PLASMA ARC TESTING TECHNIQUES FOR SPACE SHUTTLE
REUSABLE SURFACE INSULATION (RSI)

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INTRODUCTION

Reusable Surface Insulation (RSI) is considered a prime candidate for thermal protection of large areas of the space shuttle orbiter vehicle. As part of a program supported by NASA, Manned Spacecraft Center, on assessment of technical risks associated with the development and/or use of nonmetallic materials for the reusable orbiter, Battelle-Columbus recently completed a task to provide screening data on thermal and mechanical properties of RSI materials. Results of mechanical property evaluations of three candidate RSI materials are presented in the paper by Kistler, et al, in Volume I of these Proceedings. Within this task, dynamic, multicycle, plasma arc exposures of the RSI materials were conducted in the Battelle Aerothermal Research Facility. The techniques used to characterize material response during plasma arc exposures are described in this paper.

AEROTHERMAL RESEARCH FACILITY

(Figure 1)

Plasma arc exposures of three RSI materials were conducted in the BCL Aerothermal Research Facility. General Electric's REI, Lockheed's LI-1500, and McDonnell Douglas' HCF (January 1972) were tested in multicycle exposures. The GE material was mullite fiber insulation, bulk density of 200 to 210 kg/m^3 including the coating, with SR2-55A1 (brown over green, fibrous intermediate zone) and SR2-XSR2 (brown) coatings. The Lockheed material was the silica insulation, bulk density of 260 to 290 kg/m ^{3}including the coating, with an 0042 coating (bluish-gray). The McDonnell Douglas material was the mullite HCF, bulk density of 270 to 280 kg/m^3 including the coating, with an $M5_{23}A7P_{700}$ coating (black).

The facility consists of two separate wind tunnel legs, each of which includes a continuous-flow arc heater, a conical convergent-divergent nozzle, a free-jet cabin, and a conical convergent-divergent diffuser. Each leg exhausts to the pressure recovery system, which consists of a five-stage steam ejector. Electrical power for both legs is supplied by a 1.5 saturable reactor. For these exposures, the nontoxic, nonradioactive leg of the facility was used with the high-enthalpy arc heater. A nozzle with a 2.54-cm (1-inch)-diameter throat and a 12.7-cm (5-inch)-diameter exit was used.

AEROTHERMAL RESEARCH FACILITY

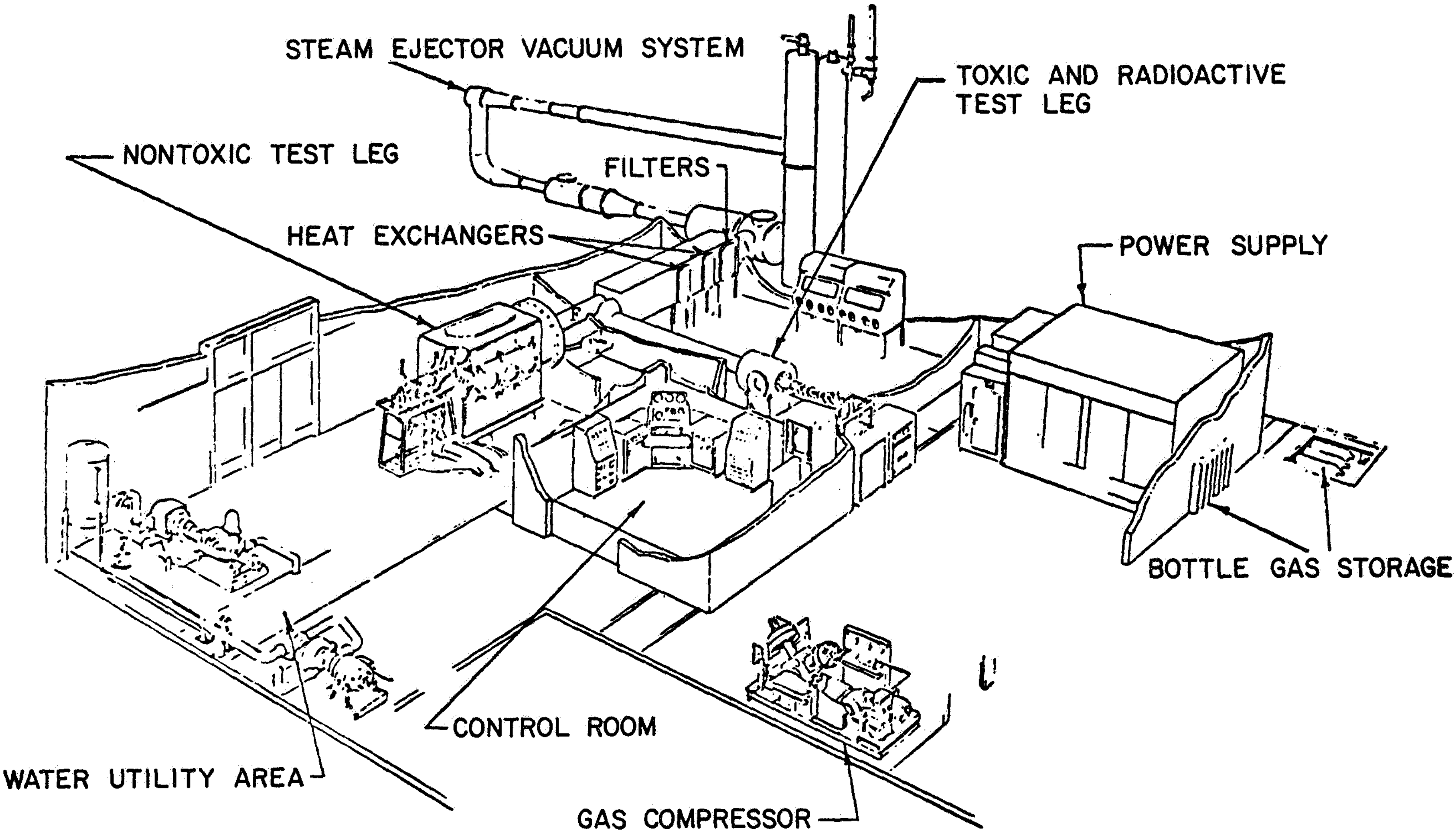

Figure 1

NOMINAL SURFACE TEMPERATURE HISTORY DURING ARC-PLASMA EVALUATIONS

(Figure 2)

One dynamic reentry profiling condition was used for the RSI specimens. The nominal surface-temperature profiling condition for the materials is shown in figure 2 along with a reentry surface-temperature history representative of a high cross-range orbiter (Area 2 on lower surface of the vehicle at 50-percent length location). In order to avoid rapid expansion of the coating relative to the insulation material and thermal-stress failure of the insulation material due to the high temperature gradients that would result from insertion of "cold" specimens into the heated test stream, electric radiant heaters were used to preheat the specimens prior to initiating the arc.

The surface of the specimens was heated to 1032-1089°K (1400-1500°F) using the radiant heaters. Two radiant heaters were mounted on a traversing mechanism in the test cabin so they could be moved away from the RSI specimens just prior to the arc heater start. The radiant heaters were positioned such that there was a narrow gap between them through which a pyrometer sighted on one of the specimens.

Limited experiments were conducted on the coating/insulator systems prior to the arc exposures to determine if cracks would develop in the coating materials as a result of the preheat thermal cycle (identical preheat cycle used as part of the arc exposures). Visual examinations of the specimens exposed to the heating cycle indicated no such failures.

When the specimen surface temperature reached the desired level, the radiant heaters were moved out of the way and the arc heater was started. Power to the radiant heaters was left on during the first five seconds in which the heaters were being moved in order to minimize cooldown of the specimens prior to convective heating from the arc-heated gas. The time interval between first movement of the radiant heaters and initiation of the arc was approximately eight seconds. The specimens were then convectively heated by the arc-heated gas for approximately 20 minutes following the surface temperature history shown in figure 2. At approximately 30 minutes into the cycle, the power and gas flow to the arc heater was terminated, and the specimens were allowed to cool until the temperature of the coating was 422°K (300°F) or less. The cooling water to the holder in which the specimens were mounted was also turned off when the arc-heater power was terminated. This procedure was repeated so that each pair of specimens received four such cycles.

NOMINAL SURFACE TEMPERATURE HISTORY DURING ARC-PLASMA EVALUATIONS

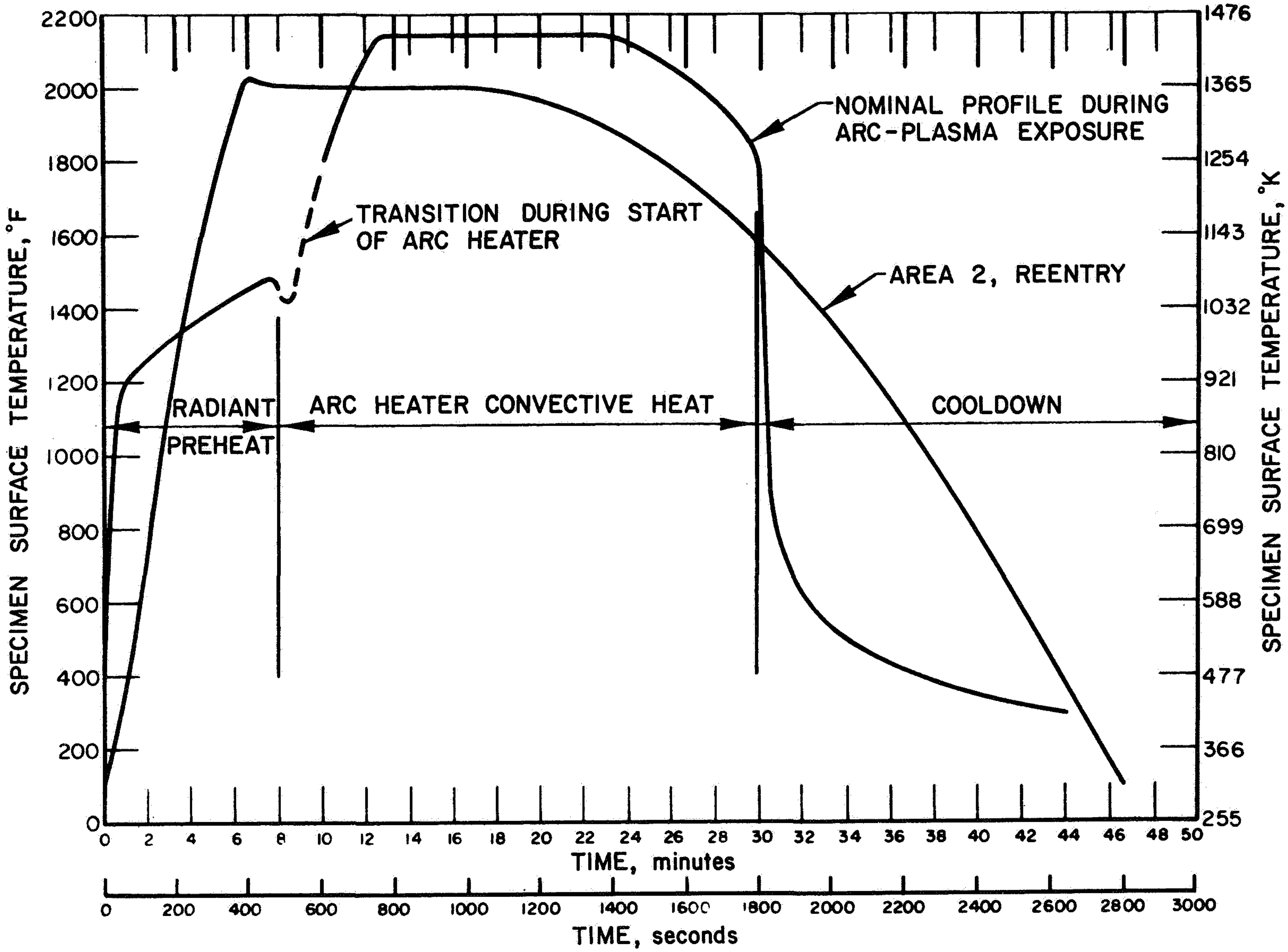

Figure 2

DETAILS OF RSI SPECIMEN HOLDER USED IN PLASMA-ARC EXPOSURES

(Figure 3)

RSI specimens having nominal dimensions of 2.54 x 2.54 x 14.99 cm were tested. Two specimens were tested simultaneously so that the specimen surface area exposed to the test gas was nominally 5.08 x 14.99 cm. In each run, specimens supplied from only one contractor were mounted and exposed. The specimens were paired so that geometric discontinuities at the specimen-to-specimen interface were minimized in order to avoid large temperature nonuniformities at the interface.

The specimens were mounted in a copper model holder 1.9 cm thick with machined passages for water cooling. Overall dimensions of the water-cooled holder are 13.9 cm wide and 26 cm long (gas flow direction). A cutout was provided in the holder for the specimens, which were seated on a 0.62 cm thick aluminum plate located below the water-cooled model holder. The specimens were not bonded to the aluminum plate. The cutout was nominally 5.88 x 15.7 cm and was centered with respect to the width of the holder. The cutout extended from 8.9 cm to 24.7 cm from the leading edge of the holder in the flow direction.

The specimens protruded approximately 0.62 cm below the bottom surface of the water-cooled holder. The aluminum plate, on which the specimens were seated, was fastened to the water-cooled holder. The position of the 0.62 cm thick plate could be readily varied by adjustment of the fastening screws to provide the proper specimen height and orientation relative to the water-cooled holder. Cerafelt insulation, 192 kg/m^3 (12 pcf), was placed around the portion of the specimens protruding below the water-cooled holder. This material served to maintain low heat losses from the specimens to the enclosed surroundings beneath the water-cooled model holder.

Zircar insulation was placed between the sides and ends of the specimens and the water-cooled copper to reduce heat losses from the specimens and to minimize stresses induced in the specimens by fastening.

The water-cooled holder was set at an angle of attack of 18 degrees with respect to the test gas stream. This angle was previously used in exposures of metallic space-shuttle candidate TPS materials.

DETAILS OF RSI SPECIMEN HOLDER USED IN PLASMA-ARC EXPOSURES

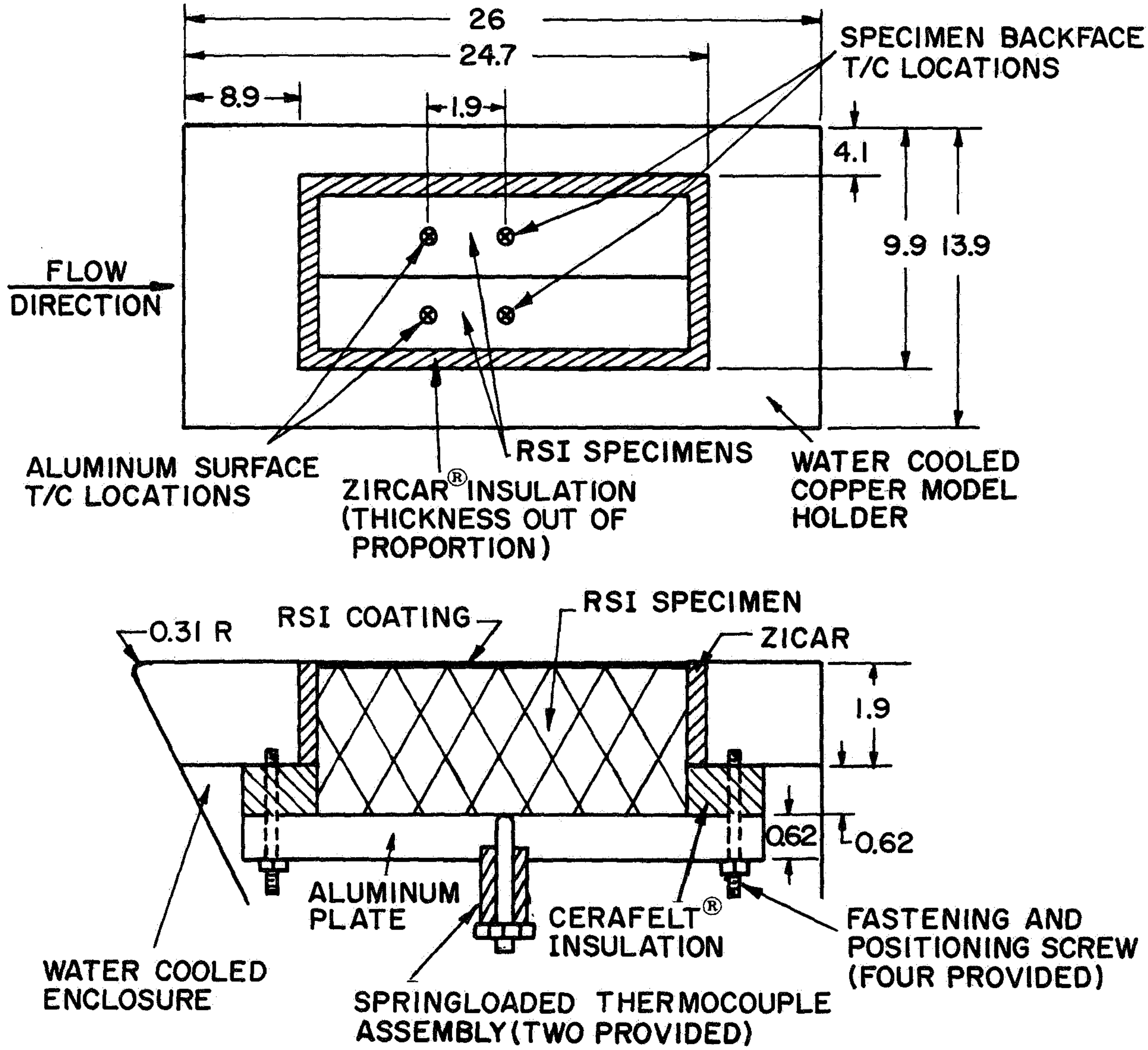

Figure 3

INSTRUMENTATION USED DURING PLASMA-ARC EXPOSURES

(Figure 4)

A spring-loaded, 28-gauge, chromel-alumel thermocouple was used to determine the backface temperature of each specimen during exposure. A light spring was used to avoid penetration of the thermocouple bead into the RSI material.

Two infrared pyrometers were used to measure the surface temperature of the specimens. One pyrometer (Thermodot TD-9) has a centerband sensing wavelength of 0.8 μm and the other pyrometer, manufactured by Ircon, Inc. (Model 300), senses in the wavelength range of 2.0 to 2.6 μm with a peak response of 2.3 μm. The response of the TD-9 is relatively insensitive to the surface emittance, whereas accurate knowledge of the surface emittance is necessary to obtain accurate specimen surface temperatures using the Model 300. The TD-9 pyrometer was sighted at the center of one of the specimens (with respect to length and width) and was used for arc-heater control of the gas enthalpy and specimen surface temperature with time. The Model 300 pyrometer was sighted at a location adjacent to the TD-9 site. The Model 300 pyrometer, which is suitable for measuring temperatures as low as 366°K (200°F), was used to obtain specimen surface temperature during preheat and cooldown before and after the arc-plasma exposures. This pyrometer was also used during the time when the arc heater was in operation, although not for control purposes. Also, because the pyrometers were mounted on top of the test cabin, it was necessary to connect the signals for radiation attenuation due to the test cabin window.

Black-and-white infrared photographs were taken during the nominal temperature exposure portion of the cycles to determine the temperature gradients over the entire exposed surface area of the specimens. Kodak HIE 35-mm infrared film was used for these pictures with an 87C filter over the camera lens.

A Spatial Data Datacolor System was used to convert the shades of gray in the infrared photographs to a spectrum of colors. In this technique, the surface temperature variation is displayed by a series of colors.

INSTRUMENTATION USED DURING PLASMA–ARC EXPOSURES

- BACKFACE THERMOCOUPLES
- INFRARED PYROMETRY

			EMITTANCE SETTINGS		
			MDAC (HCF)	LMSC (LI)	GE (REI)
THERMODOT	TD–9	0.8 μM	0.915	0.84	0.65
IRCON	300	2.3 μM	0.85	0.9	0.6

- INFRARED PHOTOGRAPHY

  BLACK AND WHITE 35 MM

  COLOR ANALYZER

Figure 4

ENVIRONMENTAL CONDITIONS FOR COATED RSI PLASMA-ARC EXPOSURES

(Figure 5)

Environmental conditions for the RSI materials are summarized in figure 5. The arc heater reservoir pressure was measured experimentally using a pressure transducer and the bulk gas enthalpy was calculated using the energy balance technique. Surface pressures were measured using water-cooled blocks that fit into the water-cooled copper model holder. Surface shear stresses were calculated using a technique described by Harney and Petrie[2].

Heat transfer rates were measured at arc heater conditions identical to those needed to obtain the nominal temperature levels for the LMSC and MDAC and GE specimens.[1] Heat-flux calorimeters were positioned in a water-cooled block located in the water-cooled plate in place of the RSI materials. The heat-flux calorimeters were located at approximately 2.29 and 5.33 cm from the leading edge of the cutout in the water-cooled plate. Measured cold wall heat transfer rates for the MDAC/GE arc heater condition are 38 and 32 x 10^4 W/m^2 for the front and rear calorimeters, respectively. The measured heat transfer rates for the LMSC arc heater condition are 60 and 51 x 10^4 W/m^2 for the front and rear calorimeters, respectively. Calculated cold-wall heat-transfer rates using the method of Reference 2 are 37 and 33 x 10^4 W/m^2 for the MDAC/GE condition and 62 and 51 x 10^4 W/m^2 for the LMSC condition.

ENVIRONMENTAL CONDITIONS FOR COATED RSI
PLASMA-ARC EXPOSURES

SPECIMEN TYPE	SURFACE TEMPERATURE °F	SURFACE TEMPERATURE °K	RESERVOIR PRESSURE ATM	RESERVOIR PRESSURE KN/M^2	GAS TOTAL ENTHALPY BTU/LB	GAS TOTAL ENTHALPY MJ/KG	SURFACE PRESSURE[(a)] Torr	SURFACE PRESSURE[(a)] KN/M^2	AVERAGE SURFACE SHEAR STRESS PSF	AVERAGE SURFACE SHEAR STRESS N/M^2
GE	2135	1440	1.1	112	3500-4300	7.1-10.0	12.5	1.7	2.0	96
LSMC	2135	1440	1.3	132	5800-6600	13.5-15.3	16	2.1	2.1	101
MDAC	2135	1440	1.1	112	3500-4100	7.1- 9.5	12.5	1.7	2.1	101

(a) Based on average of six pressure measurements obtained at one run condition.

Figure 5

COMPARISON OF SPECIMEN SURFACE TEMPERATURES OBTAINED FROM PYROMETERS

(Figure 6)

Specimen temperatures obtained from the pyrometers during the nominal temperature portion of the cycle are compared in figure 6. For the emittance settings used, a maximum temperature difference of approximately 75°K (135°F) is indicated at the two wavelengths. Potential sources of error contributing to the differences in indicated temperatures by the pyrometers are (1) calibration inaccuracies of the pyrometers (calibration accuracies are 33.3°K (60°F) for the Model 300 pyrometer and 15°K (27°F) for the TD-9; (2) arc radiation reflected from the specimen surfaces (e.g., Land has found that the background radiant flux from an arc heater was highest at a wavelength of about 0.5 μm, with a lower peak at a wavelength of 0.8 μm, and a decreasing intensity with increasing wavelength[3]); (3) differences in infrared transmission of the coatings (limited data published by Lockheed indicate that coating transmission is 0.1 percent or less in the wavelength range of 1.5 to 2.0 μm[4]); and (4) incorrect values for the coating emittances at the sensing wavelengths of the two pyrometers (relatively little data have been published on the variation of coating emittance with wavelength). On the balance, it appears that the nominal coating temperatures obtained from the pyrometers are in reasonably good agreement.

During the specimen exposures, attempts were made to see if a gray body emittance could be determined by varying the pyrometer emittance settings until the indicated temperatures were identical. However, due to errors associated with arc reflected radiation, nongrayness of the coatings, and inaccuracies associated with the pyrometer calibrations, the resulting emittance values were unrealistic in comparison to published data[4-6].

COMPARISON OF SPECIMEN SURFACE TEMPERATURES
OBTAINED FROM PYROMETERS

WAVELENGTH		EMITTANCE SETTING			INDICATED SPECIMEN TEMPERATURE, °K (°F)		
μm	μIN.	MDAC	LMSC	GE	MDAC	LMSC	GE
0.8	32	0.915	0.84	0.65	1440 (2135)	1440 (2135)	1440 (2135)
2.0	79	0.85	0.9	0.6	1495 (2230)	1367 (2000)	1367 (2000)

Figure 6

NOMINAL SPECIMEN SURFACE TEMPERATURE VARIATION IN FLOW DIRECTION

(Figure 7)

Nominal leading edge to trailing edge temperature gradients obtained during the nominal temperature portion of the exposures are shown in figure 7. Values of the ratio of the leading-edge-to-trailing-edge temperatures can be compared to a value of 1.14 which was obtained on the basis of laminar convective heat-transfer-rate distribution (fully catalytic wall), negligible axial conduction in the RSI material, and a reradiation-equilibrium exposed-surface boundary condition. The specimen surface temperatures at a distance of 7.6 cm from the leading edge were obtained from the TD-9 pyrometer output at the emittance settings shown in figure 6. Temperatures at 7.6 and 14.2 cm from the leading edge were obtained from (1) a calibration of the infrared film density with relative film energy level, (2) a calculated relationship between the surface temperature and the radiant energy, and (3) a known specimen surface temperature (from the pyrometer) and the corresponding film density.* Thus, although the absolute temperatures may be in error due to errors associated with temperature measurement with the pyrometer, the differences in surface temperature (axial gradient) should be accurate.

It can be seen that the highest surface temperature gradients were obtained for the MDAC specimens. A check of the infrared photographs for all of the specimen exposures revealed consistently higher surface temperature gradients for the MDAC specimens than for the GE and LMSC specimens. These high apparent temperature gradients could be due to (1) nonuniform, elevated temperature, coating emittance characteristics at a wavelength of approximately 0.8 μm; (2) significantly different coating surface characteristics in terms of reflection of arc radiation as compared with the GE and LMSC coatings; or (3) possible degradation of the coating during elevated temperature exposure, which could change the surface emittance characteristics. Although there was some flow of the MDAC coating as a result of the plasma-arc exposures, this degradation should not have resulted in higher gradients on both the front and rear portions of the specimens.

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* See reference (7) for detailed discussion on calibration of infrared film and application of infrared photographic techniques to plasma arc testing.

NOMINAL SPECIMEN SURFACE TEMPERATURE VARIATION IN FLOW DIRECTION

MATERIAL	DISTANCE FROM LEADING EDGE OF SPECIMEN, CM (INCH)	SPECIMEN SURFACE TEMPERATURE, °K (°F)	RATIO OF LEADING EDGE TO TRAILING EDGE TEMPERATURE
GE	0.76 (0.3)	1460 (2173)	1.09
	7.6 (3.0)	1440 (2135)	
	14.2 (5.6)	1340 (1949)	
LMSC	0.76 (0.3)	1494 (2232)	1.11
	7.6 (3.0)	1440 (2135)	
	14.2 (5.6)	1343 (1954)	
MDAC	0.76 (0.3)	1520 (2273)	1.2
	7.6 (3.0)	1440 (2135)	
	14.2 (5.6)	1266 (1819)	

Figure 7

INFRARED PHOTOGRAPH OF GE SPECIMENS DURING PLASMA-ARC EXPOSURE

(Figure 8)

An infrared photograph of two GE specimens taken during plasma-arc exposure is shown in figure 8. Actually, the photographs of figures 8-10 are negatives so that the hotter leading portions of the specimens appear as dark regions whereas the cooler portions appear as lighter regions.

In spite of the efforts to minimize physical discontinuities at the specimen-to-specimen interface, it can be seen that there is a temperature gradient across the interface. The surface temperatures shown in the figure are those listed previously in figure 7 and were obtained as described in the discussion of that figure. A more comprehensive mapping of the surface temperature distribution can be obtained by recording the photographic density of the transparency according to a fixed grid system. In this way, isotherms of the surface can be displayed such that temperature increments as small as 5°K can be resolved.

INFRARED PHOTOGRAPH OF GE SPECIMENS DURING PLASMA-ARC EXPOSURE

Note: Arc-heated gas flow is from left to right.

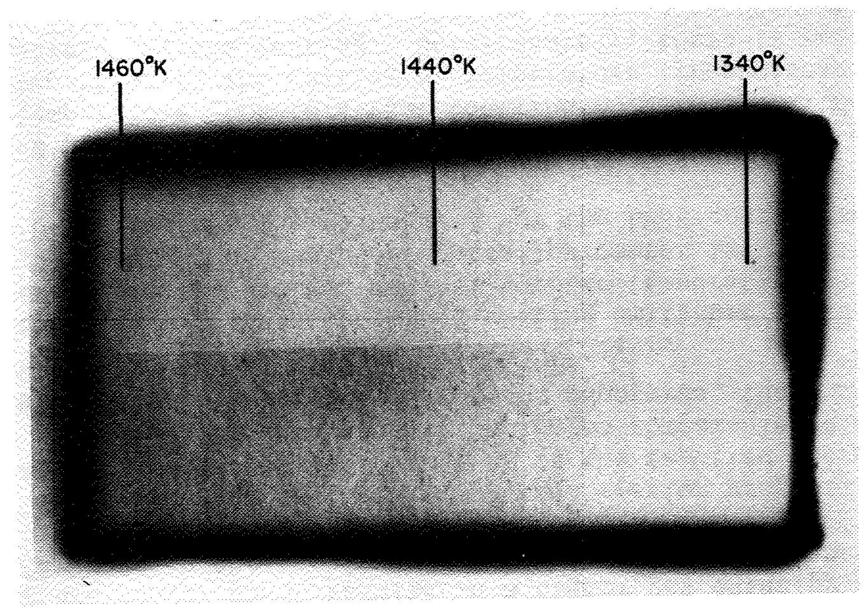

Figure 8

INFRARED PHOTOGRAPH OF LMSC SPECIMENS DURING PLASMA-ARC EXPOSURE

(Figure 9)

An infrared photograph (negative) of two LMSC specimens taken during plasma-arc exposure is shown in Figure 9. It can be seen that the region in which the surface temperature is 1440° K appears darker (hotter) than the corresponding region for the GE specimens (Figure 8). This is due to the higher emissivity of the LMSC coating as compared to the emissivity of the GE coating.

During the plasma-arc exposures, it was necessary to operate the arc heater at higher input power levels in order to achieve the desired nominal maximum surface temperature (1440° K) for the LMSC specimens. Operation at a higher arc-heater power results in a higher gas enthalpy and a correspondingly higher convective heat-transfer rate to the specimens. Several possible explanations for this phenomenon include (1) differences in heat-transfer conduction losses, (2) incorrect (too high) emittance settings on the pyrometers, (3) differences in reflective and transmission properties of the coating, and (4) differences in surface catalytic efficiencies. A check of the reported thermal conductivities and thermal diffusivities of the three insulation materials indicates comparable values with no significant differences among the materials. Also, during the plasma-arc exposures, the LMSC specimens exhibited the lowest backface temperature rise of the three RSI materials.

Pyrometer emittance settings higher than the actual coating emittance would require increased power levels (and gas enthalpies) to obtain the desired nominal surface temperature as indicated by the pyrometer output signal. However, the output of the TD-9 control pyrometer is relatively insensitive to emittance setting, and it is believed that the value used for the LMSC coating surface emittance is reasonably accurate.

Differences in reflective properties of the coatings could also affect the power level needed to achieve the nominal surface temperature. Factors that contribute to this include radiation characteristics of the arc, optical properties of the coating at temperature (transmissivity, emissivity, reflectivity), and topographic properties of the coating. Unfortunately, there is relatively little property information available for the RSI coating systems so that an accurate assessment of their effects cannot be made. However, it is believed that differences in the reflective properties of the coatings would not result in the need to operate at significantly higher power levels for the LMSC specimens.

Differing surface catalytic efficiencies could necessitate operation at different power levels to achieve the same surface temperature. In the plasma-arc exposures, most of the oxygen was dissociated (as compared with a sizable but smaller portion during shuttle entry), and little nitrogen is dissociated. It is possible that differences in surface catalytic efficiencies of the LMSC material as compared with the GE and MDAC materials could have resulted in the need for significantly higher gas enthalpies in order to achieve the same surface temperature.

INFRARED PHOTOGRAPH OF LMSC SPECIMENS DURING PLASMA-ARC EXPOSURE

Note: Arc-heated gas flow is from left to right.

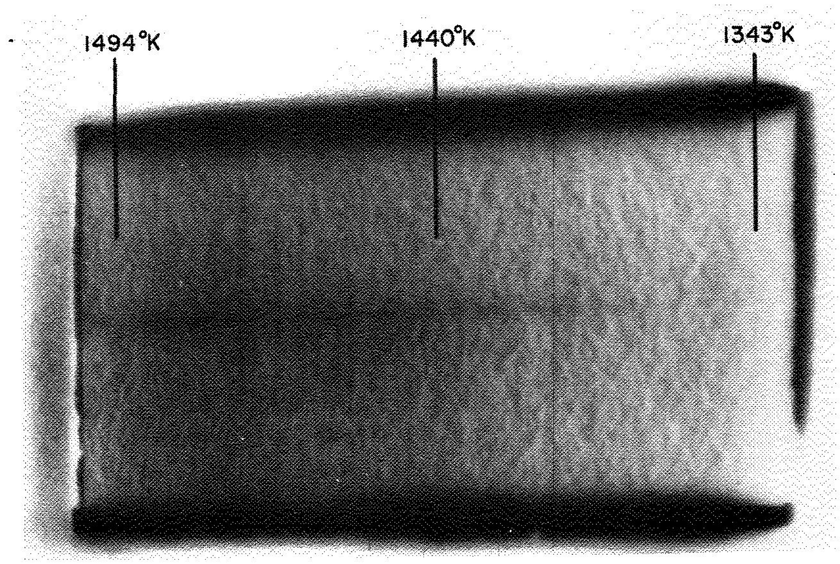

Figure 9

INFRARED PHOTOGRAPH OF MDAC SPECIMENS DURING PLASMA-ARC EXPOSURE

(Figure 10)

An infrared photograph (negative) of two MDAC specimens taken during plasma-arc exposure is shown in figure 10. The region in which the surface temperature is 1440°K is darker than the corresponding region for the GE specimen and lighter than the corresponding region for the LMSC specimen. This is consistent with the relative emittance values of the three coating systems, i.e., LMSC, MDAC, and GE, in decreasing value of coating emittance.

INFRARED PHOTOGRAPH OF MDAC SPECIMENS DURING PLASMA-ARC EXPOSURE

Note: Arc-heated gas flow is from left to right.

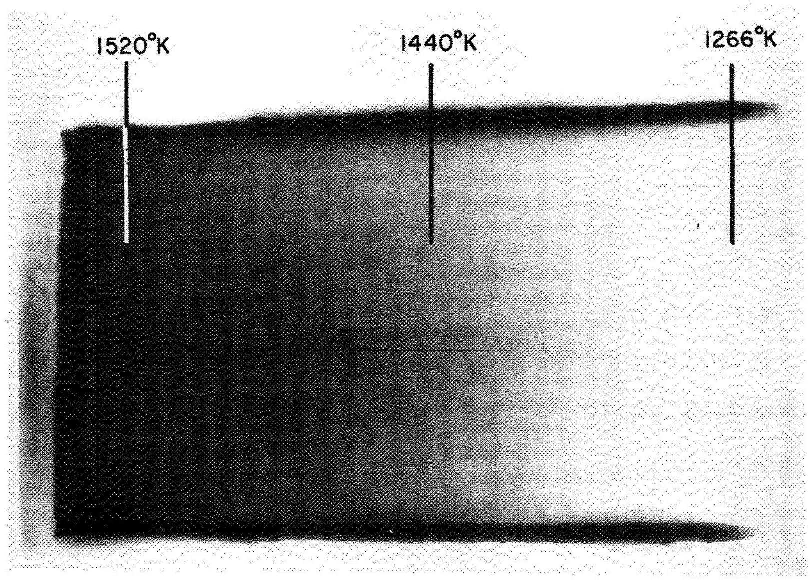

Figure 10

ISODENSITY CONTOURS OF INFRARED PHOTOGRAPH - GE SPECIMENS

(Figure 11)

A color enhanced (reproduced here in black and white) picture of the infrared photograph of the GE specimens is shown in figure 11. In the original, each color represents a photographic density interval considered to be a region of constant temperature. For the Spatial Data Datacolor System used to obtain this image enhanced photograph, the number of colors can be varied by altering the density interval to a maximum of 32 colors. In this figure these colors appear as various shades of gray. For a fixed, preselected photographic density interval, the number of colors on the photograph is proportional to the surface temperature gradient.

The temperature discontinuity previously identified in the infrared photograph of figure 8 at the specimen-to-specimen interface can be clearly seen in figure 11. The central portions of the specimens can be characterized as regions of relatively uniform temperature distribution.

ISODENSITY CONTOURS OF INFRARED PHOTOGRAPH - GE SPECIMENS

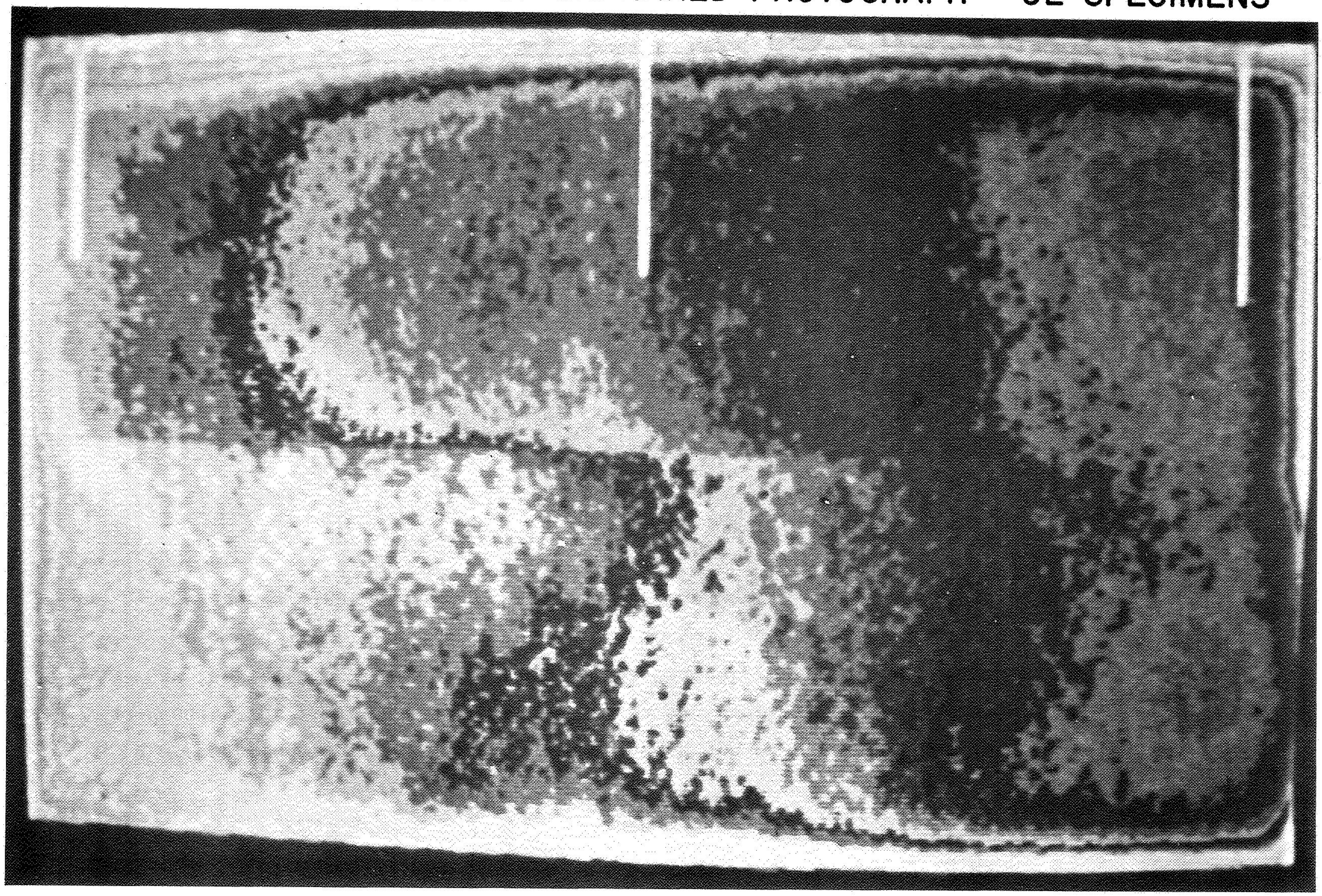

Figure 11

ISODENSITY CONTOURS OF INFRARED PHOTOGRAPH - LMSC SPECIMENS
(Figure 12)

A color enhanced picture of the infrared photograph of the LMSC specimens is shown in figure 12. The density interval used in this photograph is identical to that used in figure 11. It can be seen that the temperature distribution in the central region of the specimens is relatively uniform. The broad light band running from the bottom center to the upper left of the photograph is due to extraneous light present when the photograph of the image enhanced black and white infrared photograph was made.

ISODENSITY CONTOURS OF INFRARED PHOTOGRAPH - LMSC SPECIMENS

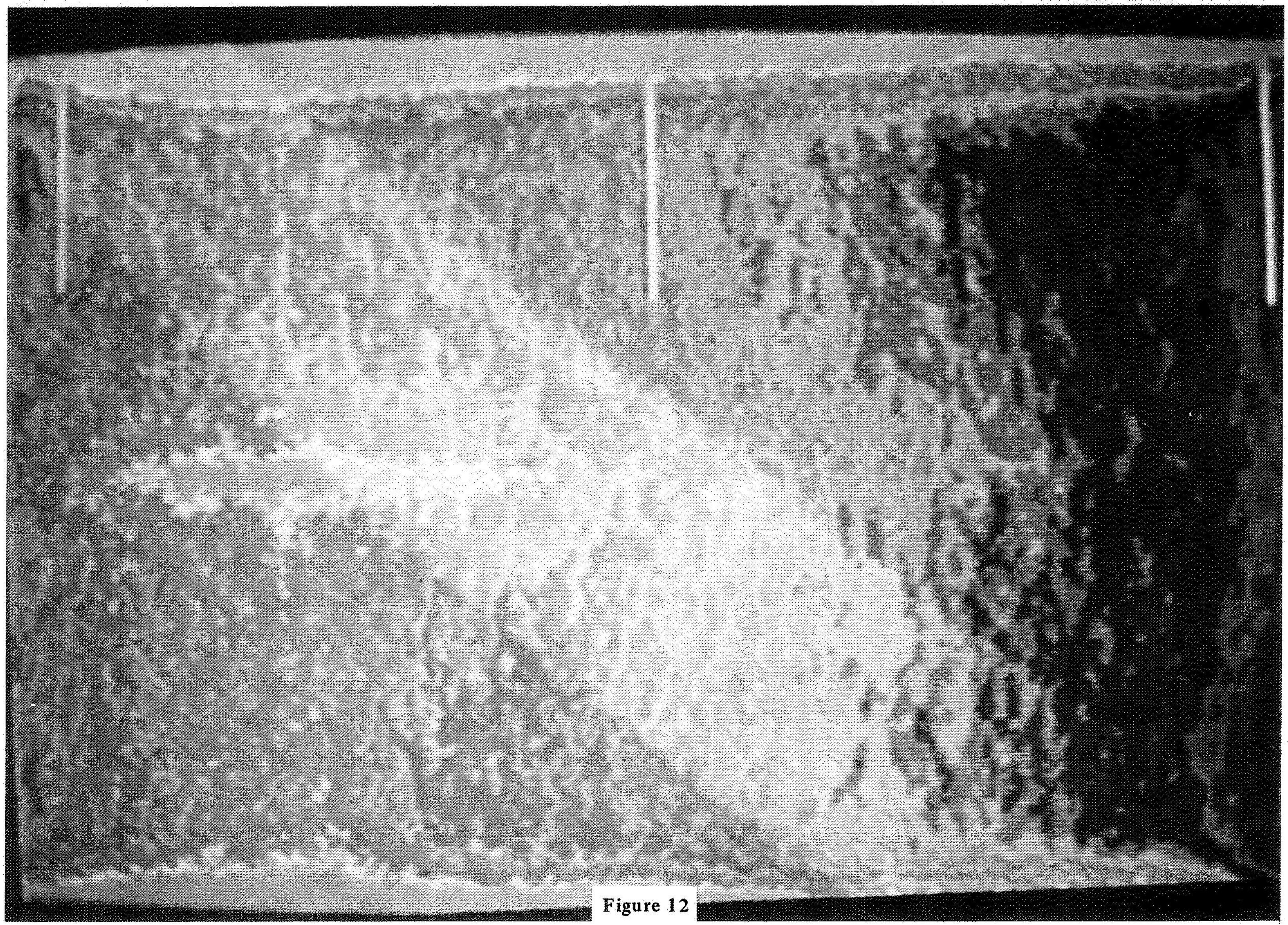

Figure 12

ISODENSITY CONTOURS OF INFRARED PHOTOGRAPH - MDAC SPECIMENS
(Figure 13)

A color enhanced picture of the infrared photograph of the MDAC specimens is shown in figure 13. The relatively high temperature gradients in the central portion of the specimens can be ascertained from the large number of color bands in this region. An identical density increment was used for this photograph as was used for figures 11 and 12.

The temperature range represented by each color in figures 11-13 is approximately 20°K. A finer increment of temperature per color can be achieved by selecting a finer density interval on the Datacolor System. This would result in a greater number of constant density intervals for the density range of the photograph.

ISODENSITY CONTOURS OF INFRARED PHOTOGRAPH - MDAC SPECIMENS

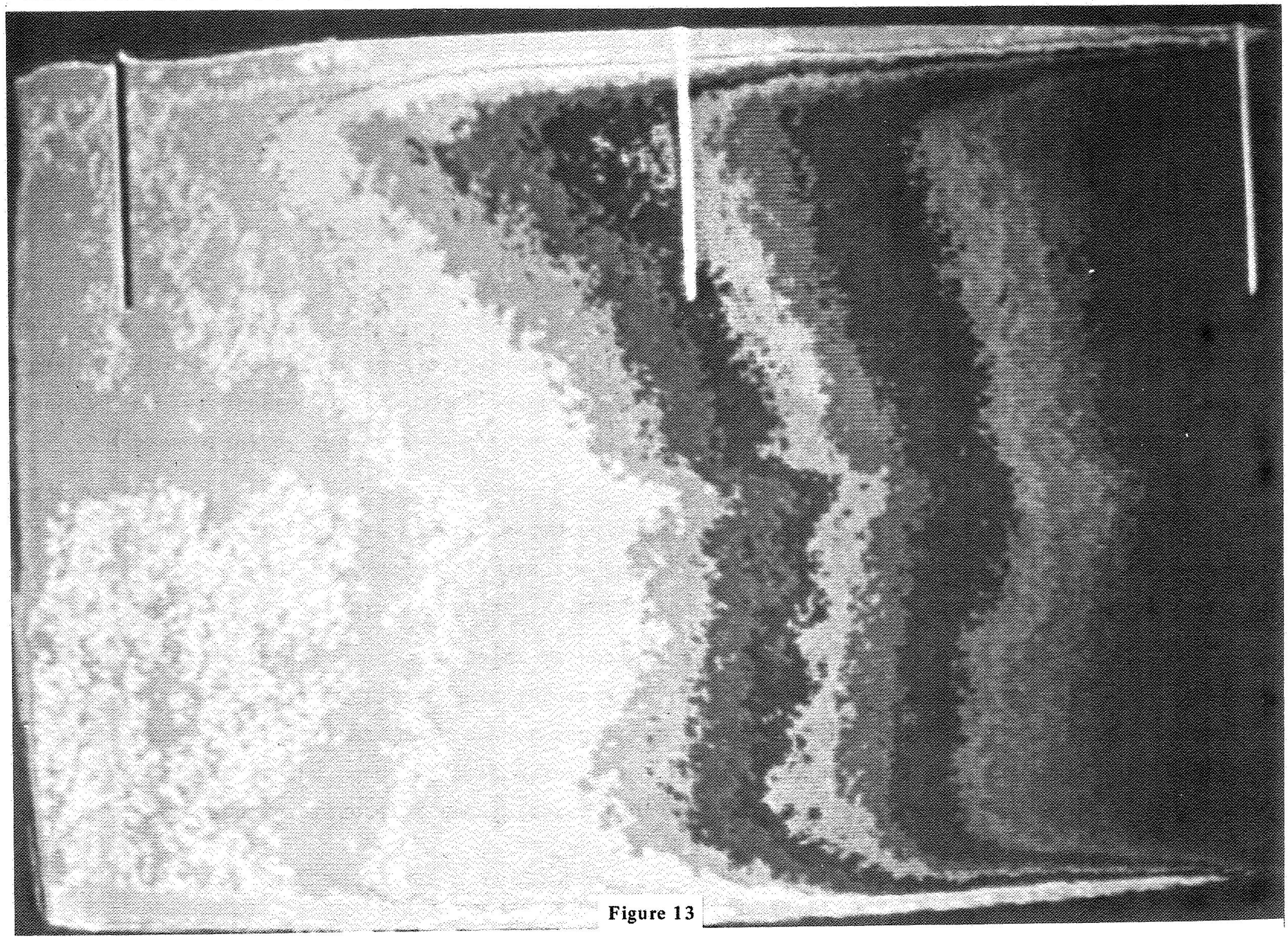

Figure 13

ISODENSITY CONTOURS AND DENSITY PROFILE - MDAC SPECIMENS

(Figure 14)

A color enhanced picture of the infrared photograph of the MDAC specimens is shown in figure 14 along with a plot of the local density value for a section through the RSI material. The density interval used in this picture is one-half that used in figure 13. Thus, there are twice as many color contours for a given temperature interval in this figure as there are in figure 13. The temperature range represented by each color is approximately 10°K.

The amplitude of the plotted curve (as measured from the abscissa through the specimen) at any axial location on the specimen represents the local density or surface temperature. From this plot, the axial surface temperature gradients can be readily determined by direct measurement from the abscissa.

The percentage of the surface area at any specified temperature level can be automatically obtained by integration of the color bands representing the desired temperature level or increment. This integration is performed electronically within the Datacolor System and the result is displayed on a digital voltmeter. With this technique, it is possible to determine the percentage of the specimen surface above or below specified temperatures.

ISODENSITY CONTOURS AND DENSITY PROFILE - MDAC SPECIMENS

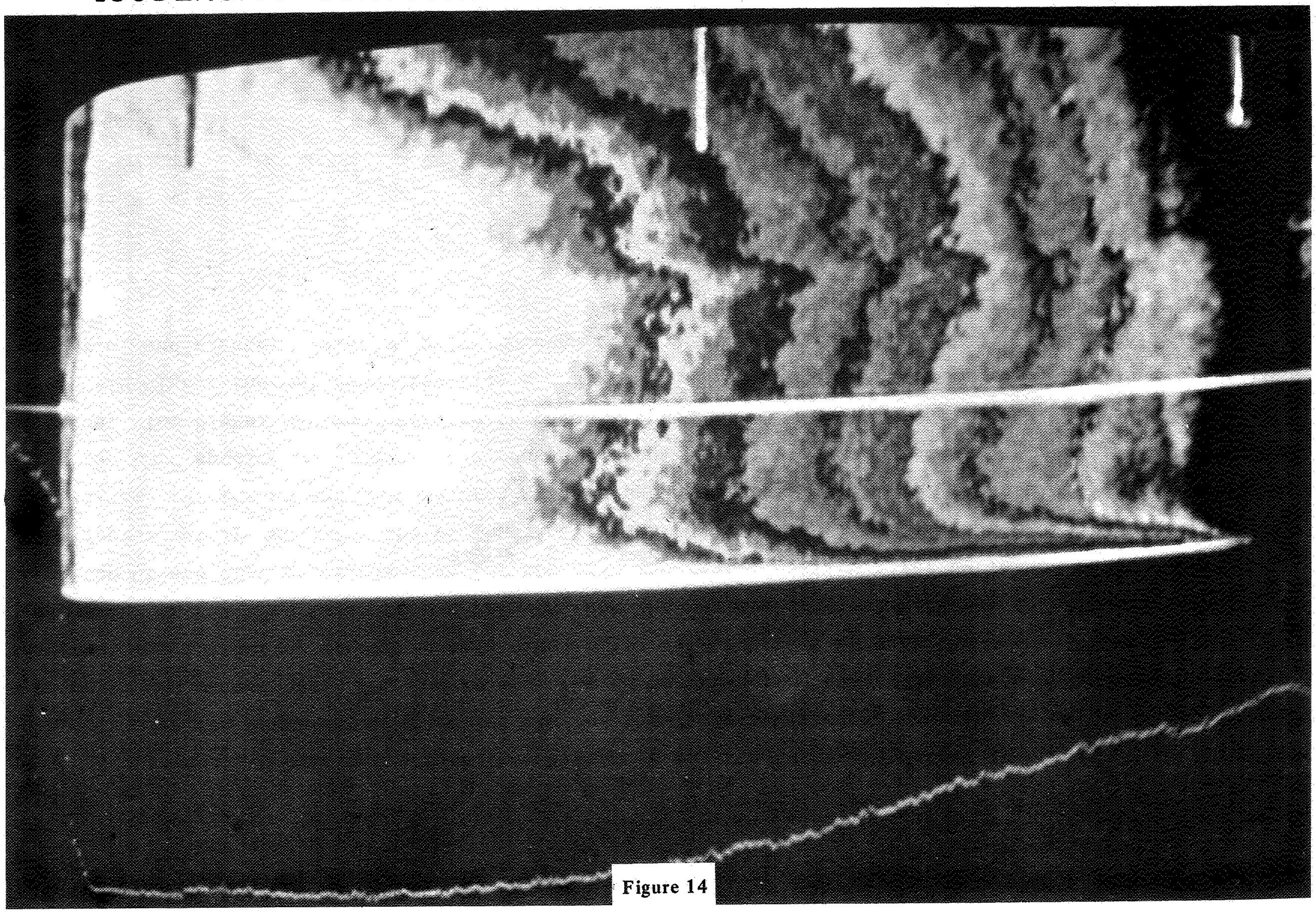

Figure 14

SPECIMEN BACKFACE TEMPERATURES DURING PLASMA-ARC EXPOSURES

(Figure 15)

Representative backface temperature histories for the three RSI materials are shown in figure 15. In each case the temperature histories are for the first cycle of the multicycle test. Also, in order to provide a common basis for comparison, the temperature-time histories have been shifted horizontally so that arc initiation occurs at zero time. This was necessary because the preheat time varied depending on RSI material. It can be seen that the maximum specimen backface temperatures are higher for the GE and MDAC materials than for the LMSC material. Maximum first cycle backface temperatures are approximately 380°K for the GE material, 370°K for the MDAC material, and 320°K for the LMSC material. For the GE and MDAC materials these peaks occurred just prior to termination of the arc. For the LMSC specimens, however, the peak backface temperatures occurred slightly following arc termination. The higher maximum backface temperatures for the GE and MDAC specimens are probably due to slightly higher thermal conductivities and diffusivities of these materials in comparison to the LMSC material and greater radiation shine-through for the larger diameter, mullite fiber materials.

SPECIMEN BACKFACE TEMPERATURES DURING PLASMA-ARC EXPOSURES

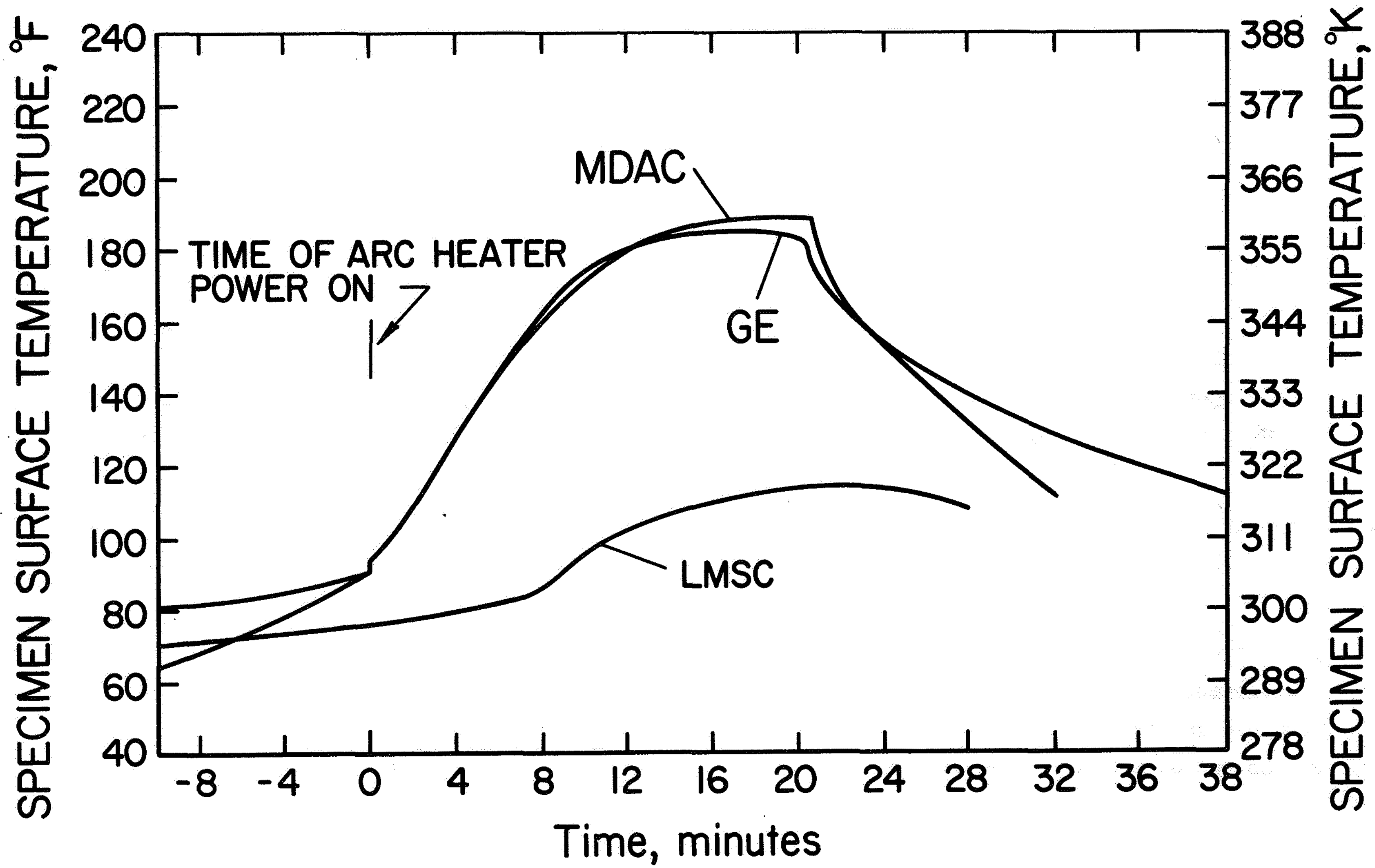

Figure 15

CONCLUDING REMARKS

Relatively accurate surface temperature characterization of RSI materials can be obtained during plasma arc exposures. Infrared pyrometry, infrared photography, and color image enhancement are useful techniques that can be used in arc-heated wind tunnel environments to measure surface temperature levels and degree of temperature uniformity. Variation in surface temperatures as small as 5 to 10°K can be distinguished with the infrared and color enhancement techniques.

Accurate information on specimen emittance and emittance change in a dynamic, plasma-arc environment is difficult to obtain because of pyrometer calibration inaccuracies, arc-reflected radiation, and nongrayness of the surface.

Higher arc-heater power levels are required to heat the LMSC RSI to the nominal surface temperature as compared to power levels needed to achieve the nominal surface temperatures for the GE and MDAC materials. Differences in surface catalytic efficiencies of the coatings are probably responsible for the higher required power levels.

Higher backface temperatures are experienced for the GE and MDAC specimens than for the LMSC specimens.

REFERENCES

1. Bartlett, E.S., et al, "Degradation and Reuse of Radiative-Thermal-Protection-System Materials for the Space Shuttle", Final Report, Battelle Columbus Laboratories, Columbus, Ohio, October 25, 1972, Contract NAS8-26205.

2. Harney, D.J. and Petrie, S.L., "Hypersonic Surface Pressure and Heat Transfer on Slender Bodies in Variable Composition and Nonequilibrium Atmospheres", AFFDL-TR-70-31 (April 1970), 42 pp.

3. Land, D.W., "Superalloy Material Tests in a Plasma Arc Tunnel", Space Simulation, NASA SP-298, May 1972, Paper No. 64, pp. 703-721.

4. "Space Shuttle Thermal Protection System Development", Volume I, Final Report, Lockheed Missiles and Space Company, Inc., LMSC-D152738, January 17, 1972, Contract NAS9-12083.

5. "Reusable Surface Insulation (RSI) Thermal Protection Development for Shuttle", Volume I, Final Report, McDonnell Douglas Astronautics Company-East, MDC E0-557, March 21, 1972, Contract NAS9-12082.

6. "Reusable Surface Insulation Thermal Protection System Development Program", Final Report, General Electric Company, GE-EYP-012, May 1972, Contract NAS9-12084.

7. Kistler, C.W., et al, "Evaluation of Nonmetallic Thermal Protection Materials for the Manned Space Shuttle", Volume V, Final Report, Battelle Columbus Laboratories, Columbus, Ohio, NASA CR-115667, June 1, 1972.