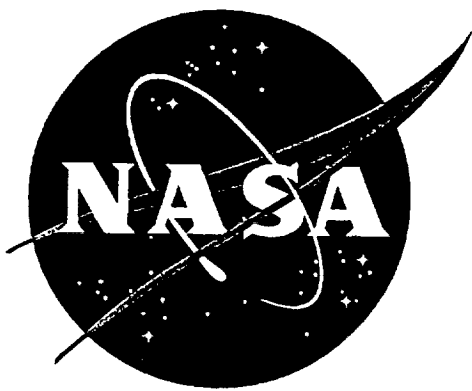


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# Development of Sensors for Ceramic Components in Advanced Propulsion Systems

## Final Report

W. H. Atkinson and R. R. Strange  
United Technologies Corporation  
Pratt & Whitney  
East Hartford, Connecticut 06108

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February 28, 1995

To: National Aeronautics and Space Administration  
Lewis Research Center  
21000 Brookpark Road  
Cleveland, Ohio 44135

Attention: Dr. Daniel L. P. Ng, Project Manager  
Mail Stop 77-1

Subject: Development of Sensors for Ceramic Components in Advanced Propulsion  
Systems - Final Report

Reference: Contract NAS3-25141

Enclosure: Twenty Five copies of subject report, NASA CR-195324 (PWA-6113-73)

We are pleased to submit Twenty Five copies of the subject report in accordance with the requirements of the referenced contract.

Very truly yours,

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A handwritten signature in cursive script, reading "William H. Atkinson".

William H. Atkinson  
Program Manager

cc: Administrative Contracting Officer  
Defense Plant Representative Office

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## 1. SUMMARY

The objectives of the "Development of Sensors for Ceramic Components in Advanced Propulsion Systems" program were to analyze, evaluate and recommend sensor concepts for the measurement of surface temperature, strain and heat flux on ceramic components for advanced propulsion systems and to conduct laboratory development of sensor systems for the measurement of surface temperatures. Such sensor systems require unique properties and exceptional durability due to both the need for compatibility with the non-metallic materials expected to be used in hypersonic propulsion systems and the need to operate in an extremely hostile environment with regard to temperature, pressure and cycling.

The "Development of Sensors for Ceramic Components in Advanced Propulsion Systems" program was separated into two phases. The objective of Phase I was to provide a survey and analysis of sensor system concepts for measuring surface temperature, strain and heat flux on ceramic components in advanced propulsion systems. Possible designs, components, and promising concepts for development were identified. An analysis was performed to determine which of the promising concepts are the most appropriate for ceramic components in advanced propulsion systems. The results of this effort were previously published in NASA CR 182111.

As a result of Phase I, three approaches for measuring surface temperature were recommended for further development: pyrometry, thin-film sensors, and thermographic phosphors. The objectives of Phase II were to fabricate and conduct laboratory demonstration tests of these three systems. A summary report of the Phase II effort, including conclusions and recommendations for each of the categories evaluated, has been submitted to NASA and is awaiting publication.

As an add-on task, emittance tests were performed on six materials furnished by NASA-Lewis Research Center. Measurements were made of various surfaces at high temperature using a Thermogage emissometer. This report describes the emittance test program and presents a summary of the results.

## 2. INTRODUCTION

In Phase I of this program, a survey of measurement techniques for temperature, strain and heat flux applicable for use on ceramic materials at very high temperatures was conducted. An evaluation of the identified techniques was then performed to select the three most promising approaches in each category. The evaluation considered a number of factors, but the useable temperature range and compatibility with the ceramic or composite materials were the major constraints. The desire to go to 2260K makes non-contact optical techniques very appealing. On this basis, pyrometry and thermographic phosphors were selected. A surface mounted contact sensor would be required if optical access was not feasible. Thin-film thermocouples are amenable to the ceramic and composite materials. Even though the thin-film thermocouples are temperature limited, they were selected as a sensor concept feasible for moderate temperature applications. A discussion of the survey results and evaluation procedure is given in Reference 1 and the results are summarized below.

Pyrometry is a non-contact technique and, hence, is not temperature limited. In fact, the higher the temperature, the more energy the pyrometer has with which to work. There are drawbacks that complicate the implementation of pyrometry. Accurate measurement of temperatures by pyrometry requires a knowledge of the emittance of the surface. For ceramic materials the emittances vary widely, and in some instances are a strong function of both wavelength and temperature. The transparency or translucency of the materials give rise to problems in interpreting the results. Pyrometry is also sensitive to the presence of reflected radiation which can produce a significant bias in the results.

During the initial contract effort, the emittance of materials was measured both at Pratt & Whitney and United Technologies Research Center (UTRC). A commercial emissometer was used at Pratt & Whitney to measure the emittance of ceramic materials at different wavelengths and temperatures. The results obtained with this device indicated that most of the ceramic materials of interest have emittances that are high and independent of temperature at the long wavelengths (from  $8\mu$  to  $14\mu$ ). This prompted the consideration of long wavelength pyrometry in this program as appropriate for the ceramic and composite materials.

Thermographic phosphors offer a novel approach to the temperature measurement problem. The measurement technique is optical, similar to pyrometry, and the phosphor materials are high temperature ceramics such as yttria. Hence, the technique appears to be temperature limited by the melting point of the ceramic as long as a phosphor is identified with an appropriate fluorescent quench time. The technique has been shown to work well in the presence of both reflected radiation and flame. Recently, there have been very significant advances in this technique (Reference 2). A concern for this technique is the durability of the phosphors at temperatures above 1475K. Various bonding techniques are being investigated by the Department of Energy (DoE) under an Air Force contract. In order to use the same materials as in the Air Force work and to make use of the existing coating technology, DoE was chosen to apply the phosphors for the contract. The two phosphors applied by DoE to our samples were yttrium oxide doped with europium ( $Y_2O_3:Eu$ ) and YAG doped with terbium (YAG:Tb).

Thin-film sensors were being considered for use on the ceramic materials as a method not requiring optical access. Conventional wire thermocouple installation methods, such as tack welding and embedding wires into trenches, are not applicable to the ceramic materials for reasons of both mechanical disturbance, point defects due to machining, cracks due to mismatch in thermal expansion and thermal disturbances (mismatch in thermal conductivity and specific heat). The thin-film sensors fabricated with metallic elements are limited in their maximum temperature capabilities, but will be very useful for a significant portion of the laboratory test requirements.



Thin-film sensors offer other advantages in their size, installation and performance. The sensors are very thin and introduce a negligible amount of mechanical, thermal, or aerodynamic perturbation and, therefore, provide a true measure of the surface temperature. They add a relatively small mass to the test piece and do not change the physical or mechanical properties. This becomes more significant when thin structures or small test pieces are involved. Thin-film sensors are installed with no structural modification to the test piece and can be located anywhere on the test piece. These factors make the thin-film sensors very attractive despite their temperature limitations.

The materials considered under the contract varied widely in physical and mechanical properties. A thin-film thermocouple program to develop application techniques for each of these materials was beyond the scope of this effort. Therefore, the scope was limited to two electrically non-conducting materials, and to three different application techniques: R.F. sputtering, ion beam etch deposition, and ion implantation and evaporation. The intent was to evaluate the current technology in each of these techniques in applying films to silicon nitride and Compglas® substrates rather than develop application techniques. The thin-film work was performed both at Pratt & Whitney Florida and United Technologies Research Center.

One of the major concerns with thin-film sensors is the ability to provide electrical insulation from substrates which are electrical conductors at high temperatures. The oxide insulators used tend to become semiconductors at the elevated temperatures. For this reason, a two-part approach to the thin-film sensors was used. For low to moderate temperatures, noble metal temperature sensors were applied to the ceramic materials. In the higher temperature area, the changes in the properties of ceramic insulators were investigated as a mechanism to determine the temperatures.

The materials considered under the contract were selected by mutual agreement with NASA and Pratt & Whitney. Six materials were investigated. These were considered as engineering materials, and were intended to be commercial samples rather than very high purity laboratory samples. Silicon nitride ( $\text{Si}_3\text{N}_4$ ) was purchased from Kyocera. Silicon carbide was obtained from Carborundum. Mullite was obtained from Coors. General Plasma supplied zirconia. Pratt & Whitney supplied Compglas® and a silicon nitride/silicon carbide composite material.

As previously mentioned, the results of this initial program were submitted to NASA in the Phase II report. At the conclusion of the initial contract effort, NASA requested Pratt & Whitney to conduct additional emittance tests on six samples supplied by NASA. This report contains the results of those additional emittance tests.

### 3. EMITTANCE TEST PROGRAM

At Pratt & Whitney, emittance measurements of various surfaces at high temperature were made using a Thermogage emissometer. Figure 1 shows a schematic of that device, while the device itself is shown in Figure 2. For emittance measurements, the test specimen was mounted on a graphite rod connected to a pneumatic actuator. This allowed the specimen to be translated rapidly from the center of the black body furnace where it was surrounded by hot walls, to the end of the furnace where the sample surroundings were cool. A radiometer was positioned to view the test specimen at both locations. Depending on the purpose of the test, a broad spectrum radiometer may be used to obtain "total normal" emittance, or a narrow spectral band radiometer may be used to obtain data in particular spectral bands. The output from the radiometer was connected to a digital oscilloscope to record the data taken during the emittance testing.

At the start of emittance testing, the sample was brought up to the test temperature of interest, and allowed to reach equilibrium, within the black body. The radiometer was positioned to obtain data from the specimen. A trace on the oscilloscope was triggered. The radiometer was then shuttered for a brief period of time to obtain a zero energy baseline. The radiometer was then unshuttered and the black body energy was measured; then the specimen was propelled out to the end of the black body tube and the energy from the specimen was measured. The movement to the end of the black body tube was fast enough that the change in specimen temperature was negligible. Once at the end of the tube, the specimen began to cool radiatively. This produced an oscilloscope trace similar to Figure 3. The emissivity of the specimen was calculated from the ratio of the energy emitted at the end of the black body tube before cooling to the energy emitted by the specimen inside the black body. During a typical test series, data were acquired in all desired spectral ranges at the lowest test temperature of interest. Testing then proceeded to successively higher temperatures.

Emittance tests were performed on six materials furnished by NASA-Lewis Research Center. Data were acquired at several temperatures and on detectors in seven different wavelength bands, as shown below.

<u>Unit</u>	<u>Detector</u>	<u>Spectral Response</u>	<u>Plot Data</u>
2000	Silicon	0.4 $\mu$ - 1.1 $\mu$	0.95 $\mu$
"G"	Germanium	1.56 $\mu$ - 1.72 $\mu$	1.6 $\mu$
6000	Lead Sulfide	2.0 $\mu$ - 2.6 $\mu$	2.3 $\mu$
7000	Indium Antinomite	4.8 $\mu$ - 5.3 $\mu$	5 $\mu$
8000	Pyroelectric	7.77 $\mu$ - 8.07 $\mu$	8 $\mu$
4000	Pyroelectric	8 $\mu$ - 14 $\mu$	10 $\mu$
Thermopile	Thermopile	0.5 $\mu$ - 14 $\mu$	--

For plotting purposes, the wavelength of maximum sensitivity was chosen. For the 8 $\mu$  to 14 $\mu$  pyroelectric sensor, with a bandpass filter, the spectral response is relatively flat over the range. For this case, we have chosen the nominal wavelength that corresponds to the average black body radiant energy over the 8 $\mu$  to 14 $\mu$  band, and this was calculated at approximately 10 $\mu$ . Repeat values were recorded and averaged to determine the reported emittance values. The number of repeat points was determined by the differences in the individual readings. As the scatter increased, the number of repeats was increased. At a particular temperature, the emittance tests took approximately one hour. Over that time period, the temperature control of the emissometer allowed some temperature variations. The indicated set temperature, therefore, actually represents a range of temperatures. All testing was done in an argon atmosphere to prevent oxidation of the graphite heater structure.

Previous testing had used a nitrogen atmosphere, but this was found to cause a reduction reaction on some of the samples tested. The shift to an argon purge minimized the reduction reactions during these tests, and no reactions were observed.

The sample tests were as follows:

- Sample #1A – SiC/Ti-15-3 Composite [ $\pm 30^\circ$ ]. 15Va-3Cr-3Al-3Ta (stay below 600C).
- Sample #1B – Ti-15-3 Matrix. 15Va-3Cr-3Al-3Ta (stay below 600C).
- Sample #2 – SiC/Ti-24Al-11Nb (at. %) Composite. (Stay below 800C.) Piece has been polished on 180 grit SiC paper to remove the Mo cladding reaction on surface. Sample No. is T.O. 88-96#4.
- Sample #3 – 9 vol. % Tungsten Fiber/Copper Composite. Max temp. 560C in argon.
- Sample #4 – Reaction Bonded Silicon Nitride (RBSN) Reinforced in 2-D array (cross-ply  $\pm 45^\circ$ ) with SCS-6 SiC Fibers ( $\sim 140 \mu\text{m}$  diameter) ( $\sim 30$  vol. % loading).
- Sample #5 – Reaction Bonded Silicon Nitride (RBSN) Monolithic, No Fiber Reinforcement.
- Sample #6 – Reaction Formed SiC, SiC + Si  
No Fiber Reinforcement. 111991.

## 4. EMITTANCE TEST RESULTS

### 4.1 Sample #1 – SiC/Ti-15-3 Composite

There were two parts of this sample: one was the composite material, and the other was the matrix only. The intent of running both was to determine if the presence of SiC fibers affected the emittance of the surface.

Sample 1A, the composite material, was tested in an argon atmosphere at two temperatures: 640K (642K to 678K), and 810K (803K to 844K). After testing, the sample (Figure 4) had a slight bluish cast. The emittance data, as a function of wavelength, are shown in Figure 5, and the reduced data are shown in Table 1. Figure 6 shows the thermopile output covering the range from 0.5 $\mu$  to 14 $\mu$  as a function of temperature. This output should be indicative of the total normal emittance of the material.

Sample 1B, the Ti-15-3 matrix material, was tested in an argon atmosphere at two temperatures: 590K (581K to 583K), and nominally 810K. After the 590K run, the sample had turned a copper color and had areas of blue, as shown in Figure 7. After the 810K run, the copper color and blue areas were gone (Figure 8). The emittance data, as a function of wavelength, are shown in Figure 9, and the reduced data are provided in Table 2. Figure 10 shows the thermopile output covering the range from 0.5 $\mu$  to 14 $\mu$  as a function of temperature.

### 4.2 Sample #2 – SiC/Ti-24-11 Composite

This sample was tested in an argon atmosphere at three temperature levels: 590K (583K to 633K), 810K (791K to 833K), and 1030K (1005K to 1050K). After the 810K run, the sample had a bluish cast and appeared to be spotted. This is shown in Figure 11. At the start of the 1030K point, the emittance value increased with time, indicating that a change was occurring on the surface. The sample was removed for inspection and then reinstalled. The temperature was slowly brought back to 1030K and allowed to stabilize for 15 minutes before acquiring data. The sample appearance after stabilization is shown in Figure 12. The sample had a copper color cast after the stabilization. The emittance data, as a function of wavelength, are shown in Figure 13, and the reduced data are provided in Table 3. Figure 14 shows the thermopile output covering the range from 0.5 $\mu$  to 14 $\mu$  as a function of temperature.

### 4.3 Sample #3 – Tungsten/Copper Composite

This sample was tested in an argon atmosphere at two temperatures: 590K (580K to 586K), 810K (800K to 822K). Figure 15 shows the appearance of the sample after the 810K run. The emittance data, as a function of wavelength, are shown in Figure 16, and the reduced data are provided in Table 4. Figure 17 shows the thermopile output covering the range from 0.5 $\mu$  to 14 $\mu$  as a function of temperature.

### 4.4 Sample #4 – Reaction Bonded Silicon Nitride (RBSN) Reinforced with SiC Fiber

This sample was tested in an argon atmosphere at six temperature levels: 560K (550K to 573K), 1120K (1089K to 1144K), nominally 1310K, 1500K (1478K to 1544K), 1750K (1741K to 1772K), and 1920K (1894K to 1928K). After the 1750K run, the surface had changed around the outside edge, where it was close to the graphite holder. It had the appearance of mud caking or alligator skin. This is shown in Figures 18 through 20. After the 1920K run, the surface had changed significantly. The color had changed from dark grey to light grey and the surface had eroded, exposing the reinforcing material. This is shown in Figures 21 through 23. The emittance data, as a function of wavelength, are

shown in Figure 24, and the reduced data are provided in Table 5. Figure 25 shows the thermopile output covering the range from  $0.5\mu$  to  $14\mu$  as a function of temperature.

#### **4.5 Sample #5 – Reaction Bonded Silicon Nitride (RBSN) Monolithic, No Fiber Reinforcement**

Sample #5 was a monolithic Reaction Bonded Silicon Nitride (RBSN) with no fiber reinforcement. The sample was tested in an argon atmosphere at five temperature levels: nominally 980K, 1250K (1244K to 1278K), 1480K (1450K to 1489K), 1640K (1630K to 1661K), and 1750K (1750K to 1755K). After the 1640K run, the surface had a light gray coating. After the 1750K run, the surface had eroded (Figure 26) and had a hairline crack extending across the sample. The crack was too fine to be evident in the photograph of Figure 26. The white areas in the pre-test photograph are actually surface features which appear to be left from machining, and appear white from the reflection of the light used in illuminating the sample under the microscope. The emittance data, as a function of wavelength, are shown in Figure 27, and the reduced data are given in Table 6. Figure 28 shows the thermopile output covering the range from  $0.5\mu$  to  $14\mu$  as a function of temperature.

#### **4.6 Sample #6 – Reaction Formed SiC, SiC + Si, No Fiber Reinforcement**

This sample (Figure 29) was tested in an argon atmosphere at four temperature levels: 870K (853K to 880K), 1140K (1130K to 1172K), 1420K (1439K to 1478K), and 1750K (1700K to 1761K). The emittance data, as a function of wavelength, are shown in Figure 30, and the reduced data are provided in Table 7. Figure 31 shows the thermopile output covering the range from  $0.5\mu$  to  $14\mu$  as a function of temperature.

## 5. DATA ANALYSIS

In general, the emittance values reported are believed to be accurate within  $\pm 0.1$ . The measurements were made over a wavelength interval with some variations in temperature with time. Each of these factors adds to the uncertainty of the reported value. At low temperatures, there was very little energy available to the detectors, and the signal-to-noise ratio was very poor. Some samples showed good repeatability, while others showed considerable variability in the repeat points. The lack of repeatability may be a result of measurement problems, or it may indicate that the surface is not stable. In general, the total normal emittance values measured by the thermopile were somewhat higher than would be expected from the spectral data. The most probable cause of the high thermopile data would be a slight misalignment of the sensor that would allow radiation from the furnace wall to reach the detector.

## 6. REFERENCES

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2. Noel, B. W., et al., "Evaluating Thermographic Phosphors in an Operating Turbine Engine," ASME Paper No. 90-GT-266, presented at 35th International Gas Turbine and Aeroengine Congress and Exposition, Brussels, Belgium, June 11-14, 1990 (see also Trans. ASME, *Journal of Engineering for Gas Turbines and Power*, Vol. 113, April 1991, pp. 242-245).

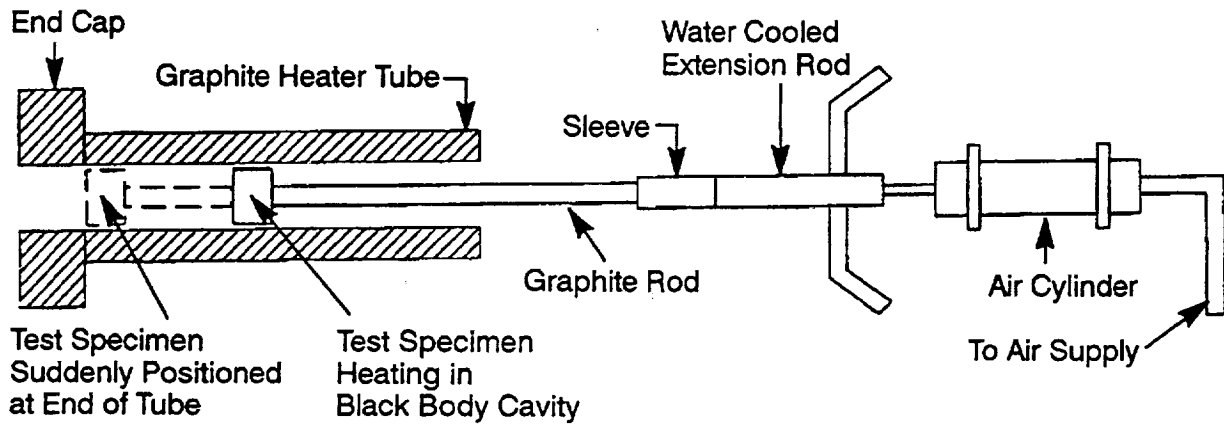


Figure 1 Schematic Diagram of Thermogage Emisometer

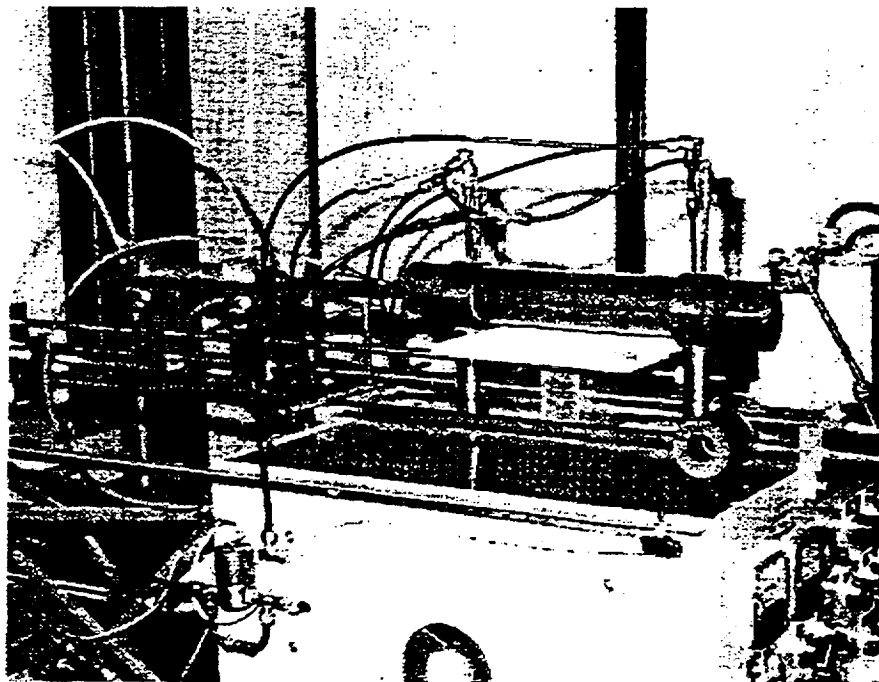


Figure 2 Photograph of Thermogage Emisometer



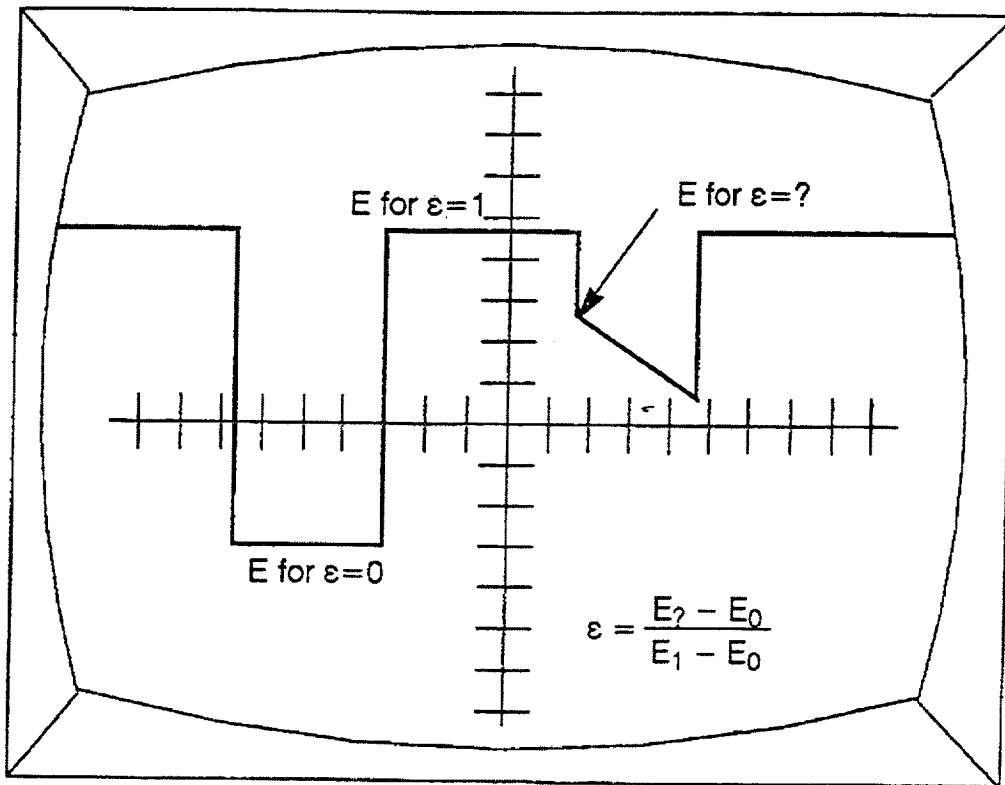


Figure 3 *Emisometer Oscilloscope Trace*

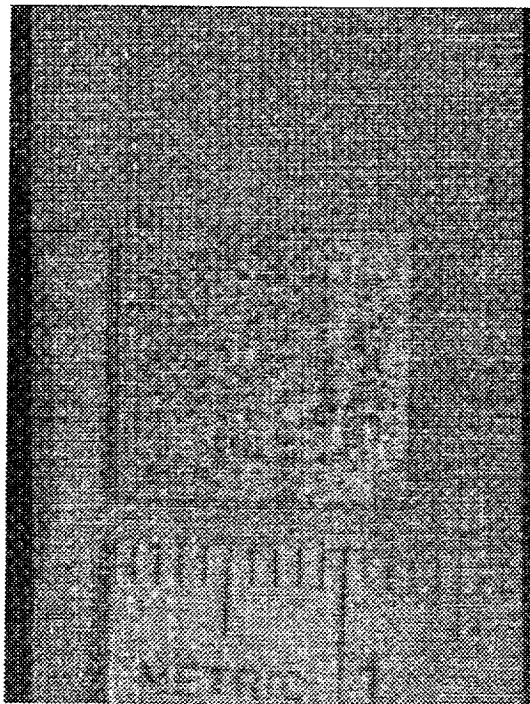


Figure 4 *Sample 1A, SiC/Ti-15-3 Composite: Post-Test Appearance*

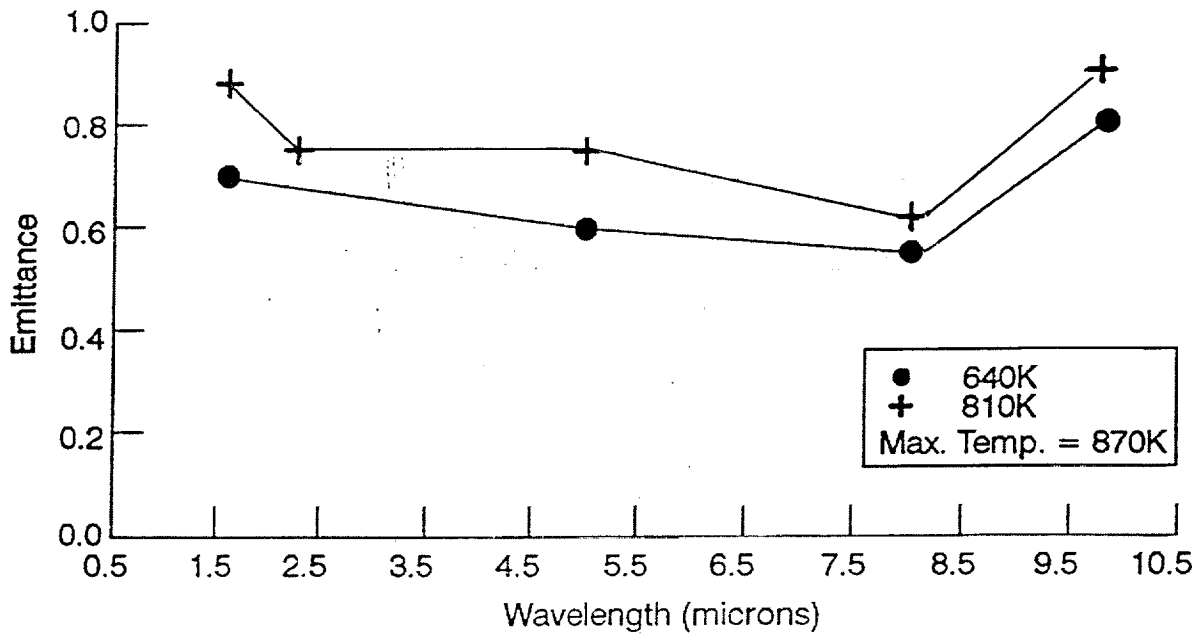


Figure 5 Sample 1A, SiC/Ti-15-3 Composite: Emittance Versus Wavelength

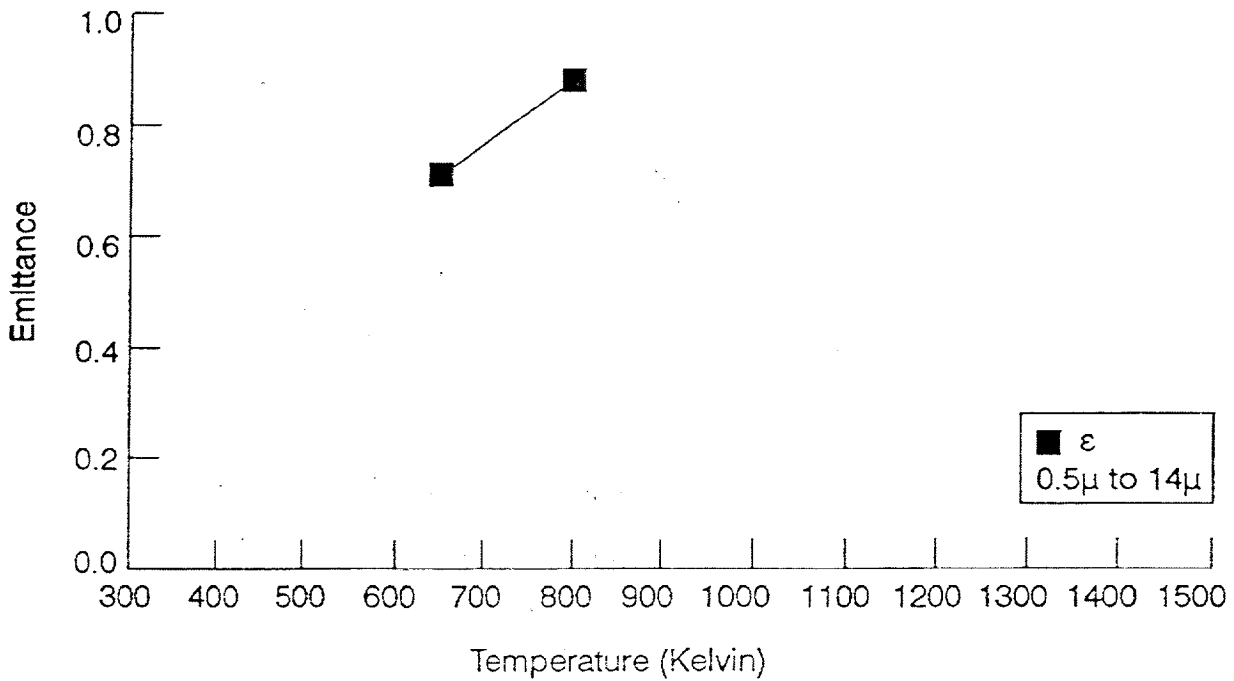
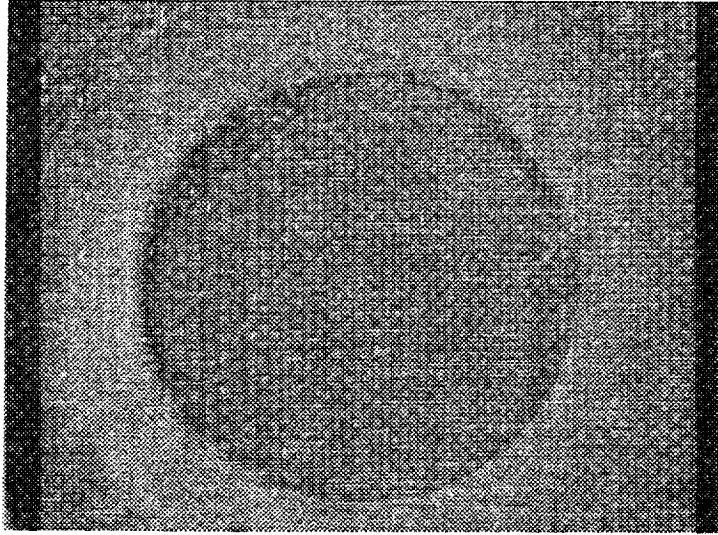
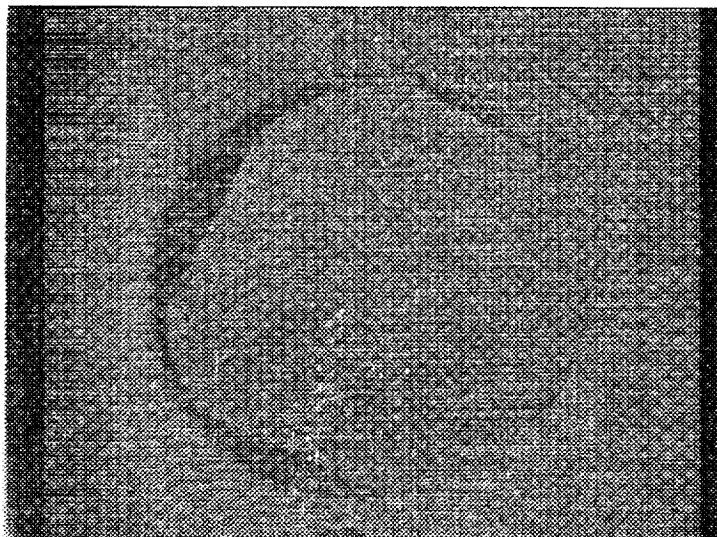


Figure 6 Sample 1A, SiC/Ti-15-3 Composite: Thermopile Data – Emittance Versus Temperature



*Figure 7*      *Sample 1B, Ti-15-3 Matrix: After 616K-644K Point*



*Figure 8*      *Sample 1B, Ti-15-3 Matrix: After 810K Point*

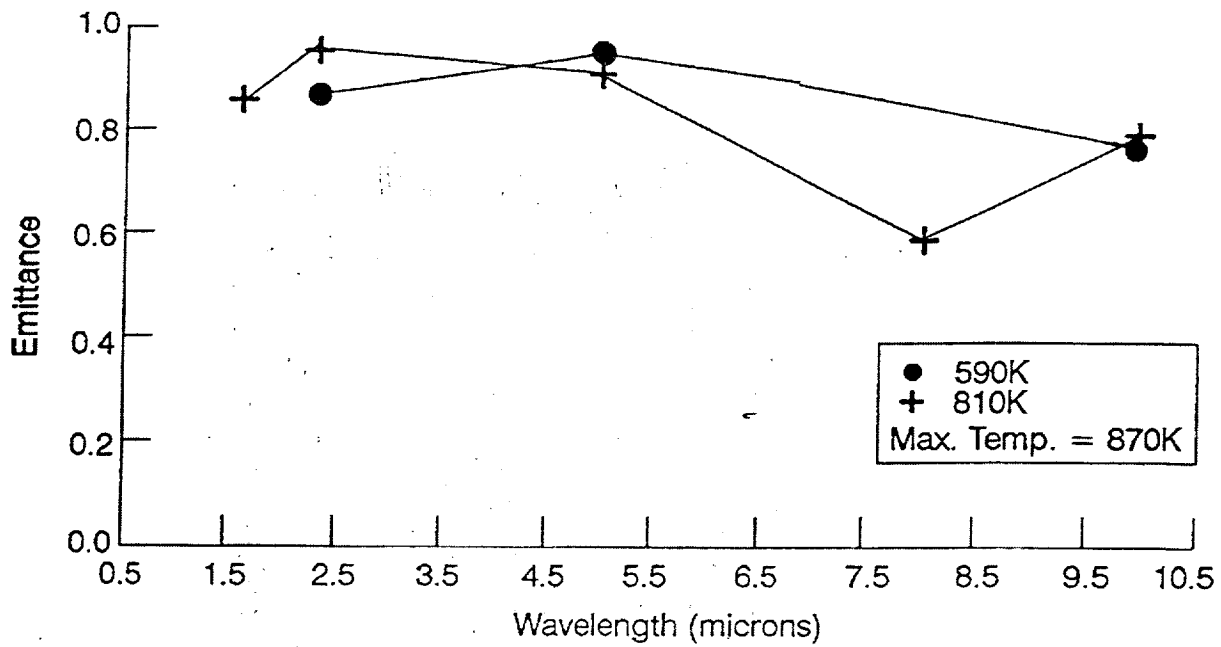


Figure 9 Sample 1B, Ti-15-3 Matrix: Emittance Versus Wavelength

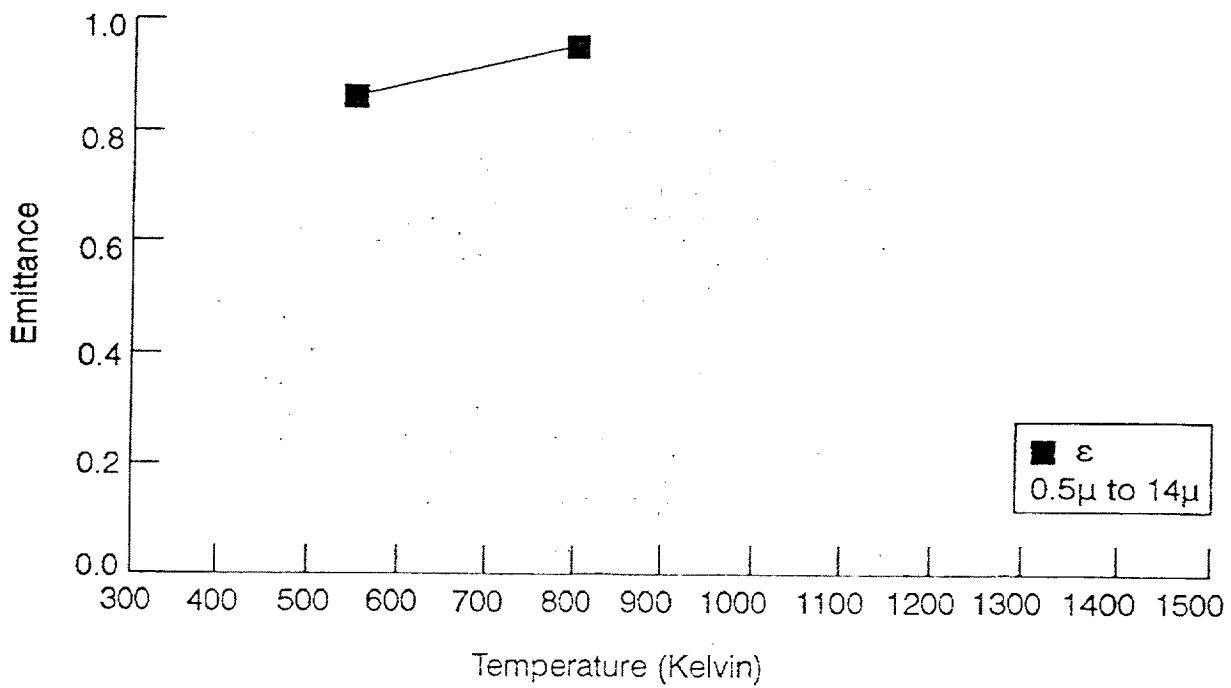
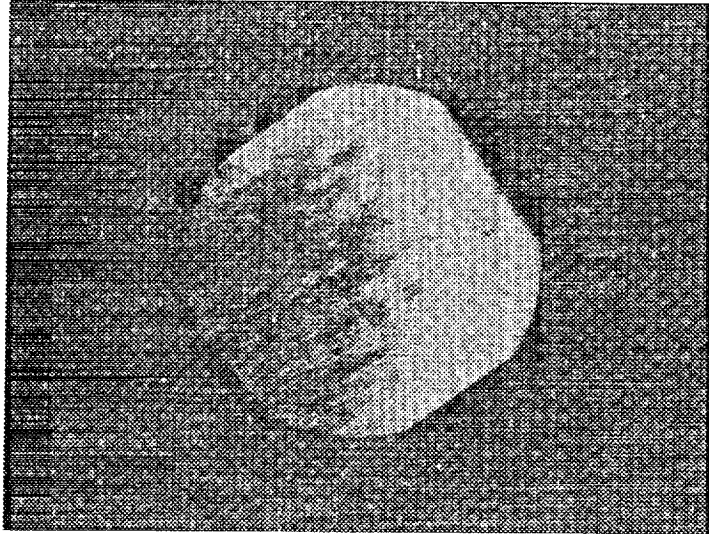
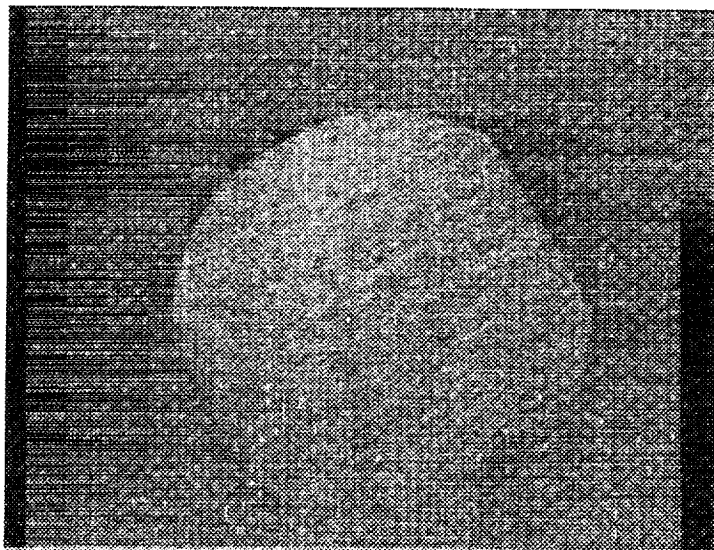


Figure 10 Sample 1B, Ti-15-3 Matrix: Thermopile Data – Emittance Versus Temperature



*Figure 11 Sample 2, SiC/Ti-24-11 Composite: After 810K Point*



*Figure 12 Sample 2, SiC/Ti-24-11 Composite: After 1030K Point*

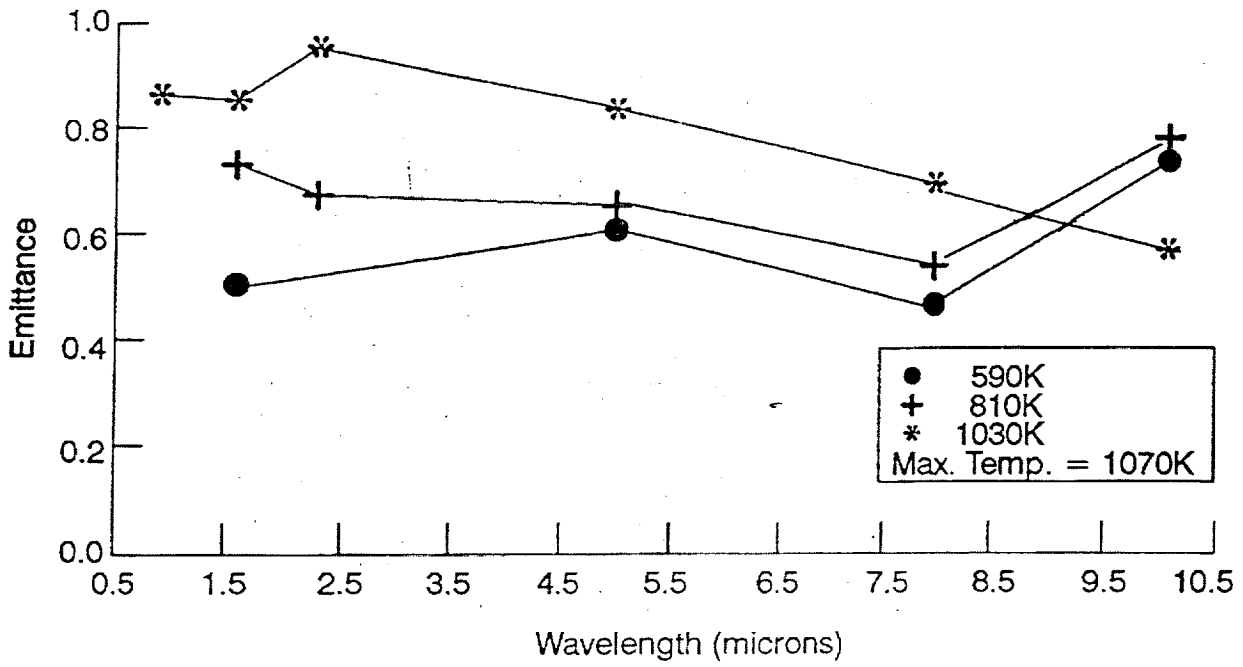


Figure 13 Sample 2, SiC/Ti-24-11 Composite: Emittance Versus Wavelength

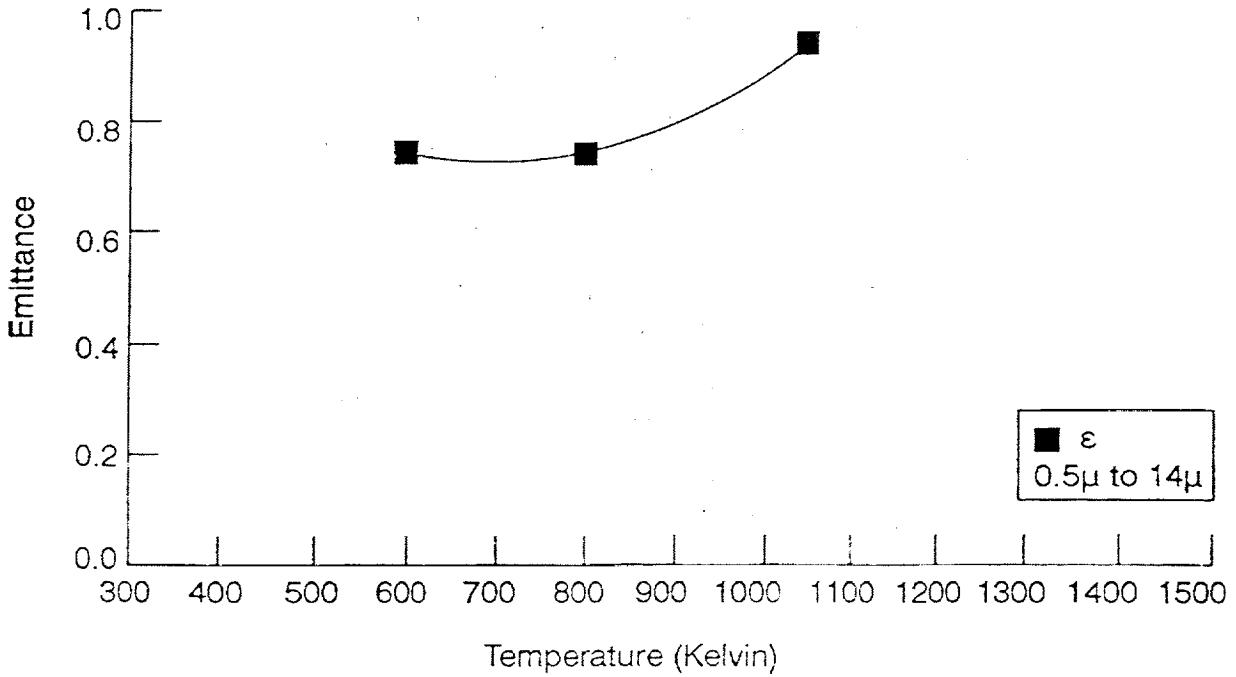
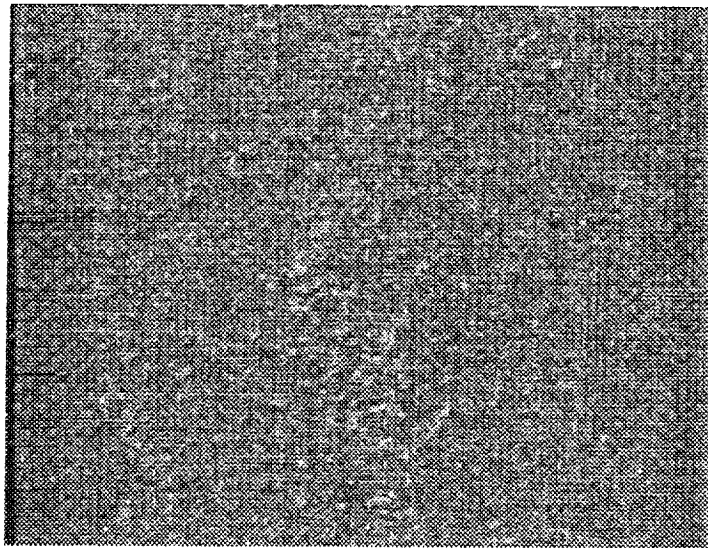
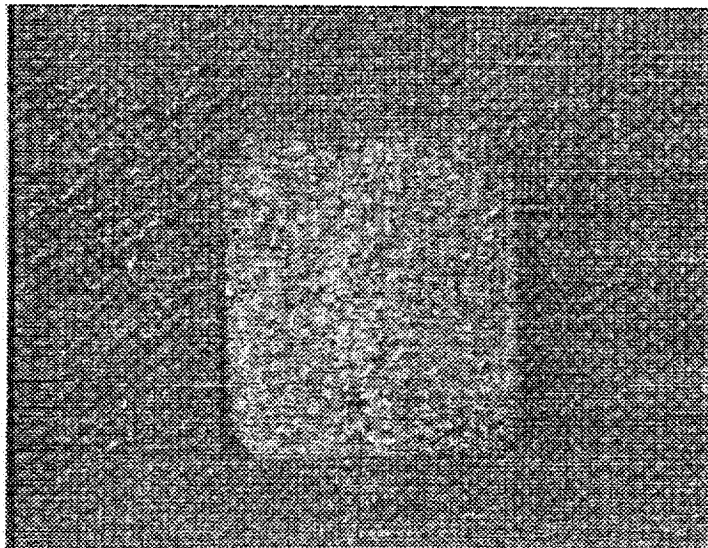


Figure 14 Sample 2, SiC/Ti-24-11 Composite: Thermopile Data – Emittance Versus Temperature



(a)



(b)

*Figure 15 Sample 3, W/Cu Composite After 810K Point: (a) 6X Magnification, and (b) 3X Magnification*

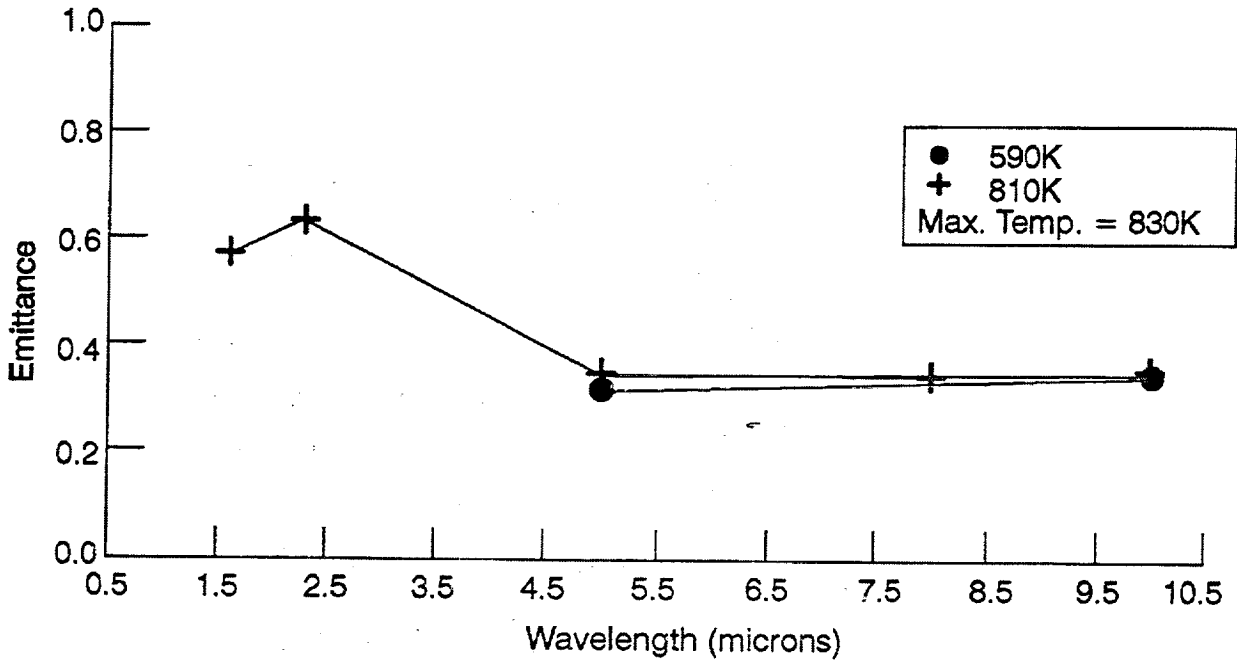


Figure 16 Sample 3, W/Cu Composite: Emittance Versus Wavelength

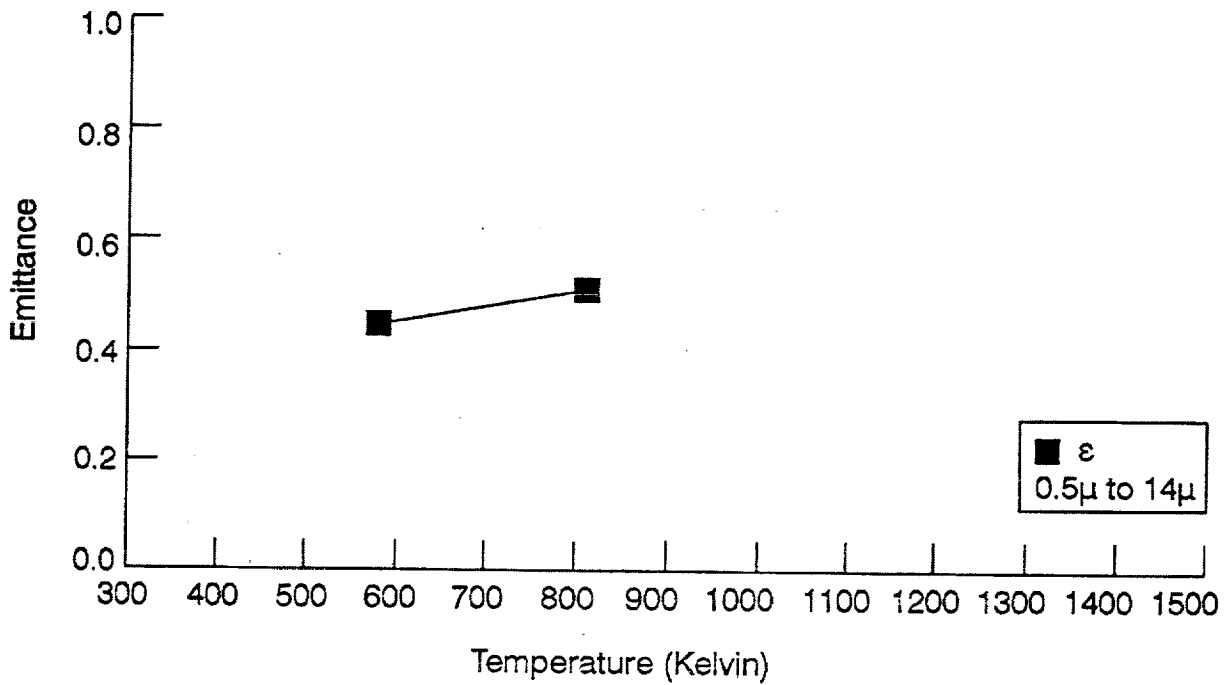
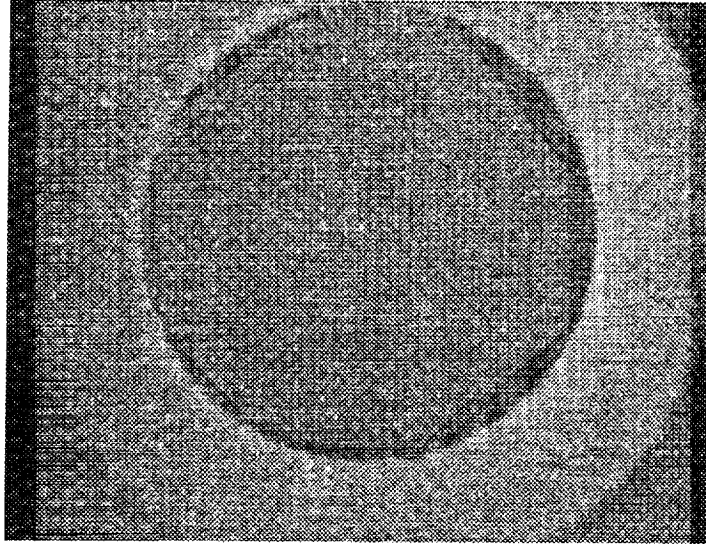
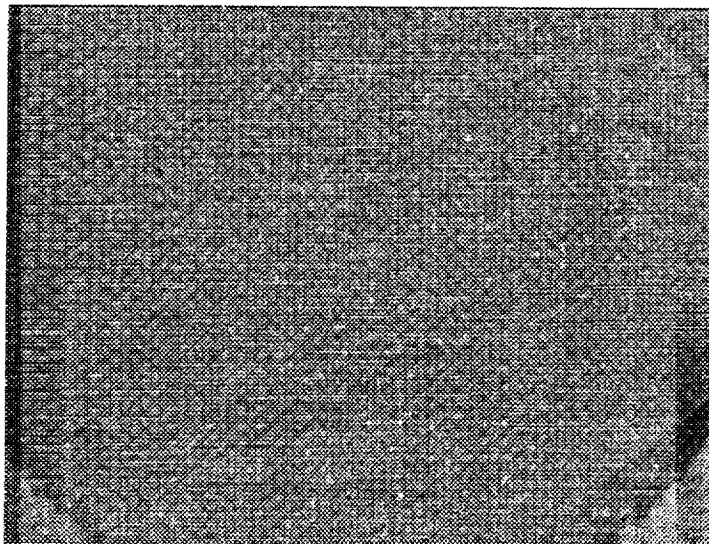


Figure 17 Sample 3, W/Cu Composite: Thermopile Data – Emittance Versus Temperature

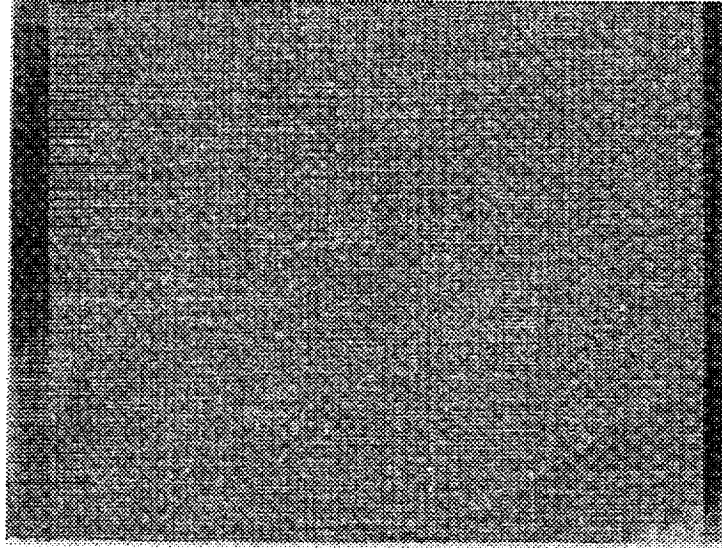




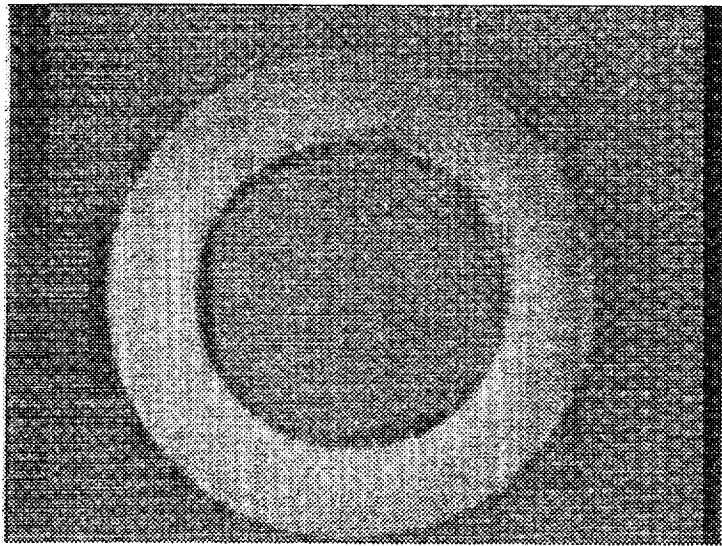
*Figure 18*      *Sample 4, Reaction Bonded Silicon Nitride (RBSN) Reinforced with SiC Fiber: After 1750K Point*



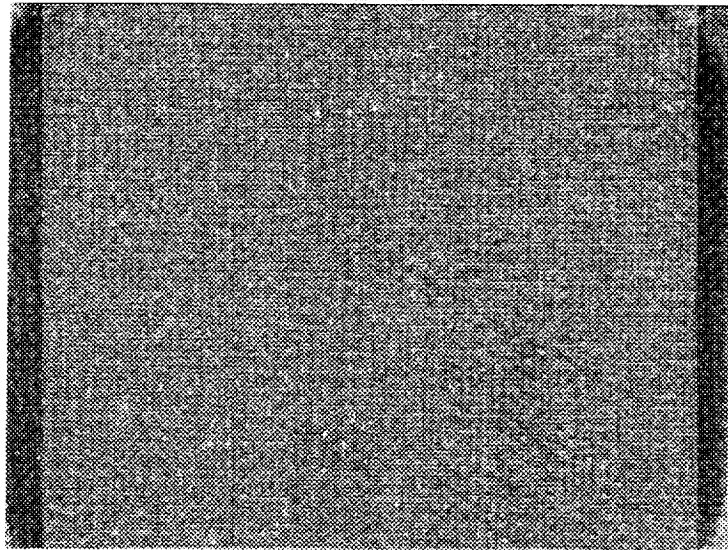
*Figure 19*      *Sample 4, Reaction Bonded Silicon Nitride (RBSN) Reinforced with SiC Fiber: After 1750K Point*



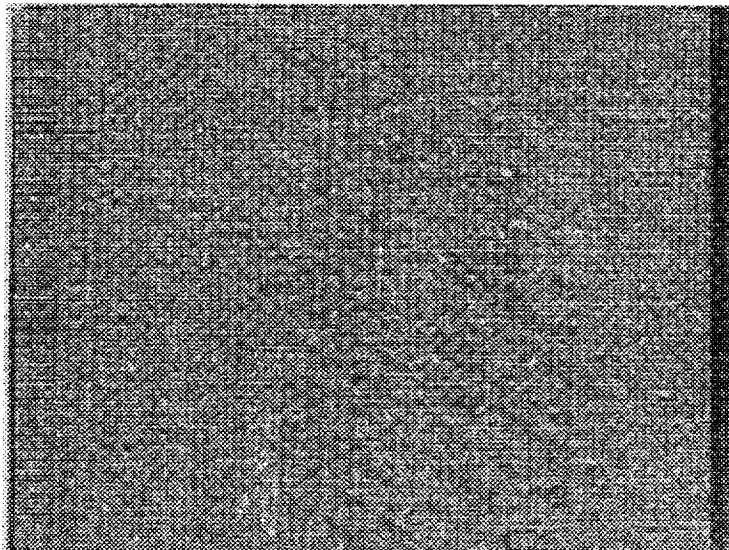
*Figure 20*      *Sample 4, Reaction Bonded Silicon Nitride (RBSN) Reinforced with SiC Fiber: After 1750K Point*



*Figure 21*      *Sample 4, Reaction Bonded Silicon Nitride (RBSN) Reinforced with SiC Fiber: After 1920K Point*



*Figure 22 Sample 4, Reaction Bonded Silicon Nitride (RBSN) Reinforced with SiC Fiber: After 1920K Point*



*Figure 23 Sample 4, Reaction Bonded Silicon Nitride (RBSN) Reinforced with SiC Fiber: After 1920K Point*

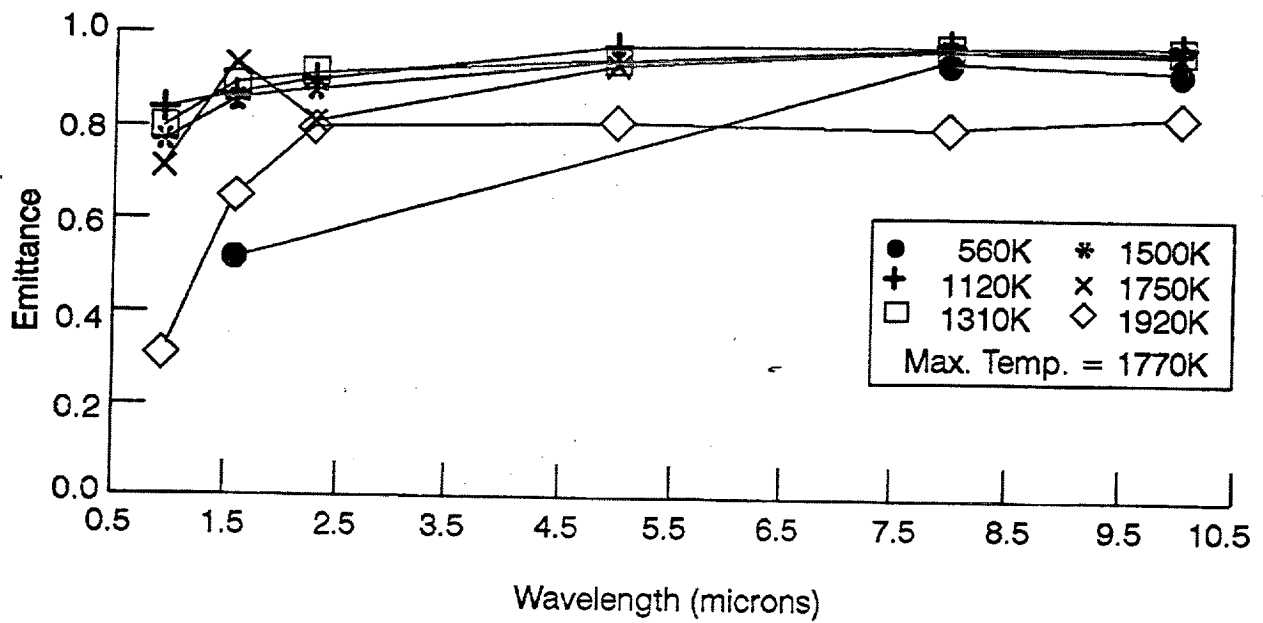


Figure 24 Sample 4, Reaction Bonded Silicon Nitride (RBSN) Reinforced with SiC Fiber: Emittance Versus Wavelength

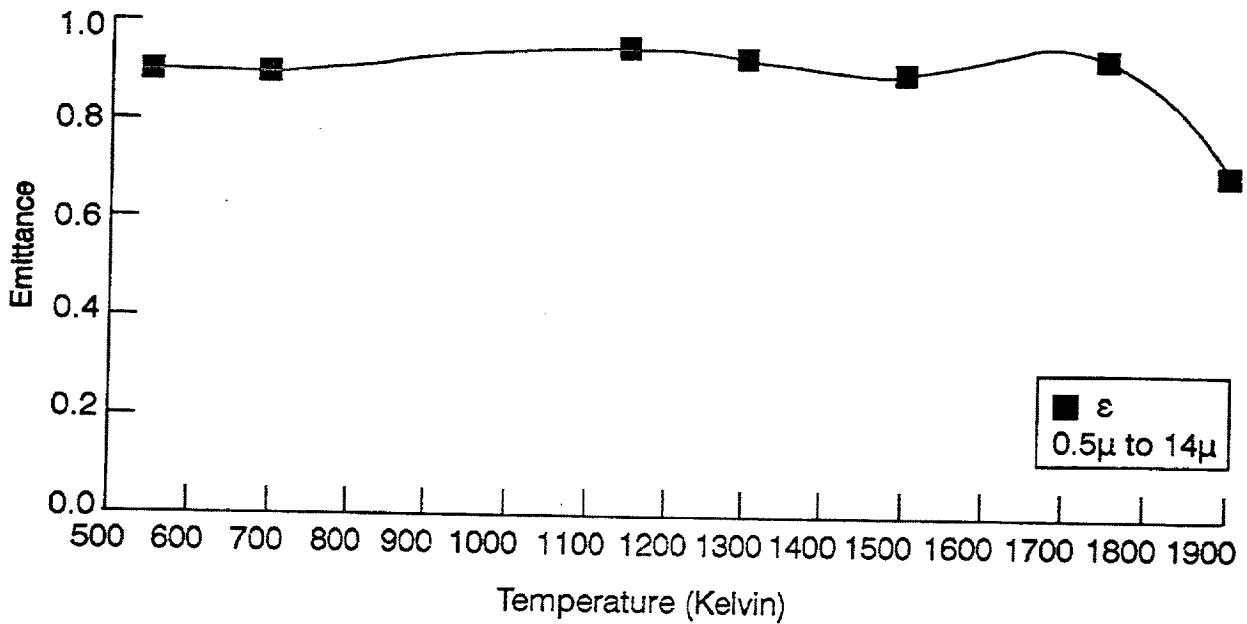
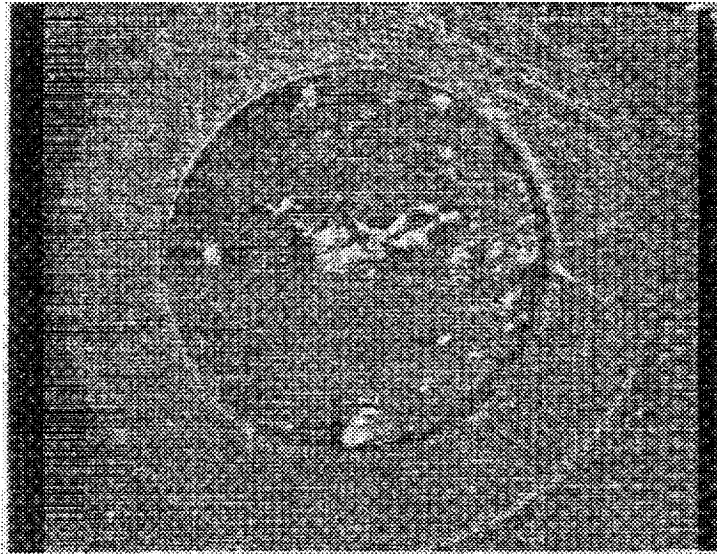
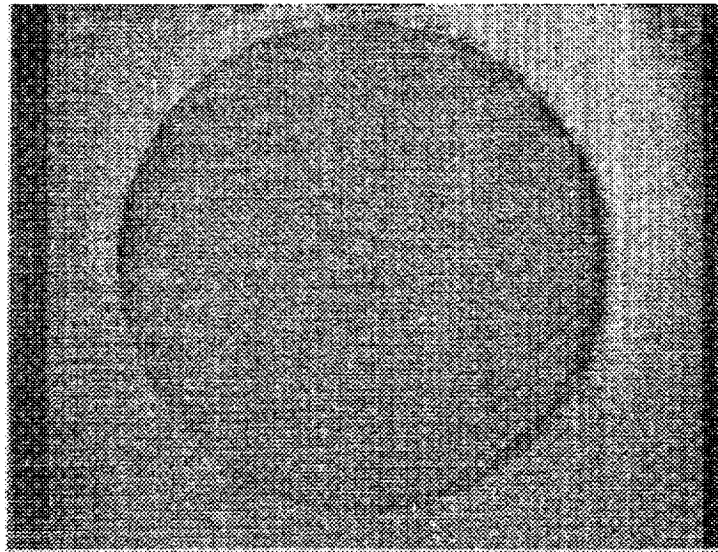


Figure 25 Sample 4, Reaction Bonded Silicon Nitride (RBSN) Reinforced with SiC Fiber: Thermopile Data - Emittance Versus Temperature



(a)



(b)

*Figure 26 Sample 5, Reaction Bonded Silicon Nitride (RBSN) Monolithic, No Fiber Reinforcement:  
(a) Pre-Test, and (b) After 1750K Point*

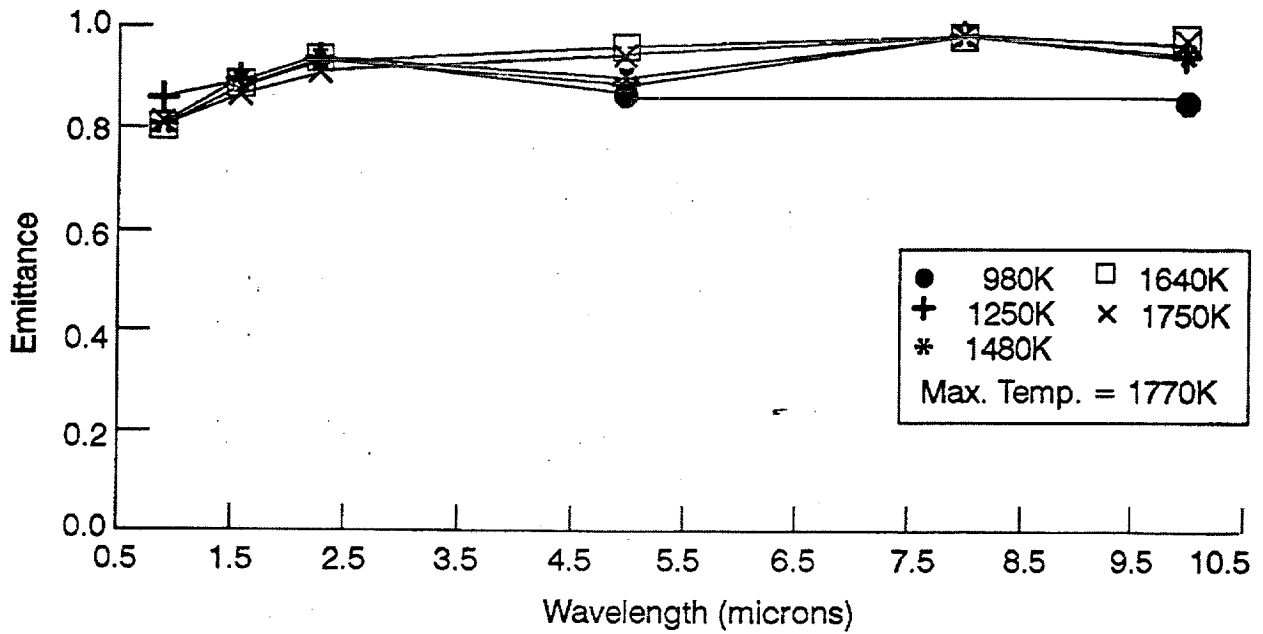


Figure 27 Sample 5, Reaction Bonded Silicon Nitride (RBSN) Monolithic, No Fiber Reinforcement: Emittance Versus Wavelength

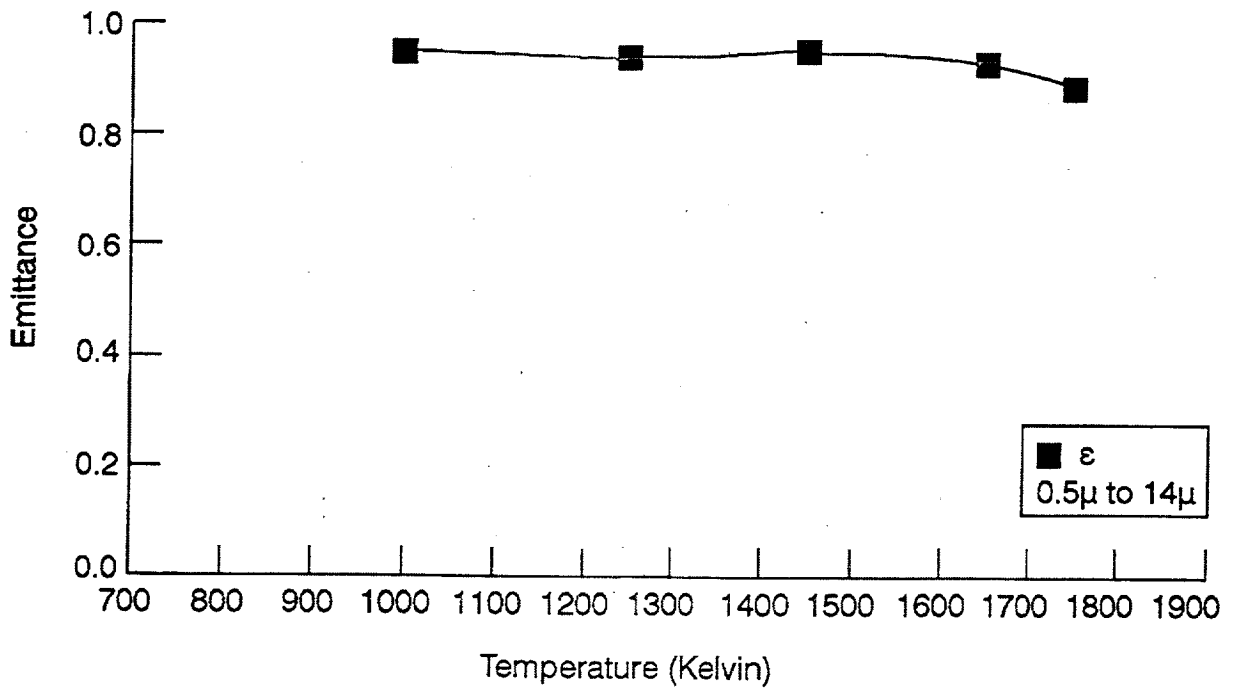
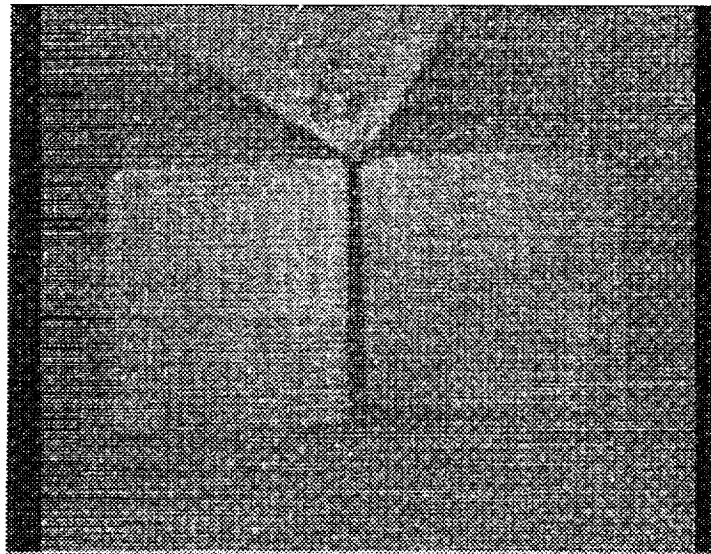
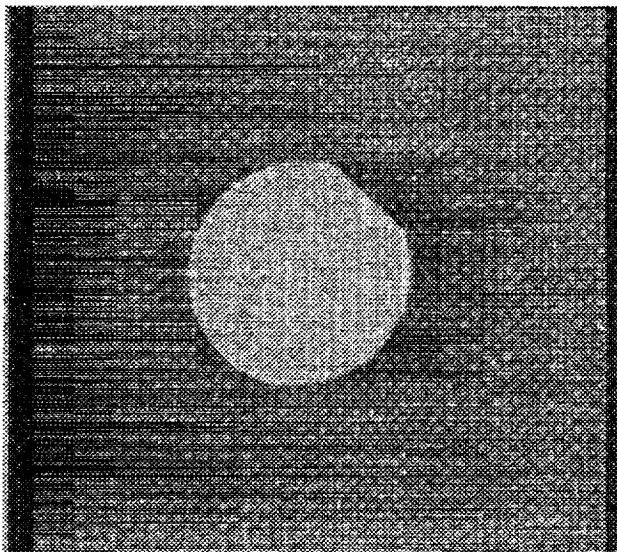


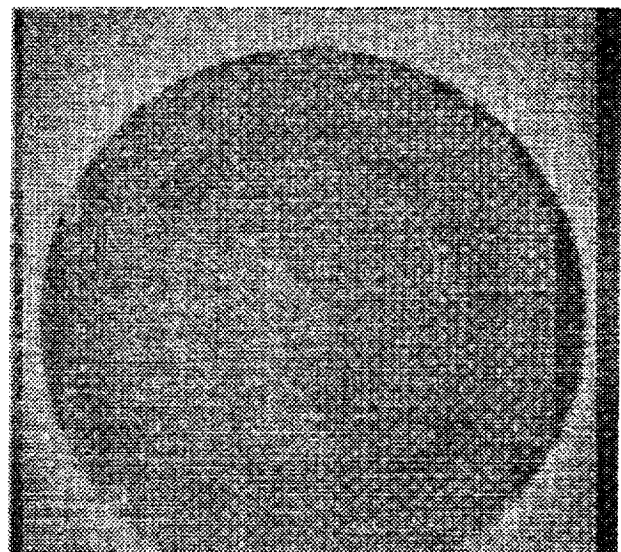
Figure 28 Sample 5, Reaction Bonded Silicon Nitride (RBSN) Monolithic, No Fiber Reinforcement: Thermopile Data – Emittance Versus Temperature



(a)



(b)



(c)

Figure 29 Sample 6, Reaction Formed SiC, SiC + Si, No Fiber Reinforcement: (a) Pre-Test, (b) After 1420K Point, and (c) After 1750K Point

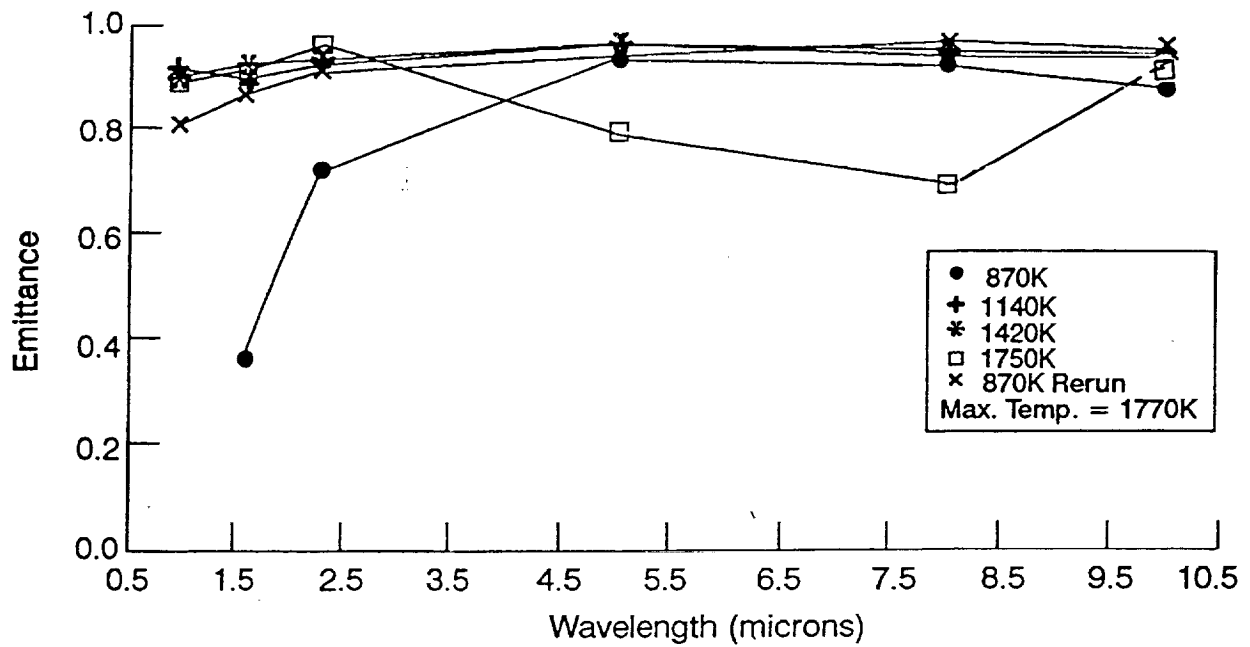


Figure 30 Sample 6, Reaction Formed SiC, SiC + Si, No Fiber Reinforcement: Emittance Versus Wavelength

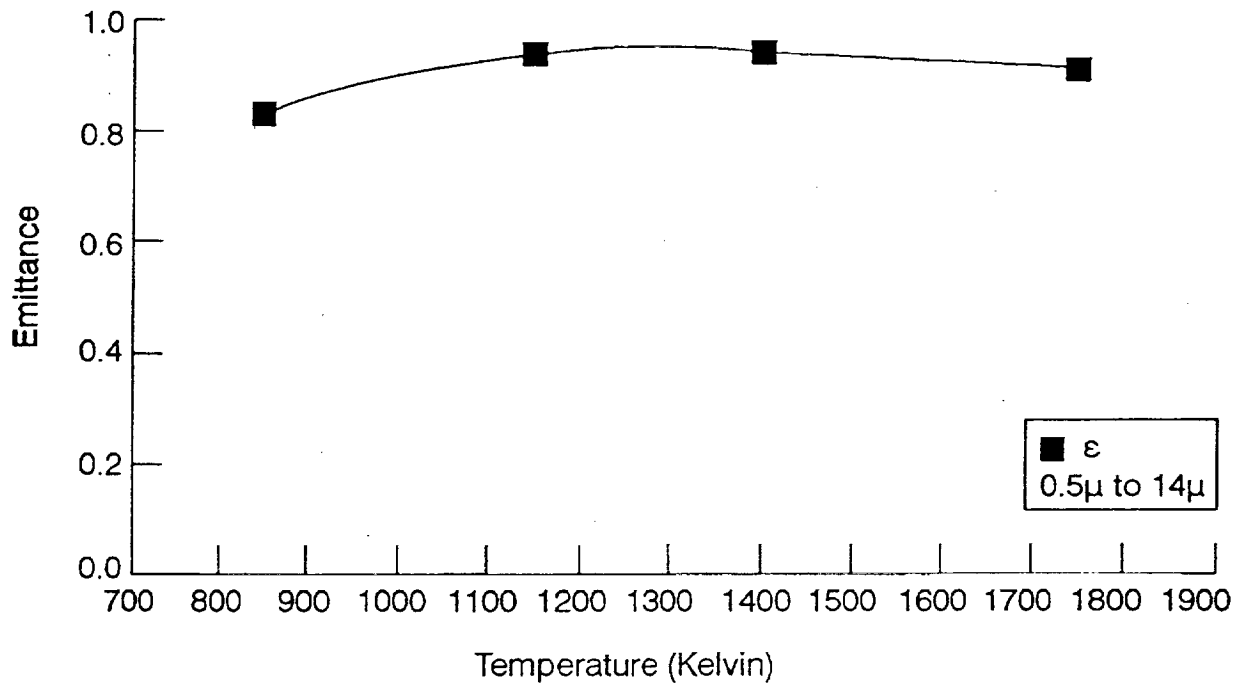


Figure 31 Sample 6, Reaction Formed SiC, SiC + Si, No Fiber Reinforcement: Thermopile Data - Emittance Versus Temperature



TABLE 1  
EMITTANCE DATA SHEET

Sample # 1A  
Date 2/18/92 &  
2/19/92

Sample Type SiC/Ti-15-3 Composite  
Operator F. C. Fries

Disk # 1

Max. allowable temp. = 870K

Step	Time	Deg. K Temperature	2000 0.95 $\mu$	"G" Series 1.6 $\mu$	6000 2.3 $\mu$	7000 5 $\mu$	8000 8 $\mu$	4000 8-14 $\mu$	Thermopile 0.5-14 $\mu$	Comments*
1	1315 1400	642 to 678	N/A	0.70	N/A	0.60	0.55	0.8	0.71	1
2	N/A	803 to 844	N/A	0.88	0.75	0.75	0.62	0.88	0.88	

\* Comments & Notes: 1 Signal/noise ratio on some instrumentation is bad,  $\pm 0.1$  "ε" #s  
Numbers reflect an average of at least 3 readings. All samples run in argon gas.  
Max. temp. = 870K. Slightly bluish cast observed after run.

TABLE 2  
EMITTANCE DATA SHEET

Sample # 1B Sample Type SiC/II-15-3 Matrix Disk # 5  
 Date 4/1/92 Operator E. C. Fries

Max. allowable temp. = 870K

Step	Time	Deg. K Temperature	2000 0.95 $\mu$	"G" Series 1.6 $\mu$	6000 2.3 $\mu$	7000 5 $\mu$	8000 8 $\mu$	4000 8-14 $\mu$	Thermopile 0.5-14 $\mu$	Comments*
1		581 to 583			0.87	0.95		0.77	0.86	1
2		810	N/A	0.86	0.96	0.91	0.59	0.78	0.95	2

\* Comments & Notes: 1 Same picture post 590K point: Sample has a copper color with areas of blue.  
 2 Post-run picture: Copper color and blue are now gone.

TABLE 3  
EMITTANCE DATA SHEET

Sample # 2 Sample Type SIC/PI-24-11 Composite Disk # 4  
 Date 3/30/92 Operator F.C. Fries

Max. allowable temp. = 1070K

Step	Time	Deg. K Temperature	2000 0.95 μ	"G" Series 1.6 μ	6000 2.3 μ	7000 5 μ	8000 8 μ	4000 8-14 μ	Thermopile 0.5-14 μ	Comments*
1	<del>1315</del> 1415	590 583 to 633	Out of range	0.51	0.53	0.61	0.46	0.72	0.74	1
2	<del>0900</del> 1015	810 791 to 833	N/A	0.74	0.68	0.66	0.54	0.76	0.74	2
3	<del>1200</del> 1400	1030 1005 to 1050	0.87	0.86	0.96	0.84	0.69	0.58	0.94	3

\* Comments & Notes: 1 Some instruments are below range temperaturewise, but raw output of detector is readable.  
 2 Sample has a blue cast and spotted -- Note pictures.  
 3 Started 1030K point with 7000 -- Emittance keeps moving ↑ -- Surface change. Will reinstall and slowly reset 1030K -- Settled out for 15 min. before data to be taken.

TABLE 4  
EMITTANCE DATA SHEET

Sample # 3  
Date 3/16/92  
3/17/92

Sample Type W/Cu Composite  
Operator E.C. Fries

Disk # 4

Max. allowable temp. = 830K

Step	Time	Deg. K Temperature	2000 0.95 μ	"G" Series 1.6 μ	6000 2.3 μ	7000 5 μ	8000 8 μ	4000 8-14 μ	Thermopile 0.5-14 μ	Comments*
1	0930	590 580 to 586	N/A	N/A	N/A	0.32	N/A	0.38	0.45	1
2	1020	810 800 to 822	N/A	0.57	0.63	0.35	0.35	0.38	0.51	

\* Comments & Notes: 1 N/A: Not available -- Below instrument range.

TABLE 5  
EMITTANCE DATA SHEET

Sample # 4      Sample Type Reaction Bonded Silicon Nitride (RBSN)      Disk # 2  
 Date 2/27/92      Reinforced with SiC Fiber  
 Operator E. C. Fries

Max. allowable temp. = 1770K

Step	Time	Deg. K Temperature	2000 0.95 μ	"G" Series 1.6 μ	6000 2.3 μ	7000 5 μ	8000 8 μ	4000 8-14 μ	Thermopile 0.5-14 μ	Comments*
1		550 to 573	N/A	0.52	N/A	N/A	0.94	0.88	0.90	
2		1089 to 1144	0.84	N/A	0.90	0.97	0.97	0.97	0.95	
3		1478 to 1544	0.77	0.86	0.88	0.94	0.96	0.95	0.90	
4		1310	0.80	0.89	0.91	0.94	0.97	0.94	0.93	
5		1741 to 1772	0.71	0.93	0.81	0.93	0.96	0.91	0.93	1
6		1894 to 1928	0.31	0.65	0.80	0.81	0.80	0.87	0.70	2

\* Comments & Notes: 1 Some change to surface around outside edge. Note pictures.  
 2 Surface has eroded and color is a light grey - was dark grey.  
 Matrix material showing. Note pictures.

Rec. 1 - 4 Step 6 Disk 2.

TABLE 6  
EMITTANCE DATA SHEET

Sample # 5      Sample Type Reaction Bonded Silicon Nitride (RBSN)      Disk # 3  
 Date 3/9/92      Monolithic, No Fiber Reinforcement  
 Operator F. C. Fries

Max. allowable temp. = 1770K

Step	Time	Deg. K Temperature	2000 0.95 μ	"G" Series 1.6 μ	6000 2.3 μ	7000 5 μ	8000 8 μ	4000 8-14 μ	Thermopile 0.5-14 μ	Comments*
1	0930	980	N/G	N/G	0.96	N/G			0.96	1
1	<del>1015</del> 1120	980 1050 to 1061	N/A	0.88	0.94	0.86	N/A	0.83	0.95	
2	<del>0820</del> 0950	1250 1244 to 1278	0.86	0.89	0.94	0.88	0.97	0.84	0.94	
3	<del>1215</del> 1400	1480 1450 to 1489	0.81	0.89	0.93	0.89	0.97	0.86	0.95	
4	<del>0830</del> 1040	1640 1630 to 1661	0.80	0.88	0.93	0.95	0.97	0.92	0.93	2
5	<del>0845</del> 1030	1750 1750 to 1755	0.805	0.865	0.91	0.94	0.965	0.94	0.885	3

\* Comments & Notes: 1 Rerun this point – too many signal problems. Bad signal form.  
 2 After 1640K point, surface has a light grey coating.  
 3 After 1750K point, surface has eroded and is cracked.

TABLE 7  
EMITTANCE DATA SHEET

Sample # 6      Sample Type Reaction Formed SiC, SiC + Si      Disk # 2  
 Date 3/3/92      Operator F.C. Fries      No Fiber Reinforcement

Max. allowable temp. = 1770K

Step	Time	Deg. K Temperature	2000 0.95 μ	"G" Series 1.6 μ	6000 2.3 μ	7000 5 μ	8000 8 μ	4000 8-14 μ	Thermopile 0.5-14 μ	Comments*
1	0900 1000	Target 870 ±25	N/A	0.36	0.72	0.93	0.92	0.80	0.83	
2	1200	1140 ±25 1130 to 1172	0.92	0.89	0.92	0.96	0.95	0.93	0.94	
3	1400	1420 1439 to 1478	0.90	0.92	0.93	0.96	0.94	0.93	0.94	
4	3/5/92 1400	1700 to 1755 1700 to 1761	0.87	0.91	0.96	0.79	0.69	0.86	0.91	

\* Comments & Notes: Installed new graphite tube between Steps 1 and 2.

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Dept. of Materials Science and Engineeri  
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Kingston, RI 02881

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13. ABSTRACT (Maximum 200 words) The "Development of Sensors for Ceramic Components in Advanced Propulsion Systems" program was divided into two phases. The objectives of Phase I were to analyze, evaluate and recommend sensor concepts for the measurement of surface temperature, strain and heat flux on ceramic components for advanced propulsion systems. The results of this effort were previously published in NASA CR-182111. As a result of Phase I, three approaches were recommended for further development: pyrometry, thin-film sensors, and thermographic phosphors. The objectives of Phase II were to fabricate and conduct laboratory demonstration tests of these systems. A summary report of the Phase II effort, together with conclusions and recommendations for each of the categories evaluated, has been submitted to NASA. Emittance tests were performed on six materials furnished by NASA Lewis Research Center. Measurements were made of various surfaces at high temperature using a Thermogage emissometer. This report describes the emittance test program and presents a summary of the results.				
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