INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION

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SPRING COLLEGE IN MATERIALS SCIENCE
ON
'CERAMICS AND COMPOSITE MATERIALS'
(17 April - 26 May 1989)

APPLICATIONS OF ADVANCED CERAMIC MATERIALS
(Appendix I - References + Appendix II- Illustrations)

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Applications of advanced ceramic materials

Fu Xiren

Appendix I References

(1) Applications of advanced structural ceramics

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Appendix II Illustrations

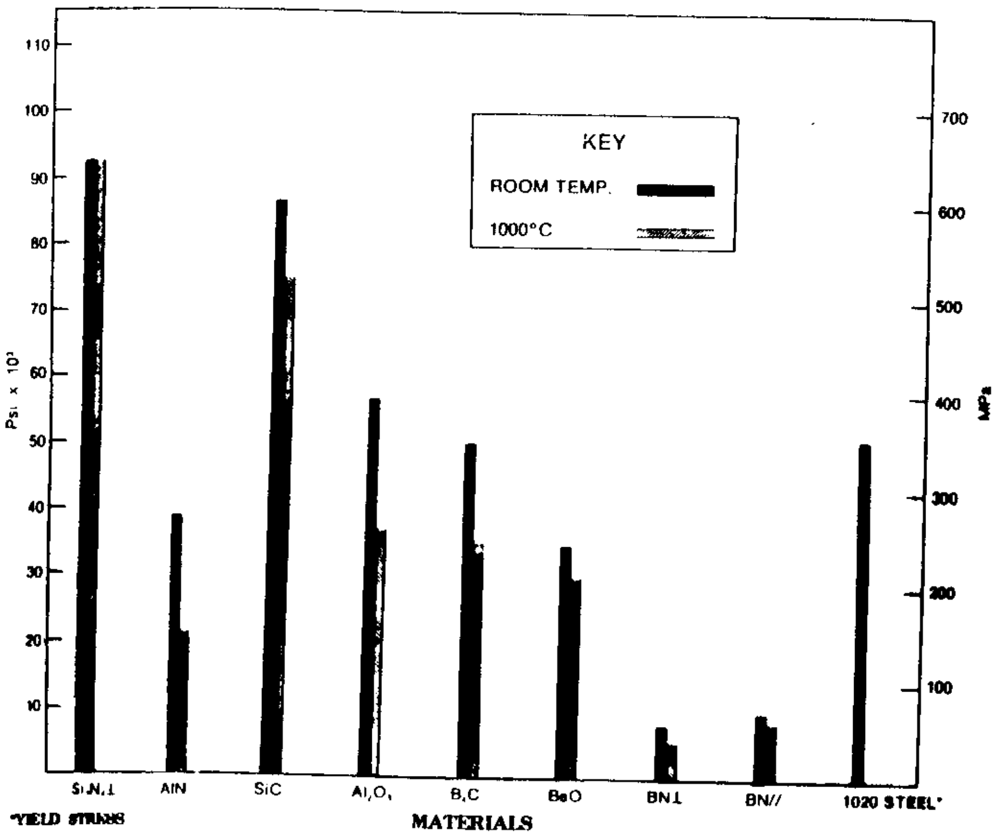
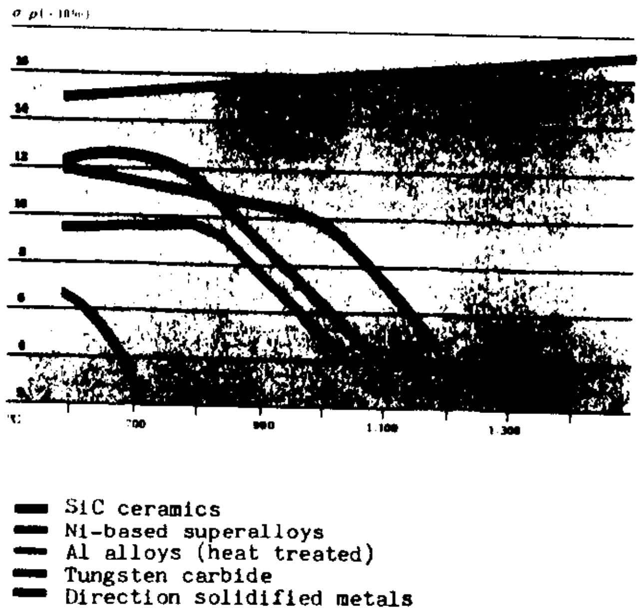
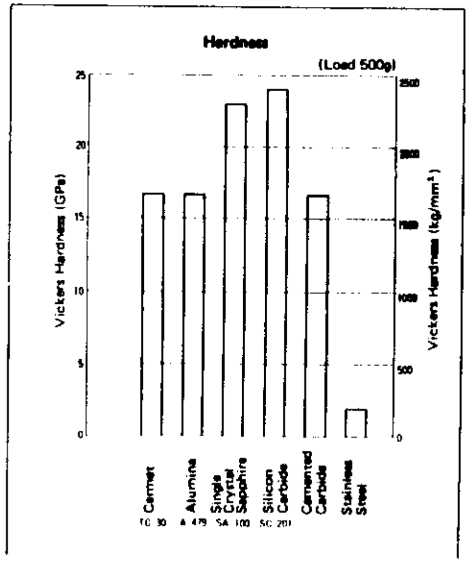


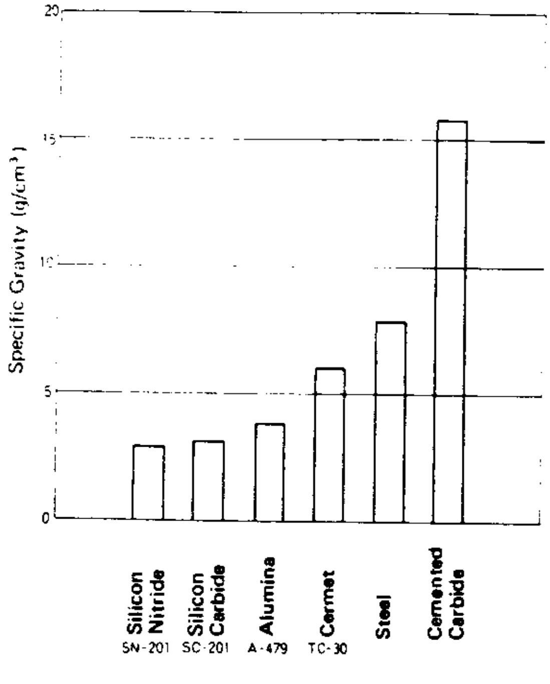
FIGURE II - BEND STRENGTH (MODULUS OF RUPTURE)



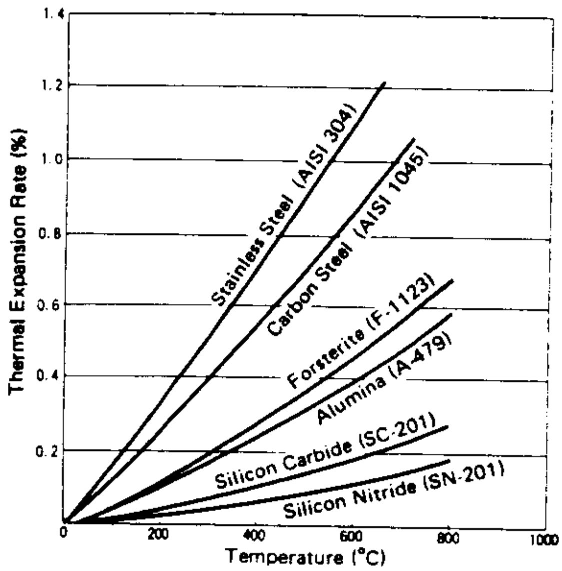
Strength of ceramics & metals at elevated temperatures



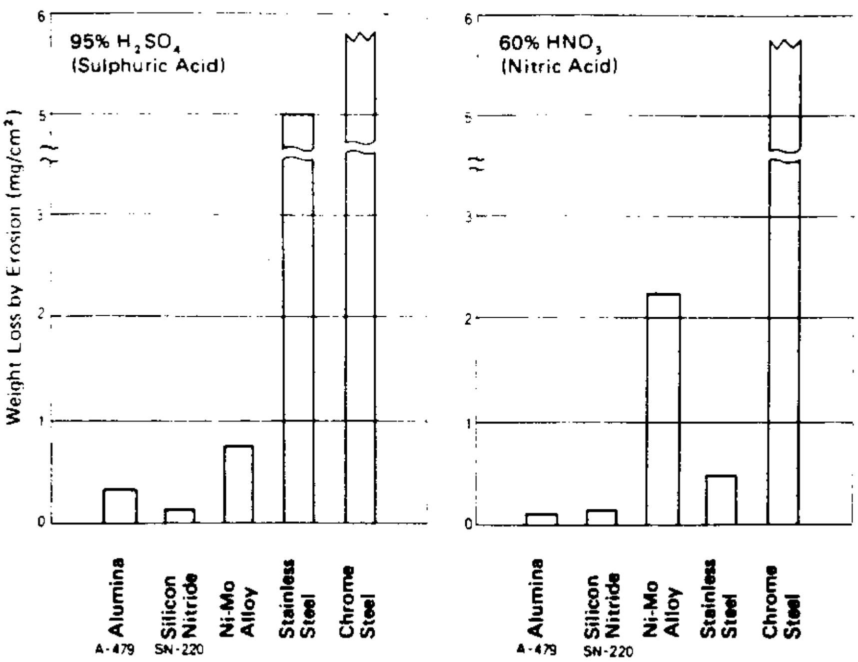
Specific Gravity



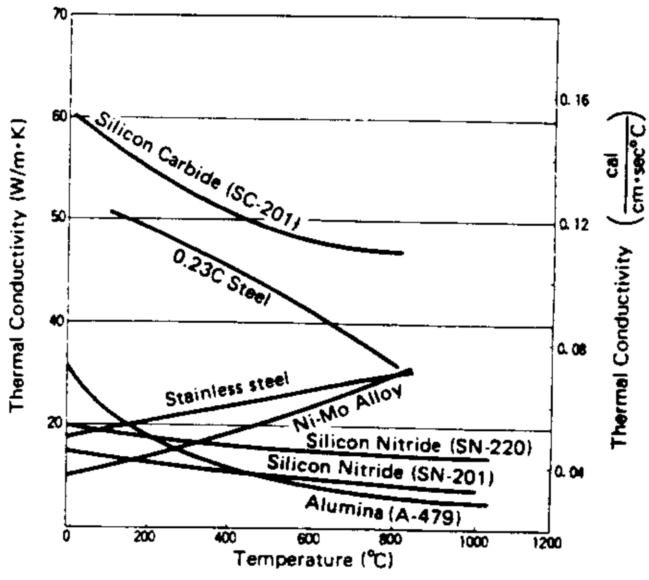
Thermal Expansion



Chemical Durability (30 min Boiling)



Thermal Conductivity



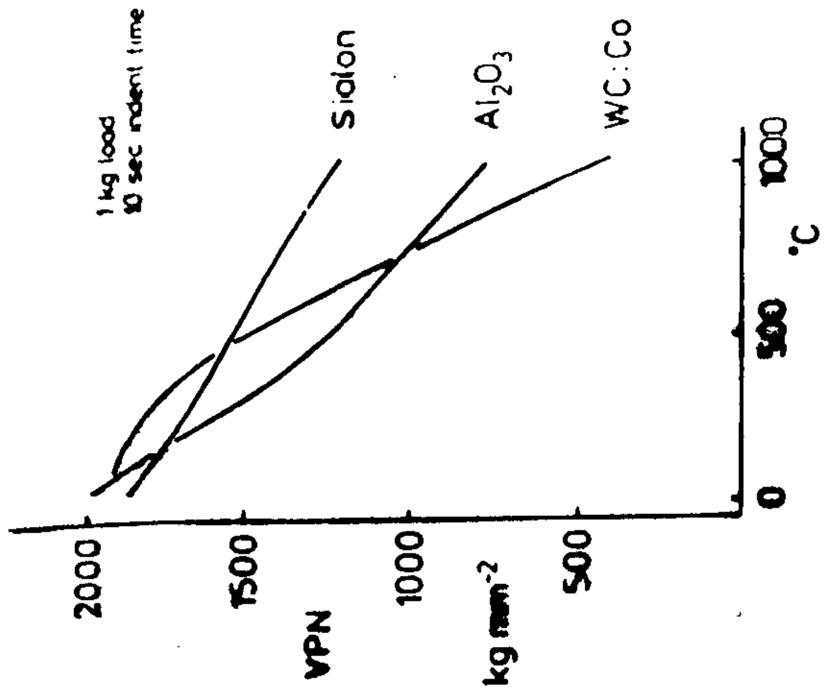
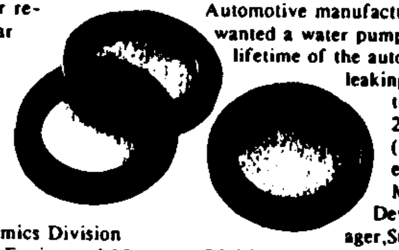


Fig. 1[illegible]. [illegible] of Sialon. Al_2O_3, and WC : Co cutting tool tips.

Ceramic cutting tool tips for milling



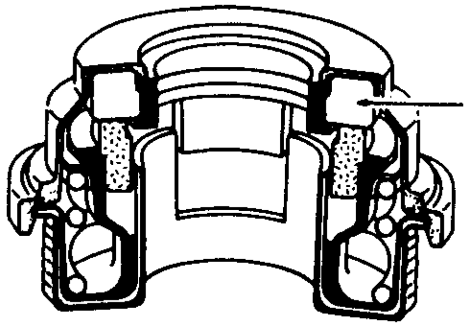
Silicon carbide mechanical seal faces for automotive water pumps are replacing seal faces that currently are made of materials such as aluminum oxide. Because of a greater resistance to both wear and thermal shock, sintered-alpha silicon carbide has proved more suitable in meeting the performance needs of European cars.

The Structural Ceramics Division of the Standard Oil Engineered Materials Company currently produces several tens of thousands of Hexoloy® SA (sintered alpha-silicon carbide) seals per week for use by European automakers. Today these include Volkswagen/Audi, the Porsche 959S, and Fiat turbodiesels. Daimler-Benz is making preproduction tests. Demand is increasing, and annual production of 3-4 million seals is projected for 1989.

Automotive manufacturers have long wanted a water pump that lasts the lifetime of the automobile without leaking. This time frame translates into 200,000 km (120,000 miles), explains Jim MacBeth, Market Development Manager, Structural Ceramics Division. With the advent of longer warranties (up to 7 years/70,000 miles), more aluminum in engines, and changes in coolant compositions, the water pump seal has become a major warranty issue.

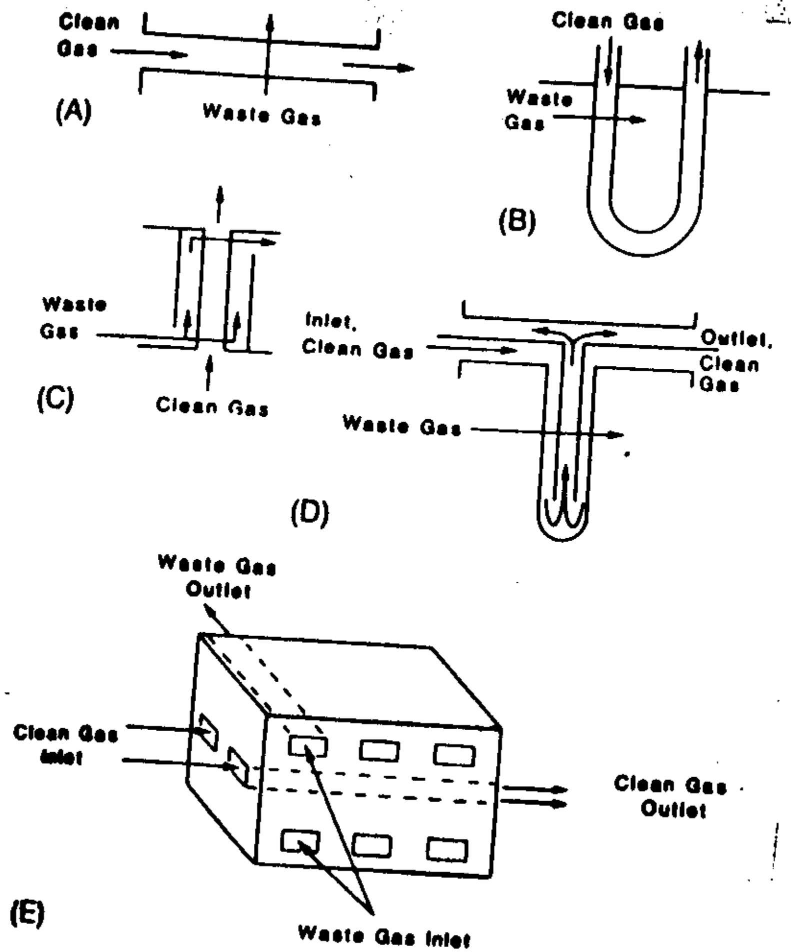
MacBeth says that production of these seal faces is Standard Oil's first oppor-

Silicon carbide mechanical seal faces for automotive pumps

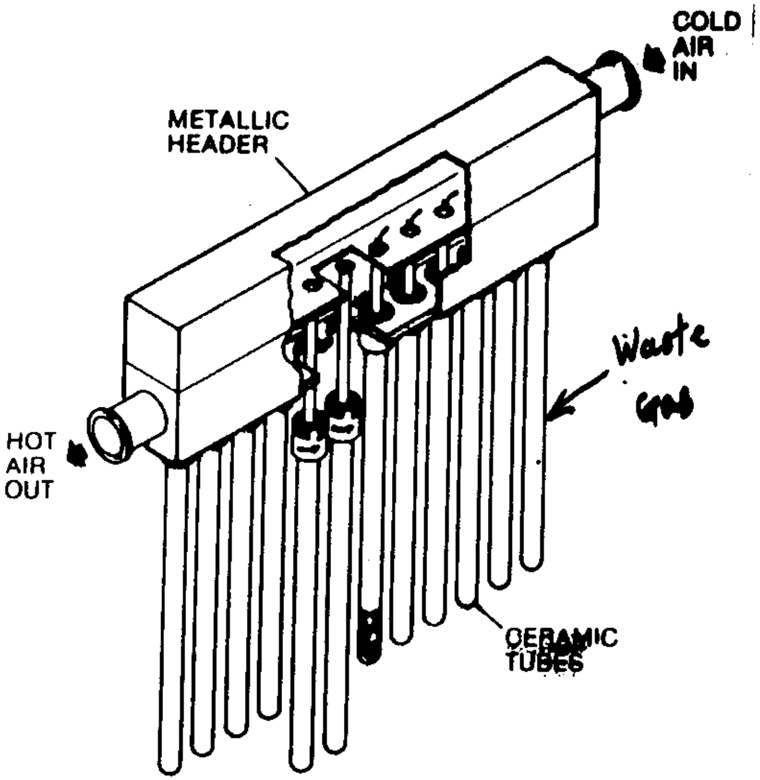


SiC seal face in automotive water pump

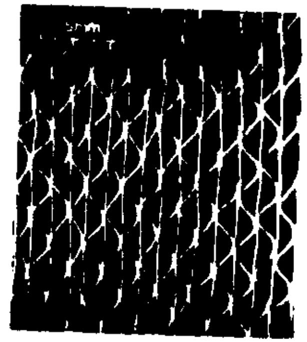
Ceramic location pins for welding



Ceramic heat exchanger conceptual designs: (A) tube-in-shell, cross-flow; (B) "U"-tube, cross-flow; (C) tube-in-shell, parallel flow; (D) bayonet tube, cross-flow; (E) compact plate and fin, cross-flow.

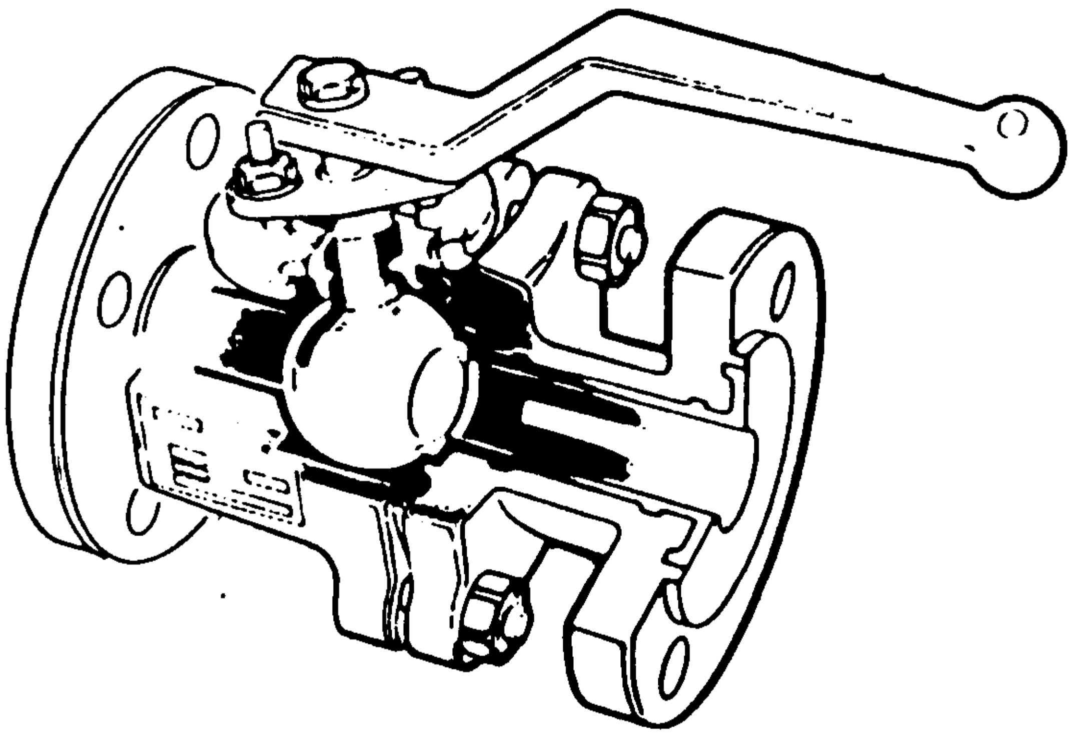


Ceramic recouperator module as used on an aluminum remelt facility. (Illustration courtesy of Solar Turbines Int'l)

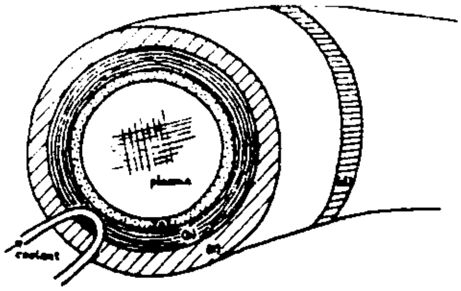


Ceramic heat exchanger

A model of gas-cooled solar energy power generating station



Ceramic elements for ball valve fittings.



a) low-Z liner to maintain plasma purity (e. g., Tokamak) or refractory in-ulator to in-sulate plasma from blanket (Theta Pinch);
b) ceramic blanket;
c) ceramic shield (or reflector);
d) ceramic insulator (e. g., to act as current breaker in Tokamak concept

Fig. 19 General schematic of fusion reactor design indicating areas for potential ceramic application

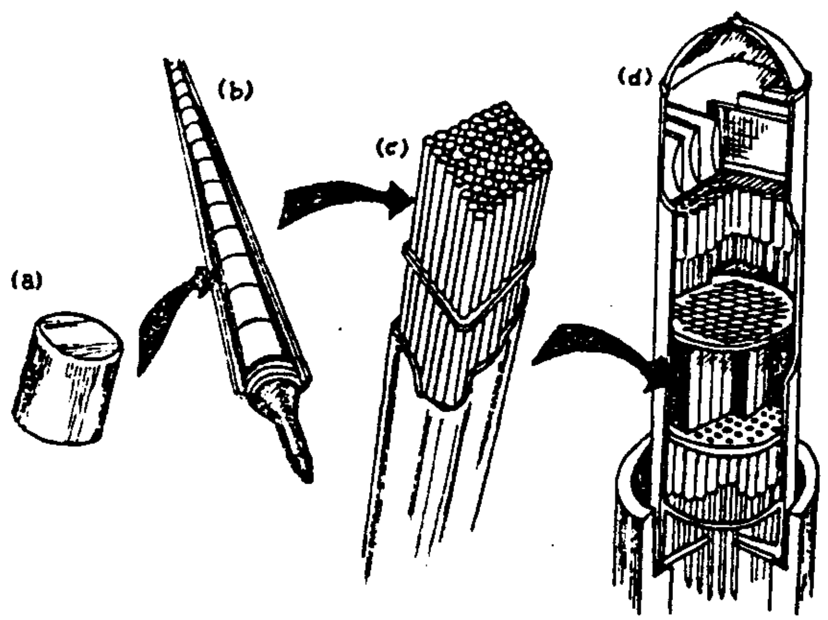


Fig. 1 Components of water reactor core
a) fuel pellet (or burnable poison pellet)
b) fuel rod (or burnable poison rod)
c) fuel assembly (containing many fuel rods and a few burnable poison rods)
d) reactor core (containing several hundred fuel assemblies – BWR is the specific example

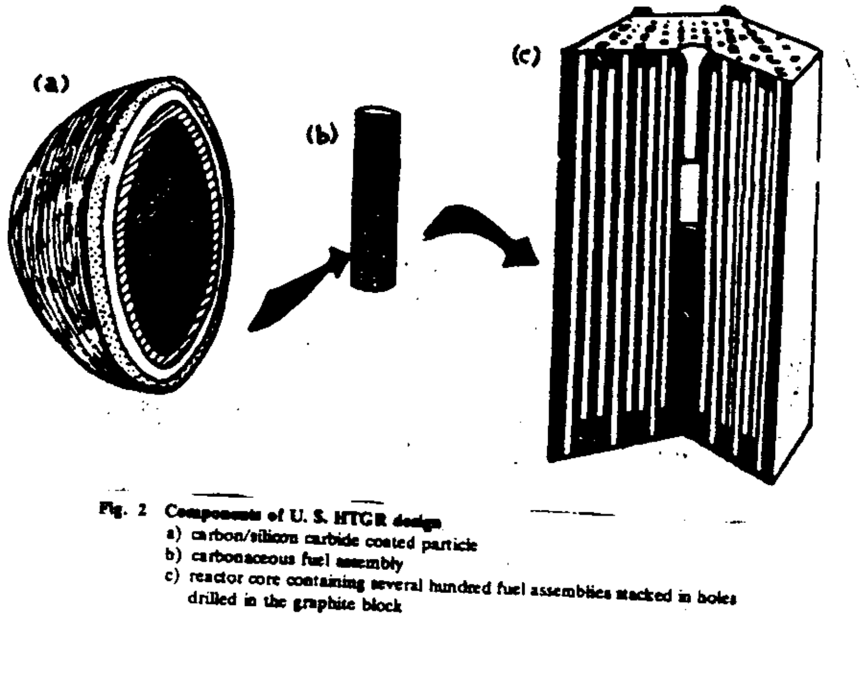
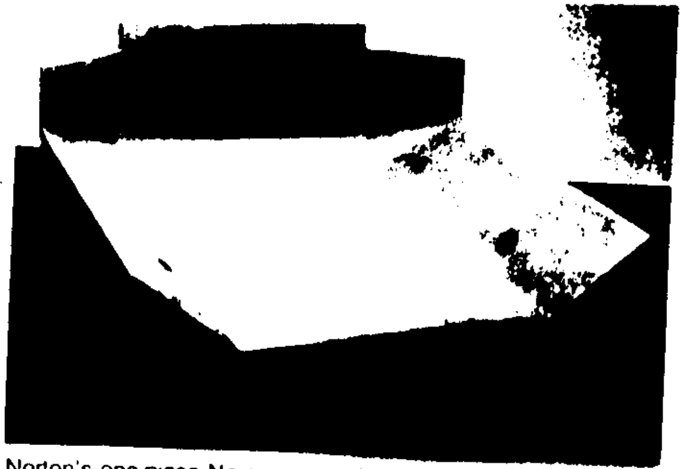
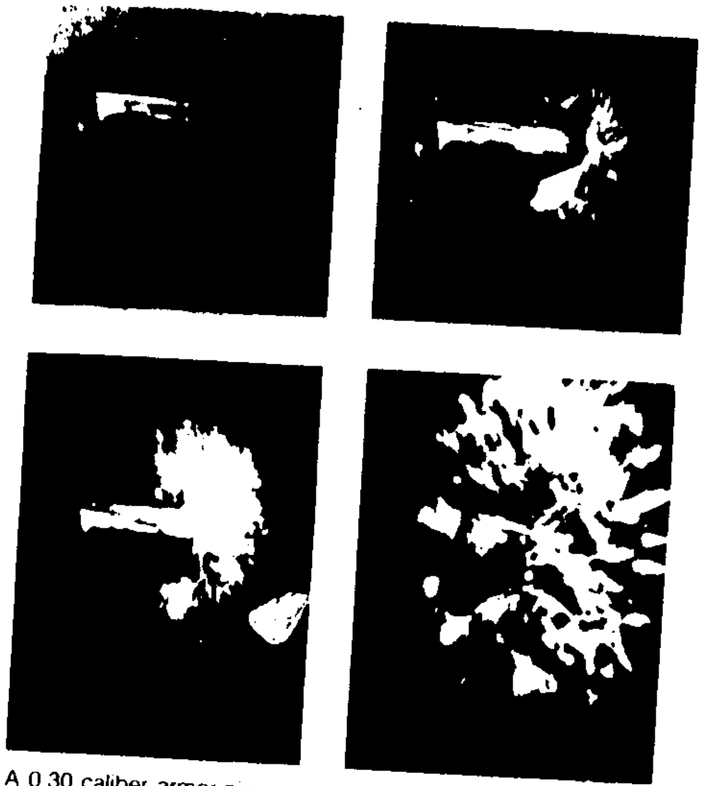


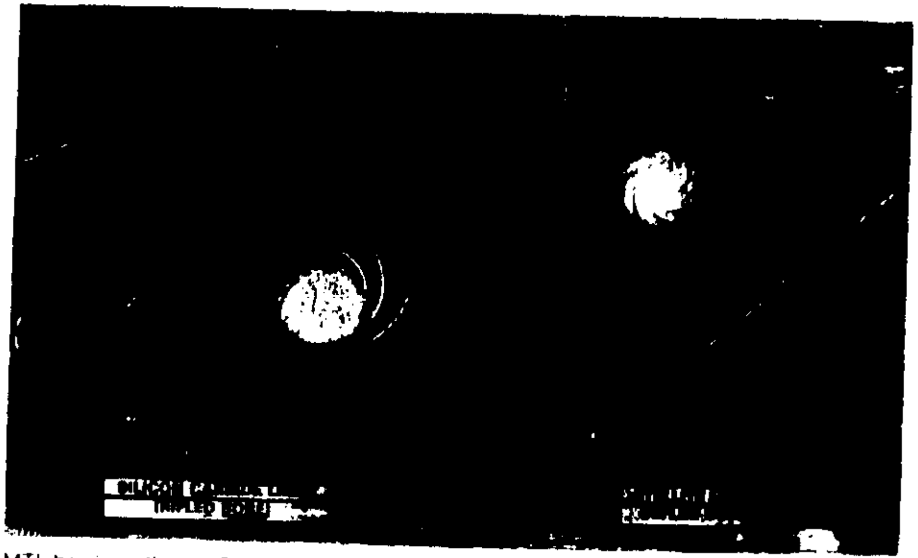
Fig. 2 Components of U. S. HTGR design
a) carbon/silicon carbide coated particle
b) carbonaceous fuel assembly
c) reactor core containing several hundred fuel assemblies stacked in holes drilled in the graphite block



Norton's one-piece Noroc armored seat bottom.

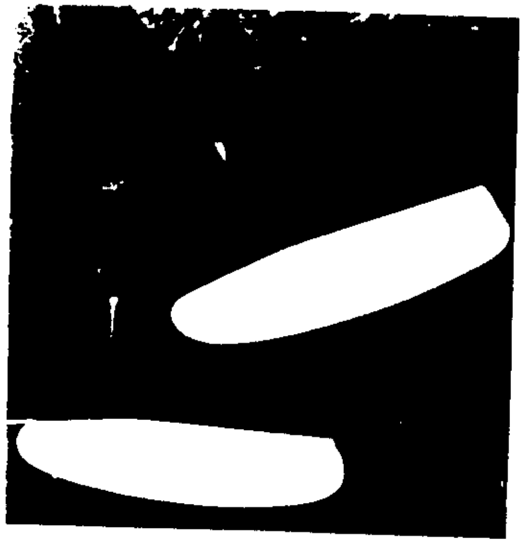


A 0.30 caliber armor-piercing projectile, traveling at 850 m/s strikes and shatters against a 1.9 cm-thick plate of Noroc armor.



MTL has investigated SiC tube as potential replacement for stellite liners used in gun barrels. Advantages of the ceramic liners include increased wear resistance, increased erosion resistance, higher temperature operation, lighter weight, and potentially lower cost.

Ceramic-tipped tweezers catch on



Ceramic golf putters

Table 1. WORLDWIDE MARKET PROJECTIONS FOR HIGH PERFORMANCE STRUCTURAL CERAMIC PARTS

(MILLIONS OF $)

APPLICATION	1985	1995	2005
HEAT ENGINE CERAMICS*	30	1,000	4,000
BEARINGS	NEGLIGIBLE	200	400
CUTTING TOOLS & METALWORKING	75	150	300
INDUSTRIAL WEAR PARTS	300	450	900
BIOMEDICAL & DENTAL INCLUDING CROWN	1,000	2,000	4,000
	1,385	3,800	9,600

* INCLUDES INDUSTRIAL HEAT EXCHANGERS

ESTIMATES BY B.N. KATZ BASED ON VARIOUS SOURCES, INCLUDING U.S. DOC, LTCB OF JAPAN, TRADE PUBLICATIONS, AND PRIVATE DISCUSSIONS ESTIMTES EXCLUDE CURRENT AND PROJECTED MILITARY APPLICATIONS

(2) Applications of advanced functional ceramics

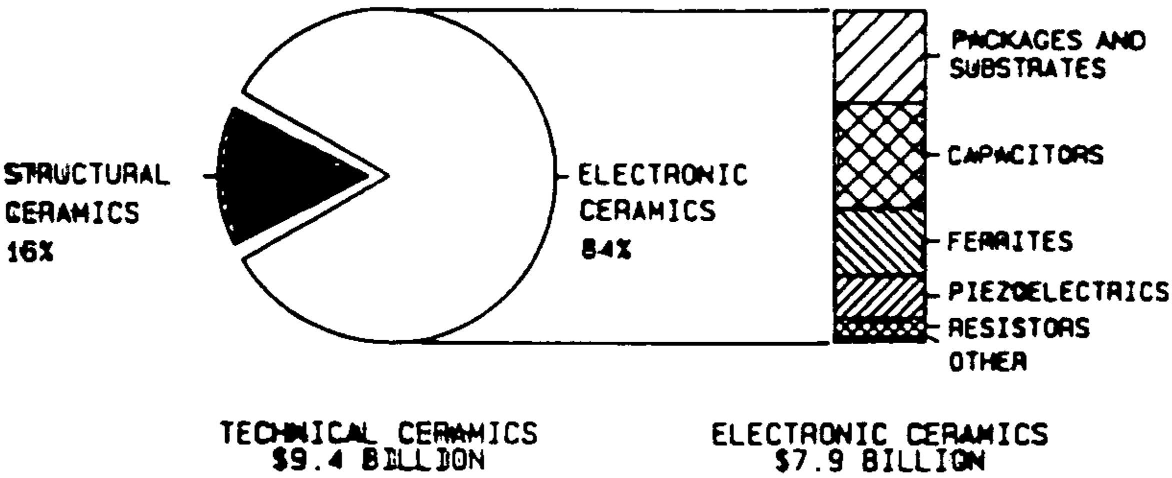
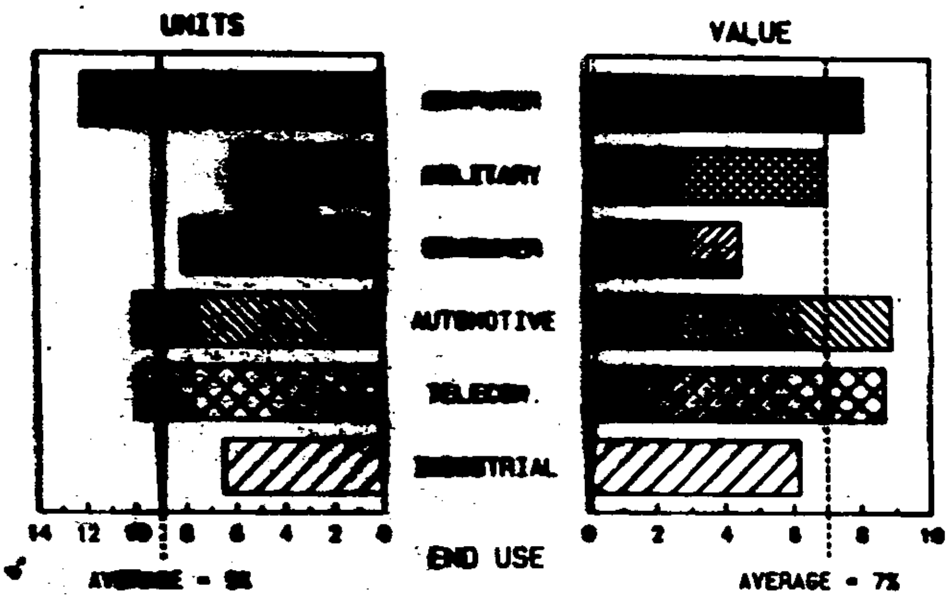


Fig. 1. Estimated world sales of technical ceramics, 1987. (Source: Kline & Co., Inc.)

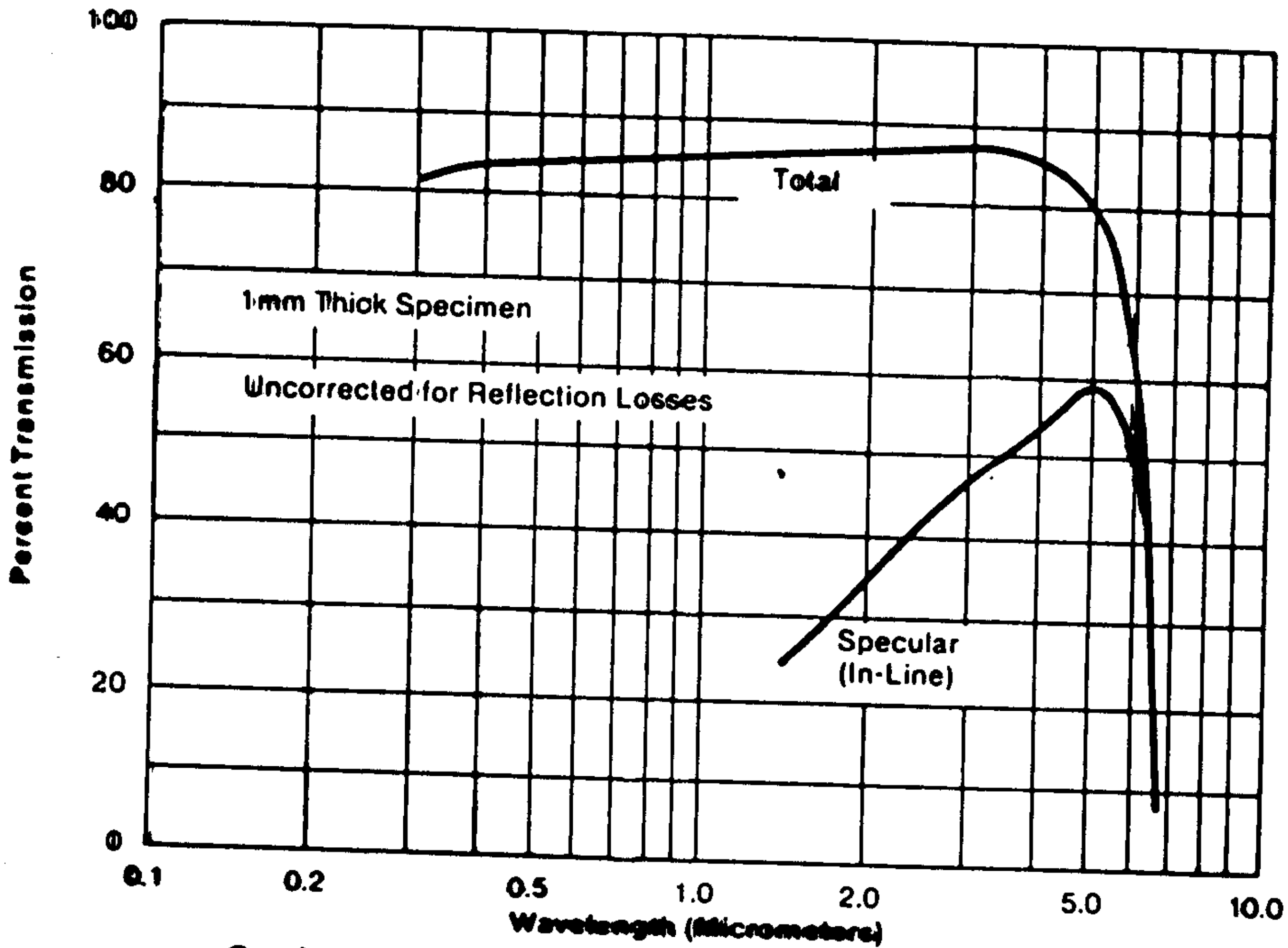


Average annual growth for electronic ceramics by end use, 1987–92. (Source: Kline & Co., Inc.)

[illegible] Advanced Ceramics Sales, 1977–1995

[illegible]	1977 ($ million)	[illegible] ($ million)	1991 ($ million)	1995 ($ million)
[illegible]	813	4 [illegible]	10 820	21 375
[illegible]	58	433	885	1 625
[illegible]	0	neg	80	675
Other	34	167	329	825
[illegible]	905	5 [illegible]	12 200	24 500

[illegible] Group, Inc.



Optical Transmission Curves for Transtar™

FIGURE 1. EEU-2/P flashblindness goggles.

SCHEMATIC OF SINGLE-STAGE DEVICE
"ON" CONDITION

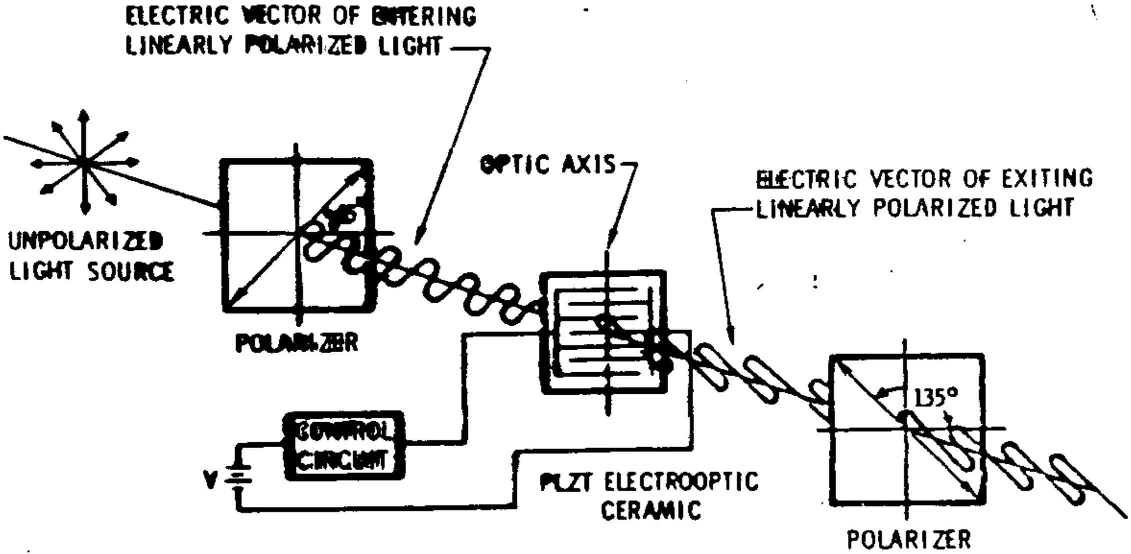
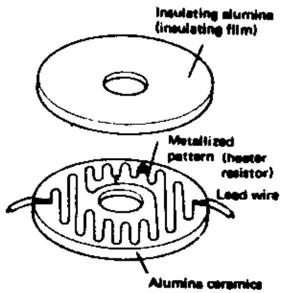
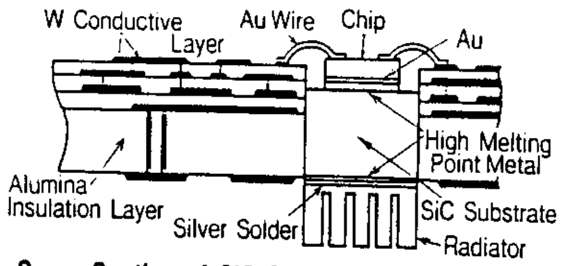


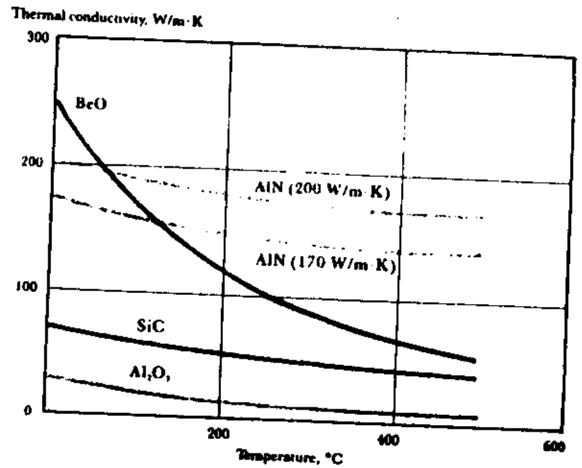
Fig. 1. ON-state configuration of a PLZT electrooptic shutter; the PLZT ceramic is shown functioning as a half-wave plate.

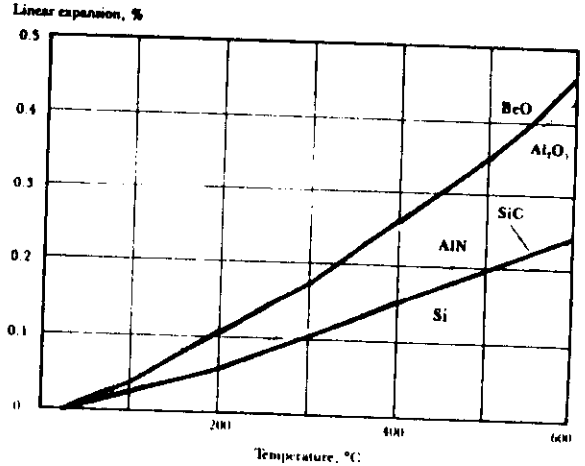


Ceramic heater



Cross Section of SiC Substrate combined with Alumina Multilayer Substrate





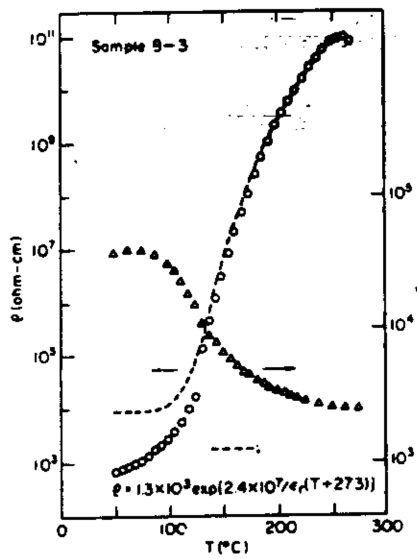
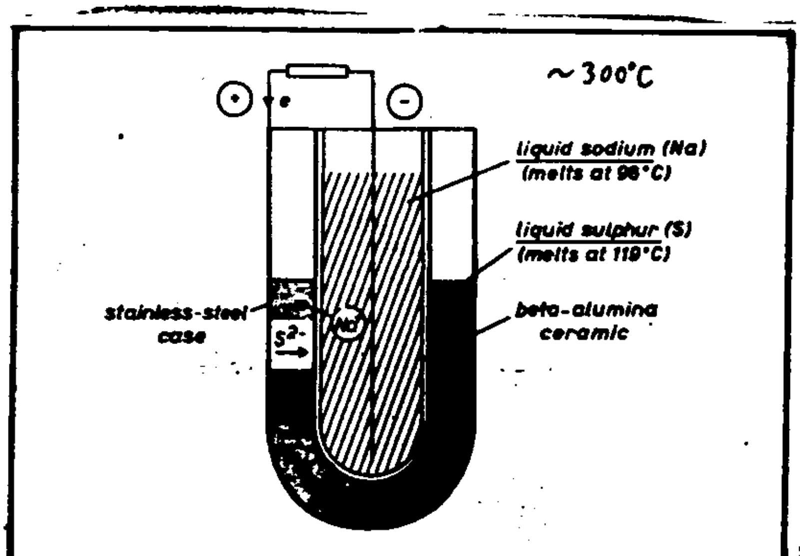
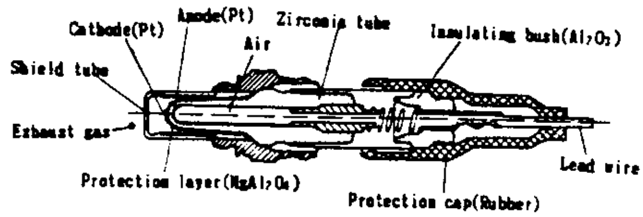


Fig. 2. PTCR effect in Sb_2O_3 doped $BaTiO_3$ (M. Kuwabara, *J. Amer. Ceram. Soc.* 64(11):639–644 (1981)).



Sodium - sulphur battery



(Structure)

Zirconia oxygen sensor

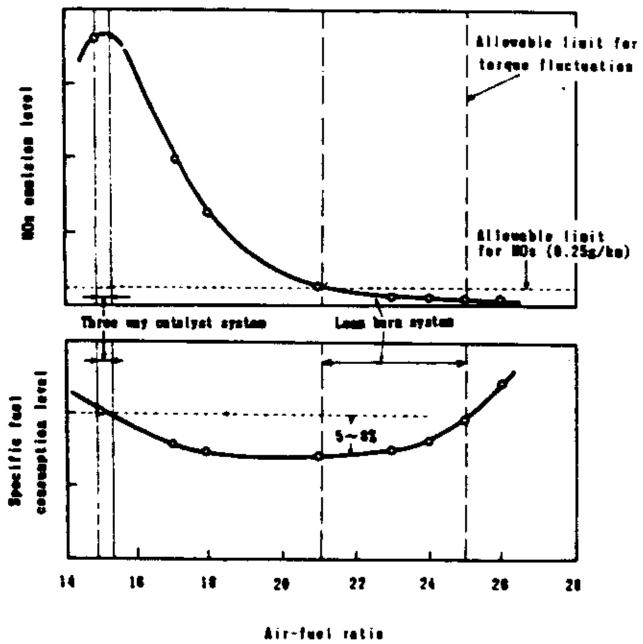


Fig. 6. NO_x emission and fuel consumption as a function of air-fuel ratio (Ref. 6).

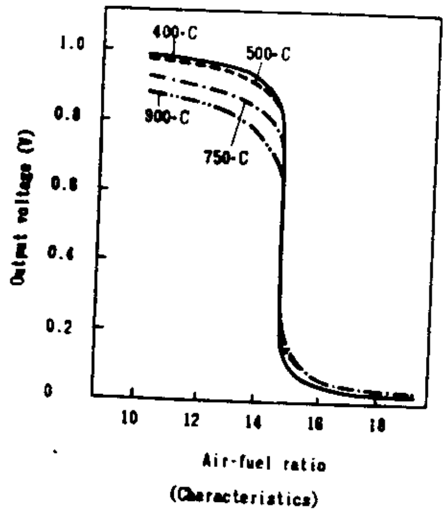


Fig. 7. Zirconia stoichiometric air-fuel-ratio sensor (Ref. 8).

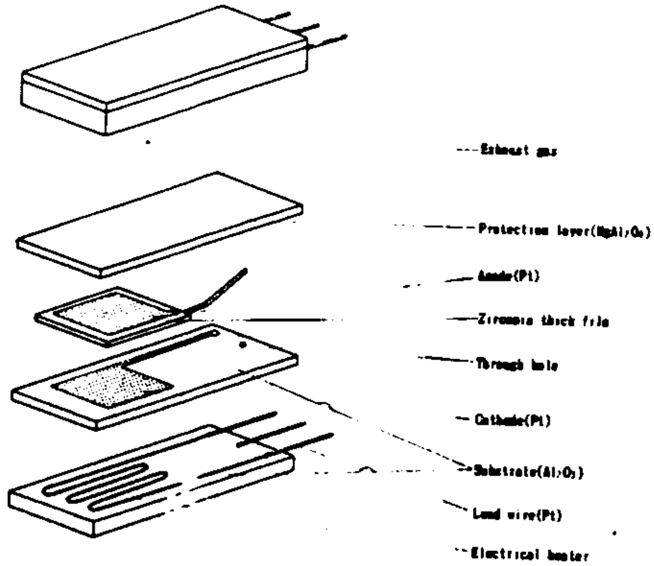


Fig. 8. Schematic diagram of zirconia thick-film sensor (Ref. 9).

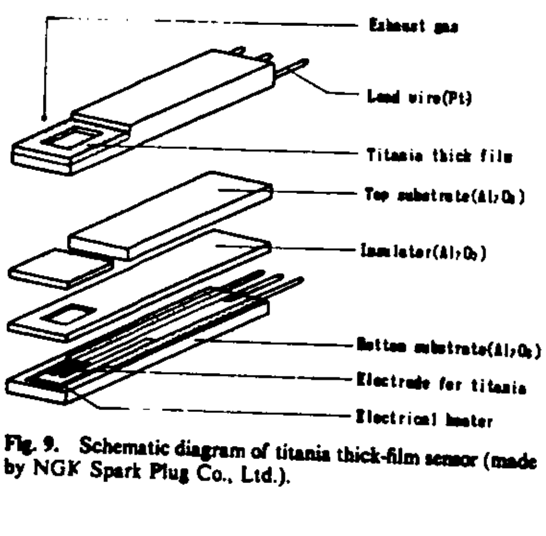
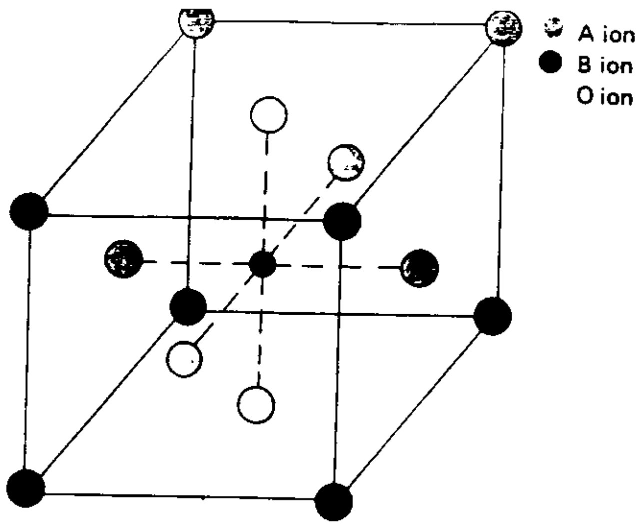


Fig. 9. Schematic diagram of titania thick-film sensor (made by NGK Spark Plug Co., Ltd.).



ABO_3 structure

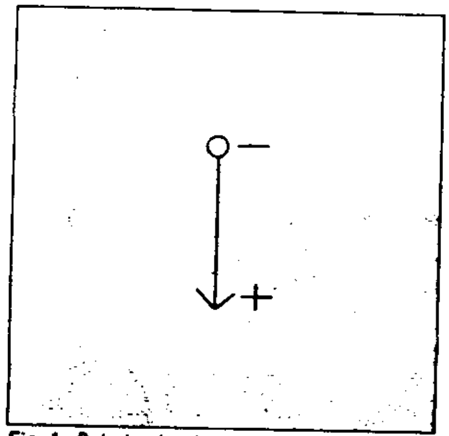


Fig. 1 Polarization in a single crystal of piezoelectric ceramics

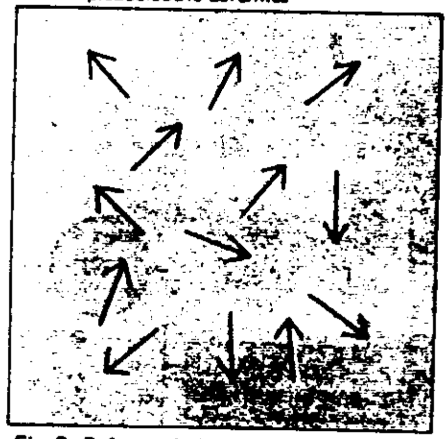


Fig. 2 Before polarization

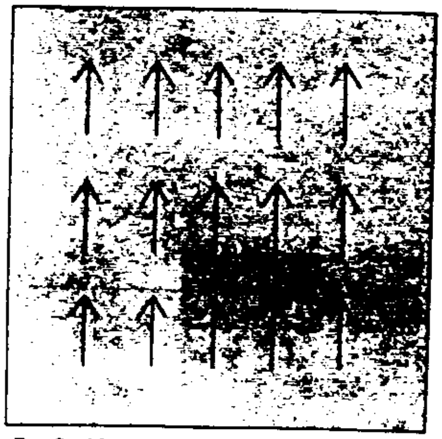


Fig. 3 After polarization

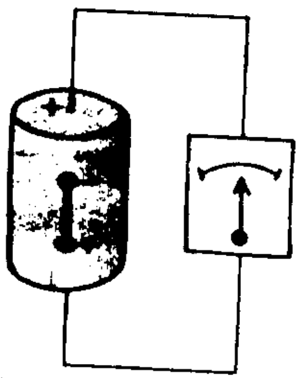


Fig. 4 No load

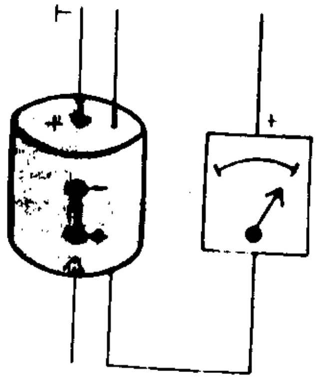


Fig. 5 Positive voltage is generated by compression

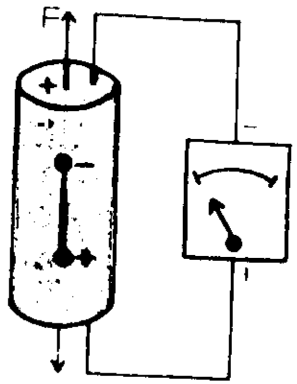


Fig. 6 Negative voltage is generated by elongation

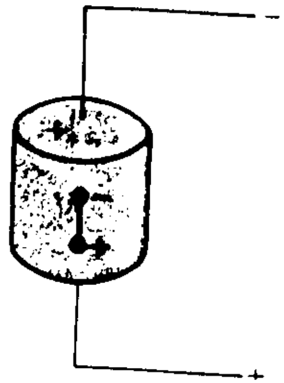


Fig. 7 Contracted by application of negative voltage

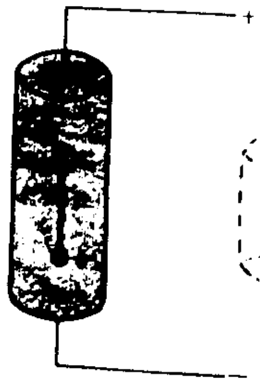


Fig. 8 Expanded by application of positive voltage

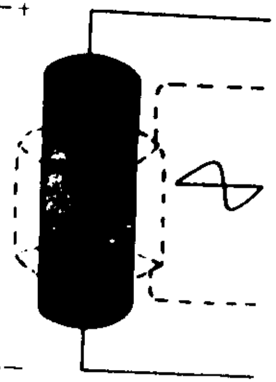


Fig. 9 Expanded and contracted alternately by application of AC voltage

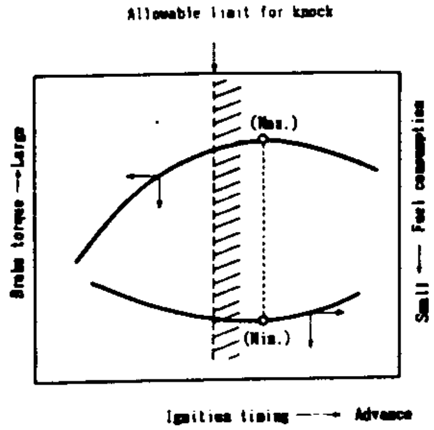


Fig. 11. Fuel consumption and brake torque as a function of ignition timing (Ref. 13).

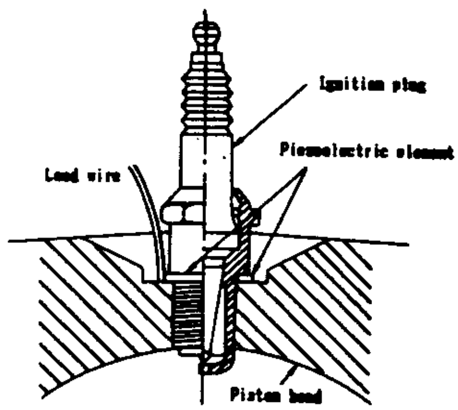


Fig. 12. Washer type cylinder knock sensor (Ref. 15).

Saturation Flux Densities and Resistivities of Magnetic Materials

Material	B_s Saturation flux density (gausses)	ρ Resistivity (ohm-cm)
Iron	21 500	10×10^{-6}
Silicon-Iron	20 000	50×10^{-6}
79% Nickel Iron	8 000	55×10^{-6}
Mn-Zn Ferrite	4000–5000	$10^{2}–10^{3}$
Ni-Zn Ferrite	3000–4000	10^{6}
Yttrium-Iron Garnet	1 750	$10^{10}–10^{12}$

(52)

(3) Applications of ceramic matrix composite materials

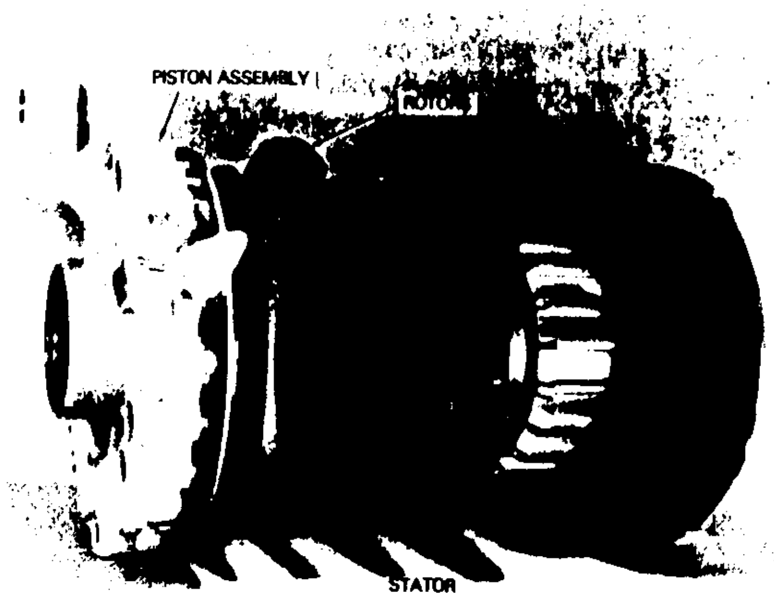


Fig. 1. C/C composite brake assembly consisting of multiple rotating and stationary disks.

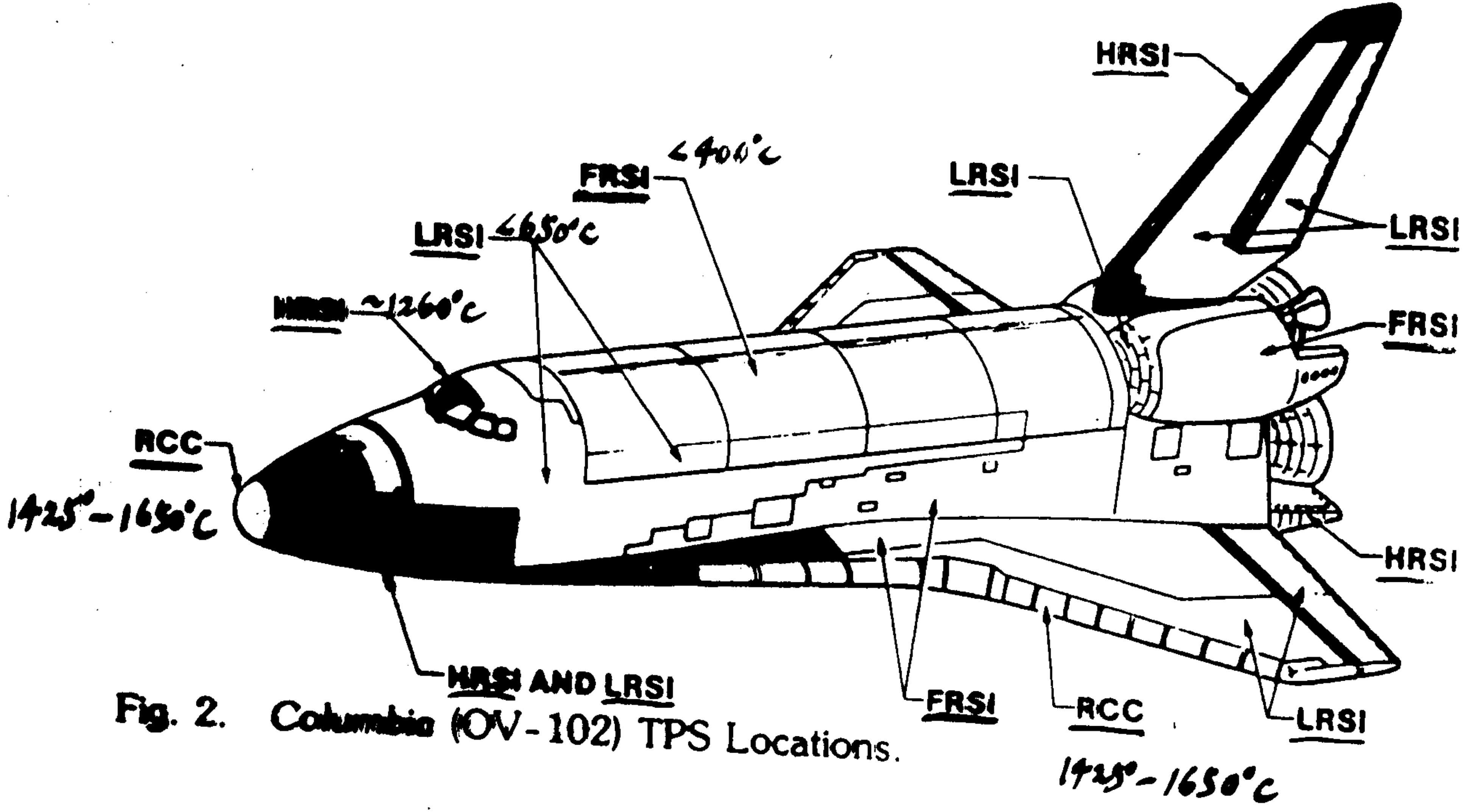


Fig. 2. Columbia (OV-102) TPS Locations.

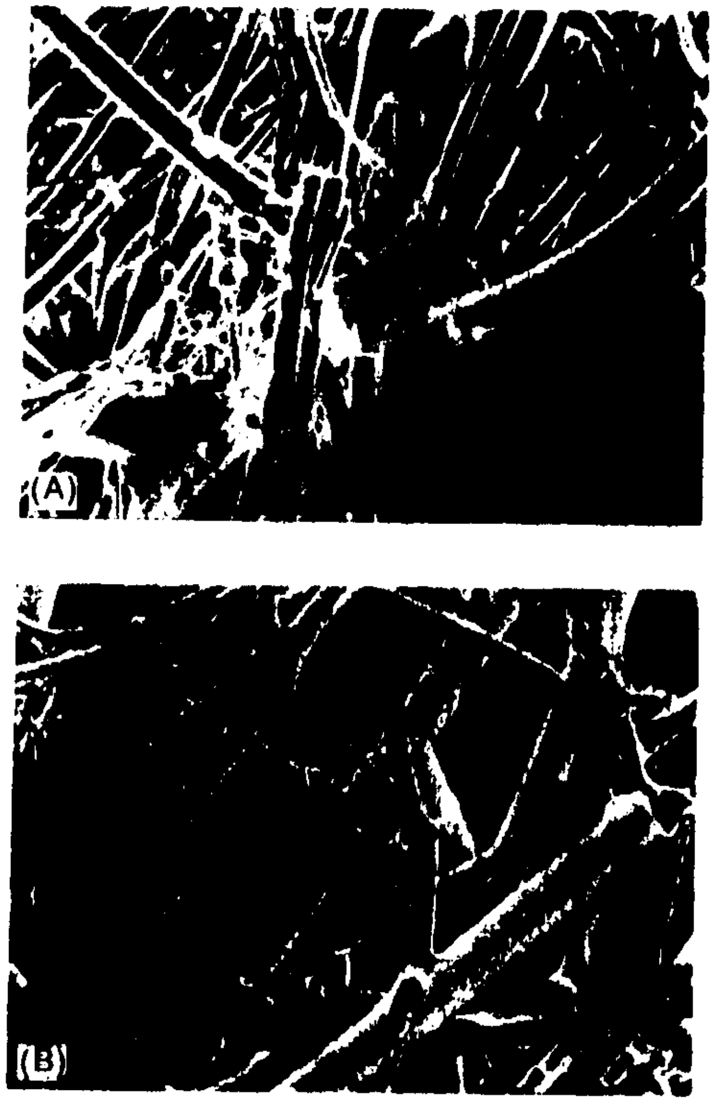


Fig. 3. (A) HRSI and (B) FRCI microstructures.

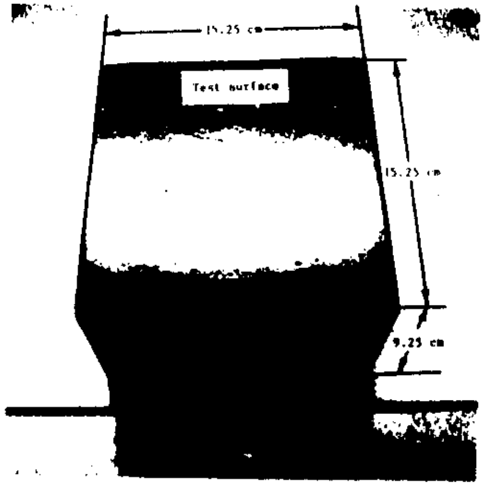


Fig. 2. As-received HRSI test tile.

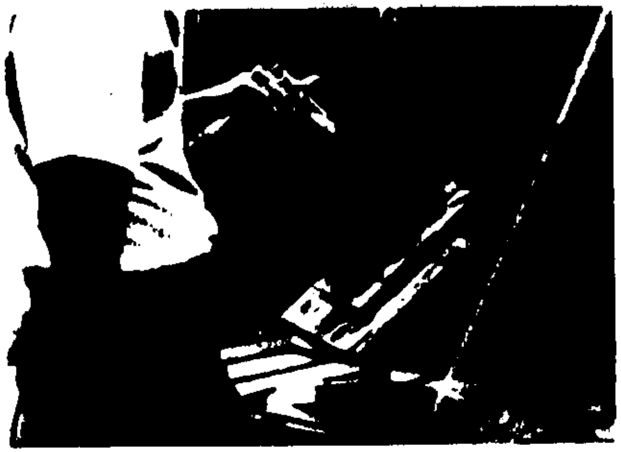


Fig. 4 Spraying of tile

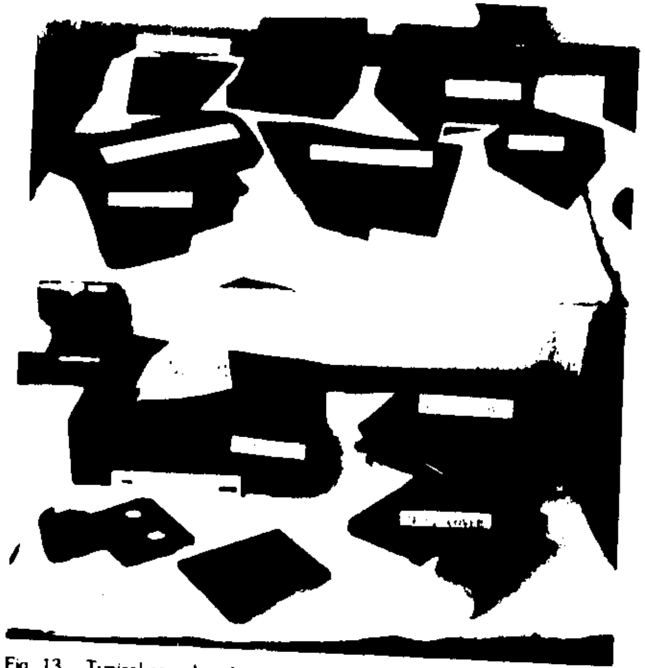
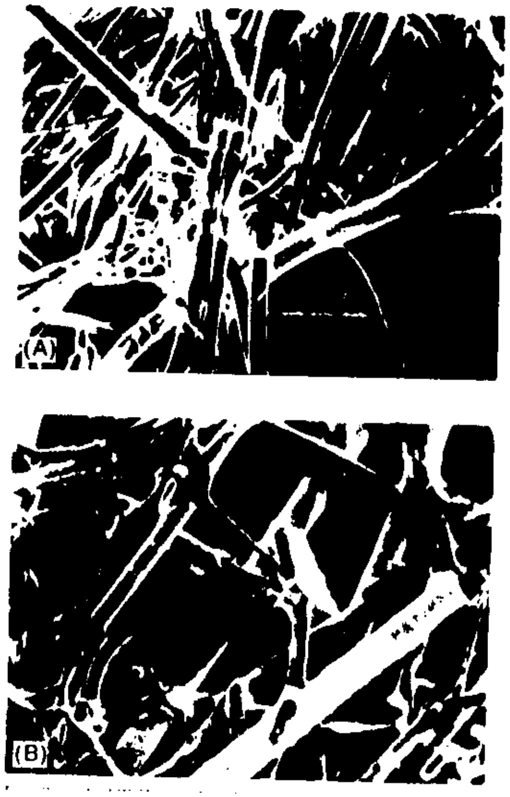


Fig. 13. Typical complex tiles.



The Shuttle Orbiter nose cap.

A contour-woven 3-D exit cone.

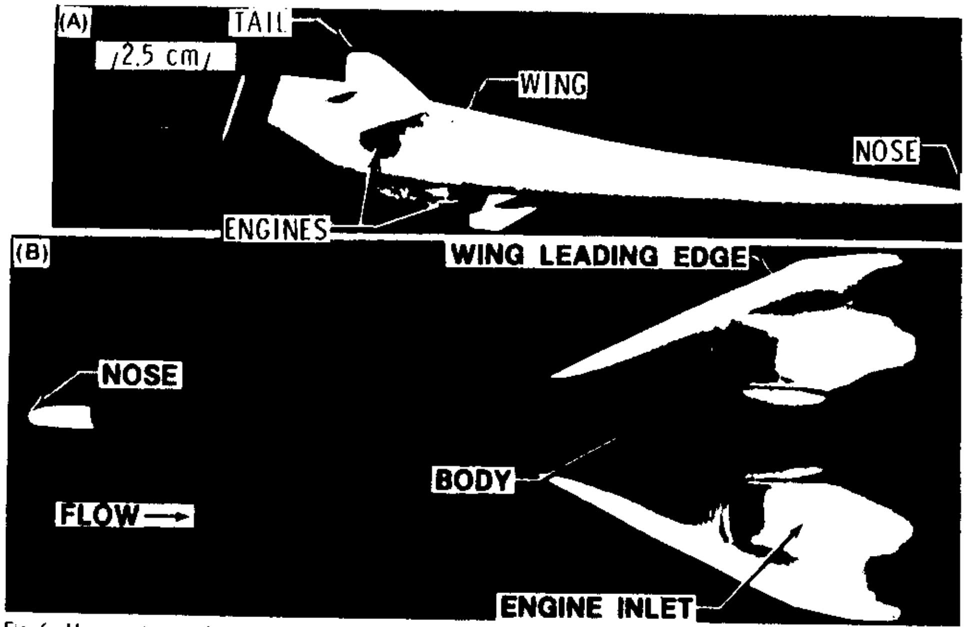


Fig. 6. Hypersonic aircraft model of slip-cast fused silica: (A) model before test; (B) model of hypersonic aircraft during

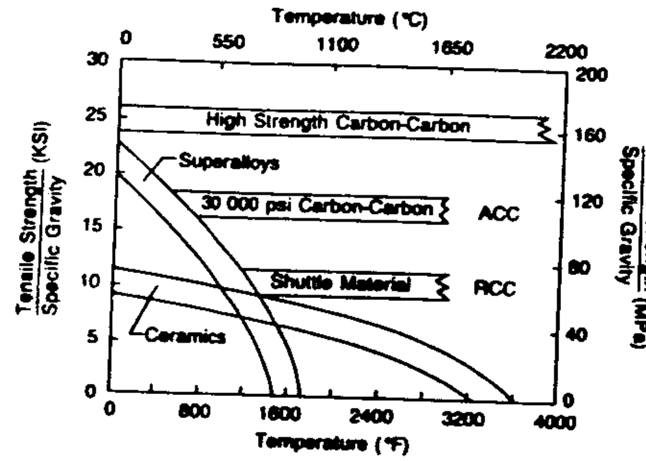


Fig. 11. Strength to density ratio for several classes of high temperature materials.

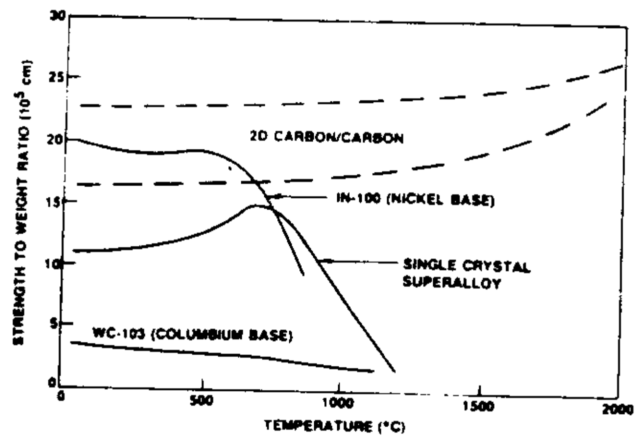


Fig. 1. Specific strength comparison of high temperature metal alloys and carbon/carbon composite.

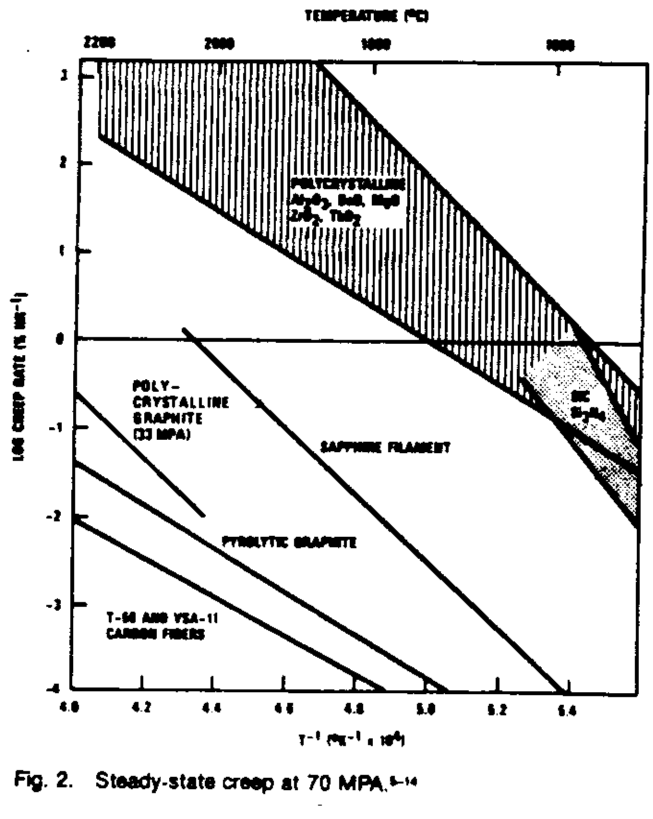


Fig. 2. Steady-state creep at 70 MPA.[5-14]

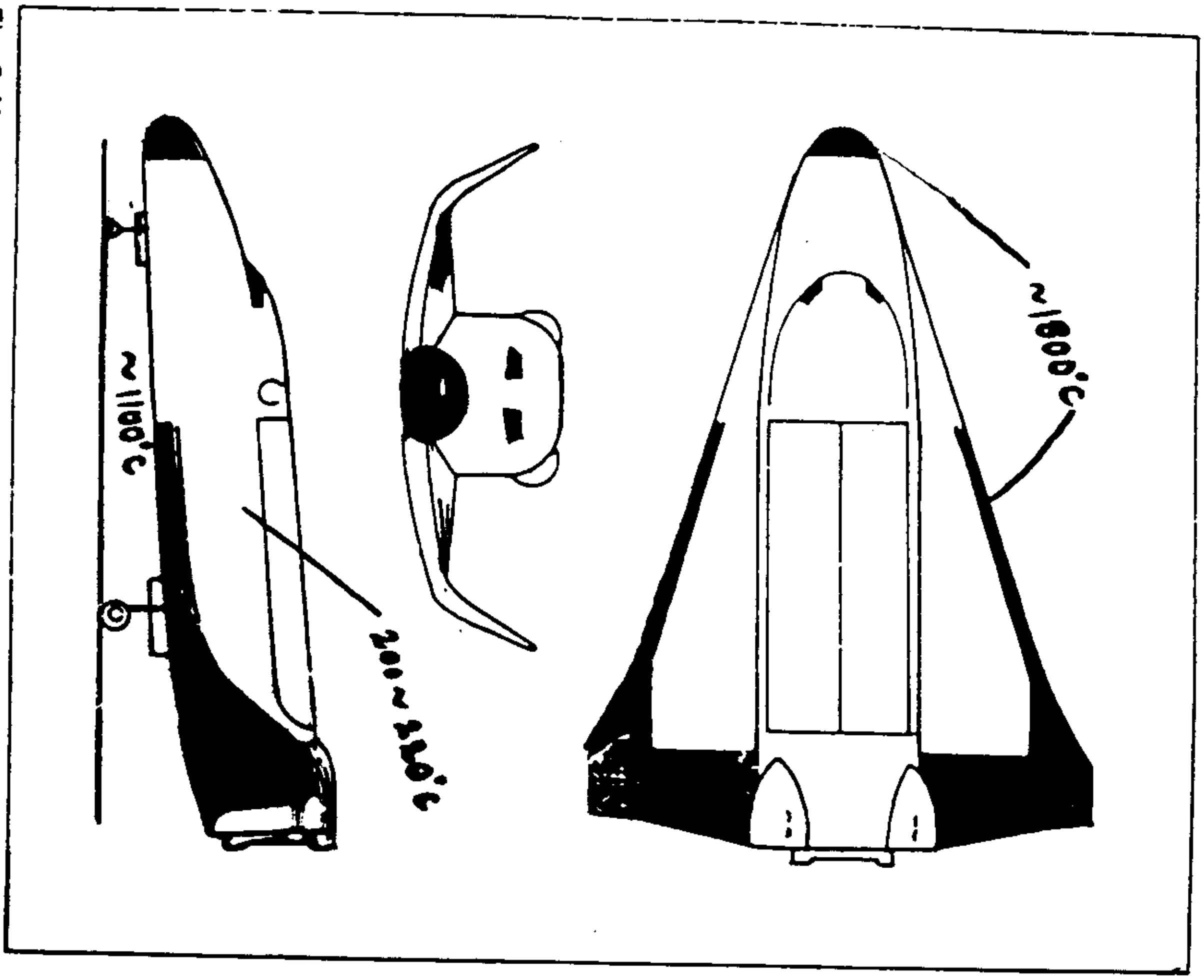
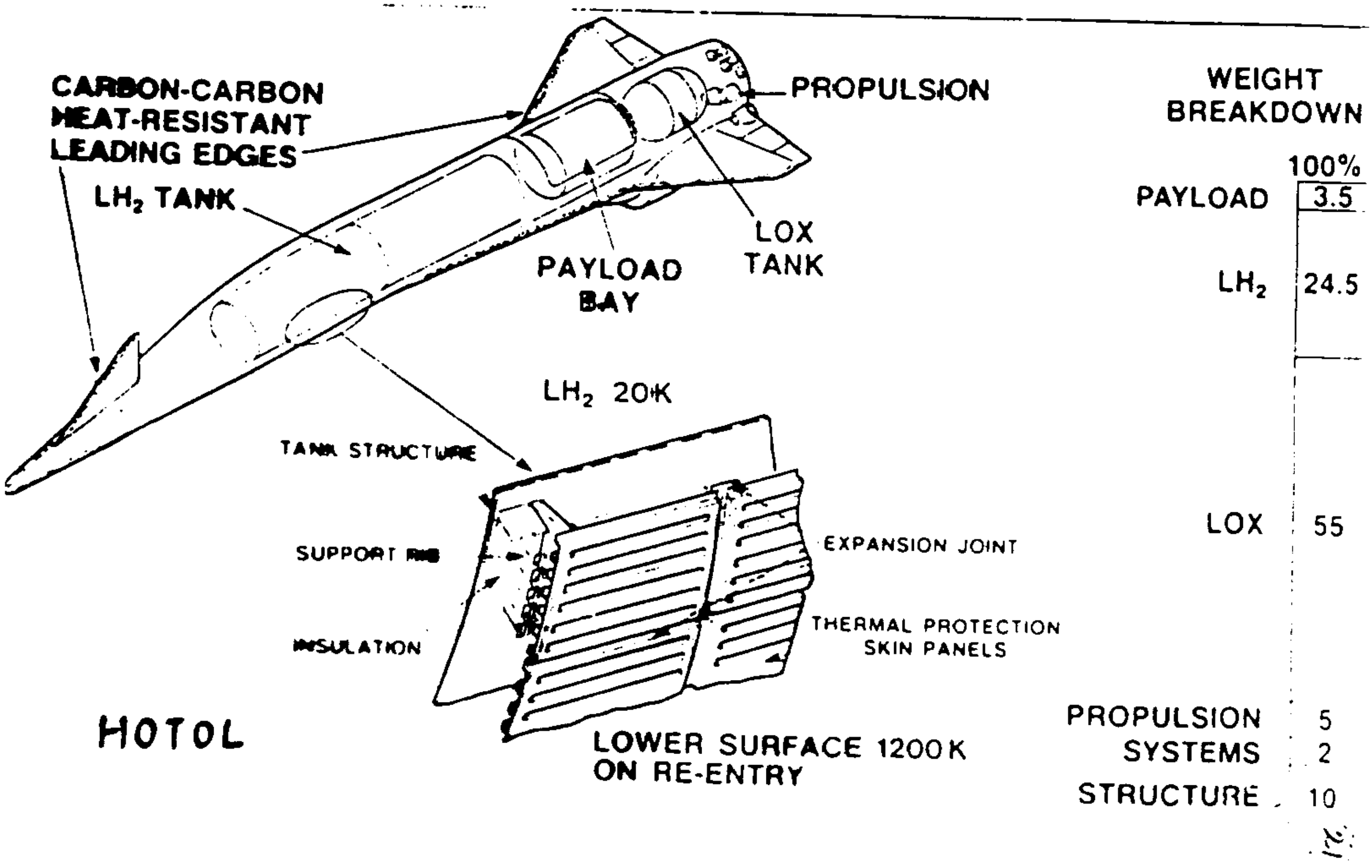
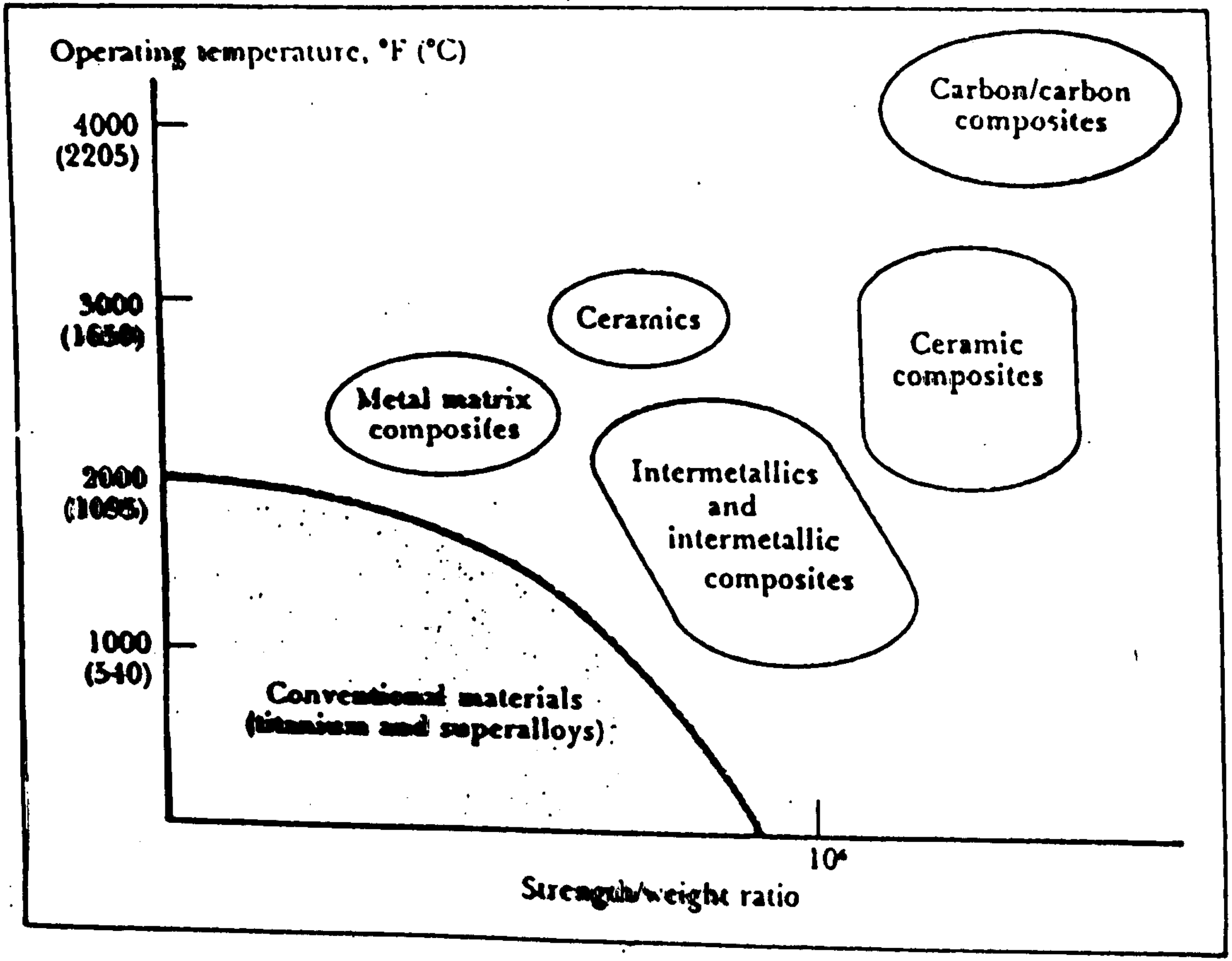
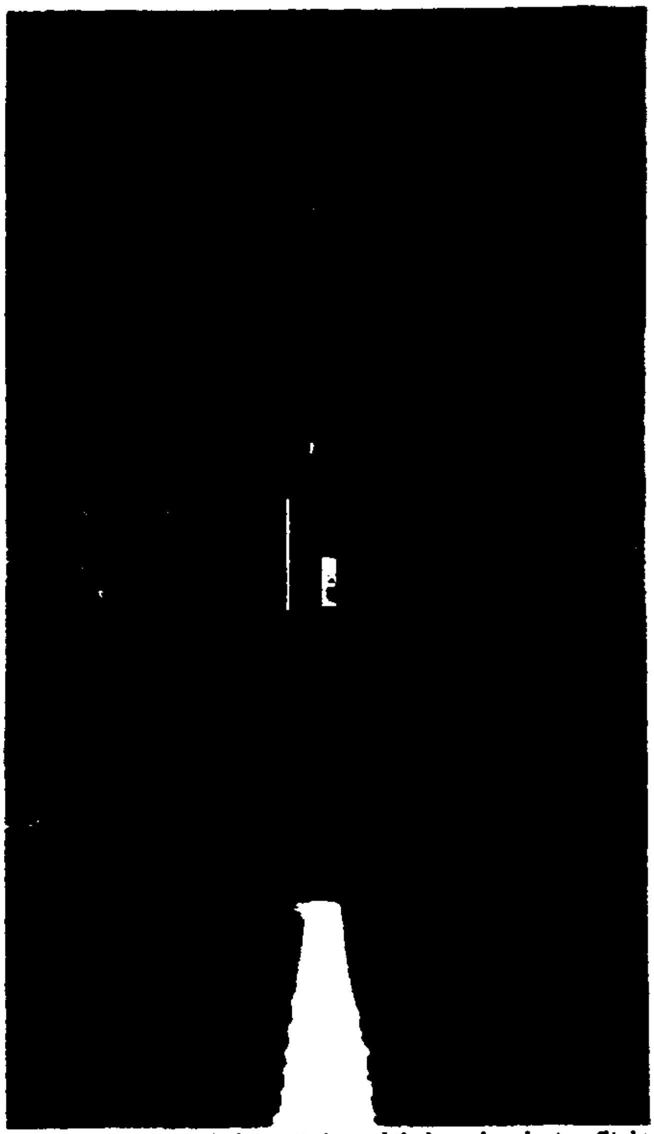


Fig. 5. Hermes.



21


Operating temperature, °F (°C)
4000
(2205)
3000
(1650)
2000
(1095)
1000
(540)
Carbon/carbon composites
Ceramics
Ceramic composites
Metal matrix composites
Intermetallics and intermetallic composites
Conventional materials (titanium and superalloys)
10⁴
Strength/weight ratio



Pershing II missile lifts off the mobile launcher during flight testing. A high-performance C/C rocket nozzle gives the Pershing II twice the range of the Pershing IA. By electronically comparing the target area with pre-stored target location data, the missile can strike with pinpoint accuracy. Courtesy, Martin Marietta.