1 of 2

MFTF

MIRROR FUSION TEST FACILITY

**VACUUM VESSEL
COST ANALYSIS**

Prepared by

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JULY 1977

MASTER

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SAN RAMON OPERATIONS
2801 OLD CROW CANYON ROAD
SAN RAMON, CALIFORNIA 94583

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1. PURPOSE

At the request of Victor Karpenko, Project Manager for LLL's Mirror Fusion Test Facility (MFTF), EG&G, Inc., has prepared this independent cost and schedule analysis for the proposed MFTF Vacuum Vessel. Gerald Dittman, LLL Project Engineer for the MFTF vacuum vessel system, and Wayne Pollard, LLL Staff Engineer, collaborated with EG&G and provided the vacuum vessel requirements. EG&G's analysis has attempted to show sufficient detail to provide adequate definition for estimating cost.

2. SUMMARY

The analysis has defined the weight of the completed Vacuum Vessel with neutral beam source tanks, diagnostic cells, and base support structure to be 565,490 lbs. The construction network and engineering schedule indicates that 78 weeks will be required from award of bid to vessel acceptance (completion of the vacuum certification test). The estimated cost of the vessel is \$3,987,500 (or approximately \$7.05/lb).

Refer to Drawing LSK 2404, Section 6 (Cost Analysis), which shows the essential features of the vacuum vessel.

3. SYSTEM REQUIREMENTS

Vacuum vessel system requirements were established by G. L. Dittman and are contained in the "MFTF Project Requirements and Cost Estimate Update", Vol. I and II, July 1977, Lawrence Livermore Laboratory. The following was extracted from that report.

3.1 FUNCTION

The Vacuum-Vessel System will integrate the various MFTF mechanical systems and will be the focal point of the experimental facility. The Vacuum-Vessel System will maintain the vacuum environment for the plasma, will house the superconducting magnet, and will provide access and mounting structures for the majority of the elements that make up the experimental configuration.

3.2 STRUCTURAL REQUIREMENTS

The structural integrity of the Vacuum-Vessel System must be sufficient to insure that the operational performance requirements can be accomplished. Each subsystem design will consider working pressure, impact, dead weight, equipment attachment, and earthquake loads as well as stresses induced by thermal gradients. Maximum allowable stress values will be determined by applicable codes and standards.

3.2.1 Vacuum Tank

- (1) The external operating pressure will be 100 kPa (760 Torr) for the vacuum tank.
- (2) The construction material will have high strength and low magnetic permeability.
- (3) The main vessel will provide penetrations, mounting surfaces, and physical support for the following major subsystems:
 - (a) Startup neutral-beam modules
 - (b) Sustaining neutral-beam modules
 - (c) Neutral-beam source tanks
 - (d) Cryo-panels
 - (e) Plasma-streaming guns
 - (f) Sublimation pumps
 - (g) Beam dumps

- (h) Experimental diagnostics
 - (i) External vacuum feed
 - (j) Magnet current feed
- (4) The vacuum tanks will provide penetrations, mounting surfaces and connections for the following support subsystems:
- (a) Electrical power leads
 - (b) Monitoring instrumentation
 - (c) Liquid helium and nitrogen distribution networks
 - (d) Low-conductivity cooling water
 - (e) Air lines
- (5) Adequate thickness and additional structural stiffening will be provided to the vacuum tank walls for attachment of the various subsystems to maintain the required safety factors.
- (6) Structural members of the vacuum tanks will be protected from cryogenic temperatures and will be shielded from plasma radiation and ion deposition.
- (7) The vacuum tanks fall into the category of fracture-critical components. The design will include adequate consideration of material fracture toughness.

3.2.2 Support Structures

- (1) Support structures will support their design load with a safety factor of approximately 4 based on material yield strength.
- (2) Support structures will withstand seismic loadings corresponding to a maximum ground acceleration of 2.5 m/s^2 .
- (3) Load redundancy and crack-arrest provisions will be incorporated into the design to minimize the fracture-critical aspects of the support structures. Trade-offs will be made to provide high fracture toughness versus low nominal working stress.

3.3 VACUUM-VESSEL SYSTEM DESIGN APPROACH

3.3.1 Design Approach

The design approach for the Vacuum-Vessel System is an engineering system optimization, and a selection of commercial equipment where applicable, to meet the functional and design requirements within budgetary and schedule constraints.

(1) Vacuum Tanks

The vacuum tank subsystem makes up the bulk of the vacuum vessel system. It includes the four neutral-beam source tanks and the main chamber. Each source tank will support a complement of beam injector assemblies. Each source tank is in turn supported by the main chamber walls at the chamber's mid-point, 90° apart. Instrumentation ports will be located between each of the source tanks. Penetrations and supports for the streaming guns will be provided on the top end of the main chamber and penetrations for the magnet system support structure will be provided at the lower end. Essentially all surfaces of the vacuum tanks will support cryopanel. The tank material will be type 304 or 316 stainless steel.

(a) Main Chamber

The main chamber (Figure 3-1) will be sized at a minimum to accommodate the magnet and provide the vacuum and thermal environment to maintain the coil at 4°K. The wall areas of the vessel will be sufficiently large to accommodate the 240 m² of cryopumping panels. The chamber will be cylindrical, with a diameter of 9 m and a length of 8 m. The enclosure will be formed by capping this cylinder for an overall length of 12 m.

Large ports will be located on the main chamber for attaching the neutral beam source tanks. Additional ports for diagnostic instrumentation will also be provided.

Access is provided through the ends of the cylinder for installation of internal components and mounting of the target-plasma guns.

(b) Neutral-Beam Source Tanks

Four tanks for neutral-beam source modules will be provided (Figure 3-2). These tanks will have sufficient face area to accommodate a total of 48 neutral-beam source modules.

The tank volume will be divided into two internal pumping regions separated by apertures and contain thermal absorbers and cryopanel.

[illegible]

MET

Sufficient wall area will be available for 100 m² of cryopumping panels distributed between the two chamber regions.

(c) Vessel Material Thickness

Preliminary structural analysis of the vacuum vessel system using the design loads discussed above has resulted in the following thickness estimates for the various sections of the vacuum tanks. Continuing analysis and detail design will refine these estimates, especially in areas where localized effects occur (stiffening pads, doublers, reinforcing rings, etc.). However, the total weight estimated is not expected to increase.

End Closures of Main Vessel

The end closures of the main vessel will be sized as ellipsoidal shells with a nominal thickness of 3 cm. A stiffening pad used to mount the plasma streaming guns is presently sized as a 10-cm panel inserted into the top end closure. These same arrangements and thicknesses will be used for the lower end closure to mount plasma-fan diagnostic instrumentation.

Main Body

The main body thickness will be 3 cm. The doublers around all penetrations will be an additional 1.3-cm thick. The 15-foot midsection of the main body that encompasses the source tank and diagnostic port penetrations will be 5-cm thick.

Skirt Support Structure

The skirt support structure will be a 3-m high, 3-cm thick cylinder.

Source Tanks

The end closures of the source tanks are 2.5-cm thick with a 10-cm stiffener pad for mounting the neutral-beam injector assemblies. The remainder of the source tank structure will be 2-cm thick.

Magnet Support Shrouds

The magnet support shrouds will be 1.3-cm thick.

Flanges

All flanges will be sized at 1.5 times the thickness of the shell to which they will be attached.

(d) Vacuum Tank Installation

The currently envisioned installation procedure for the vacuum tank subsystem will be to erect the structure on site.

The main chamber will be fabricated from roll-formed plate in the shop using tack welds for preliminary assembly. The tack welds will be ground away and the formed plates will then be shipped to the site for reassembly and final welding. The flanged ends of the main chamber will be fabricated and finish-machined in the shop. A short cylindrical section will be welded to each flange and the two subassemblies will then be shipped to the site. The cylindrical section of the main chamber will then be completed on site by circumferentially welding the skirted flanges to the main cylinder.

The vessel support structure will be shop fabricated in the same fashion as the main chamber with reassembly and final welding occurring on site.

The vessel's lower end will be fabricated from formed and sectioned plates. The plates will be assembled and finish welded in the shop to form the ellipsoidal shape. The flanged end of the dome will be fabricated, finish-machined, and welded to the structure in the shop. The lower dome will then be shipped to the site and welded to the skirt support to form the lower portion of the vessel.

The vessel's upper end will be fabricated in the same way as the lower end. It will also be shipped to the site as a subassembly and bolted to the main chamber. The neutral-beam source tanks and diagnostic port closures will be fabricated in the shop as subassemblies. They will be bolted to the vessel to complete the structures.

(2) Support Structure

The support structure interface with the vacuum vessel will be achieved by a ring attachment which is an integral part of the vacuum vessel. This will minimize secondary stresses in both the vessel and the support attachment.

The centroid of the meridional section through the ring will lie as nearly as possible under the midline of the vessel wall. The center of the support structure will then lie as close as possible under the centroid. Preliminary analysis indicates that the vacuum vessel, when subjected to a lateral ground acceleration of 2.5 m/s^2 for seismic loading, will not cause tension in any of the support structures. One conclusion to be drawn from this is that the load amplification from the static condition is less than a factor of two.

The support design will be an axisymmetric skirt. The length of the skirt is determined by the lower end design of the vessel and the clearance required between the closure and the floor. The vessel ends will be ellipsoidal in profile with a minimum of 1.5-m floor clearance, resulting in a 3-m skirt length.

The skirt interface with the floor will be a flange bolted directly to the footings. The bolts will be sized to carry the entire lateral shear due to the seismic loading. Friction will therefore be considered a safety margin.

The support structure will be fabricated from type 304 or 316 stainless steel.

4. PROJECT SCHEDULE

The attached engineering schedule indicates the major tasks, task span, and approximate completion dates used by EG&G in this analysis.

This total project phase represents 117 weeks.

The following construction network describes the relationship of these tasks to the overall sequence of events.

ENGINEERING BAR CHART

JOB NUMBER B-320-01

JOB DESCRIPTION METE
VACUUM VESSEL (VY)

PROJECT ENGINEER JOHN GARCIA
LRL TECHNICAL CONTACT G. DITTMAN

TOTAL PROJECT BUDGET

1977 DATE 7-14-77

SHEET ONE OF THREE

REMARKS:

DISTRIBUTION:

ENGINEERING BAR CHART

JOB DESCRIPTION METE V. V.

JOB NUMBER B-320-01
PROJECT ENGINEER JOHN GARCIA
LRL TECHNICAL CONTACT G. DITTMAN
TOTAL PROJECT BUDGET _____
SHEET TWO OF THREE

1978

DATE 7-14-77

1979

FISCAL WEEKS	1978												1979											
	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN
SUB TASKS	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
LLL ENGINEERING/DESIGN																								
DESIGN REVIEW																								
EXHIBIT SPEC. & DWG'S																								
REQ'S																								
REVIEW BIDS																								
AWARD CONTRACTS																								
FINAL DESIGN BY VENDORS																								
LLL APPROVAL																								
VESSEL FABRICATION																								
INSPECTION																								
PREP. FOR SHIPPING																								
SHIP TO LLL																								
RECEIVE & PRE-STAGE																								
FIELD ERECTION																								
ASSEMBLY IN PIT																								
VACUUM LEAK TEST																								
VESSEL DISASSEMBLY																								

REMARKS:

DISTRIBUTION:

5. NETWORK ANALYSIS

The first step in the development of an integrated program plan is the generation of an accurate project network analysis. The following assembly network shows the sequence of major engineering, fabrication and assembly tasks envisioned by EG&G as necessary for completion of the MFTF Vacuum Vessel. The major tasks are further broken down and analyzed for the cost estimate in Section 6.

6. COST ANALYSIS

This report was developed to provide Lawrence Livermore Laboratory with an independent cost analysis for the engineering design, construction, field erection, and vacuum leak testing for the stainless steel vacuum vessel proposed for the Mirror Fusion Test Facility.

This analysis shows that the proposed vessel can be designed, fabricated and erected in the pit in Building 431, and vacuum leak tested for a cost of \$3,987,500. The estimated finished weight of the vacuum vessel is 565,490 lb which represents a cost of \$7.05/lb.

This analysis was based on the following assumptions:

- (1) That State Highway Division 4 will allow a 31-ft diameter x 15-ft high, 130,000-lb load to be transported from the Port of Oakland to Lawrence Livermore Laboratory.
- (2) That pulse arc welding will be used for all shop and field fabrication.
- (3) That plasma arc will be used for all cutting and weld preparation of the stainless steel plate.
- (4) That the vessel subassemblies are to be pre-staged in Building 431 and erected in the pit in Building 431.
- (5) That the use of the existing 60-ton house crane will be limited, and local drayage crews and mobile cranes will be employed as required.
- (6) That the vacuum leak testing of the vessel heads, diagnostic cells, and neutral beam source tanks will be conducted at the place of fabrication and that the testing of the remaining structure will be after vessel erection and assembly has been completed at LLL.
- (7) That the LLL external vacuum system will be available for the final vessel systems leak test. See Appendix B for Vacuum Vessel Acceptance Test Plan.

LSK 2404 A

SECTION A-A

REV	DATE	DESCRIPTION	PART NO.	LIST OF MATERIAL OR PART LIST
1	10/1/77	10-30-77		
<div style="display: flex; justify-content: space-between;"> <div> <p>EG&G SAN RAMON DIVISION</p> <p>P. O. BOX 204 SAN RAMON, CALIFORNIA 94583</p> <p>MFTF VACUUM VESSEL</p> </div> <div> <p>CODE ON REV. NO. 99626 C</p> <p>SCALE NONE</p> </div> <div> <p>REV. A</p> <p>LSK 2404</p> <p>SHEET</p> </div> </div>				
<p>LAST DATUM USED ☒</p> <p>DIMENSIONS AND TOLERANCING PER ASME Y14.5</p> <p>WELDS SHALL BE FULL STRENGTH OF PARENT MATERIAL AND IN ACCORDANCE WITH AWS OR ASME STANDARDS</p> <p>MACHINED SURFACES TO BE UNLESS OTHERWISE SPECIFIED</p> <p>DO NOT SCALE THIS DRAWING</p>				
<p>PART NO. CROSS HATCHED USED ON ASSC.</p>

ENGINEERING NOTE

MFTF

1000

PAGE

1

SUBJECT

VACUUM VESSEL COST ANALYSIS

NAME

T. Bevers

DATE

7/27/77

1000

The preliminary design and weight study (Appendix A) of the vacuum vessel indicated a "best estimated finished weight = 616 KIPS." After a more refined weight study was done during the Vacuum Vessel Cost Analysis, the final vacuum vessel finished weight is 565,490 lbs. The difference is primarily due to conservative weight assumptions made at the preliminary design stage instead of actual weight calculations done for the Vacuum Vessel Cost Analysis.

ENGINEERING COST ESTIMATE

PROJECT MFTF - VACUUM VESSEL (VV) COST ESTIMATE

JOB NO. B-320-01 BY T. Bevers CHECKED J. Garcia DATE 7-13-77 SHEET 1 OF 1

ITEM	DESCRIPTION	QTY.	UNIT	MATERIAL		LABOR			TOTAL ITEM COST	TOTAL ITEM COST \$/LB. **
				UNIT COST	TOTAL (\$K)	UNIT MAN HOURS	TOTAL MAN HOURS	(\$K)		
1000	Cost Estimate									
1100	Material	Lot			1,066.79				1066.79	
1200	Sub-Assembly Fabrication				193.2		26,168	654.3	847.5	
1300	Sub-Assembly Machining						15,101	407.7	407.7	
1400	Field Assembly and Erection				171.4		7,910	276.9	448.3	
1500	Shipping/Handling Fixtures				39.6		4,378	109.4	149.0	
1600	Shipping				41.8				41.8	
1700	Field Services/Equipment				231.1				231.1	
1800	Vacuum Testing				15.0		2,820	70.5	85.5	
1900	Engineering and Design				2.0		3,000	584.0	586.0	
2000	Capital Equipment*				160.0*				160.0*	
	Total (Vacuum Test by Others)				1,920.9		59,377	2102.8	4023.7	7 ¹²
	Total (Vacuum Test by LLL)								3987.5	7 ⁰⁵
	* Not included in totals.									
	** Based on a finished wt. = 565.49 KIPS									

1000

ENGINEERING COST ESTIMATE

PROJECT MFTF - VV MATERIAL

JOB NO. B-320-01 BY T. Bevers

CHECKED _____

DATE 7-12-77

SHEET 1 OF 1

ITEM	DESCRIPTION	QTY.	(KIPS) UNIT	MATERIAL		LABOR			TOTAL ITEM COST	
				UNIT COST	TOTAL (\$K)	UNIT MAN HOURS	TOTAL MAN HOURS	\$		
1100	VV Material			(K\$)						
1110	Upper Head	1	105.8	(1)	148.12					
1115	Streaming Gun Close Off	125	.013	.054	6.75					
1120	Lower Head	1	117.20	(1)	164.08					
1130	Shell	1	250.51	(1)	350.71					
1150	Support Skirt	1	40.0	(1)	56.00					
1160	Neutral Beam Source Tank	4	27.81	(1)	155.74					
1165	N.B. Source Tank Close-Offs	48	.26	.400	19.2					
1180	Diagnostic Provision Chambers	Lot	12.84	(1)	17.98					
1190	Misc. Materials	Lot	5.9	103.29K	51.21					
	Sub-Total		657.6		969.79					
	10% Handle/Profit				97.0					
	Total				1066.79			\$	1066.79	
1198	VV Finished Weight		565.49							
	(1) \$1.40/lb.									

QTY REQD.	PART NO.	DESCRIPTION	ZONE	ITEM NO.
LIST OF MATERIAL OR PART LIST
DRAWING <i>per Gorgell</i> CHECKED DESIGNER ENGINEER PROJ. ENG.	C-30-77	P. O. BOX 204, SAN RAMON, CALIFORNIA 94583		
	MFTF PREERECTION SUBASSEMBLIES			
	CODE OR IDENT. NO.	SIZE	REV	
	99626	C	A	
	SCALE NONE	CALC. WT.	SHEET	

SUBJECT

V. V MATERIAL

NAME

T. BEVERS

DATE

7/12/77

1100 V V MATERIAL

THE FOLLOWING FIGURE REPRESENTS
THE SUB-ASSEMBLED PARTS OF THE
VACUUM VESSEL

ENGINEERING NOTE

MFTF

1110

PAGE

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SUBJECT

V V MATERIAL

NAME

T. BEVERS

DATE

6/28/77

1110 UPPER HEAD (29.52' Ø F&D HEAD)

ASSUME 4" R IN CROWN OF HEAD 224' Ø
WILL BE SUFFICIENT MATERIAL FOR REINFORCEMENT
AND DEFLECTION REQUIREMENTS

KIPS

R'S

(1) 78" x 4"

(4) 82" x 4"

(6) 85" x 193" x 1/4"

(6) 20" x 193" x 1/4"

$$\left. \begin{array}{l} (4) \\ (6) \end{array} \right\} 284 \text{ K IN}^3 \times R = 80.4 \text{ KIPS}$$

FLG. 7" x 11" x 31' x 12" x π x R25.4 KIPS105.8 KIP

ENGINEERING NOTE

MFTF

1115

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SUBJECT

V V MATERIALS

NAME

T. BEVERS

DATE

7/7/77

1115 STREAMING GUN CLOSE-OFF COST (\$)

3"-150# BLIND FLANGE "MODIFIED".

MATE: 6061-T6

7 1/2" OD x 15/16" THICK

6" B.C. DIA

8-3/4" Ø HOLES

4 1/2" ID "O" RING No 2-425

8-5/8" Ø S.S. BOLTS

PRICE QUOTES (WESTERN FORGE-MR. McCURDY)

FLANGES	\$ 35/PC.	* 1	35
BOLTS	\$ 2/PC	* 8	16
O-RING	\$ 3 / PC	* 1	3
			<hr/>
			\$54/FLG

*125

\$6,750

ENGINEERING NOTE

MFTF

1120

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SUBJECT

V V MATERIAL

NAME

T. BEVERS

DATE

6/28/77

1120 LOWER HEAD WEIGHT (KIPS) 29.52' ϕ SAME AS UPPER HEAD EXCEPT 1 1/4" ϕ WAS 1 1/2" ϕ HEAD PLATES(1) 78" ² x 4"(4) 82" ² x 4"

(6) 85" x 193" x 1 1/2"

(6) 20" x 193" x 1 1/2"

289.07 IN.³ x ρ

=

81.8 KIPS

FLANGE (SAME AS UPPER HEAD FLG.)

25.4 KIPS

MAGNET SUPPORT SHROUDS $W = \pi D_m t l \rho$ (60" DIA x 1/2" t) $= \pi * 60 * .5 * 78" * .283$ $= 2.08 \text{ KIPS}$

FLANGES 100 LBS ea.

TOTAL = 2.18 KIPS

GRAND TOTAL (4) 2.18 KIPS $\rightarrow$

8.72 KIP

BELLOWS (60" DIA.)WT: 60" * π * 1/2" * 12" EFF. = 320 LBS

FOR (4)

1.28 KIP

117.20 KIPS

SUBJECT

V V MATERIAL

NAME

T. BEVERNS

DATE

7/11/77

1130 SHELL MATERIAL COURSE WEIGHTS (KIPS)COURSE WEIGHTS

KIPS

UPPER SHELL (29.52' ϕ x 5.8' LG.)

$$WT. = 1.25'' \times 5.8' \times 12'' \times 29.52' \times 12'' \times \pi \times \rho = 27.4 \text{ KIPS}$$

MIDDLE SHELL (29.52' ϕ x 15' LG.)

$$WT. = 2.0'' \times 15' \times 12'' \times 29.52' \times 12'' \times \pi \times \rho = 113.4 \text{ KIPS}$$

LESS HOLES FOR PENETRATIONS

$$(4) \frac{\pi (9.74' \times 12'')^2}{4} \times 2'' \times \rho = 24.3$$

$$(4) \pi \frac{78.74^2}{4} \times 2'' \times \rho = 11.0$$

$$(8) \pi \frac{39.37^2}{4} \times 2'' \times \rho = 5.5$$

(FOR WT. ONLY) - 40.8 KIPS

PLUS FLANGED STUBS

N.B. TANKS (4) (9.75' ϕ x 25" LG.)

$$WT = 4 [9.75' \times 12'' \times \pi \times .75'' \times 25''] \rho$$

$$+ 4 (3'' \times 6'' \times 123'' \times \pi) \rho = 15.7 \text{ KIPS}$$

2M ϕ FLANGED STUBS (2M ϕ x 15" LG.)

$$WT = 4 (78.74'' \times \pi \times .75'' \times 15'') \rho$$

$$+ 4 (83.74'' \times \pi \times 2'' \times 5'') \rho = 6.13 \text{ KIPS}$$

ENGINEERING NOTE

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SUBJECT

V V MATERIAL

NAME

T. BEVERS

DATE

7/11/77

1130 SHELL MATERIAL (CONTD)COURSE WTS.

(KIPS)

MIDDLE SHELL (CONTD)

PLUS FLANGED STUBS

1 M ϕ DIAGNOSTIC PROVISIONS X 15" LG.

$$WT = 8 (39.37 * \pi * .75 * 15") \rho$$

$$+ 8 (43.37 * \pi * 1.5 * 4") \rho$$

=

5.0 KIPS

TOTAL FOR FLANGED STUBS = 26.83 KIPS

TOTAL FOR MIDDLE SHELL COURSE

$$WT = 113.4 + 26.83$$

=

140.23
KIPSLOWER SHELL COURSE - 1 1/2" ϕ (29.52' ϕ X 5.8' LG.)

$$WT = 1.5 * 5.8 * 12 * 29.52 * 12 * \pi * \rho =$$

32.88
KIPSBODY FLANGES (7" X 11")

$$WT = 7" * 11" (29.52 * 12 + 11) \pi * \rho = 25 \text{ KIPS}$$

$$\text{FOR (2)} \quad WT = 2 * 25 =$$

50.0 KIPS

GRAND TOTAL FOR SHELL & FLANGES

250.51
KIPS

40.0 KIPS

GRAND TOTAL

$$= 188 \times \frac{44}{100} = 0.1 \text{ KIPS}$$

$$\text{WT} = (44) 1" \phi \times 6'2.6 \times \frac{188}{100}$$

BOLTS

$$= 7.1 \text{ KIPS}$$

$$\text{WT} = 2" \times 11" \times \pi \times 360.24 \times 0$$

BASE RING

$$= 6.4 \text{ KIPS}$$

$$\text{WT} = (44) \times 8'12 \times 4' \times 1.375 \times 0$$

LONG. STIFFNR.

$$= 3.7 \text{ KIPS}$$

$$\text{WT} = 2" \times 6" \times \pi \times 346.25 \times 0$$

RING STIFFNR.

$$= 22.7 \text{ KIPS}$$

$$\text{WT} = \pi \times 29.52 \times 12 \times .75 \times 8'12 \times 0$$

SKIRT

USING 3/4" F w/ STIFFNERS

1150 SUPPORT SKIRT (29.52' ϕ x 8'2.6)

SUBJECT	V V MATERIAL		NAME T. BEVERS	DATE 7/11/77
		ENGINEERING NOTE	MFTF		
PAGE 13	1150				

SUBJECT

V V MATERIAL

NAME

T. BEVERS

DATE

7/12/77

1160 NEUTRAL BEAM SOURCE TANK MATERIAL WEIGHT

SOURCE TANK MAIN HOUSING

 WEIGHT
(KIP)

AS CALCULATED BY L. HUNT

HOUSING STRUCTURE

18.0

SUBJECT

V V MATERIAL

NAME T. BEVERS

DATE 7/12/77

1160 NEUTRAL BEAM SOURCE TANK MATERIAL WEIGHT
SOURCE TANK DISHED HEAD

168" DIA. X 3/4" THICK

W/ 5"x6" FLANGE

FLANGE WT:

$$(180^2 - 168^2) \frac{\pi}{4} \times 5" \times .283 = \underline{4.64 \text{ KIPS}}$$

DISHED HEAD WT:

 FOR 168" DIA. HEAD, USE A
176" BLANK DIA.

 FROM LUKENS STEEL CO. ENG. DATA
WT. FOR 3/4" 176" DIA. = 5.17 KIPS

SUB TOTAL FOR (1) TANK WT. =

$$18.0 + 4.64 + 5.17 = \underline{27.81 \text{ KIPS}}$$

GRAND TOTAL FOR (4) N.B. SOURCE TANKS

111.24 KIPS

SUBJECT

V V MATERIAL

NAME

T. BEVERS

DATE

7/7/77

1165 N.B. SOURCE TANK CLOSE-OFF COST (K#)

A-A

MAKE FROM 1"R X 24" X 36" 6061-T6 AL.

INCLUDED WERE (32) $\frac{3}{8}$ " ϕ HOLES AND

SINGLE GROOVE FOR $\frac{1}{4}$ " O-RING GASKET.

(32) $\frac{3}{4}$ " ϕ S.S. BOLTS, GR. 8

QUOTE PER UNIT ~ \$400 (WESTERN FORGE)

WT. = 245# + 15# BOLTS = 260# / UNIT ^{MR M'CURDY}

TOTAL COST FOR LOT (48 X 400) =

(K#)

\$19.2

ENGINEERING NOTE

MFTF

1180

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SUBJECT

V V MATERIAL

NAME T. BEVERS

DATE 7/11/77

1180 DIAGNOSTIC PROVISION CHAMBERS WEIGHTS (KIPS)2 M ϕ (4) CHAMBERS

$$\frac{3}{4}" \text{ DISHED HEAD} = 1.15 \text{ KIPS}$$

$$\begin{aligned} \text{FLANGE WT.} &= 2" \times 5" \times 83.74 \times \pi \times P \\ &= .75 \text{ KIPS} \end{aligned}$$

STUDS & NUTS

$$\begin{aligned} \text{WT} &= (132) \frac{3}{4}" \phi \times 6" \text{ LG} \\ &= (132) \frac{97.4 \#}{100} = .13 \text{ KIPS} \end{aligned}$$

$$\begin{array}{r} \text{SUB TOTAL} \\ \hline 2.03 \text{ KIPS} \end{array}$$

$$\begin{array}{r} \text{TOTAL} : (4) 2.03 \\ \hline 8.12 \text{ KIPS} \end{array}$$

1 M ϕ (8) CHAMBERS

$$\frac{5}{8}" \text{ DISHED HEAD} = 0.3 \text{ KIPS}$$

$$\begin{aligned} \text{FLANGE WT.} &= 1.5" \times 4" \times 43.37 \times \pi \times P \\ &= 0.25 \text{ KIPS} \end{aligned}$$

STUDS & NUTS

$$\begin{aligned} \text{WT} &= (68) \frac{5}{8}" \phi \times 5" \text{ LG} \\ &= 68 \times \frac{57}{100} = .04 \text{ KIPS} \end{aligned}$$

$$\begin{array}{r} \text{SUB TOTAL} \\ \hline 0.59 \text{ KIPS} \end{array}$$

$$\begin{array}{r} \text{TOTAL } (8 \times .59) = \\ \hline 4.72 \text{ KIP} \end{array}$$

$$\begin{array}{r} \text{GRAND TOTAL} \\ \hline \hline 12.84 \text{ KIPS} \end{array}$$

ENGINEERING NOTE

METF

1191.4

PAGE

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SUBJECT

V V MATERIALS

NAME

T. BEVERS

DATE

7/12/77

1190 MISC MATERIAL WEIGHT/COST1191 SCRAP WEIGHT (KIPS)

EACH SECTION HAD DIFFERENT PERCENTAGES OF
SCRAP DEPENDING ON SHAPE. SUMMARY IN KIPS:

1110 - 8.1 , 1120 - 9.0 , 1130 - 5.4

1150 - 0.7 , 1160 - 12.0 1180 - 2.0

1100 TOTAL SCRAP
COST @ \$140/#

37.2 KIP
\$ 52.08

1192 GASKET COSTS (\$)

(4) SETS EA. $\frac{1}{4}$ " ϕ CHORD STOCK FOR

2 - 9 m ϕ HEADS

4 - 2.95 m ϕ N.B.

4 - 4.6 m ϕ N.B.

} 39,800 FT @ \$11.25/C FT.

\$ 4478

8 - 1 m ϕ DIAG.

4 - 2 m ϕ DIAG.

4 - 1.6 m ϕ SUPPTS

} 10,950 FT @ \$11.25/C FT

\$ 1232

125 - 8 cm ϕ GUNS

48 - 80" CIRC.; N.B. HEAD

SUB

\$ 5710

SHIPPING

200

TOTAL

\$ 5910

ENGINEERING NOTE

MFTF

1193 +

PAGE

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SUBJECT

V V MATERIALS

NAME

T. BEVERS

DATE

7/12/77

1190 MISC. MATL. COSTS (K\$)1193 BOLTS GR. 8

200 - 2" ϕ x 12" LG	HEADS
200 - 1" ϕ x 10" LG	N.B. Hd.
150 - 3/4" ϕ x 8" LG	N.B.
100 - 5/8" ϕ x 7" LG	DIAG
100 - 3/4" ϕ x 8" LG	DIAG
75 - 5/8" ϕ x 6" LG	SUPPTS
600 - 1/2" ϕ x 3" LG	CON
300 - 1/2" ϕ x 3" LG	B.Hd. DRG

SUB T.

\$ 25.0

SHIPPING

.3

TOTAL

\$ 25.31194 BELLWS 60" ϕ

PER AMB FLEX HOSE QUOTE

60" SS. W/FLGS & TESTED

~ 5000/UNIT

(4)

\$ 20.0

ENGINEERING NOTE

MFTF

1198

PAGE

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SUBJECT

V V FINISHED WEIGHT

NAME T. BEVERS

DATE 7/13/77

1198 V V FINISHED WEIGHT

THE WEIGHT OF THE FINISHED VACUUM CONTAINMENT VESSEL WAS ESTIMATED FROM SECTION 1100 OF THE VESSEL COST ESTIMATE. THIS WEIGHT WAS FOR THE VESSEL STRUCTURE INCLUDING THE DIAGNOSTIC PROVISION CHAMBERS (12) AND NEUTRON BEAM SOURCE TANKS (4). INTERNAL STRUCTURE AND CRYOPANELS WERE NOT INCLUDED.

WEIGHT SUMMARY

(KIPS)

1. UPPER HEAD	105.80
2. SHELL	250.51
3. SHELL PENETRATIONS	- 40.8
4. LOWER HEAD	117.20
5. SUPPORT SKIRT	40.00
6. DIAGNOSTIC CELLS	12.84
7. N.B. SOURCE TANKS	111.24
8. BOLTS, NUTS, MISC	5.90
9. SCRAP	- 37.2

GRAND TOTAL

565.49 KIPS

SHEET 1 OF 2

ITEM	DESCRIPTION	QTY.	UNIT	MATERIAL		LABOR			TOTAL ITEM COST
				UNIT COST	TOTAL(\$K)	UNIT MAN HOURS	TOTAL MAN HOURS	25/Hr. K \$	
1200	V V Sub-Assembly Fabrication								
1210	Upper Head	1					3,540	88.5	88.5
1220	Upper Shell	1					432	10.800	10.8
1230	Middle Shell	1					805	20.1	20.1
1240	Lower Shell	1					582	14.6	14.6
1250	Lower Head	1					3,840	96.0	96.0
1260	N.B. Source Tanks	4				710	2,840	71.000	71.0
1270	Diagnostic Provision Chambers	Lot					1212	30.300	30.3
1280	Skirt						344	8.6	8.6
1290	Flanges	Lot					1,044	26.1	26.1
1292	Welding Supplies	Lot			140.19				140.19
1293	Forming/Rolling	Lot			53.0				53.0
	Sub-Total				193.19		14,639	366.0	558.2
	Labor η = 80%, Correction						18,299	457.5	457.5
	10% Repair						1,830	45.8	45.8
	Sub-Totals						20,129	503.3	503.3

SUBJECT

V V SUB-ASSEMBLY FABRICATION

NAME

T. BEVERS

DATE

7/6/77

1200

WELDING VOLUMES FOR GIVEN R THICKNESS

ASSUME VOLUME OF WELD FROM A
 90° INCLUDED $\angle$ & .030 LAND THICKNESS
 + 30% FOR BACK GOUGING TO CLEAN METAL
 AND REINFORCEMENT

$$V \sim 2\left(\frac{1}{2} b l^3\right) \quad \text{WHERE } b = \frac{t}{2}$$

$$\therefore V = \frac{t^3}{8}$$

$$\text{TOTAL } V = \frac{t^3}{8} (1.3)$$

$$\text{WELD RATE} = 4\#/\text{HR}$$

$R \ t$ (IN.)	VOL. (IN. ³)	ρ (.283#/IN. ³)	WT/LIN. IN. (#/IN.)	WELD RATE (HR/IN.)
4	10.4	↓	2.94	.7350
2	1.3		.37	.0925
1/2	0.55		.16	.0400
1/4	0.32		.09	.0226
1	0.16		.05	.0120
3/4	0.07		.02	.0050

432

1220	UPPER SHELL	
120	LAYOUT/TIEM R	
50	LAYOUT/BURN O	
100	WELD PREP	
30	FIT/TAC	
31	WELD	
101	SHELL	
	FLG.	

3540

1210	UPPER HEAD	
600	WELD PREP HS	
1000	LAYOUT/BURN/SW	
220	FIT/TACK	
	WELDING	
1017	HEADS 210+807	
602	STIFERS 602	
101	FLGS 101	

FABRICATION LABOR (MAN HOURS)
 INCLUDES: LAYOUT, HANDLE, BURN, CUT,
 FIT UP, SETUP, WELD PREP,
 TACKUP, WELDING, ETC.

1200 V. V SUB-ASSY FAB

SUBJECT V. V SUB-ASSY. FABRICATION	NAME T. GEVERS	DATE 6/29/77	PAGE 25	ENGINEERING NOTE	MTF	1210 +

ENGINEERING NOTE

MFTF

1230 +

PAGE

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SUBJECT

V V SUB-ASSY. FABRICATION

NAME

T. BEVERS

DATE

6/29/77

1200 V V SUB-ASSY FAB (CONTD)FAB. LABOR (MAN HOURS)HRS1230 MIDDLE SHELL (HRS)

LAYOUT/TRIM 184

WELD PREP 230

WELD

2MØ 101

DIAG 290

391

TOTAL

805

1240 LOWER SHELL (HRS)

LAYOUT/TRIM 140

LAYOUT/BORN Ø 60

WELD PREP 180

FIT/TAC 40

WELD

SHELL 38

FLG. 124162

TOTAL

582

1250 LOWER HEAD (HRS)

LAYOUT/BURN R's 870

WELD PREP 860

FIT/TAC 320

WELD

HEADS 257

807

STIFFERS 602

FLG 1241990

TOTAL

3840

ENGINEERING NOTE

MFTF

1260/1270

PAGE

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SUBJECT

V V SUB ASSY FABRICATION

NAME T. BEVERIS

DATE 6/29/77

1200 V V SUB-ASSY. FAB.

FAB LABOR -

(HRS)

1260 N.B. SOURCE TANKS (4)

LAYOUT / TRIM / BURN	220
WELD PREP / HANDL	95
FIT / TAC	75
WELD	320

710

*4

28401270 DIAGNOSTIC PROVISION CHAMBERS1272 (4) 2mØ

LO. / TRIM / BURN	20
WELD PREP	7
FIT / TAC	5
WELD	105

137

*4

548

1274 (8) 1mØ

LO / TRIM / BURN	10
WELD PREP	5
FIT / TAC	3
WELD	65

83

*8

664

TOTAL

1212

ENGINEERING NOTE

METF

1280 +

PAGE

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SUBJECT

V V SUB-ASSY. FABRICATION

NAME

T. BEVERS

DATE

6/29/77

1200 V V SUB ASSY FAB. (CONT'D)

FAB LABOR (MN HRS)

HRS

<u>1280</u>	<u>SKIRT</u>	(HRS)
	LAYOUT/TRIM	160
	WELD PREP	40
	WELD	
	R	9
	BAR	5
	RING	55
	L	75
		<u>144</u>

344

1290 FLANGES (4) 7"X11"

L.O./TRIM	25
SAW WELD PREP.	325
WELD	694
	<u>1044</u>

1044

ENGINEERING NOTE

MFTF

1292

PAGE

30

SUBJECT

V V MATERIALS

NAME T. BEVERS

DATE 6/30/77

1292 WELDING SUPPLIES

WELDING RATES, GAS USAGE, AND PRICES
WERE BASED ON INFORMATION FROM
EUGENE MUSLADINE, EG&G WELDING CONSULTANT

BASED ON FAB WELDING MAN
HRS OF 7193 HRS AND A
WELD METAL LAY RATE OF
4 lb./HR FOR THE PA-3 WELDERS
USING .045" DIA. FILLER, THE
WT. OF FILLER METAL USED
WAS 7193 HRS. * 4 lb./HR = 28.8 KIPS.

ASSUME 10% FOR REPAIR.

TOTAL WT. = 28.8 * 1.10 = 31.68 KIPS.

PRICE FOR 25* SPOOLS OF .045" Ø
308-L FILLER WAS \$3.89/lb.

COST FOR FILLER = 31.68 * 3.89 = 123.24 (K\$)

GAS AGAIN BASED ON 7193 * 1.10 =
7912 HRS OF WELDING AND
USAGE @ 16 CU. FT./HR AND
\$7.50/CCF, THE COST OF GAS

WAS 7912 * 16 * \$7.50/100 C.F. = 9.45

PLASMA ARC SUPPLIES 7.50

TOTAL (K\$) 140.19

SUBJECT

V V SUB-ASSY. MACHINING

NAME

BEVERS

DATE

2/6/77

MACHINING ESTIMATE ASSUMPTIONSA. MILLING

- 1.) MILLING TOOL 4" WIDE
- 2.) CUTTING SPEED 70 fpm
- 3.) FEED SPEED PER TOOTH = .0005
- 4.) CUTTING DIA = 4" W/11 TEETH

REF. MACHINERY'S HDBK 12th ed. Pg 1744+

$$\therefore N = \frac{12V}{\pi D} = \frac{12 \times 70 \text{ fpm}}{\pi \times 4} = 66.85 \text{ rpm}$$

$$f_m = f_t \times n_t \times N \\ = .0005 \times 11 \times 66.85 = 3.68 \text{ ipm}$$

- 5.) MILLING SPEED USED 3.7 IN./MIN.

B. DRILLING

- 1.) CUTTING SPEED, DRILLING 50 fpm
- 2.) " " , REAM 30 fpm
- 3.) FEED, .015 IN/DRILL REV.

$$\text{FOR 2" DIA} \quad N = \frac{12 \times 50}{\pi \times 2} = 95.5 \text{ rpm}$$

$$\begin{array}{ll} \text{SPEEDS} & \text{DRILLING } f = .015 \times 95.5 = 1.43 \text{ IN./MIN.} \\ & \text{REAMING } f = 1.43 \times \frac{30}{50} = 0.86 \text{ IN./MIN.} \end{array}$$

$$\text{FOR 1" DIA} \quad N = \frac{12 \times 50}{\pi \times 1} = 191$$

$$\begin{array}{ll} \text{SPEEDS} & \text{DRILLING } f = 0.015 \times 191 = 2.87 \text{ IN./MIN.} \\ & \text{REAMING } f = 2.87 \times \frac{30}{50} = 1.72 \text{ IN./MIN.} \end{array}$$

ENGINEERING NOTE		MTF	1310	PAGE 33
SUBJECT		V V SUB-ASSY. MACHINING				
NAME		T. BEVERS				
DATE		6/29/77				

1300 V V SUB-ASSY. MACHINING

MACHINE OPERATIONS - MAN HOURS

(HRS)

1310 HEAD/SHELL FLANGES (4)

BOLT HOLES 1064

FACING 352

GROOVES 420

INSP/HANDL 300

POST WELD FIELD MACHINING 200

1320 N.B. TANK FLANGES (4 PER UNIT)

DRILLING, FACING,

GROOVES, INSPECT,

HANDLING

200 HRS/TANK

(4) TANKS

1330 DIAGNOSTIC FLANGES

1 M Φ 150 + 8 UNITS 1200

2 M Φ 300 + 4 UNITS 1200

2000

1340 SKIRT BASE

FACE

BOLT HOLES

INSPECT/HANDLING

15

65

30

110

SUBJECT

V V SUB-ASSY. MACHINING

NAME T. BEVERIS

DATE 2/6/77

1350 STREAMING GUN ATTACH

MAN HRS. PER GUN ATTACH

LAYOUT & LOCATE

1. FACE	.3 HR
2. (8)-5/8" DIA HOLES	1.0 HR
3. SEAL SURFACE	.3 HR
4. LANDING	.4 HR
5. 3 1/8" DIA. HOLE	.8 HR

 2.8 HR/ATTACH

HANDLING/START/MOVE

.5 HR/ATTACH

ENGINEERING NOTE

METF

1350

PAGE

35

SUBJECT

V V SUB-ASSY. MACHINING

NAME T. BEVERS

DATE 7/6/77

1350 STREAMING GUN ATTACH (CONT'D.)

MAN HRS. PER GUN ATTACH

FITUP & MACHINE

1.) FACE	.5 HR
2.) 6- $\frac{3}{4}$ " ϕ HOLES (DRILL)	1.4 HR
3.) TAP 8- $\frac{5}{8}$ " ϕ HOLES	2.0 HR
4.) FINISH SEAT	.8 HR
5.) LAND	.5 HR
6.) CHAMFER	.4 HR
7.) BORE 3 $\frac{1}{8}$ " ϕ	1.4 HR
8.) REAM 3 $\frac{1}{8}$ " ϕ	.6 HR
9.) DEBURR/CLEAN	1.0 HR

9.1 HR

SUB TOTAL MACHINE LABOR	11.9 HR
10% REPAIR	1.2 HR
30% INSPECTION	3.6
SUB TOTAL	<hr/> 16.7 HRS/GUN

ASSUME 125 PENETRATIONS

2088 HRS

SUBJECT

V V SUB-ASSY. MACHINING

 NAME **E. ADAMS**

 DATE **7-7-77**
1360 NEUTRAL BEAM SOURCE
TANK CLOSE-OFF
PREP.

 TYPICAL SECTION
 (48 PLACES)

SOURCE TANK HEAD

SECTION A-A

LABOR WAS BASED ON VENDOR NOT
 HAVING NUMERICALLY CONTROLLED
 EQUIPMENT. GREAT COST SAVINGS
 IF THE VENDOR DOES HAVE N.C.
 EQUIPMENT.

ENGINEERING NOTE

MFTF

1360

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SUBJECT

V V SUB-ASSY. MACHINING

NAME

T. BEVERS

DATE

7/12/77

1360 NEUTRAL BEAM SOURCE TANK CLOSE-OFF
PREPARATION - LABOR MAN HRS.

LABOR HRS PER ATTACHMENT

<u>LAYOUT & LOCATE</u>	<u>HRS.</u>
1. FACING	.5
2. 32- $\frac{7}{8}$ " ϕ HOLES	3.0
3. GROOVE	1.5
4. SEAL SURFACE	1.5
5. LAND	.7
6. BORE	1.0

SETUP & MACHINE

1. FACING	2.5
2. DRILL (32)- $\frac{7}{8}$ " ϕ HOLES	5.0
3. TAP (32) HOLES	8.0
4. GROOVE	4.0
5. SEAL SURFACE	1.0
6. LAND	1.5
7. CHAMFER	.7
8. FINISH BORE	2.0
9. DEBURR + CLEAN	2.0

SUB TOTAL MACH. LABOR 34.9 HRS

10% REPAIR 3.5 HRS

30% INSPECTION 10.5 HRS

SUB TOTAL 48.9 HRS

GRAND TOTAL FOR 48, 48 * 48.9 HRS =

2347 HRS

ENGINEERING COST ESTIMATE

PROJECT MFTF - V V FIELD ASSEMBLY/ERECTION

JOB NO. B-320-01 BY T. Bevers

CHECKED _____

DATE 7-13-77

SHEET 1 OF 2

ITEM	DESCRIPTION	QTY.	UNIT	MATERIAL		LABOR			TOTAL ITEM COST	
				UNIT COST	TOTAL (\$K)	UNIT MAN HOURS	TOTAL MAN HOURS	(1) K \$		
1400	V V Field Assembly/Erection									
1410	Miscellaneous Field Prep.	Lot					900	31.5	31.5	
1420	Skirt Assembly	1					65	2.3	2.3	
1430	Lower Head	1					187	6.5	6.5	
1440	Lower Shell	1					90	3.2	3.2	
1445	Middle Shell	4				362.5	1,450	50.8	50.8	
1450	Upper Shell	1			50.0		450	15.8	65.8	
1460	Upper Head	1					155	5.4	5.4	
1470	Diagnostic Provision Cells	8					625	21.9	21.9	
1480	N.B. Tanks	4					150	5.3	5.3	
1485	Scaffold Moves/Handling	Lot					500	17.5	17.5	
1490	Repair	Lot					116	4.1	4.1	
1495	Clean Vessel	Lot					500	17.5	17.5	
1497	Fabrication Supplies	Lot			21.4				21.4	
1498	Post Erection Disassembly and Move	Lot			100.0		1,140	39.9	139.9	
	(1) Based on \$35 /Hr.									

1400

SUBJECT

V V FIELD ASSY. / ERECTION

NAME

T. BEVERS

DATE

7/13/77

1400 V V FIELD ASSY. / ERECTION

THE VIEW SHOWN BELOW DEPICTS THE SUB-ASSEMBLED SECTIONS OF THE VACUUM VESSEL AS THEY WILL ARRIVE AT L.L.L. BEFORE ASSEMBLY & ERECTION.

ENGINEERING NOTE

MFTF

1410+

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SUBJECT

V V FIELD ASSY. & ERECTION

NAME T. BEVERS

DATE 6/29/77

1400 V. V. FIELD ASSY./ERECTION

ASSEMBLY COSTS (MAN HRS)

	FABRICATION	MAN HOURS	HRS
<u>1410</u>	RECEIVE/INSP/OFFLOAD SUB-ASSEMBLED SECTIONS STORE REC/INSP/OFFLOAD FIXTURES/EQUIP	500 100 300	900
<u>1420</u>	SKIRT ASSY. HANDL/FIT/TAC WELD	50 15	65
<u>1430</u>	LWR. HEAD HANDL/FIT/TAC ASSY. VAC. R'S WELD TO SKIRT	50 12 125	187
<u>1440</u>	LWR SHELL HANDL/FIT/INSTL INSTL SEAL ASSY.	50 10 30	90
<u>1445</u>	MID. SHELL HANDL/FIT/INSTL. FIXT. HANDL FIT/TAC WELD ROUNDS WELD LONGS INSTL. FIXT.	400 280 200 170 400	1050

ENGINEERING NOTE

MFTF

1450+

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SUBJECT

V V FIELD ASSY. / ERECTION

NAME

T. BEVERS

DATE

6/29/77

1400 V.V. FIELD ASSY. / ERECTION (CONT'D)

ASSY. COSTS

FABRICATION MAN HOURS

HRS

<u>1450</u>	UPPER SHELL		
	HA. /FIT/TAC	150	
	WELD ROUNDS	<u>300</u>	
			450
	MOVE ASSEMBLED SHELL TO PIT (BIGGE)		50 K\$
<u>1460</u>	UPPER HEAD		
	HANDL / FIT / INSTL	100	
	INSTL. SEAL	15	
	ASSY.	<u>40</u>	
			155
<u>1470</u>	DIAG. PROV. CELLS		
	HANDL / FIT / TAC	50	
	WELD NECK	250	
	WELD REPAD	100	
	HANDL / FIT / TAC REPAD	25	
	ASSY. CELL	<u>200</u>	
			625
<u>1480</u>	N.B. SOURCE TANKS		
	HANDL / FIT / INSTL	80	
	ASSY.	<u>70</u>	
<u>1485</u>	HANDLING SCAFFOLDING,		150
	EQUIP, MISC. DURING FAB →		500
<u>1490</u>	REPAIR 10% (1160 WELD HRS)		116
<u>1495</u>	CLEAN VESSEL		500

ENGINEERING NOTE

MFTF

1497

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SUBJECT

V V FIELD ASSY. / ERECTION

NAME

T. BEVENS

DATE

6/30/77

1497 FABRICATION SUPPLIESFILLER METAL

(K#)

WELD HRS. $1160 \text{ HRS} \times 1.1 = 1276 \text{ HRS}$

WIRE RATE 4 LB./HR

WIRE = $4 \times 1276 = 5104 \#$ @ \$3.89/# = \$19,855

19.9

WELDING GAS

HRS. OF WELDING - 1276

GAS RATE 16 CU.FT. / HR

GAS USED $16 \times 1276 = 20,416 \text{ CU.FT.}$ COST @ $7.50/100 \text{ CF} = \underline{\underline{\$1,531}}$

1.5

TOTAL

\$ 21.4

ENGINEERING NOTE

MFTF

1498

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SUBJECT

V V FIELD ASSY. / ERECTION

NAME

T. BEVERS

DATE

2/13/77

1498	POST ERECTION DISASSEMBLY & MOVE	HRS	K\$
DISASSY.	TOP HEAD & MOVE	120	
		HRS	
DISASSY	SHELL	50	
	NB TANKS	100	
	DIAGN. CELLS	100	
	HANDL	200	
	MOVE (BIGGE)		50 K
		450	
RE ASSY.	SHELL, ETC.	450	
	MOVE (BIGGE)		50 K
RE ASSY	TOP HEAD	120	
		<u>1140 HRS</u>	<u>\$ 100 K</u>

ENGINEERING NOTE

MFTF

1510

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SUBJECT

V V SHIPPING / HANDLING FIXTURES

NAME

T. BEVERS

DATE

7/12/77

1510 FABRICATION FIXTURES

THESE FIXTURES WERE USED TO ASSIST HANDLING DURING FABRICATION AND SOME SHOULD BE DESIGNED TO BE USED DURING SHIPPING & ERECTION.

<u>FIXTURE USE</u>	<u>FAB LABOR</u> (HRS)	<u>MATERIAL WT.</u> (K#)
HEADS	300	15
N.B. TANKS	200	5
DIAGNOSTIC PROV'S.	140	1
SHELL	175	7
SKIRT	130	2
LIFT DEVICES	300	15
MISC.	300	5
 TOTAL	 <u>1545 HRS</u>	 <u>50.0 KIPS</u>

FAB. MATERIAL COSTS (K\$)

LOT GAS .5

LOT WELD FILLER 1.5

LOT WELD ROD 1.5

FIXTURE MATL. @ \$0.3/# 15.0

18.5 K\$

ENGINEERING NOTE

MFTF

1520

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SUBJECT

V V SHIPPING/HANDLING FIXTURES

NAME

T. BEVERS

DATE

7/12/77

1520 SHIPPING FIXTURES

<u>FIXTURE USE</u>	<u>FAB LABOR</u> (HRS.)	<u>MATERIAL WT.</u> (KIPS)
SHELL	300	5
N.B. TANKS	200	2
SKIRT	200	2
MISC	200	2
	<u>900 HRS.</u>	<u>11 KIPS</u>

<u>FAB. MATERIAL COSTS</u>	<u>(K\$)</u>
LOT GAS	.3
LOT WELD FILLER	.5
LOT WELD ROD	.5
FIXTURE MAT'L. @ \$0.3/#	3.3
	<u>4.6 K\$</u>

ENGINEERING NOTE

MFTF

1530

PAGE

48

SUBJECT

Y V SHIPPING / HANDLING FIXTURES

NAME

T. BEYERS

DATE

7/12/77

1530 ERECTION FIXTURES

<u>FIXTURE USE</u>	<u>FAB. LABOR</u> (HRS.)	<u>MATERIAL WT.</u> (KIPS)
SKIRT	200	10
SHELL	300	30
MISC	100	10
	<u>600 HRS.</u>	<u>50 KIPS</u>

<u>FAB. MATERIAL COSTS</u>	<u>(K\$)</u>
LOT GAS	.5
LOT WELD FILLER/ROD	1.0
FIXTURE MAT'L. @ \$0.3/#	15.0
TOTAL	<u>16.5 K\$</u>

ENGINEERING NOTE

MFTF

1800

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SUBJECT

V V VACUUM TESTING

NAME

T. BEVERS

DATE

7/13/77

1800 V V VACUUM TESTING

Due to the difficulty involved at assembly, double o-rings should be utilized on all flanged openings one meter in diameter or greater. This will allow a leak check of these openings immediately without having to evacuate the entire vessel. The integrity of the seal would be insured prior to the complete vessel leak check. This would also be a valuable design feature after the vessel is operational and any large covers are removed and reassembled.

Openings smaller than this should not be difficult to handle at assembly and hence a valid seal should be attained with one o-ring.

SHELL BODY FLANGE

ENGINEERING NOTE

MFTF

1810

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SUBJECT

V V VACUUM TESTING

NAME

T BEVENS

DATE

6/29

1810 PRE-TEST ASSEMBLIESFAB LABORHRS

ASSEMBLY OF (2) 9MØ HEADS TOGETHER

HANDLING	40	
FAB GASKETS	100	
ASSY. HEADS	100	
DISASSY. HEADS	100	(HRS)
BREAK SKIRT	40	
HANDL/STORE	40	
MISC	100	
ASSY. CLOSE-OFFS	400	

SUB TOTAL

920

ASSEMBLY OF 2 N.B. TANKS TOGETHER

TANK TO TANK ASSY. (1 SET)

HANDLING	30
FAB. GASKET	50
ASSY. TANKS	20
DISASSY. TANKS	20
HANDL/STORE	10
MISC	20
ASSY. CLOSE-OFFS	75

225 HRS x 2 =

450

SUB TOTAL

1370

15% INSPECT/REPAIR

206

TOTAL

1576

PROJECT - V V ENGINEERING/DESIGN

FOR NO.	BY	CHECKED	DATE	SHEET	OF
	T. Bevers		7-14-77	1	1

[illegible]

ENGINEERING NOTE

MFTF

1910

PAGE

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SUBJECT

V V ENGINEERING & DESIGN

NAME

T. BEVERS

DATE

7/13/77

1910 VENDOR ENGINEERING/DESIGN

ASSUME L.L.L. HAS COMPLETE RESPONSIBILITY
FOR VACUUM VESSEL DESIGN.

<u>TASK</u>	<u>RATE</u> <u>(\$/HR)</u>	<u>MAN HRS</u>	<u>COST</u> <u>(K\$)</u>
ASME CODE VARIFICATION	30	200	6.0
SEISMIC ANALYSIS	30	200	6.0
COMPUTER TIME			2.0
SHOP DRAWINGS	20	600	12.0
ENGINEERING SUPPORT-SHOP	30	1000	30.0
ENGINEERING SUPPORT-FIELD	30	1000	30.0
		<u>3000 HRS</u>	<u>86.0 K\$</u>

ENGINEERING NOTE

MFTF

1920

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SUBJECT

V V ENGINEERING / DESIGN

NAME

T. BEVERS

DATE

7/13/77

1920 LAWRENCE LIVERMORE LABORATORY ENGINEERING
AND DESIGN

EXACT TASKS ARE UNKNOWN AT THIS
STAGE OF DEVELOPMENT, BUT AN
ALLOWANCE OF 500 K\$ WILL BE
USED FOR THIS ESTIMATE .

ENGINEERING NOTE

MFTF

2000

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SUBJECT

V V CAPITAL EQUIPMENT

NAME

T. BEVERS

DATE

7/7/77

2000 CAPITAL EQUIPMENT

	(K\$)
1. PULSE-ARC WELDING SYSTEM 3 @ \$20K	60
2. PLASMA ARC BURNER 2 @ 15K	30
3. WELDING POSITIONERS & BOOMS	20
4. WELDING HEAD GUIDANCE SYSTEM (3) @ \$4K	12
5. MISC.	38
TOTAL	<hr/> 160K

APPENDIX A

PRELIMINARY DESIGN

ENGINEERING NOTE

MFTF

PAGE

1

SUBJECT

V V PRELIMINARY DESIGN

NAME

T. BEVERS

DATE

6/22/77

PURPOSE: THIS PRELIMINARY STUDY WAS PERFORMED FOR THE EXPLICIT PURPOSE OF A "FIRST TIME" ESTIMATE OF THE MFTF VACUUM VESSEL DESIGN AND WEIGHT. IT INCLUDES DESIGN CALCULATIONS, WEIGHT ESTIMATES, SEISMIC ANALYSIS, SUPPORT REQUIREMENTS, AND FIELD ERECTION JOINT LOCATIONS.

SUMMARY: THE BEST ESTIMATED FINISHED WEIGHT OF THE VACUUM VESSEL, NEUTRAL BEAM SOURCE TANKS, DIAGNOSTIC CELLS, AND VESSEL SUPPORT WAS 616,100 LB. THE VACUUM VESSEL DESIGN WEIGHT USED WAS 766,000 LB.

ENGINEERING NOTE

MFTF

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SUBJECT

VV PRELIMINARY DESIGN

NAME

T. Bevers

DATE

6/23/77

DESIGN REVIEW

1. The upper head is self reinforcing with a 2 inch crown thickness, but would require a rigorous deflection analysis with a stiffened head configuration. For convenience at this stage of development, a 4 inch crown thickness with no additional stiffening was used for the head design and weight calculations. Further study is needed for a stiffened head design.

2. The vessel, in general, for this study was designed such that no stiffening was needed. A further study might indicate thinner plate material with stiffeners is also structurally adequate and a cost savings.

SUBJECT

VV PRELIMINARY DESIGN

NAME

T. BEVERS

DATE

6/23/77

DESIGN REVIEW

THE VIEW BELOW DEPICTS THE SUB-ASSEMBLED SECTIONS AS THEY WOULD BE RECEIVED AT LLL.

VACUUM
TANK

PLATE
COURSES

FIELD ASSEMBLY JOINTS

SECTION A-A

LSK 2404 REV A

PART NO.		SYN		ZONE		REVISIONS		DATE		APPROVED	
REV		REV		REV		REV		REV		REV	
LIST OF MATERIAL OR PART LIST						<div style="text-align: center;"> <p>EG&G SAN RAMON DIVISION P. O. BOX 204, SAN RAMON, CALIFORNIA 94583</p> <p>MFTF VACUUM VESSEL</p> </div>					
<p>LAST DATUM USED </p> <p>DIMENSIONS AND TOLERANCING PER USASI Y14.5</p> <p>WELDS SHALL BE FULL STRENGTH OF PARENT MATERIAL AND IN ACCORDANCE WITH AWS OR ASME STANDARDS</p> <p>MACHINED SURFACES TO BE UNLESS OTHERWISE SPECIFIED ✓</p> <p>DO NOT SCALE THIS DRAWING</p>						<p>CODE OF DESIG. NO. 99626 DATE C LSK 2404 REV A</p> <p>SCALE NONE C.A.C. 87 SHEET</p>

ENGINEERING NOTE

MFTF

PAGE

1

SUBJECT

VCV PRELIMINARY DESIGN

NAME

T. BEVERS

DATE

6/21/77

EXTERNAL DESIGN MFTF VESSEL

REF. ASME SECTION VIII, DIV. 1 (S '76)

DESIGN CRITERIA

 $P = 15 \text{ PSI}$ TEMP $< 60^\circ \text{C}$

MAT'L. 304 S.S.

 $F_y = 30,000 \text{ PSI}$ (MIN. YIELD STRESS) $F_t = 75,000 \text{ PSI}$ (MIN. TENSILE STRESS)

EXT. PRESS CHARTS FIG. UHA-2B.1 P. 294

CORR. ALLOW = 0

TOP HEAD

PER UG-28 THE REQ'D THICKNESS FOR
EXT. PRESSURE WAS $1\frac{1}{16}"$. SEE APPENDIX
PG. A, & A2

ASSUMING A 3" DIA. SCH. 80 STUB
FIND HEAD t FOR SELF REINFORCING

GUN REINFMT.

a) HEAD REQ'D $t_{100\%} = 1\frac{1}{16}$ HEAD $t = 4"$

ENGINEERING NOTE

MFTF

PAGE

2

SUBJECT

V V PRELIMINARY DESIGN

NAME

T. BEVERIS

DATE

6/21/77

EXT. DESIGN MFTF VACUUM VESSELTOP HEAD

GUN REINFMT.

b) STUB WALL MIN.

.189 USE SCH 80 .300 N

.262 M

ID = 2.9

c) $t_{rn} = \text{NIL}$

d) REINFMT:

* UG-37(c)

$$A_{reqd} = (2.9 * 1.063) / 2 * 1.541 \text{ in}^2$$

$$A_1 = (E_1 t - F t_r) (t_n + t) 2$$

$$= (1 * 4 - 1 * 1.063) (.3 + 4) 2$$

$$= 12.63 \text{ in}^2 > 1.541 \text{ in}^2 \text{ OK}$$

TRY $t = 2$

$$A_1 = (1 * 2 - 1 * 1.063) (.3 + 2) 2$$

$$= 4.31 \text{ in}^2 > 1.541 \text{ in}^2 \text{ OK}$$

USING 4" Φ AT CROWN OF UPPER HEAD ~ 248" DIA
AND 1 1/4" Φ FOR THE REMAINDER OF THE CROWN,
KNUCKLE, AND STRAIGHT FLANGE.

ENGINEERING NOTE

MFTC

PAGE 3

SUBJECT VCV PRELIMINARY DESIGN

NAME T. BEVERS

DATE 6/23/77

EXT. PRESS. DESIGN

ASSUME NO PENETRATIONS

USE FIG. UHA-28.1 (18CR-8NI) 304 SS

P. 294

REF. ASME P.V. CODE SECTION VIII DIV. I 5-76

SHELL (L = 26.24')

D = 29.54'

CA = 0

REF. UG-28 (a)
ASSUME T = 1/2"

$$D_o/t = 29.54 \times 12 / 1.5 = 236.32$$

$$L/D_o = 26.24 \times 12 / 354.5 = .888$$

$$A = .00043 \quad (\text{FIG UG-28.0})$$

$$B = 6000 \quad (\text{FIG UHA-28.1})$$

$$P_c = \frac{AB}{3(D_o/t)} = \frac{4 \times 6000}{3 \times 236.32} = 33.852 \text{ PSI}$$

$$P_c = 33.9 \text{ PSI} > 15 \text{ OK}$$

$$@ t = 1 \quad D_o/t = 354.5 \quad L/D_o = 314.9 / 354.5 = .89$$

$$A = .0023 \quad B = 3700 \quad P_c = 4 \times 3700 / 3 \times 354.5 = 13.9$$

Use 1/8" t for t_{reqd}. CONSERV.

ENGINEERING NOTE

MFTF

PAGE

4

SUBJECT

VCV PRELIMINARY DESIGN

NAME

T. BEVERS

DATE

6/21/77

SHELL REINF.

ASSUME SHELL COURSES AT THE CENTER
OF THE SHELL ARE 2" THICK

REINFMT FOR SOURCE TANK

$$a) t_{reg'd 100\%} = 1\frac{1}{8}" \text{ (EXT. PRESS) REF.}$$

$$t = 2" \quad t_{rn} =$$

$$b) A_{reg'd} = (9.74 \times 12 \times 1.125) / 2 = 65.74 \text{ D}''$$

PER UA-7 $\frac{2}{3} A_{reg'd}$ TO BE WITHIN $\frac{1}{4} d \sim 44.05$

$$A_1 = (Et - Ft_r) d / 2^* \quad * UA-6$$

$$= (1.2 - 1.125) 9.74 \times 12 / 2 = 51 > 44.05 \text{ ok}$$

$$A_1 (\text{TOTAL}) = 2 \times 51 = 102$$

$$A_2 = (t_n - c) 2h$$
$$= (.75 - 0) 2 \times 2.5 \times .75$$

$$A_2 = 2.81 \text{ D}'' \quad 2.81$$

$$A_w = .75^2 \times 2 = 1.13$$

$$105.93 > 65.74$$

ok

ENGINEERING NOTE

MYTF

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SUBJECT

VCV PRELIMINARY DESIGN

NAME

T. BEVERS

DATE

6/21/77

NEUTRAL BEAM SOURCE TANK ADDL LOADS

INTO SHELL.

V = 60 KIPS
M = 4.423 X 10⁶ IN-LB.
RE: "LOCAL STRESSES IN CYL. SHELLS" - PROF. P.P. Bijaard
r₀ = 5
t = 1
R_m = 15' T = 2"

$$\therefore r = R_m / T = 90$$

$$\theta = .875 r_0 / R_m = 0.29$$

$$K_u = 2.52$$

$$K_b = 2.106$$

FROM P = 15 PSI

$$\sigma_x = PR/2t = -675 \text{ PSI}$$

$$\sigma_\phi = PR/t = -1350 \text{ PSI}$$

FROM TABLE 5, PG 6

$$\sigma_x = -3841 \text{ PSI}$$

$$\sigma_\phi = -4394 \text{ PSI}$$

Table 5—Computation Sheet for Local Stresses in Cylindrical Shells

PAGE
6

1. Applied Loads*

Radial load, $P = \underline{\hspace{2cm}}$ lb.
 Circ. Moment, $M_c = \underline{4423}$ in. lb. $E6$
 Long. Moment, $M_L = \underline{\hspace{2cm}}$ in. lb.
 Torsion Moment, $M_T = \underline{\hspace{2cm}}$ in. lb.
 Shear Load, $V_c = \underline{\hspace{2cm}}$ lb.
 Shear Load, $V_L = \underline{60K}$ lb.

2. Geometry

Vessel thickness, $T = \underline{2}$ in.
 Attachment radius, $r_o = \underline{60}$ in.
 Vessel radius, $R_m = \underline{180}$ in.

3. Geometric Parameters

$$\gamma = \frac{R_m}{T} = \underline{90}$$

$$H = (0.875) \frac{r_o}{R_m} = \underline{.29}$$

Stress Concentration due to:

- a) membrane load, $K_n = \underline{2.52}$
 b) bending load, $K_b = \underline{2.106}$ R_m

*NOTE: Enter all force values in accordance with sign convention

CYLINDRICAL SHELL

From Fig.	Read curves for	Compute absolute values of stress and enter result—	STRESSES — if load is opposite that shown, reverse signs shown							
			A _u	A _L	B _u	B _L	C _u	C _L	D _u	D _L
3C	$\frac{N\phi}{P/R_m}$	$K_n \left(\frac{N\phi}{P/R_m} \right) \cdot \frac{P}{R_m T}$	-	-	-	-	-	-	-	-
1C	$\frac{M\phi}{P}$	$K_b \left(\frac{M\phi}{P} \right) \cdot \frac{6P}{T^2}$	-	+	-	+	-	+	-	+
3A	$\frac{N\phi}{M_c/R_m^2\beta}$	$K_n \left(\frac{N\phi}{M_c/R_m^2\beta} \right) \cdot \frac{M_c}{R_m^2\beta T}$					-	-	+	+
1A	$\frac{M\phi}{M_c/R_m\beta}$	$K_b \left(\frac{M\phi}{M_c/R_m\beta} \right) \cdot \frac{6M_c}{R_m\beta T^2}$					-	+	+	-
3B	$\frac{N\phi}{M_L/R_m^2\beta}$	$K_n \left(\frac{N\phi}{M_L/R_m^2\beta} \right) \cdot \frac{M_L}{R_m^2\beta T}$	2788	-	+	+				
1B or 1B-1	$\frac{M\phi}{M_L/R_m\beta}$	$K_b \left(\frac{M\phi}{M_L/R_m\beta} \right) \cdot \frac{6M_L}{R_m\beta T^2}$	1606	+	+	-				
Add algebraically for summation of ϕ stresses, $\phi\phi = -4394$ $PS1$			-4394							
4C	$\frac{N_x}{P/R_m}$	$K_n \left(\frac{N_x}{P/R_m} \right) \cdot \frac{P}{R_m T}$	-	-	-	-	-	-	-	-
2C	$\frac{M_x}{P}$	$K_b \left(\frac{M_x}{P} \right) \cdot \frac{6P}{T^2}$	-	+	-	+	-	+	-	+
4A	$\frac{N_x}{M_c/R_m^2\beta}$	$K_n \left(\frac{N_x}{M_c/R_m^2\beta} \right) \cdot \frac{M_c}{R_m^2\beta T}$					-	-	+	+
2A	$\frac{M_x}{M_c/R_m\beta}$	$K_b \left(\frac{M_x}{M_c/R_m\beta} \right) \cdot \frac{6M_c}{R_m\beta T^2}$					-	+	+	-
4B	$\frac{N_x}{M_L/R_m^2\beta}$	$K_n \left(\frac{N_x}{M_L/R_m^2\beta} \right) \cdot \frac{M_L}{R_m^2\beta T}$	-1513	-	+	+				
2B or 2B-1	$\frac{M_x}{M_L/R_m\beta}$	$K_b \left(\frac{M_x}{M_L/R_m\beta} \right) \cdot \frac{6M_L}{R_m\beta T^2}$	-2329	+	+	-				
Add algebraically for summation of X stresses, $\phi x = -3841$										
Shear stress due to Torsion, M_T		$\tau_{\phi x} = \tau_{x\phi} = \frac{M_T}{2\pi r_o^2 T}$	+	+	+	+	+	+	+	+
Shear stress due to load, V_c		$\tau_{\phi\phi} = \frac{V_c}{\pi r_o T}$	+	+	-	-				
Shear stress due to load, V_L		$\tau_{\phi\phi} = \frac{V_L}{\pi r_o T} \quad 159$					-	+	+	+
Add Algebraically for summation of shear stresses, $\tau =$										
COMBINED STRESS INTENSITY, S										
1) When σ_ϕ & σ_x have like signs		$S = \frac{1}{2} \left[\tau_{\phi\phi}^2 + \sigma_x^2 + \sqrt{(\sigma_\phi - \sigma_x)^2 + 4\tau_{\phi\phi}^2} \right]$								
2) When $\tau = 0$		$S = \text{largest of } \sigma_\phi, \sigma_x \text{ or } \sigma_\phi - \sigma_x $								
3) When σ_ϕ & σ_x have unlike signs		$S = \sqrt{(\sigma_\phi - \sigma_x)^2 + 4\tau_{\phi\phi}^2}$								

$N_L/(M_L/R_m^2\beta)$ so determined by (C_L) from Table 8 (see para. 4.3).

4.2.2.5.2: When considering bending moment (M_L) : $\beta = K_L \sqrt[3]{\rho_1 \beta_2}$ where K_L is given in Table 8.

4.3 Calculation of Stresses

4.3.1 STRESSES RESULTING FROM RADIAL LOAD, P.

4.3.1.1 Circumferential Stresses (σ_ϕ):

Step 1. Using the applicable values of β and γ

* SEE ¹⁰ APPENDIX C

Stresses in Shells

ENGINEERING NOTE

MFTF

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SUBJECT

VCV PRELIMINARY DESIGN

NAME

T. BEVERS

DATE

6/22/77

NEUTRAL BEAM SOURCE TANK ADD'L LOADS
INTO SHELL. (CON'D.)

TOTAL PRESSURE & EXTERNAL LOADS

$$\sigma_x = -675 - 3841 = -4516 \text{ PSI} < 10,200^* \text{ PSI}$$

$$\sigma_\phi = -1350 - 4394 = -5744 \text{ PSI} < 10,200 \text{ PSI}$$

OR

$$* \text{ ALLOW } \sigma: A = \frac{.125}{R/t} = \frac{.125}{180/2.0} = .00139$$

$$\text{FROM FIG UHA-28.1 } B = 10,200$$

$$\therefore \text{ ALLOW } \sigma = B = \underline{\underline{10,200 \text{ PSI}}}$$

NEUTRAL BEAM SOURCE TANK PRELIM.

DESIGN & LOADS ANALYSIS ARE IN APPENDIX (d)

ENGINEERING NOTE

MFTF

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SUBJECT

V V PRELIMINARY DESIGN

NAME

T. BEVERS

DATE

6/28/77

SKIRT DESIGN (SEISMIC)

REF UG-23 ASME CODE SECT. VIII D.1

MAX ALLOW σ IN COMPRESSION:

$$t = 1.5$$

$$A = \frac{.125}{R/t} = \frac{.125}{180/1.5} = .001042$$

$$B = 9100 \text{ PSI (FOR SKIRT)}$$

$$t = .75$$

$$A = \frac{.125}{180/.5} = .000347$$

$$B = 4600 \text{ PSI}$$

$$\text{@ HEAD } t = 1.5 \text{ \& } P_a = 28.7$$

$$B = 6800 \text{ PSI}$$

$$\therefore \text{@ } 14.7 \quad \sigma_H = 6800 * \frac{14.7}{28.7} = 3483 \text{ PSI (IN HEAD)}$$

STRESS @ HEAD/SKIRT WELD

$$\sigma_b = 630 \text{ PSI} \quad (W = 766K)$$

$$\sigma_{W_{1.5g}} = 1351 \text{ PSI} \quad (t_s = .75)$$

$$\sigma_{TOT} = \sigma_b + \sigma_W + \sigma_H = -3746$$

ASSUME 0.8 JOINT FACTOR

$$\sigma_{TOT} = -5464 \text{ PSI} < .8 * 9100 = 7280 \text{ OK}$$

SUBJECT
V V PRELIMINARY DESIGN
NAME
T. BEVERS
DATE
6/22/77
SEISMIC ANALYSIS FOR SKIRT SUPPORT
RE: P.V. H46K P. 49 3 ed.
PERIOD OF VIB.

$$T = .0000265 \left(\frac{H}{D} \right)^2 \sqrt{\frac{WD}{t}}$$

 where $D = 30'$
 $H = 34'$
 $t = 1\frac{1}{2}"$
 $W = 766K$
 $X = 27'$
 $W = 766K/27 = 28.37 K/FT$

$$T = .0000265 \left(\frac{34}{30} \right)^2 \sqrt{\frac{28,370 \times 30}{1.5}}$$

$$= .0256 \text{ SEC.}$$

FROM RESPONSE SPECTRUM CURVE (APPENDIX C)

$$S_{a \text{ max}} = \frac{1}{2}g \quad \therefore \text{ACC} = \frac{1}{2} \left(\frac{1}{2}g \right) = 0.25g$$

LATERAL

$$\text{MOM @ SKIRT BASE} \quad 766K \times .25 \times 21' \times 12 = 48.3E6 \text{ IN-LB}$$

$$\sigma_b = \frac{Mc}{I} = \frac{48.3E6 \times 180}{\pi 180^3 \times 1.5} = \pm 315 \text{ PSI}$$

$$\sigma_{WT} = (1.5)766,000 / \pi D t = -676 \quad (.5g \text{ VERT})$$

$$\sigma_{\text{TOTAL}} = -991 \text{ PSI} < 9100 \text{ PSI} \quad \text{OK}$$

SUBJECT
V V PRELIMINARY DESIGN
NAME
T. BEVERS
DATE
6/22/77
SEISMIC ANALYSIS FOR SKIRT/HEAD JCT.
STRESS IN HEAD FROM VESSEL WT.

$$\sigma_w = -451 \text{ PSI}$$

$$\sigma_{w_{sei}} = -225 \text{ PSI } (.5g) \uparrow$$

STRESS IN HEAD FROM (.25g) → LAT.

$$\sigma_b = -315 \text{ PSI}$$

STRESS IN HEAD FROM PRESSURE

$$6800 \text{ PSI} \times \frac{15}{28.7} = 3554 \text{ PSI (SEE PG 8)}$$

∴ THE TOTAL σ AT THE HEAD/SKIRT JUNCTION $\cong -3554 + \sigma_b + \sigma_{w_{seis}} + \sigma_w$

$$\cong -4545 < .6 \times 6800 = 4080 \text{ NO!}$$

FOR VESSEL DESIGN WT. = 766 KIPS AND USING 3/4" THICK SKIRT, THE LOWER HEAD AT THE SKIRT/HEAD INTERSECTION NEEDS REINFORCEMENT.

SUBJECT

V V PRELIMINARY DESIGN

NAME

T. BEVERS

DATE

6/26/77

SKIRT DESIGN

RE: P.V. Hdbk Pg 62

GIVEN: $M_T = 4.03E6$ FT-LB

 $W = 766,000$ LB

 $D = 354.48$ IN.

 $R = 177.24$ IN.

 $S = 70/4 = 17.5$ KSI

 $E = 0.60$ (BUTT WELD)

MOMENT (.25g) $\rightarrow M_T = 4,030,000$ FT-LB

$$t = \frac{12 M_T}{R^2 \pi S E} = \frac{12 \times 4.03E6}{177.24^2 \pi 17,500 \times .6} = .046$$

VESSEL WT. (1.5G) $W = 1,149,000$

$$t = \frac{W}{D \pi S E} = \frac{1,149,000}{354.48 \pi \times 17,500 \times .6} = .10$$

REQUIRED $t = 0.146$ IN.

USING $3/4"$ PL W/ RING & STIFFENERS

SUBJECT
V.V PRELIMINARY DESIGN
NAME
T. BEVERS
DATE
6/26/77

ANCHOR BOLT & BASE RING DESIGN

RE: P.V. Hdbk Pg 67

GIVEN: $M = 48.3 \text{ EG IN-LB}$

$W = 766,000 \text{ LB}$

FIND;

$$k = \frac{1}{1 + (S_a / \pi f_{cb})} = \frac{1}{1 + (25,000 / 10 \times 1142)} = .3136$$

COMPRESSION @ B.C.

$$f_{cb} = f_c \frac{2kd}{2kd + l} = 1200 (.9535) = 1144 \text{ PSI}$$

CLOSE TO ASSUMED $f_{cb} = 1142$

$\therefore$ USE $k = .31$

FROM TABLE D PG 66

$$C_c = 1.54$$

$$C_t = 2.41$$

$$j = .782$$

$$z = .436$$

REQ'D. AREA OF ANCHOR BOLTS

$$B_t = \frac{2\pi \frac{12 M - W z d}{C_t S_a j d}}$$

$$= \frac{2\pi \frac{12 \times 4.03 \text{ EG} - \frac{766}{2} \times .436 \times 360}{2.41 \times 25,000 \times .782 \times 360}}$$

SUBJECT
V V PRELIMINARY DESIGN
NAME
T. BEVEIRS
DATE
6/26/77

ANCHOR BOLT / BASE RING DESIGN (CONT'D.)

$$\underline{B_t} = -4.51 \text{ in}$$

∴ BOLTS ARE IN COMP.

$$\underline{F_t} = \frac{M - W_e D}{j D} = \frac{4.03E6 - 383,000 \times .436 \times 30}{.782 \times 30} = -43,252$$

$$\underline{t_s} = \frac{B_t}{\pi d} = \frac{-4.51}{\pi 360} = 0.00398$$

$$\underline{l_q} = 11 - t_s = 10.996$$

COMP. LOAD ON CONCRETE

$$\begin{aligned} \underline{f_{cb}} &= \frac{F_c}{(l_q + n t_s) \pi C_c} = \frac{725048}{(10.996 + 10 \times 0.00398) 180 \times 1.57} \\ &= 237 \text{ PSI} \end{aligned}$$

$$\underline{S_a} = \frac{F_t}{t_s \pi C_t} = \frac{-43,252}{0.00398 \times 180 \times 2.41} = 2.11 E6$$

SINCE BOLTS ARE IN COMP.

$$K \sim 1$$

$$\therefore C_c = 3.142$$

$$C_t = 0.0$$

$$j = 0.750$$

$$z = 2.50$$

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ANCHOR BOLT / BASE RING DESIGN (CONT'D)

 ASSUMING THAT $f_c \sim f_{cb} \sim 500 \text{ PSI}$

$$t_B = 1. \sqrt{3 \frac{f_c}{S}} = 6" \sqrt{3 \times \frac{500}{17500}} = 1.76"$$

 USE 2" Φ

CONCLUSION:

SINCE EVEN A 1/2" Φ SKIRT WOULD REQUIRE STIFFENING, A CONSERVATIVE ESTIMATE OF 3/4" Φ WITH A 6" x 1/2" RING AT THE CENTER AND WITH (44) 2x2x3/8" L x 8' LG SHOULD ADEQUATELY STIFFEN THE SKIRT FROM ITS CRITICAL BUCKLING LOAD. ACTUAL SIZE SHOULD BE STUDIED FURTHER.

NEW WEIGHT:

a) SKIRT 175 Φ	22.7
RING	1.0
L	2.0
BASE/BOLTS	7.4
	<hr/>

33.1 K

2

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MAGNET SUPPORT SHROUD DESIGN

100.7 K

BOLTS / MISC 3.5 K

* 4 97.2 K

Ca. FLG 24.3 K

ROD' FLANGES

33.1 K

RING / L's / BOLTS 3.3 K

BASE = $\pi D_m A$ 7.1 K
 $= \pi 360 * 11 * 2 * .283$

W = $\pi D T$ 22.7 K
 $= \pi 355 * .75 * 96 * .283 =$

SHELL

SKIRT SUPPORT

80 K

TOTAL

HEAD 14" F 30 K

CROWN 4" R 50 K

UPPER HEAD

KIPS

CONTAINMENT VESSEL WEIGHTS

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WEIGHT CALC'S / ESTIMATESKIPSLOWER HEAD

CROWN 4" R 50 K

HEAD 1 1/2" R 36 K

TOTAL

86 K

UPPER / LWR SHELL

$$W_u = 5.8 \times 12 \times \pi \times 360 \times 1.25 \times .283 = 27.9 K$$

$$W_L = 5.8 \times 12 \times \pi \times 360 \times 1.5 \times \rho = 33.4 K$$

61.3 KMIDDLE SHELL

$$W = 15 \times 12 \times \pi \times 360 \times 2 \times \rho = 115.3 K$$

$$\text{LESS } (4) \times \frac{\pi 115^2}{4} \times 2 \times \rho = - 23.5$$

$$(4) \times \frac{\pi 78.74^2}{4} \times 2 \times \rho = - 11.0$$

$$(8) \times \frac{\pi 39.37^2}{4} \times 2 \times \rho = - 5.5$$

75.3 KDIAGNOSTIC CELLS(8) 1 m ϕ 12 K(4) 2 m ϕ 12 K24 K

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WEIGHTS CALC.LOWER HEAD PENETRATIONASSUME 48" ϕ SUPPORT FOR MAGNETASSUME 60" ϕ VACUUM SHROUD $\frac{1}{2}$ " t
FLANGED AT BASE.

$$W = \pi D_m t \rho$$

$$= \pi 60 \times .5 \times 78 \times .283 = 2.08 K$$

$$+ 100 \text{ FOR FLG.} \quad 2.18 K$$

$$\times 4$$

$$8.72 K$$

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WEIGHT CALC'S. (CONT'D)

KIPS

NEUTRAL BEAM TANKS

TANK 18. K

HEAD 12 K

INTERN. STR. 6 K

TOTAL 36 K

*4

144 K

ADDITIONAL WEIGHT DATA IN
APPENDIX (F)WEIGHT SUMMARYKIPS

UPPER HEAD

80

SHELL

136.6

DIAG. CELLS

24

NEUTRAL BEAM TANKS

144

LOWER HEAD

86

SKIRT SUPPORT

33.1

BODY FLANGES

100.7

MAGNET SUPPORT SHROUD

8.7

616.1 KDESIGN WEIGHT

VESSEL

616 KIPS

MISC. TO INCLUDE:

150 KIPS

CRYOPANELS, STREAM-

ING GUNS, N.B. INJECTORS,

INTERVL STRUCT., PIPING,

TOTAL

766 KIPS

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APPENDIX

CONTENTS

PG.

- a. EXT. PRESS CALC'S. & DATA
- b. UPPER HEAD DEFLECTION STUDY
- c. DESIGN CURVES FOR Bijlaard's STRESSES
- d. NEUTRAL BEAM PRELIM. DESIGN & LOADS
- e. RESPONSE SPECTRUM CURVE - TESLA FAULT
- f. VACUUM VESSEL & HARDWARE WEIGHT DATA.
- g. SKIRT CHECK

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HEAD
THICKNESS

1.5
1.25
1.0
.75
.5

0

4

8

12

16

20

24

28

30

SAY 1 1/16" REQ'D t

29.54 FOOT DIA. HEAD
REQ'D THICKNESS
REF. SECT. VIII, DIV. 1 (5'76")
ASME CODE

ALLOWABLE EXT. PRESSURE

P_a

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REQ'D HEAD THICKNESS

 ASSUME $t = .75$

$$A = \frac{.125}{R/t} = \frac{.125}{354.5 / .75} = .000265$$

$$B = 3600$$

$$P_a = \frac{B}{R/t} = \frac{3600}{472.7} = 7.62 \text{ PSI}$$

 ASSUME $t = 1.0$

$$A = \frac{.125}{354.5 / 1.0} = .000353$$

$$B = 4900$$

$$P_a = \frac{B}{R/t} = \frac{4900}{354.5 / 1.0} = 13.82 \text{ PSI}$$

 ASSUME $t = 1.125$

$$A = \frac{.125}{354.5 / 1.125} = .000396$$

$$B = 5500$$

$$P_a = \frac{5500}{354.5 / 1.125} = 17.45$$

 ASSUME $t = 1.5$

$$A = \frac{.125}{354.5 / 1.5} = .00053$$

$$B = 6800$$

$$P_a = \frac{6800}{354.5 / 1.5} = 28.7$$

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HEADS - ASSUME FLANGED & DISHED HEADS
VACUUM VESSEL UPPER HEAD

$$D_0 = 29.54' = 354.5'' , D_0 = R$$

REF UG-28(d)

 ASSUME $t = 1.5$

$$A = \frac{.125}{R/t} = \frac{.125}{354.5/1.5} = .000529$$

$$B = 7500$$

$$P_a = \frac{B}{R/t} = \frac{7500}{354.5/1.5} = 31.7 \text{ PSI}$$

$$P_a = 31.7 \text{ PSI} > 15 \quad \text{OK}$$

SOURCE TANK HEADS

$$D_0 = 15.09' = 181''$$

 ASSUME $R \sim D_0 = 181''$

 ASSUME $t = .75''$

$$A = \frac{.125}{R/t} = \frac{.125}{181/.75} = .000518$$

$$B = 7200 \quad (\text{FIG UHA-28.3})$$

$$P_a = \frac{B}{R/t} = \frac{7200}{181/.75} = 29.83 \text{ PSI} > 15 \quad \text{OK}$$

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FIG UGO-28.0 REF. ASME CODE, SECT. VIII, DIV. 1

FIG. UGO-28.0 GEOMETRIC CHART FOR CYLINDRICAL VESSELS UNDER EXTERNAL OR COMPRESSIVE LOADING
 (For all materials)

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FIG. UHA-28.1 REF. ASME CODE SECT. VIII, DIV. 1

FIG. UHA-28.1 CHART FOR DETERMINING SHELL THICKNESS OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE WHEN CONSTRUCTED OF AUSTENITIC STEEL (18 Cr-8 Ni, Type 304) (Note 8)

HEAD DEFLECTION STUDY
RADIAL DISPLMT. OF SPHERE

$$R = L = 354.5'' + \frac{t}{2}$$

$$E = 29 \text{ E06}$$

$$P = 15 \text{ PSI}$$

$$t = 1\frac{1}{4}''$$

$$S = \frac{PR}{2t}$$

$$\delta = \frac{E}{RS} (1-\nu)$$

For $t = 1\frac{1}{4}''$

$$S = \frac{15 \times 355,125}{2 \times 1.25} = 2,131 \text{ PSI}$$

$$\delta = \frac{355,125 \times 2,131}{29 \text{ E06}} (.7) = .018$$

For $t = 4''$
 $t = 4'' \quad S = .011$

$$S = \frac{15 \times 356.5}{2 \times 4} = 668$$

$$\delta = \frac{356.5 \times 668}{29 \text{ E06}} (.7) = .00575$$

REF. ROARK
4th ed. P 299
TABLE XIII

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STIFFNESS DEF.

ASSUME $A = 200 \times 360 = 60,000 \text{ in}^2$
 $W = PA = 15 \times 60,000 = 900 \text{ KIPS}$

W PER CROSS BEAM = 450 KIPS

$$y = -\frac{1}{24} \frac{Wx}{EI} (x^3 - 2x^2 + x^3)$$

$$y_{mx} @ x = \frac{L}{2} = -\frac{5}{384} \frac{WL^3}{EI}$$

$$f = 360 \quad W = 450 \text{ KIPS} \quad E = 26 \text{ EG}$$

$$I = \frac{bL^3}{12} = \frac{.5 \times 36^3}{12} = 1944 \text{ in}^4$$

$$y_{mx} = -\frac{5 \times 450,000 \times 360^3}{384 \times 29 \text{ EG} \times 1944} = 4.8''$$

FIXED ENDS

$$f = 196$$

ASSUME 5 BEAMS TAKE 2,000 KIPS
 OR 400 KIPS/BEAM

$$f = 235$$

$$y = -\frac{5 \times 400,000 \times 235^3}{384 \times 29 \text{ EG} \times 1944} = 1.2''$$

FIXED ENDS : 123

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HEAD DEFLECTION STUDY

Case 41, Rock T. I Pg. 227

$$b = a = 210$$

$$a/b = 1$$

$$\beta = .31$$

$$\alpha = .0138$$

$$y_{mx} = \frac{\alpha w b^4}{E t^3} = \frac{.0138 * 15 * 216^4}{29 E 6 * 2^3} = 9''$$

$$a = 210$$

$$b = 52$$

$$a/b = 4 \rightarrow \infty$$

$$y_{mx} = \frac{.0284 * 15 * 52^4}{29 E 6 * 2^3} = .00072''$$

ASSUMPTIONS ARE QUESTIONABLE?

T. Bevers

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streaming gun mounting plate.

$$3 \times 19.5 \text{ ft}^2$$

$$\approx 3 \times 20 \text{ ft}^2$$

$$= 60 \text{ ft}^2$$

Ref. P. 392 Romk

$$\sigma_A = \frac{\beta \cdot \sigma_b}{t}$$

$$\frac{\sigma_b}{t} \rightarrow \infty$$

$$\beta_1 = 0.5$$

$$\beta_2 = 0.25$$

$$\alpha = 0.0284$$

$$\sigma_A = \frac{0.25 \cdot (16.74) (36)^2}{t^2}$$

$$= \frac{14,000}{t^2}$$

$$t^2 \geq \frac{5423 \cdot k}{14,000}$$

$$[k \sigma_A \leq \sigma_{allowable} = 10,000 \text{ psi.}]$$

$$t^2 \geq (1.52 k)$$

$$t \geq 1.62 \text{ inch}$$

But to keep the deflection to minimum use 4" thick

Deflection

$$f_{1.6} = \frac{0.0284 \times 15 \times (36)^4}{30 \times 10^6 (1.6)^3} = \frac{5.8}{10^3} = 5.8 \times 10^{-3} \text{ in}$$

$$f_{1.6} = \frac{1}{(1.6)^3} f_{1.6} = \frac{5.8}{156} \times 10^{-3} = 3.7 \times 10^{-4} \text{ in}$$

$$f = 14.7 + 0.3 + \frac{150 \times 100}{60 \times 1000}$$

$$= 16.74 \text{ psi.}$$

ASSUME
1" plate.
(OWN W/ THIS FIGURE WILL INCREASE.)

 k : Stress Concentration factor

$$k = 3.0 \text{ (MAX.)}$$

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SOURCE TANK - PRELIMINARY DESIGN

NAME

L. HUNT

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LOAD ON DOME

SUBJECT

SOURCE TANK - PRELIMINARY DESIGN

NAME C. ADAM

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LOAD ON SOURCE TANK MOUNTING FLANGE -

$$M = 22000 \times 3 + 8000 \times 40 + 12000 \times 70 + 18000 \times 112 = 3242000 \text{ IN-LB}$$

$$\text{SHEAR (VERTICAL)} = 60000 \text{ LB} \times 19.65 = 1,18 \text{ E}^6 \text{ IN-LB}$$

V = 60 KIPS
 W_{SHEAR} = 4,023 EG IN-LB

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SOURCE TANK WEIGHT EST.

NAME

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SOURCE TANK MAIN HOUSING

 THICKNESS $\frac{3}{4}$ "

MAT - 304 SST

 SCALE $\frac{1}{4}" = 1'-0"$

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LOCAL STRESS DESIGN - SOURCE TANK HEADS

 REF. "LOCAL STRESSES IN SPHERICAL & CYL.
SHELLS DUE TO EXTERNAL LOADS"

by WICHMAN, HOPPER, MERSHON

BASED ON PROF. P.P. BILLAARD'S WORK

M@ SHELL: 54,000 IN-LB

V = 1,500 LBS.

PARAMETERS

SHELL

$$U = \frac{C_1}{.875 \sqrt{R_m T}} = \frac{6}{.875 \sqrt{181 \times .75}} = .59$$

ATTACHMENTS

 HOLLOW ☐ ATTMT.

$$\gamma = \frac{r_m}{.875 t} = \frac{6}{.875 \times 2} = 3.43$$

t = 2"

PARAMETERS (CONT'D)

ATTACHMENTS
HOLLOW ☐

$$\rho = \frac{f}{I} = \frac{.175}{2} = .38$$

REF. FIG. SM-1

FOR $U = .59$ $r = 3.43$ $\rho = .38$
 USING $U = .59$ $r = 5$ $\rho = 0.25$

$N \times T \sqrt{R_m T} / M = 0.077 \sim 0.08$
 $M \times \sqrt{R_m T} / M = 0.19 \sim 0.19$

STRESSES

RAD. MEMBRANE σ ($N \times T$)

$$\frac{N \times T}{M} = \frac{N \times T \sqrt{R_m T}}{M} * \frac{T^2 \sqrt{R_m T}}{M}$$

$$= .08 * \frac{.175^2 \sqrt{181 \times .175}}{59,000}$$

$$\sigma = 659 \text{ PSI}$$

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STRESSES (CONT'D)RADIAL BENDING σ , $\frac{6 M_x}{T^2}$

$$6 M_x / T^2 = \frac{M_x \sqrt{R_m T}}{M} * \frac{6 M}{T^2 \sqrt{R_m T}}$$

$$\sigma = 0.19 * \frac{6 * 54000}{.75^2 \sqrt{181 * .75}}$$

$$\sigma = 9393 \text{ PSI}$$

COMBINED σ_x w/ K's

$$\sigma_x = -K_N \frac{N_x}{T} - K_b \frac{6 M_x}{T^2}$$

ASSUME $7/16$ " RADIUS @ INTER SECT.

$$K_N = 1.5661 \quad K_b = 1.328$$

$$\sigma_x = -1.5661 * 659 - 1.328 * 9393$$

$$\sigma_x = -1032 - 12474 = -13,506 \text{ PSI}$$

HEAD σ

$$\text{ASSUME } S = \frac{.1 P}{E} + \frac{P L M}{E E}$$

SECT VIII
DIV. 1

$$\therefore S = 6228 \text{ PSI}$$

where $P = 1500$

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SOURCE TANK DESIGNHEAD σ , EXT PRESS

$$t = \frac{PLM}{2SE - .2P}$$

$$2SE - .2P = \frac{PLM}{t}$$

$$S = \frac{.P}{E} + \frac{PLM}{Et}$$

$$S = \frac{1.5}{1.0} + \frac{15 \times 181 \times 1.72}{1.0 \times .75}$$

$$S = 1.5 + 6226 \rightarrow 6228 \text{ PSI}$$

SUBJECT

SOURCE TANK , PRELIMINARY DESIGN

NAME

L. HUNT

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MAT'L - COPPER

WT = $100^2 \times \frac{\pi}{4} \times .25 \times .32 = 628 \text{ lb.}$

APERTURE PLATE

SCALE $\frac{1}{2}'' = 1'-0''$

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SOURCE TANK WEIGHT EST.

NAME C. HUNT

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$$(100 - 92^2) \frac{\pi}{4} \times 1 \times 2.81 = 339 \text{ lb}$$

$$102 \pi \times 60 \times 75 \times 2.81 = 4051 \text{ lb}$$

$$\frac{102 + 168}{2} \pi \times 9 \times 75 \times 2.81 = 804$$

SAY 18000
TOTAL WT. 17775 lb
WITHOUT CRYO PANELS
21555 lb
W/CRYO PANELS
SAY 23000

CRYO PANEL
 $54 \pi \times 50 \times 11 = 1624 \text{ lb}$

$$[102^2 \times \frac{\pi}{4} - 66 \times 49] \times 75 \times 2.81 = 1165$$

$$WT = [2(\frac{50 + 66}{2} \times 39) + 2(\frac{30 + 40}{2} \times 39)] \times 75 \times 2.81 =$$

$$WT = 1528 \text{ lb}$$

$$(180^2 - 168^2) \frac{\pi}{4} \times 2 \times 2.81 = 1843 \text{ lb}$$

CRYO PANEL $160 \pi \times 39 \times 11 = 2156 \text{ lb}$

SPRUE TANK
 MAIN NOUSING

GUSSET
 $9 \times 7 \times 1 \times 2.81 \times 60 = 1062 \text{ lb}$

$$168 \pi \times 39 \times 75 \times 2.81 = 4338 \text{ lb}$$

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$$1.2 \times 160 = 590 \# \times 5 = 3000 \#$$

Say 370,000 lb

$$\begin{array}{r} 225 \\ 144 \\ \hline 369,000 \end{array}$$

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MAIN TANK = $(360 \pi \times 1.5 \times 315 \times 2.81) \div 1.5 = 225,000 \text{ lb}$

150,000

SOURCE TANK (MAIN HOUSE) = 18,000

DOME = $\frac{12,000}{30,000 \text{ lb}}$

Say 36,000 $\div 3 = 12,000$

$\times 4 = 48,000 \text{ lb}$

$$\begin{array}{r} 335 \\ 629 \\ \hline 964 \end{array}$$

$$\begin{array}{r} 16,100 \\ 112,392 \\ \hline 128,492 \end{array}$$

11009

WEIGHT - FLANGE - $(180^2 - 168^2) \frac{\pi}{4} \times 5 \times .281 = 4608$
 DOME - $\pi \left(\frac{168^2 + 14^2}{4} \right) \times 1 \times .281 = 6401$

DOME (SOURCE TANK)

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ANCHOR BOLT DESIGN (Pg 69)

$$T = \frac{12M}{A_B} - \frac{W}{C_B} = \frac{12 \times 48.12 E 6}{\frac{\pi 358^2}{4}} - \frac{768,3000}{\pi 358}$$

$$T = 5736 - 683 \rightarrow 5700 \#/IN$$

$$B_a = \frac{T C_B}{S_B N} = \frac{5700 \pi 358}{25,000 \times 52} = 4.93 \text{ "}$$

FROM TABLE A PG. 63

 3" ϕ ROOT AREA = 5.621

$$l_1 = 358" \quad l_2 = 278"$$

$$BC = 360"$$

$$S_B = \frac{T C_B}{B_A N} = \frac{5700 \pi 360}{5.621 \times 52} = 22,055 \text{ PSI}$$

o/r

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V V PRELIMINARY DESIGN

NAME T. BEVERIS

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SKIRT DESIGN STABILITY

 a) Assume $t = .75$

Ref. Pg 8 Weight Est.

$$\sigma_b = 945 \times \frac{.5}{.75} = 630$$

$$\sigma_{wt/sec} = 2026 \times \frac{.5}{.75} = 1351$$

$$\sigma_m = 3910$$

$$\sigma_{TOT} = 5891 < 6500 \text{ PSI}$$

OK

$$P = \frac{5891 \times 2 \times t}{R} = \frac{5891 \times 2 \times .75}{180} = 49.09$$

$$L/D_0 = .27$$

$$D_0/t = \frac{360}{.75} = 480$$

$$A = .00048$$

$$B = 6500 \text{ PSI}$$

$$P_a = \frac{4 \times 6500}{3 \times 480} = 18.06$$

APPENDIX B

ACCEPTANCE TEST PLAN

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VV ACCEPTANCE TEST PLAN

NAME

T. Bevers

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APPENDIX B VACUUM VESSEL ACCEPTANCE TEST PLAN

A final vacuum leak test of the assembled vessel will be performed by the Lawrence Livermore Laboratory. The plan is to utilize the MFTF External Vacuum System now being designed by Pete Holl, LLL project engineer.

An alternate system exists which is capable of vacuum leak testing the vessel in the event the external is not ready. Trailer 132 is a large mobile unit which is located at the EG&G North Las Vegas Facility. This portable vacuum pumping station could be transported to Livermore and utilized if required at a minimal cost to the project. A brief description of this hardware is attached.

Vacuum tank sub-assemblies such as the vessel heads, neutral beam source tanks, and diagnostic cells will be vacuum leak tested in back-to-back pairs at the vendor's fabrication facilities.

Local industrial firms specializing in vacuum leak testing services should be available to contract directly for these tests.

A Mobile Multistage 3000-cfm Pumping System *

N. G. Wilson

EG&G, San Ramon Operations, San Ramon, California
(Received 28 July 1972)

A trailer-mounted two-stage booster mechanical pumping system has been constructed for use in evacuation of large vacuum vessels in remote locations. The pumping system is composed of three nominal 1500-cfm air-cooled Roots blowers and four nominal 150-cfm mechanical pumps. It includes a high conductance cryogenic baffle, a self-contained helium leak detection station with a high speed oil diffusion pump, a liquid cryogenic system for supply of cryogenic fluids to the two cryogenic traps, and dry gas for use in backfilling of vessels as required. A programmed start-up and run-down control is provided for simplified, safe operation of the pumping system. A simplified method of presenting pumping system performance and a design analysis procedure for matching of mechanical pumps to the boosters are described.

Introduction

In the underground nuclear testing program of the United States Atomic Energy Commissions, Lawrence Livermore Laboratory, there exists a continuing need for large vacuum vessels. The installation and operation of these vacuum vessels, assembled in the Nevada desert and other remote locations under severe environmental conditions has shown the desirability of the use of portable pumping systems to perform initial pumpdown and vacuum cleanup of these vessels. The use of portable vacuum systems minimizes potential hazards and possible damage of the sustaining vacuum systems which are integral to the vacuum vessel installation.

I. System Requirements

A vacuum system based upon the use of mechanical Roots-type booster pumps in cascade and multiple mechanical rotary piston pumps in parallel

has been produced which is capable of producing pressures less than 2×10^{-4} Torr with a nominal speed of 3000 cfm. Basic to the design of the vacuum system is the requirement that the system be self-contained in a 10X50 ft tandem wheel trailer van, and operable in unprotected environments ranging from sea and dry air winds of 50 mph or more at temperatures of -10° to $+130^{\circ}\text{F}$ with relative humidity ranging from 5% to 100%. The layout of the vacuum system is also expandable with minimum modification to permit the mechanical pumping system to be doubled in capacity and to permit the eventual installation of a large titanium sublimation/sputter ion pumping module for operation in the high vacuum range.

II. Mechanical Systems

The vacuum system developed is shown in Fig. 1. In this system two air-cooled, positive-displacement

FIGURE 1. Mobile multistage pumping system. (All equipment shown in dotted lines to be added later).

* The work reported here was conducted under U. S. Atomic Energy Commission Contract AT(29-1)-1183.

FIGURE 2. Mobile multistage pumping system schematic.

Roots-type booster pumps, backed by an identical Roots pump in series with a group of five oil-sealed rotary piston air-cooled mechanical pumps, form the

FIGURE 3. Interior of trailer.

primary pumping system. Expansion of this system to double capacity is also shown in Fig. 1. Appropriate valving and manifolding is provided to permit by-passing of any pump group in the event of pump malfunction as shown schematically in Fig. 2. Figure 3 shows the internal arrangement of the mechanical pumps and the position of the three booster pumps.

A high-speed 6-in. diam oil diffusion pump system and helium mass spectrometer leak detector is built into the inlet manifold of the primary pumping system. The arrangement provides the capability of using the entire vacuum pumping system to function as a leak detection station for testing large vacuum vessels. The leak detection station is also used in normal maintenance of the trailer pumping system when required.

In order to provide capability of reduced ultimate pressure and high pumping speed for condensible vapors, a 14-in. diam high-conductance chevron liquid nitrogen (LN₂) baffle has been incorporated into the primary pumping system. The baffle shown schematically in Fig. 4 is provided with an integral bakeout heater system to permit thermal cycling of the baffle from LN₂ temperature to 100°C and re-cooling to LN₂ temperature in less than 30 min. In the baffle a LN₂ reservoir is connected to a group of four flow-through tubes inside the baffle which cool the baffle chevrons by conduction. In high gas flow operation,

FIGURE 4. 14-in. diam cryogenic baffle schematic.

LN₂ circulates through the baffle tubes by a "lift pump" action derived from the generation of gaseous nitrogen (GN₂) inside the LN₂ tubes, thus maintaining a constant baffle temperature. When bake-out of the baffle is desired, the valve and heater control system closes V₁ and supplies power to the 4-kW heater system inside the LN₂ tubes of the baffle. The LN₂ formerly inside the baffle tubes is thereby forced back into the reservoir before significant heating has taken place, thus conserving LN₂ and reducing the heat cycle by eliminating the need to vaporize significant amounts of LN₂. After a predetermined time interval, V₂ closes and V₃ opens. Internal sensors limit the baffle temperature to a pre-selected level, at which time valve V₃ closes, and V₁ and V₂ open. Valve V₂ is provided with a metering orifice to admit LN₂ to the heater baffle at a rate which does not thermal-shock the baffle structures. Filling of the 7-l reservoir from two LN₂ storage containers or from an external LN₂ supply is performed by an automatic liquid level control.

III. Electrical and Instrumentation Systems

Control of all pumps and valves in the primary pumping system is performed by an integrated control, logic, and graphic display system. The electrical architecture of this system is such that the primary electrical switch gear is provided with interlocked overtemperature and pressure limits necessary to provide full equipment protection. The logic incorporated in the control system permits preprogrammed start-up shut-down sequencing of pumps with the necessity of operator direction start or stop operation only. Instrumentation included in the primary pumping system covers pressure from atmosphere to

less than 1×10^{-4} Torr with diaphragm-operated potentiometer transducers, thermocouple vacuum transducers, an Alphatron and a cold-cathode discharge gauge. As required, signals derived from these instruments are utilized in the control system. The control system electronic architecture is such that interfacing with a process control digital computer is easily performed. At such time as additional pumping capacity is installed in the trailer, installation of a process control computer will be necessary because of the additional system operation complexity.

IV. Piping Analysis

The design of the vacuum system and prediction of the operating conditions within the vacuum system is such that consideration of gas flows in the viscous laminar and viscous turbulent ranges are of principal importance. In order to perform the necessary pressure-profile analysis by which pipe line sizes, etc., can be determined, careful use of the Poiseuille equation is required. The poiseuille equation¹ in its usual form for a circular pipe

$$Q = \frac{\pi a^4 p_{av} (p_1 - p_2)}{8 \eta l} \quad (1)$$

Q —microlbar cubic centimeters per second

a —pipe radius in centimeters

p_1 —pressure at pipe inlet in microbars

p_2 —pressure at pipe outlet in microbars

$p_{av} = \frac{1}{2}(p_1 + p_2)$

η —gas viscosity in poise

l —pipe length in centimeters

is strictly applicable only for flows in which the Reynolds number is less than 1000–2200. Where the

flow in the pipe is shown to be turbulent ($Re > 2200$) and/or not fully formed, the Poiseuille equation is modified³ as

$$Q = \pi a^4 p_{av} (p_1 - p_2) / 8\eta l \left[1 + 1.14 \left(\frac{m}{8\pi\eta k T} \right) \left(\frac{Q}{l} \right) \right], \quad (2)$$

where k is the Boltzmann constant, m is the molecular mass in grams, and T is the absolute temperature in degree kelvin. In order to calculate the pipe conductance it has been common practice to assume an arbitrary pressure drop³ from which the average pressure required in the Poiseuille equation can be calculated. Through an iterative process a suitable pipe size is thus obtained. The procedure is unnecessarily awkward and not convenient when analysis of a given system is desired. In any specific pumping system, the pumps utilized are known. Equation (2) can therefore be rearranged, solving for p_1 in terms of the pipe geometry, the gas characteristics, the system throughput Q and the pump speed S as

$$p_1 = \left[2Q / \frac{\pi a^4}{8\eta l} \left\{ 1 + 1.14 \left(\frac{m}{8\pi\eta k T} \right) \left(\frac{Q}{l} \right) \right\}^1 + \left(\frac{Q}{S} \right)^2 \right]^{\frac{1}{2}}. \quad (3)$$

Equation (3) for air at 25 K (where pressure is in microns Q is in micron-liters per second, a and l are in centimeters and S is in liters per second) is

$$p_1 = \left[2Q / 2.84 \frac{a^4}{l} \left\{ 1 + 3.83 \times 10^{-4} \left(\frac{Q}{l} \right) \right\}^1 + \left(\frac{Q}{S} \right)^2 \right]^{\frac{1}{2}}. \quad (4)$$

Equation (3) is a general relationship which describes the pipe entrance pressure for viscous flows when the pump speed is known though all ranges of Q which the pump can produce, up to the condition where gas compressibility must be considered,⁴ i.e., Mach number $\geq \frac{1}{3}$. In any pipe pressure calculation, the mean-free path of the gas in the pipe must be evaluated to determine the pressure at which the Poiseuille equation applicability fails and molecular flow effects predominate.

V. Performance Presentation

The presentation of pumping system performance for any pumping system in cascade can be easily determined by plotting the pump inlet pressure vs Q (throughput) on a single log-log plot (Fig. 5). In this plot it is assumed that two booster pumps operating in cascade are backed by a mechanical pump. Since in such a pumping system the gas flow through all pumps is constant the inlet operating conditions can be determined at any " Q " value. Thus at a selected

FIGURE 5. Pump pressure vs throughput with piping pressure drops.

value Q_1 on Fig. 5, the inlet pressure of each pump in the pumping system is seen to be p_1 , p_2 , and p_3 . If a pressure drop due to inlet piping from the primary pump to the vacuum vessel and piping between pumps is assumed, a set of curves reflecting these pressure drops is obtained from Eq. (3) which further assists in presenting the system operating conditions. In Fig. 5, p_0 is the actual inlet pressure at the vacuum vessel, the Δp along the pipe being $(p_0 - p_1)$; the pressure drop between the primary blower and the interstage blower is $(p_2' - p_2)$; the pressure drop between the interstage blower and the mechanical pump is $(p_3' - p_3)$. p_0 , p_2' and p_3' are determined from Eq. (4) using the inlet pressure of each pump p_1 , p_2 , and p_3 at the specified throughput Q_1 .

In matching blower systems, the pressure differential between the blower inlet and outlet is limited by the blower temperature, motor horsepower, etc. The pressure differential which will be developed in the hypothetical pumping system shown in Fig. 5 is observed by inspection to be $p_2 - p_1$ (or $p_2' - p_1$) for the primary to interstage pump differential and $p_3 - p_2$ (or $p_3' - p_2$) for the interstage to mechanical pump differential.

Once a plot such as that of Fig. 5 is available, it is useful in actual pumping system operation to evaluate the operating condition of the system since any deviation would indicate a malfunction or leak in the system.

VI. Unusual Consideration for Mobile Operation

Several unusual considerations involved in the design of the vacuum system described in this paper

FIGURE 6. LN2 distribution system.

should be discussed. The most restrictive of these considerations is the necessity of operation at remote locations with minimum utility services such as water. If water cooling is required, it is necessary to carry complete, self-contained heat exchanger facilities. Since these facilities are quite large and of considerable expense it was concluded that air-cooled pumps would be utilized in the mobile multistage pumping system if possible. It was found practical and highly cost effective to utilize air cooled, direct drive Roots-type booster pumps and air-cooled mechanical pumps in lieu of liquid cooled mechanical pumps. The parallel grouping of five mechanical pumps in lieu of two larger pumps was also found advantageous in that as the throughput drops with pressure, the number of parallel pumps required decreases permitting reduction of running power requirements, wear, etc. In this system the four mechanical pumps regularly utilized in pumpdown are single-stage pumps. A pump of a compound type is included as an "installed spare" as well as a pump to provide reduced system ultimate pressure.

A consideration also of considerable importance when operating with LN2 in the cryogenic trap or baffle is that of the LN2 system operation. Since only limited space is available for on-board LN2 storage, the maximum cryogenic system efficiency is desirable. Further it is desirable that dry nitrogen be available for vacuum vessel back-filling. The solution to both of these requirements is met through the use of two 160-l LN2 storage-gas generator dewars as shown in Fig. 6. In this system, flexible stainless steel hoses insulated with "zip-on" polyurethane foam insulation are used to distribute LN2 to the trap and baffle. A single distribution hose is used to supply LN2 to the trap or baffle, each of which is provided with its own LN2 solenoid control valve. In this configuration the hose is at the LN2 system pressure at all times. At the end of a fill cycle, the heat input through the insu-

lation forces LN2 in the hose back to the dewars, thereby minimizing fluid loss. The distribution hose can also be connected to an external supply source for refilling of the on-board dewars or direct supply of the trap and baffle. The gas generation capability of the dewar is derived from a pressurizer coil between the inside and outside wall of the dewar which picks heat from ambient conditions for vaporization of stored LN2. The gas supply line from the dewars is manifolded such that an external gas supply can be interconnected.

VII. Conclusion

The vacuum system described has shown it to be possible to produce a portable vacuum pumping capability requiring only electrical power for operation. The system has been found to be very flexible in operation and capable of producing pressures of less than 1×10^{-6} Torr. A pipe pressure calculation method has been developed and a performance presentation technique shown which simplifies design analysis and is an aid to operating personnel in evaluation of system performance.

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