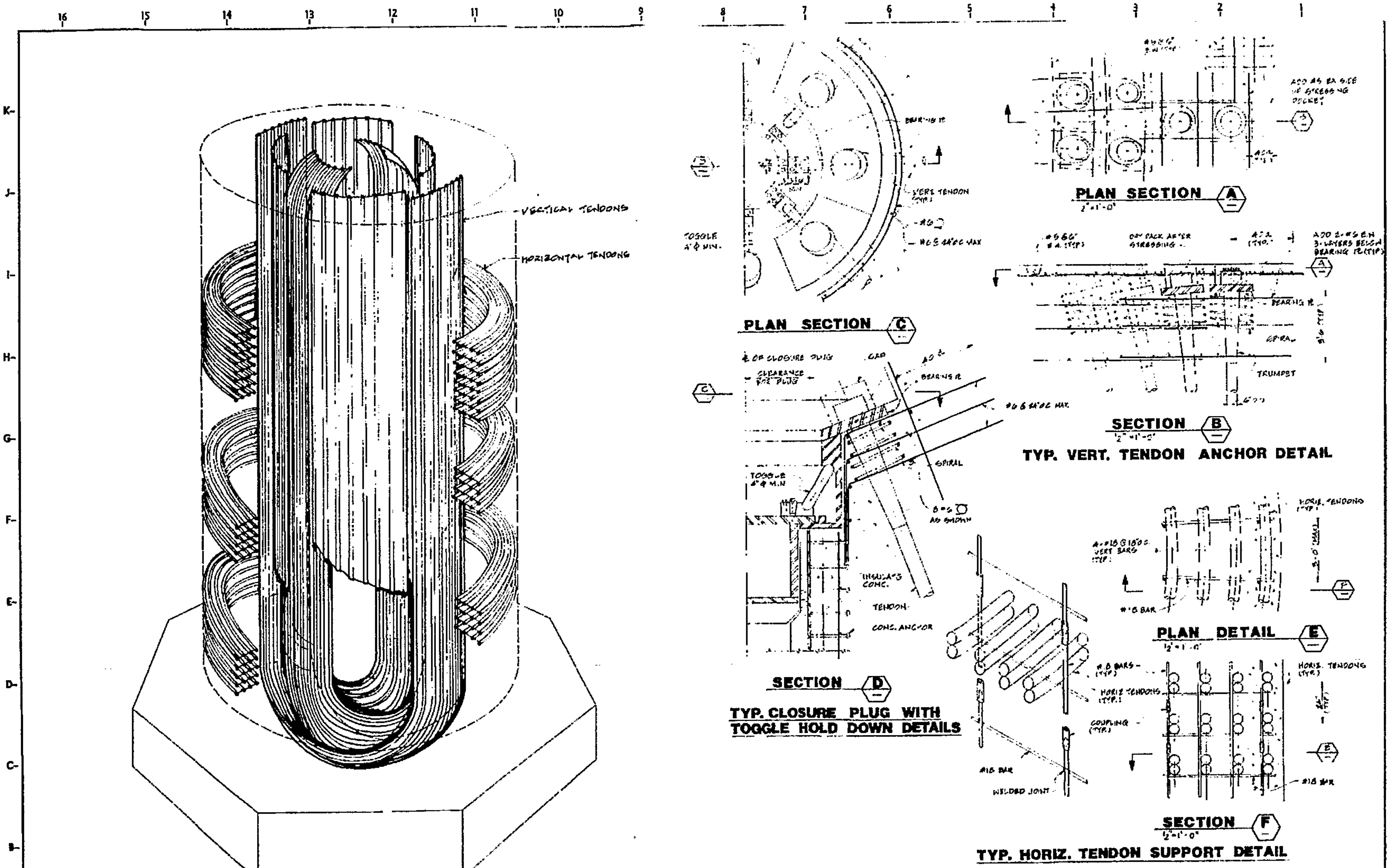
REFERENCES DRAWING NO.	DESCRIPTION
D-01-VS-11	CCD-SX DETAILS
D-01-VS-10	CCD-SV ELEVATION

NO.	DATE	BY	CK.	SEC	PROJ.	CLIENT	DESCRIPTION
0	[illegible]	[illegible]	[illegible]	[illegible]	RDK		

BY B. REDMANN	DATE 2-6-78
CHECKED T.Y.	2-10-78
SECTION C.C.S.	2-10-78
PROJECT RDK	2-10-78
CLIENT	

RMP
THE RALPH M. PARSONS COMPANY
PASADENA, CALIFORNIA

TITLE CONCRETE COAL DISSOLVER-SEPARATOR VESSEL ACCESS PLUG DETAIL
SCALE NONE
ACCOUNT NUMBER
JOB NUMBER 5435-6
DRAWING NUMBER D-01-VS-12
REV. 0



LOOPING TENDON ARRANGEMENT SCHEMATIC

PLAN SECTION Ⓒ

SECTION Ⓓ

TYP. CLOSURE PLUG WITH TOGGLE HOLD DOWN DETAILS

PLAN SECTION Ⓐ

1" = 1'-0"

SECTION Ⓑ

½" = 1'-0"

TYP. VERT. TENDON ANCHOR DETAIL

PLAN DETAIL Ⓔ

½" = 1'-0"

SECTION Ⓕ

½" = 1'-0"

TYP. HORIZ. TENDON SUPPORT DETAIL

Figure 6-12

T. Y. LIN INTERNATIONAL STRUCTURAL ENGINEERING	99190	TITLE: Typical Detail	DWG. NO. **0-1**
	DESIGNED BY D.M. DRAWN BY F.P. CHECKED BY F.C. 4-21-78	PROJECT: COAL CONVERSION PCPV	
		FOR: RMP / DOE	

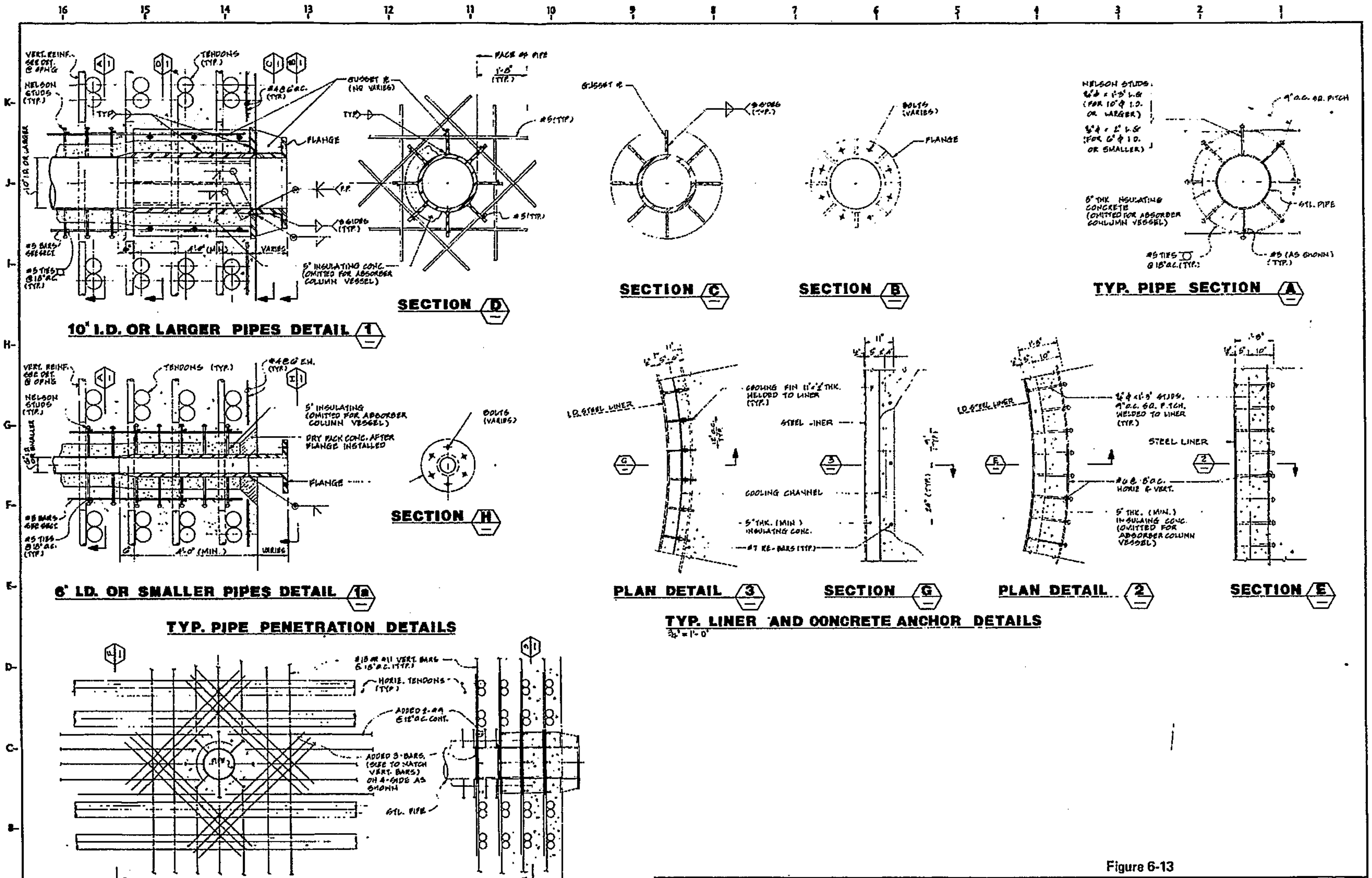
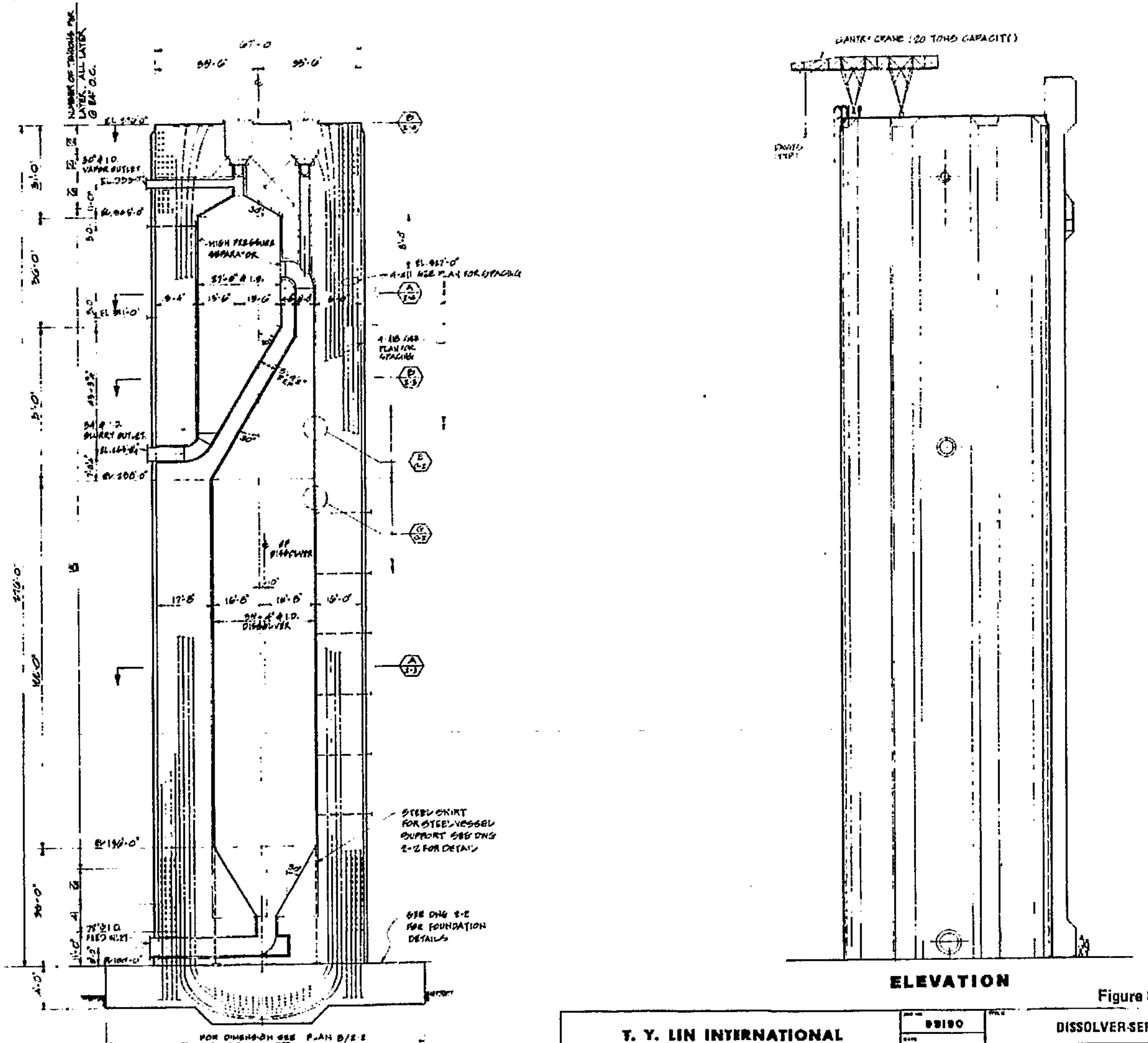


Figure 6-13

T. Y. LIN INTERNATIONAL STRUCTURAL ENGINEERING	99190	Typical Detail	0-2
	DESIGN BY D.H.		
	DRAWN BY F.H.	PROJECT: COAL CONVERSION PCPV	
	CHECKED BY P.C.		
	ISSUE DATE 8-31-78	FOR: RMP / DOE	



SECTION (A)
1/16" = 1'-0"

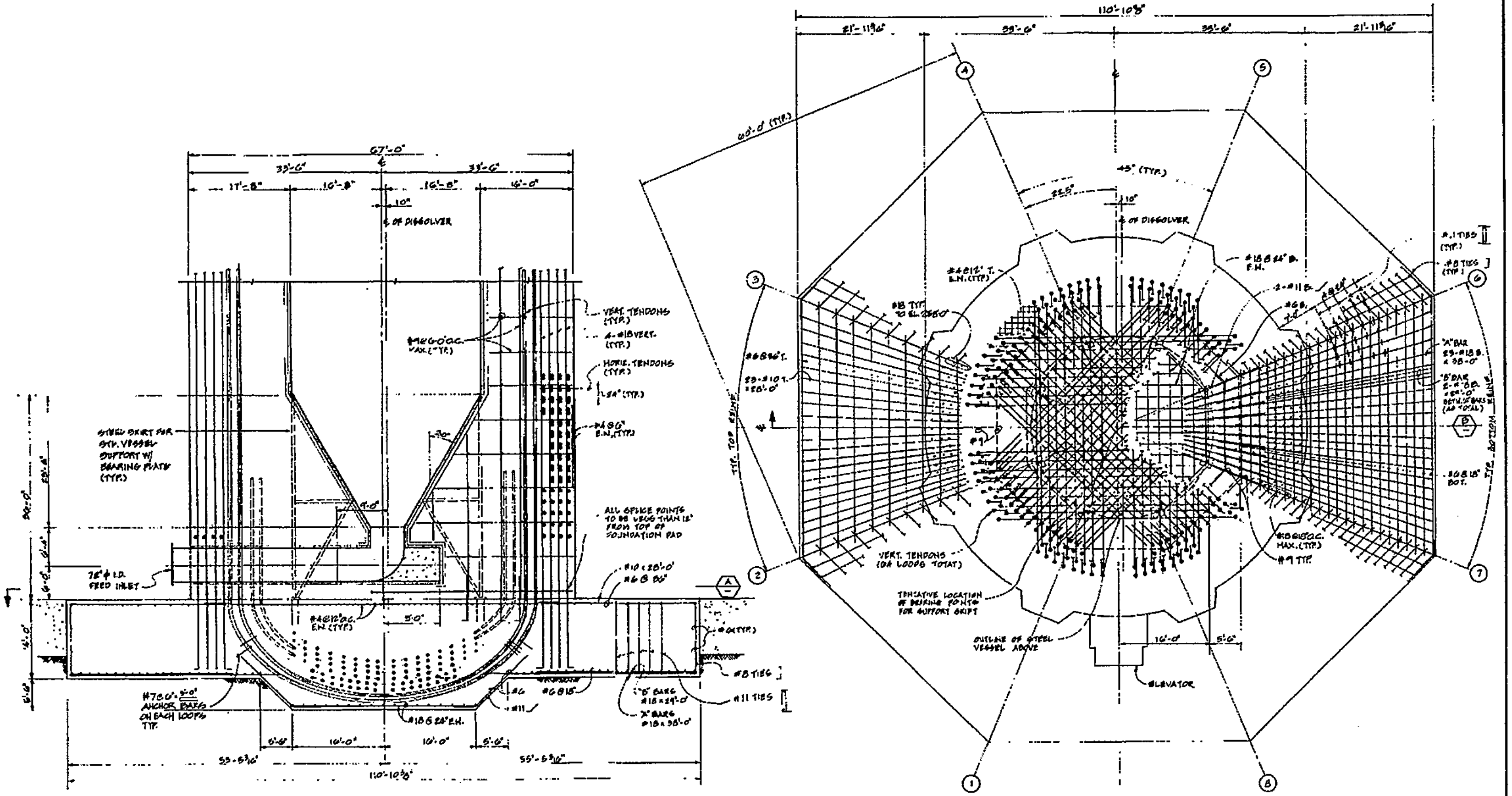
ELEVATION

Figure 6-14

T. Y. LIN INTERNATIONAL
STRUCTURAL ENGINEERING

09190	DISSOLVER-SEPARATOR VESSEL	2-1
O.N.	COAL CONVERSION PCPV	
F.H.	RMP / DOE	
P.C.		
6-21-78		

6 26



SECTION B
1/8" = 1'-0"

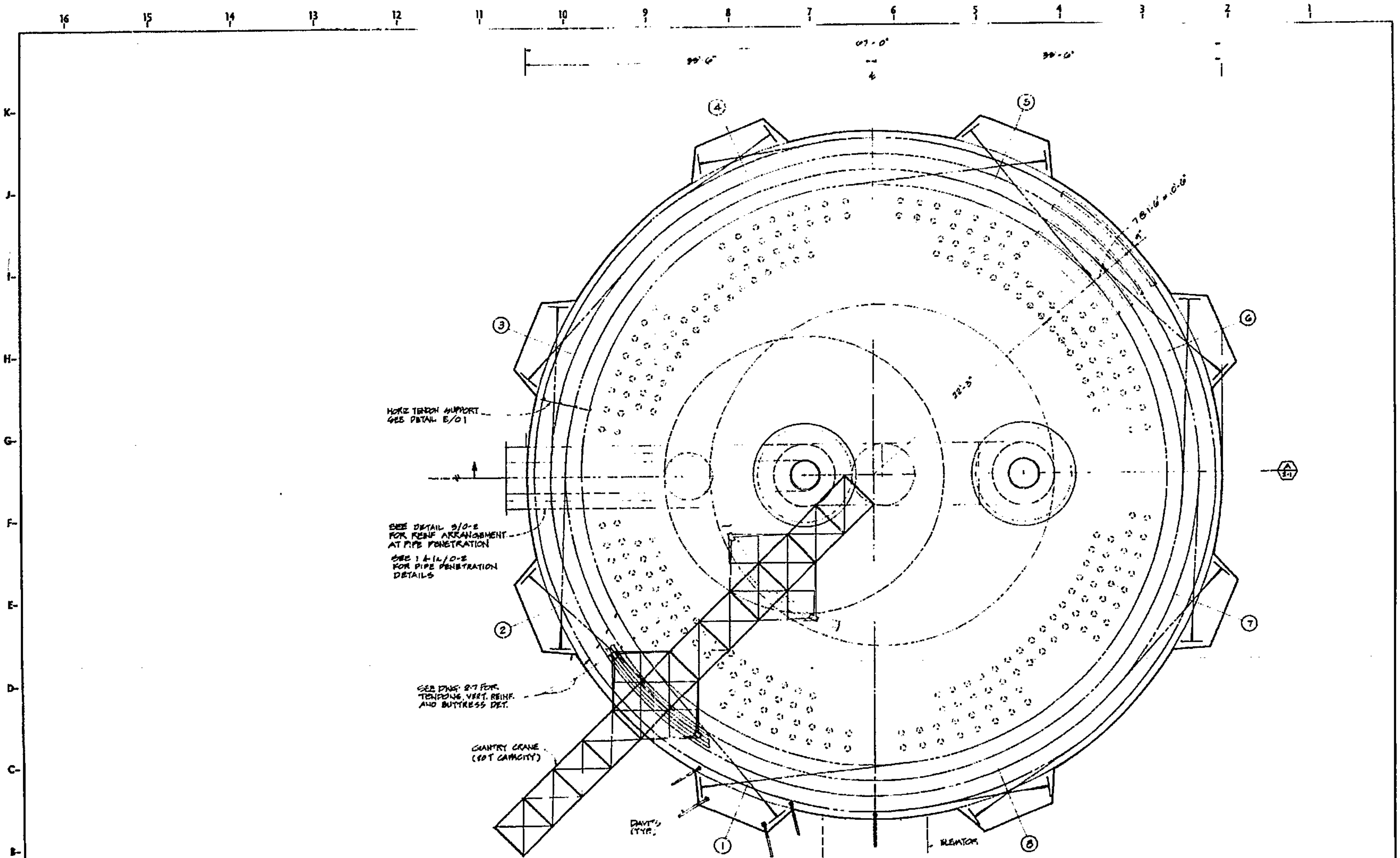
FOUNDATION PLAN

SECTION A
1/8" = 1'-0"

Figure 6-15

T. Y. LIN INTERNATIONAL
STRUCTURAL ENGINEERING
315 BAY ST., SAN FRANCISCO, CALIF. · PHONE 982-1000

JOB NO.	99190
SCALE:	
DESIGNED BY	F. J.
DRAWN BY	F. H.
CHECKED BY	F. C.
ISSUE DATE	8-31-78
TITLE:	DISSOLVER-SEPARATOR VESSEL
PROJECT:	COAL CONVERSION PCPV
FOR:	RMP / DOE
DRWG. NO.	2·2



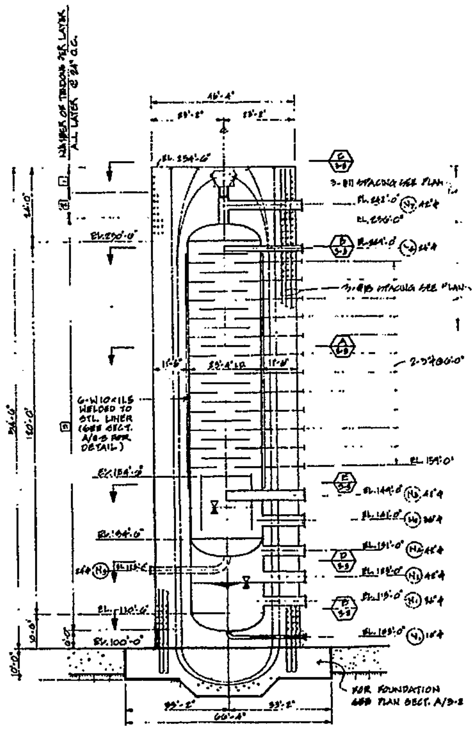
CONSOLIDATED PLAN

1/4" = 1'-0"

Figure 6-16

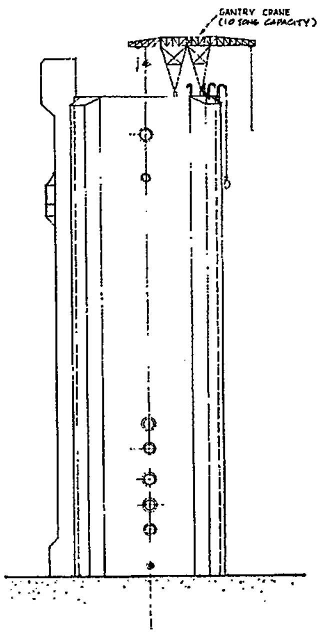
T. Y. LIN INTERNATIONAL
STRUCTURAL ENGINEERING
[illegible]

99190	DISOLVER-SEPARATOR VESSEL	2·5
Z.H.	COAL CONVERSION PCPV	
F.H.		
P.C.	RMP / DOE	
5-31-78		



SECTION A

1/16" = 1'-0"



ELEVATION

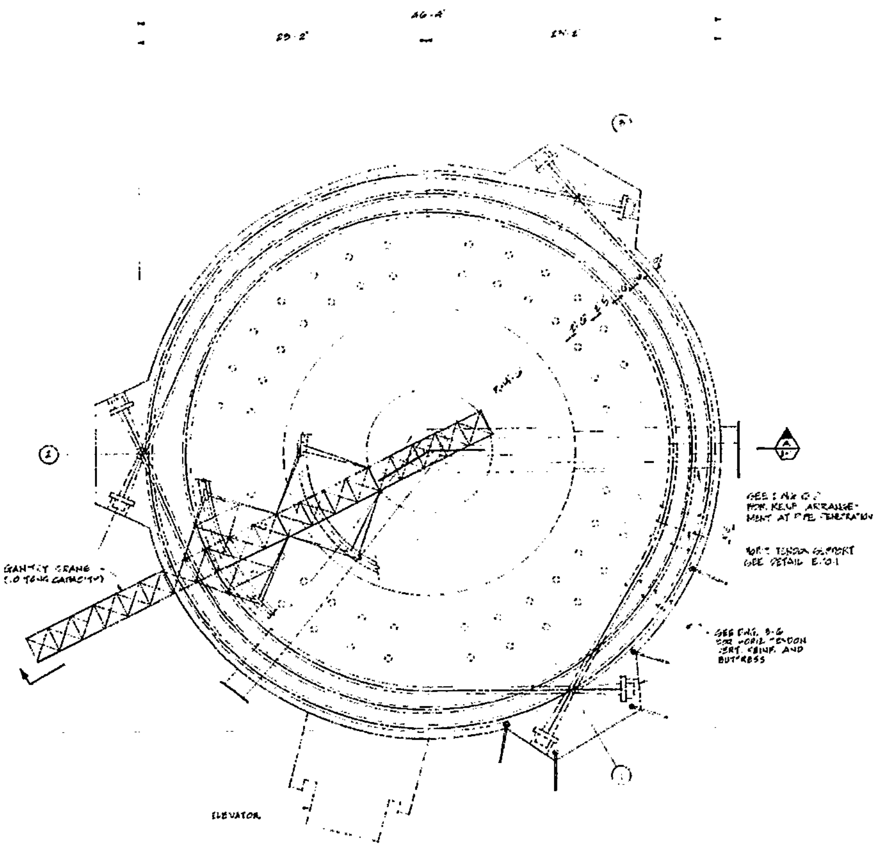
1/16" = 1'-0"

Figure 6-17

T. Y. LIN INTERNATIONAL STRUCTURAL ENGINEERING 315 BAY ST., SAN FRANCISCO, CALIF. • PHONE 982.1000	JOB NO.: 99190 DATE: DESIGNED BY: O.H. DRAWN BY: E.H. CHECKED BY: P.C. PRINT DATE: 3-21-78	TITLE: ABSORBER VESSEL PROJECT: COAL CONVERSION PCPV FOR: RMP / DOE	DRWG. NO. **3-1**

(A)

6-29



CONSOLIDATED PLAN

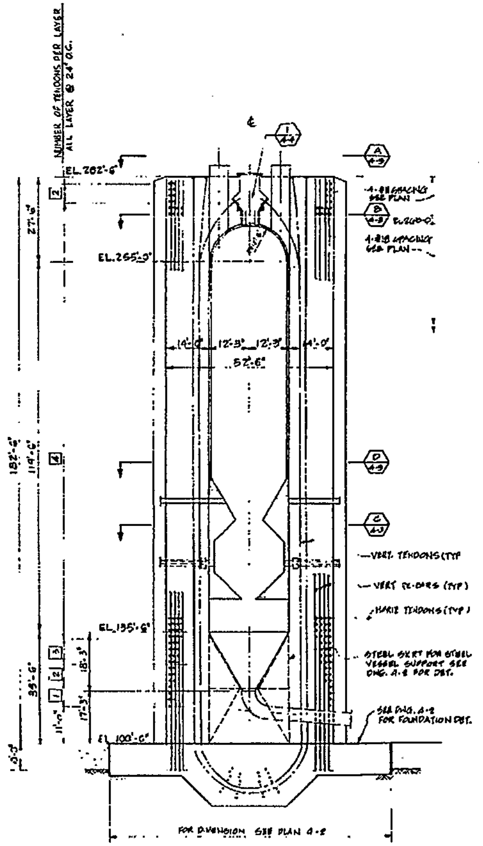
1/4"=1'-0"

Figure 6-18

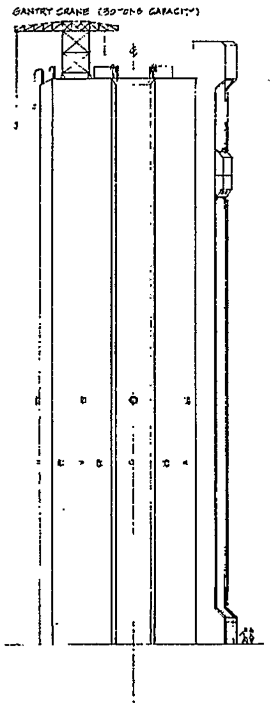
T. Y. LIN INTERNATIONAL STRUCTURAL ENGINEERING	99190	ABSORBER VESSEL	3·4
	C. N. F. H. F. C. 5-31-78	COAL CONVERSION PCPV	
		RMP / DOE	

G-30 (A)

6-30



SECTION A
1/16" = 1'-0"



ELEVATION
1/16" = 1'-0"

Figure 6-19

T. Y. LIN INTERNATIONAL
STRUCTURAL ENGINEERING
315 BAY ST., SAN FRANCISCO, CALIF. • PHONE 982-1050

JOB NO. 99190
DESIGN BY D. H.
DRAWN BY E. C.
CHECKED BY P. C.
ISSUE DATE 5-31-78

TITLE: GASIFIER VESSEL
PROJECT: COAL CONVERSION PCPV
FOR: RMP / DOE

DRWG. NO. 4-1

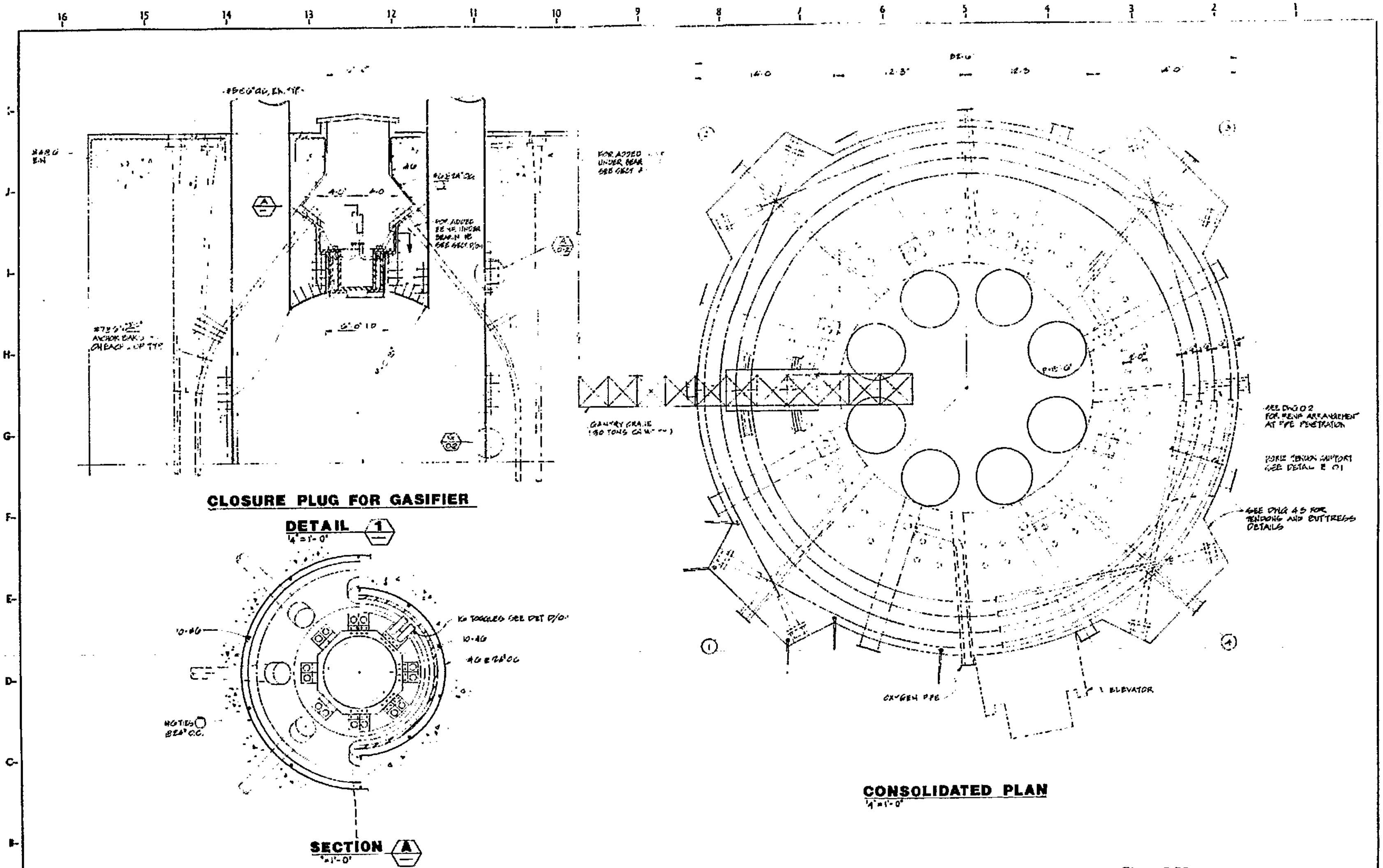


Figure 6-20

T. Y. LIN INTERNATIONAL
STRUCTURAL ENGINEERING
315 BAY ST. SAN FRANCISCO CALIF. · PHONE 982-1000

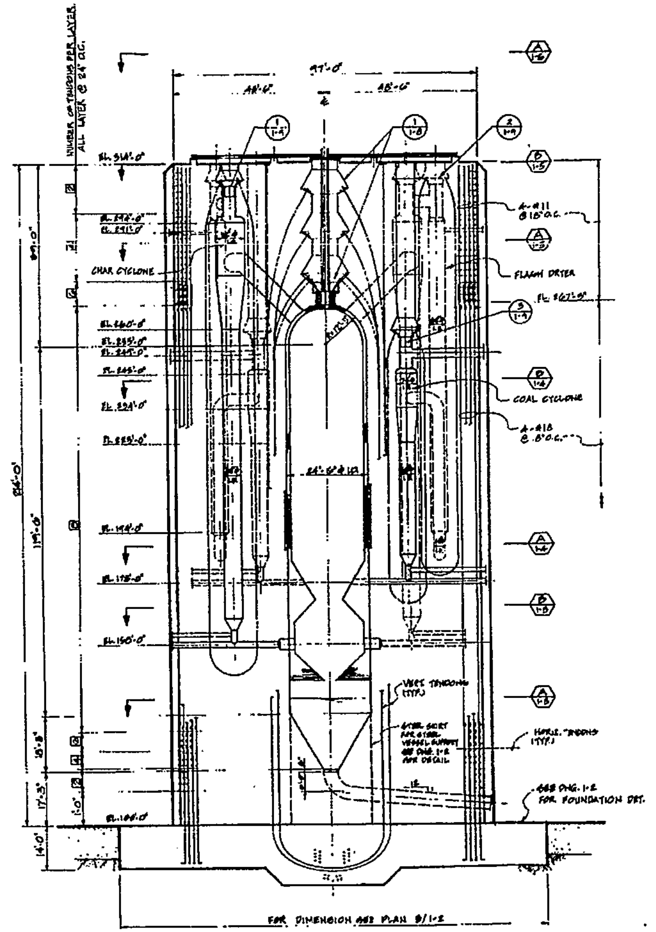
99190
D. N.
F. H.
P. T.
5-31-78

GASIFIER REACTOR VESSEL
COAL CONVERSION PCPV
RMP/ DOE

4·4

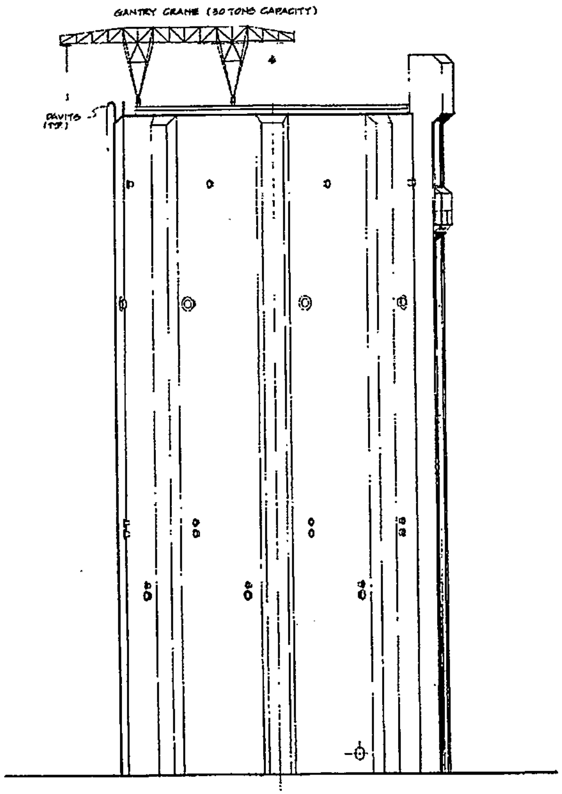
(A)

6-32



SECTION A

1/16"=1'-0"



ELEVATION

1/16"=1'-0"

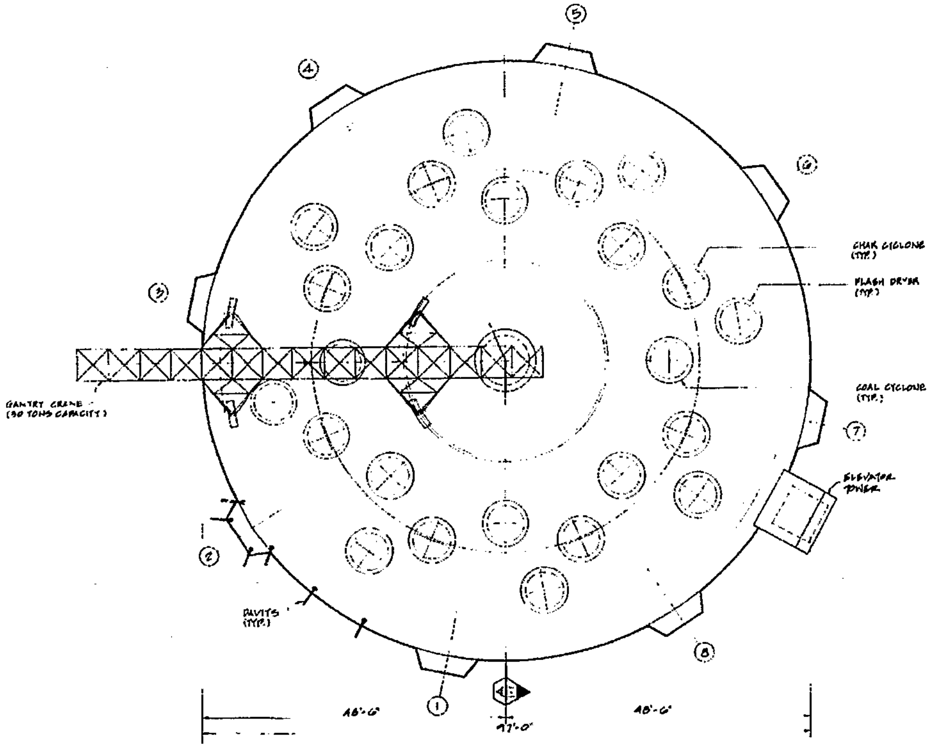
Figure 6-21

T. Y. LIN INTERNATIONAL
STRUCTURAL ENGINEERING
315 BAY ST. SAN FRANCISCO, CALIF. · PHONE 982-1000

99190	TITLE: INTEGRATED GASIFIER VESSEL	DRWG. NO.	1·1
DESIGN BY D.N.	PROJECT: COAL CONVERSION PCPV		
DRAWN BY J.K.			
CHECKED BY P.C.	FOR: RMP/ DOE		
ISSUE DATE 5-21-78			

6-33 (A)

6-33



TOP VIEW

SECTION A
1/8"=1'-0"

Figure 6-22

T. Y. LIN INTERNATIONAL STRUCTURAL ENGINEERING	99190 D.H. F.H. P.C. 3-21-78	INTEGRATED GASIFIER VESSEL COAL CONVERSION PCPV RMP / DOE	**I-6**

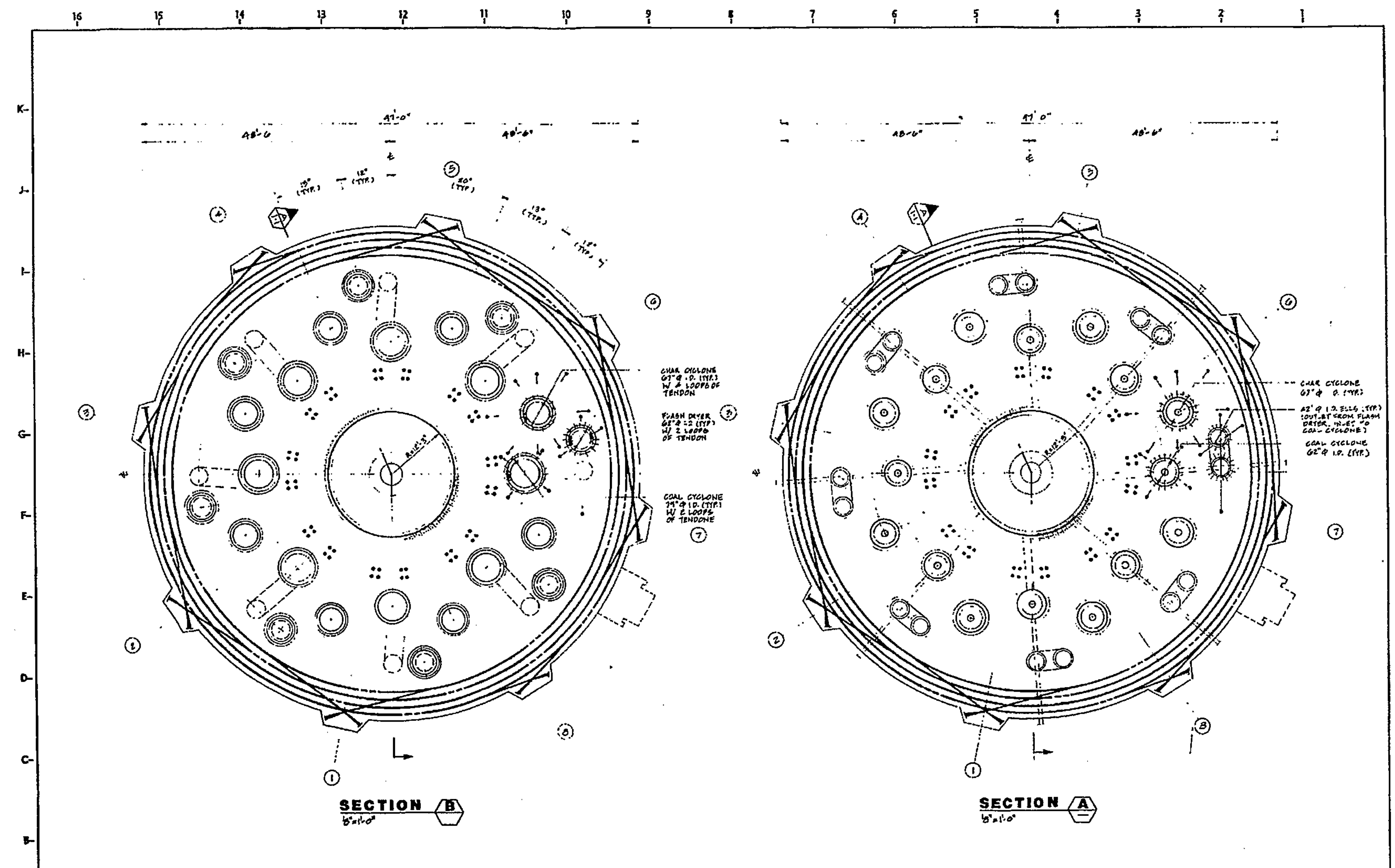


Figure 6-23

T. Y. LIN INTERNATIONAL
STRUCTURAL ENGINEERING
315 BAY ST SAN FRANCISCO CALIF • PHONE 982-1000

JOB NO.	99190
DATE	
DESIGN BY	D.H
DRAWN BY	F.H.
CHECKED BY	P.C.
ISSUE DATE	9-21-78

TITLE: INTEGRATED GASIFIER VESSEL
PROJECT: COAL CONVERSION PCPV
FOR: RMP / DOE

DWG NO. I-4

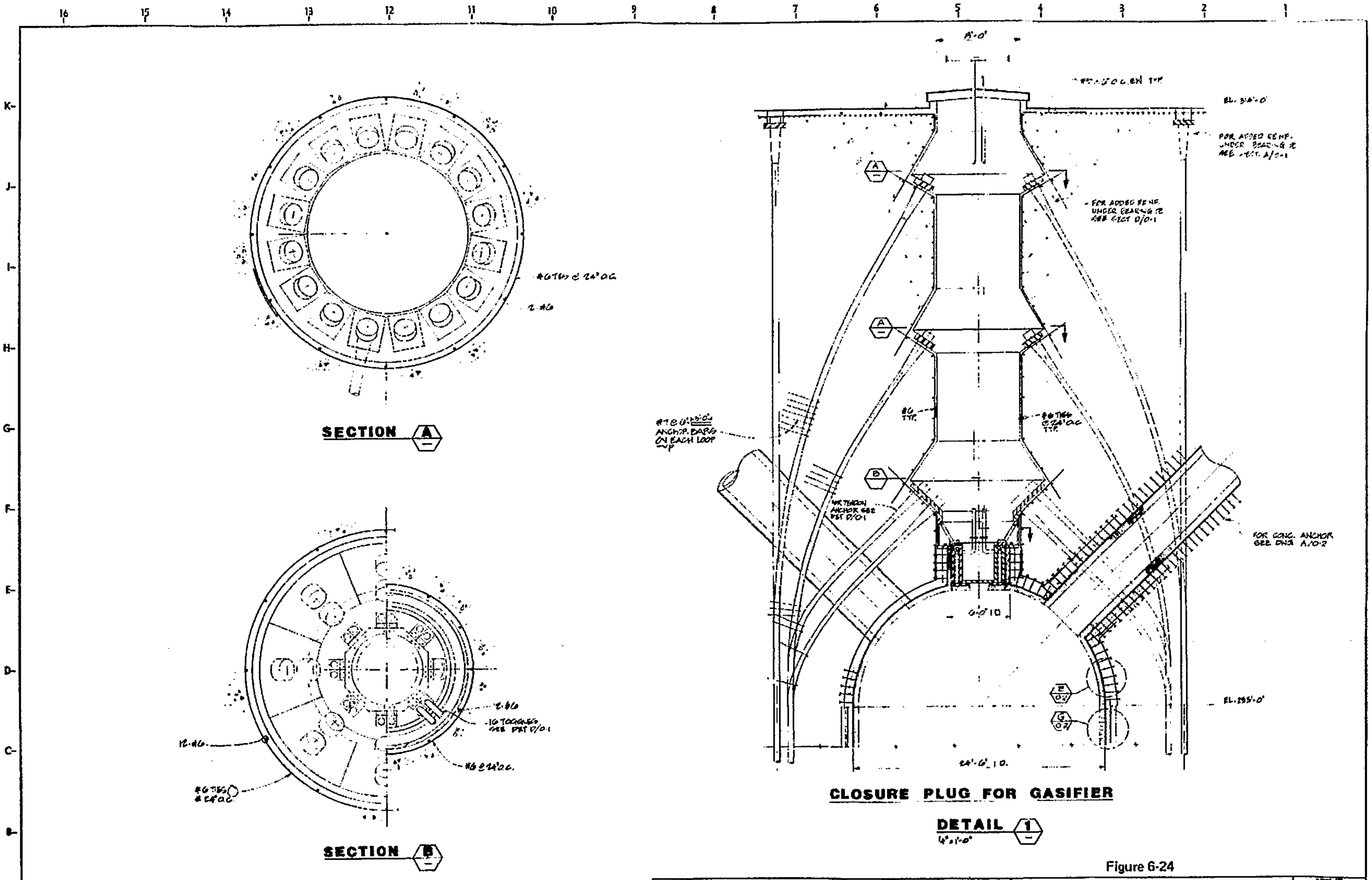


Figure 6-24

T. Y. LIN INTERNATIONAL STRUCTURAL ENGINEERING	99190 D H F.H. P. C. 9-11-78	INTEGRATED GASIFIER VESSEL COAL CONVERSION PCPV RMP / DOE	**I-8**

PROJECT: COAL GASIFICATION
ITEM: THICK-WALLED CYLINDER SOLUTION
DESIGN: D.H.
DATE: MAR. 1978

SHEET: 1
OF 4
REVISION:

```
 78/03/18. 17.03.42.
PROGRAM   THWCYL

? 200 392
? 2228 1336.8 150 10


 INT. RADIUS =   200.000 IN
 EXT. RADIUS =   392.000 IN
 INT. PRESS. =  2228.000 PSI
 EXT. PRESS. =  1336.800 PSI
 INT. TEMP.  =   150.000 F
 NO. INCRE.  =        10
```

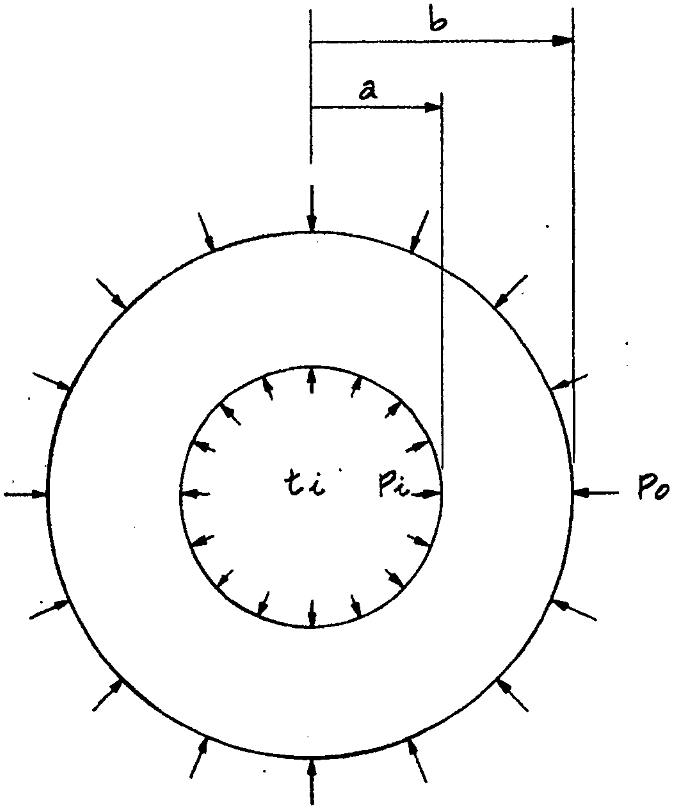


Figure 6-25 - Thick Walled Cylinder Solutions

TYIN INTERNATIONAL
STRUCTURAL ENGINEERING
315 Bay St., San Francisco, Ca. 94133.

PROJECT: COAL GASIFICATION		SHEET: 2 OF 4
ITEM: THICK-WALLED CYLINDER SOLUTION		
DESIGN: D.H.		REVISION:
DATE: [illegible]		

```
THICK-WALLED CYLINDER SOLUTION FOR LOADING DUE TO PRESSURE ONLY

                            *****        +++++         .....
                 R        SR(PSI)       ST(PSI)       SZ(PSI)   R.DIS.(IN)    R.STRAIN
       1      200.000    -2228.000     181.652                    .034390      .000172
       2      219.200    -2026.179     -20.168                    .020733      .000095
       3      238.400    -1871.127    -175.221                    .008380      .000035
       4      257.600    -1749.435    -296.913                  -.002962     -.000011
       5      276.800    -1652.176    -394.172                  -.013503     -.000049
       6      296.000    -1573.222    -473.125                  -.023398     -.000079
 1     7      315.200    -1508.252    -538.095                  -.032766     -.000104
 1     8      334.400    -1454.149    -592.199                  -.041697     -.000125
 1     9      353.600    -1408.617    -637.731                  -.050263     -.000142
 1    10      372.800    -1369.937    -676.411                  -.058520     -.000157
 1    11      392.000    -1336.800    -709.548                  -.066513     -.000170
```

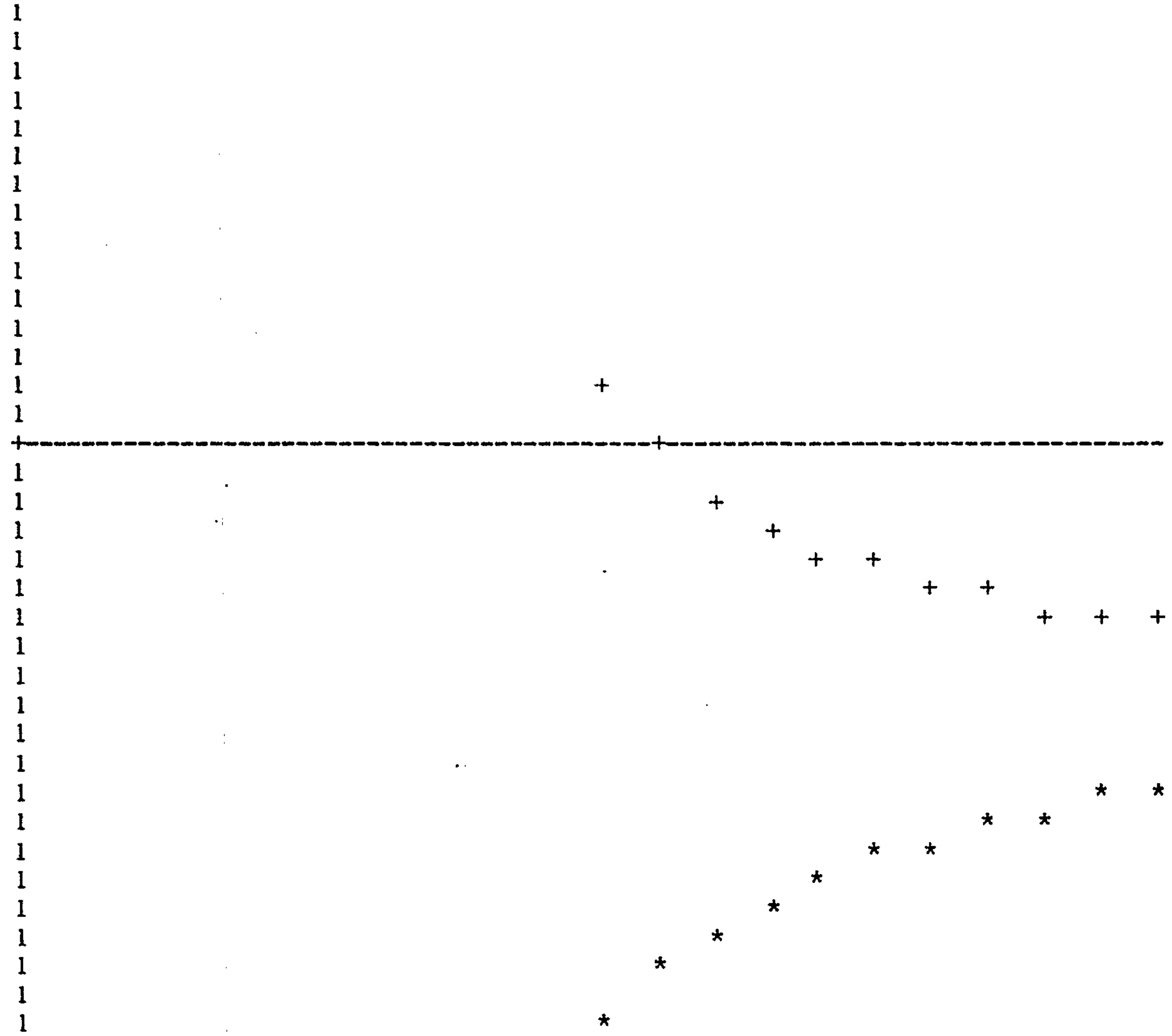


Figure 6-25 - (Contd)

T.Y. LIN INTERNATIONAL
STRUCTURAL ENGINEERING
315 Bay St., San Francisco, Ca. 94133.

PROJECT: COAL GASIFICATION
ITEM: THICK-WALLED CYLINDER SOLUTION
DESIGN: D. H.
DATE:

SHEET: 3 OF 4
REVISION:

```
THICK-WALLED CYLINDER SOLUTION FOR LOADING DUE TO TEMPERATURE ONLY


                              *****       +++++        .....
               R            SR(PSI)      ST(PSI)      SZ(PSI)   R.DIS.(IN)    R.STRAIN
      1     200.000          -.000     -1773.006    -1773.006     .074209      .000371
      2     219.200       -131.381     -1244.990    -1376.371     .092373      .000421
      3     238.400       -203.022      -810.038    -1013.061     .107011      .000449
      4     257.600       -234.245      -443.663     -677.907     .118712      .000461
      5     276.800       -237.604      -129.255     -366.858     .127917      .000462
1     6     296.000       -221.494       144.816      -76.678     .134962      .000456
1     7     315.200       -191.662       386.921      195.259     .140111      .000445
1     8     334.400       -152.121       603.232      451.111     .143578      .000429
1     9     353.600       -105.721       798.396      692.675     .145532      .000412
1    10     372.800        -54.515       975.978      921.463     .146116      .000392
1    11     392.000         -.000      1138.759     1138.759     .145450      .000371
```

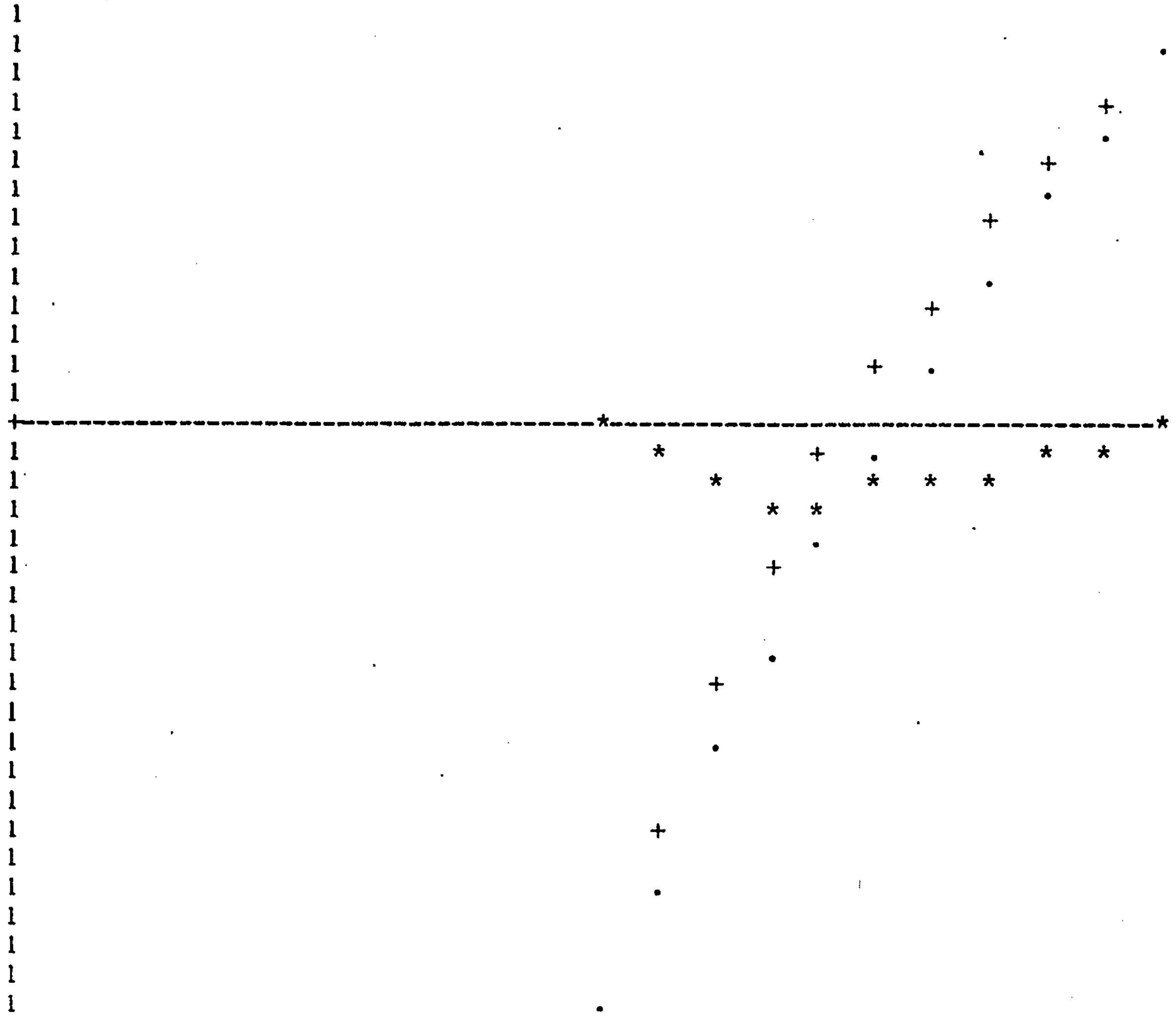


Figure 6-25 (Contd)

PROJECT: COAL GASIFICATION
ITEM: THICK-WALL CYLINDER SOLUTION
DESIGN: D. M.
DATE: [illegible]

SHEET: 4
OF 4
REVISION:

```
THICK-WALLED CYLINDER SOLUTION FOR LOADING DUE TO COMBINED PRES + TEMP


                           *****        +++++        .....
              R          SR(PSI)      ST(PSI)      SZ(PSI)   R.DIS.(IN)    R.STRAIN
   1       200.000     -2228.000    -1591.353    -1773.006     .108599     .000543
   2       219.200     -2157.560    -1265.158    -1376.371     .113106     .000516
   3       238.400     -2074.149     -985.259    -1013.061     .115390     .000484
   4       257.600     -1983.679     -740.576     -677.907     .115750     .000449
   5       276.800     -1889.780     -523.426     -366.858     .114414     .000413
   6       296.000     -1794.717     -328.309      -76.678     .111564     .000377
   7       315.200     -1699.915     -151.175      195.259     .107346     .000341
   8       334.400     -1606.270       11.033      451.111     .101880     .000305
   9       353.600     -1514.338      160.665      692.675     .095269     .000269
  10       372.800     -1424.452      299.567      921.463     .087597     .000235
  11       392.000     -1336.800      429.211     1138.759     .078937     .000201
```

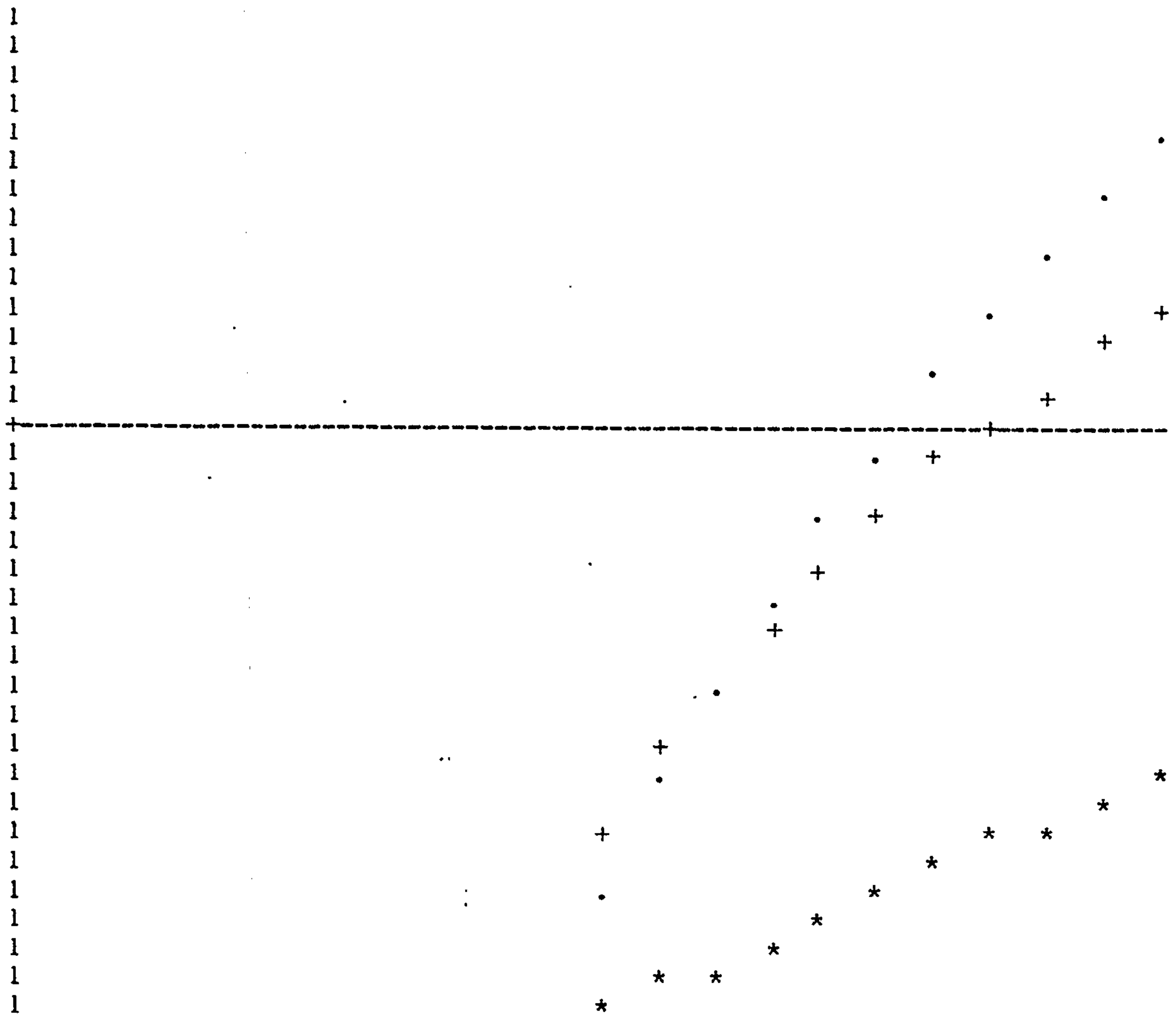


Figure 6-25 - (Contd)

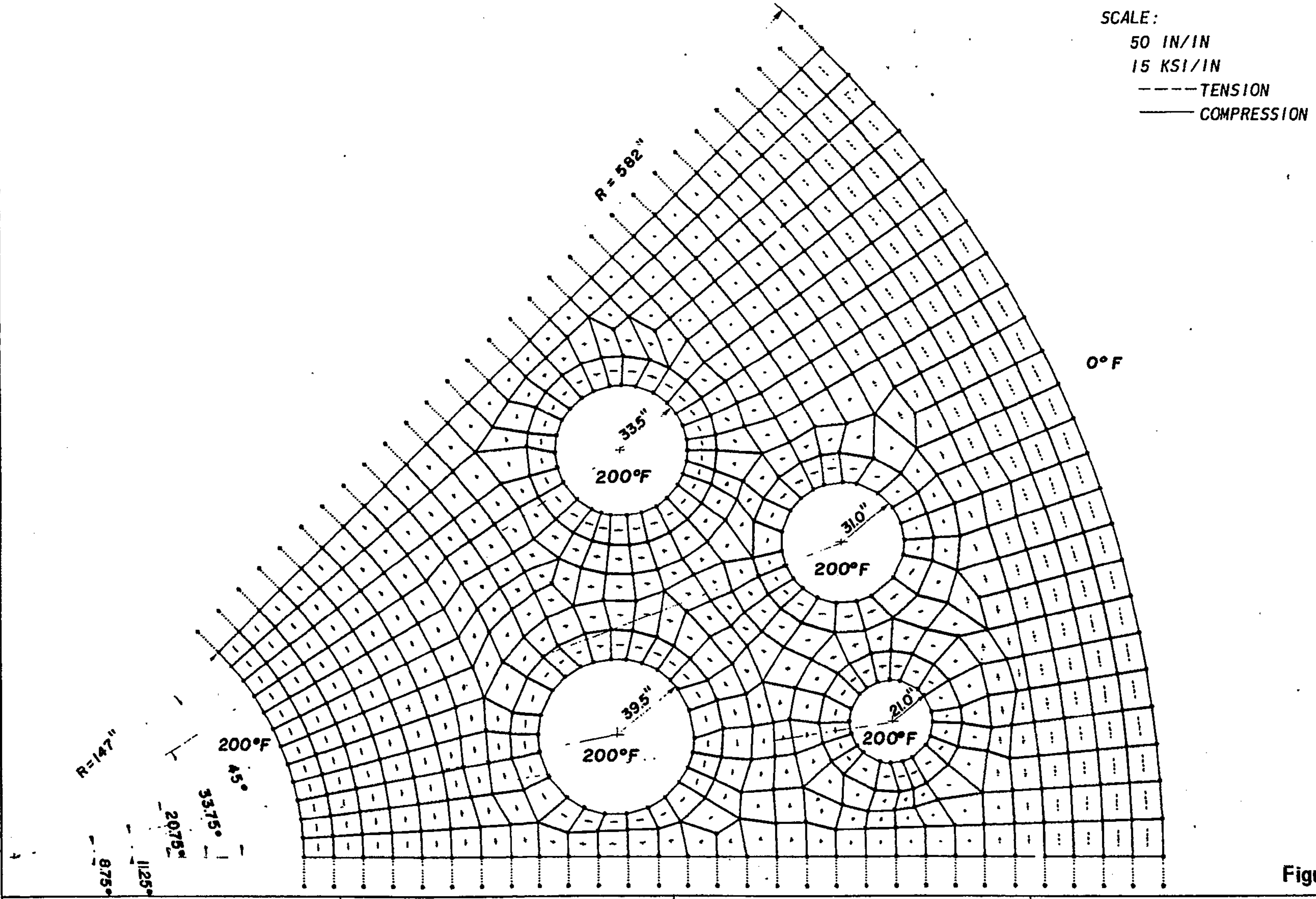


Figure 6-26

GASIFIER REACTOR VESSEL	TYLIN INTERNATIONAL	PRINCIPAL STRESSES LOAD: THERMAL (200^0 F)	10/10/77 MK

SCALE: 1" = 50"

COUNTOUR INTERAL: 10°F

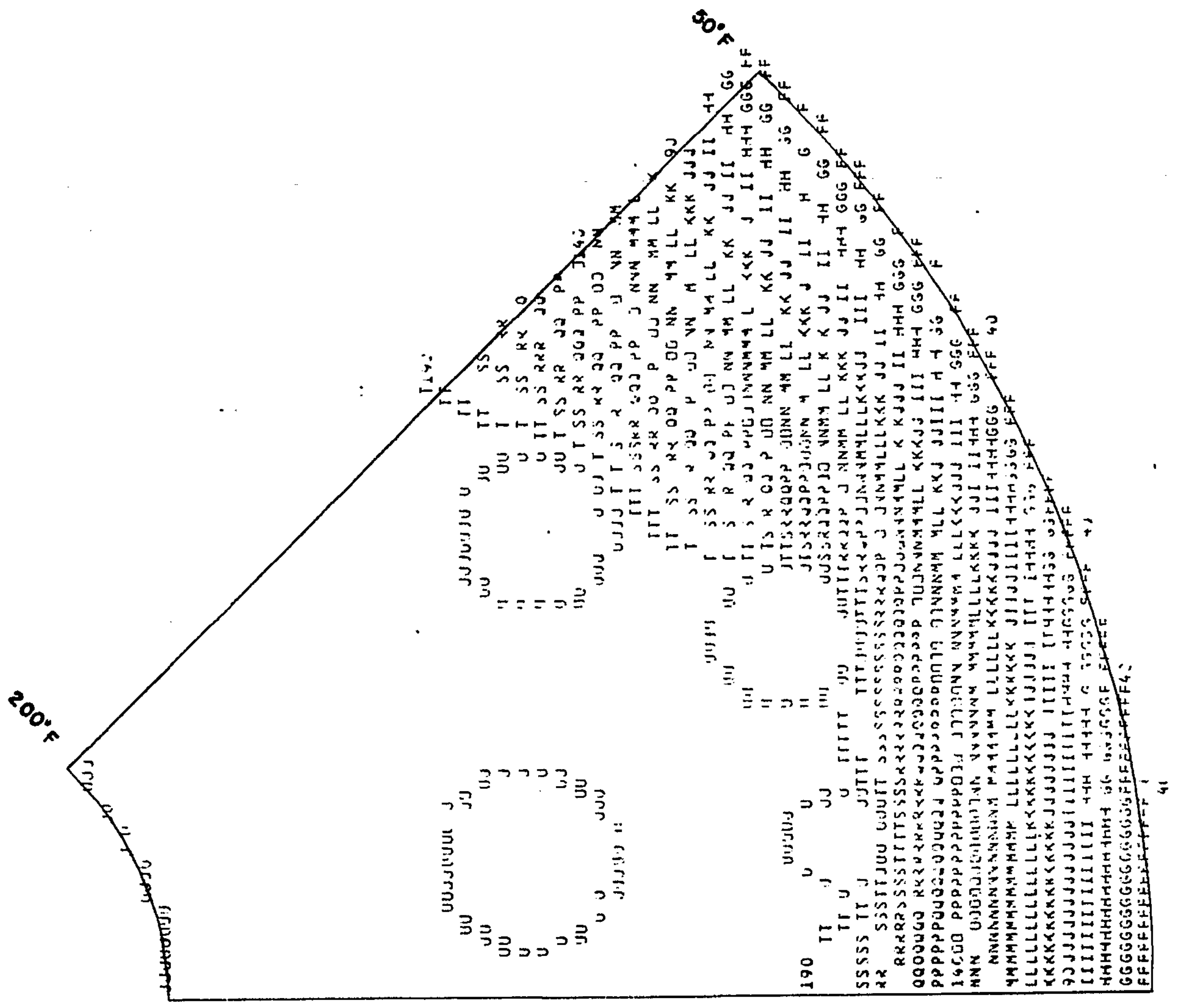


Figure 6-27

Nº	REVISION	DATE

Issued For	Date	By

TYIN INTERNATIONAL
STRUCTURAL ENGINEERING
315 Bay St., San Francisco, Ca. 94133, Tel. (415) 982-1050

SHEET TITLE: **STEADY STATE TEMPERATURE DISTRIBUTION**

PROJECT: **INTEGRATED GASIFIER REACTOR VESSEL**

SHEET Nº

SECTION 7

FABRICATION AND CONSTRUCTION

A preliminary definition of preferred procedures for fabrication and construction of large PCPVs was developed. The integrated gasifier, the most complex of the vessels studied, was selected to illustrate the procedures and fabrication/construction sequence. The results are summarized in this section.

7.1 CONCLUSIONS

Key conclusions are:

(1) Large, complex PCPVs can be built. Prior commercial experience, in the field includes prestressed concrete reactor vessels (PCRVs) and reactor secondary containment vessels used by the nuclear industry, storage vessels, bridges and buildings.

(2) Existing commercial methods and equipment can be used effectively for the construction of these vessels.

7.2 FABRICATION AND CONSTRUCTION SEQUENCE

Figure 7-1 describes the preferred sequence for fabrication/construction of the integrated gasifier vessel. The construction sequence was developed to minimize interferences between crafts.

In general, procedures and scheduling for other PCPVs would be similar to the case illustrated, recognizing that they would be less complex and the projects could be completed in less time.

Referring to Figure 7-1, following initial site preparation, the steel gasifier vessel shell will be fabricated near the erection site. The vessel welds will be radiographed and the vessel checked for leaks before installation. The exterior cooling fins, studs, and cooling tubes will be installed on the vessels and tested before erection. Steps in the fabrication operations are illustrated in Figure 7-2.

The concrete foundations, complete with vertical tendon ductwork, reinforcing bars, and wire mesh, will be poured prior to vessel erection. The concrete foundations will be prepared for vessel erection by placing mats over the concrete where necessary. The concrete will be prepared in a batch mix plant located at the construction site.

Erection of the 320-ton vessel will be done with large crawler cranes as shown in Figure 7-3. The vessel will be attached to the foundations by anchor bolts through the vessel skirt.

After erection of the vessel, the concrete slip form will be installed around it. Reinforcing steel and vertical and horizontal tendon ducts will be installed. The concrete will be poured in 5-foot lifts with each lift pour requiring about 12 hours. The concrete will be placed in the vessel structure by use of three concrete pumps located around the vessel base. Concrete placing booms will be used to distribute the concrete. A week between pours is planned to permit cooling of the concrete mass. This part of the operation is illustrated in Figure 7-4.

The concrete form will use segmental steel construction. It will have self-jacking features so that when the concrete has set, it can be backed away from the concrete and raised to the next level. An auxiliary platform will be located at the bottom of the form to permit finishing operations and installation of nozzles.

Lightweight platorms will be installed at the top of the concrete forms to permit workers to work above the reinforcing steel and concrete. It will also serve as a receiving platform for tendon ductwork and other supplies.

Styrofoam or similar removable material will be installed around areas where nozzles penetrate the vessel exterior face. After the concrete has cured, the styrofoam will be removed and the nozzle extensions welded on.

When concreting has reached a height of 50 feet, the prefabricated auxiliary equipment will be installed with the use of large portable cranes. The equipment will be supported vertically by the concrete. Temporary members will be installed to anchor the vessels in the horizontal plane, as shown in Figure 7-5. Concrete pouring, along with installation of reinforcing steel and vertical and horizontal tendons, will then continue until the vessel is topped off.

The tendon ductwork may be fabricated in the field from strip steel. The vertical ducts will be installed in 10- to 20-foot-long segments. The horizontal ducts will be formed and installed in 60-foot lengths. They will be supported by reinforcing steel prior to concrete pouring.

The installation of horizontal tendons will be done when the concrete has been suitably cured. The vertical tendons will be installed after the concrete pouring has been completed. The tendons consist of 55 strands of 1/2-inch, 270,000 psi steel cable. There are several suppliers and methods of installation of the tendons and the ductwork; one method is illustrated in Figures 7 -6 and 7-7.

Hydrostatic testing of the vessel will be completed prior to installation of refractory.

The internal cooling coils and refractory are next installed; the refractory castable is prepared externally and pumped into the vessel interior. A large gantry crane is installed to provide for refractory installation and repair, closure installation, and other service operations. The connection of external piping will be done during the installation of refractory. These final operations are illustrated in Figure 7-8.

7.3 SCHEDULE

The schedule for the integrated gasifier PCPV is shown in Figure 7-9. The predicted time from project initiation to construction completion is 61 months. A field construction period of approximately 46 months is required. A critical path network of the field activities is shown in Figure 7-10.

For comparison, the field erection time for a single-cavity PCPV is expected to be about 40 to 42 months. This shorter period results from the absence of ancillary vessel installation requirement.

7.4 DISCUSSION

The project plan described above incorporates responses to a number of design, construction and scheduling objectives which are described below.

7.4.1 SITING AND PLANT LAYOUT

The siting of the vessels was selected for efficient operations in recognition of the locations in relation to adjacent plant and facilities. Adequate freedom of movement was provided to permit high local activity occurring during constructionor operation. The plan used construction sequences which allow maximum parallel work progress.

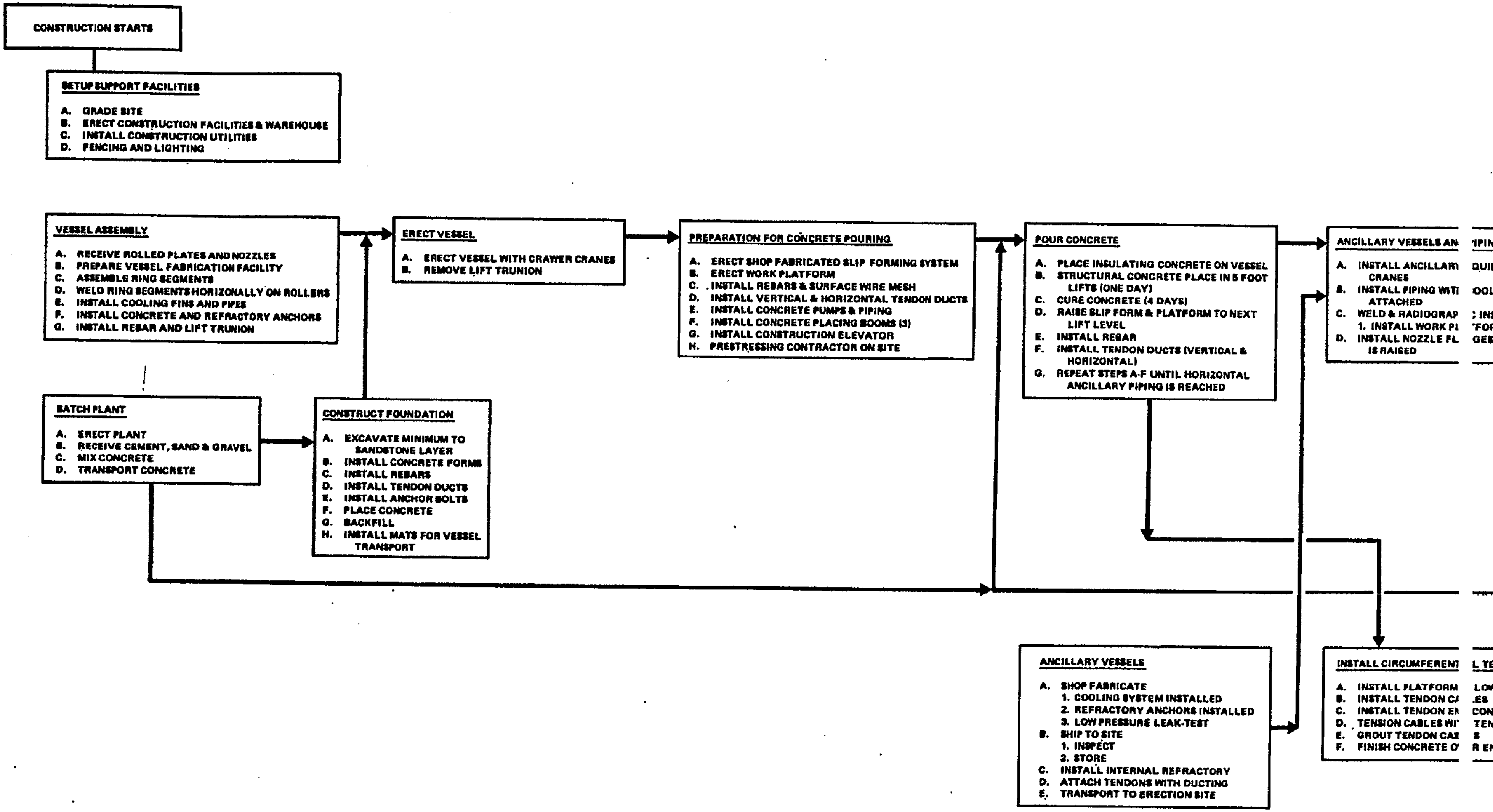
In the PCPV design illustrated, vertical transportation is of particular importance before and after completion of construction. Top cranes and elevators have been included in the present vessel layouts.

7.4.2 CONCRETE SHRINKAGE AND STRAINS DUE TO HEAT OF HYDRATION

The concrete lift schedules were planned to maximize project efficiency recognizing that the heat of hydration of the Portland cement concrete will limit the depth, size, and configuration of each concrete pour. Successful methods have included casting concrete in a full circumferential lift using low heat concrete, casting alternate sectors with a greater depth, or using chilled water in the concrete mix to prevent cracking. It is desirable to avoid discontinuities of section and marked variations of thickness and width over the area being cast.

7.4.3 CONCRETING IN CONGESTED REGIONS

To ensure that a fully compacted concrete structure is achieved, high-workability concrete mixes and careful design/planning is used, particularly where there is congestion of embedded components.


CONSTRUCTION STARTS
SETUP SUPPORT FACILITIES
A. GRADE SITE
B. ERECT CONSTRUCTION FACILITIES & WAREHOUSE
C. INSTALL CONSTRUCTION UTILITIES
D. FENCING AND LIGHTING
VESSEL ASSEMBLY
A. RECEIVE ROLLED PLATES AND NOZZLES
B. PREPARE VESSEL FABRICATION FACILITY
C. ASSEMBLE RING SEGMENTS
D. WELD RING SEGMENTS HORIZONALLY ON ROLLERS
E. INSTALL COOLING FINS AND PIPES
F. INSTALL CONCRETE AND REFRACTORY ANCHORS
G. INSTALL REBAR AND LIFT TRUNION
BATCH PLANT
A. ERECT PLANT
B. RECEIVE CEMENT, SAND & GRAVEL
C. MIX CONCRETE
D. TRANSPORT CONCRETE
CONSTRUCT FOUNDATION
A. EXCAVATE MINIMUM TO SANDSTONE LAYER
B. INSTALL CONCRETE FORMS
C. INSTALL REBARS
D. INSTALL TENDON DUCTS
E. INSTALL ANCHOR BOLTS
F. PLACE CONCRETE
G. BACKFILL
H. INSTALL MATS FOR VESSEL TRANSPORT
ERECT VESSEL
A. ERECT VESSEL WITH CRAWER CRANES
B. REMOVE LIFT TRUNION
PREPARATION FOR CONCRETE POURING
A. ERECT SHOP FABRICATED SLIP FORMING SYSTEM
B. ERECT WORK PLATFORM
C. INSTALL REBARS & SURFACE WIRE MESH
D. INSTALL VERTICAL & HORIZONTAL TENDON DUCTS
E. INSTALL CONCRETE PUMPS & PIPING
F. INSTALL CONCRETE PLACING BOOMS (3)
G. INSTALL CONSTRUCTION ELEVATOR
H. PRESTRESSING CONTRACTOR ON SITE
POUR CONCRETE
A. PLACE INSULATING CONCRETE ON VESSEL
B. STRUCTURAL CONCRETE PLACE IN 5 FOOT LIFTS (ONE DAY)
C. CURE CONCRETE (4 DAYS)
D. RAISE SLIP FORM & PLATFORM TO NEXT LIFT LEVEL
E. INSTALL REBAR
F. INSTALL TENDON DUCTS (VERTICAL & HORIZONTAL)
G. REPEAT STEPS A-F UNTIL HORIZONTAL ANCILLARY PIPING IS REACHED
ANCILLARY VESSELS
A. SHOP FABRICATE
1. COOLING SYSTEM INSTALLED
2. REFRACTORY ANCHORS INSTALLED
3. LOW PRESSURE LEAK-TEST
B. SHIP TO SITE
1. INSPECT
2. STORE
C. INSTALL INTERNAL REFRACTORY
D. ATTACH TENDONS WITH DUCTING
E. TRANSPORT TO ERECTION SITE
ANCILLARY VESSELS AN
A. INSTALL ANCILLARY CRANES
B. INSTALL PIPING WIT ATTACHED
C. WELD & RADIOGRAP
1. INSTALL WORK PL
D. INSTALL NOZZLE FL IS RAISED
IPIN
QUI
OOL
; IN
'FOI
GES
INSTALL CIRCUMFERENT
A. INSTALL PLATFORM
B. INSTALL TENDON C
C. INSTALL TENDON E
D. TENSION CABLES WI
E. GROUT TENDON CA
F. FINISH CONCRETE O
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7-5 (A)

7-5 (B)

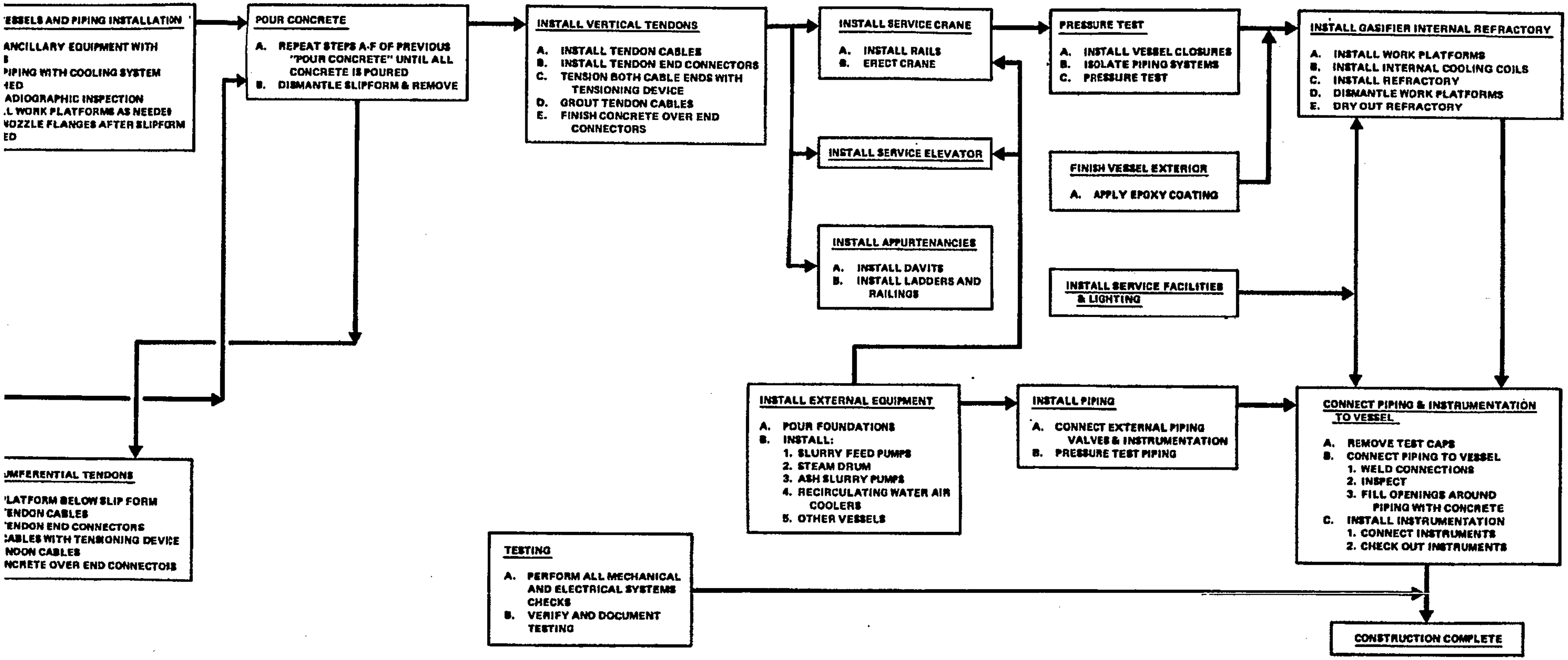

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Figure 7-1 - Construction Sequence – Integrated Gasifier Vessel

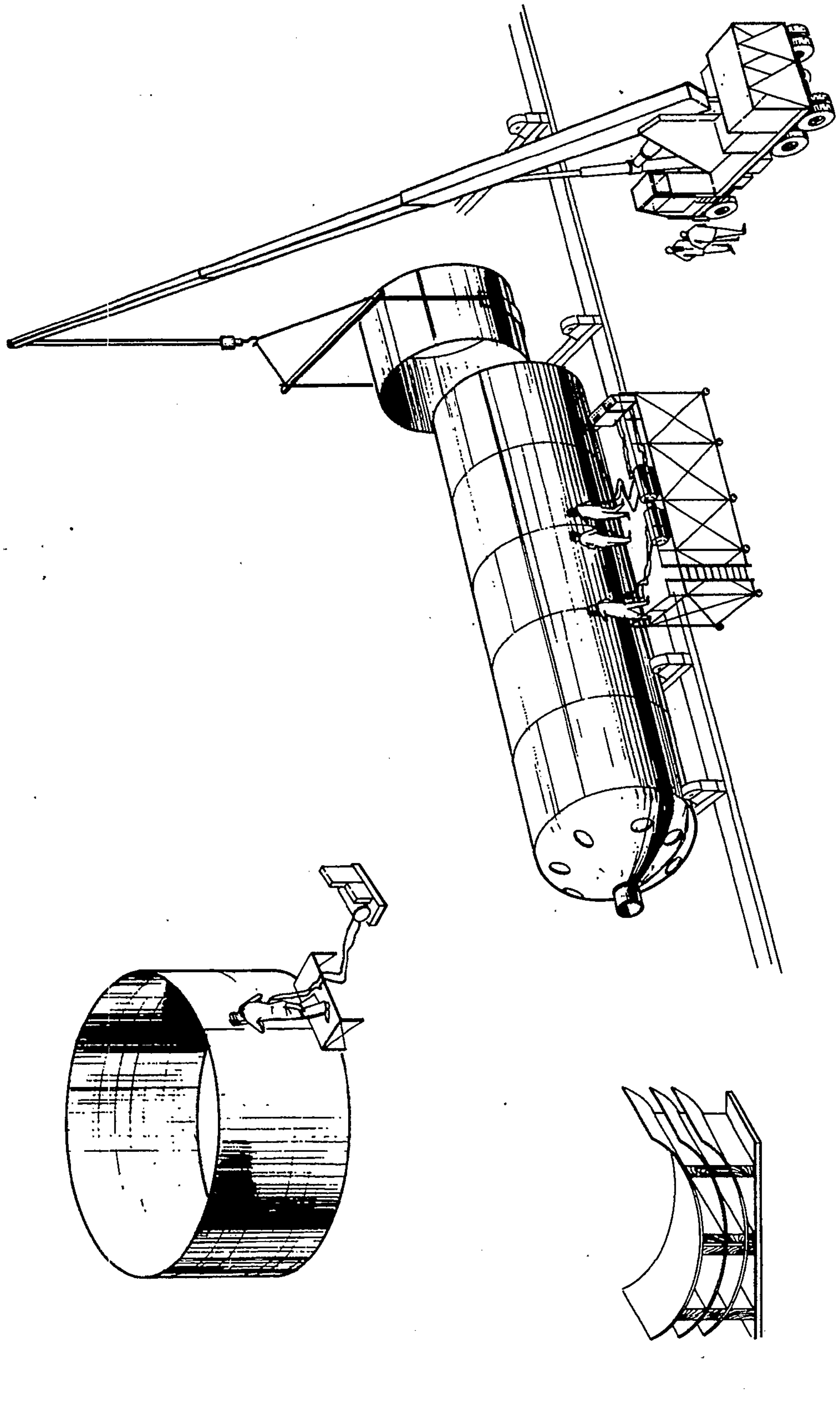

Figure 7-2 - Fabrication of Shell – Integrated Gasifier Vessel

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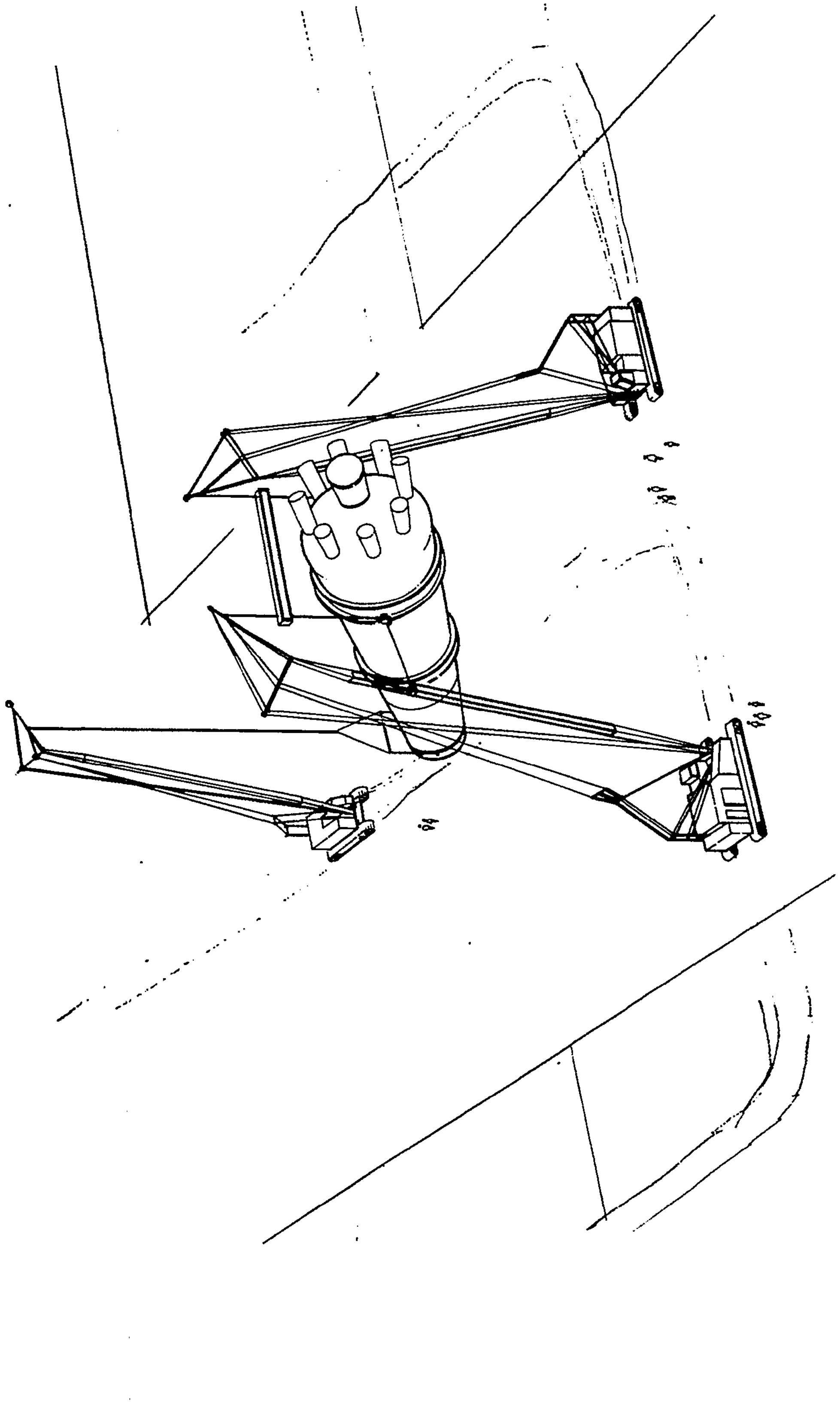


Figure 7-3 - Erection of Vessel – Integrated Gasifier Vessel

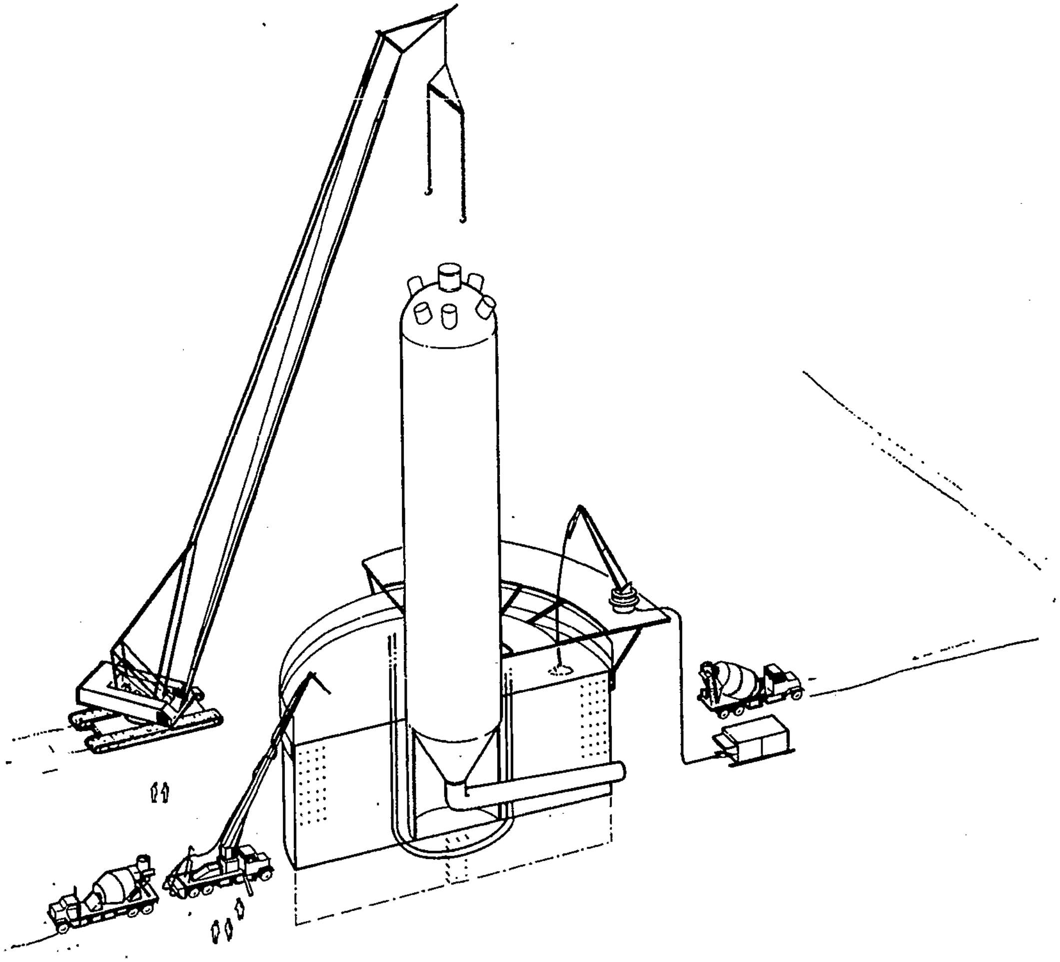


Figure 7-4 - Installation of Slip Form and Casting of Lower Portion — Integrated Gasifier Vessel

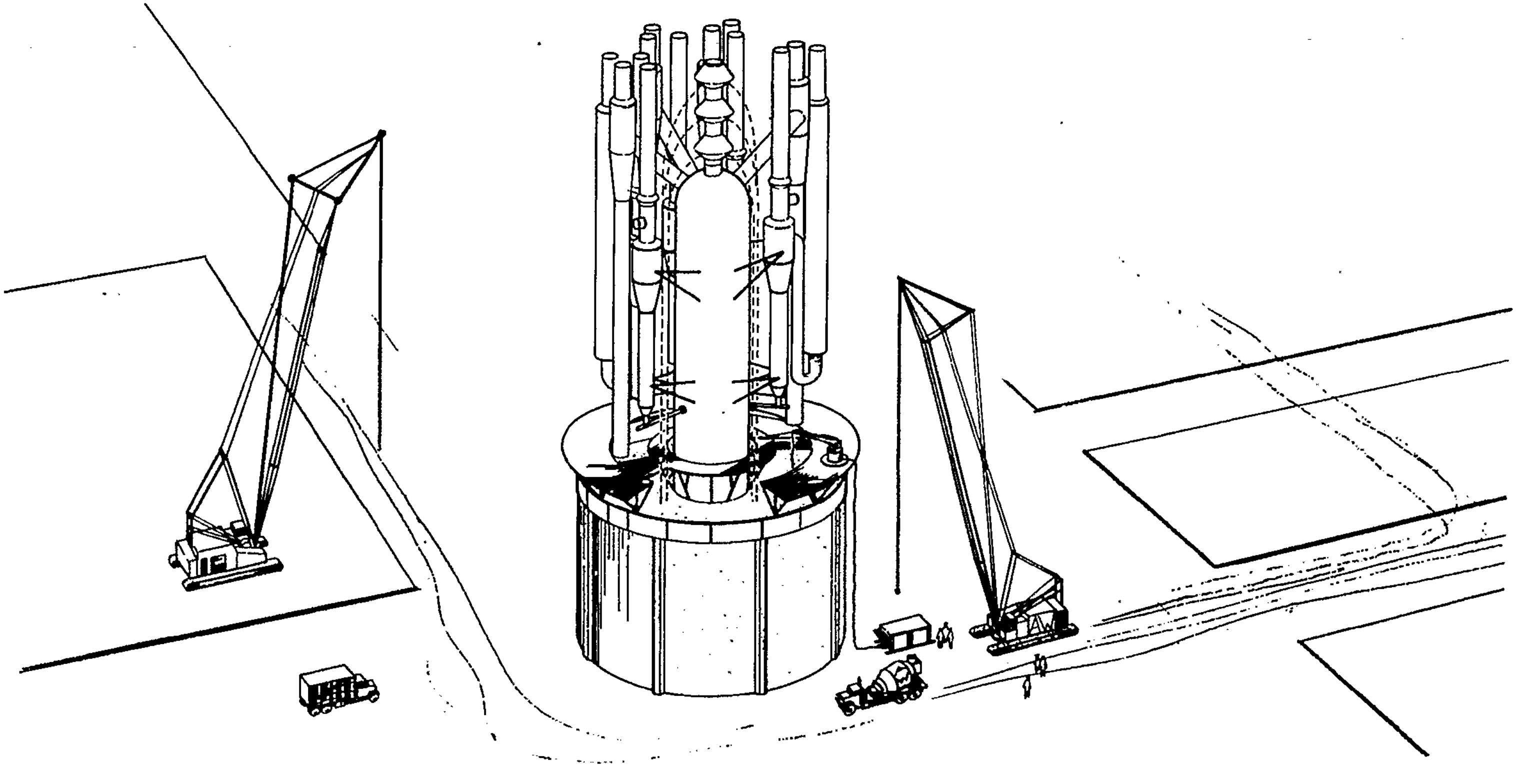
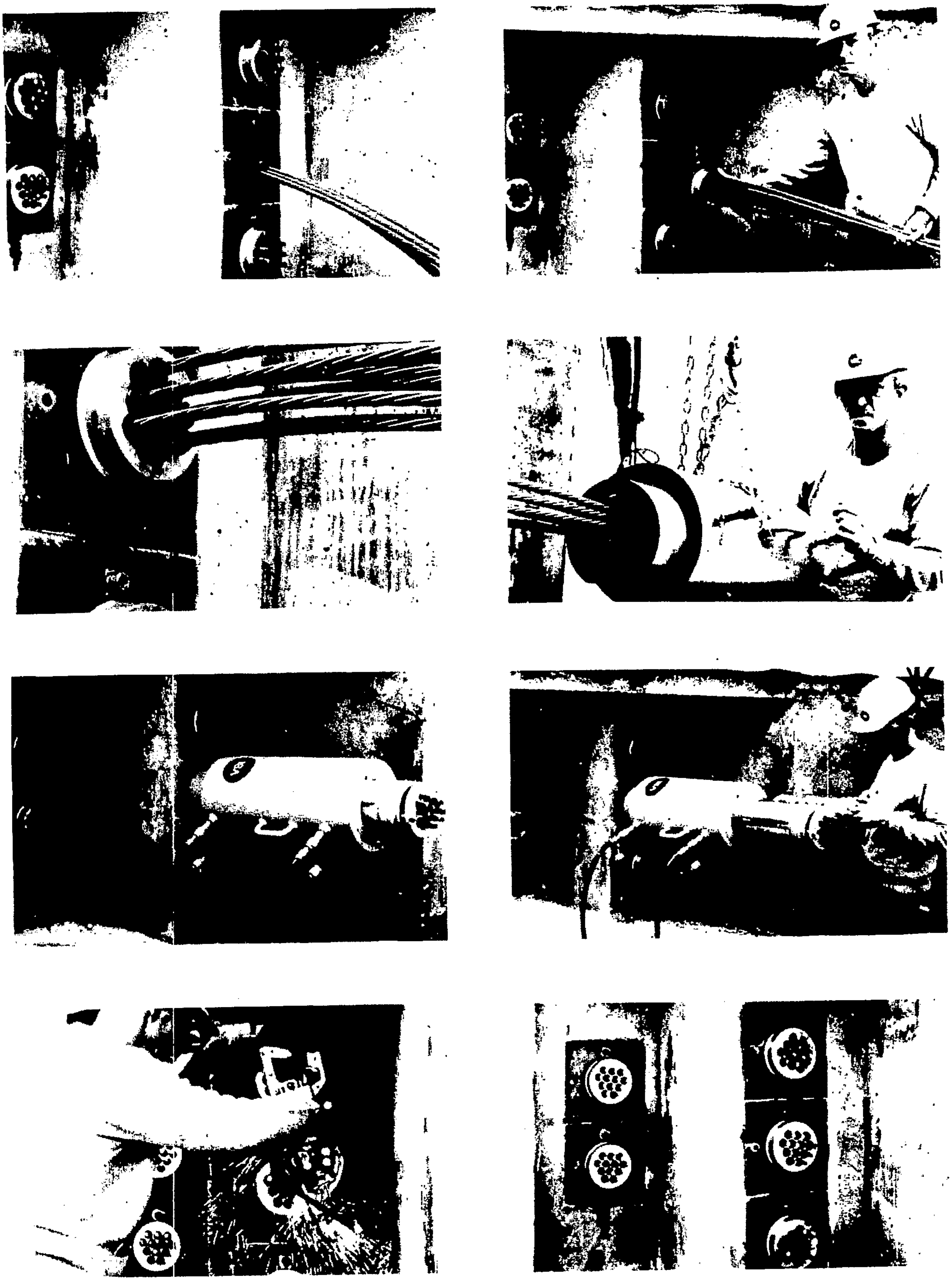


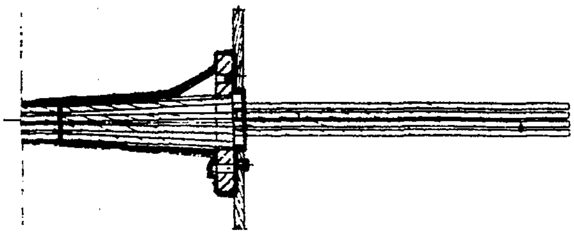
Figure 7-5 - Installation of Auxiliary Equipment —
Integrated Gasifier Vessel



(PHOTOS COURTESY OF VSL)

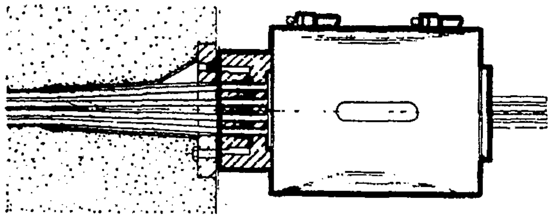
Figure 7-6 - Stressing Procedure

Phase 1



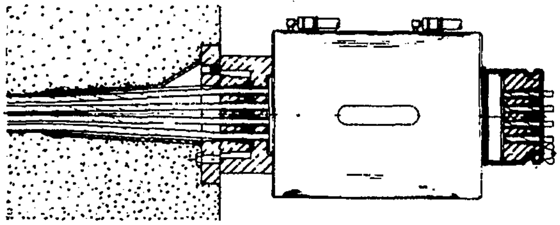
■ Bearing plate with sleeve is attached to formwork ■ Either rigid tubing without strands or flexible tubing containing strands is placed.

Phase 2



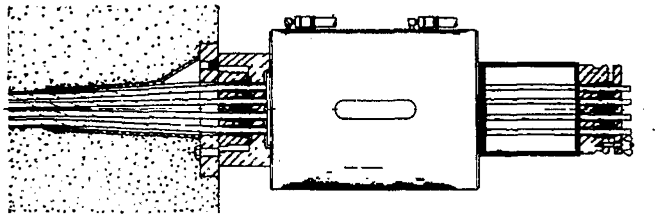
■ After curing of concrete, formwork is removed from anchorage zone ■ Strands are drawn through duct if rigid tubing is used ■ Anchor head and grippers are fitted ■ Center-hole jack is placed over strands.

Phase 3



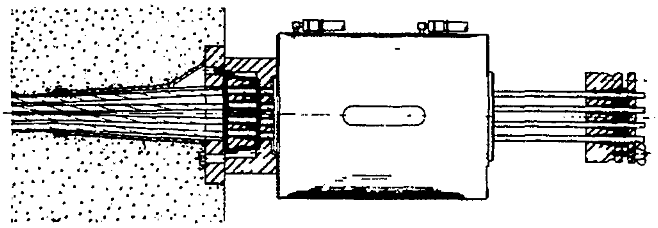
■ Pulling head is fitted. If required, a load cell can be placed between pulling head and jack piston.

Phase 4



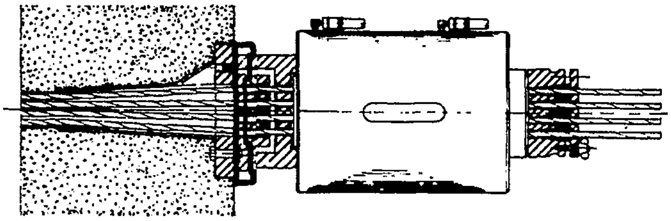
■ Tendon is stressed ■ Pressure gauge reading and cable elongation are recorded.

Phase 5



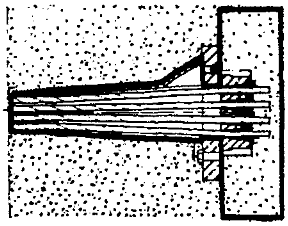
■ Jack piston is retracted ■ Force is transferred to the structure through anchorage.

Phase 6



■ If required, a shim can be placed between anchor head and bearing plate to compensate for anchorage take-up.

Phase 7



■ Stressing equipment is removed ■ Projecting strands are cut off and anchorage sealed ■ Cable is grouted, if required ■ Anchorage is capped with concrete.

(COURTESY OF VSL)

Figure 7-7 - Stress Sequence

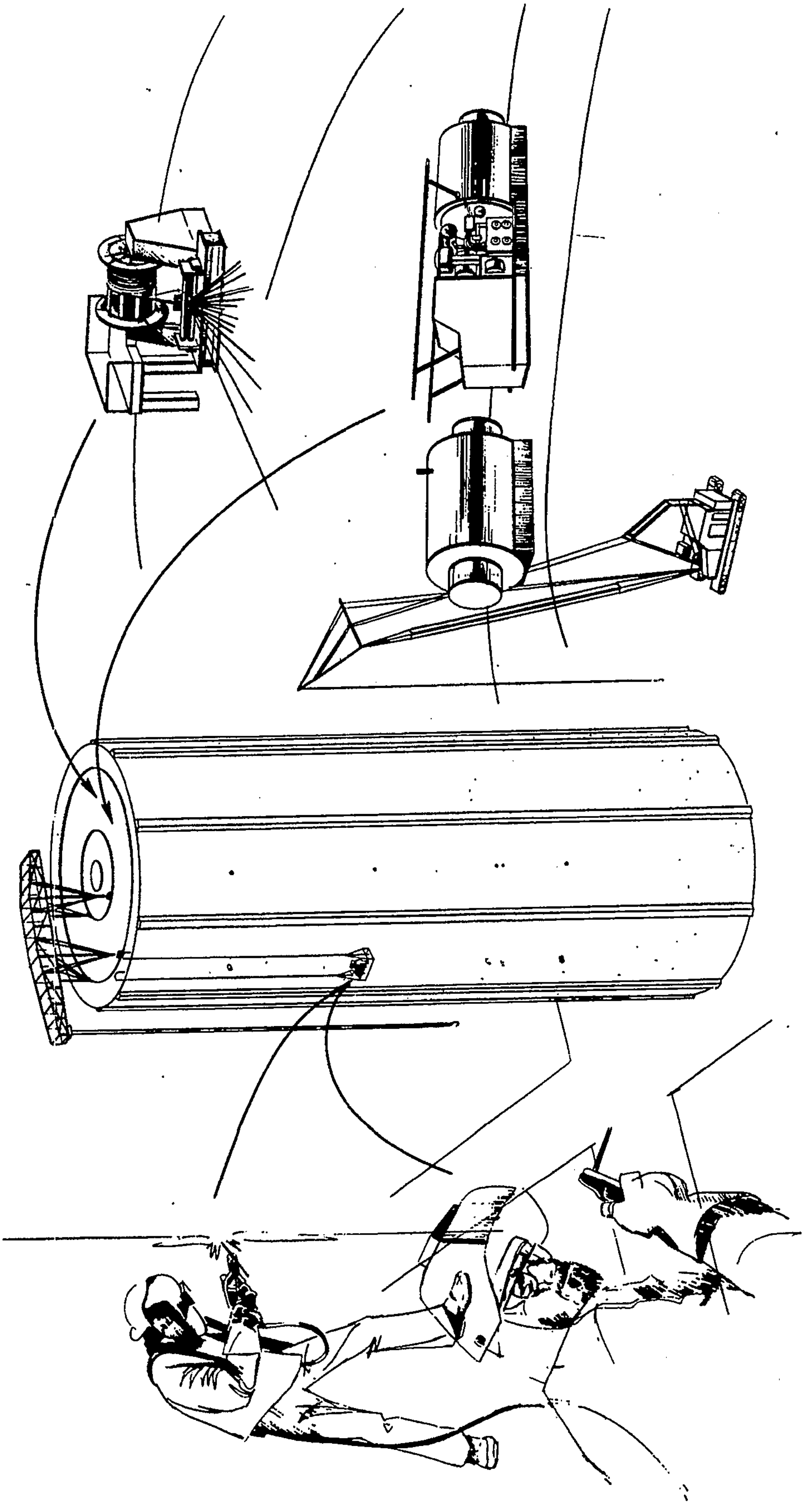


Figure 7-8 - Final Construction — Integrated Gasifier Vessel

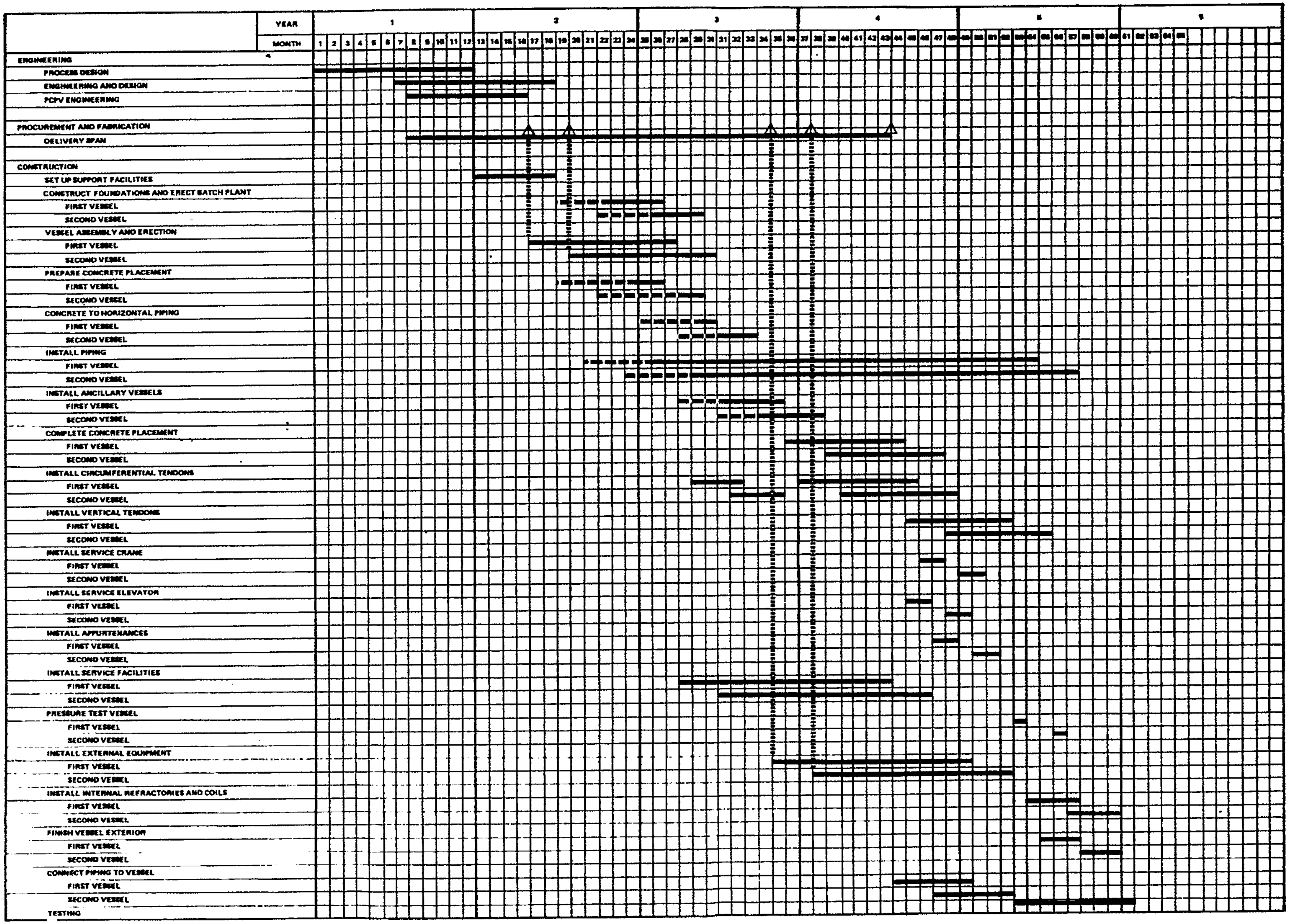


Figure 7-9 - Overall Schedule – Integrated Gasifier Vessel

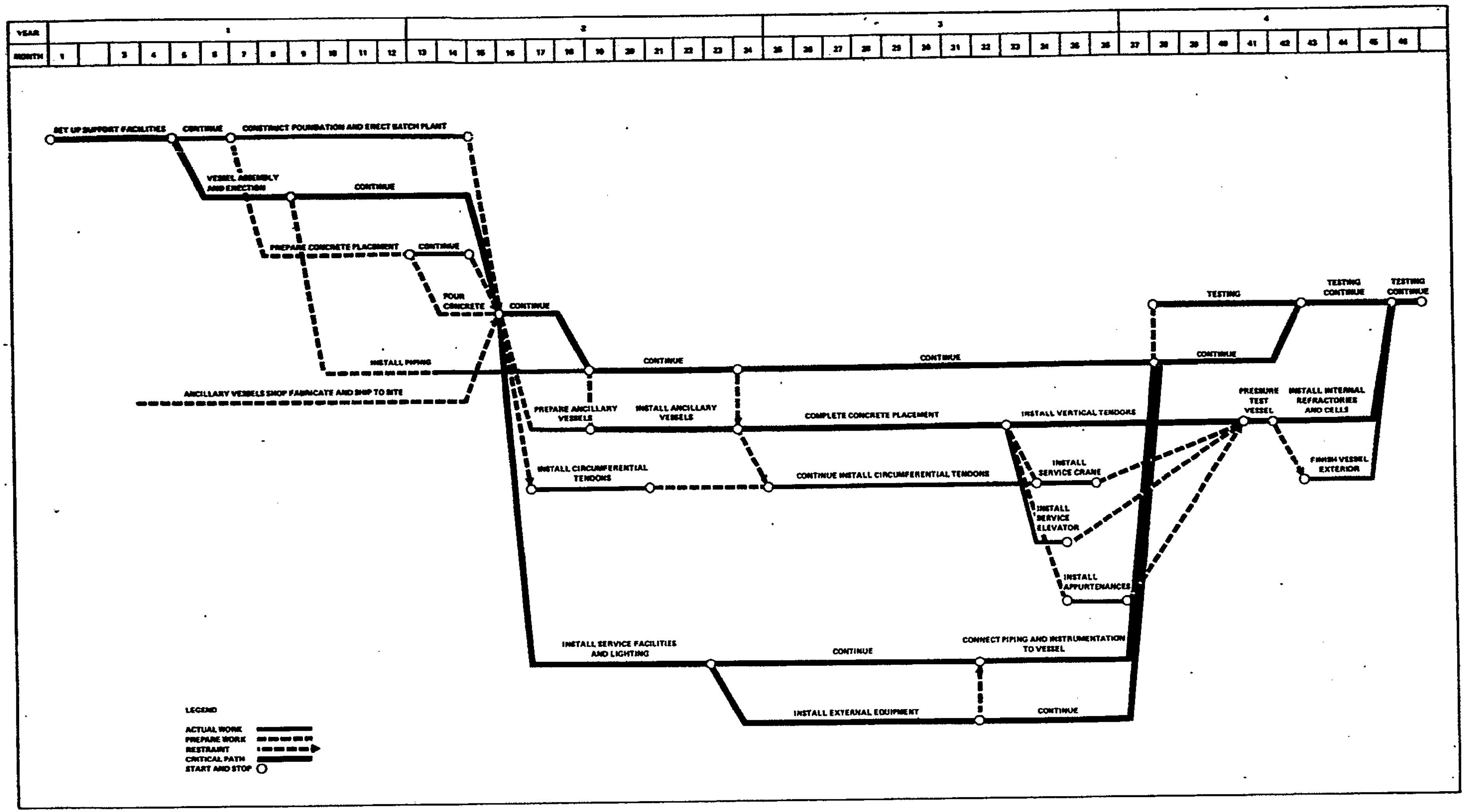


Figure 7-10 - Construction CPM Schedule — Integrated Gasifier Vessel

SECTION 8

TECHNICAL FEASIBILITY

This section deals with the ability of PCPVs to meet the process and operational requirements of future coal conversion plants.

8.1 VESSEL SIZE, MATERIALS AND CONSTRUCTION CONSIDERATIONS

A survey of the steel pressure vessel requirements for the Oil/Gas process[1] for the production of a total of about 110,000 equivalent BPSD (6×10^6 Btu/bbl) indicates that 16 services are possible candidates for PCPVs. These 16 services require a total of 26 steel pressure vessels with 4-inch thick walls. This quantity could be reduced to 16 if PCPVs were substituted for steel vessels.

In the Oil/Gas report[1] there are 51 pressure vessels. If the plant capacity is increased threefold using the same design and sizes, it would require 153 pressure vessels. By the use of PCPVs in conjunction with steel vessels, this quantity could be reduced to a total of 41 pressure vessels, with 15 to 18 of PCPV construction and the remainder of conventional steel construction.

The shipment of shop-fabricated steel vessels is limited by crane capacities to about 1,000 to 1,200 tons by navigable waterway. If rail shipment is required, the vessel outside diameter is limited to about 14 feet. There are presently about 10 shops in the United States capable of building heavy-walled pressure vessels of 10 to 12 inch wall thickness for all uses - nuclear, boilers, as well as process vessels.

There is a very limited number of suppliers of heavy-wall pressure vessel grade steel plate in the United States. There is one company in the United States, one in Europe, and one in Japan with capability to produce 12 to 15 inch thick plates with weights of 90,000 to 100,000 pounds. There are a number of suppliers of pressure vessel grade steel plate of lesser thickness.

There is one U. S. firm experienced in the field fabrication of heavy walled pressure vessels. At least two other firms have organizations for the field erection of such vessels.

Structural concrete in the desired quantities and quality for the PCPVs is widely available in the United States. There are presently four steel companies in the United States that supply the 270 ksi strength cable tendons with a capacity of 80,000 to 100,000 tons per year. The present consumption of this cable is 200,000 to 250,000 tons per year, with about 80% being supplied from foreign countries, primarily Japan. Two other major U. S. steel firms have, in the past, produced this cable. There is believed to be a large overcapacity to produce these cables in foreign countries.

The tendon ducts are made of 14 to 18 gauge galvanized steel sheet. Six firms in the United States are presently fabricating the ducts.

A comparison was made of the total weight, including foundations and associated structural steelwork, of the PCPVs against steel vessels of about the same total capacity. This data is shown in Table 8-1. The PCPVs weighed 4 to 10 times as much as the steel vessels. Concrete in the PCPVs contributed 88% to 92% of their total weight.

A comparison was made of the total steel requirements using PCPVs as compared to conventional steel pressure vessels. The results are summarized below for reduction (or gain) using PCPV construction.

- Integrated gasifier - 23% reduction
- Gasifier only - 33% reduction
- Dissolver separator - 62% reduction
- Absorber - 38% gain

8-2 INSPECTION

It is a common practice (mandatory in some states) to periodically inspect pressure vessels after they are placed in operation to assure that no defects have developed. This is necessary to avoid possible injury to personnel, damage to other equipment, or unscheduled plant shutdowns.

In conventional steel pressure vessels this may involve such items as visual inspection, thickness measurements, ultrasonic tests, magnetic particle inspection, dye penetrant tests, or radiographic tests when the vessel is not in service.

Several monitoring methods are also utilized to give warnings while the steel vessels are in operation. These techniques include small weep holes in the shell to disclose when the corrosion allowance has been used up; the use of temperature sensitive paints, skin thermocouples, infrared sensors, and other thermal sensing devices to detect "hot spots" caused by internal refractory failures; and acoustic emission devices for determination of crack growth.

For PCPVs the inspection and monitoring can be divided into two areas. The first area covers the internal refractory and refractory anchors (if used), the metal membrane wall, the concrete to membrane wall attachments, and the external cooling water tubes (if applicable).

The second area covers the structural concrete, reinforcing steel, the tendon cables, and duct work.

Table 8-1 - Weight Comparison[(a)] Steel Vessels Versus PCPVs (in tons)

Item	Integrated Gasifier		Gasifier Only		Dissolver Separator		Absorber	
	PCPV	Steel	PCPV	Steel	PCPV	Steel[b]	PCPV	Steel[c]
Steel shells and fins	1,870	7,760	460	2,310	590	16,300	260	1,270
Steel tendons and Ducts	4,260	-	980	-	4,320	-	1,060	-
Reinforcing steel	1,960	810	630	260	1,360	240	500	50
Cooling water piping	330	-	70	-	100	-	-	-
Internal refractory	3,570	3,570	850	850	-	-	-	-
Insulating concrete	490	-	300	-	520	-	-	-
Structural concrete	122,130	16,450	31,330	1,810	72,180	4,680	21,710	960
Structural steel	-	2,350	1,150	2,350	-	-	-	-
Total	134,610	30,940	35,770	7,580	79,070	21,220	24,530	2,280

[a] Includes foundations.

[b] 9 dissolvers, 9 separators.

[c] 6 absorbers.

In the first area, the internals of the vessels may be visually inspected by entering through access plugs in the top heads. For vessels without internal refractory, the metal membrane wall thickness may be checked by either taking out plug sections of the wall or by ultrasonic techniques.

For vessels with internal refractory linings the refractory thickness may be inspected by visual and physical hand testing and if necessary, by removing sections of the refractory lining. Localized inspections of the metal membrane wall can be accomplished by first removing the refractory lining over the metal membrane.

No method is presently known for inspection of the structural concrete to membrane wall attachments, the insulating concrete, or the cooling water tubes within the concrete.

The monitoring of the integrity of the membrane wall against high temperatures or for fluid leakage appears possible. High temperatures caused by refractory failure can be monitored by use of skin thermocouples or other thermal sensing devices placed on the exterior surfaces of the metal membrane. A second means is the measurement of the differential temperature of the water in and out of each cooling tube circuit.

The leakage of fluid through the membrane wall can be partially monitored by the placement of sampling tubes located strategically on or near the external surface of the membrane wall. The success of this technique would be highly dependent upon the proximity of the sampling tube to the leak, the porosity of the concrete, cracking, and the size of the leak.

As to the second area (structural concrete, reinforcing steel, the tendon cables, and ductwork) the common practice is a visual inspection of the external surface for spalling and cracking. It may be possible to install strain gauges to observe any changes in the stress levels of the concrete, reinforcing steel, and the tendons. For unbonded tendon cables, it may be possible to check the cable tension loads after the unit had been in operation for an extended time period.

In vessels without an internal refractory lining, it could be possible to periodically hydrostatically test a PCPV. In vessels with an internal refractory lining, removal of the lining would be required before hydrostatic testing to avoid a later failure of the lining due to moisture pickup.

8.3 MAINTENANCE AND REPAIR

Accessibility to the interior of the PCPVs is provided by nozzle closures located on the top of the structures. These large closures are removed with the aid of an overhead gantry crane. Access to the bottom sections of the larger PCPVs is provided by removal of external piping spool pieces.

Certain equipment items such as coal and char eductors for gasifiers are designed to be removable for maintenance. The large slide gate valves used for solids flow control in the integrated gasifier PCPV are specially designed for repair from within.

Horizontal piping connections for temperature, pressure, and level connections are designed for rodding-out and repair from the outside.

Repair of the refractory within the smaller connecting piping (32-inch and 48-inch inside diameter refractory) of the integrated gasification vessel will be difficult at elbows and bends.

Repair of the membrane metal wall may generally be done by either welding a patch slate or overlay welding over the area to be repaired.

Internal cooling coils for the gasifier vessels are made in segments. Major repairs may be made by removing the segment from the vessel, repairing, and then reinstalling in the vessel. Minor repairs may be done in place.

Repair of the external cooling coils embedded in the concrete will be difficult. It would require removal of any internal refractory, metal membrane wall, insulating concrete, and the metal connecting plate. For these reasons, the following precautions would be taken:

- The piping is designed for a 20-year minimum life. It will be fabricated of high-quality pipe material.
- The piping is inspected and hydrostatically tested before embedding in concrete.
- High-purity water is used in the cooling loop to avoid problems with corrosion and scale buildup.

8.4 CHANGES AND MODIFICATIONS

The modification of a PCPV after construction would be difficult because of the mass of concrete, the locations of reinforcing steel tendons, and tendon ductwork; also, the tendons are designed to handle forces at specific locations.

If additional or larger nozzles are expected to be required at a later date, consideration should be given to installing them initially. They could be either blanked off or smaller piping installed inside of larger pipes for the initial operations. The later additions of nozzles would require removal of concrete, reinforcing bars, tensioning cables and ductwork, the metal membrane wall in the area, and possibly cooling coils.

Further, the addition of nozzles may effect the locations of the vertical and horizontal tendons. The effect of removal or relocation of the tendons would require very careful engineering study to ensure that the vessels structural integrity is not compromised.

The least difficult of the PCPVs to modify would be the single- or two-cavity vessels as represented by the absorber and the dissolver-separator vessels. The integrated gasifier vessel would be the most difficult to change because of the complex internal geometry.

The removal of a PCPV would be a major undertaking because of their massive weights (24,000 to 135,000 tons) and the reinforcing steel. Explosive demolition would be required.

8.5 SAFETY

The protection of personnel and equipment against a catastrophic failure of a large high-pressure vessel is a very important consideration. The primary failure would be the rupture of the pressure containing shell. The three primary causes of such ruptures would be:

- Mechanical failure
- Overpressure of shell
- Overheating of shell

In the case of a conventional steel vessel in the large sizes and high pressures used in this study, a rupture could have serious consequences. For conventional steel vessels, the materials and design methods are well established. The internal refractory materials for temperature protection are being tested in pilot plants and in various other test programs. Instrumentation and safety valves are provided to protect against overpressure.

In the case of PCPVs the mechanical design will require close scrutiny, as existing codes are not applicable to these vessels as discussed in Sections 6.4.2. The indications are that for overpressure, the concrete will crack and the tensioning cables will relieve the pressure without a catastrophic failure and after the pressure has been relieved, the concrete will again seal by the force of the tension cables. Controlling of the maximum feed pressure of the inlet streams (coal slurry, oxygen, and steam) to below the maximum design pressure will assist in limiting the internal pressures. Safety relief valves are also provided to limit the maximum internal pressure.

Overheating of the PCPV membrane wall can be caused either by refractory failure in the case of the gasifier vessels or by external cooling water failure. A refractory failure of approximately 63 square feet to within one inch of the steel membrane wall will raise the water temperature 5°F in about 1.2 hours.

A total failure of cooling water would cause the membrane wall to rise to about 900°F in 1 hour and to 1,300°F in about 6-1/2 hours. To protect against the effects of a cooling water failure, the following safeguards would be provided:

- Water circulation pumps would be spared and both motor and steam turbine drivers would be provided.
- No-flow and high outlet water temperature alarms and switches will be provided to stop oxygen and coal flow to the gasifier vessels.

SECTION 9

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APPENDIX A

REFRACTORY CHARACTERISTICS

I. STAGE I - HIGH ALUMINA PLASTIC, PHOSPHATE BONDED

Chemical Analysis (Calcined Basis)

Al_2O_3: 88-92%

SiO_2: 6% (typical)

P_2O_5: 3.4.5%

Alkalies: 0.5 maximum

Other oxides: 0.1 maximum

Technical Data

Service temperature: 3,250°F (1,790°C)

Material required for estimating: 190 lb/ft^3

Thermal conductivity: Less than 16 $Btu/in./ft^2/hr/°F$ at 2,800°F

Physical Properties

After firing and cooling:

	Temperature		Modulus of Rupture		Linear Change
Hours	°F	°C	psi	kg/cm^2	(%)
24	450	230	1,900	133	0.1 to 0.3 S
5	1,500	815	2,540	178	0.0 to 0.2 S
5	2,000	1,095	3,580	251	0.0 to 0.2 E
5	2,500	1,400	4,720	320	0.5 to 0.2 E
5	3,000	1,650	2,570	180	0.0 to 0.2 E

Panel spalling loss:
3,000°F (1,650°C) preheat: 0-4%

Average storage life: 4 months

II. STAGES I AND II - INSULATING CASTABLE (LOW IRON)

Chemical Analysis (Ignited Basis)

Ignition loss: 0.7%

SiO_2: 32-38%

Fe_2O_3: 1.0

Al_2O_3: 52-60%

TiO_2: 1.0 (typical)

MgO: 0.2 (typical)

CaO: 5-6.5%

Alkalies: 2.0 maximum

Technical Data

Service temperature: 2,600°F

Material required for estimating: 60-70 lb/ft^3

Predampening water: 10-15%

Thermal conductivity: (mean temperature)	(Btu/in./ft^2/hr/°F)
500°F (260°C)	1.65 (typical)
1,000°F (540°C)	1.54 (typical)
1,500°F (815°C)	1.84 (typical)
2,000°F (1,095°C)	2.39 (typical)

Physical Properties

After firing and cooling:

Hours	Temperature °F	°C	Cold Crushing Strength psi	kg/cm^3	Linear Change (%)
24	250	110	300-400	21-28	0.6 to 0.8 S (typical)
5	1,700	925	150-250	10-18	0.6 to 0.9 S
5	2,000	1,095	100-200	7-14	0.6 to 0.9 S
5	2,500	1,370	300-400	21-28	1.0 to 0.5 S
5	2,600	1,425	300-400	21-28	

III. STAGE II - WORKING LINING, HIGH-PURITY ALUMINUM CASTABLE

Chemical Analysis (Calcined Basis)

SiO_2: 0.1-0.2%

Al_2O_3: 92-96%

Fe_2O_3: 0.3%

CaO: 4.3-6%

MgO: 0.1

TiO_2: 0.1 maximum

Alkalies: 0.4 maximum

Technical Data

Service temperature: 3,300°F minimum

Material required for estimating: 170 lb/ft^3

Predampening water: 3-4%

Maximum grain size: 6 mesh

Thermal condition ($Btu/in./ft^2/hr/^\circ F$): Less than 11 at 2,400°F

Physical Properties

After firing and cooling:

Bulk density (after 200°F drying): 170 lb/ft^3 (typical)

Hours	Temperature °F	°C	Modulus of Rupture psi	kg/cm^2	Dimensional Firing Change, Linear (%)
24	230	110	1,400	99	0.0 to 0.1 S
5	1,750	995	1,600	113	0.0 to 0.1 E
5	2,000	1,095	1,300	92	0.1 to 0.2 E
5	2,500	1,370	2,290	162	0.1 to 0.5 S
5	2,700	1,480	3,000	212	0.1 to 0.1 E

CO: disintegration test:

100 hr unaffected -- carbon spots

200 hr unaffected -- carbon spots

APPENDIX B

COOLDOWN RATE

SUMMARY

Theoretical calculations of the cooldown rates for the absorber, dissolver, gasifier, and the char cyclones have been completed and are attached. For ease of calculation it has been assumed in each case that the purge gas is at the same temperature as the cooling water (100°F). In summary, the results are:

(1) Absorber (Figure 3-1) - It will require approximately one hour to cool the inside wall of the vessel to 110°F from an operating temperature of 120°F. It will require about 6-1/2 days to cool the inner two feet of concrete to 110°F.

(2) Dissolver (Figure 3-2) - The inner shell of the dissolver will cool to 125°F from the operating temperature of 850°F in approximately 10 hours. It will require about 11 hours for the inner 3 inches (average radius of 203 inches) of insulating concrete to cool to 125°F and 14 hours to cool to 110°F.

(3) Gasifier (Figure B-3) - The internal refractory wall of the upper stage will cool from 2,50°F to 125°F in about 20 hours. It will require about 36 hours for the first 4-1/2 inches of refractory (average radius of refractory) to cool to 125°F from a normal temperature of about 1,500°F.

(4) Char cyclones (Figure B-4) - Approximately 5 hours are required for the surface of the internal refractory to cool to 125°F from an operating temperature of 1,700°F. It will require about 8 hours for the first 3-3/4 inches (average radius of refractory) to cool to 125°F. Since the hot ducts have the same refractory thickness as the char cyclones, these results should also be representative of the ducts.

COOLING RATES FOR THE VESSELS AND DUCTS IN THE PRESTRESSED CONCRETE COAL GASIFICATION SYSTEM

The rate of cooling or heating for the vessels and ducts contained within the prestressed concrete system can be determined theoretically using the initial boundary conditions and the heat transfer coefficients at the boundary of each cylindrical surface.

Let the function $T(r,t)$ denote the temperature distribution between the inner radius $(r = a)$ and the outer radius $(r = b)$ of the vessel or duct. If $f(r)$ denotes the temperature distribution at time $t = 0$, h_a denotes the heat transfer coefficient at $r = a$, h_b denotes the heat transfer coefficient at $r = b$, T_a = temperature of the medium for r less than a, T_b = temperature of the medium for r greater than b, and K = thermal conductivity of the vessel, the boundary conditions are:

$$\text{At } r = a \qquad K \frac{\partial T(r,t)}{\partial r} - h_a[T(r,t) - T_a] = 0 \tag{1a}$$

$$\text{At } r = b \qquad K \frac{\partial T(r,t)}{\partial r} + h_b[T(r,t) - T_b] = 0 \tag{1b}$$

$$\text{At } t = 0 \qquad T(r,0) = f(r) \qquad a < r < b \tag{1c}$$

The function $T(r,t)$ must also satisfy the time-dependent heat equation:

$$\frac{\partial T(r,t)}{\partial t} = k \frac{\partial}{\partial r}\left[r \frac{\partial T(r,t)}{\partial r}\right] \tag{2}$$

for all r and all t; k is the thermal diffusivity of the vessel wall.

For simplicity, Equations 1a and 1b may be rewritten as:

$$\text{At } r = a \qquad k_1 \frac{\partial T(r,t)}{\partial r} - k_2 T(r,t) = k_3$$

$$\text{At } r = b \qquad k_4 \frac{\partial T(r,t)}{\partial r} + k_5 T(r,t) = k_6$$

For convenience, it will be assumed that $T_a = T_b = T$ although an exact solution can be obtained without this assumption. However, the solution is considerably more complicated. The solution to these problems involves Bessel functions of the first kind, $J_n(x)$, and Bessel functions of the second kind, $Y_n(x)$, where $n = 0,1$.

The solutions may be summarized by defining the following functions:

$$U_1 = k_2 J_0(a_n a) + a_n J_1(a_n a)$$

$$U_2 = k_5 J_0(a_n b) - a_n J_1(a_n b)$$

$$U_3 = k_2 Y_0(a_n a) + a_n Y_1(a_n a)$$

$$U_4 = k_5 J_0(a_n b) - A_n J_1(a_n b)$$

$$C_0(a_n, r) = Y_0(a_n r)U_1 - J_0(a_n r)U_3$$

$$C_1(a_n, r) = Y_1(a_n r)U_1 - J_1(a_n r)U_3$$

where it has been assumed that $k_1 = k_4 = 1$, $k_2 = h_a/K$, $k_5 = h_b/K$, and $k_3 = - h_a T/K = - k_6$. The numerical values a_n compose an infinite set of values which represent solutions to the equation:

$$U_1 U_2 - U_3 U_4 = 0 \tag{3}$$

$$T(r,t) = T - \frac{\pi^3}{2} \sum_{n=1}^{\infty} \frac{a_n^2 U_4^2 C_0(a_n, r) I \, e^{-k a_n^2 t}}{(a_n^2 + k_5^2)U_0^2 - (a_n^2 + k_2^2)U_4^2} \tag{4}$$

where

$$I = \int_a^b r[T - f(r)] C_0(a_n, r) \, dr \tag{5}$$

Once f(r) is specified, the integral may be carried out and the roots of Equation 3 may be determined using a computer.

ABSORBER

Since the absorber vessel is not water-cooled, it is the least complicated to treat theoretically. It can be assumed that the entire structure is at the operating temperature [$f(r) = T_0 = 120°F$] before cooldown is begun. It is also assumed that at the start of the cooldown procedure, the interior of the absorber vessel is purged with gas at the same temperature as ambient and that the total heat transfer coefficient (conduction + radiation) at the outside surface is the same as that at the inside surface. The numerical value $H = 5.0$ Btu/ft^2/hr/°F corresponding to a 5-mph wind is used in the calculation. The thermal diffusivity of the concrete was calculated to be 0.040 (ft^2/hr)$^{-1}$ corresponding to a specific heat of 0.20 Btu/lb/°F.

The integral in Equation 5 is equal to:

$$I = \frac{[bY_1(a_n b) - aY_1(a_n a)]\, U_1 - [bJ_1(a_n b) - aJ_1(a_n a)]\, U_3}{a_n}$$

While there exists an infinite number of values of a_n which satisfy Equation 3, each of which is finite, only the first few values are needed in the calculations. This is because the exponential term in Equation 4 predominates for $t > 0$ and the higher-order terms (i.e., large a_n) rapidly decrease to negligible values. It is only in the case of small t that it is necessary to include all roots for proper convergence to T_0.

The solution has been carried out to the first fourteen roots for $r = a$, $r = b$, $r = a + 1$ ft, and $r = 1/2(a + b)$ using $a = 11$ ft and $b = 22$ ft. Small changes in a and b will not affect the results. The results are plotted in Figure B-1 and the coefficients are tabulated in Table B-1.

The results of this calculation for the absorber vessel indicate that it will take approximately 96 hours for the temperature to reach 125°F at the inside radius plus 1 ft and that it will take approximately 408 hours (17 days) for the temperature to drop to 125°F at the average radius.

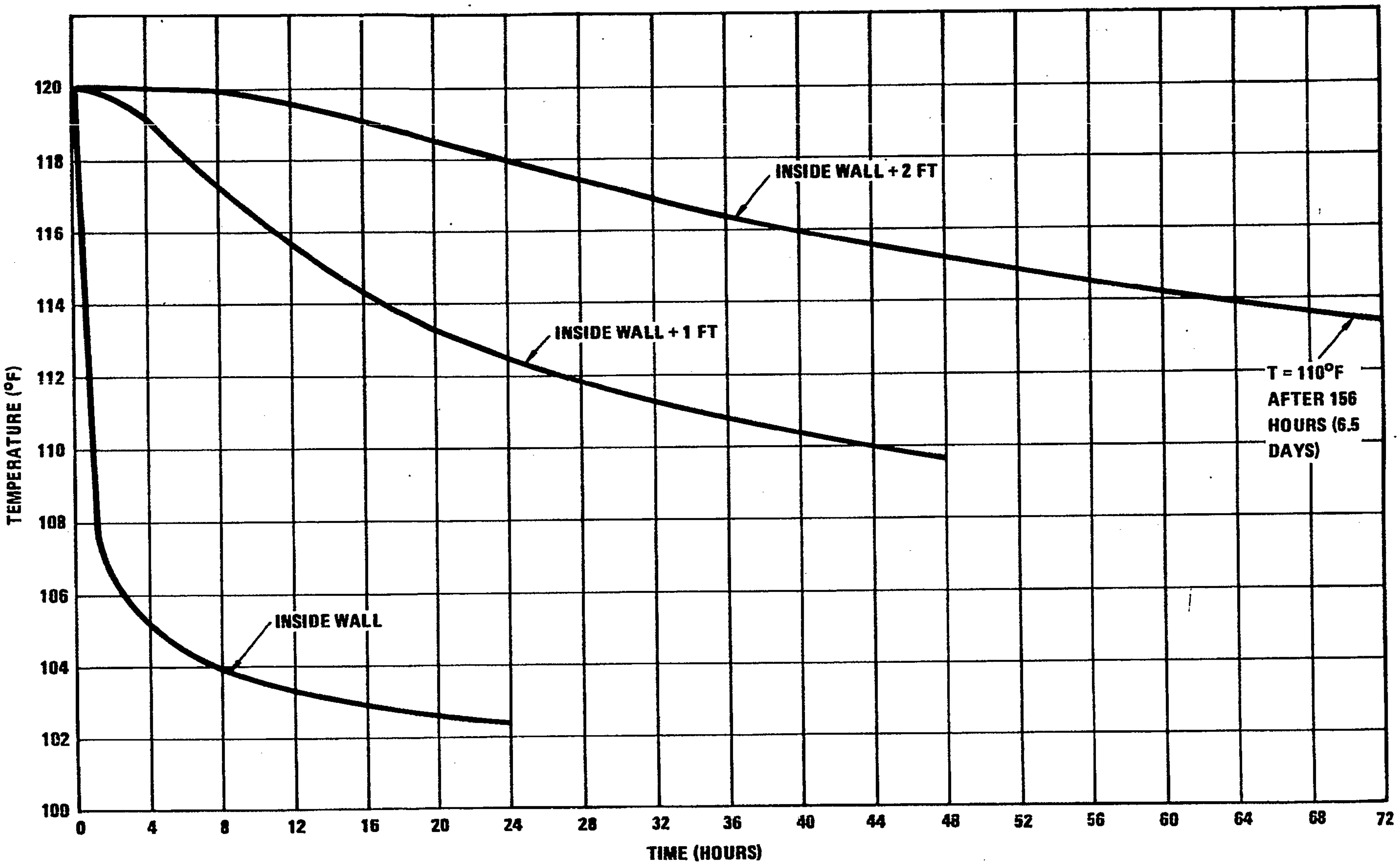


Figure B-1 - Cooling Curve for the Absorber (Assumes Operating Temperature of 120° F)

Table B-1 - Numerical Results for the Absorber

$$\text{Let } T(r,t) = T + (T_0 - T) \sum_{n=1} G_n \, e^{-ka_n^2 t}$$

Coefficient	a_n	At r = 11	At r = 12	At r = 16.5	At r = 22
G_1	0.27381	0.0853513	0.484857	0.0609583	1.27373
G_2	0.55035	-0.0147896	-0.079919	0.01058	0.000255
G_3	0.82643	0.0818709	0.4049	0.0586367	-0.413112
G_4	1.10255	-0.0143421	-0.622409	0.012625	0.00002299
G_5	1.37879	0.0780583	0.282567	0.0558845	0.24121
G_6	1.6553	-0.0133703	-0.0377762	0.00955852	-0.00004255
G_7	1.932	0.0735311	0.147001	0.052628	-0.167864
G_8	2.2091	-0.0124836	-0.0147862	0.00891902	-0.00073468
G_9	2.4864	0.0680003	0.0288064	0.0486489	0.12559
G_{10}	2.76415	-0.0114667	0.002829	0.00819319	-0.000491
G_{11}	3.04222	0.0619506	-0.049295	0.0442384	-0.0979543
G_{12}	3.3063	-0.0103945	0.12489	0.00741967	-0.0000437
G_{13}	3.59935	0.0561438	-0.078989	0.0400836	0.0789314
G_{14}	4.15794	0.0505031	-0.075335	0.0359971	-0.0648375

DISSOLVER

In the case of the dissolver vessel it is not possible to make the assumption that the initial temperature is constant. The inside surface (a = 200 in.) is at 850°F while the outside surface (b = 206 in.) is at no more than 200°F. The medium between a and b is insulating concrete which has a thermal diffusivity of 0.0126 and a thermal conductivity of 0.2917. At the start of cooldown it is assumed that each surface transmits heat to a medium at 100°F. The heat transfer coefficient at the inside surface is taken to be 1.458 while the heat transfer coefficient at the outside surface is taken to be 17.5.

The initial temperature distribution is:

$$T(r,0) = f(r) = \frac{T_a \mathrm{Ln}(b/r) + T_b \ln(r/a)}{\ln(b/a)}$$

where

$$T_a = 850°\mathrm{F},\ T_b = 200°\mathrm{F},\ a = 200\ \mathrm{in.},\ \text{and}\ b = 206\ \mathrm{in.}$$

The integral of Equation 5 is:

$$I = \left[T - \frac{T_a \ln b - T_b \ln a}{\ln(b/a)}\right]\left[\frac{bC_1(a_n b) - aC_1(a_n a)}{a_n}\right] + \frac{T_a - T_b}{\ln(b/a)}\left[\frac{C_1(a_n b) b \ln b - C_1(a_n a) a \ln a}{a_n} + \frac{C_0(a_n b) - C_0(a_n a)}{a_n^2}\right]$$

The first eight roots for a_n are given in Table B-2. The temperature as a function of time has been determined at r = 200 in., 201.5 in., 203 in., and 204.5 in. The results for r = 200 in. and r = 203 in. (average radius) are shown in Figure B-2.

These results indicate that it will have taken approximately 10 hours for the inside wall temperature to drop to 125°F and approximately 11 hours for the temperature to drop to 125°F at the average radius.

Table B-2 - Numerical Results for the Dissolver

$T = 100°F \quad T_a = 850°F \quad T_b = 200°F$

$a = 200$ in. $\quad b = 206$ in.

$$T(r,t) = T + \Sigma A_n(r)\, e^{-a_n^2 Kt}$$

Coefficient	a_n^2	r = a	r = a + 1.5 in.	r = a + 3.0 in.	r = a + 4.5 in.
A_1	21.5185	360.333	513.584	498.425	321.036
A_2	100.475	70.5582	55.4755	-35.4906	-77.1675
A_3	249.912	71.1278	-7.21898	-64.9288	58.177
A_4	473.056	21.9253	-17.8465	10.666	-1.6664
A_5	470.929	29.4514	-29.4848	26.3652	-20.4494
A_6	1144.17	8.21818	-4.88873	-3.62282	8.21308
A_7	1593.36	18.0063	2.73549	-16.381	-11.6489
A_8	2118.97	1.17564	0.946461	0.461069	0.146396
Sum of first eight terms at t = o		580	513	415.5	276
Actual value		850°F	686	523	361

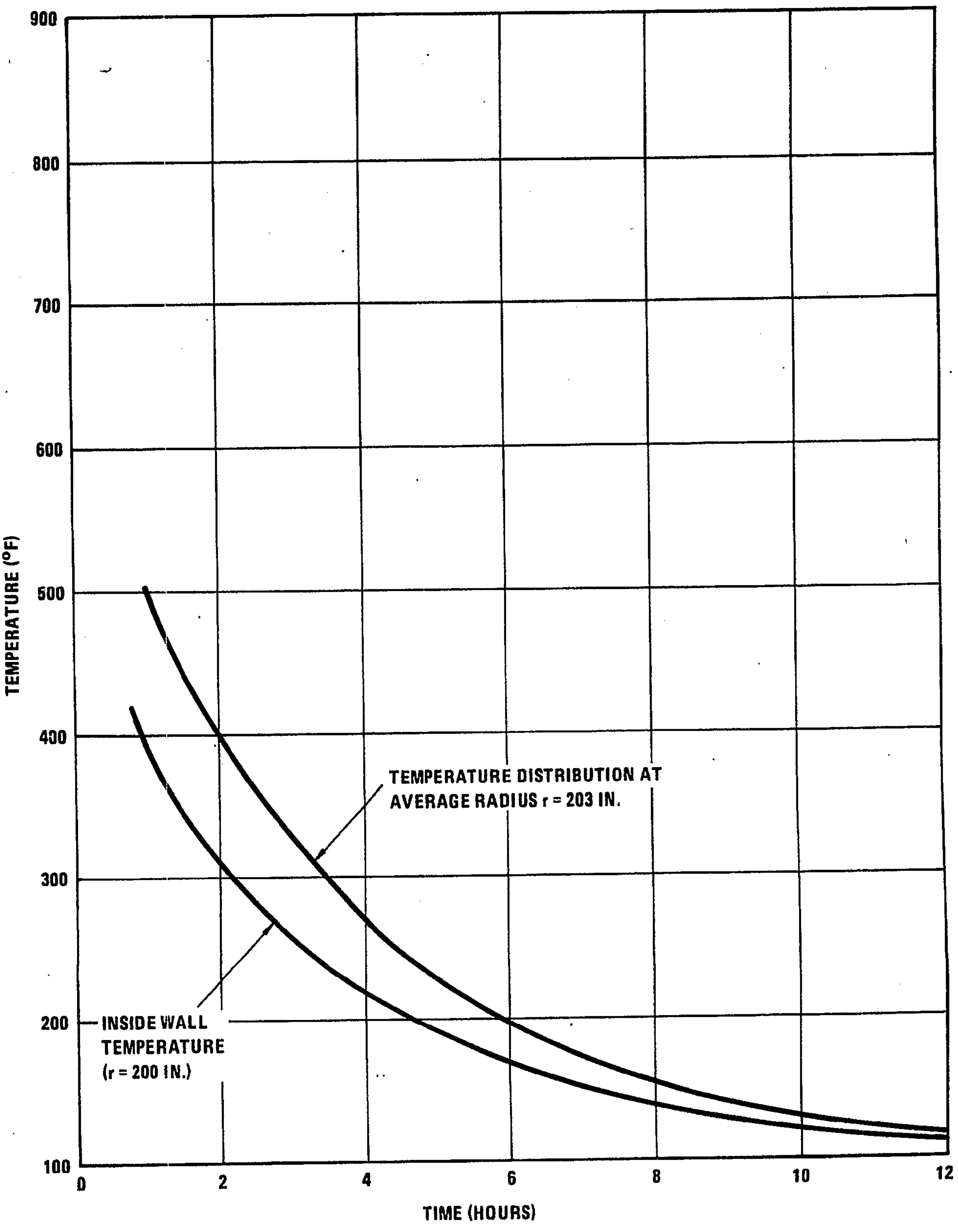


Figure B-2 - Cooling Curve for the Dissolver

GASIFIER

With the exception of the numerical values of the parameters, the solution for the gasifier is the same as that for the dissolver. The inside radius of the gasifier is 138 in. and the outside radius is 147 in. The 9-in. space is filled with two types of refractory material. The effective thermal conductivity is taken to be 0.2906 and the heat transfer coefficient at the inside surface is taken to be 10 while that at the outside surface is 1.82. The temperature of the cooling medium at the inside surface and at the outside surface is assumed to be 100°F.

Referring to the solution given for the dissolver, the solution for the gasifier is obtained with setting $T = 100$, $T_a = 2{,}500$, $T = 500$, $a = 138/12$ ft, $b = 147/12$ ft, $k_2 = 34.4$, $k_5 = 6.26$, $k_1 = k_4 = 1$, and $k_3 = k_6$.

The results are tabulated in Table B-3 and are plotted in Figure B-3. These results indicate that it will take approximately 36 hours for the temperature at the average radius to decrease to 125°F.

Table B-3 - Numerical Results for the Gasifier

Coefficient	a_n^2	r = a	r = a + 2.25 in.	r = a + 4.5 in.	r = a + 6.75 in.
A_1	11.5048	164.736	1,117.05	1,620.89	1,488
A_2	48.8053	155.288	773.468	243.027	-636.959
A_3	115.915	162.126	394.085	-498.187	40.2394
A_4	214.892	145.103	-3.45365	-136.463	253.554
A_5	346.652	133.619	-208.474	257.158	-274.261
A_6	511.72	120.309	-216.075	76.1138	144.165
A_7	710.468	115.274	-109.595	-174.652	10.3164
A_8	943.191	102.763	30.9385	-48.0012	-112.889
A_9	1,210.12	91.265	109.199	120.678	125.158
A_{10}	1,511.44	80,9026	103.002	29.7205	-69.836
A_{11}	1,847.3	72.1748	41.6127	-87.8193	-5.51614
A_{12}	2,217.82	65.1736	-27.0586	-19.6654	58.9589
Sum of first twelve terms		1,408	2,004	1,385	1,021
Actual value			(1,988)	1,484	988.3

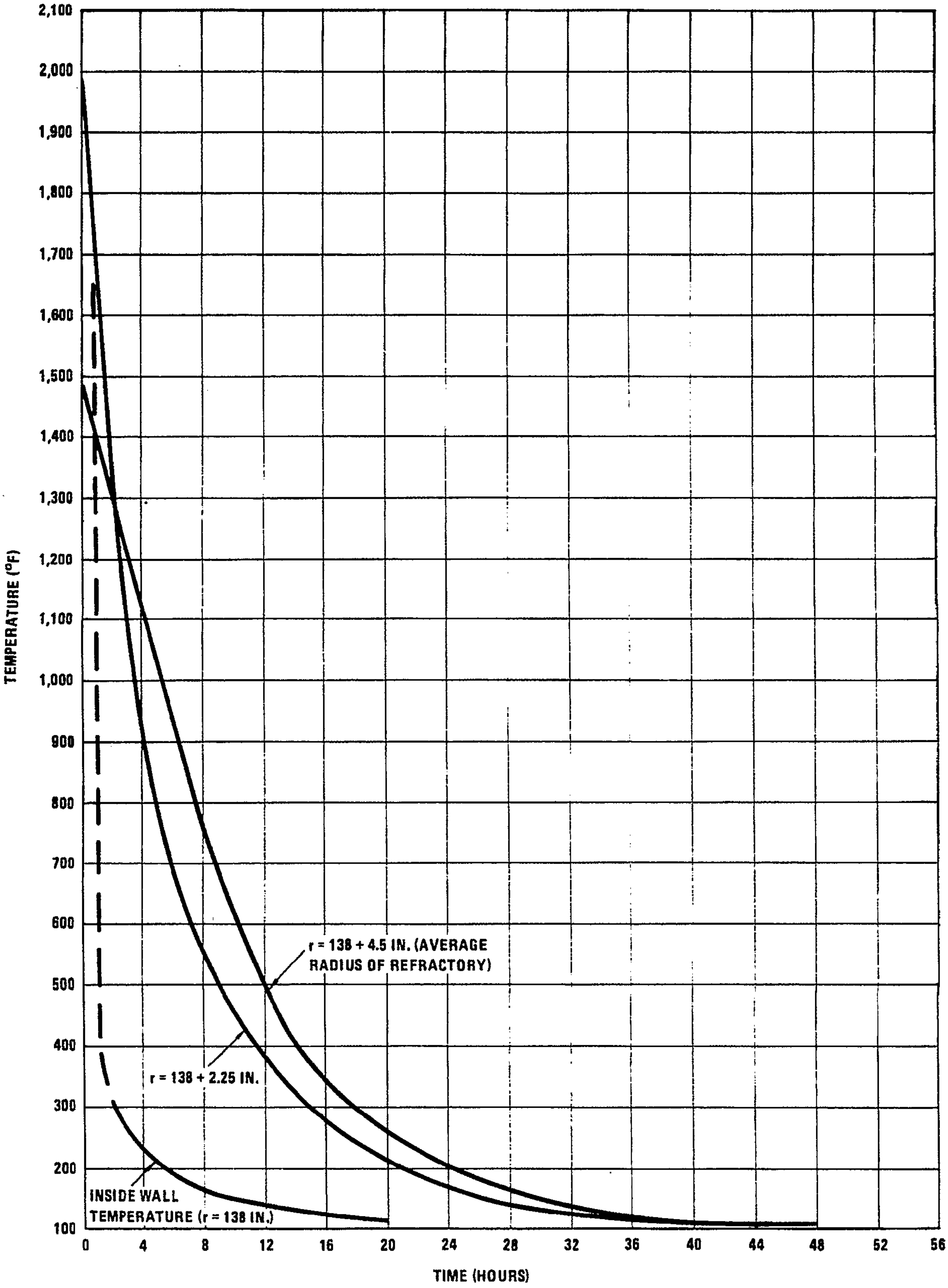


Figure B-3 - Cooling Curve for the Gasifier

CHAR CYCLONES

The solution for the char cyclones is of the same form as that for the dissolver. The relevant parameters are:

T_a = 1,700°F

T_b = 500°F

a = 48.5 in.

b = 56.0 in.

h_a = 15

h_b = 6.43

K = 1.12

T = 100

k = 0.033

The results are shown in Figure B-4. The calculation indicates that it will take approximately 8 hours for the temperature at the average radius to decrease from 1,080°F to 125°F and approximately 5 hours for the temperature at the inside wall to decrease from 1,700°F to 125°F.

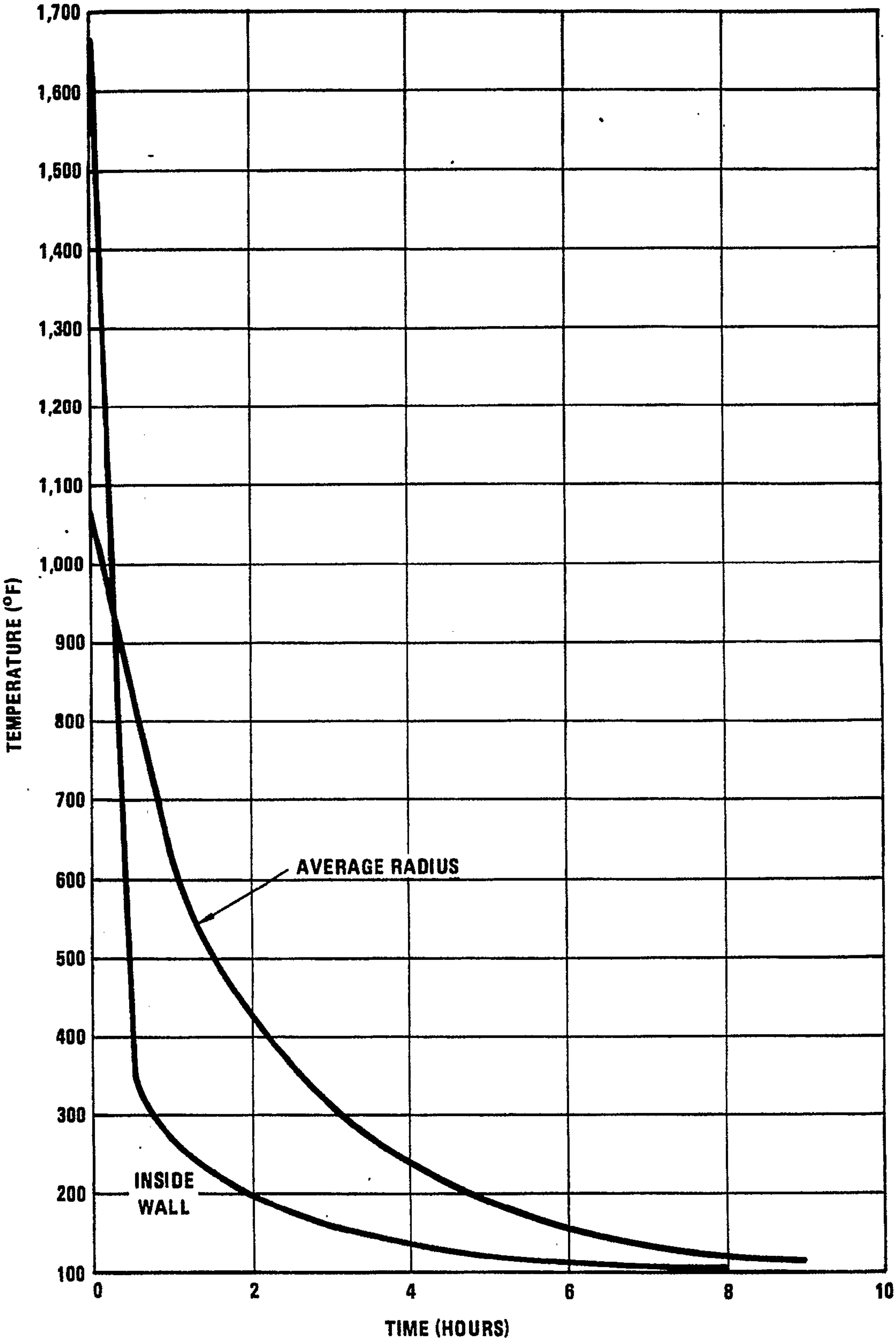


Figure B-4 - Cooling Curve for the Char Cyclones

APPENDIX C

EFFECTS OF REFRACTORY AND COOLING WATER FAILURES

Calculations of the effects of refractory failure and cooling water failure in the gasifier were performed. Three refracting failure cases and a complete cooling failure were investigated. The refractory failure cases were based on the time to sense a 5°F rise in the cooling water differential temperature between the inlet and outlet. The analyses are based upon a single vertical tube in the upper (Stage 2) section of the gasifier. These tubes are 70 feet long and are spaced one foot apart. Each tube therefore provides cooling for 70 square feet of refractory failure cases, the water flow was at the normal velocity of 2.5 feet per section.

RESULTS

The original refractory lining consists of 5 inches of high density 94% aluminum castable and 4 inches of insulating castable refractors. The results are:

Case 1: Complete failure of high density, high alumina refractory. The failure of the 5-inch thick castable for the entire length of 70 feet by 1 foot wide will result in a temperature rise of about 4.1°F in about 8 hours after refractory failure. The system will reach an equilibrium shortly after this time with about a 4-3°F temperature rise. Figure C-1 illustrates the expected situation. The inside metal membrane temperature will be about 566°F. This is based upon an internal operating temperature of 2,500°F at the lower end of the upper stage.

Case 2: Complete failure of the high alumina refractory and 2 inches of insulating refractory. It will require a 13-linear foot (13 square foot) failure, or about 18% of the refractory for a single tube, to raise the water temperature differential 5°F. This will occur about 3 hours after refractory failure. The differential water temperature will reach equilibrium at slightly over 5°F. This is shown in Figure C-2.

The internal metal temperature will be about 865°F.

Case 3: Complete failure of high alumina refractory and 3 inches of insulating refractory. A 6.3-foot (6.3 square feet) failure or a 9% failure, will cause a 5°F temperature rise in about 1.2 hours after failure. This is shown in Figure C-3.

The inside metal wall temperature will rise to about 1,240°F.

Water Flow Failure. A sudden cooling water flow failure will result in the metal wall temperature rising from the normal 500°F to about 900°F in one hour and to over 1,000°F in two hours. The expected metal wall temperatures are shown in Figure C-4.

REFRACTORY FAILURES FOR GASIFIER

In normal operation, the gasifier vessel (Stage 2) consists of a double refractory lining, a metal wall, and the exterior cooling system. In the region where the process temperature is 2,500°F, the radius of the vessel is 138 in. (inside the refractory). The innermost refractory is 5 in. thick (from r = 138 to 143 in.) and is 94% Al_2O_3 with a density of 170 lb/ft^3. The average thermal conductivity is 1.08 Btu/hr/ft/°F and the diffusivity is 0.03174/ft^2/hr. The second refractory is a low-iron lightweight insulating castable (70 lb/ft^3) with an average thermal conductivity of 0.1329 Btu/hr/ft/°F. The thickness is 4 in. (from r = 143 to 147 in.) in the lower region of Stage 2. The thermal diffusivity of this castable is 0.0095/ft^2/hr. The thickness of the metal liner is 0.5 in. (r = 147 to 147.5 in.) and the diffusivity is approximately 0.10/ft^2/hr. The region between r = 147.5 and r = 152.5 in. consists of a combination of insulating concrete and steel fins. The effective thermal conductivity is estimated to be 0.82 Btu/ft^2/hr/°F and the thermal diffusivity is about 0.032/ft^2/hr.

From the numerical values of the thermal diffusivities, the rate of heat flow in the unsteady state is controlled by the insulating castable, especially when the high-alumina castable is absent. The thickness of the metal wall and the cooling system can be expressed in terms of an equivalent thickness of insulating castable. Under normal operation (in steady state), the temperature at r = 143 is 2,175°F and the temperature at r = 147 is 504.8°F. Thus, for r between 143 and 147, the steady-state temperature distribution is given by:

$$T(r) = \frac{T_a \ln(b/r) + T_b \ln(r/a)}{\ln(b/a)} \qquad (1)$$

where

$$b = 147,\ a = 143,\ T_a = 2{,}175,\ \text{and}\ T_b = 504.8.$$

In order to find an equivalent thickness of the metal liner plus the insulating concrete, an effective value of b is found by setting T_b = 130°F, a = 143 in., and T(r) = 504.8°F when r = 147 in. The result is b = 5.0 in. and thus, the metal plus the insulating concrete is equivalent to 1 in. of insulating castable.

The boundary conditions can now be expressed in the following manner: at $t = 0^-$, the initial steady-state temperature distribution is given by Equation 1 with T_a = 2,175, T_b = 130, a = 143, and b = 148 in. At t = 0, it is assumed that a refractory failure occurs, removing a length, L, of the inner refractory (high alumina) 5 in. thick and 1 ft wide. In addition, a variable thickness of the insulating castable (L ft long and 1 ft wide) is also removed, exposing the surface of the insulating castable to 2,500°F. Since it is of interest to determine the length of failure required to change the water temperature in one cooling coil by 5°F, it can be assumed that the temperature at r = 148 in. remains constant over short vertical distances. In addition, it is assumed that the surface temperature of the castable assumes its new steady-state value instantaneously. The results of the calculations also yield the new heat flow rate per vertical foot as a function of time. Subtraction of the original steady-state heat flow per vertical foot gives the increased heat flow per vertical foot ($\dot{Q}_L$) over normal. Thus,

$$(\dot{Q}_L)L = \dot{m}C\ (\Delta T)$$

where L is in feet, $\dot{m}$ is the rate of water flow in lb/hr through one coil, and c is the specific heat of the cooling water.

The formal boundary conditions may be stated as:

$$\underline{a<r<b} \quad \text{For } t=0^- \quad T(r,0) = \frac{T_a \ln(b/r) + T_b \ln(r/a)}{\ln(b/a)}$$

$$\text{For } t\geq 0 \quad T(a,t) = T_1$$

$$T(b,t) = T_2$$

where T(r,t) must satisfy the heat equation. The general solution can be expressed through the use of the following definitions:

$$U_0(a_n r) = J_0(a_n r)Y_0(a_n b) - J_0(a_n b)Y_0(a_n r)$$

$$T(r,\infty) = \frac{T_1 \ln(b/r) + T_2 \ln(r/a)}{\ln(b/a)}$$

$$k = \text{thermal diffusivity}$$

$$D_n = \frac{T_a \ln(b) - T_b \ln(a)}{\ln(b/a)} \quad J_0(a_n a) - J_0(a_n b)$$

$$- (T_a - T_b)\ J_0(a_n a)\ln(b) - J_0(a_n b)\ln(a)$$

$$+ T_1 J_0(a_n b) - T_2(a_n a)$$

where the values of a_n are defined by the roots of the equation: $U_0(a_n a) = 0$.

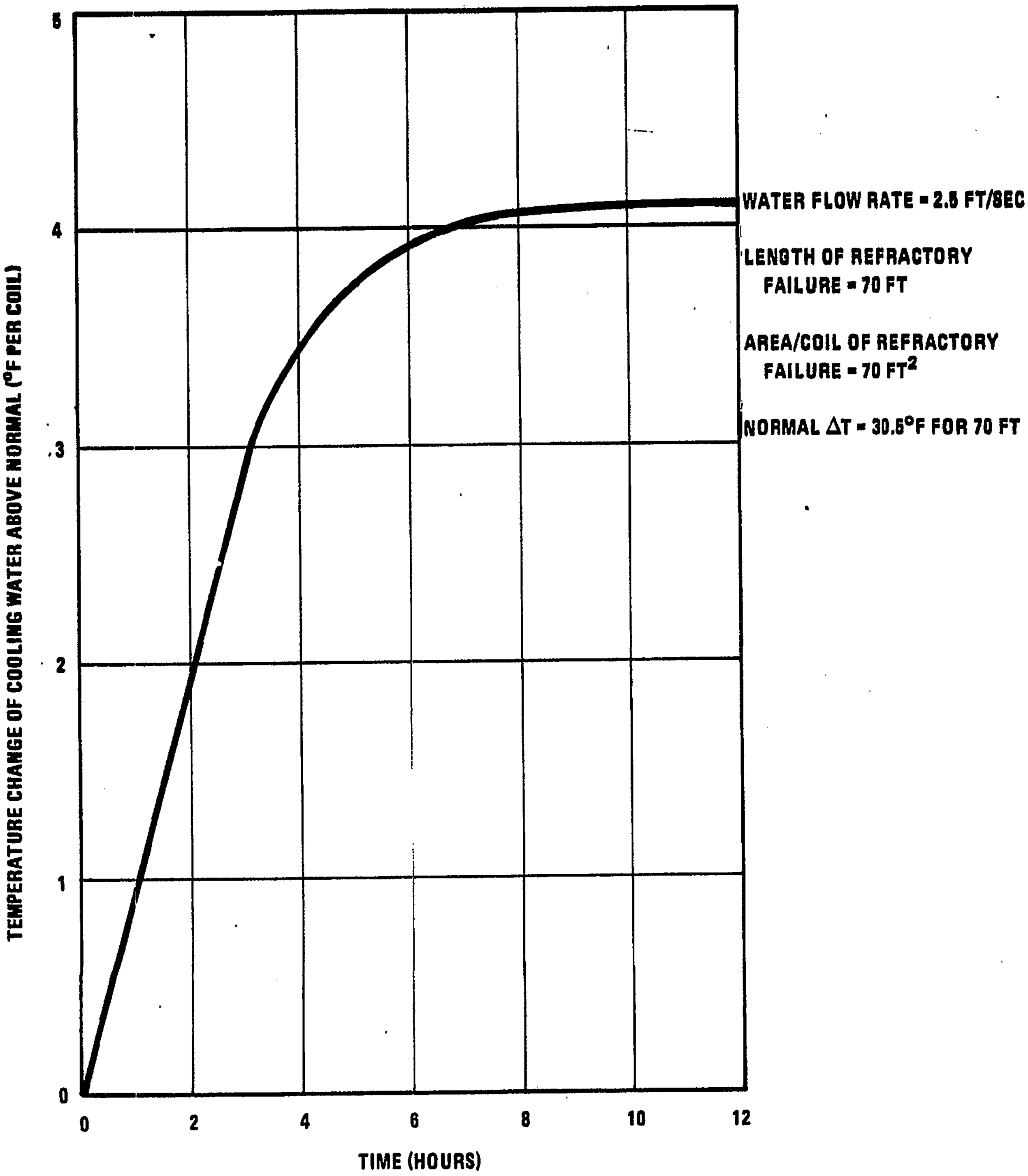
The temperature distribution is given by:

$$T(r,t) = T(r,\infty) + \pi \sum_{n=1} \frac{J_0(a_n a) D_n U_0(a_n r) e^{-k a_n^2 t}}{J_0^2(a_n a) - J_0^2(a_n b)}$$

Table C-1 gives the steady-state conditions at the beginning and at the final conditions for each of the three refractory failure cases.

Table C-1 - Steady-State Conditions for Various Gasifier Refractory Failures

Condition	Before Failure (Normal Operation)	After Failure
Case 1		
Surface temp at r = 143 in.	2,175.0°F (T_a)	2,482.3°F (T_1)
Inside metal temp	504.8°F	565.8°F
Outside metal temp	500.0°F	560.7°F
Heat flux at r = a = 143 in.	772 Btu/hr/ft^2	886 Btu/hr/ft^2
Case 2		
Surface temp at r = 143 in.	1,334.2°F (T_a)	2,470.5°F (T_1)
Inside metal temp	504.8°F	865.1°F
Outside metal temp	500.0°F	856.4°F
Heat flux at r = a = 145 in.	761 Btu/hr/ft^2	1,475 Btu/hr/ft^2
Case 3		
Surface temp at r = 146 in.	918.1°F (T_a)	2,455.6°F (T_1)
Inside metal temp	504.8°F	1,243.2°F
Outside metal temp	500.0°F	1,230.3°F
Heat flux at r = a = 146 in.	756 Btu/hr/ft^2	2,219 Btu/hr/ft^2



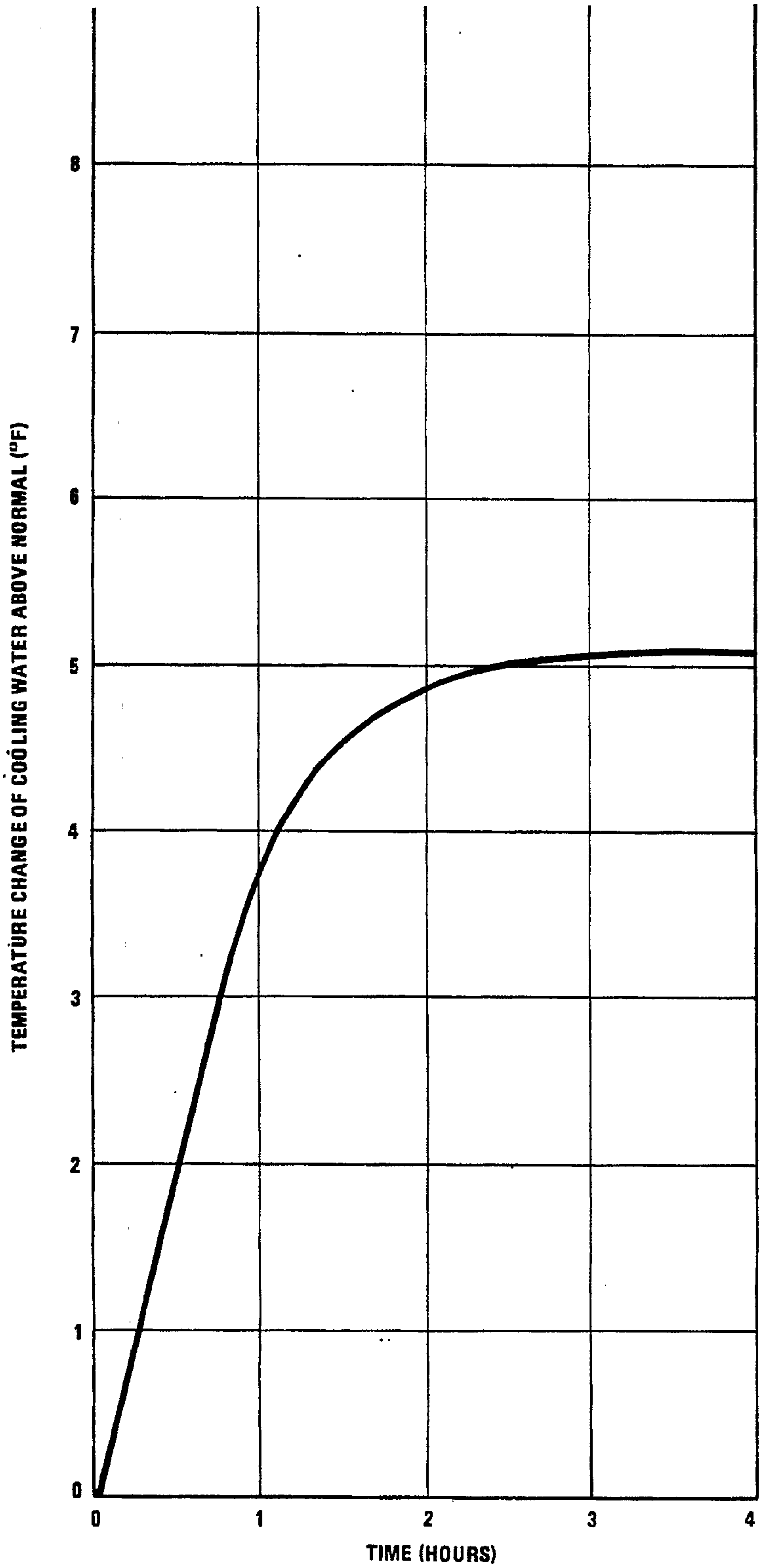
WATER FLOW RATE = 2.5 FT/SEC

LENGTH OF REFRACTORY FAILURE = 70 FT

AREA/COIL OF REFRACTORY FAILURE = 70 FT^2

NORMAL ΔT = 30.5°F FOR 70 FT

Figure C-1 - Cooling Coil Temperature Change (Above Normal) for Refractory Failure Case 1 (Innermost Refractory Gone; Insulating Refractory Intact)



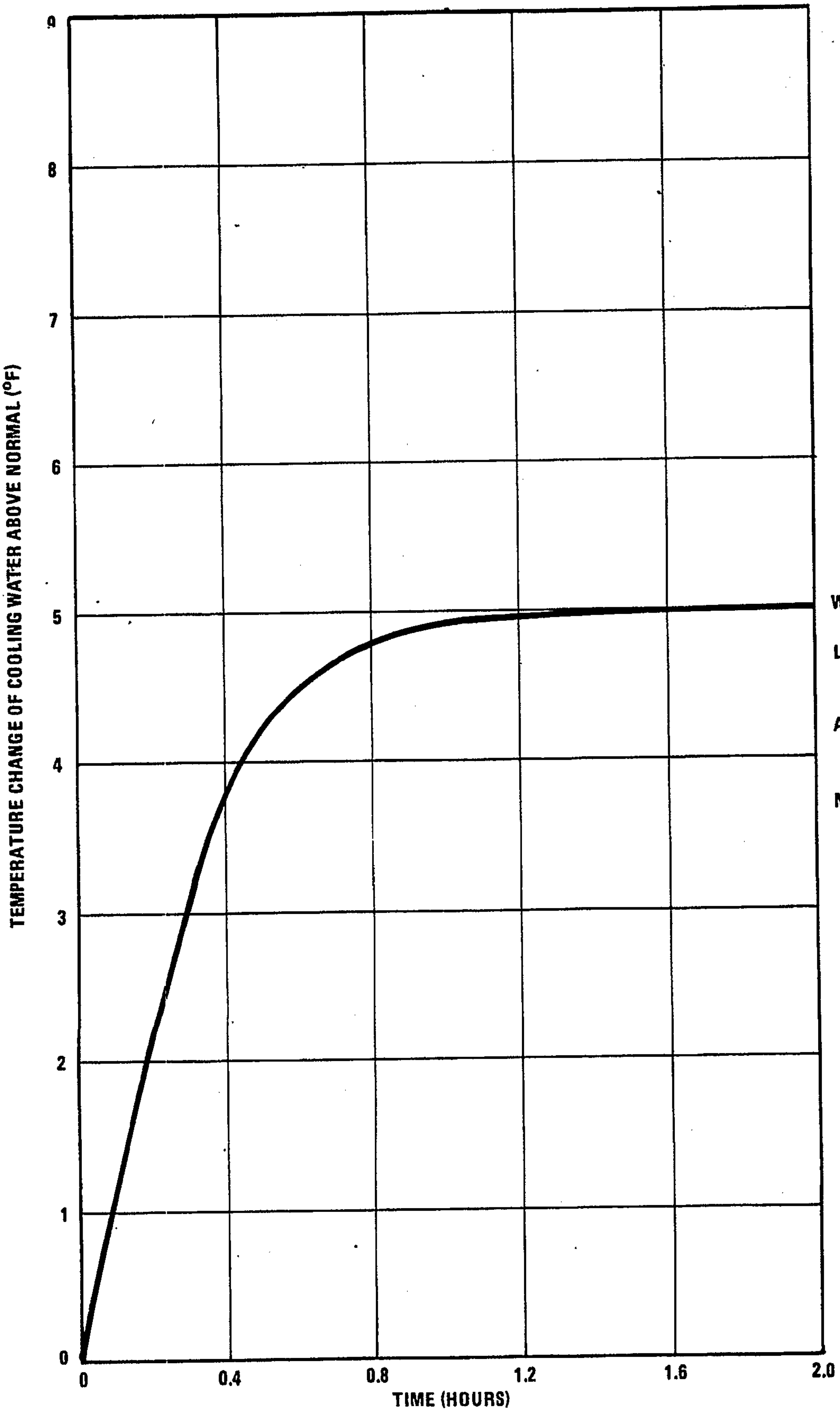
WATER FLOW RATE = 2.5 FT/SEC

LENGTH OF REFRACTORY
FAILURE = 13 FT

AREA OF REFRACTORY
FAILURE = 13 FT^2

NORMAL ΔT = 5.7°F
FOR 13 FT

Figure C-2 - Cooling Coil Temperature Change (Above Normal) for Refractory Failure Case 2 (Innermost Refractory Gone; 2 Inches of Insulating Castable Gone)



WATER FLOW RATE = 2.5 FT/SEC

LENGTH OF REFRACTORY
FAILURE = 6.26 FT

AREA OF REFRACTORY
FAILURE = 6.26 FT^2

NORMAL ΔT = 2.7°F
FOR 6.26 FT

Figure C-3 - Cooling Coil Temperature Change (Above Normal) for Refractory Failure Case 3 (Innermost Refractory Gone; 3 Inches of Insulating Castable Gone)

WATER FLOW FAILURE IN GASIFIER COOLING SYSTEM

The theory presented previously (Appendix B) can be applied to the case when the rate of water flow ceases in the external cooling system for the gasifier. It is assumed that the heat flux is zero for radii greater than that of the metal liner. That is, it is assumed that the metal liner is thermally insulated at the outside radius. The only means by which heat is transmitted (without this assumption) through the liner is by heating the cooling water which remains in the coils and by heating the insulating and structural concretes. While the concrete represents a substantial heat sink, the thermal diffusivity is of the same order of magnitude as that of the insulating castable refractory.

The resulting heating curve (see Figure C-4) represents the maximum rate of change of temperature with time, and therefore is the most conservative approach. The numerical parameters are $K_1 = K_4 = 1$, k_2== 34.4, $k_5 = 0$ (k_3 and k_6 do not appear in the calculation), $T = 2{,}500$, $T_a = 2{,}484$, and $T_b = 500$. As shown in Figure C-4, the results indicate that after 1 hour without any water flow through the cooling coils, the metal temperature is over 900°F.

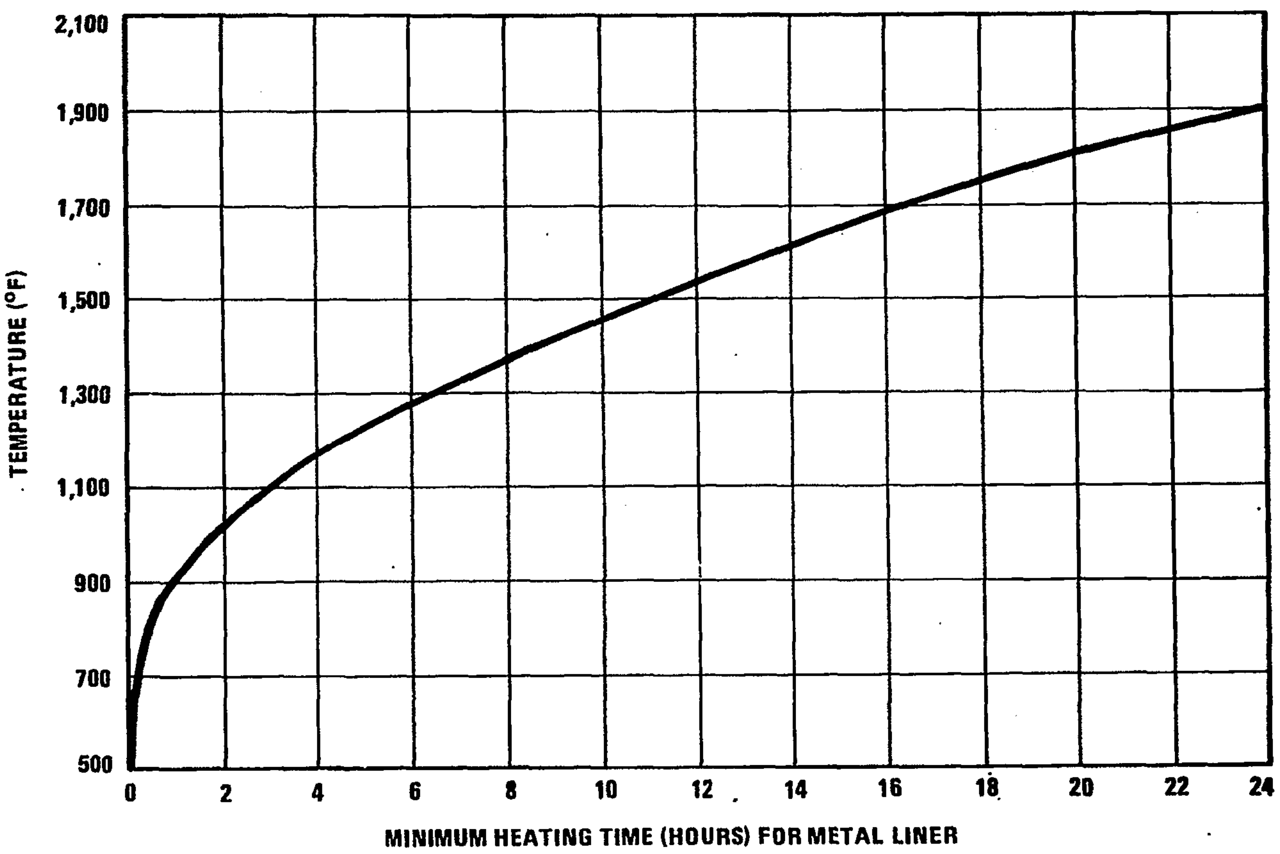


Figure C-4 - Rate of Increase of Metal Wall Temperature for Gasifier When Cooling Water Flow Ceases

APPENDIX D

BRIEF SPECIFICATIONS FOR THE CONCRETE STRUCTURE OF A PCPV

GENERAL

Good quality concrete is imperative to the successful performance of a PCPV. Strict quality control measures shall be enforced throughout the construction of the vessel. Unless otherwise specified, ACI Code 318-71 shall be applied for all prestressing work.

PORTLAND CEMENT

Types I, II, III, IV, or V, Portland Cement, conforming to the provisions of "Standard Specifications for Portland Cement" ASTM C-150, may be used. Each type has its own particular area of application. Generally, the applicability of the cement types are as follows.

Type I	- for general construction, when special properties of the other types are not required.
Type II	- to be used where moderate sulfate attack may occur.
Type III	- to be used where rapid strength of concrete is important and where the application can tolerate high heat of hydration.
Type IV	- for increased resistance against sulfate attack and lower heat of hydration than provided by Types II and III, and where the application can tolerate prolonged periods of curing.
Type V	- for maximum resistance against chemical attack, particularly sulfates.

AGGREGATES

These should be clean, hard, fine-grained, sand, crushed rock - natural sand or washed gravel - conforming to the requirements of ASTM C-33. Aggregate types which are likely to undergo physical or chemical changes and react with the alkalies in the cement shall not be used. Aggregate shall be of rough cubic or spherical shape and of consistent quality and grading.

WATER

Water shall be fresh and potable, with a chloride content of less than 500 ppm and a sulfate content of less than 1,000 ppm.

ADMIXTURES

Calcium chloride and admixtures or pigments containing calcium chloride shall not be used. Other admixtures shall be used when approved.

CONCRETE STRENGTH

The minimum concrete cylinder strength at 28 days shall be 5,000 psi for foundation and 6,000 psi for the vessel proper. Concrete specimens shall be tested in accordance with ASTM C-39, "Standard Method of Test for Compressive Strength of Molded Concrete Cylinders," at the ages of 7 and 28 days.

MIX DESIGN

The final selection of aggregate gradations, water-cement ratio, and admixtures shall be determined experimentally by a qualified concrete laboratory, but subject to the following criteria:

a. Water-cement ratio shall be 0.45 maximum, preferably 0.4.

b. Minimum cement factor shall be 7 sacks per yd^3, preferably 8 sacks

c. A small amount of pozzolan, such as good fly ash of calcined shale, shall be used as partial replacement of sand in concrete. The amount of pozzolan used shall not exceed 10% by weight of cement.

d. The use of water-reducing admixture is desirable, but subject to laboratory evidence and prior approval.

e. Air-entraining agents shall not be used.

f. Concrete coefficient of thermal expansion shall be as compatible as practical with the liner material.

g. Maximum coarse aggregate should not exceed 2 inches.

h. The experimentally determined composition of concrete shall be adhered to strictly by rigidly controlling the production procedure, and by ensuring that the materials are supplied by the same sources.

INSULATING PORTLAND CEMENT CONCRETE

Insulating concrete shall be made with good quality expanded clay aggregates or crushed fire bricks. The material shall conform to the specifications of ASTM C-330 for lightweight aggregate. The insulating concrete shall have a minimum 28-day compressive strength of 5,000 psi.

The shrinkage characteristics of the insulating concrete to be verified by trial batches shall be such that its drying shrinkage shall not be more than 0.04% after 14 days of drying. Insulating concrete shall be consolidated with external vibrators against the steel liner.

MIXING, PLACING, AND COMPRESSION OF CONCRETE

Sufficient raw material shall be stockpiled for several pours. Construction joints shall be prepared strictly in accordance with specifications and approved before the new concrete is poured. The pouring sequence shall be followed diligently.

Extreme care should be exercised in the placement and compaction of concrete to avoid causing damage to pipe fittings and cooling system. The proper vibrating tools shall be employed to fill and compact concrete in all awkward spaces in the concrete wall due to the congestion of steel, fittings, conduits, and equipment.

All personnel involved in this concreting operation shall be given a full understanding of the purpose and the importance of this operation.

FORMS AND TOLERANCES

All formwork shall be taped to prevent mortar leakage. Specified dimensional tolerances shall be strictly maintained, particularly tolerance on out-of-roundness, to ensure the uniformity of structural thickness and shape and minimize stress variation.

If slipform method is used, care should be taken to ensure that the tolerance on verticality is maintained throughout the vessel height.

CURING

Concrete should be cured immediately after each pour by wetting the concrete surfaces with fresh potable water for no less than 5 days. Curing may be accomplished by other methods, subject to approval.

CONCRETE FINISH

All exposed exterior concrete surfaces shall be finished smooth, dense, and free from honeycombing. Any unsatisfactory concrete surfaces shall be chipped to sound concrete, and repaired as instructed.

SURFACE SEAL

All exposed concrete surfaces shall be sealed with two coats of epoxy emulsion. The sealing coat shall be applied in accordance with the manufacturer's instructions. The first coat shall be applied approximately 6 weeks after the concrete is cast, and the second coat applied after the concrete structure is complete and the tendons stressed and grouted.

REINFORCING STEEL

Unless otherwise noted on drawings, deformed bars of Grade 60 shall be used. Steel reinforcement shall be free from loose rust, grease, oil, salt deposits, or other deleterious materials likely to affect the durability or the bonding properties of the steel. All steel shall be stored in the proper manner, and maintained in good condition at all times.

PRESTRESSING STEEL

Prestressing tendons, which may be in the form of wires, strands, or stranded cables, shall be of 270 K type conforming to ASTM A-416.

Prestressing strand shall have a nominal diameter of 0.5 inches or 0.6 inches.

ANCHORAGES

All post-tensioned prestressing steel shall be secured at both ends by approved permanent-type anchorages. All anchorages shall hold the prestressing steel at a load producing a stress of not less than 95% of the specified ultimate tensile strength of the prestressing steel. The anchoring device shall distribute the load of the concrete such that the final unit compressive stress on the concrete directly underneath the plate or assembly shall not exceed 3,000 psi.

Where special anchorages are specified or shown in the drawing, they shall be made strictly in accordance with specified design requirments; e.g., the ring anchor plates around the restraining ledge on top of the main plug.

DUCTS

Duct enclosure for prestressing steel shall be rigid ferrous metal, galvanized, mortar tight, and accurately placed at the designated locations. Ducts shall have sufficient strength to maintain their alignment and shall not be damaged, dented, or displaced during concreting operation. Splices shall be tight fitting sleeves and the spliced joint shall be bonded with waterproof tape. Air vents shall be provided at all high points in the tendon profile.

After installation in the forms, the ends of the ducts shall be covered as necessary to prevent the entry of water or debris.

PRESTRESSING

All prestressing shall be carried out by use of hydraulic jacks to provide the forces as specified in the plans. Unless otherwise specified, the average working stress in the prestressing steel shall not exceed 60% of the specified minimum ultimate tensile strength of the steel. The loss in stress in post-tensioned prestressing steel due to creep and shrinkage of concrete, creep of steel, and sequence of stressing shall be assumed to be 20,000 psi. The loss in stress due to creep and shrinkage of the concrete, creep of steel, and elastic compression of concrete shall be assumed to be 35,000 psi. Friction coefficients shall be in accordance to values as specified in the Code.

GROUT

Grout shall consist of Portland cement fine sand and water and may contain an approved admixture. Portland cement shall be Type 1 or Type II. Water shall be of the same quality as used for mixing structural concrete. Water content shall be not more than 5 gallons per sack of cement (94 lb). Grout shall not be retempered and shall be continuously agitated until it is pumped. Grout shall have a minum 28-day strength of 2,500 psi. Grouting equipment shall be furnished with a pressure gauge having a full scale reading of not more than 300 psi.

CONCRETE COVER

Concrete cover to all reinforcing steel and prestressing tendons shall be not less than 4 inches and 6 inches, respectively.

WIRE MESH

Wire mesh reinforcement shall conform to ASTM A-185.

STRUCTURAL STEEL

Structural steel shall conform to ASTM A-36 unless otherwise specified. The standard of workmanship shall comply with AISC Manual of Steel Construction.

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