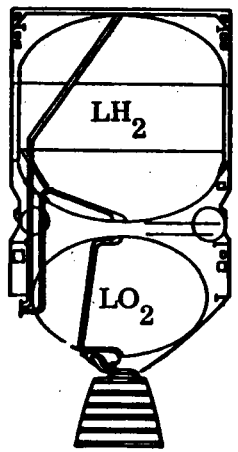
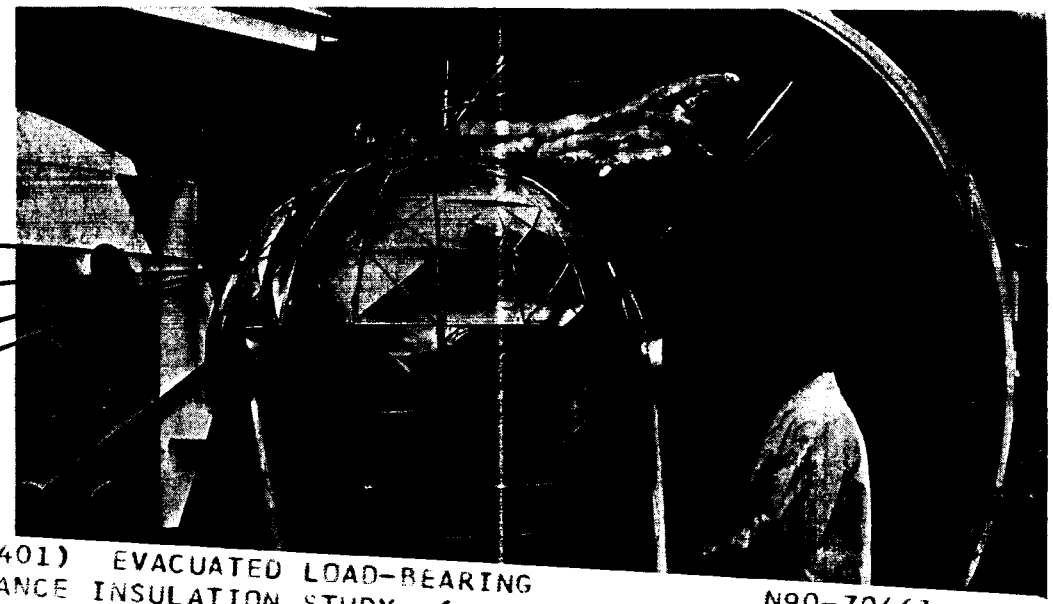
EVACUATED LOAD-BEARING HIGH PERFORMANCE INSULATION STUDY

CONTRACT NAS 3-17817
(MAY 74 – AUG 77)





(NASA-CR-185401) EVACUATED LOAD-BEARING HIGH PERFORMANCE INSULATION STUDY (Lockheed Missiles and Space Co.) 61 p

N90-70461

Unclas
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PERFORMED FOR: THE NASA/LEWIS RESEARCH CENTER
J. R. BARBER, PROGRAM MANAGER

BY: THE LOCKHEED RESEARCH LABORATORY
R. T. PARMLEY, PRINCIPAL INVESTIGATOR

#0235137
P-61

OBJECTIVES

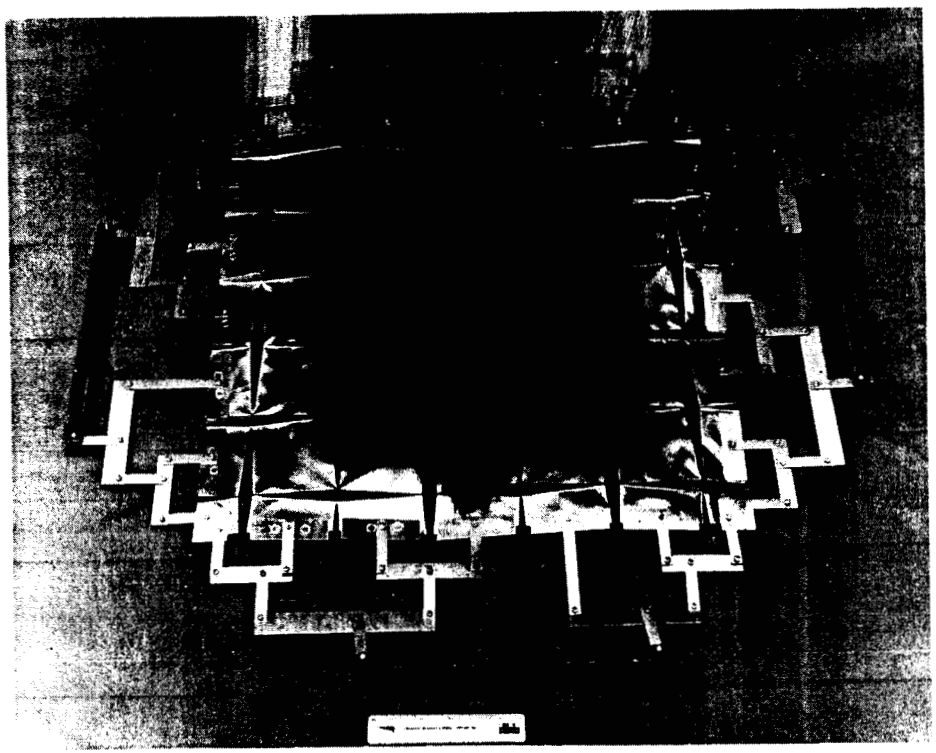
DEMONSTRATE

- DESIGN
- SCALING FACTORS
- MANUFACTURING AND REPAIR
- JACKET FLEXURE
- VACUUM INTEGRITY
- MICROSPHERE PROPERTIES
- MICROSPHERE PROCESSING
- TEST ARTICLE THERMAL PERFORMANCE
  - TEMPERATURE
  - COMPRESSIVE LOAD
  - GAS PRESSURE
  - MULTIPLE FLIGHT CYCLES

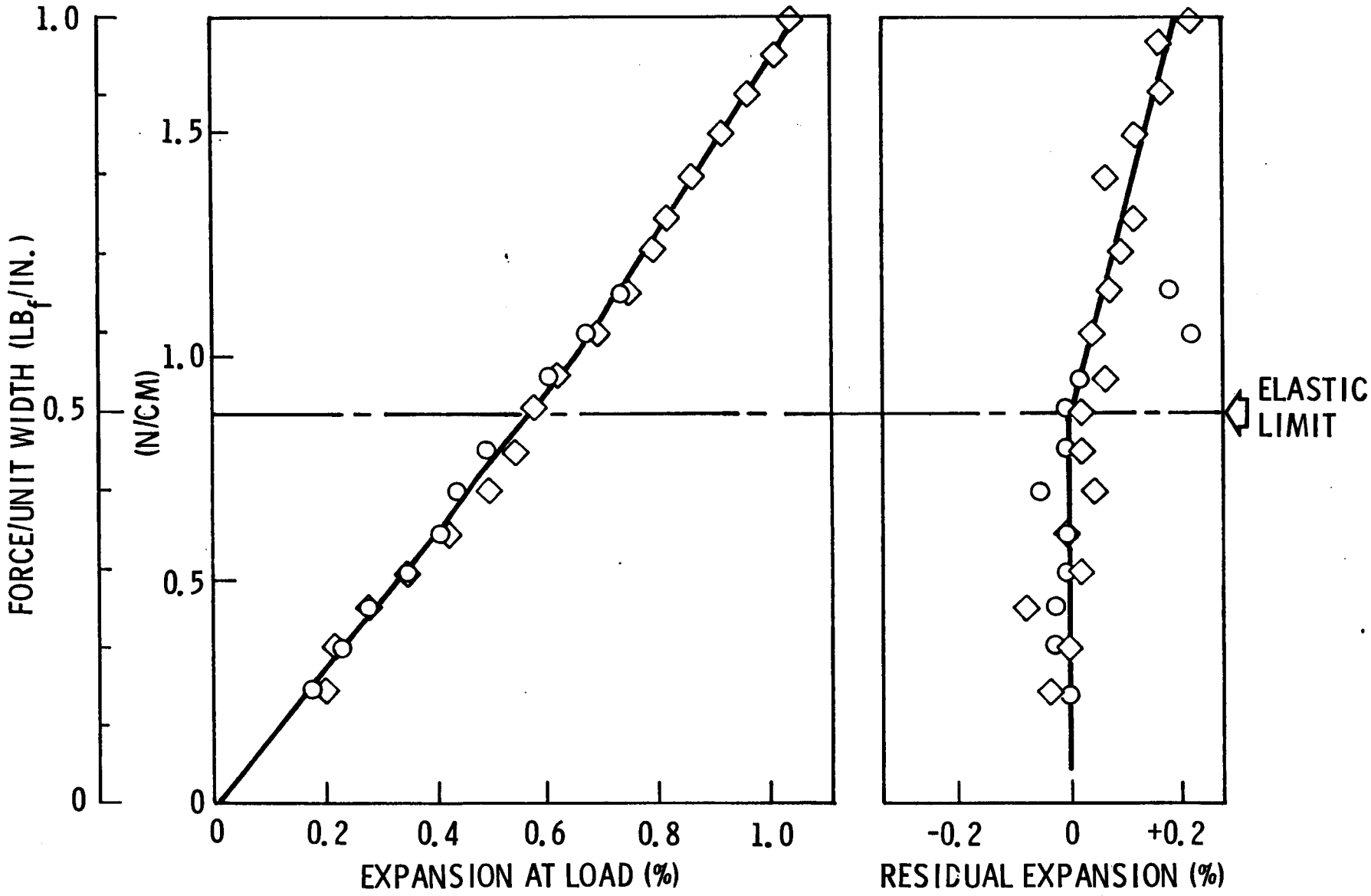
SCALE

- SPACE TUG PERFORMANCE VERSUS HE PURGED MULTILAYER SYSTEM

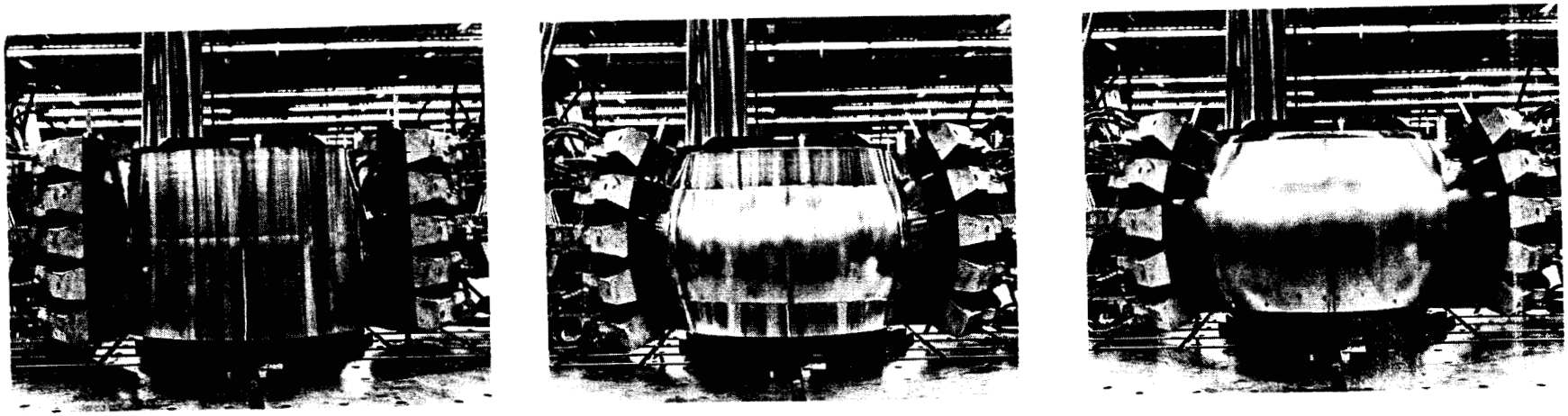
VACUUM JACKET DEVELOPMENT



FLAT PANEL EXPANSION DATA



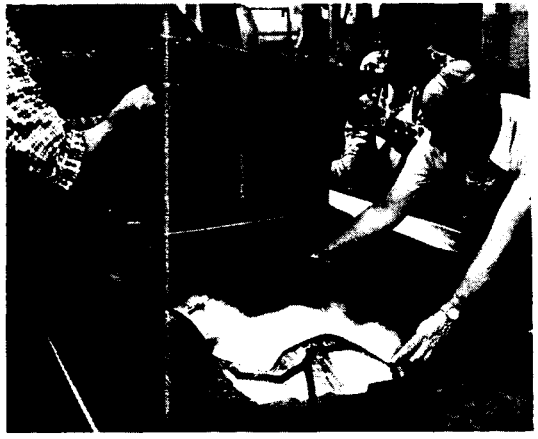
JACKET STRETCH FORM



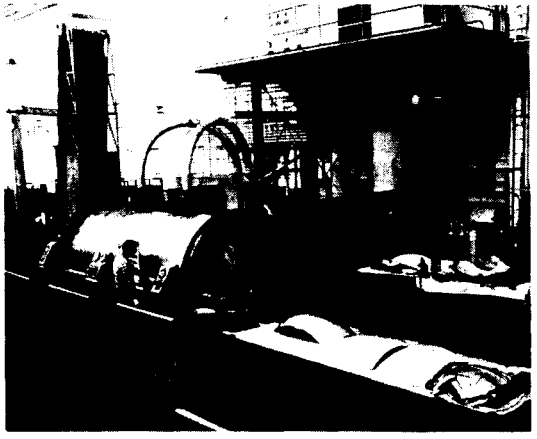
0.08-MM 321 ANNEALED STAINLESS STEEL

JACKET HYDROPRESS FORM

LUBRICATE DIE



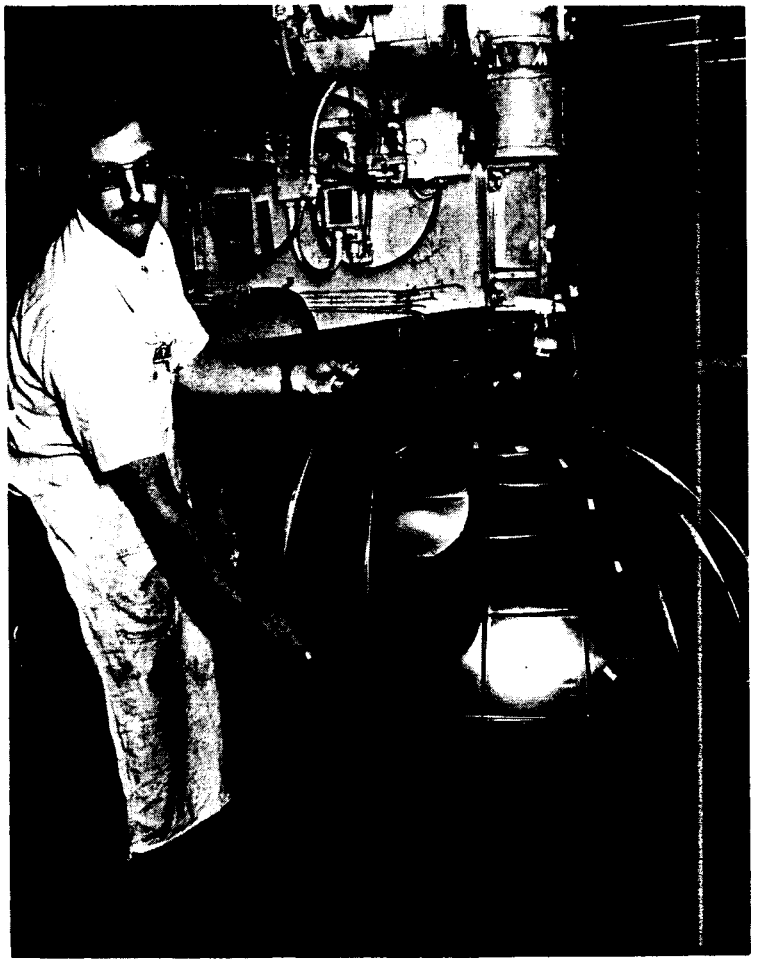
LAYUP POLYETHYLENE SHEET, STAINLESS STEEL, ADIPRENE RUBBER



FORM AT 1000 PSI, REMOVE POLYETHYLENE SHEET, FORM AT 2500 PSI

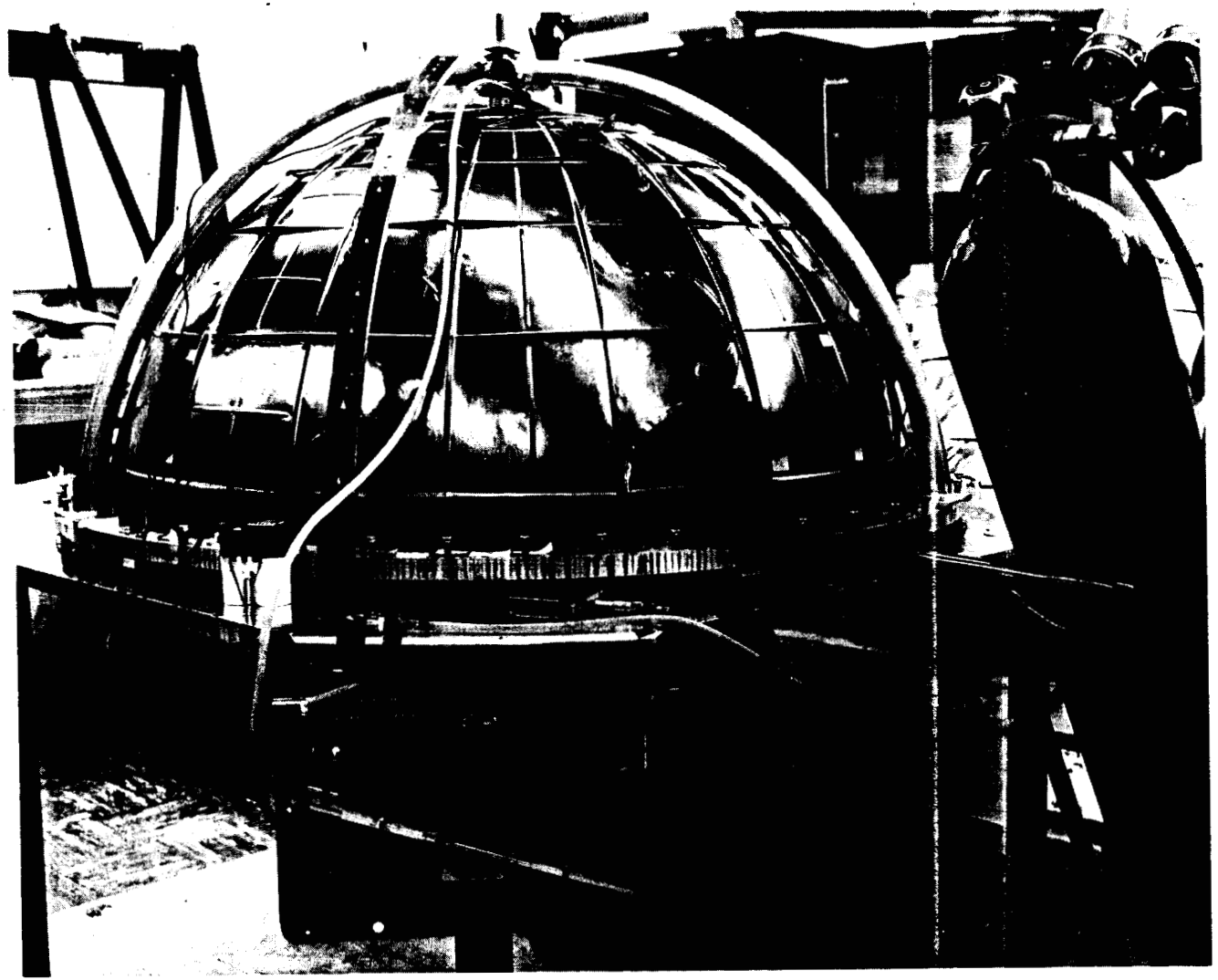
HAND PLANISH, REMOVE WITH AIR HOSE

JACKET WELDING

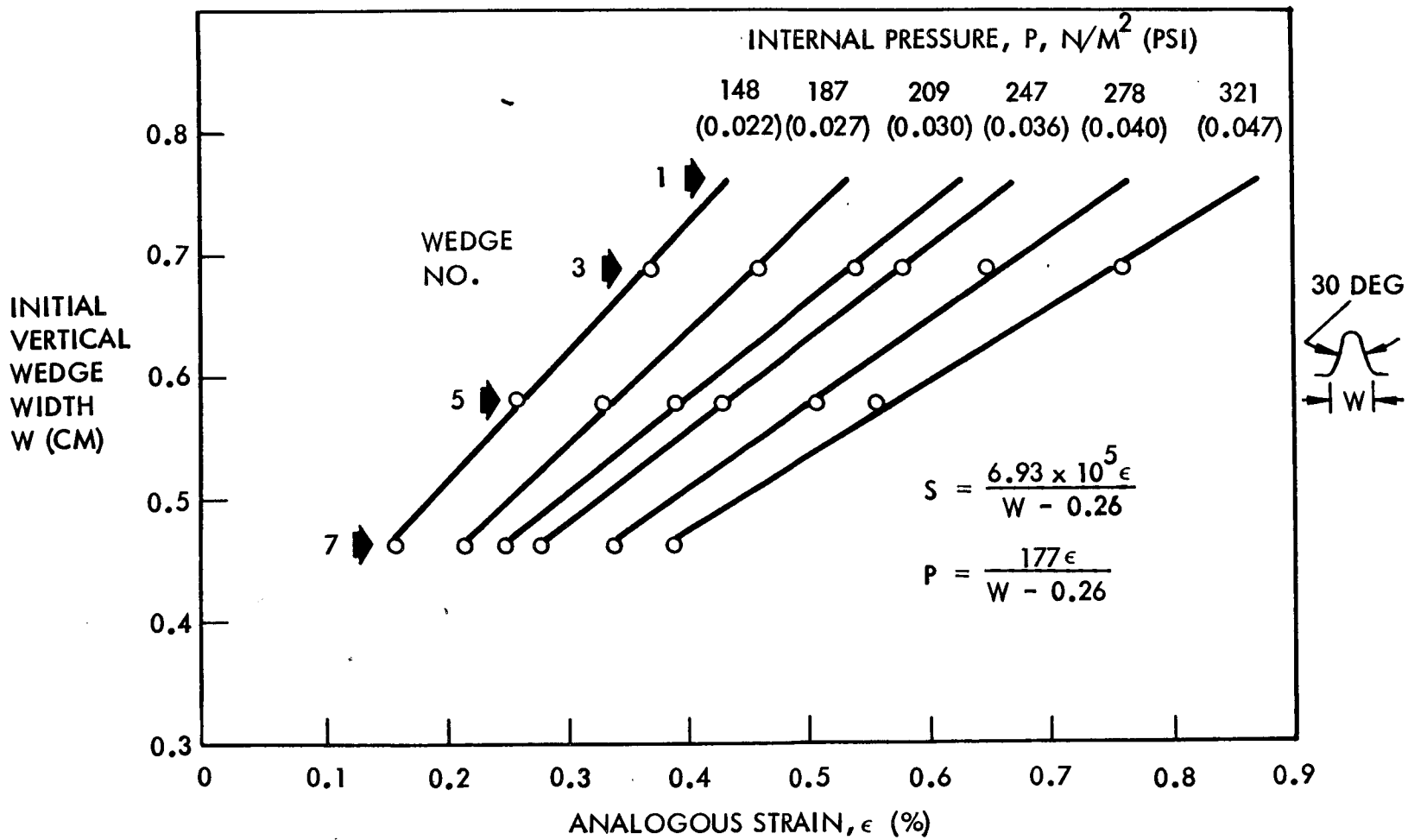


- 50-KVA SCIAKY SEAM WELDER
- OVERLAP JOINT
- 10 OVERLAPPING SPOT WELDS PER CM
- CONTINUOUS FUSION ZONE 0.2 CM WIDE

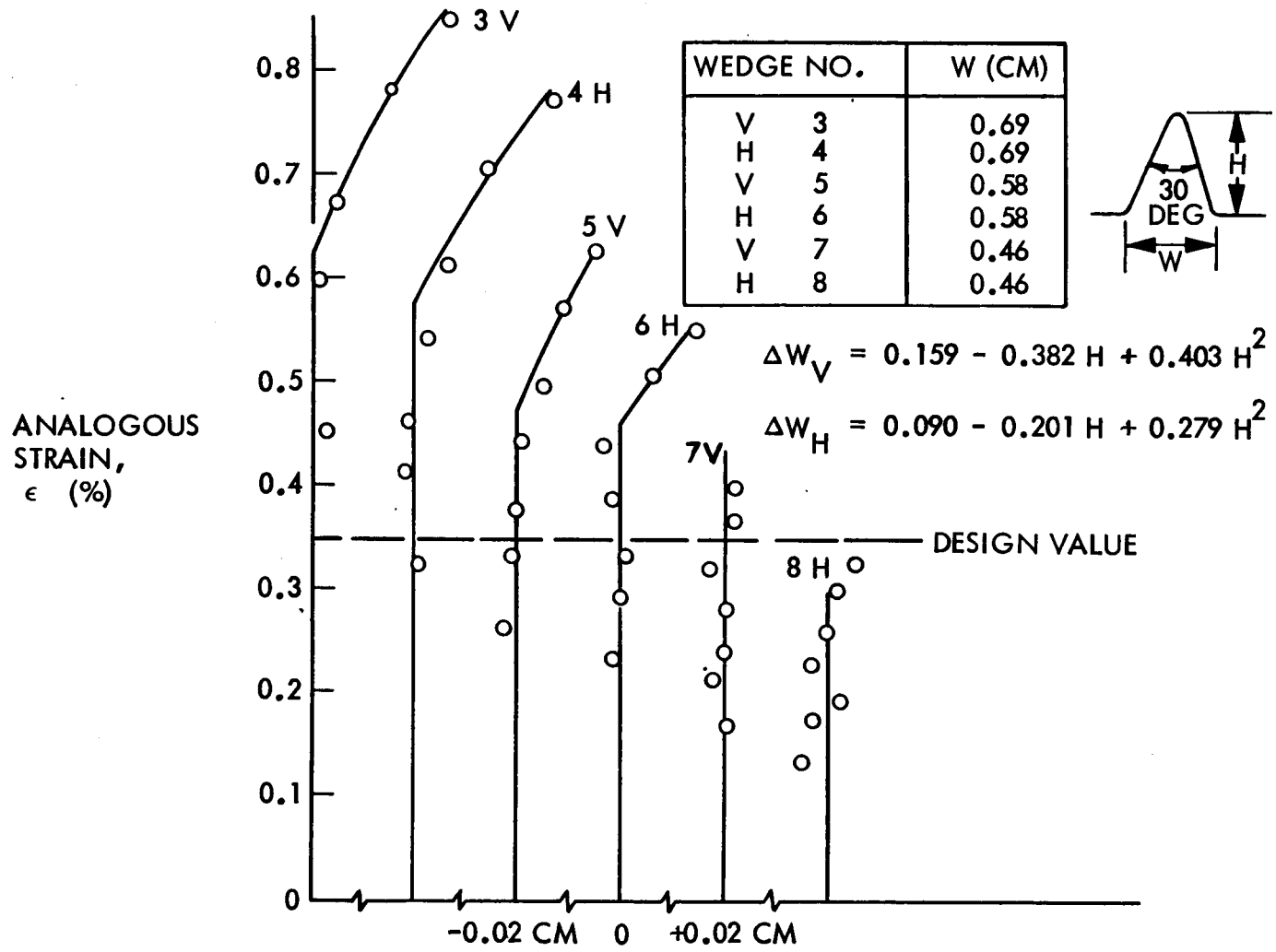
HEMISPHERE EXPANSION TEST



HEMISPHERE WEDGE EXPANSION
(IN THE ELASTIC RANGE)



ELASTIC LIMIT OF HEMISPHERE WEDGES

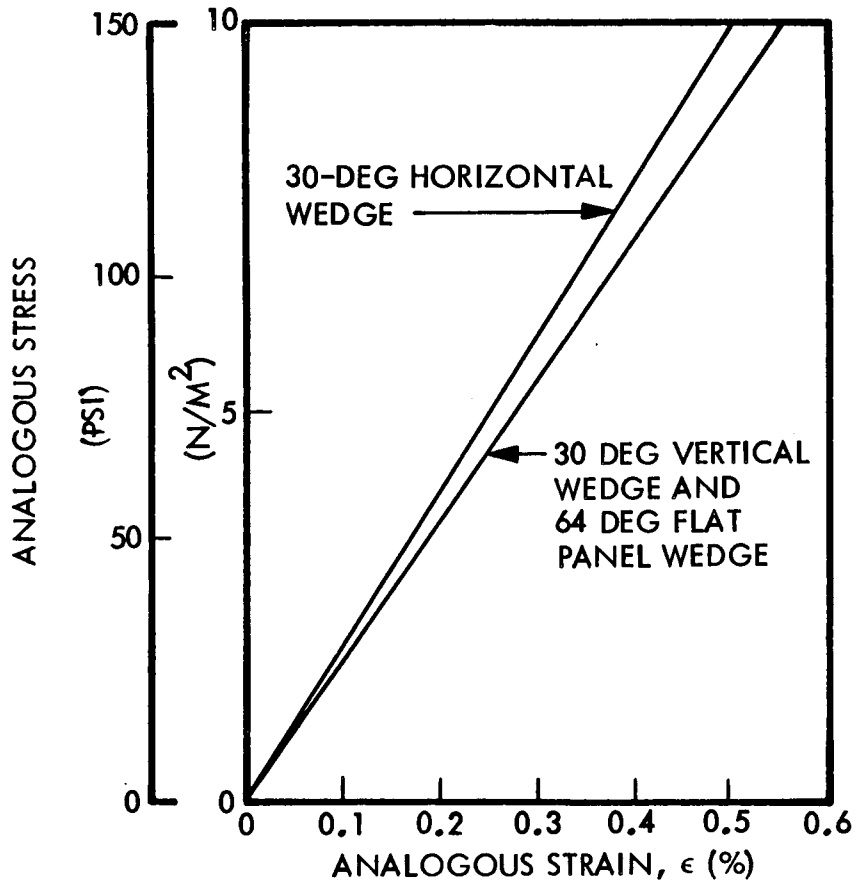


WEDGE NO.		W (CM)
V	3	0.69
H	4	0.69
V	5	0.58
H	6	0.58
V	7	0.46
H	8	0.46

RESIDUAL EXPANSION, ΔW, AT 0 PRESSURE (FOLLOWING PRESSURE LOAD)

FLAT PANEL VERSUS HEMISPHERE

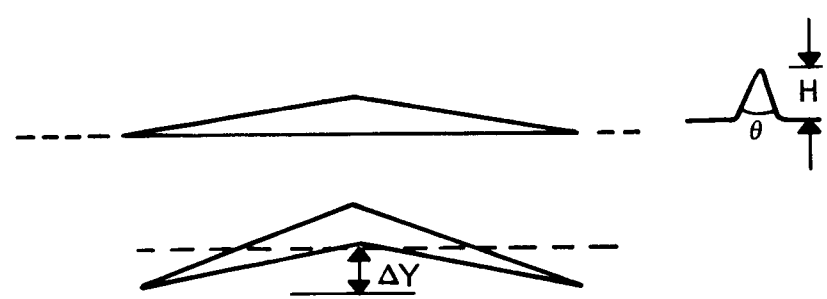
ELASTIC EXPANSION



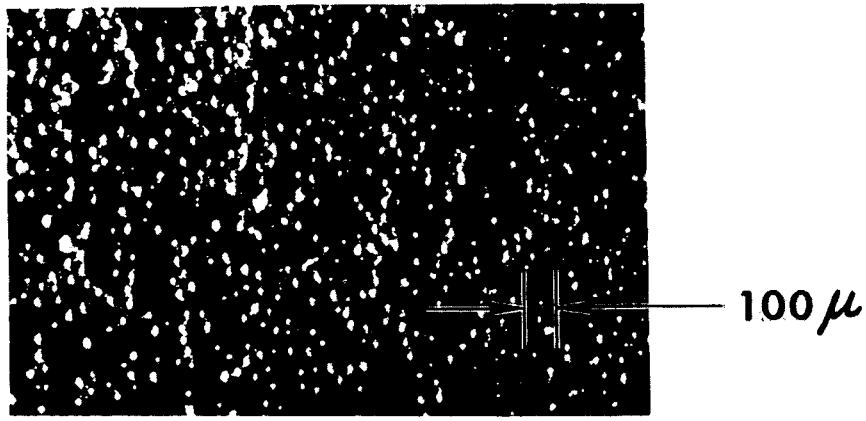
ELASTIC LIMIT
(Vs. WEDGE ANGLE)

WEDGE ANGLE (DEG)	MEASURED ΔW (CM)	PREDICTED ΔW (CM) $(\alpha\sqrt{\Delta X/\Delta X})$
FLAT PANEL		
64	0.11	REF.
HEMISPHERE		
30 (V)	0.19	0.17
30 (H)	0.18	0.17

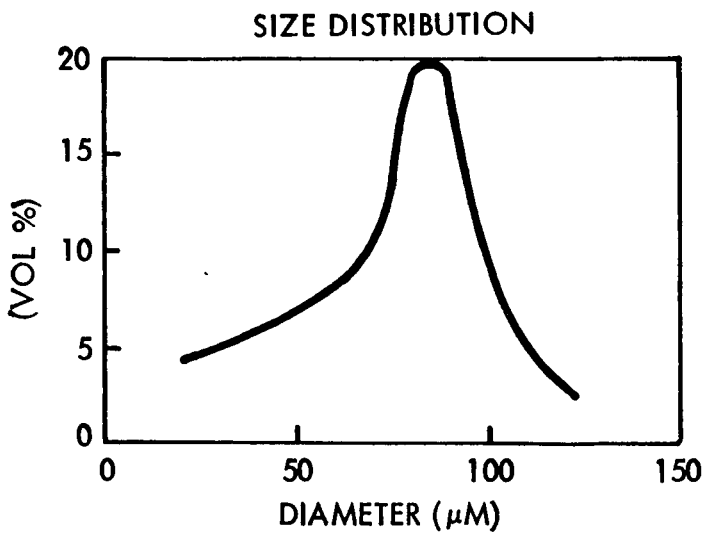
$$\Delta Y = \frac{H}{2}\left(\frac{\cos\theta_2 - \cos\theta_1}{\cos\frac{\theta_2}{2}\cos\frac{\theta_1}{2}}\right)$$

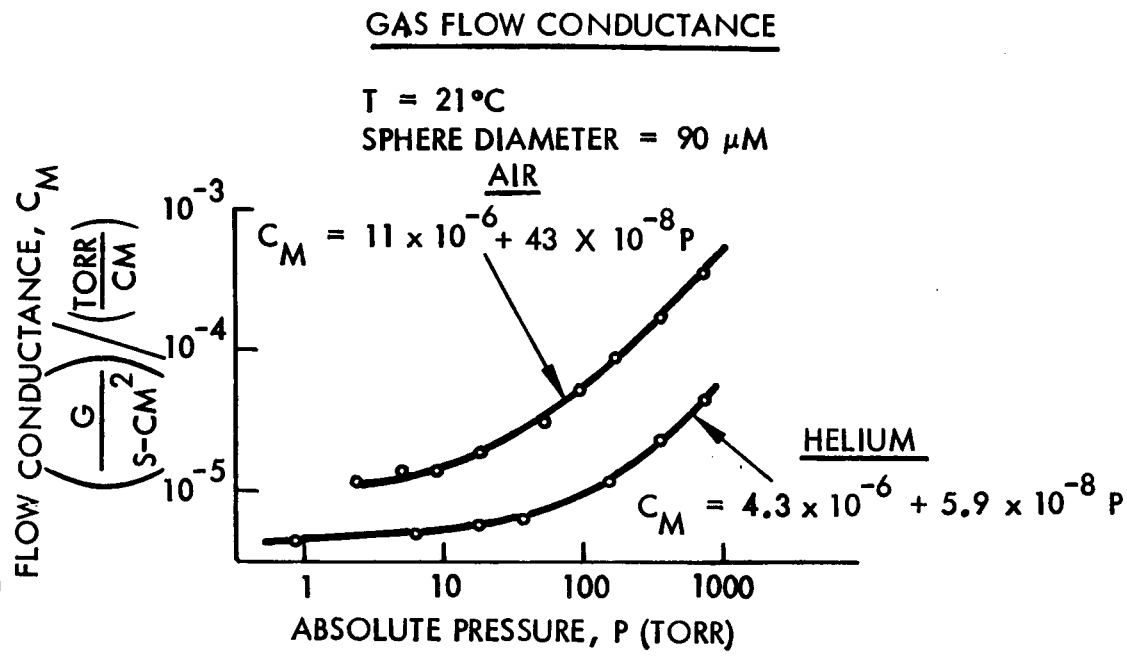


MICROSPHERE INSULATION PROPERTIES

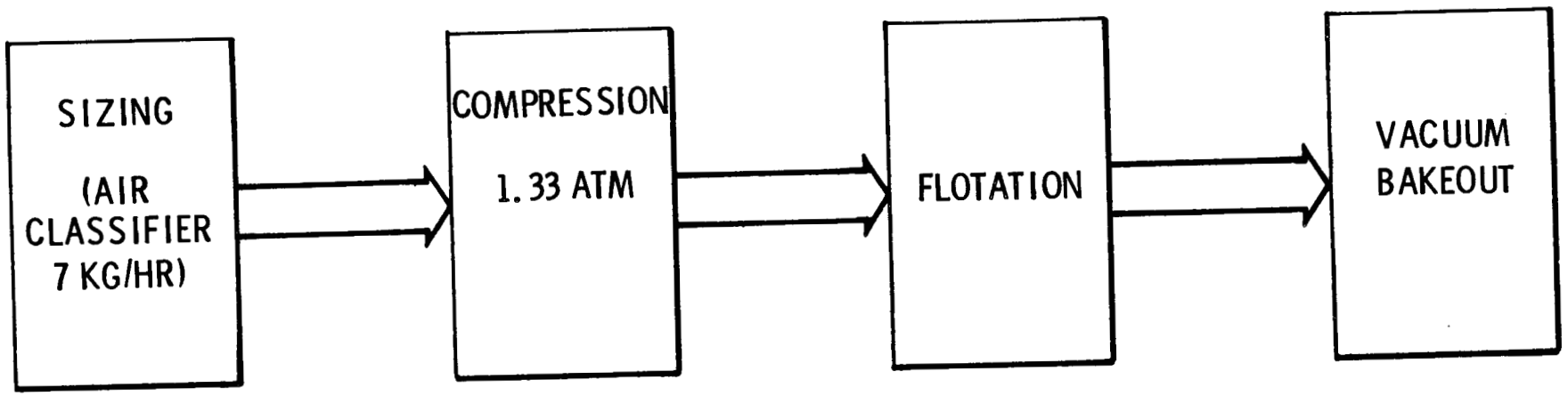


MATERIAL: BOROSILICATE GLASS
WALL THICKNESS: 0.5 TO 1 μM
INTERNAL PRESS: 212 TORR (BEFORE VAC BAKEOUT)
BULK DENSITY: 0.069 G/CC
MAX. TEMP: 482°C

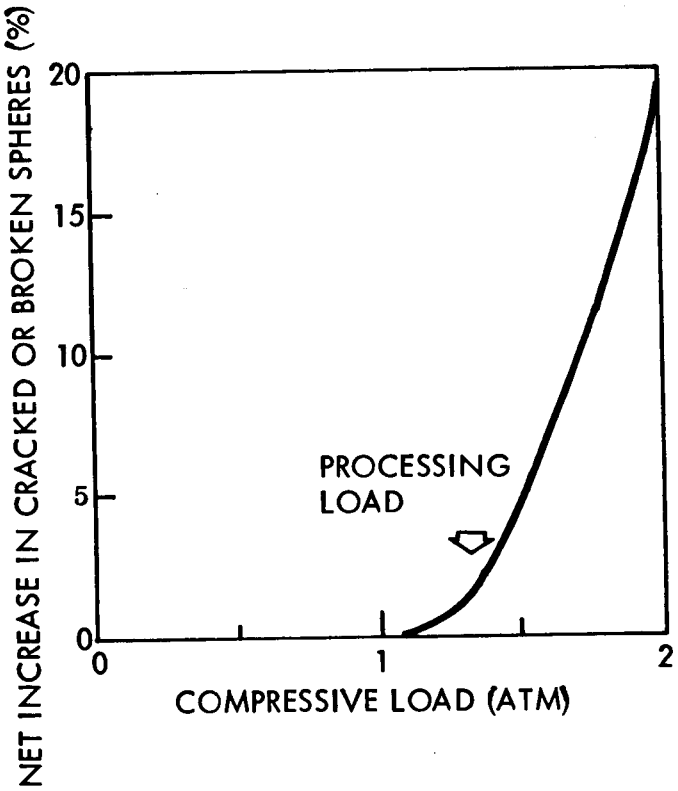




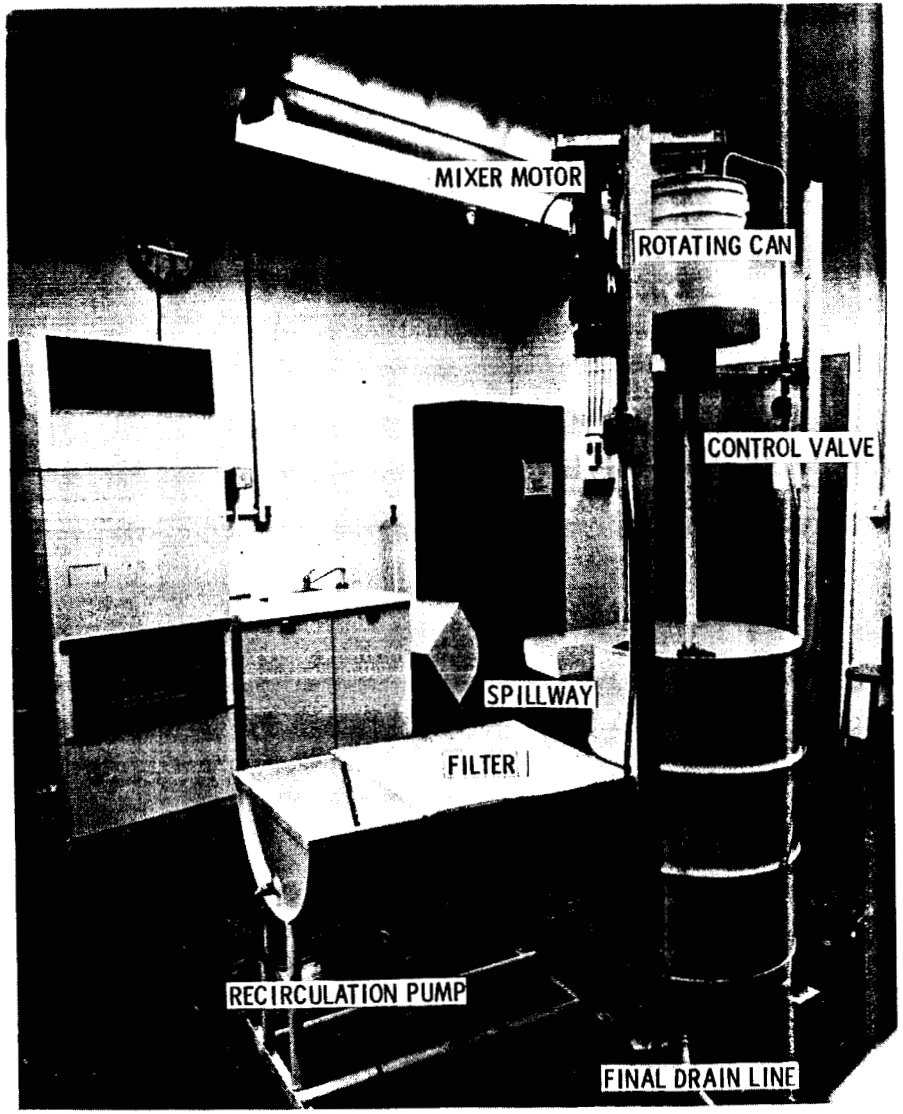
MICROSPHERE INSULATION PROCESSING



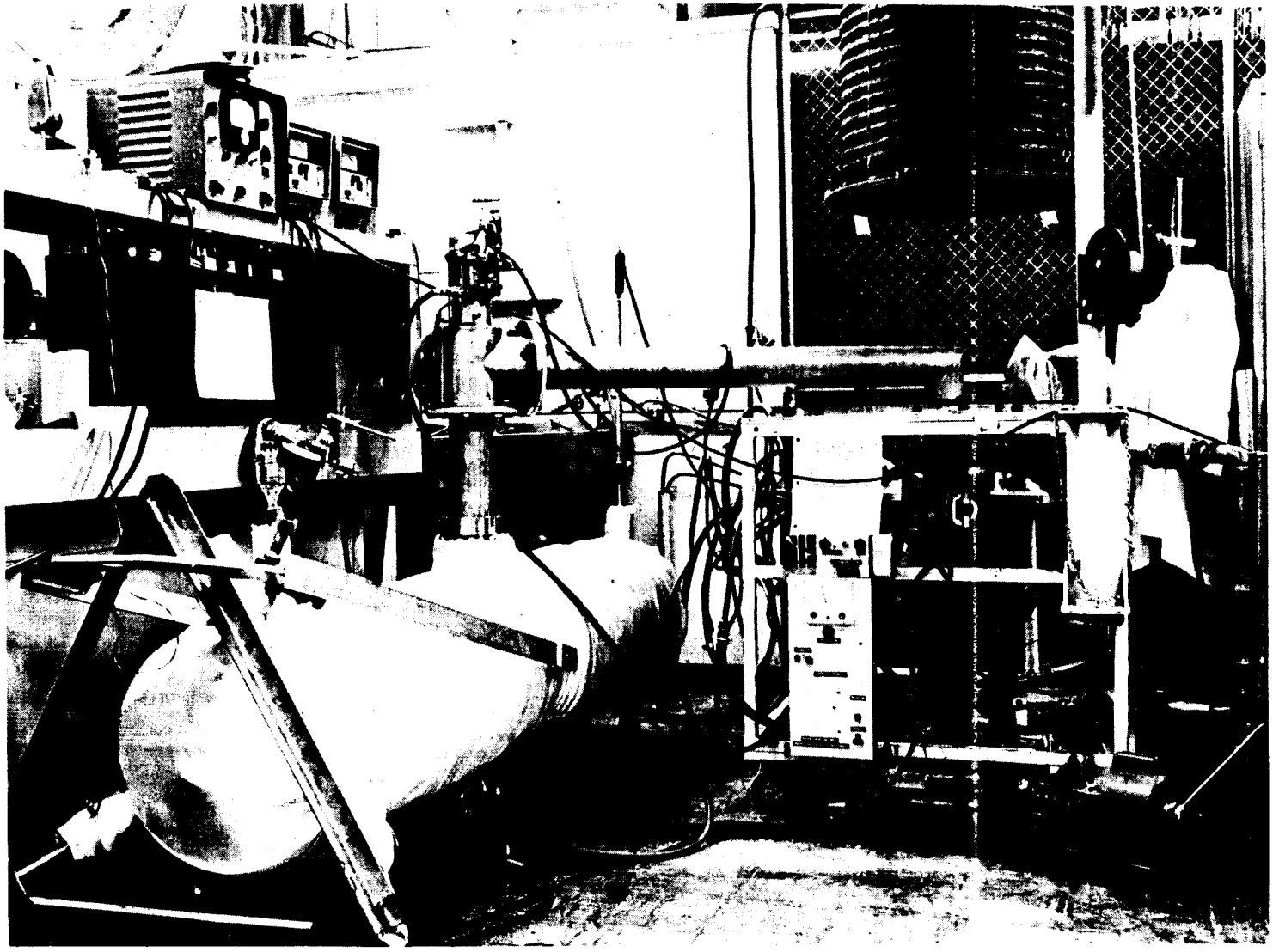
MICROSPHERE COMPRESSION



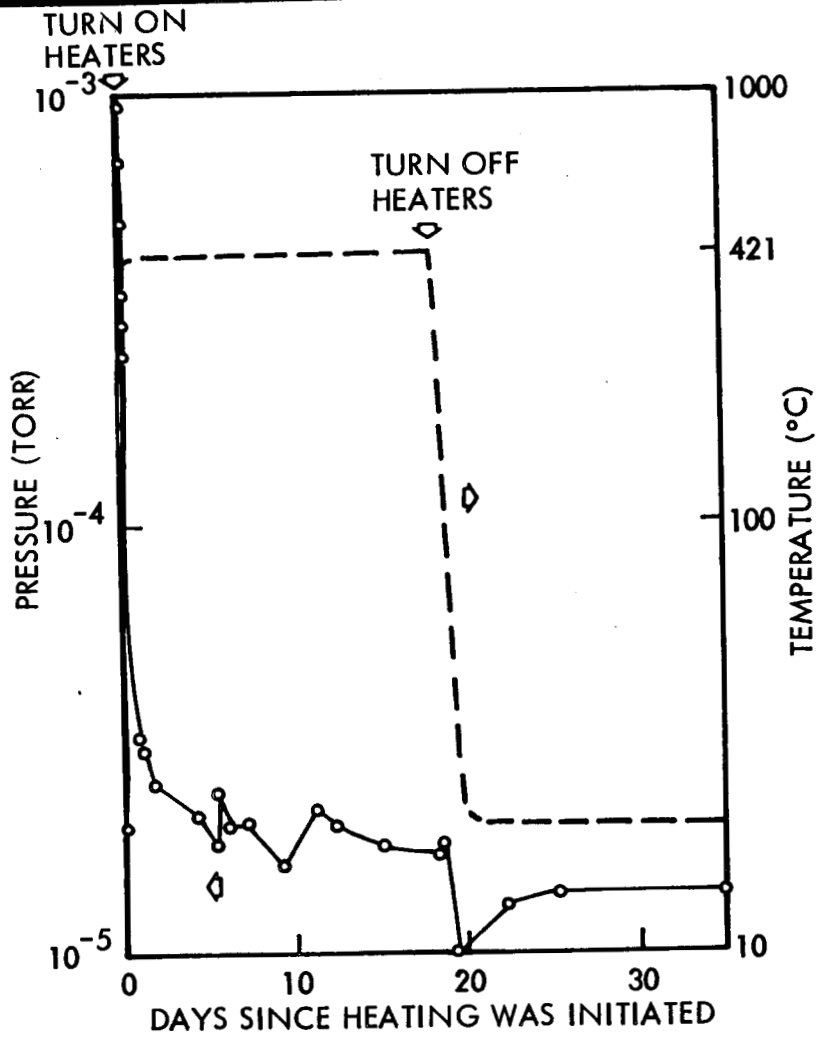
SEPARATION OF UNBROKEN MICROSPHERES

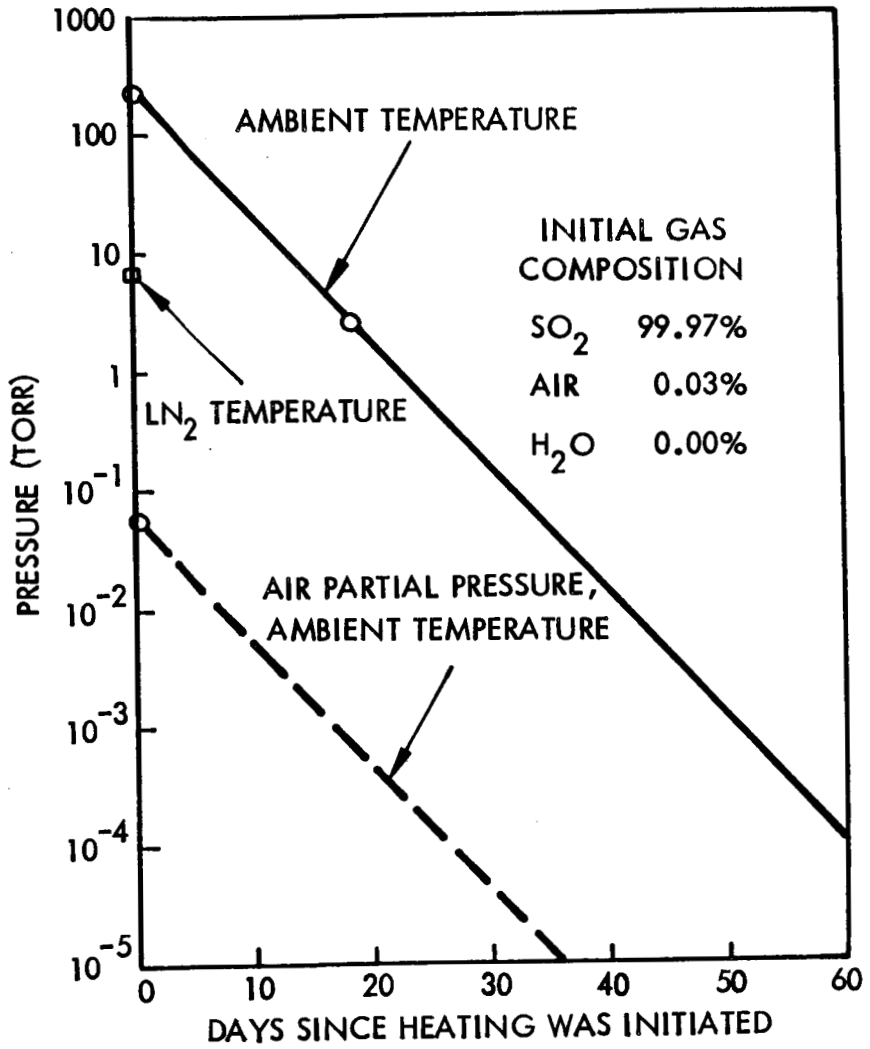


VACUUM BAKEOUT OF MICROSPHERE INSULATION



VACUUM BAKEOUT TEST DATA



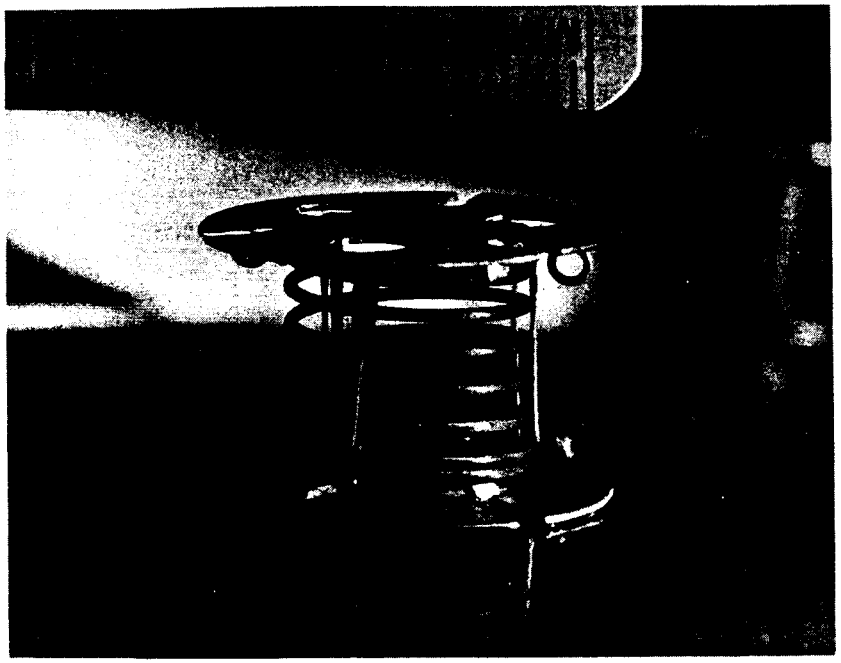


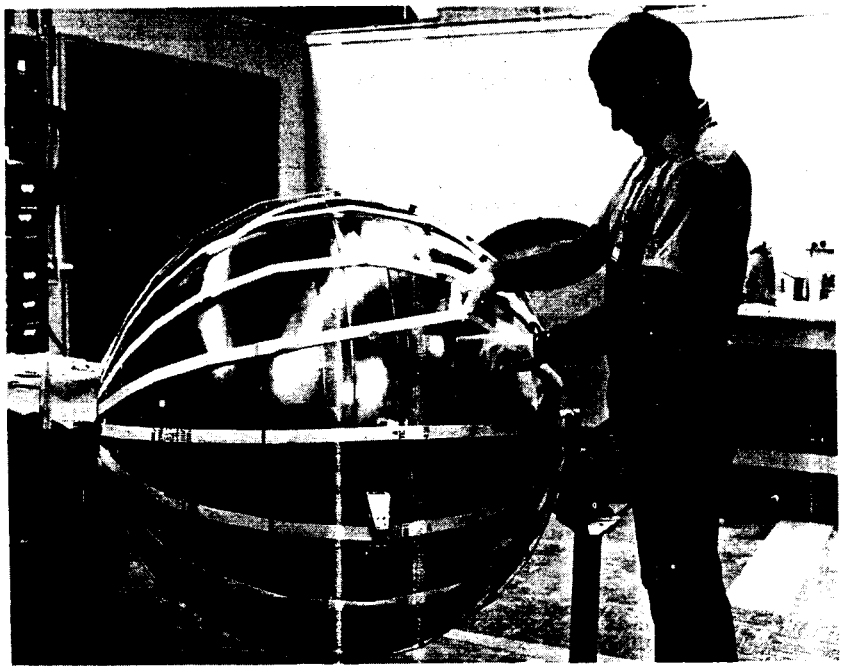
TEST ARTICLE ASSEMBLY

GOLD COATING

NO CHANGE IN ϵ OR GOLD REMOVAL (TAPE TEST)
AFTER 30 LN_2 SHOCK CYCLES

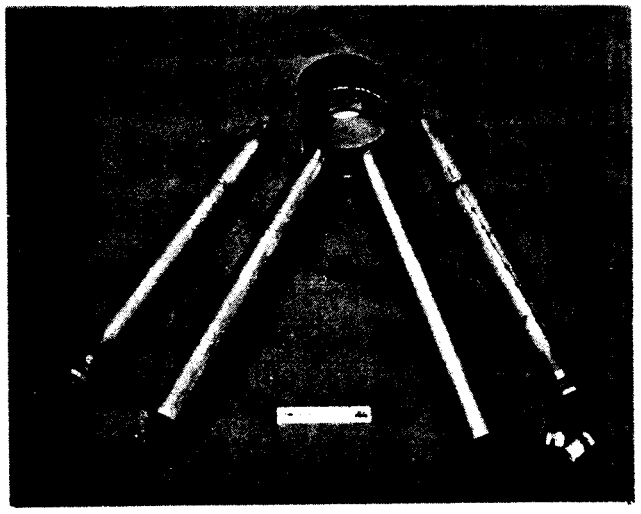
JACKET SUPPORT



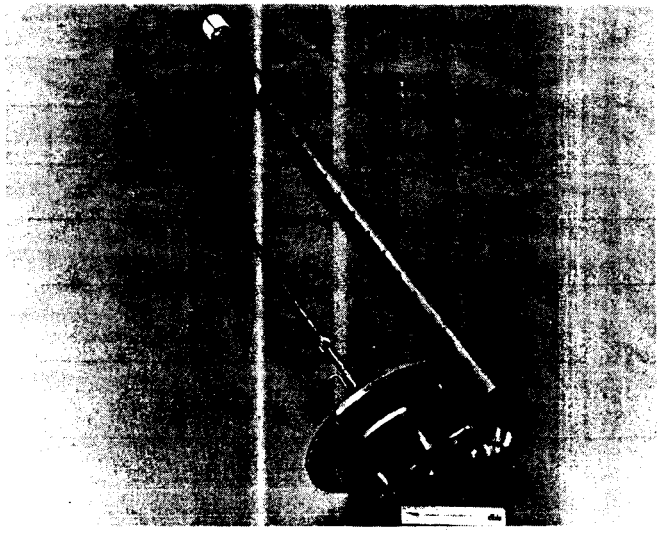


PARAMETER	PER SPRING ASSEMBLY	TOTAL
COMPRESSED SPRING FORCE	8.4 N (1.9 LB_F)	1390 N (313 LB_F)
TENSILE STRENGTH	236 N (53 LB_F)	38,900 N (8745 LB_F)

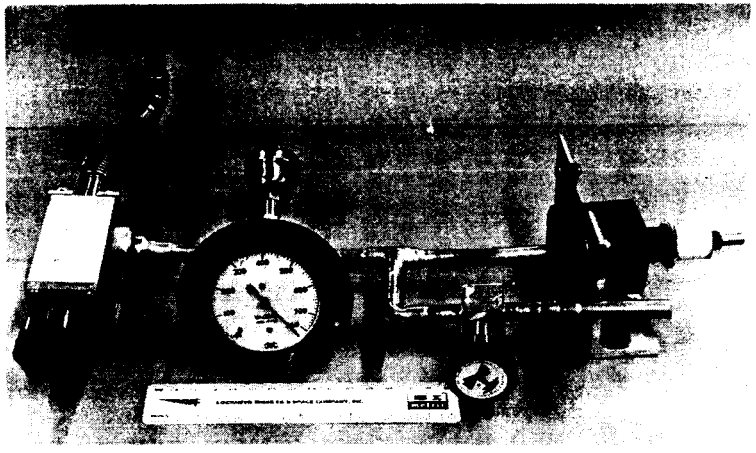
MAJOR SUBASSEMBLIES



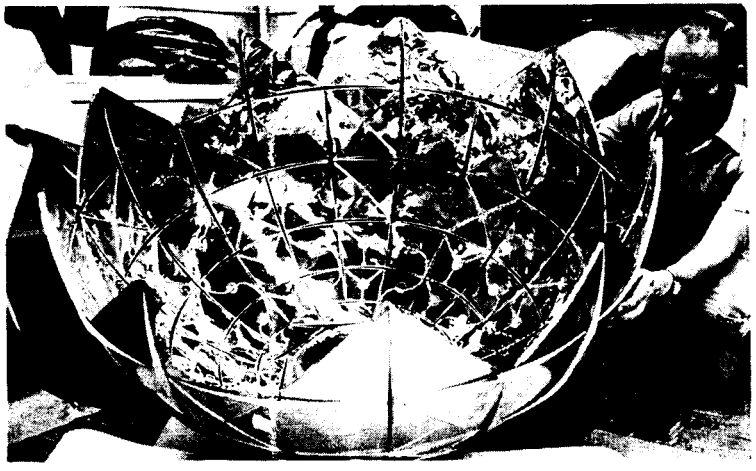
STRUT ASSEMBLIES



TANK ACCESS COVER ASSEMBLY

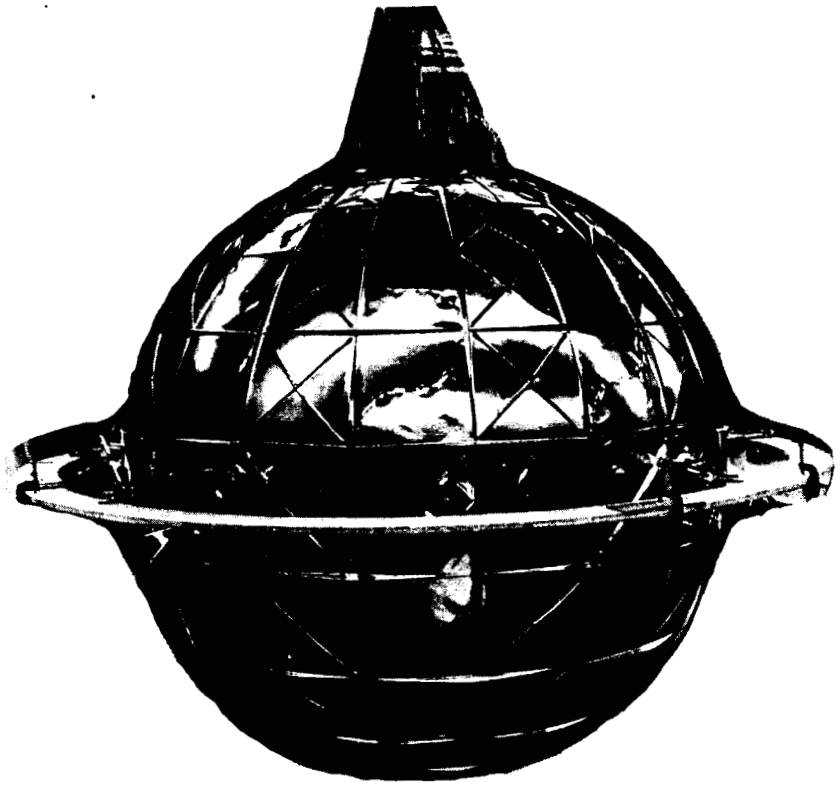


BOTTOM JACKET PRESSURE SENSORS

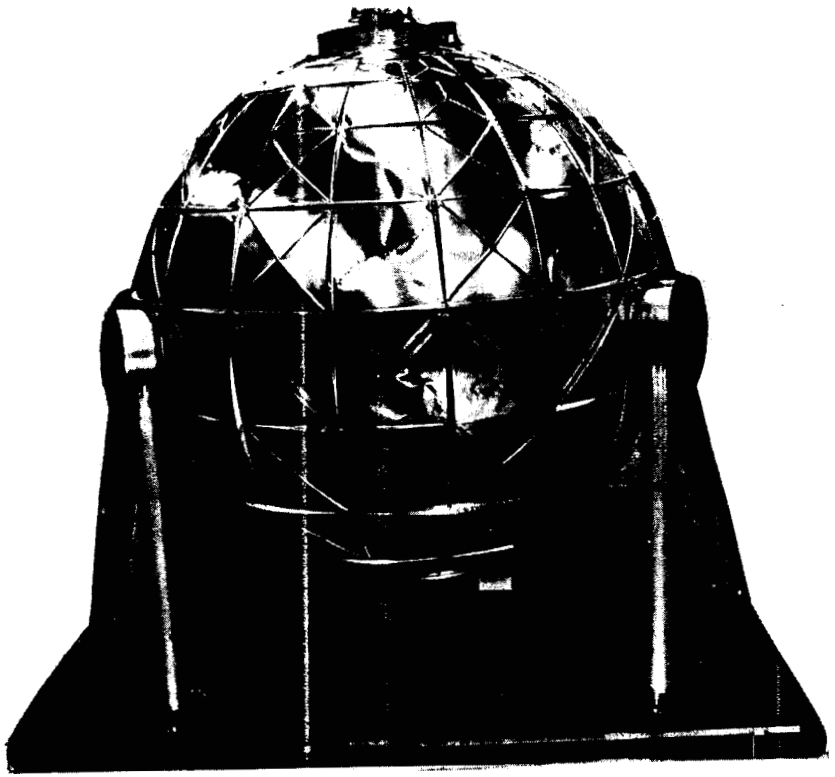


JACKET HEMISPHERE

JACKET FINAL ASSEMBLY

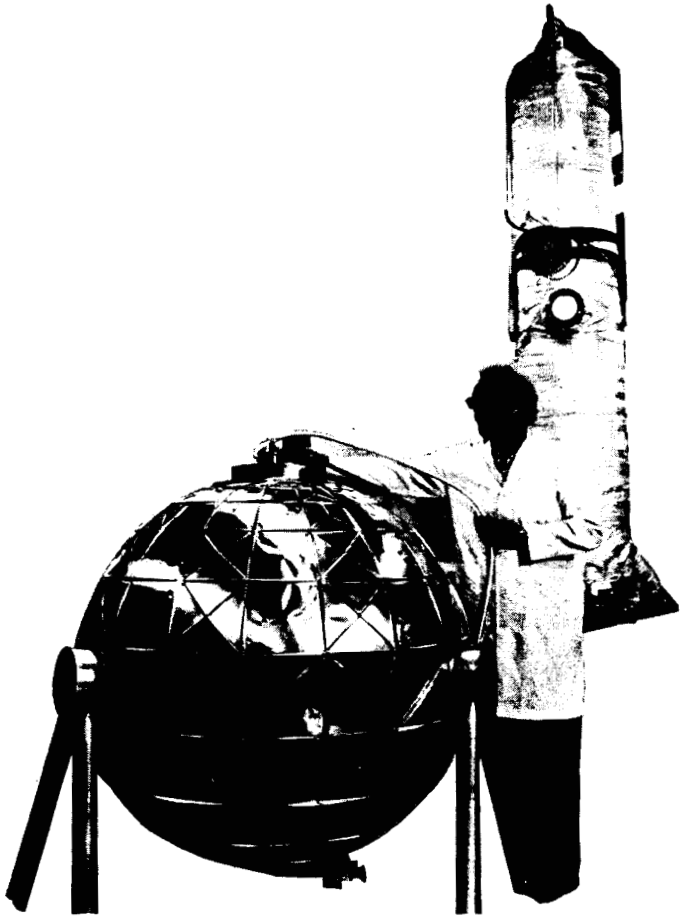


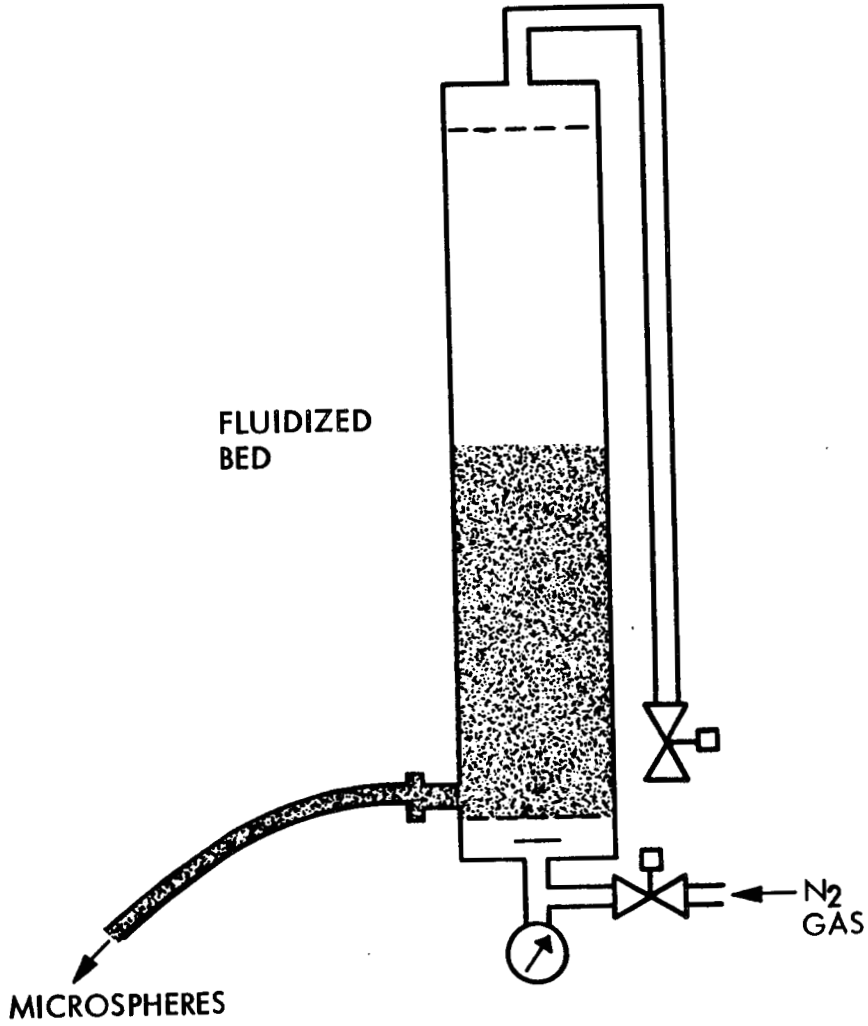
SOLDER FINAL CLOSURE



INSTALL STRUTS

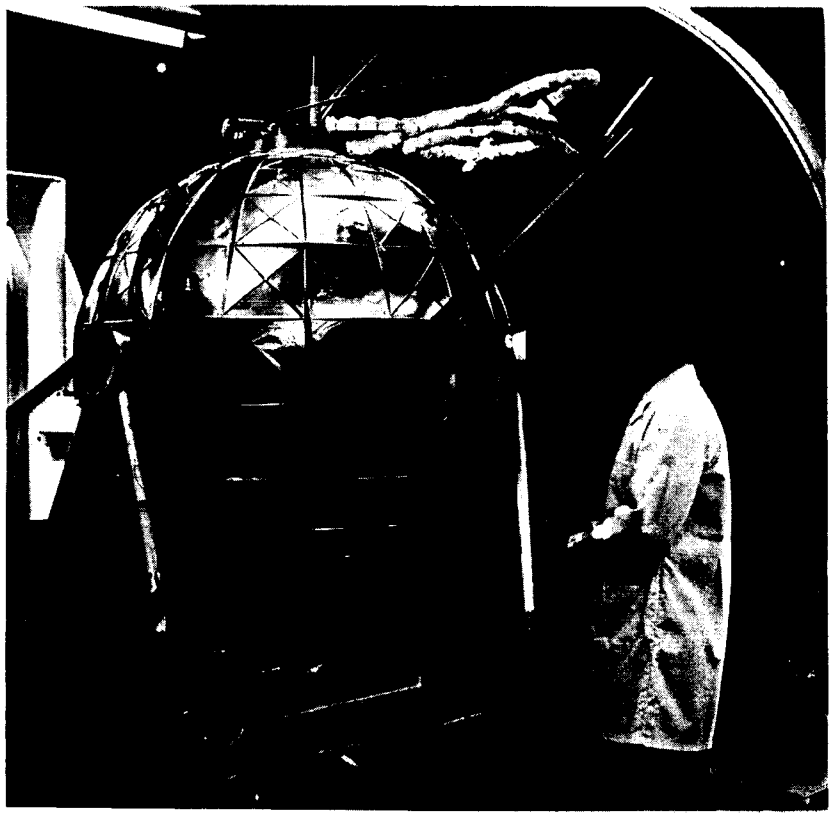
MICROSPHERE TRANSFER





GAS PRESSURE: 1030 N/M^2 (0.15 PSI)
GAS FLOW RATE: 8×10^{-4} M^3/MIN (0.03 FT^3/MIN)

TEST ARTICLE



TEMPERATURE (101 EA)

- JACKET (74 TC)
- FILL LINE (1 DIFF. TC)
- STRUTS (3 TC, 9 DIFF. TC)
- INSIDE TANK (7 DIFF. TC, 7 PRTs)

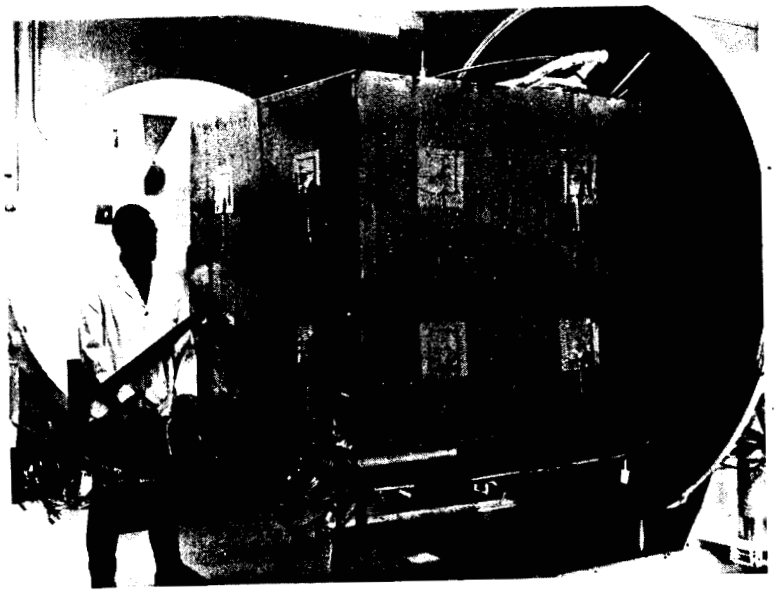
LIQUID LEVEL (5 EA)

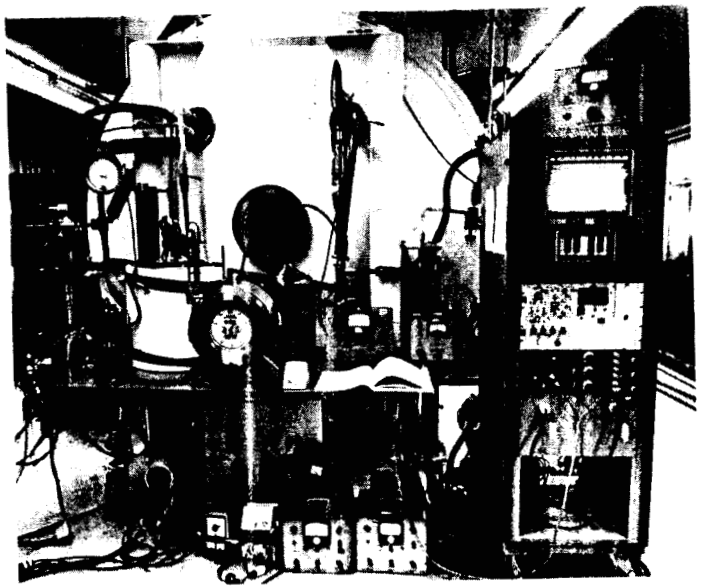
- CARBON RESISTORS

INSULATION PRESSURE (7 EA)

- TOP (3 EA 760 TO 10^{-7} TORR)
- BOTTOM (4 EA, 760 TO 10^{-8} TORR)

TEST SETUP





WARM BOUNDARY

TEMPERATURE: ±3°K

CHAMBER PRESSURE: 685 TO 10^{-6} TORR

TANK PRESSURE MEASUREMENT

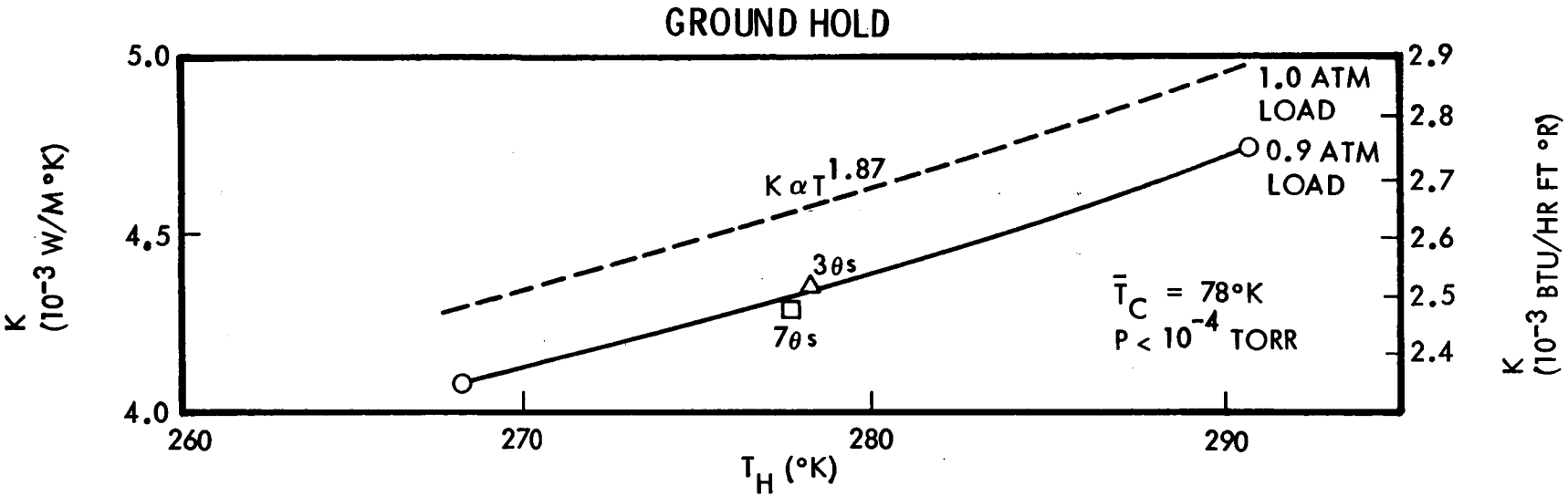
QUARTZ BOURDON TUBE (±0.026 TORR)

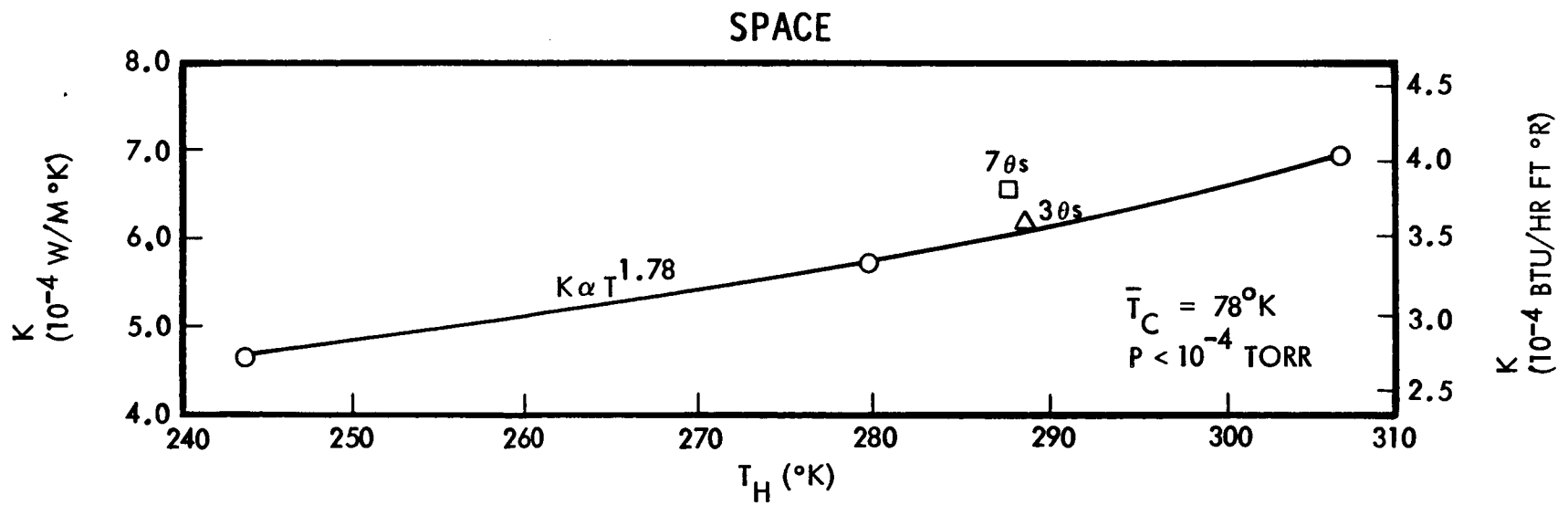
BOILOFF

GROUND HOLD: VARIABLE AREA FLOW METER

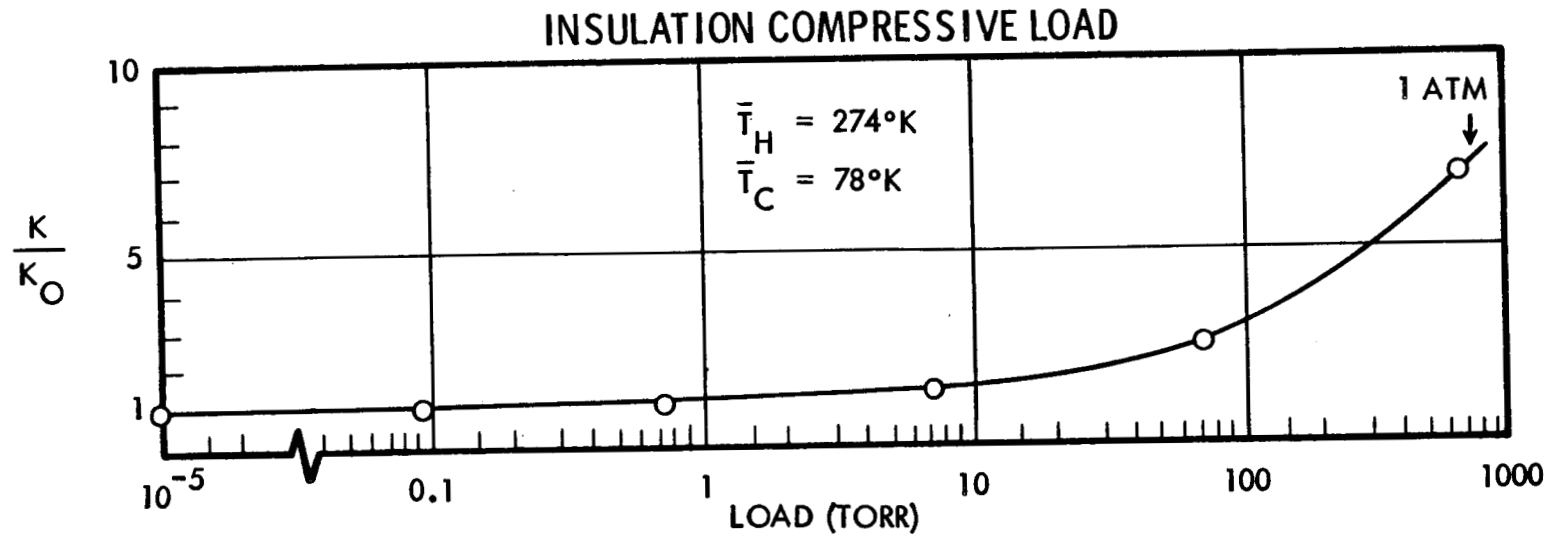
SPACE HOLD: PRECISION WET TEST METER

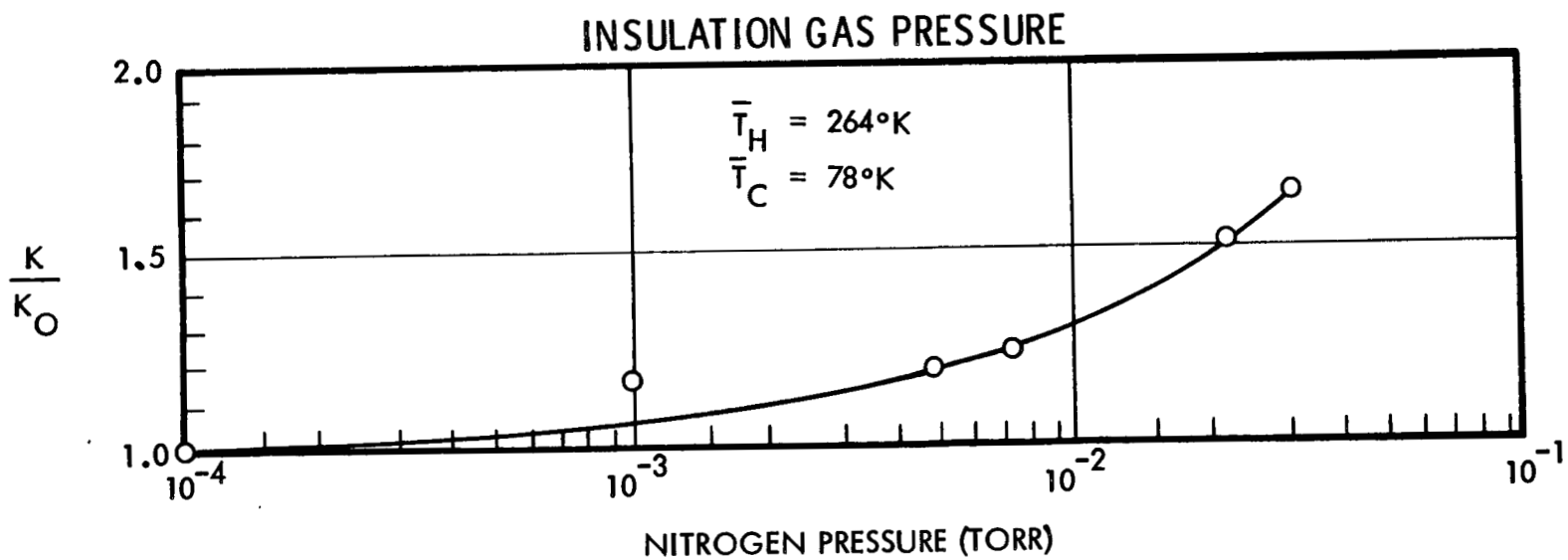
THERMAL PERFORMANCE



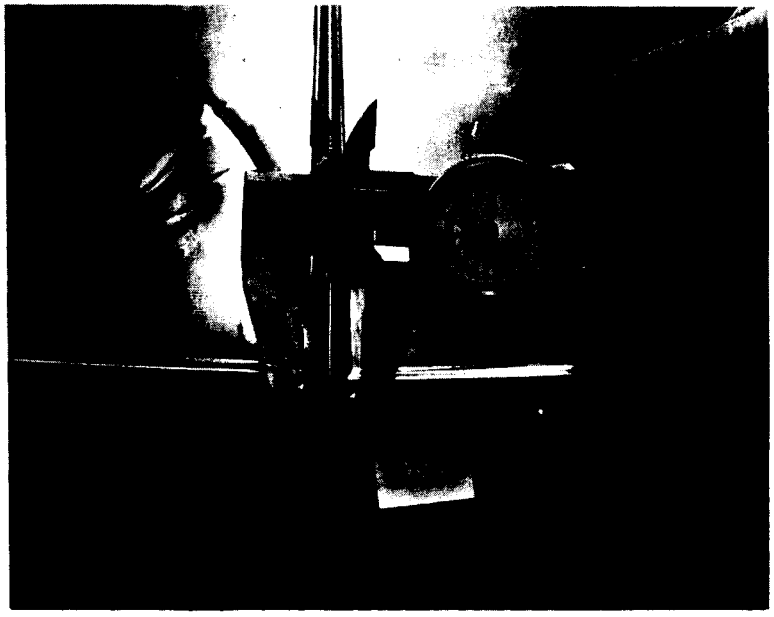


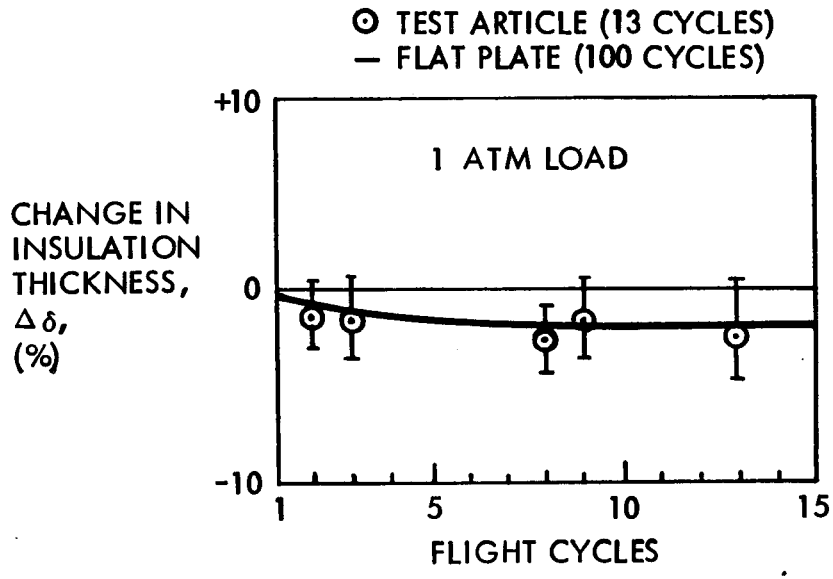
EFFECTS OF COMPRESSIVE LOAD AND GAS PRESSURE





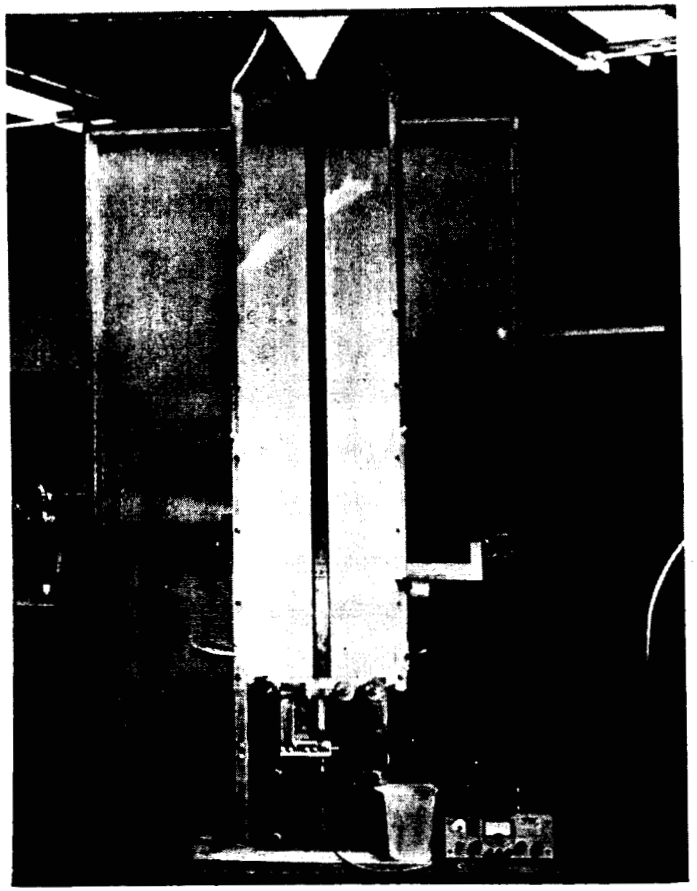
MICROSPHERE PACKING

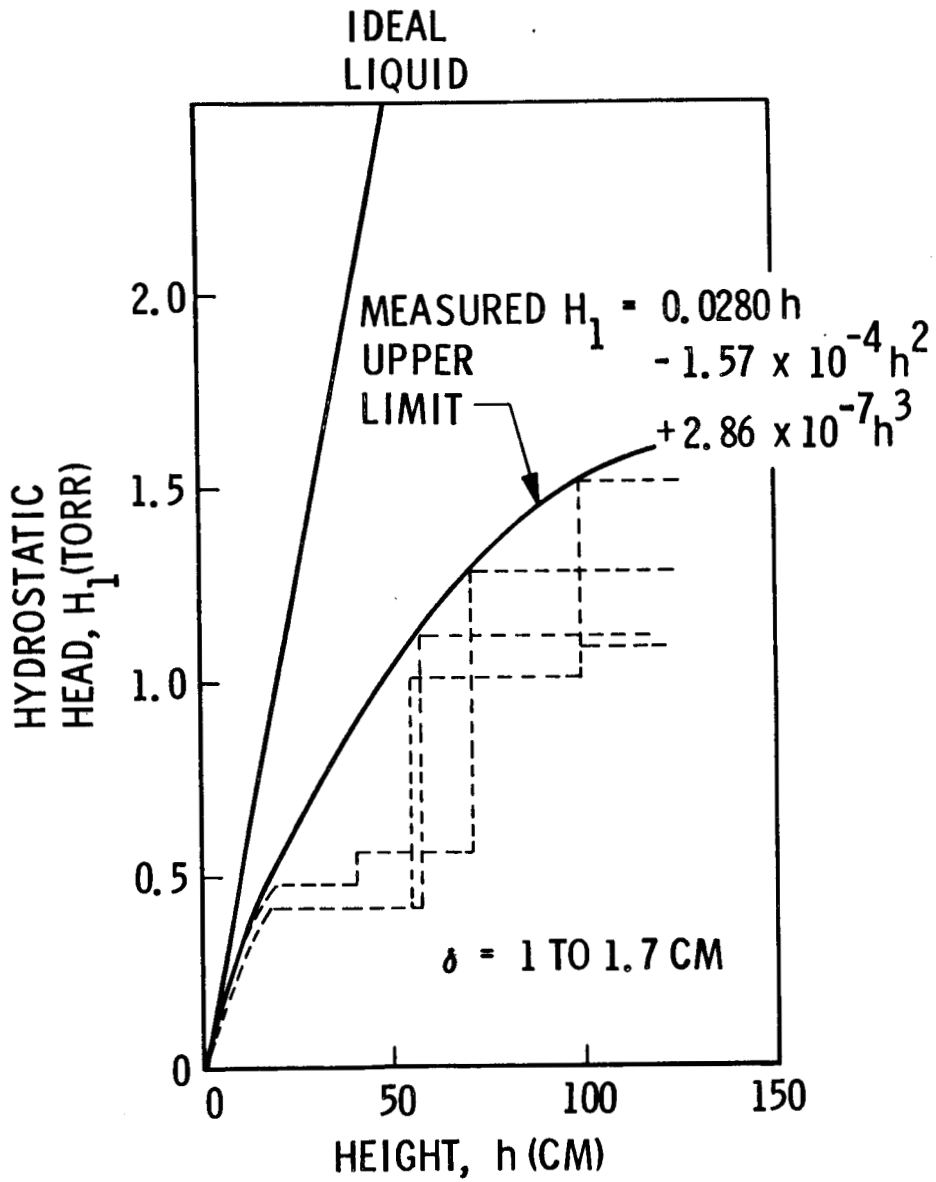




NO CHANGE IN PERCENT UNBROKEN SPHERES

MICROSPHERE SELF-WEIGHT





MICROSPHERE THERMAL MODEL

$$k = k_{sc} + k_{gc} + k_r$$

SOLID CONDUCTION $k_{sc} = (1.21 \times 10^{-4})\,(P+H)^{.56}\left[3.13 \times 10^{-3}\, T_H\,(1+\theta) - 2.61 \times 10^{-6}\, T_H^2\,(1-\theta^3/1-\theta)\right]$

GAS CONDUCTION $k_{gc} = k_g \left[\dfrac{5.8\,(1-m)^2}{1 - \dfrac{k_g}{k_{gr}}} \left(\dfrac{1}{1 - \dfrac{k_g}{k_{gr}}} \ln \dfrac{k_{gr}}{k_g} - 1 - \dfrac{K}{2} \right) + 1 \right]$

RADIATION $k_r = \left[\dfrac{n^2}{0.75\,\beta\ell + \dfrac{1}{n\epsilon_H} + \dfrac{1}{n\epsilon_C} - 1} \right] \sigma\,\ell\, T_H^3\,(1+\theta)\,(1+\theta^2)$

DEFINITION OF TERMS (MICROSPHERE THERMAL MODEL)

A = area of jacket (m^2)

d_{gr} = microsphere diameter (m)

F = deflection force/spring assembly (N)

H = integrated microsphere self-weight, $0.0140h - 3.94 \times 10^{-5} h^2 + 4.78 \times 10^{-8} h^3$ (Torr)

h = maximum vertical height of jacket (cm)

k = thermal conductivity (W/m^oK)

k_g = $\dfrac{k_{go}}{1 + \dfrac{2\chi L}{\delta_a}}$ (W/m^oK)

k_{go} = gas thermal conductivity at standard conditions (W/m^oK)

k_{gr} = $k_s \left[\dfrac{1 + \dfrac{2m(1-\nu)}{(2\nu+1)}}{1 - \dfrac{m(1-\nu)}{(2\nu+1)}} \right]$ (W/m^oK)

k_s = thermal conductivity of glass (W/m^oK)

K = $1 - k_g/k_s$

ℓ = insulation thickness (m)

L = mean free path (m)

m = void fraction

n = refractive index of microspheres, 1.56

N = number of spring assemblies

P = external compressive load, Torr for $10^{-2} > P > 0.015 \dfrac{NF}{A}$

Pr = Prandtl No.

T_H, T_C = absolute hot and cold boundary temperatures, respectively (^oK)

α = accommodation coefficient

β = extinction coefficient of microspheres, 9450 (m^{-1})

γ = specific heat of gas (Cal/g^oK)

δ_a = $\dfrac{2md_{gr}}{3(1-m)}$ (m)

ϵ_H, ϵ_C = gold coating boundary temperature total hemispherical emittance, metal to vacuum $\sim 0.000065T + 0.005$

θ = T_C/T_H

ν = k_s/k_g

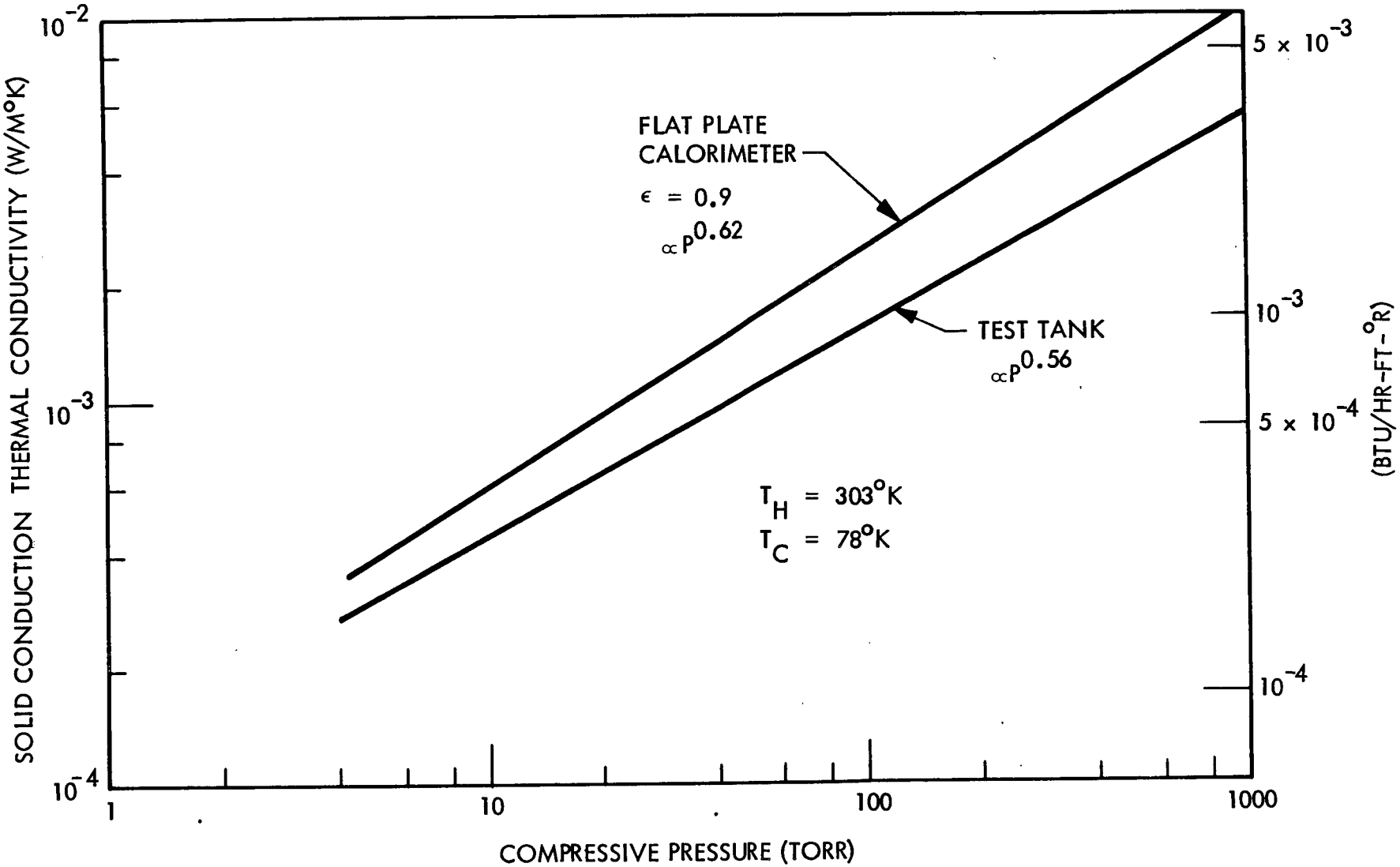
σ = Stefan Boltzmann constant, 5.6×10^{-8} ($W/m^2{}^oK^4$)

χ = $\dfrac{2\gamma}{\gamma+1} \dfrac{1}{Pr} \dfrac{2-\alpha}{\alpha}$

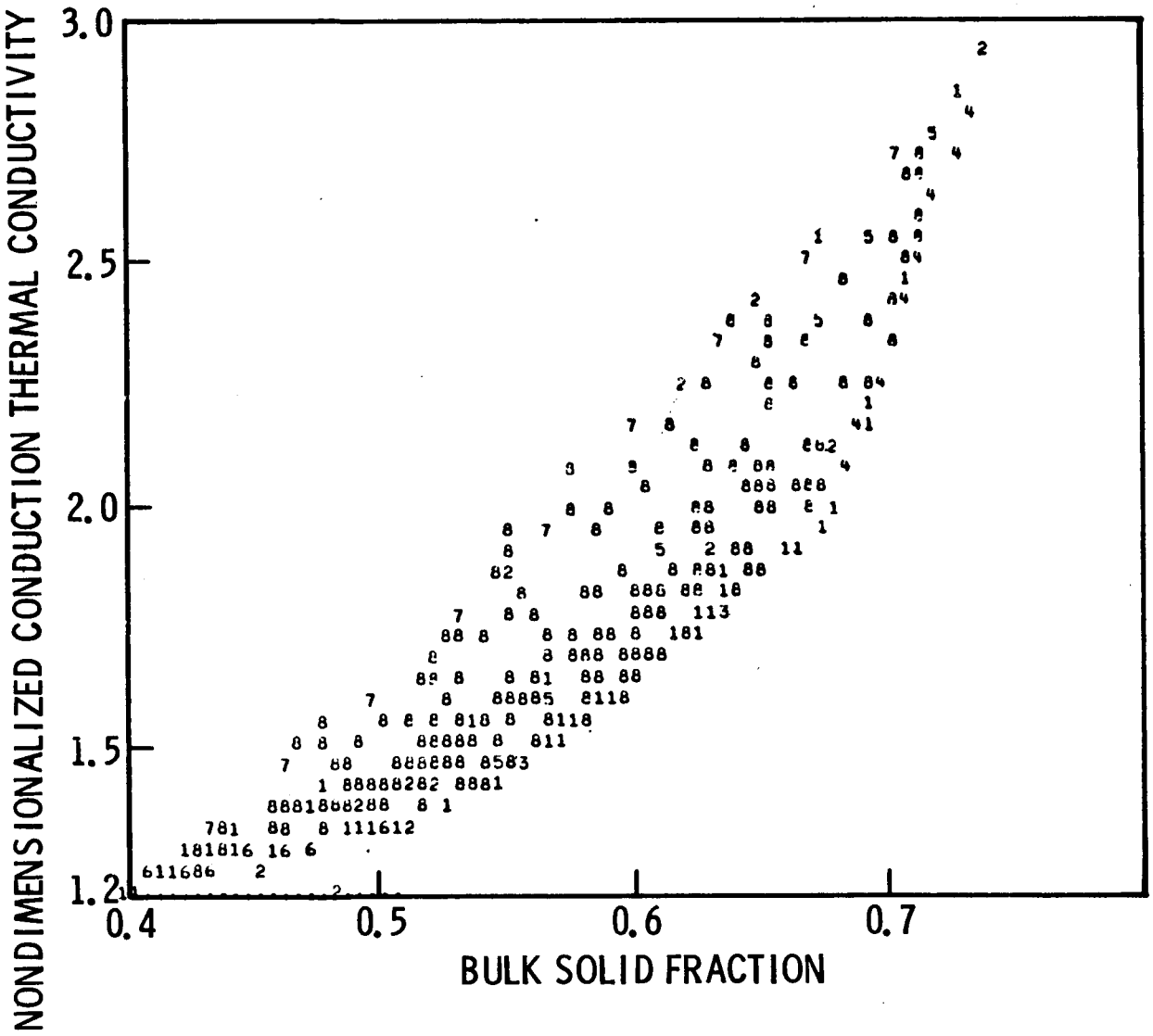
PREDICTED VS MEASURED HEAT RATES

T_H K	MICROSPHERES		SPRING-ASSEMBLIES %	LI900 BLOCKS %	STRUTS %	TOTAL, W	
	CONDUCTION %	RADIATION %				CALCULATED	MEASURED
GROUND HOLD							
268	89.4	8.7	1.0	0.7	0.2	273	260
SPACE HOLD							
244	22.3	61.2	8.8	6.2	1.5	26.0	29.8

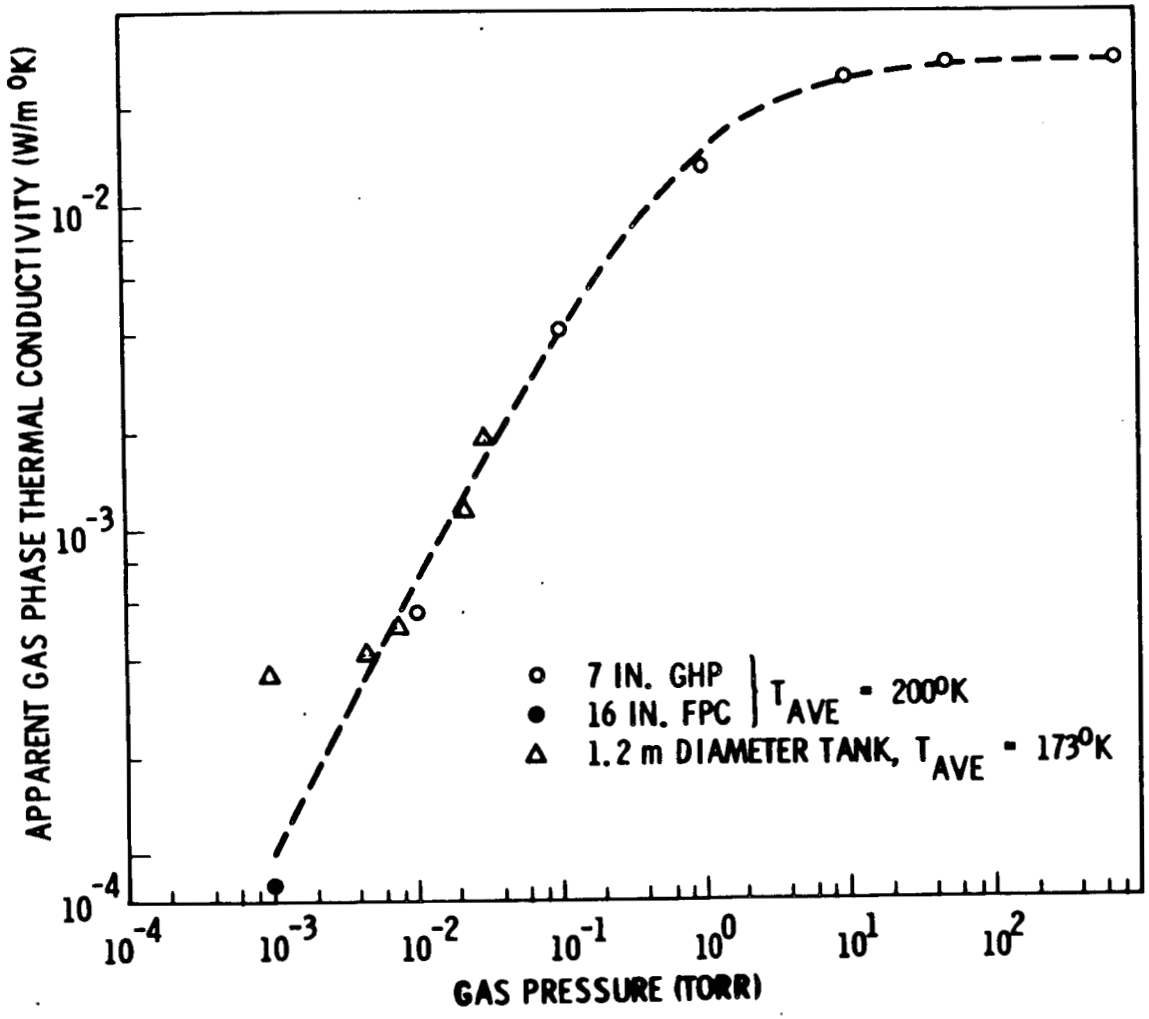
SOLID CONDUCTION PHASE THERMAL CONDUCTIVITY COMPARISON (FOR MICROSPHERES)



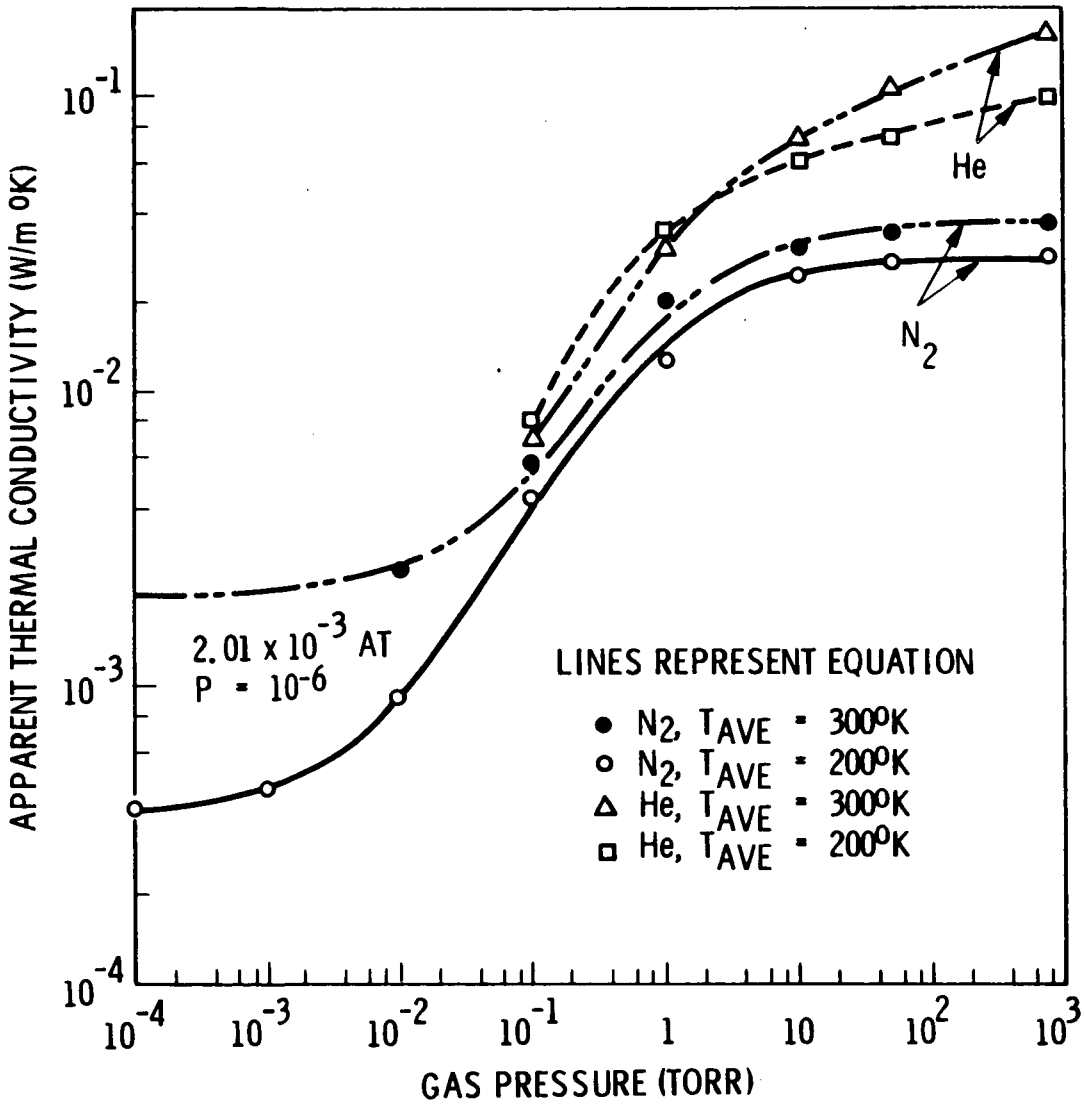
EFFECT OF PACKING GEOMETRY ON SOLID CONDUCTION CONDUCTIVITY (FOR MICROSPHERES)



NITROGEN GAS PHASE THERMAL CONDUCTIVITY (FOR MICROSPHERES)



MICROSPHERE THERMAL CONDUCTIVITY (AS A FUNCTION OF GAS SPECIES AND PRESSURE)



TEST ARTICLE WEIGHT

% OF TOTAL		kg
27.9	JACKET	4.09
0.7	SCREEN FILTERS	
2.0	VACUUM PORT	
0.2	PRESSURE PORT	
0.5	FILL PORT	
5.6	RIGID AREAS	
18.3	FLEX AREAS	
0.6	EPOXY/GOLD	
29.3	3 STRUT ASSEMBLIES	4.29
26.5	CYLINDER + 2 STRUTS (3 EA.)	
1.7	COVER (3 EA.)	
0.2	WARM END CLOSEOUT (6 EA.)	
0.4	SCREWS, NUTS, SOLDER	
0.5	BICYCLE SPOKES (6 EA.)	
5.0	TANK RELATED PARTS	0.73
0.6	EPOXY/GOLD	
4.4	SPRING ASSEMBLIES + EPOXY	
37.8	MICROSPHERES	5.53
100.0		14.64

VACUUM JACKET PERFORMANCE

PUMPDOWN TIME

- 10^{-2} TORR, 6 HR
- 10^{-5} TORR, 1 MIN (CO_2 CRYOPUMPED)

MINIMUM PRESSURE WITH 1-ATM LOAD

- TOP 2×10^{-5} TORR (LEAK DETECTOR)
- BOTTOM 10^{-6} TORR (ION PUMP)

VACUUM INTEGRITY (13 FLIGHT CYCLES)

NO LEAKS

- 23.2 M OF SEAM WELDS
- MEMBRANE
- WEDGES (INCLUDING SEVERAL DAMAGED WEDGES)
- STIFFENED AREAS

LEAKED WHEN CYCLED

- SOLDERED FINAL CLOSURE JOINT
- WARM END OF STRUTS

DEFLECTION

- EQUATOR WEDGES OVEREXPANDED DURING ASSEMBLY
- JACKET PERFORMED AS DESIGNED DURING CYCLING
- WEDGE BUCKLING AROUND STRUT COVERS (DUE TO INCOMPLETE MICROSPHERE FILL)

RECOMMENDED JACKET IMPROVEMENTS

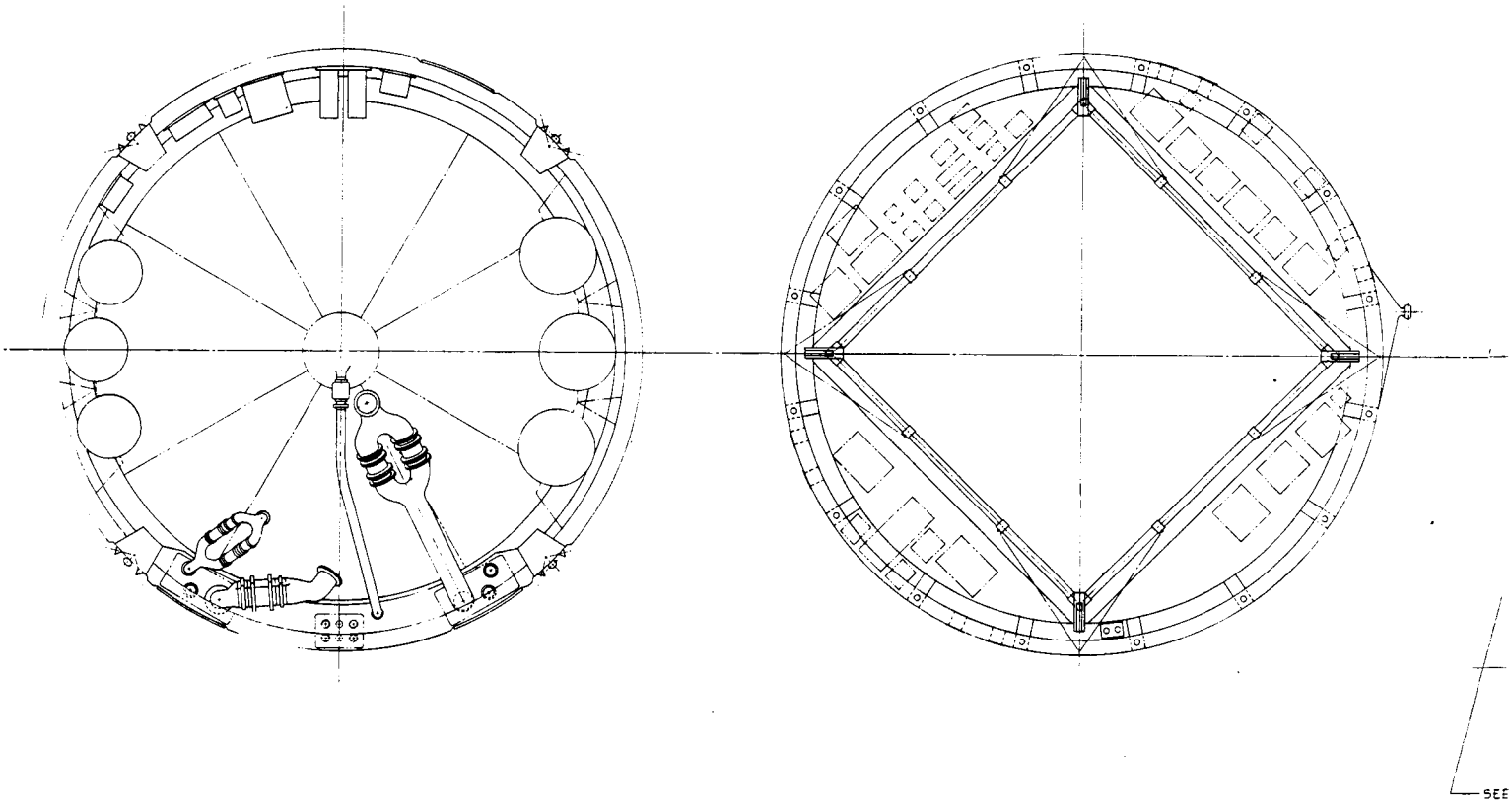
- WELDED FINAL CLOSURE JOINT
- SEAM WELDED STRUT JOINT
- CONVOLUTED DIAPHRAGM STRUT COVER, SEPARATE MICROSPHERE FILL PORTS
- HIGHER FLOW CONDUCTANCE FILTERS
- CONICAL, TAPERED SPRING ASSEMBLY, SINGLE KEVLAR STRAND
- DESIGN WEDGES FOR UNIFORM RADIAL EXPANSION WITH INCREASING PRESSURE

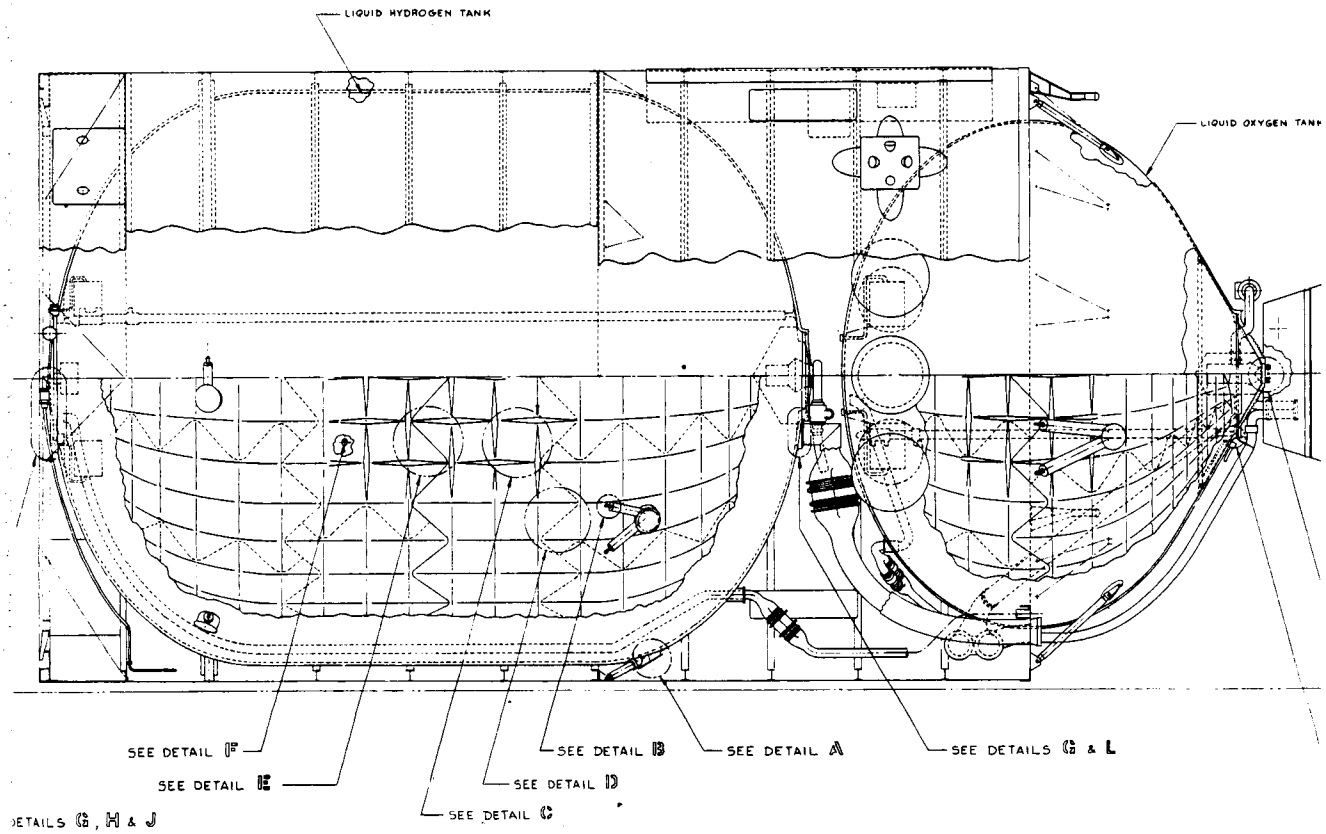
SPACE TUG SYSTEM

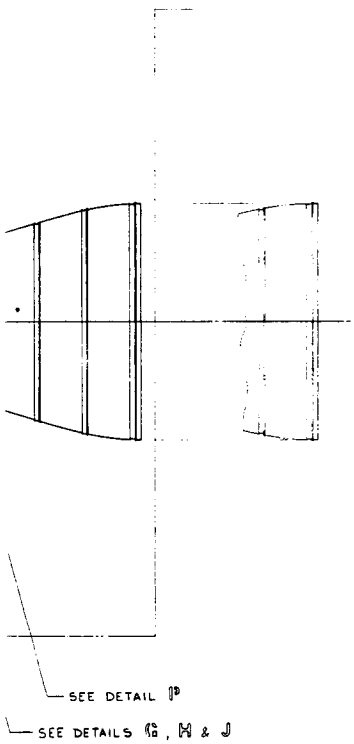
JACKET CHARACTERISTICS

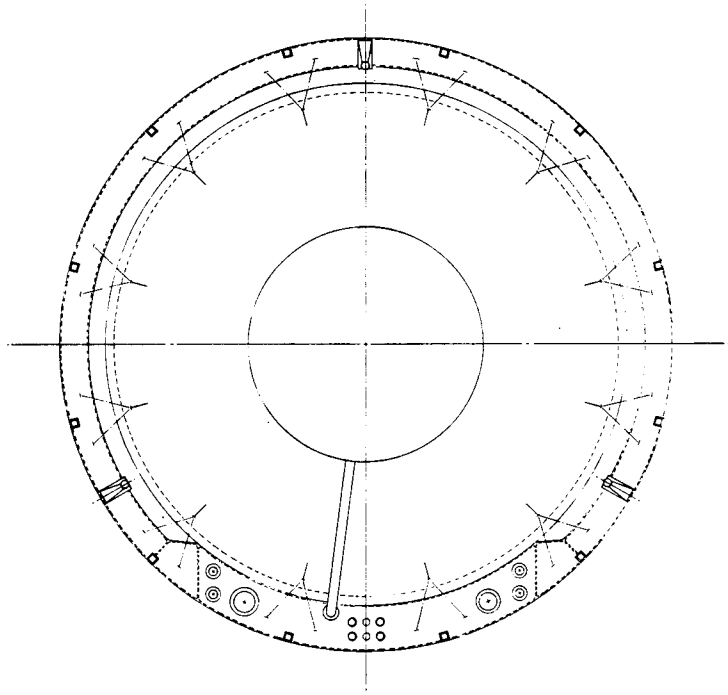
	LO_2 TANK	LH_2 TANK
MATERIAL	321 ANNEALED STAINLESS STEEL	
THICKNESS (MM)	0.08	
UNIT WT (KG/M^2)	0.62	
LENGTH OF WELDED JOINTS (M)[a]	184	393
NUMBER OF CIRCUM. SQUARES	36	42
NUMBER OF EQUATOR GORES	12	14
NUMBER OF SPRING ATTACHMENTS	814	1444
WEDGE CHARACTERISTICS		
• MAXIMUM HEIGHT (CM)	1.16	1.19
• MINIMUM HEIGHT (CM)	0.59	0.62
• ANGLE (DEG)	30	30
• EQUATOR SPACING (CM)	32.1	31.2
SPACING OFF TANK WALL (CM)	2.90	2.02

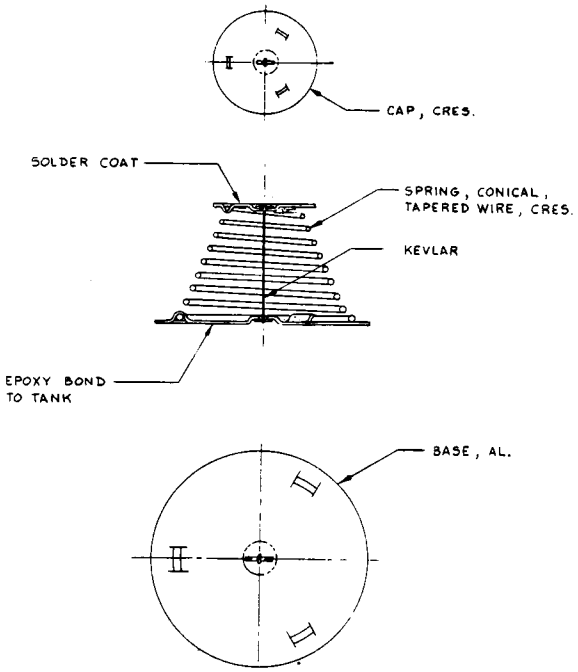
(a) LENGTH OF TEST ARTICLE WELDED JOINTS IS 23 M.


SEE

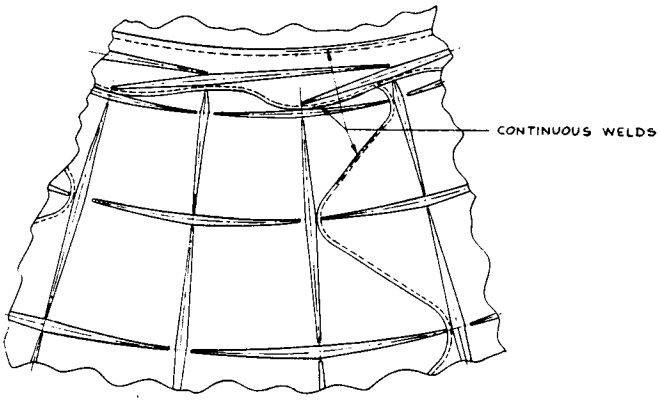

LIQUID HYDROGEN TANK
LIQUID OXYGEN TANK
SEE DETAIL F
SEE DETAIL E
SEE DETAIL C
SEE DETAIL D
SEE DETAIL B
SEE DETAIL A
SEE DETAILS G & L
DETAILS G, H & J


SEE DETAIL P
SEE DETAILS G, H & J

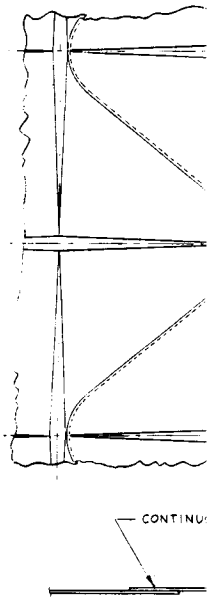




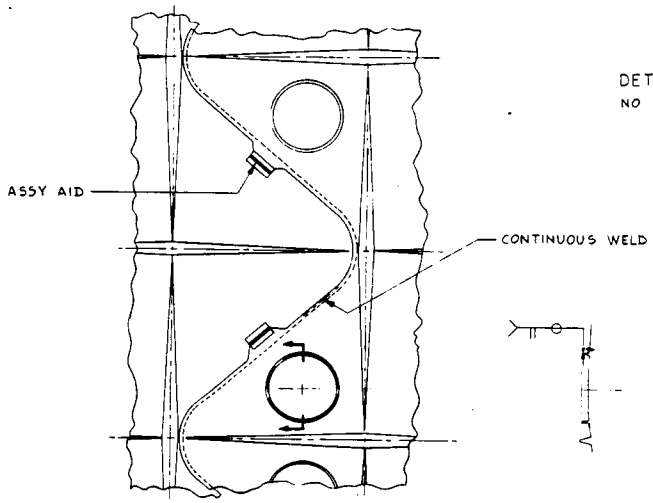
DETAIL 1
SCALE 5/1



DETAIL 6
NO SCALE

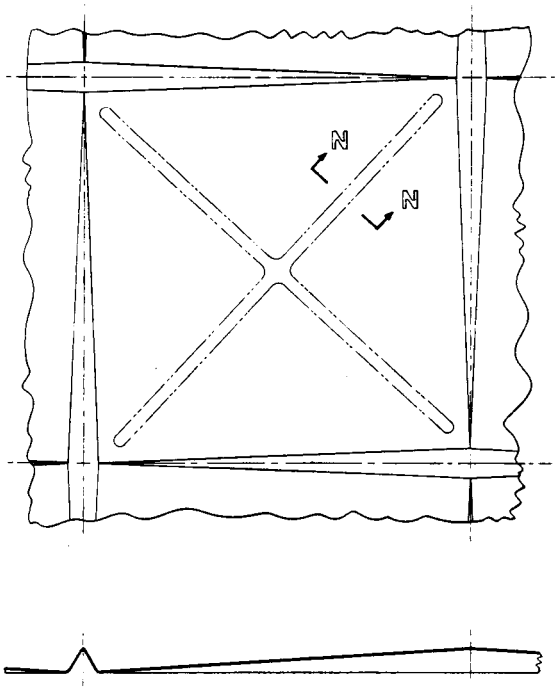


DETAIL 10
NO SCALE



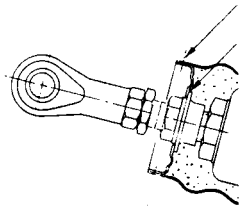
DETAIL 15
NO SCALE

S WELD



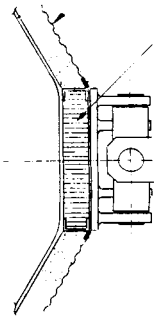
DETAIL G
SCALE 2/3

SECTION N - N

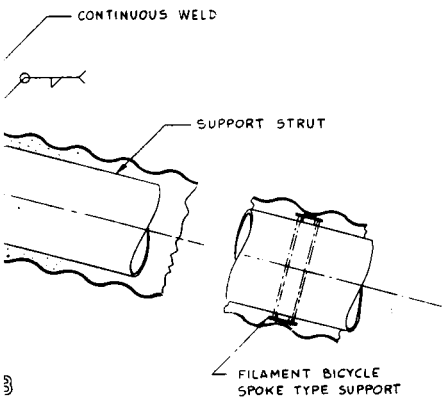


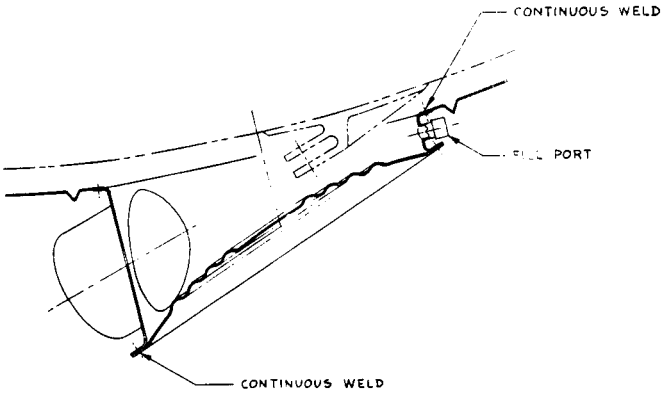
DETAIL I
SCALE 1/1

CON



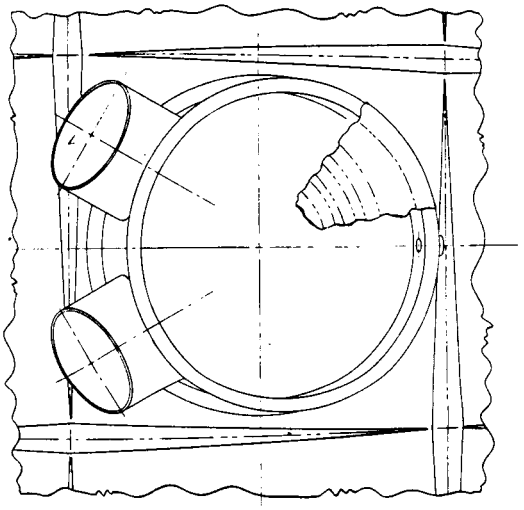
DETAIL P
NO SCALE
SIMILAR CONCEPT USEI
ENGINE ACTUATOR ATTA





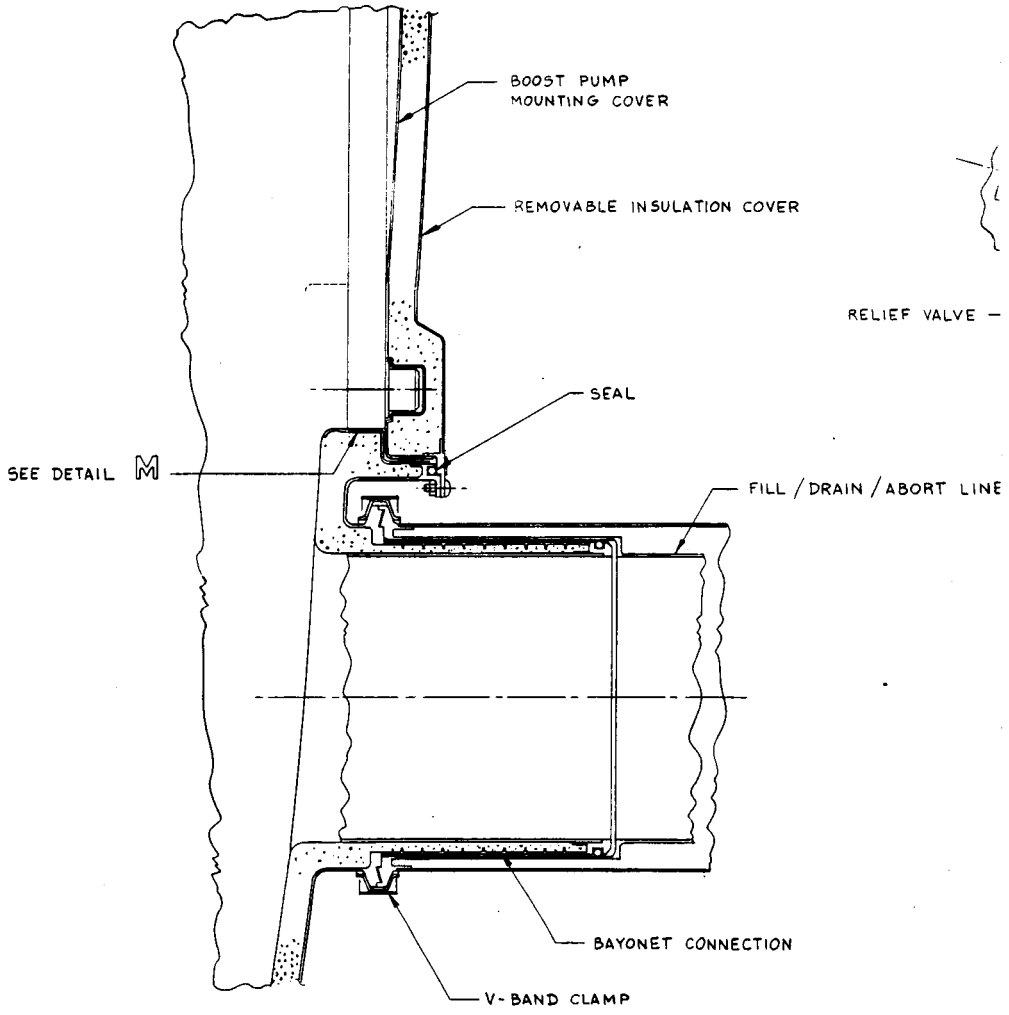
CENTRIC CORRUGATIONS

— PERFORATED FIBERGLASS
HONEYCOMB

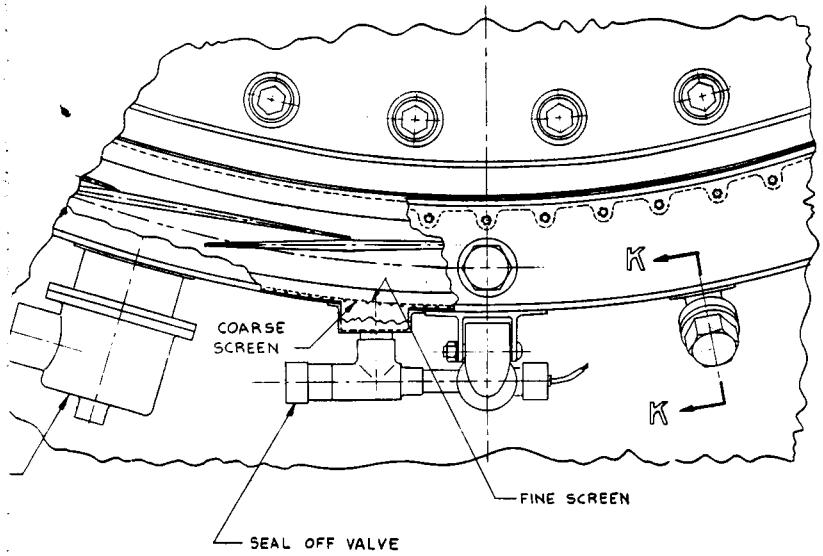


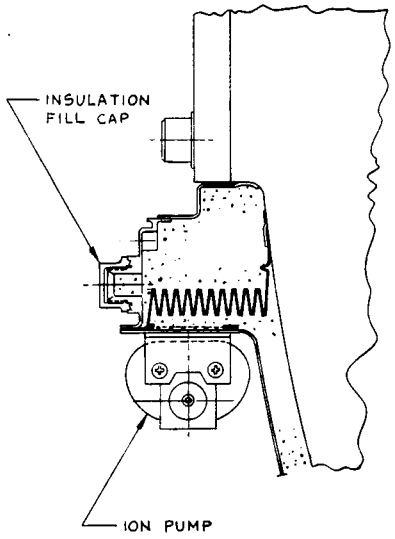
DETAIL A
SCALE 1/1

FOR
CHMENTS

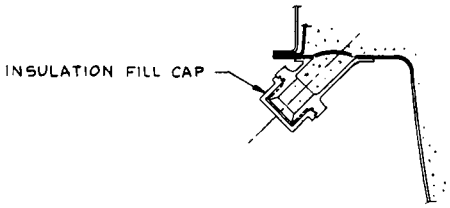


DETAIL L
SCALE 1/1

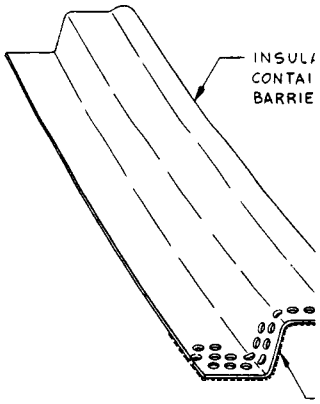




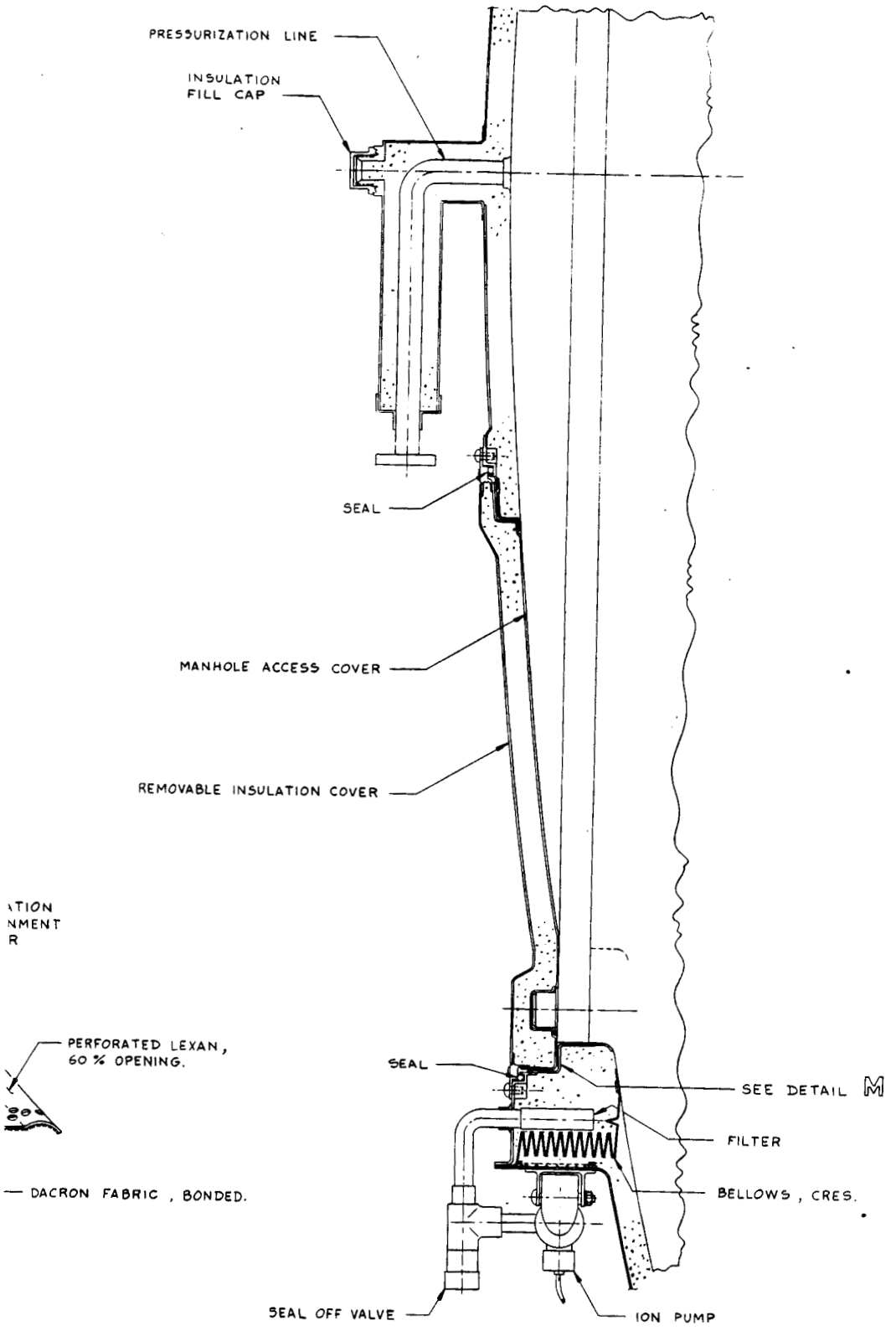
DETAIL J
SCALE 1/1



SECTION K-K
SCALE 1/1



DETAIL M
NO SCALE

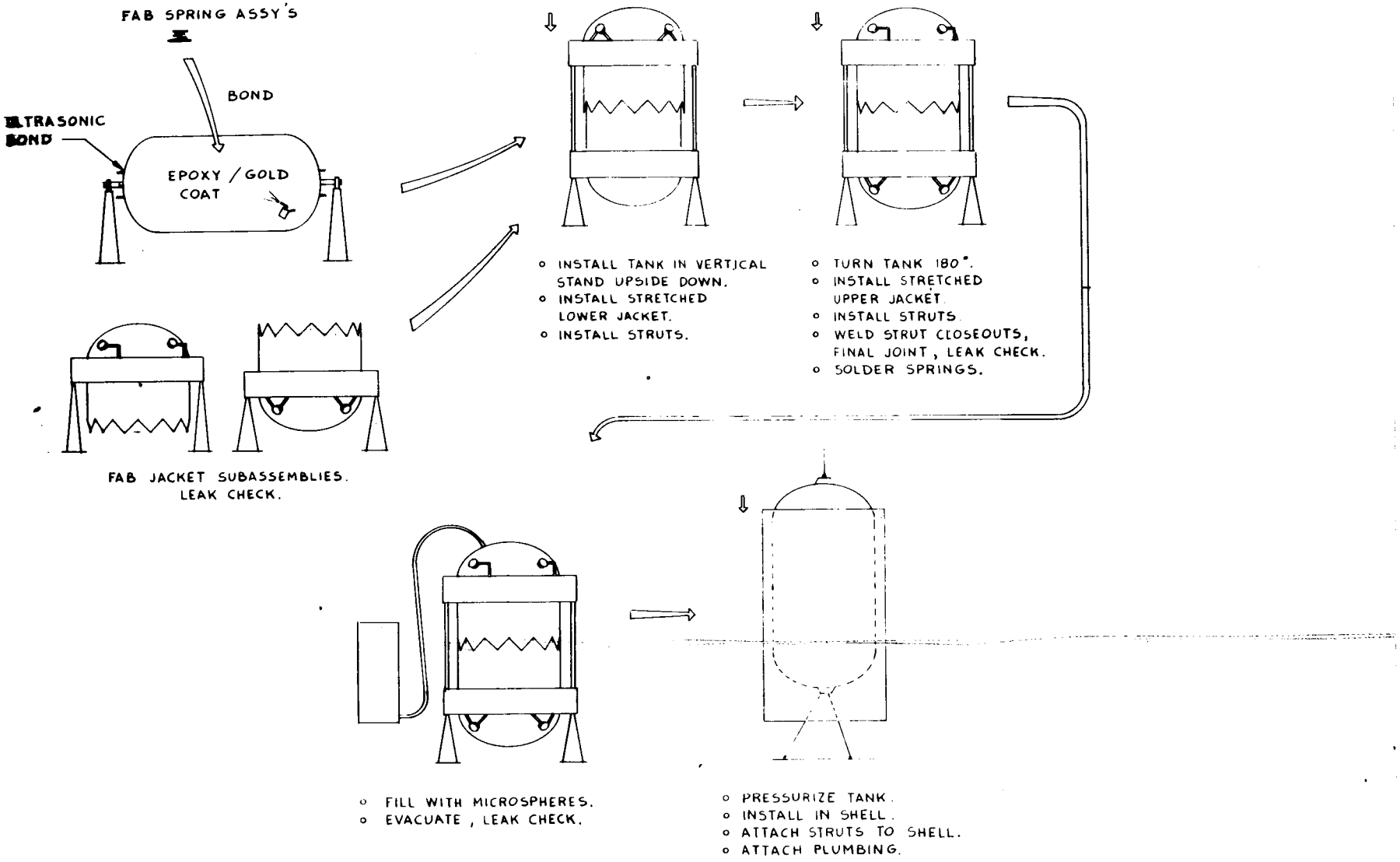


DETAIL H
SCALE 1/1

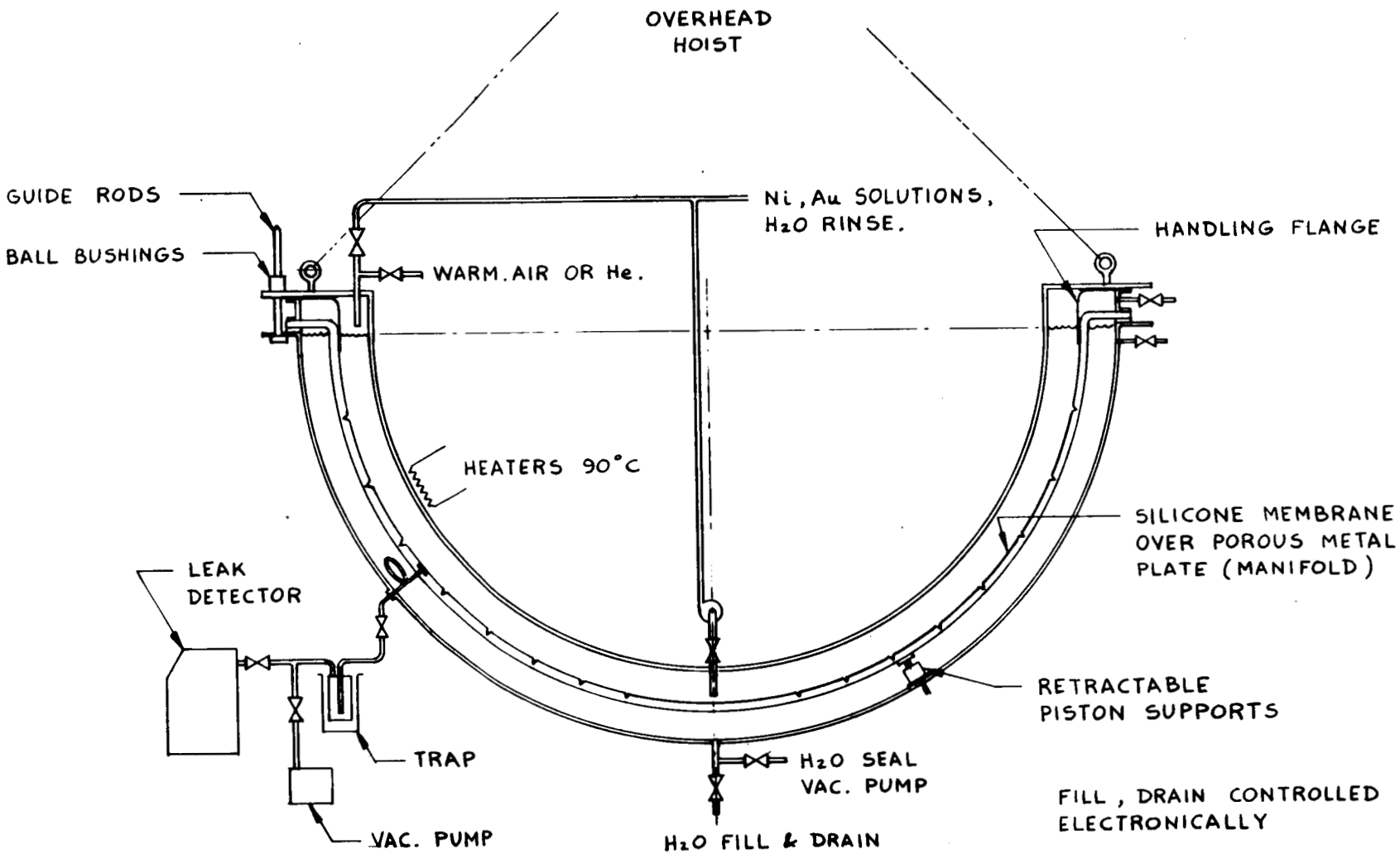
FACILITY AND TOOLING REQUIREMENTS

- FACILITIES AND EQUIPMENT
  - 20,000 FT^2 OF GOOD HOUSEKEEPING AREA
  - SPRAY BOOTH
  - OVERHEAD CRANES
  - HYDROPRESS
  - STRETCH PRESS
  - RESISTANCE SEAM WELDER
  - LEAK DETECTORS
  - VACUUM OVEN
- FORMING DIES (15 EA.)
- JACKET WELDING AND LEAK CHECKING FIXTURES (4 EA.)
- TANK ROTATION FIXTURE (2 EA.)
- JACKET STORAGE FIXTURES
  - SMALL PARTS (200 EA.)
  - SUBASSEMBLIES (12 EA.)
- MICROSPHERE PROCESSING EQUIPMENT (6 EA.)

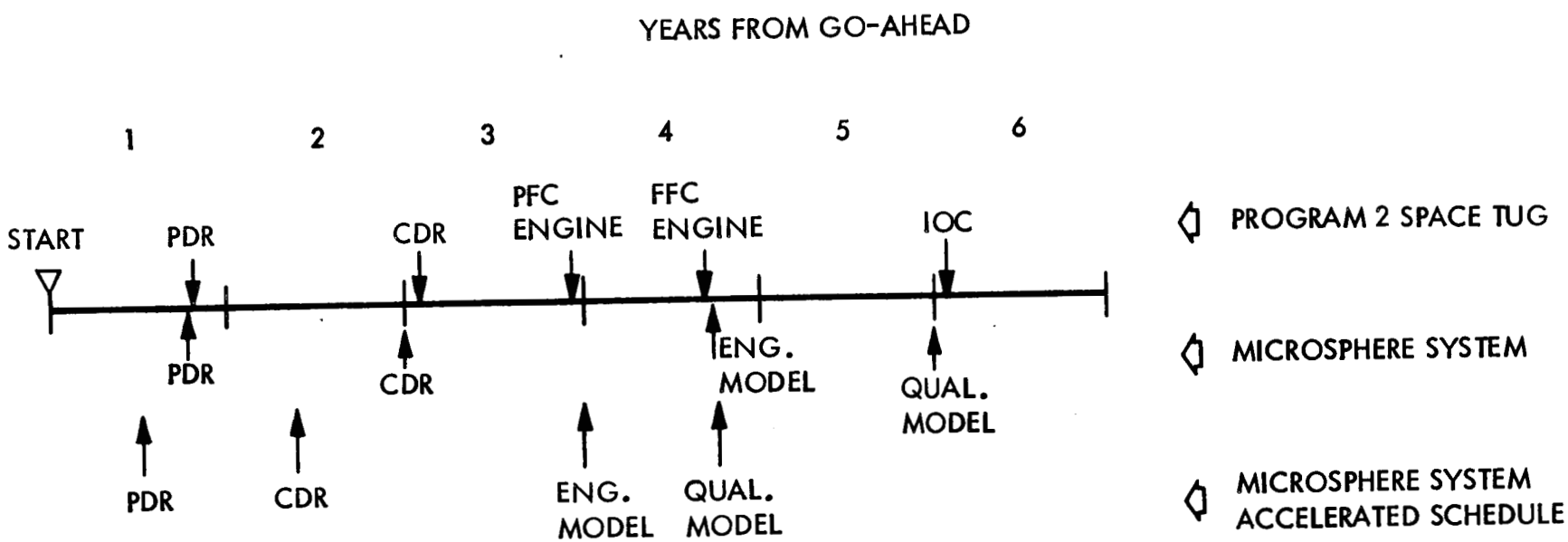
ASSEMBLY SEQUENCE (LH_2 TANK)



ALTERNATE JACKET FABRICATION METHOD



MAJOR MILESTONE COMPARISON



COST COMPARISON
(MILLIONS OF 1973 DOLLARS)

COSTS	He PURGED MULTILAYER SYSTEM			MICROSPHERE SYSTEM
	INSULATION	CONTROLS	ORBITER[a] PURGE SYSTEM	
NONRECURRING COSTS				
DDT&E	9.2	1.3	2.6	8.1
GROUND HARDWARE	0.5	—	0.8	0.4
	9.7	1.3	3.4	8.5
RECURRING COSTS				
PRODUCTION, 17 TUGS	6.3	1.6	4.3	5.3
INITIAL SPARES	0	0.2	0.6	0.1
OPERATIONS, 243 FLIGHTS	1.4	1.3	1.9	0.2
	7.7	3.1	6.8	5.6
	17.4	4.4	10.4	14.1

(a) ALSO USED TO PURGE TANKS

PRORATED BURNOUT WEIGHT COMPARISON (KG)

	GOAL	MICROSPHERE SYSTEM	He PURGED SYSTEM
INSULATION SYSTEM	57.6	297.2	57.6
TUG PURGE SYSTEM	92.1	–	488.6
SHUTTLE CARGO BAY RELATED WEIGHTS	5.8	–	5.8
BOILOFF (163 HOURS)	36.7	132.6	36.7
TOTAL	⩽192.2	429.8	588.7
% CHANGE	REF	+124	+206

THERMAL PERFORMANCE COMPARISON

ITEM	GROUND HOLD BOILOFF RATE (KG/HR)		INTEGRATED MISSION BOILOFF (163 HOURS) (KG)	
	LO_2	LH_2	LO_2	LH_2
GOAL	123	219	29	65
MICROSPHERE INSULATION SYSTEM	20	30	46	294

SYN-EQ PAYLOAD PERFORMANCE COMPARISON

EVENT	PAYLOAD PERFORMANCE				
	CHANGE (%)				
	GOAL KG	MICROSPHERE SYSTEM		He-PURGED MULTILAYER SYSTEM	
		BASED ON TEST DATA	$k_{SC} \rightarrow 0$ IMPROVED Au	WITH PURGE FAIRING	W/O PURGE FAIRING
DEPLOYMENT	≥ 3597	- 11.6	- 3.2	-28.7	-11.6
RETRIEVAL	≥ 2260	- 11.4	- 3.1	-28.1	-11.4
ROUND TRIP	≥ 1370	- 11.8	- 3.3	-28.9	-11.7

MAJOR CONCLUSIONS

JACKET

- LEAK TIGHT, $<10^{-4}$ TORR
- WELDED JOINTS ARE RELIABLE; SOLDER JOINTS ARE NOT
- FLEXS ELASTICALLY
- GOOD INSULATION THICKNESS CONTROL
- ENGINEERING DATA FOR SCALING TO OTHER TANK SIZES, SHAPES
- LIGHT-WEIGHT SYSTEM

INSULATION

- REPEATABLE THERMAL PERFORMANCE, 7 FLIGHT CYCLES
  - GROUND HOLD, $\Delta = 0\%$
  - SPACE, $\Delta = +7\%$
- EXCELLENT THERMAL PERFORMANCE UNDER LOAD
- NO SPHERE BREAKAGE AFTER 13 FLIGHT CYCLES (100 IN FLAT PLATE)
- VACUUM REQUIREMENT
  - GROUND HOLD, $\leq 10^{-2}$ TORR
  - SPACE, $\leq 10^{-4}$ TORR

RECOMMENDATIONS

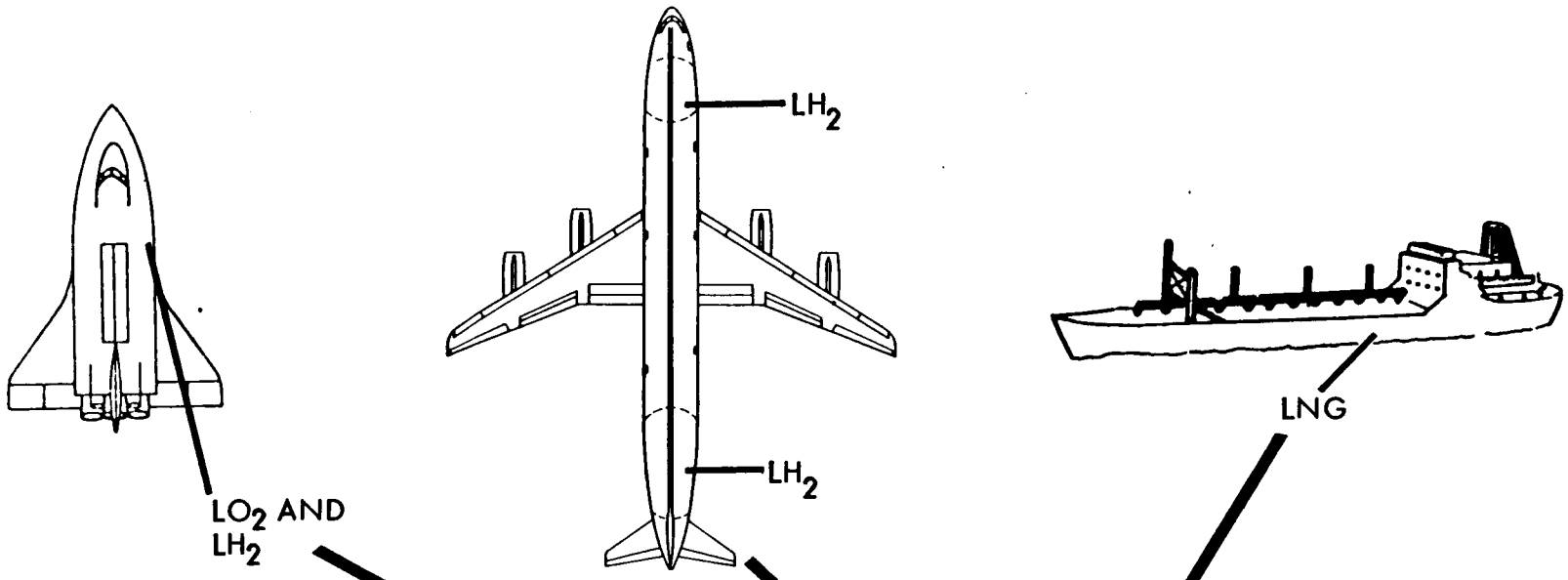
- REDUCE RADIATION HEAT TRANSFER FOR SPACE APPLICATIONS
- INVESTIGATE LOWER COST JACKET FABRICATION METHODS
- DEVELOP CONICAL SPRING SUPPORT
- DEVELOP FINAL CLOSURE WELDING METHOD
- DEVELOP CONVOLUTED DIAPHRAGM STRUT COVERS

OTHER APPLICATIONS

SINGLE-STAGE-TO-ORBIT SHUTTLE

SUBSONIC AND HYPERSONIC COMMERCIAL AIRCRAFT

LNG TRANSPORT



LIFE	100 FLIGHTS	20 YEARS	30 YEARS
CRYOGEN MASS 10^6 KG	LO_2 1.2 LH_2 0.2	LH_2 0.03	LNG 30