

Actively Cooled Structures For The High Heat Flux Application

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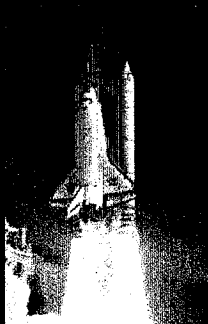
Presented at UCLA APEX Study Meeting Oct. 15-17, 1997

Agenda

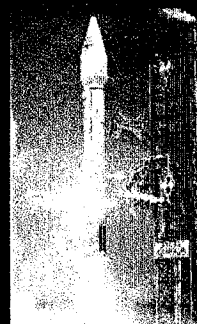
- **Background**
- **High Performance Thermostructure**
- **Actively cooled structures - Copper Alloys**
 - **SSME Main Combustion Chamber**
 - **Lead Edge Panel**
 - **Glidcop Heat Exchangers**
- **Ceramic Composite Heat Exchangers**
 - **Carbon-Carbon Heat Pipe**
 - **Brazing of Carbon-Carbon Composites**
 - **C/SiC Actively Cooled Panel**
- **Transpiration Cooled Main Injector Plate**

Product Overview

Propulsion



Space Shuttle



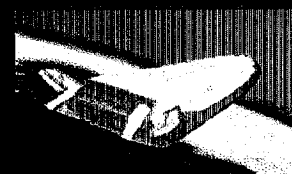
Atlas



Delta



EELV



Reusable
Launch
Vehicle



Kinetic
Energy
Weapons

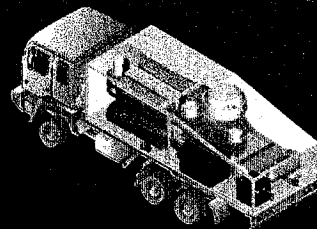
Laser & Electro-Optics



Tactical Laser

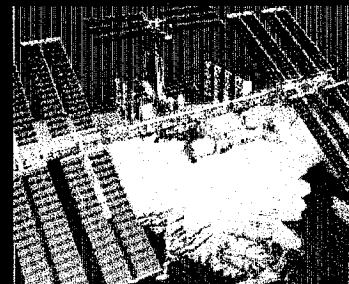


Technical Services

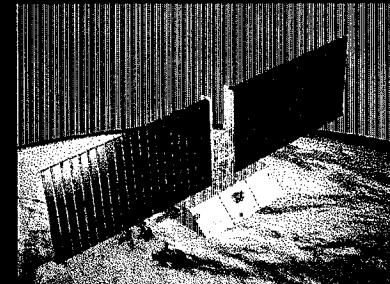


COIL Tactical
Application

Power

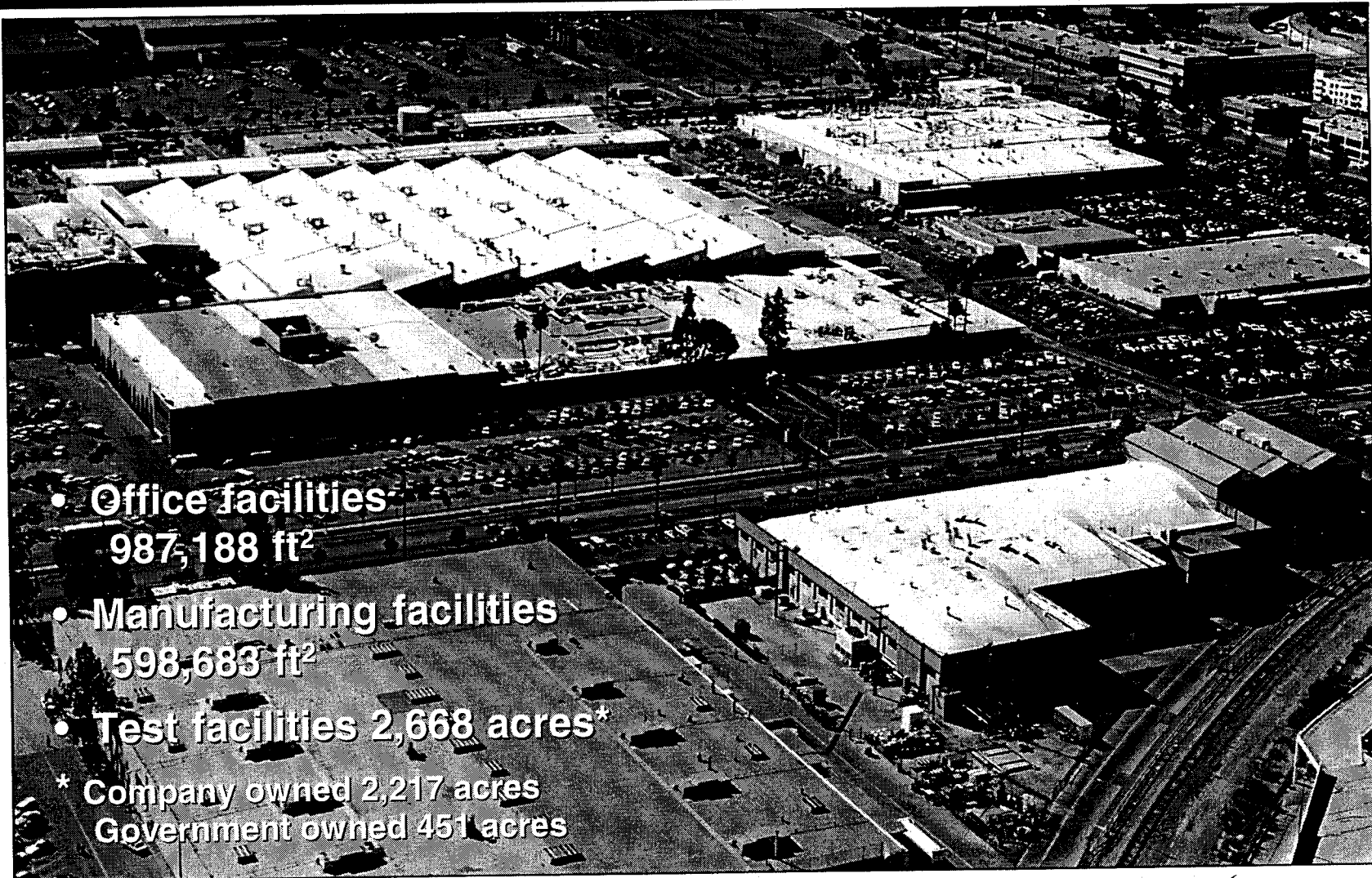


Space Station



Teledesic

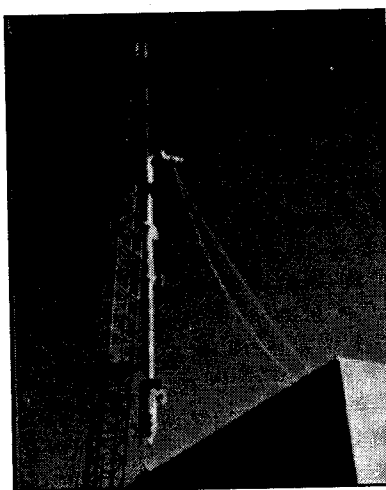
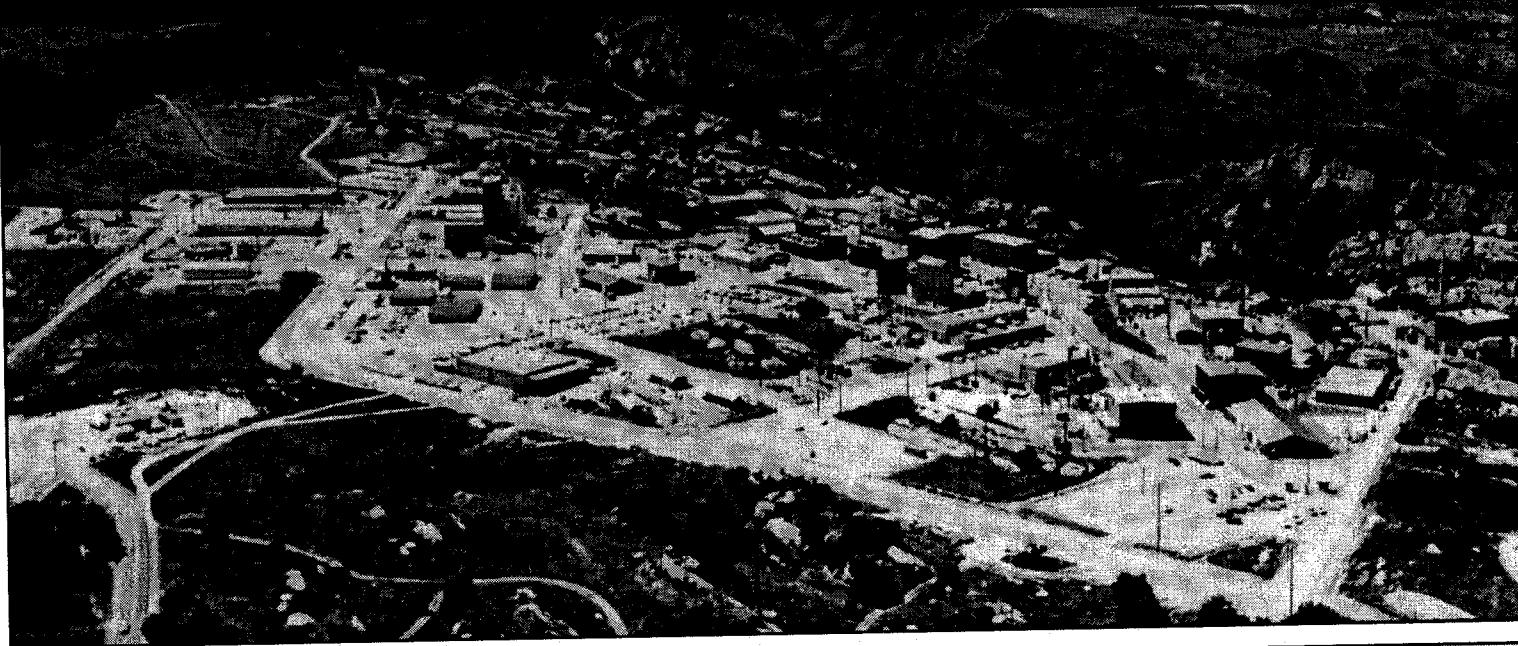
Canoga Facilities



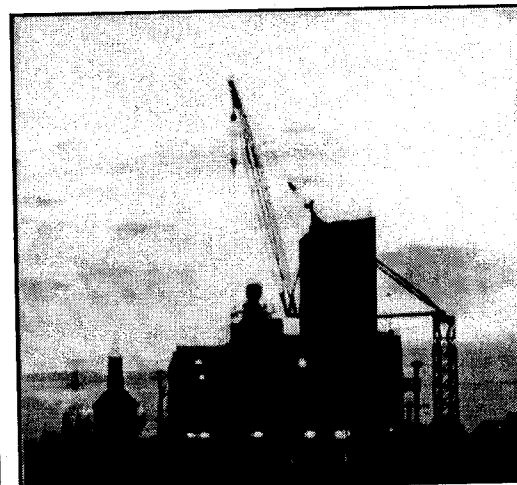
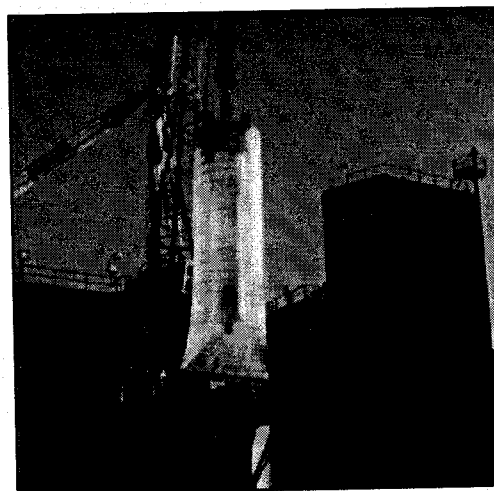
- Office facilities
987,188 ft²
- Manufacturing facilities
598,683 ft²
- Test facilities 2,668 acres*

* Company owned 2,217 acres
Government owned 451 acres

Energy Technology Engineering Center (ETEC)



Steam Generator Testing



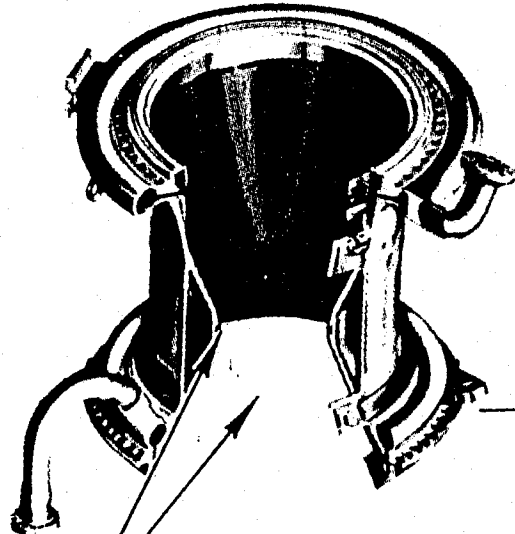
Sodium Pump Test Facility

HIGH PERFORMANCE THERMOSTRUCTURES

- **THERMOSTRUCTURE REQUIREMENTS**
 - MAXIMUM PERFORMANCE
 - MAXIMUM LIFE
 - MINIMUM WEIGHT
- **COMPONENT DESIGNS DEVELOPED FROM TRADE STUDIES**
 - HEAT TRANSFER
 - STRUCTURES
 - MATERIALS
 - MECHANICAL PROPERTIES
 - THERMOPHYSICAL PROPERTIES
 - FABRICABILITY



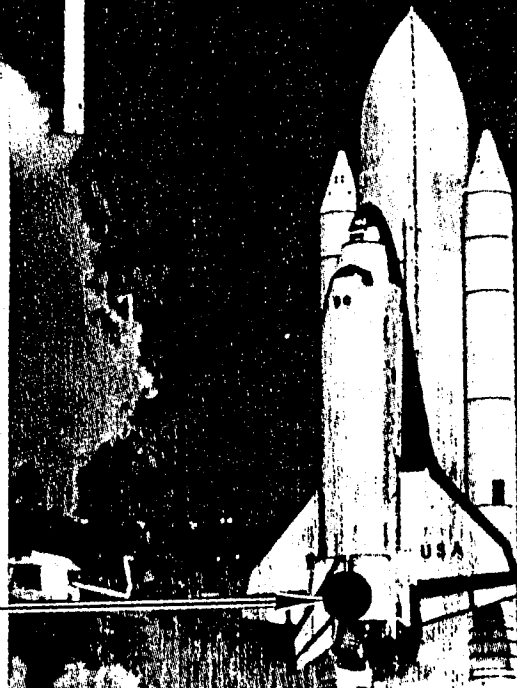
Main Combustion Chamber



$P_s = 21 \text{ MPa (3,000 psi)}$

$T_w = 540^\circ\text{C (1000}^\circ\text{F)}$

Hydrogen Inlet – $-220^\circ\text{C, 41 MPa}$
($-364^\circ\text{F, 6,000 psi}$)

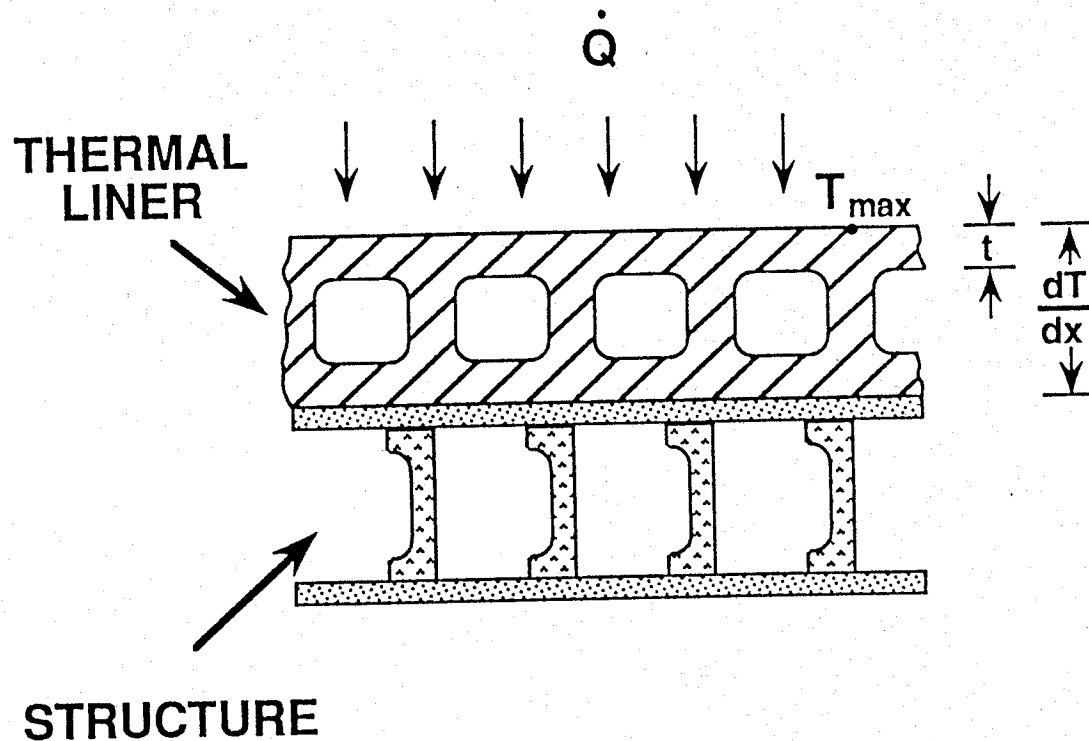


Rockwell International
Propulsion Division

SC91C-31-18
M178

ACTIVELY COOLED STRUCTURES

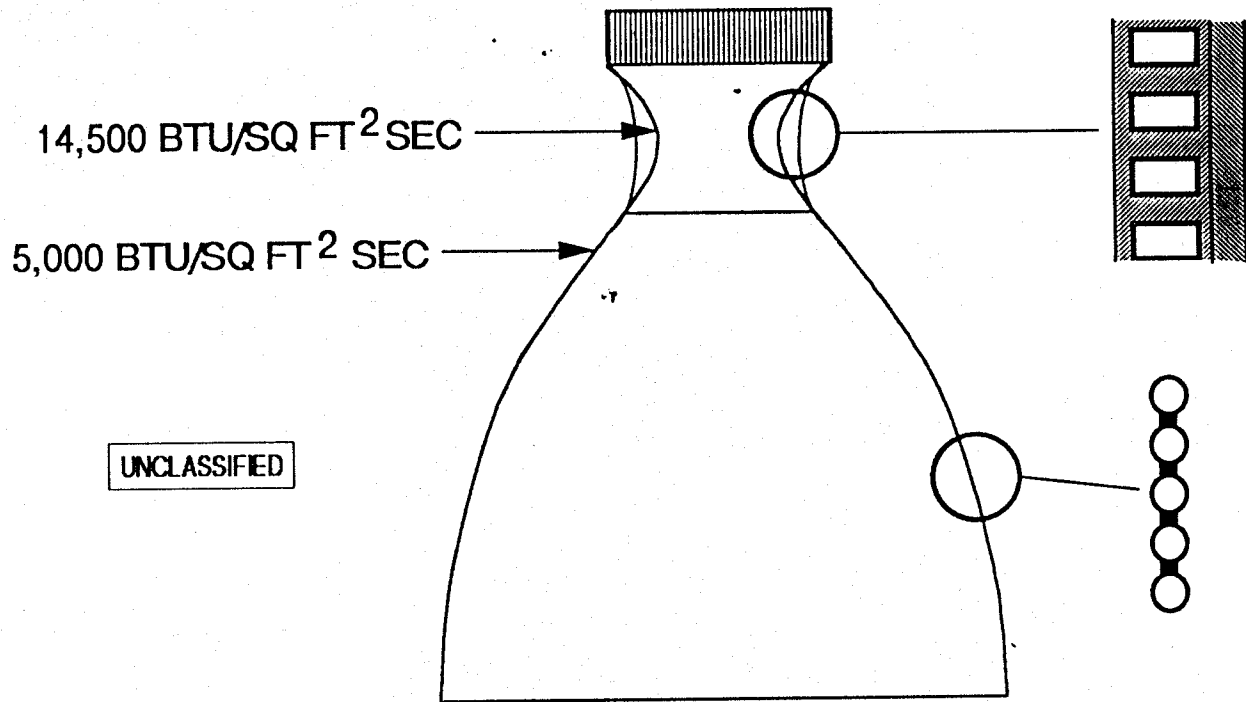
DESIGN CONSIDERATIONS



- **GEOMETRY GOVERNED BY**
 - COOLANT PRESSURE & FLOWRATE
 - THERMAL CONDUCTIVITY
 - WEIGHT
 - FABRICABILITY
- **DURABILITY**
 - START-UP & SHUTDOWN CYCLE
 - FATIGUE FROM THERMAL STRAINS
 - THERMAL EXPANSION
 - MODULUS
 - CREEP OF HOT SIDE FACESHEET
 - THERMAL STABILITY

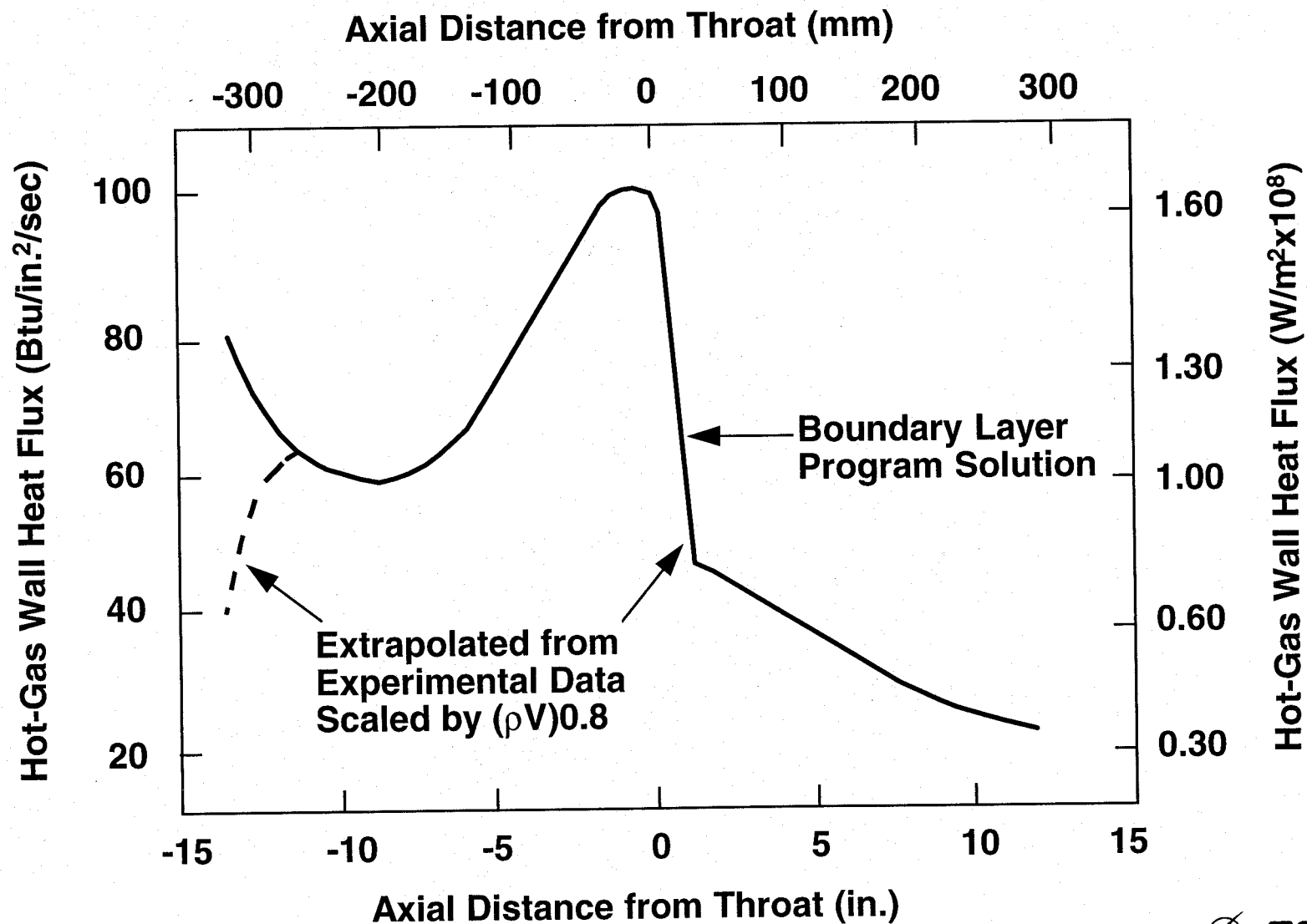


HIGH HEAT FLUX STRUCTURES - SSME MCC AND NOZZLE (U)

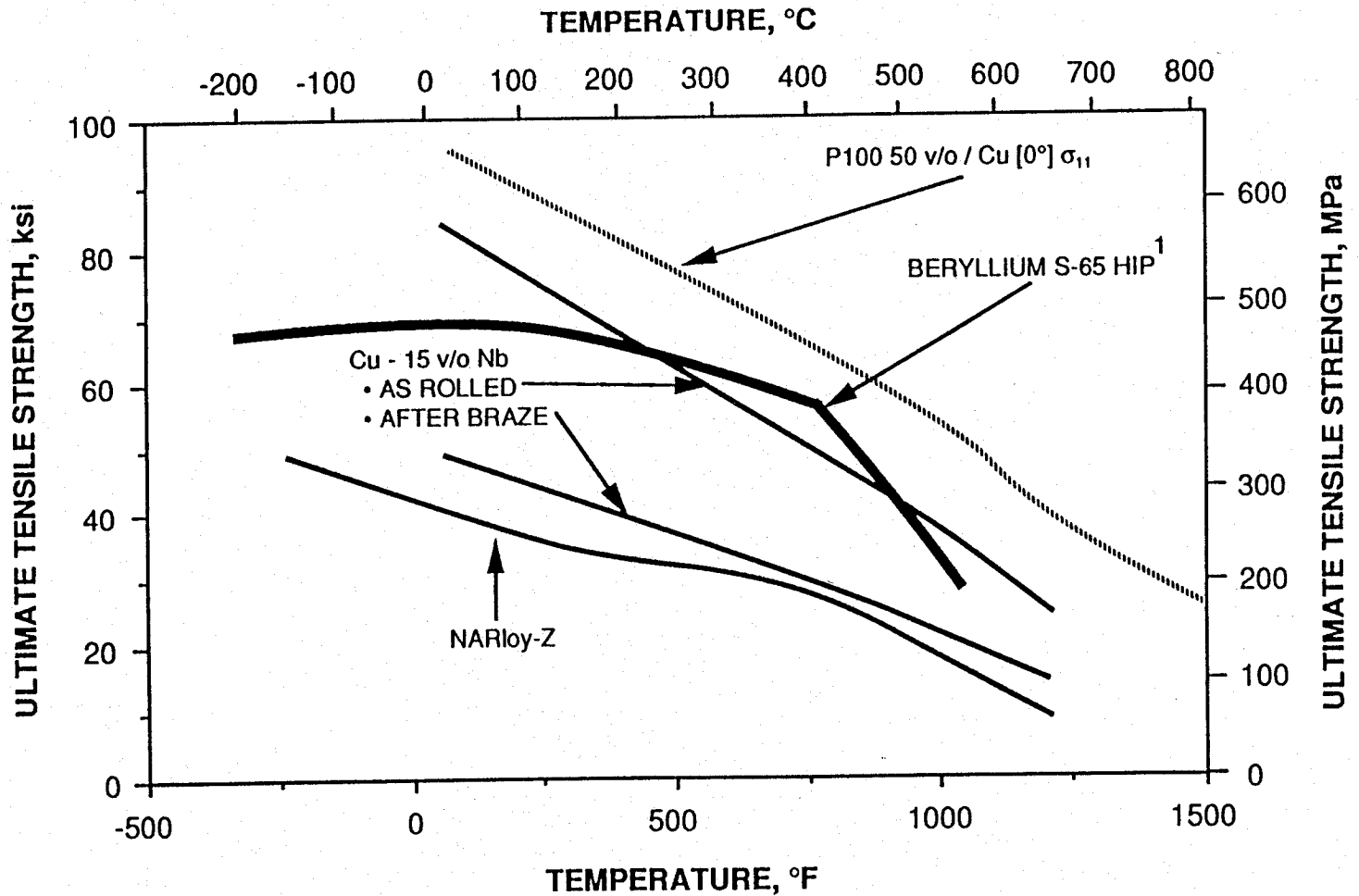


STRUCTURAL DESIGN, FABRICATION AND MATERIALS
FOR LONG LIFE HIGH HEAT FLUX HARDWARE

Hot-Gas Wall Heat Flux for a High-Pressure Thrust Chamber



STRENGTH OF HIGH CONDUCTIVITY MATERIALS

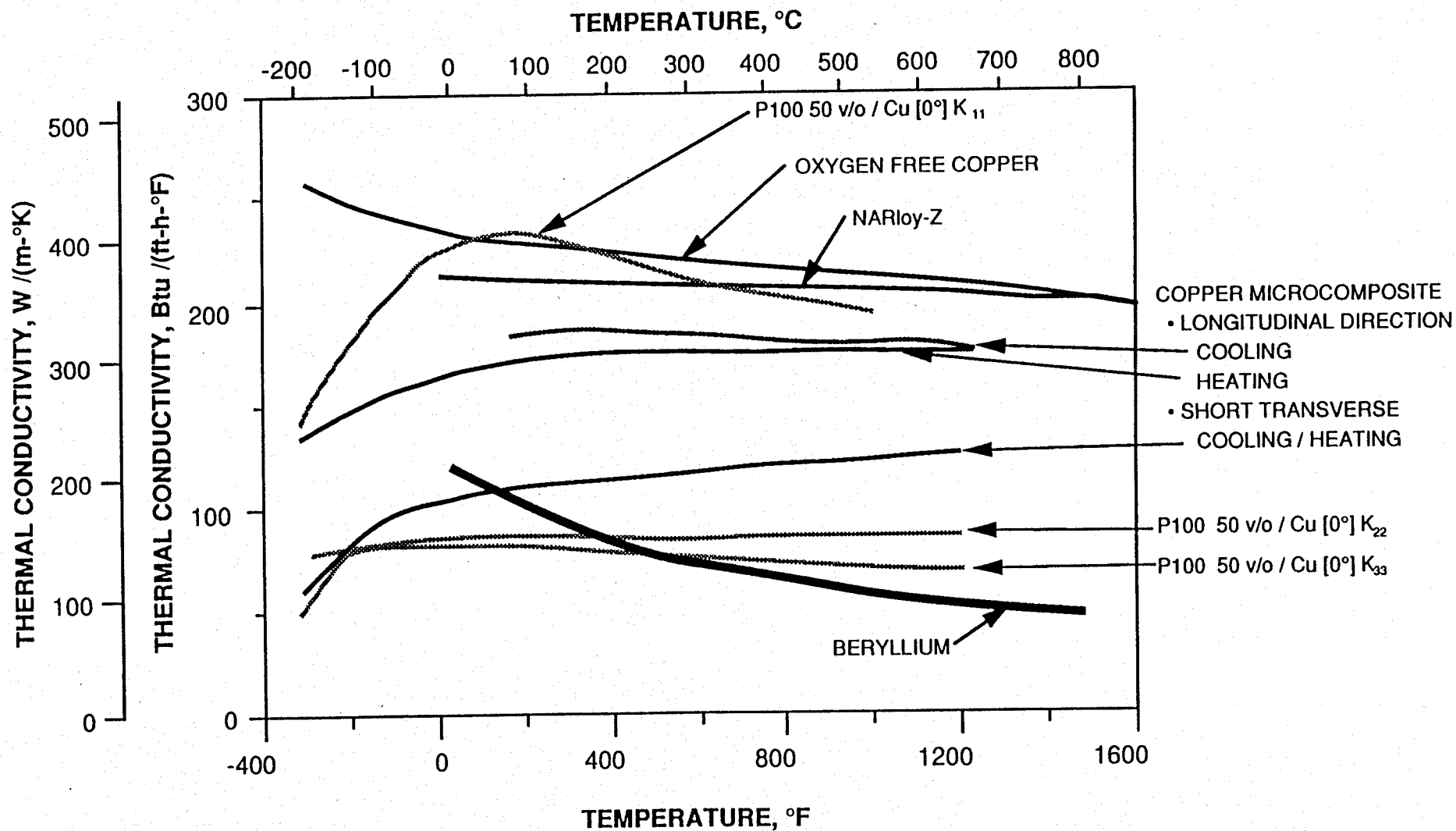


¹ BERYLLIUM DATA FOR BOTH
2000 PSIG HYDROGEN
2000 PSIG HELIUM

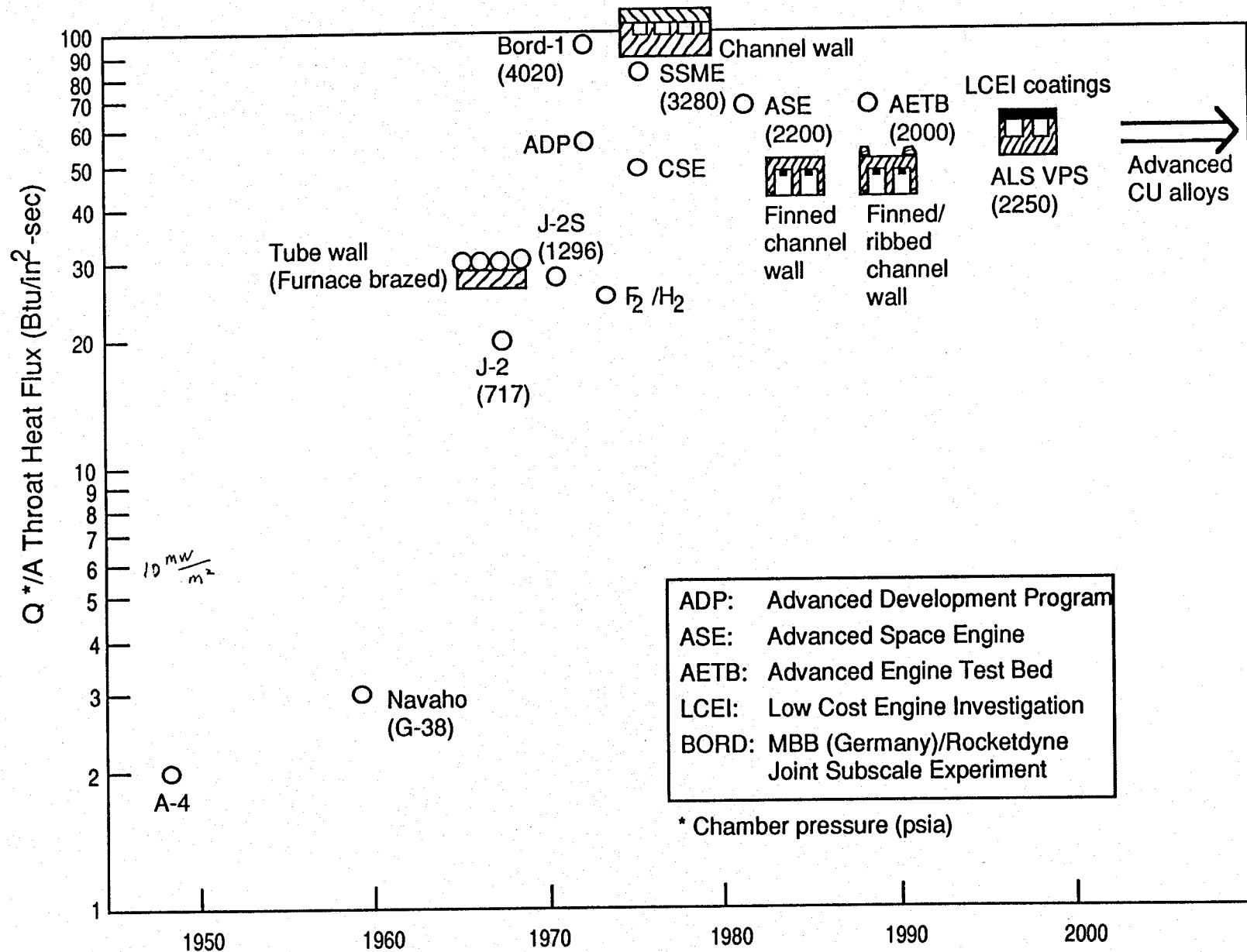


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Rocketdyne Division

THERMAL CONDUCTIVITY OF HIGH CONDUCTIVITY MATERIALS



ARRAY OF THRUST CHAMBER COOLING TECHNIQUES DEMONSTRATED



Rocket Engine Materials and Structures Thrust Chambers

Engine	Heat Flux Btu/(in ² sec)	Material	Structure	Max.Temp F	Life cycles
SSME	90	NARloy-Z	Channels	1000	55
J-2	18	Type 347 SS	Tubewall	1000	<5
F-1	8	Inconel X	Tubewall	750	<5
Atlas (Substainer)	3	Type 347 SS	Tubewall	700	<5
Delta (Booster)	2.5	Ni-200	Tubewall	650	<5

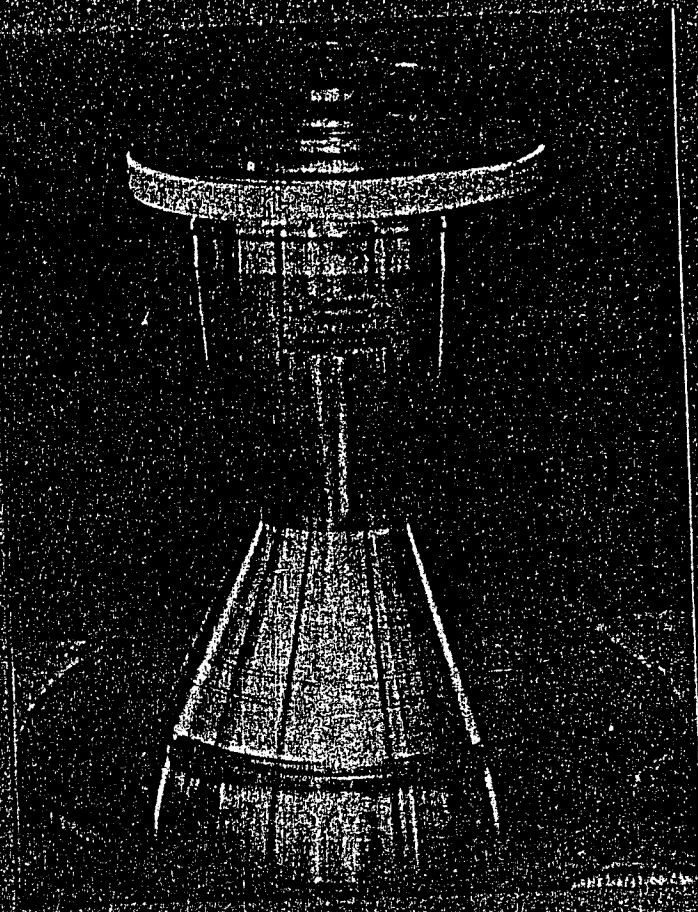
Nozzles

Engine	Heat Flux Btu/(in ² sec)	Material	Structure	Max.Temp F	Life cycles
SSME	2-20	A286	Tubewall	800	55
J-2	1-6	Type 347 SS	Tubewall	500	<5
F-1	1-3	Inconel X	Tubewall	500	<5
Atlas (Substainer)	0.5-2	Type 347 SS	Tubewall	450	<5
Delta (Booster)	0.3-1.5	Ni-200	Tubewall	400	<5

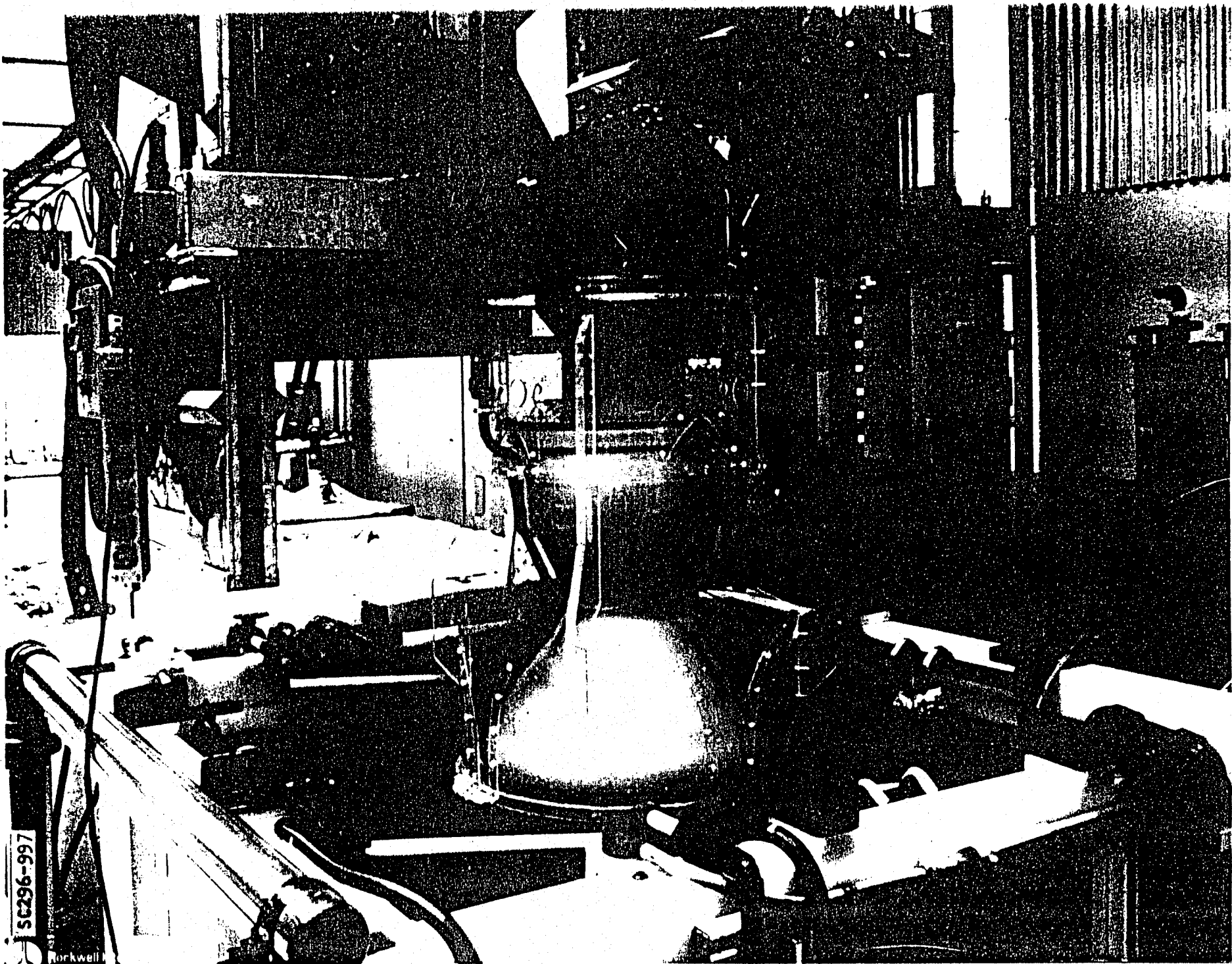
Copper Alloy Fabrication & Bonding Approaches

- Fabrication process development
 - Forming
 - Machining
 - Gun drilling
 - Roll bonding
 - Electrodeposition
 - Plasma spraying
- Bonding
 - Diffusion bonding
 - Inertia welding
 - Ultrasonic welding
 - Laser welding
 - Hot isostatic pressure
 - CAVD for braze alloy
 - Al₂O₃ particulate reinforcement of braze joint
 - Science center approach for surface cleaning/surface activation bonding

FIRST MAIN COMBUSTION CHAMBER



SC439-405

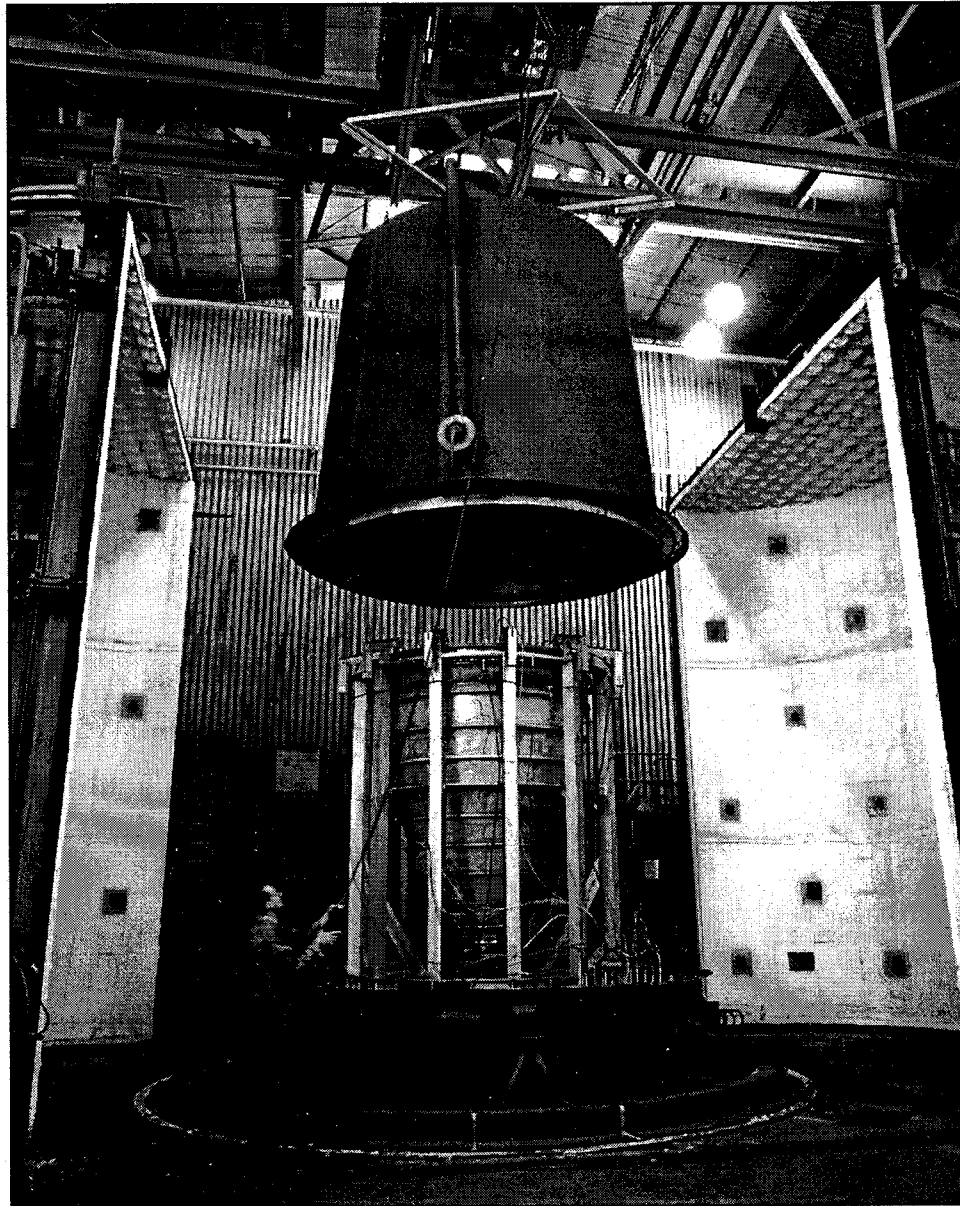


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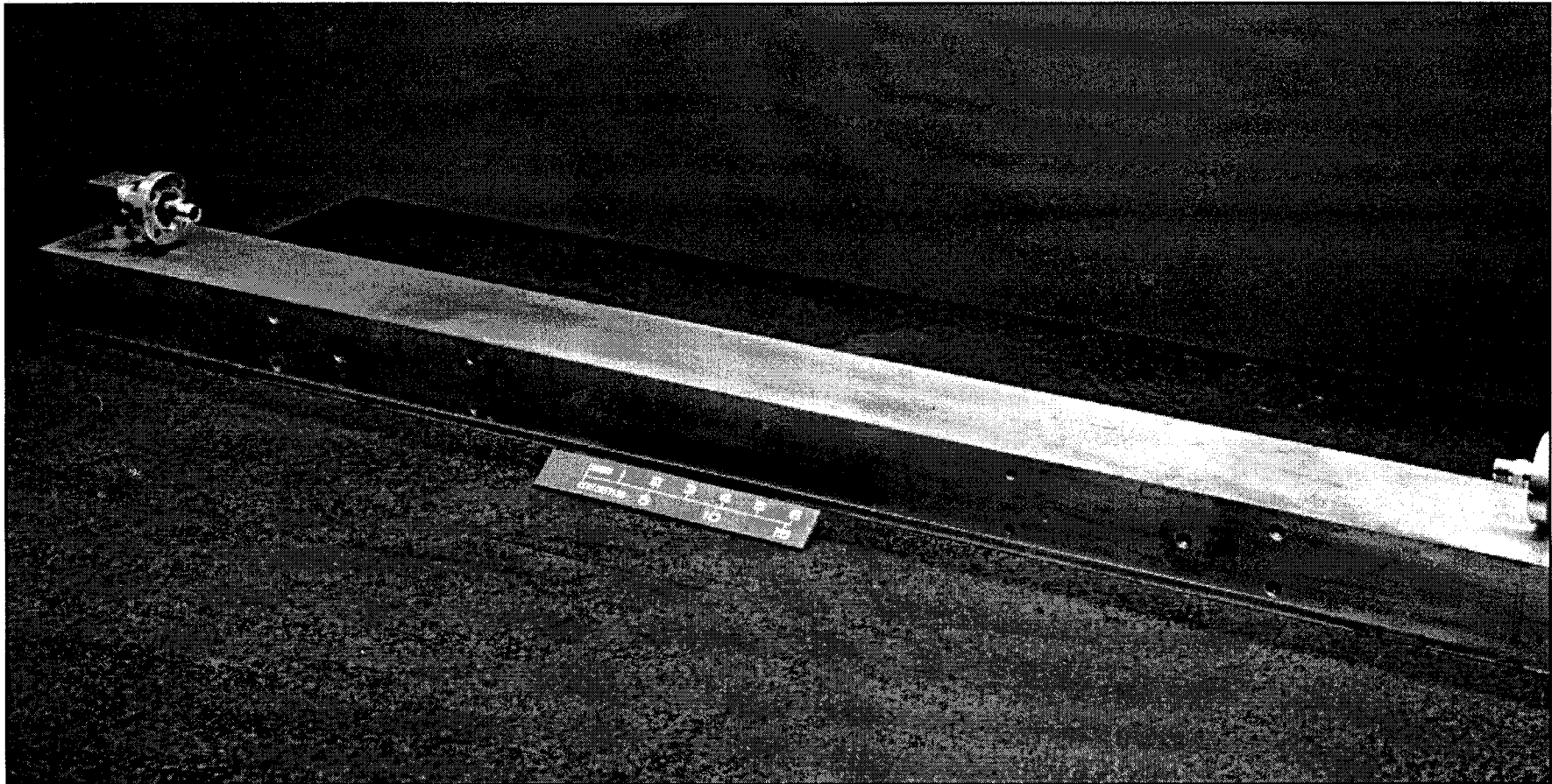
SSME Nozzle Braze Clam Shell Furnance

Pacific Scientific Furnance



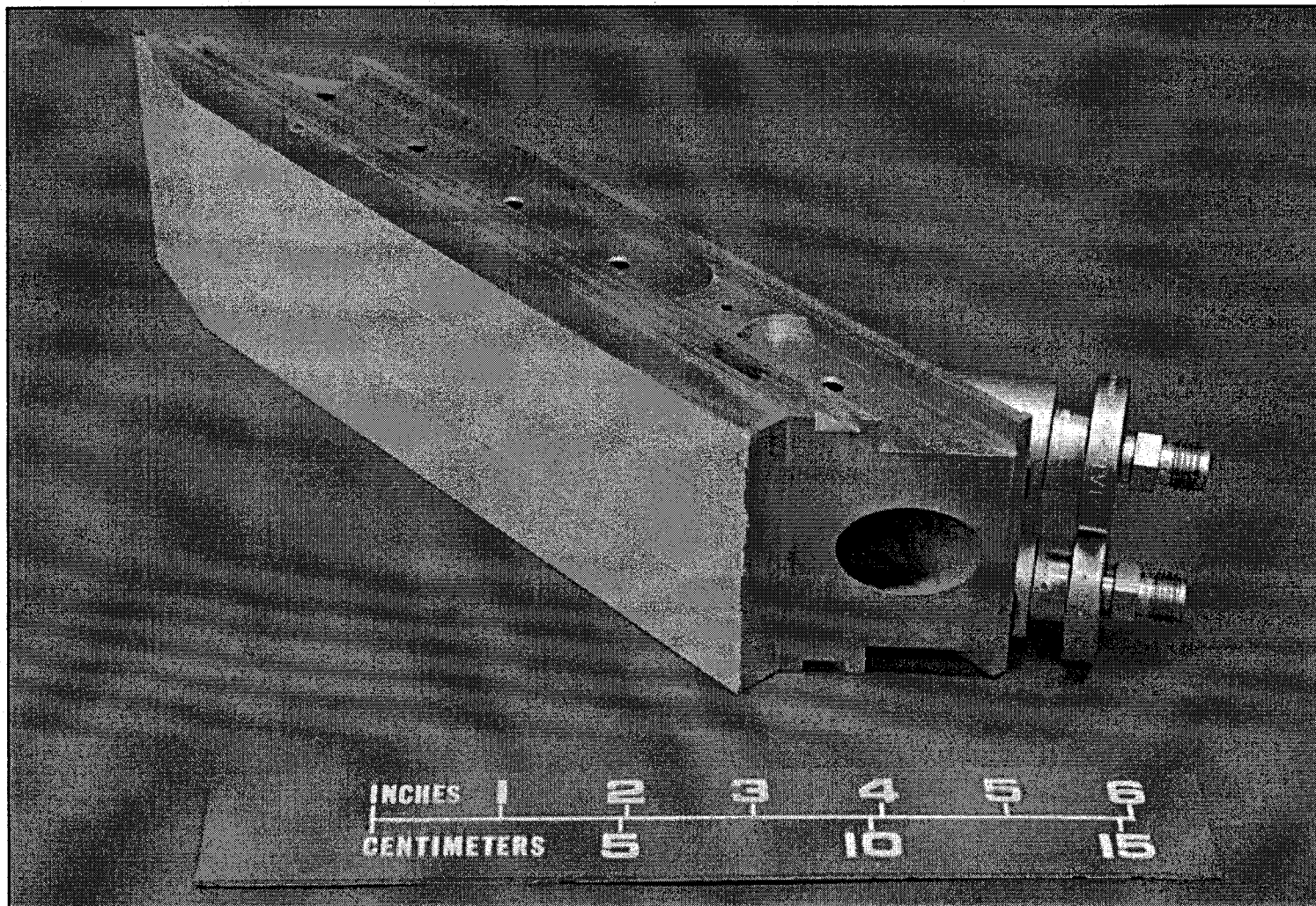
Brazed Glidcop Laser Mirror

Mirror Surface Against Measuring Table



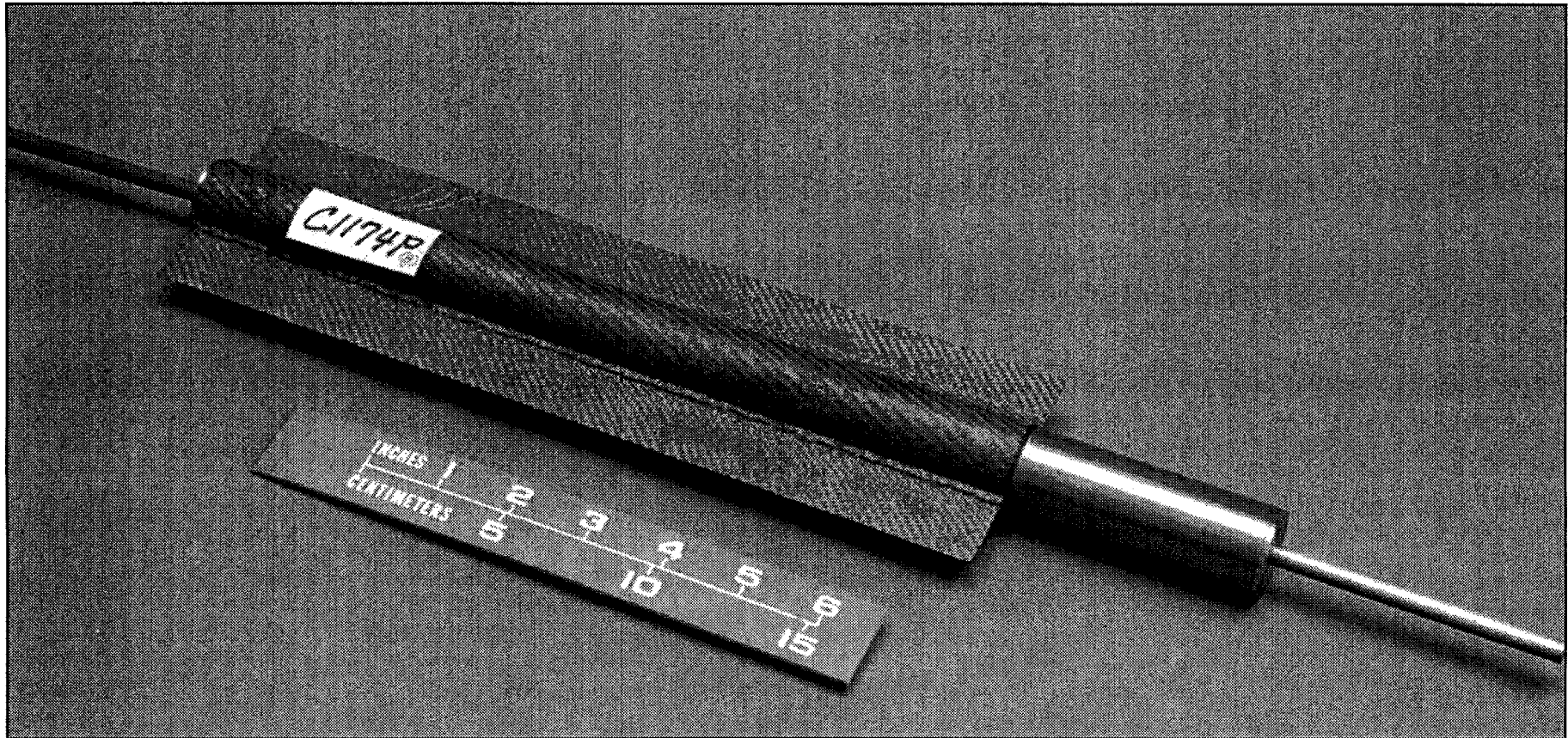
Brazed Glidcop Laser Mirror

Mirror Surface Taped for Protection



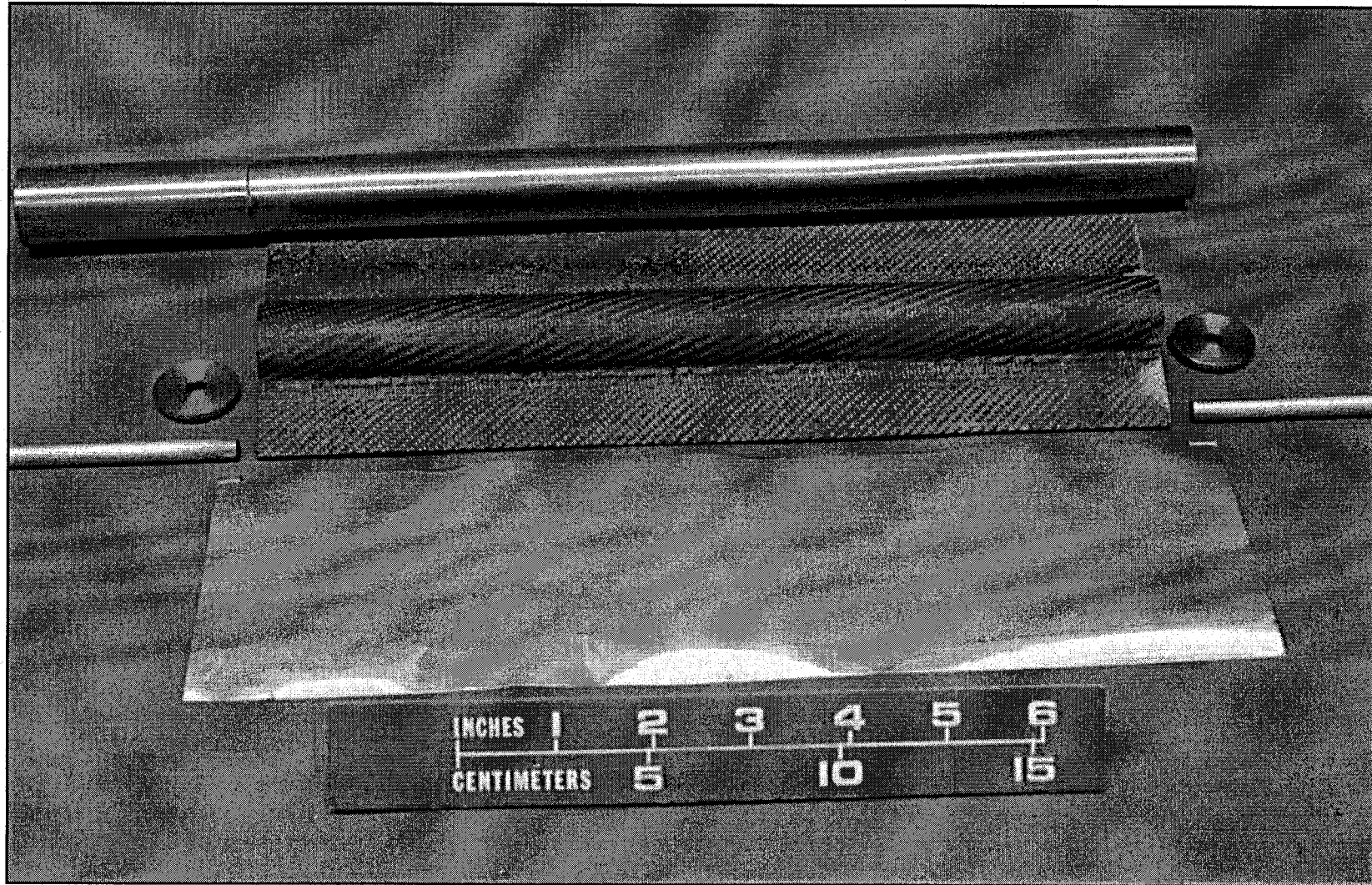
Carbon-Carbon Heat Pipe

0.040-in.-Thick Radiator Tube Brazed to Nb-1%Zr Tube

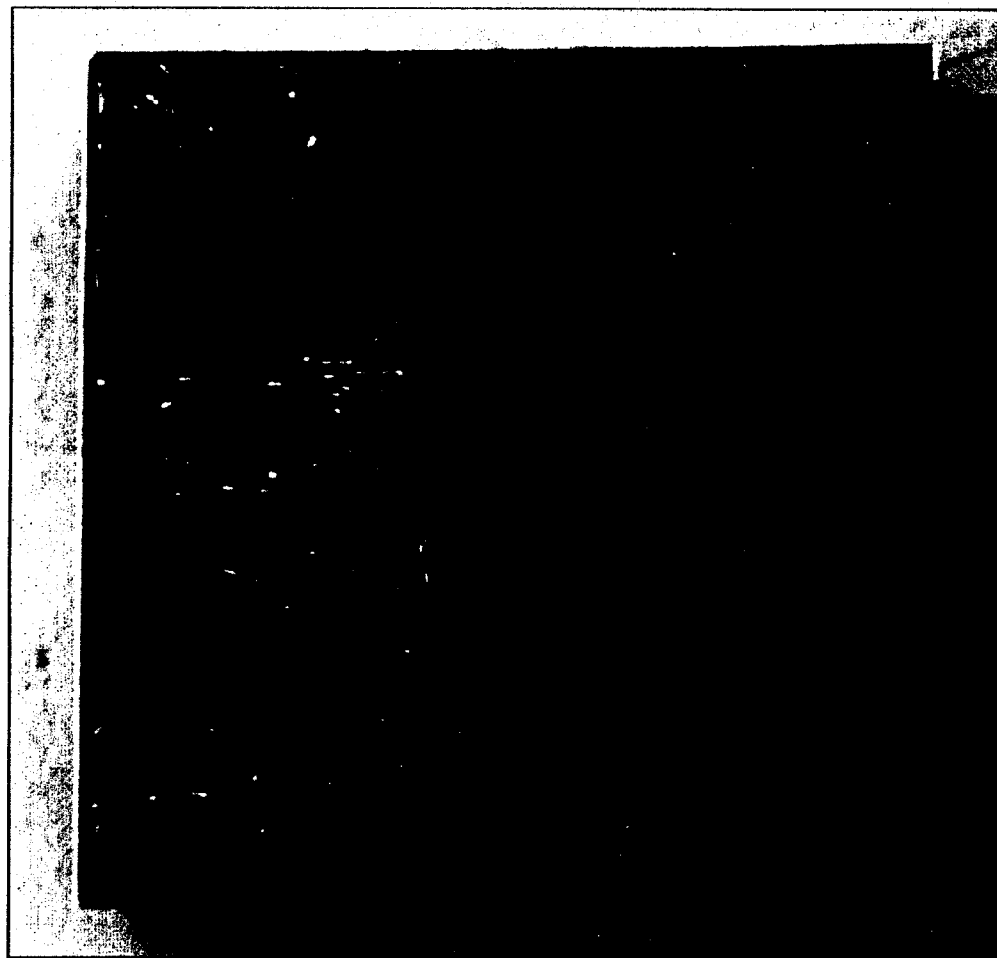


Carbon-Carbon Composite to Niobium (Nb-1%Zr) Heat Pipe

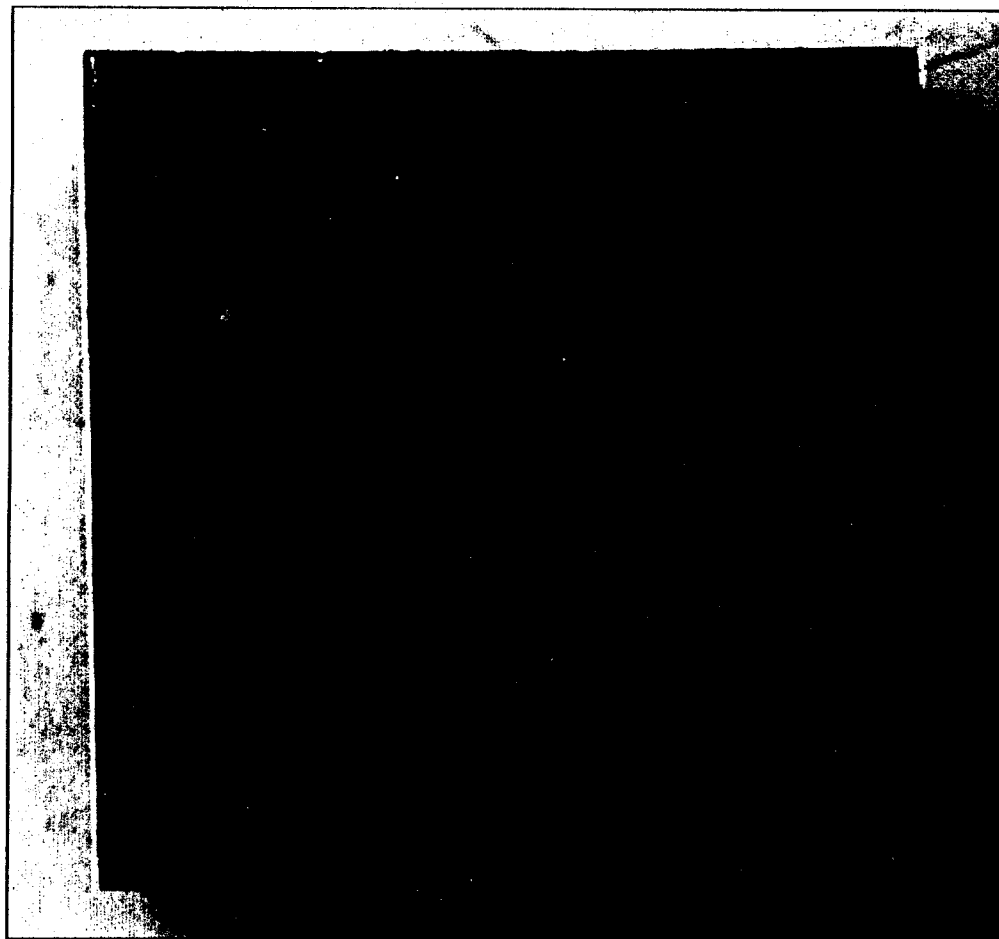
Brazed with CUSIL ABA



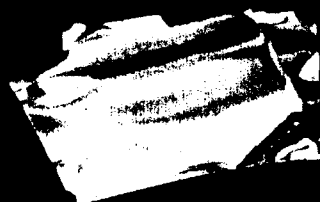
Allied Signal 3-D C-C Composite



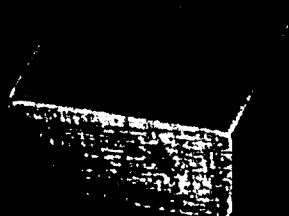
FMI 4-D Fine Weave C-C Composite



Carbon-Carbon Composite/Copper Brazing Coupon Assembly



Braze Foil
Cusil ABA

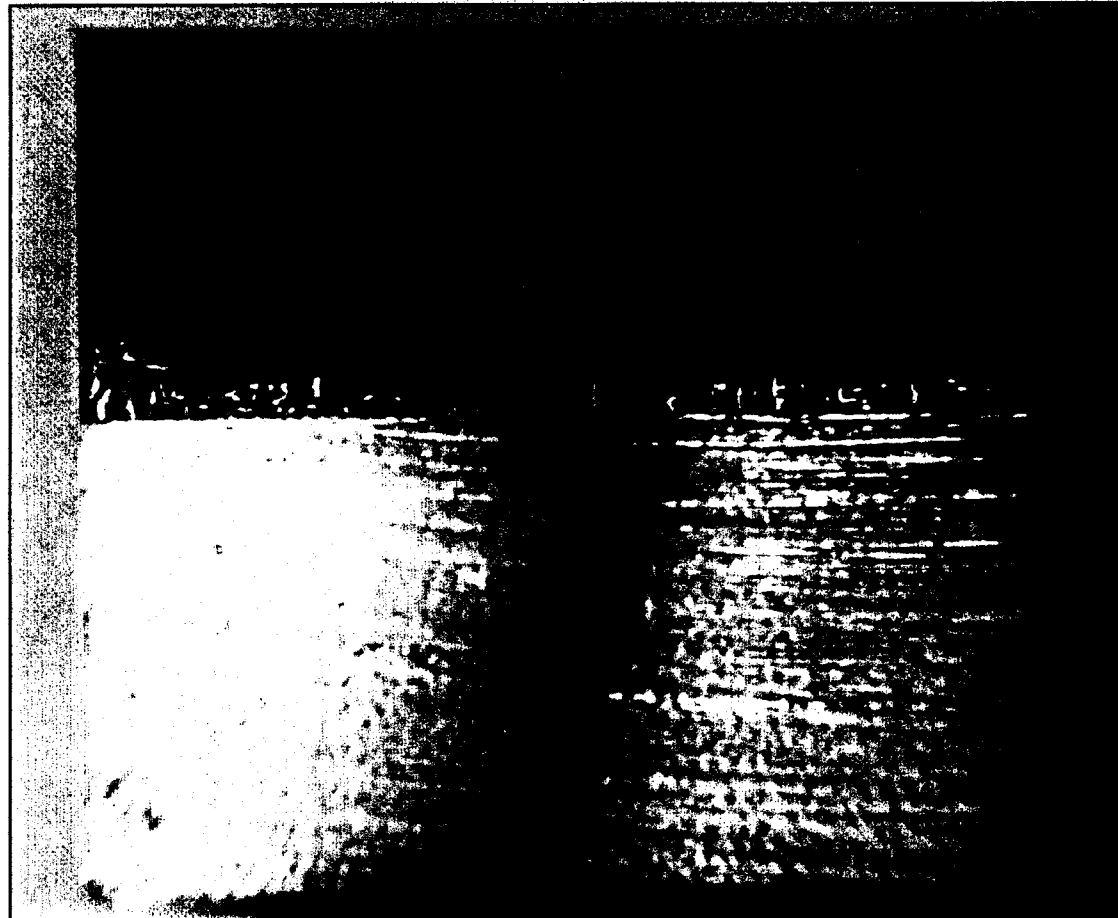


OFHC Copper
(25 x 25 mm block)

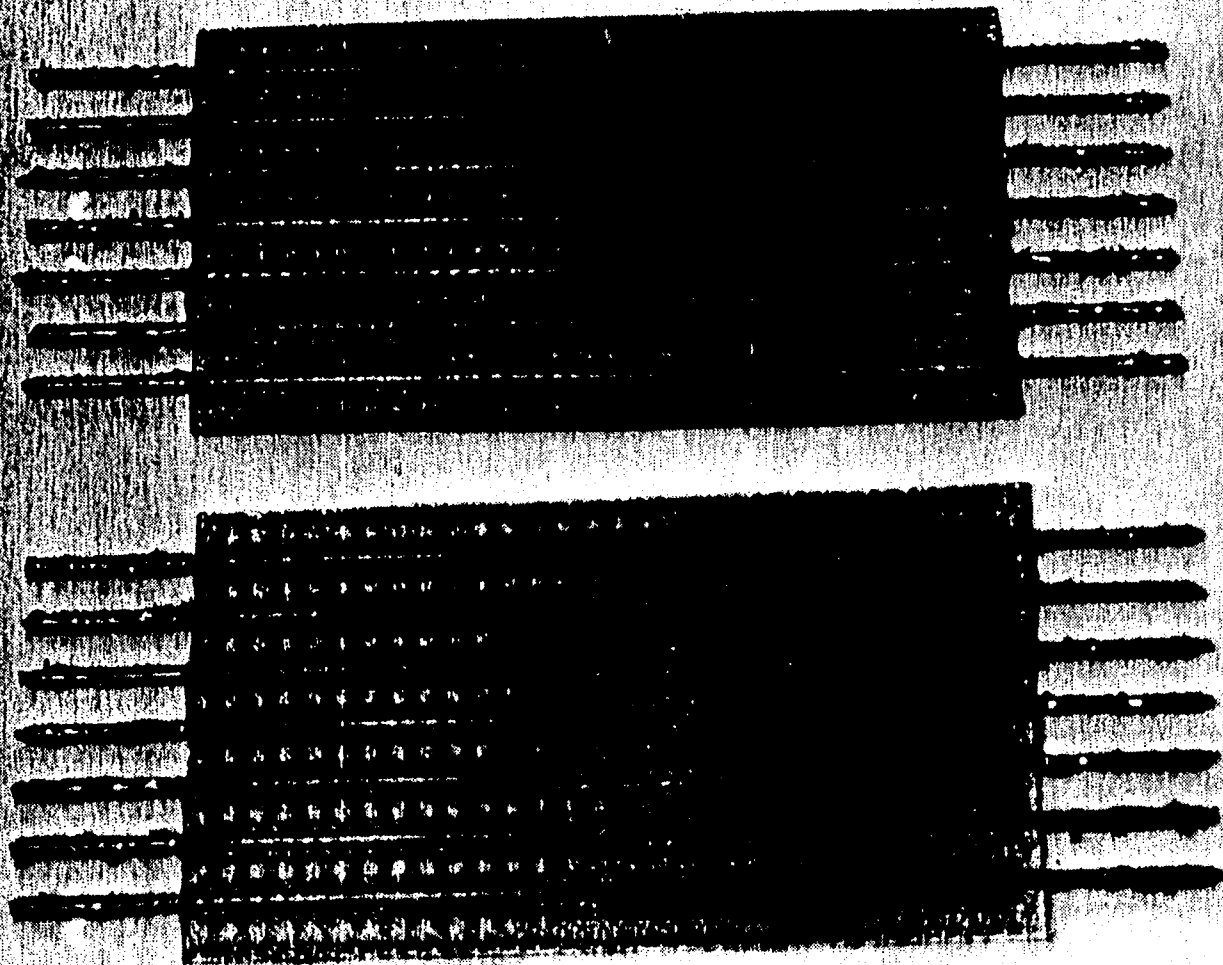
Carbon-Carbon
Composite
FMI 4-D Coarse Weave

Brazed
Coupon

Dissected Section Showing Greater Penetration of Ticusil into SEPCARB at Edges



5X

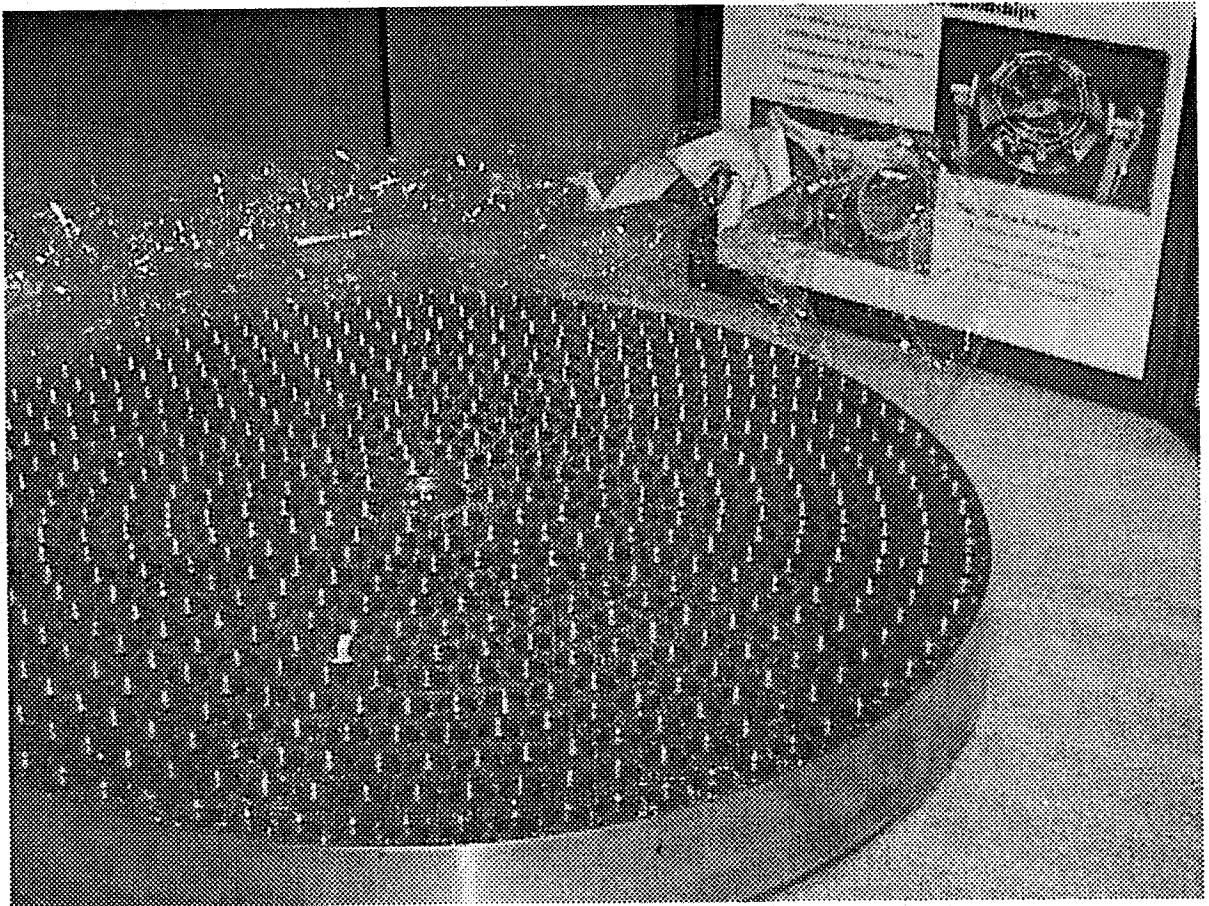


C/SiC Actively Cooled Panels
Produced for General Dynamics

Transpiration Cooled Main Injector Plate

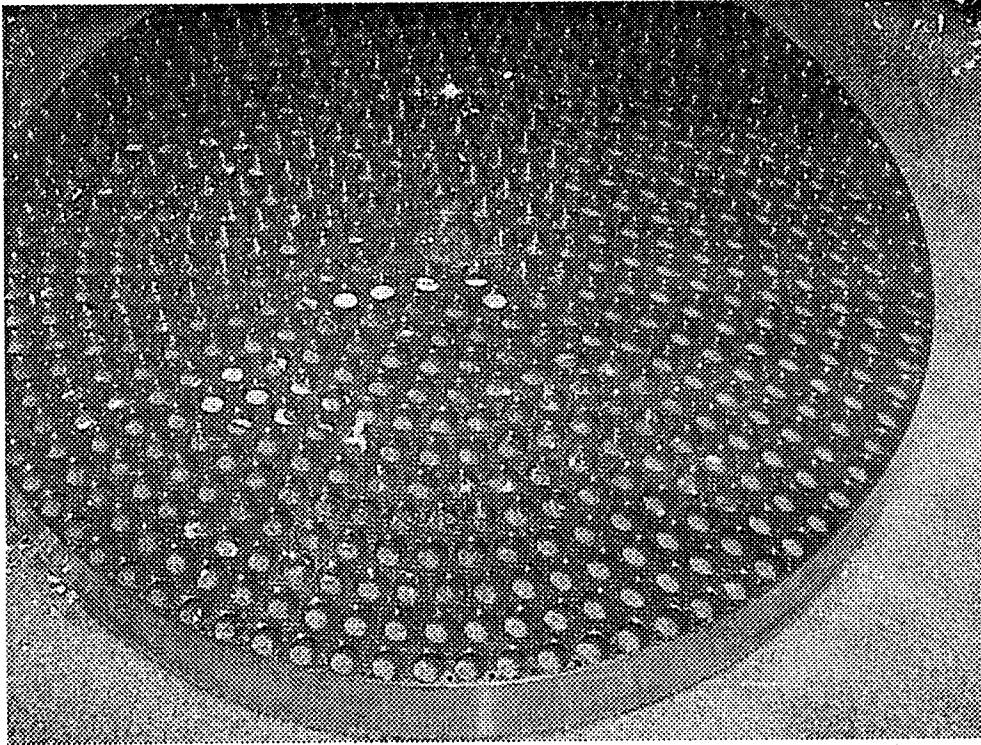
SSME Main Injector

Primary Plate with Main Injector holes
18 inch diameter



SSME Main Injector

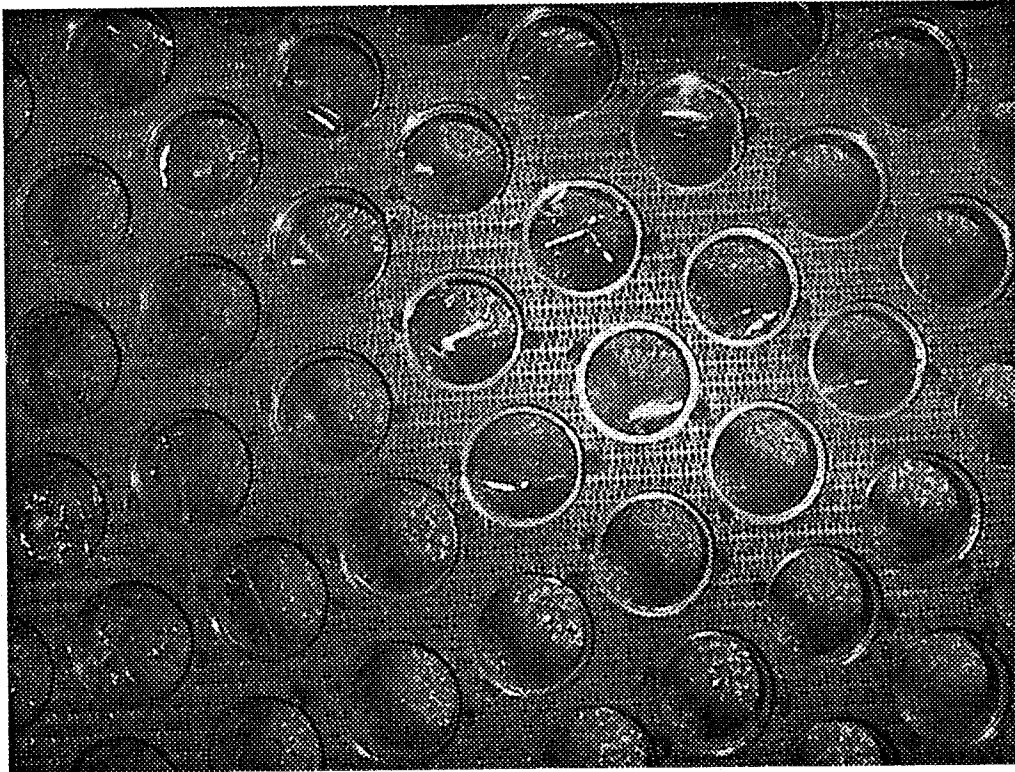
Rigimesh Primary Plate



- 18 inch diameter
- 0.25 inch thick
- Type 347 ss rigimesh
- EB welded to A286 ring
- Transpiration cooled with H_2 gas at 0F
- 10 to 20 Btu/in²/sec (16 to 32 MW/m²)

SSME Main Injector

Rigimesh Primary Plate



- **Main injector holes with swaged index holes**
- **Tolerance against plugging & weldable**