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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Describes techniques and instrumentation for measuring infrared (IR) radiation during development and production tests of military ground vehicles and weapons. Covers measurements of IR signatures of vehicles and IR temperature measurements of weapon tubes during firing programs. ~~Includes~~ pertinent areas/surfaces/conditions for survey and sample plots, graphs, and photographs for reporting results. ~~Applicable to~~ tests conducted on land.

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US ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

DRSTE-RP-702-101
*Test Operations Procedure 2-2-812 18 July 1979
AD No.

INFRARED MEASUREMENTS OF VEHICLES AND WEAPONS

1. SCOPE. This TOP describes techniques and instrumentation for measuring infrared (IR) radiation during development and production tests of military ground vehicles and weapons. Such measurements are made to determine IR signatures of vehicles and temperatures of weapon tubes during a firing program. Graphs and diagrams are presented to indicate typical measurements but are not intended to represent a particular test firing or evaluation.

2. FACILITIES AND INSTRUMENTATION.

2.1 Facilities.

ITEM	REQUIREMENTS
Vehicle test course	As applicable for operation of wheeled or tracked vehicles at full speed. (See TOP 1-1-011.)

*This TOP supersedes MTP 2-2-812, 5 June 1970.

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ITEM (Cont'd)	REQUIREMENTS (Cont'd)
Open area	Large enough for test vehicle to fill field of view of radiometer; background as required in test design.
Firing range	As applicable to weapon under test.
Digital conversion facility	As applicable to weapon under test.

2.2 Instrumentation.

ITEM	MAXIMUM ERROR OF MEASUREMENT*
IR Radiometer	Capability of measuring radiance at wavelengths of 2 to 20, 3 to 5, and 8 to 14 micrometers to ± 0.02 mW/(cm^2·sr)
IR imaging system with extended area blackbody temperature source	± 0.02 mW/(cm^2·sr)
Calibrated contact thermometer	±1° C
Ambient temperature measuring device	±1° C
IR thermometer and recording galvanometer	±3° C
Spectral radiometric measuring equipment	± 0.02 mW/(cm^2·sr·µm)
Noncontact IR temperature measuring device and recording equipment	±3° C

*Values may be assumed to represent ±2 standard deviations; thus the stated tolerances should not be exceeded in more than 1 measurement out of 20.

3. PREPARATION FOR TEST.

3.1 Planning. Plan each IR measurement project based on the following considerations:

3.1.1 Vehicles. Vehicle exhausts, radiators, tires, suspension systems, and even exposed metal surfaces (especially where warmed by engine heat through operation or by solar heating) emit IR radiation and permit detection of the vehicle by sensory directed weapons or surveillance systems. IR measurements are made of vehicles to assess their detectability and to identify temperature variations (ΔT) that could make the vehicle vulnerable to heat-seeking weapons. Consideration can then be given to shielding the hot spots or redesigning to suppress the IR radiation.

Personnel heaters or on-board auxiliary generators create signatures and are considered to be IR sources in addition to the basic vehicles.

3.1.2 Weapons. IR emissions from weapons are measured primarily to determine at a distance the increases in weapon-tube temperature as a result of a high rate of fire. This is done to determine the temperature at which cookoff can occur.

3.2 Checklist. Prepare a test operations checklist similar to the guide in Appendix A.

3.3 Vehicle/Weapon Condition. Check the vehicle or weapon condition as appropriate in accordance with the list in Appendix B. Add to the list other parameters of interest as necessary.

3.4 Instrumentation. Check out and set up instrumentation as required for each subtest and ensure proper calibration.

3.5 Data Required.

a. Vehicle/weapon condition (3.3 above).

b. Climatic support data, as detailed in Appendix B, for each test series, to cover the period of the test as well as the prior 24-hour period.

c. Description of facilities and instrumentation.

4. TEST CONTROLS.

a. IR signature tests will normally be conducted under weather conditions that typify the season and geographic location under investigation.

b. Signature data will be collected during both diurnal and nocturnal periods. For diurnal tests the effects of solar radiation shall be considered as part of the overall signature, and monitored in terms of solar load (including other standard weather conditions) during the test. The standard set of signature data will contain data taken on days with a high solar load and on nights whose preceding days had low solar loads. The range in solar load will be consistent with the season and the geographic location that the test is intended to represent.

c. Each test item will be tested in the configuration normally employed during field use, with all components and accessories mounted and operating. It will be painted as required for combat and be tested free of mud, dust, snow, ice, frost, and water.

5. PERFORMANCE TESTS.

5.1 Measurements for IR Signatures of Vehicles. Table 1 shows the standard vehicle operating conditions under which the basic signature data are obtained in the radiometer tests, temperature tests, and imagery analysis described in Paragraphs 5.1.1, 5.1.2, and 5.1.3.

5.1.1 Radiometer Tests.

5.1.1.1 Method. Radiometer observations will be made using an IR radiometer that measures radiance in the wavelength intervals of 2 to 20, 3 to 5, and 8 to 14 micrometers of the spectrum, as described in Appendix D, on a standing vehicle operated under conditions a, b, and c of Table 1.

a. Make the measurements in 360° azimuth every 45° starting at 180° rear view, and 180° in elevation at 45° or 30° intervals from front to rear and side to side on axis aspects. The ranges at which the measurements are made depend upon the field of view of the radiometer. Select the ranges so that at minimum range the projected field of view of the radiometer just encompasses the average dimension of the heated exhaust area. At maximum range the field of view should encompass the approximate size of the vehicle for front/rear observation and one-half the dimension of the side view. Side-view measurements will be identified by two readings, "front half" and "rear half." Data at ranges between maximum and minimum observation points may be selected as desired.

b. Make the measurements in three standard wavelength bands: 2 to 20, 8 to 14, and 3 to 5 micrometers.

c. To support each set of radiometer data, take a radiometer terrain background measurement of the following:

Terrain adjacent to vehicle

Gravel road, dirt field, or sand area

Grass/field area

Tree area

Horizon

For proper comparison, measurement of the background should be taken on the same day as and just prior to the test-item measurements.

Table 1 - Operating Conditions for Vehicle Signature Tests

a.	Static solar exposure	Expose vehicle, nonoperating, to outside ambient conditions for 24 hours before test.
b.	Standard slow idle	After standard warmup,* position vehicle at test station to remain at idle (600 to 700 engine rpm) for 15 minutes before test observation.
c.	Standard fast idle	After standard warmup,* position vehicle at test station to remain at fast idle (1200 to 1500 engine rpm) for 5 minutes before test observation.
d.	Standard slow operation	Move vehicle steadily at 5 mph in low range or 1-2 gear for 5 minutes.
e.	Standard moderate speed operation	Move vehicle steadily at 10 mph in high range or high gear for 5 minutes.
f.	Standard high speed operation	Move vehicle steadily at 20 mph or 3/4 maximum red-line engine rpm for 5 minutes.

*Standard warmup: operation of vehicle 15 minutes over clockwise course and 15 minutes over counterclockwise course in high range or high gear at 10 to 20 mph or 2000 to 2400 engine rpm. Additional 5 minutes' warming and in-transit time allowed to move vehicle from starting point to warmup area.

d. If the exhaust outlet is not directly visible to the radiometer during the azimuth range observations, but can be seen from an overhead viewing position, make an overhead measurement at an elevation angle that will permit direct viewing of the outlet area. Such a test may be conducted from a platform or similar elevated structure using the same procedures as outlined in a above. If the exhaust outlet is not visible in azimuth or elevation because of its unique location, geometry, or structural features, include its survey in the close-in radiometer measurements (Paragraph e below).

e. In addition to the range observations made at extended ranges from the target, obtain a series of close-in survey readings under vehicle operating conditions a, b, and c of Table 1. Select the surface areas/vehicle components to be measured to represent various isothermal regions; typically:

Exhaust outlet area	Track skirt
Armor surrounding exhaust outlet area	Suspension
Air intake grills	Hull, not associated with engine compartment
Air exit grills	Turret
Armor surrounding engine compartment	Engine compartment external features

5.1.1.2 Data Required.

Type of Measurement 1/	Units of Energy	Apparent Temperature
Close-in survey data 2/	mW/(cm^2·steradian) watts/steradian 4/	°C
Range data 3/	mW/(cm^2·steradian)	ΔT°C 5/
Background data	mW/(cm^2·steradian)	°C

1/ For each standard wavelength band.

2/ For each facet surface selected for observation.

3/ For projected field of view against target.

4/ Apparent non-contrast. ["Watts/steradian" is a non-contrast term, representing the measurement of radiant flux itself, and not a comparison of surface areas. Comparison of surface areas requires the measurement "mW/(cm^2· steradian)."]

5/ Apparent temperature difference between test item and specified background.

5.1.2 Temperature Tests.

5.1.2.1 Method.

a. Instrument the test vehicle with an on-board temperature measuring system capable of acquiring temperature data via thermocouple or thermistor sensors. The area selected for thermocouple attachment is called a facet. Facets are selected to represent quasi-isothermal vehicle features and the thermal variations observed over the exterior of the vehicle by radiometer examination. Identify the facets by nomenclature and indicate surface area in sq cm. The facets/components to be instrumented with sensors will correspond in general to the areas surveyed during the "close-in" radiometer test, Paragraph 5.1.1.1e. Approximately 20 to 30 attachment points will be involved, with emphasis on the engine compartment area. In addition to temperatures at these points, record the following temperatures:

Ambient air	Compartment exit air at grill
Interior air, hull	Compartment intake air at grill
Exhaust gas	

b. Since radiometer data are only representative of a standing vehicle under no-load conditions, the temperature data provide a means for predicting the vehicle signature under the operational conditions of d through f of Table 1. The temperature data are used as the basis for performing calculations converting temperature to radiance. Use the formula and emissivity factors, Appendix E, for this calculation. Of primary interest is the exhaust outlet area and associated "bright" thermal sources exterior to the vehicle and heated by engine exhaust transfer. Show results for the three standard wavelength bands in radiance and radiant intensity for identified vehicle features of the exhaust networks or engine compartment.

5.1.2.2 Data Required. Record temperatures under the vehicle conditions stated in Table 1 for each sensor location.

5.1.3 Thermal Energy (Temperature) Distribution.

5.1.3.1 Method.

a. Using an IR imaging system (Figure 1), map the temperature of the entire vehicle under test. This test is usually conducted under nocturnal or very low diurnal solar load conditions to minimize the effects of solar reflection and heating but may be conducted, when required, during daytime in the spectral regions of 3 to 5 and 8 to 14 micrometers.

b. Obtain thermal imagery for the static vehicle conditions outlined in Table 1 in 360° azimuth at cardinal points of 0, 90°, 180°, and 270° and for background radiance in each wavelength. Imagery may be in an uncalibrated form since it is primarily required to assess the following vehicle signature traits:

- Exhaust gas emission
- Exhaust gas secondary heating
- Thermal conductivity from exhaust outlet area
- Areas of high on-board reflectivity
- High thermal contrast areas in engine compartment
- Heat leaks from engine compartment
- Track and suspension

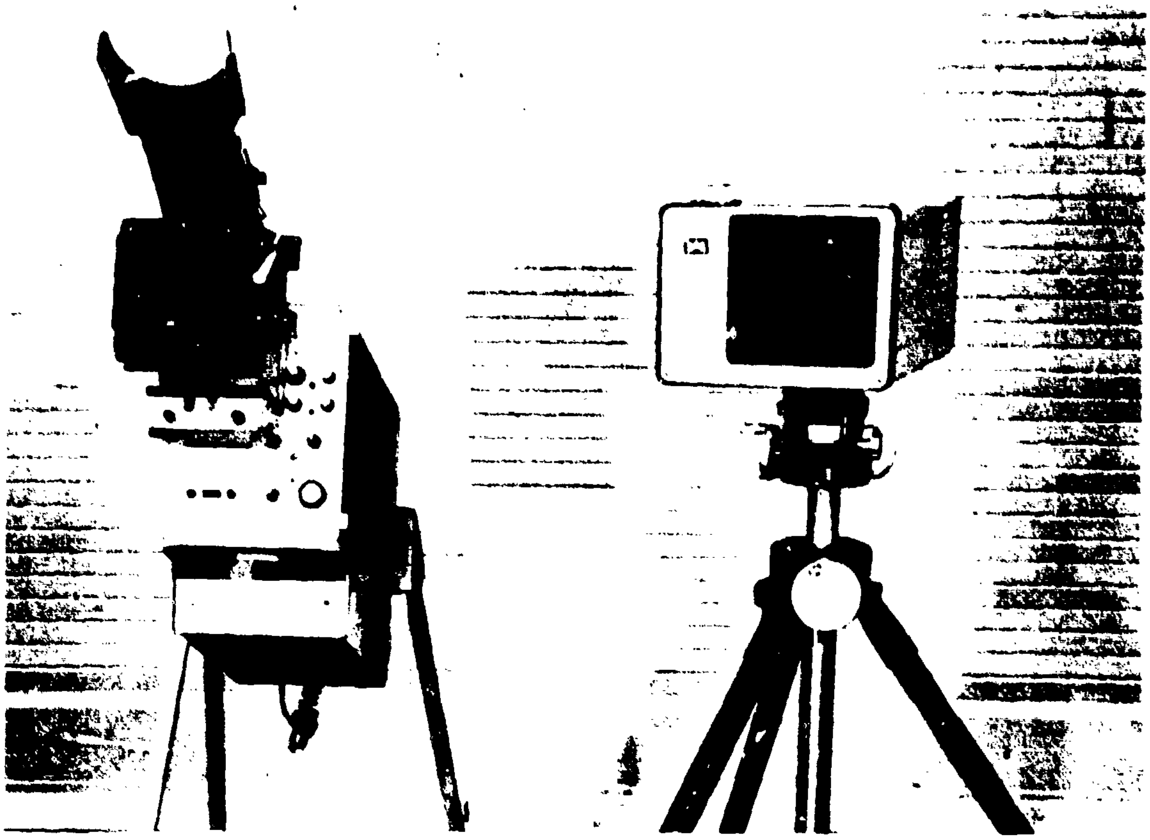


Figure 1. IR Camera Used to Obtain Thermal Photographs in the 3 to 5 and 8 to 14 Micrometer Spectral Region.

5.1.3.2 Data Analysis

a. Analyze the imagery acquired to determine identifiable thermal features (cue-points) that would make the vehicle vulnerable to recognition or identification. Categorize the cue-points in terms of importance relative to suppression measures necessary to reduce the effect of thermal recognition and identification. In addition, use the imagery to support the radiometer data by indicating the extent and level of engine heating into armor compartment areas. Thermal features observed in the imagery may be compared with radiance values measured during the radiometer tests.

b. Acquired imagery data may be evaluated through the use of gray-scale and isothermal graphs as shown in Figures 2 and 3 or by a digital conversion facility using a computer interface to convert pixel elements to radiance values.

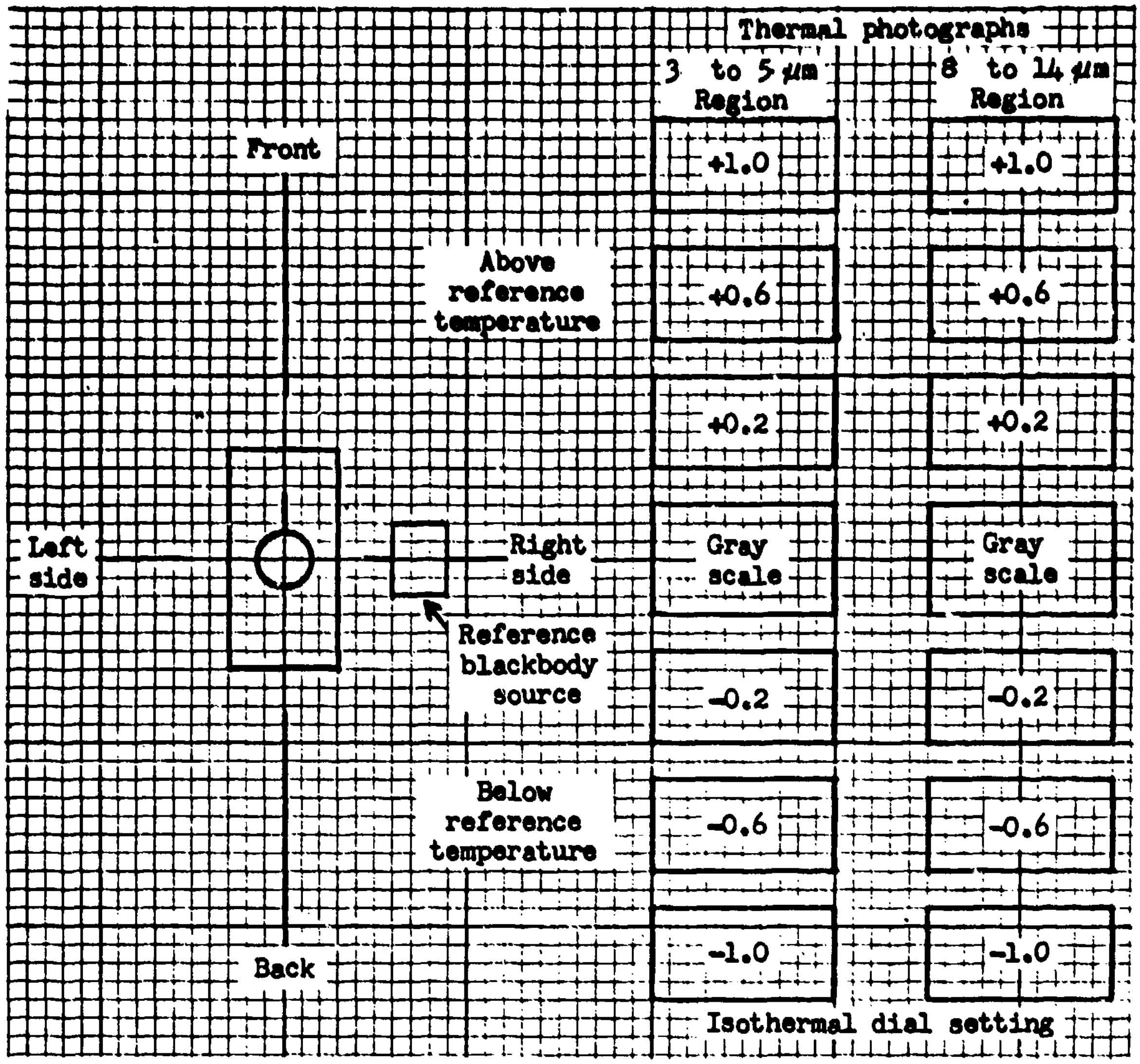
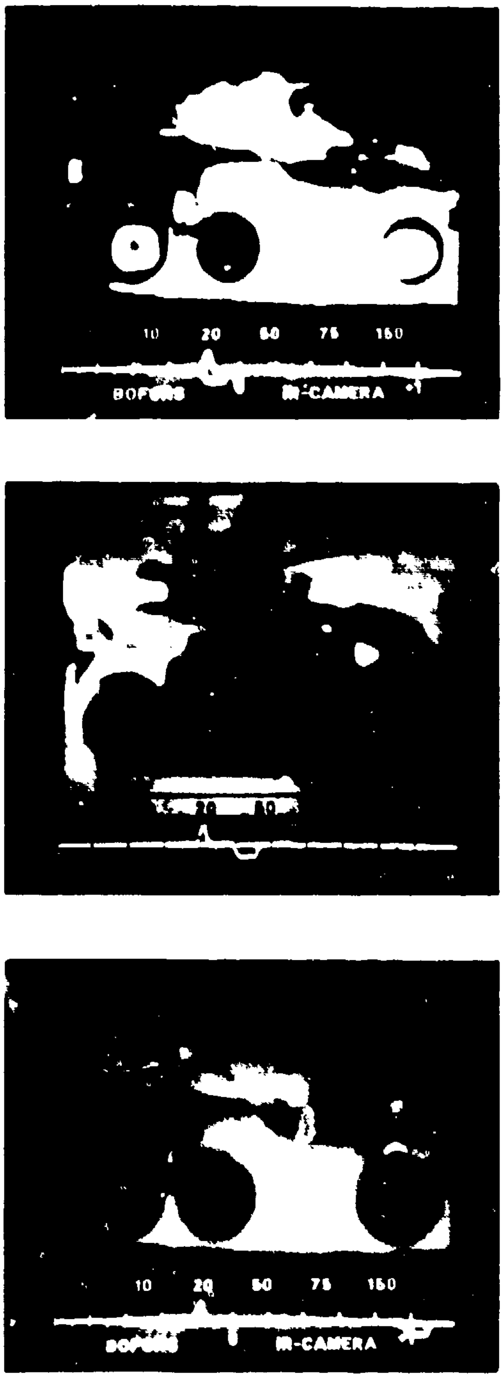


Figure 2. Gray-Scale and Isothermal Photographs of Right Side of Test Vehicle in the 3 to 5 and 8 to 14 Micrometer Regions of the Spectrum.



a. Isothermal view: temperature below reference temperature level.

b. Gray-scale view: overall temperature distribution.

c. Isothermal view: temperature above reference temperature level.

Figure 3. Sample Isothermal Photographs and Gray-Scale Photograph (8 to 14 Micrometer Region).

5.1.4 Spectral Radiant Intensity. Spectral radiant intensity, the fourth parameter needed for the optimal measurement of IR emission from a vehicle, is generally obtained using an interferometer or a spectral radiometer covering the 1 to 14 micrometer wavelength region.

5.1.4.1 Method.

a. Operate the vehicle in accordance with condition c of Table 1 and take the view measurements for the parameter of interest as in the preceding test phases. (The typical spectral signature of the background and right side of a vehicle in the 3 to 5 micrometer region is shown in Figure 4. A typical analysis of a vehicle with data entries for the right side only is shown in Figure 5.)

b. If required, evaluate the vehicle in the horizontal plane as well as a vertical plane, at the distance at which the vehicle fills the field of view of the measuring instrument.

c. To obtain information about the temporal or spatial effects of warmup of a vehicle, use the measuring instrument at a single aspect of the vehicle. (Typical spectral signatures of the vertical back aspect - general exhaust location - are shown in Figure 6. These begin with signatures of a cold vehicle and continue at intervals of one-half minute, 5 minutes, 30 minutes, and 2 hours after engine starts.)

5.1.4.2 Data Required.

a. Vehicle speed and time of start and finish of each operation over test course.

b. Spectral radiant intensity of the vehicle at each aspect viewed.

5.2 IR Temperature Measurements of Weapon Tubes. Alternatively an optical, non-contact infrared thermometer, as described in Appendix C, or a contact thermocouple system may be used to measure the surface temperature of the weapon tube. Instrument output may be digitally recorded as a hard copy on paper or punched tape for data analysis.

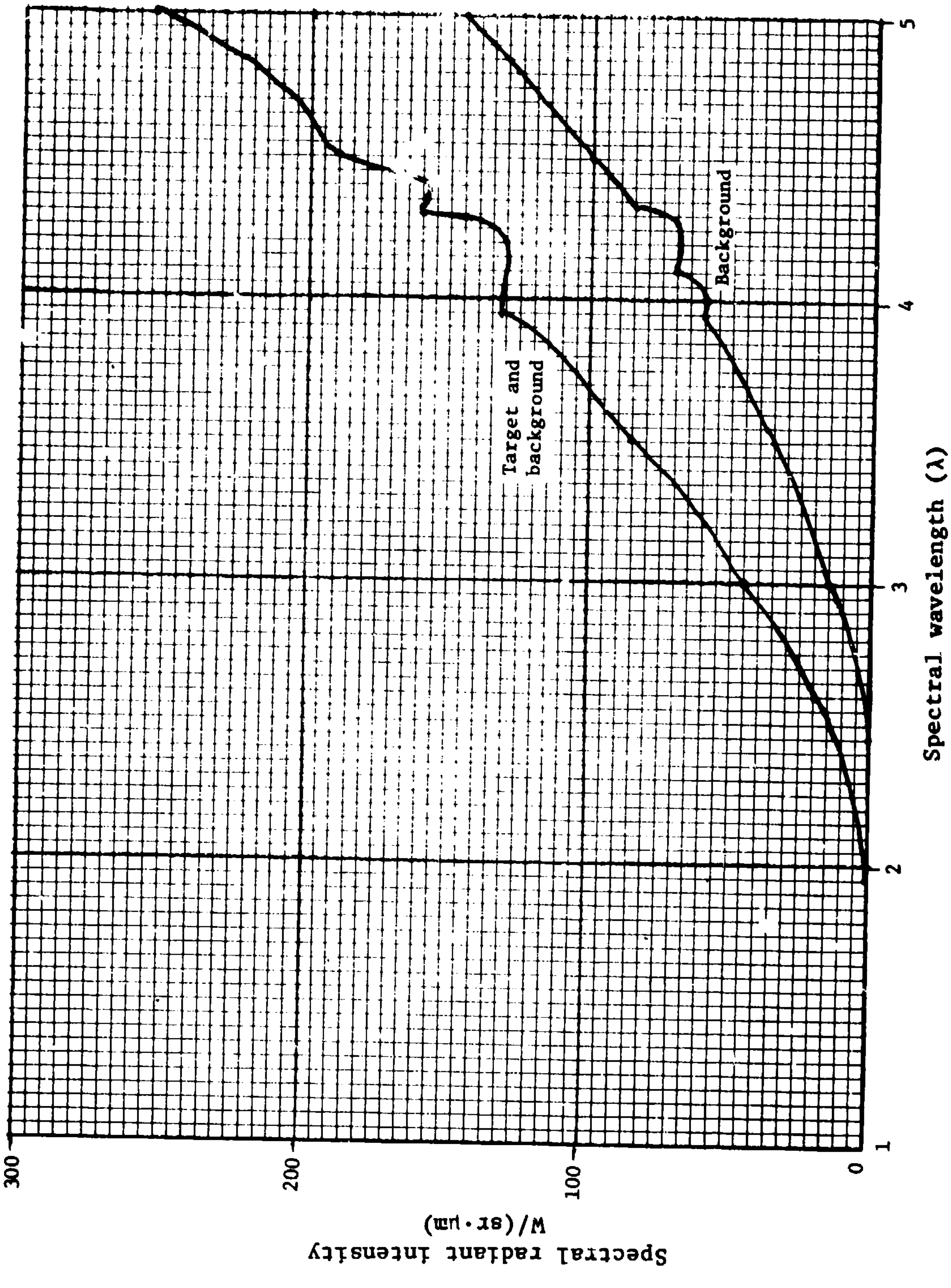


Figure 4. Spectral Signature of Vehicle (Right Side) and Background in the 3 to 5 Micrometer Region of the IR Spectrum.

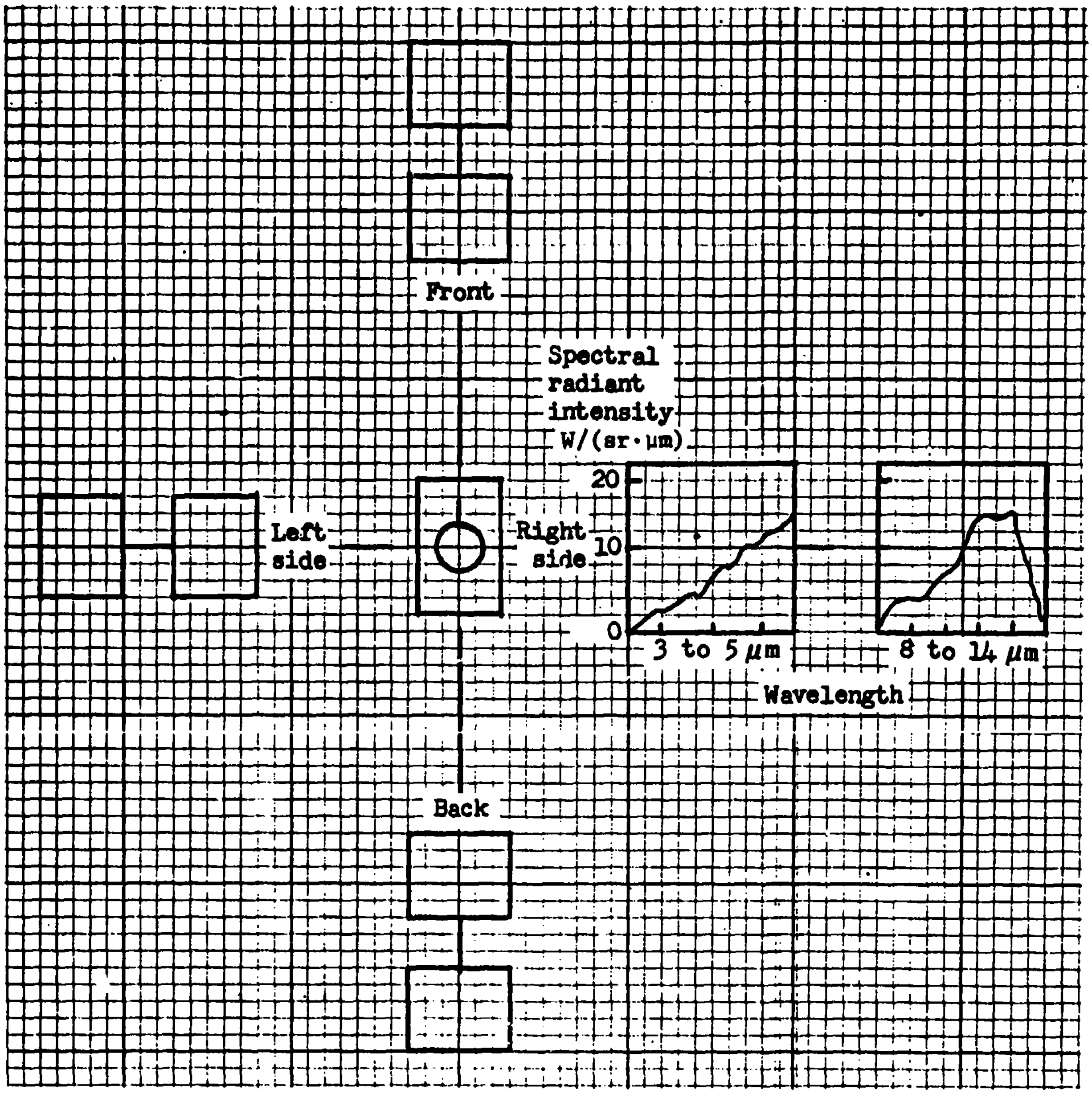


Figure 5. Spectral Signature Data for Test Vehicle at 100-Meter Distance in 3 to 5 and 8 to 14 Micrometer Regions.

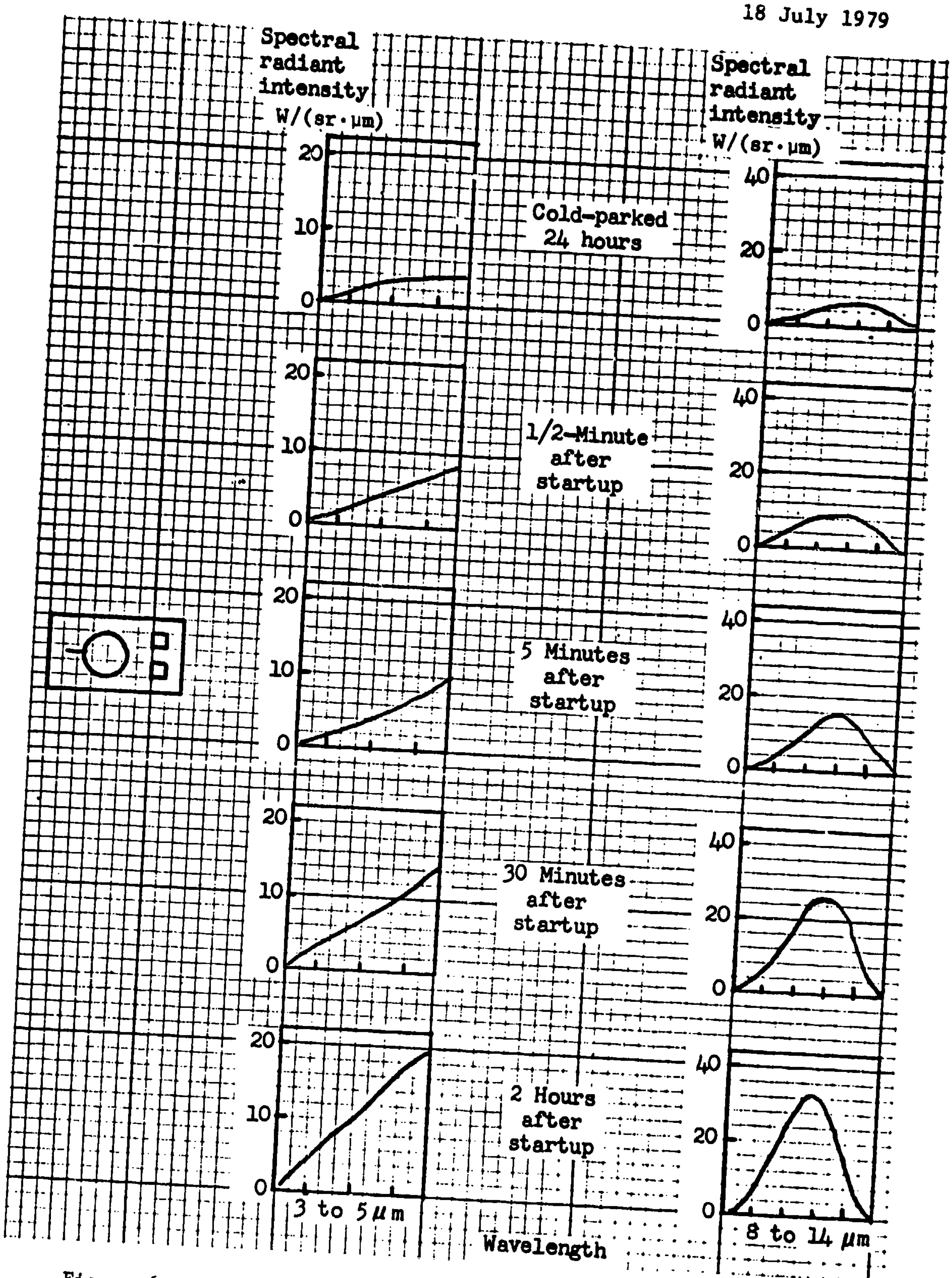


Figure 6. Variation in Spectral Energy Output in the 3 to 5 and 8 to 14 Micrometer Regions as Vehicle Warms Up.

5.2.1 Method.

a. Shortly after the weapon is fired, position the IR system to measure surface temperature on the tube, starting at the base and continuing by manual scan to the muzzle end at a constant rate. The temperature will be recorded, and the recording will include the scale range selected for the IR thermometer. A typical galvanometer recording is shown in Figure 7. In this case the scale range covers a span of temperature from 97.8° to 200° C.

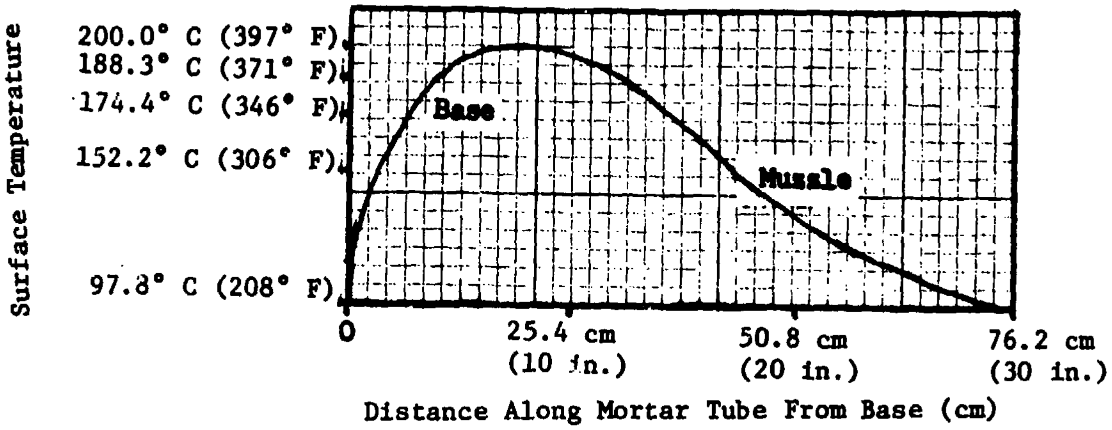


Figure 7. Typical Galvanometer Record of Surface Temperature Scan of a Representative Mortar Tube 2 Minutes After Firing.

b. Replot the data from the galvanometer recordings to an appropriate scale as in Figure 8 for direct comparison with thermocouple data taken on the same weapon. This thermocouple data, found in Figure 9, shows the distribution of temperature at five different locations along a representative mortar tube at time sequences of maximum and 2 minutes after fire. In this 2-minute-after-fire thermocouple record there is close agreement with the data from the IR thermometer of Figure 8. The different ambient outside temperatures probably account for the temperature difference of about -18° C between Figures 8 and 9.

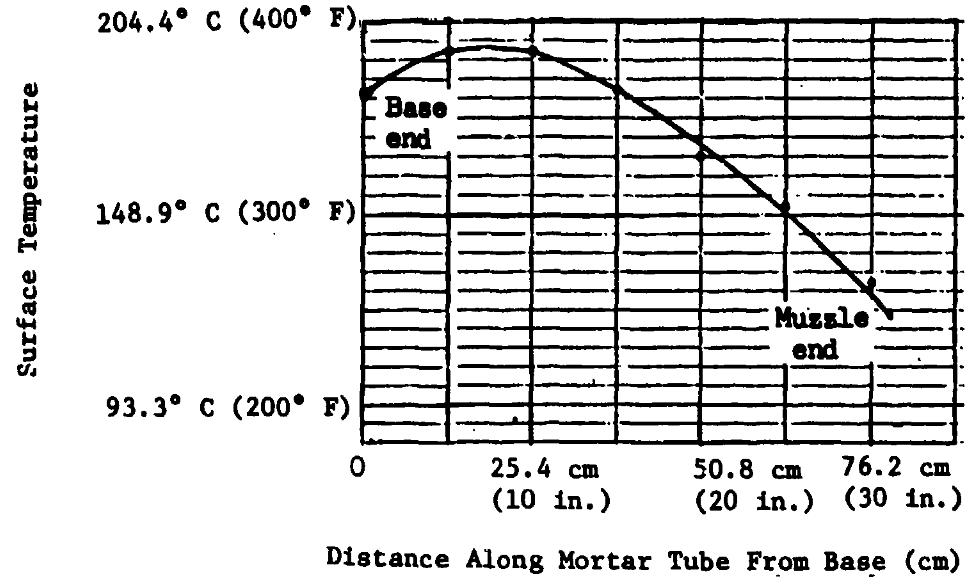


Figure 8. Surface Temperature Distribution Measured by IR Along a Representative Mortar Tube 2 Minutes After Firing.

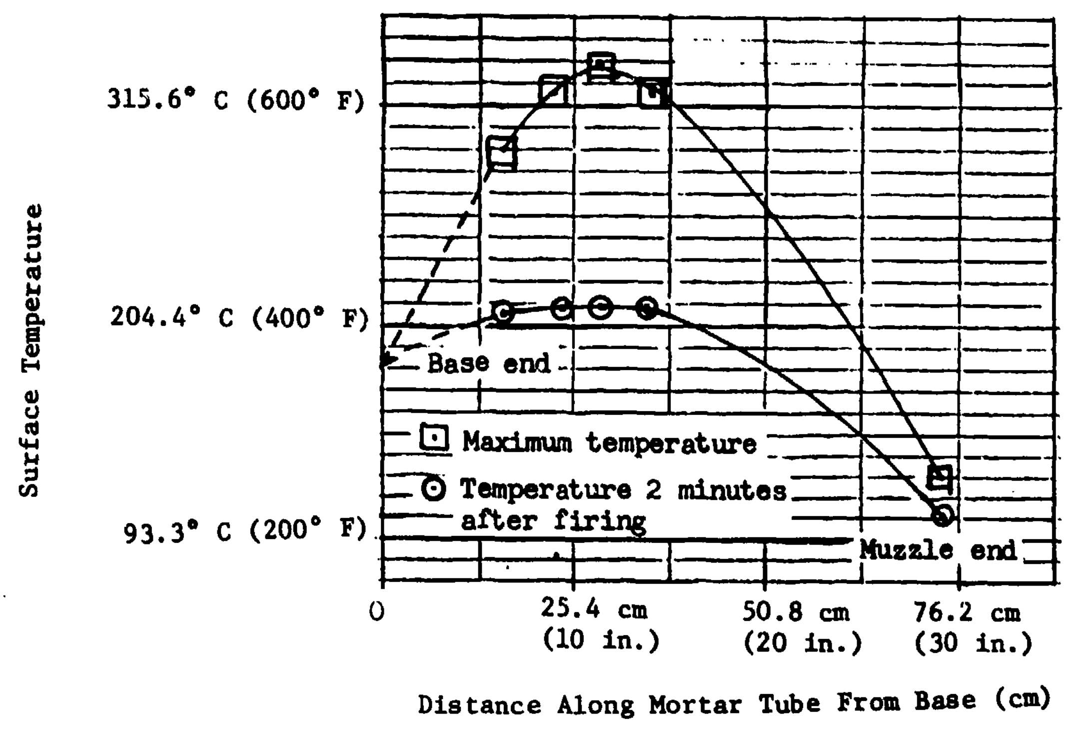


Figure 9. Temperature Distribution Along Representative Mortar Tube at Selected Thermocouple Locations After Firing.

5.2.2 Data Required.

a. Temperature data as recorded by the galvanometer.

b. Thermocouple data, if taken, for comparison.

c. Time after firing that measurements were taken (e.g., 2 minutes after firing).

6. DATA REDUCTION AND PRESENTATION.

6.1 Vehicle Signature. Imagery and radiometer data may be presented on polar plots to indicate radiant intensity, contrast and non-contrast in apparent watts/steradian; in tables of radiance for various vehicle operating states, surfaces and wavelength regions; and in tables of apparent $\Delta T°C$ for various vehicle operating states, surfaces and backgrounds.

6.2 Tube Temperature. The method used for the reduction and presentation of the tube temperature data obtained with the IR thermometer and recorded on the galvanometer is illustrated in Paragraph 5.2.

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APPENDIX A
GUIDE FOR TEST OPERATIONS CHECKLIST

Item	Yes	No	NA
1. Test parameters established.			
2. All operating personnel briefed on test requirements, special procedures, hazards, and any unusual aspects of test.			
3. All required instrumentation calibrated, properly installed, and operational.			
4. Safety requirements accomplished (checklist completed and SOP posted at test site).			
5. Required data recorded.			
6. Other.			

APPENDIX B
DATA COLLECTION SHEETS

Record the following data and attach the documentation indicated as applicable.

B-1. Vehicle/Weapon Condition

Vehicle/Weapon identification ____________________
Serial number ____________________
Date of manufacture ____________________
Tube size, model ____________________
Type of propellant/ammunition ____________________

Odometer	Kits
Paint condition:*	Speeds in gear
a. New paint	Engine identification
b. Weathered	Direction of exhaust
c. Imperfections	Area of exhaust
d. Base metal rust	Payload
Surface dust/dirt (See Paragraph 4c.):*	Documentation:
a. Clean	Photographic survey
b. Dusty	Drawing of engine compartment and exhaust area
c. Mud covered	Detailed dimensions of engine exhaust network and engine compartment
d. Snow/frost/ice covered	Speed versus rpm table
e. Wet	
Paint color	
Mechanical condition:*	
a. New	
b. Normal	
c. Noticeable malfunctions	
d. Reduced power output	

*Subjective observations.

B-2. Climatic Support Data

Date

Location

Air temperature

Relative humidity

Soil temperature

Soil description

Radiometric soil temperature

Sun elevation

Rainfall rate

Rainfall total

Cloud cover

Sky condition

Meteorological range

Visibility

Light level

Wind speed/direction

Absolute solar load

B-3. Test Course/Firing Range Description

B-4. Instrumentation (Nomenclature, Description, Location)

B-5. Test Data (List of Inputs for Plot, Graphs, Photographs)

APPENDIX C
IR THERMOMETER

The noncontact IR thermometer can be used to obtain temperature measurements of mortars and other weapons during and after firing. It usually consists of two units, an optical sighting head that is focused on the area of interest and a display console to indicate temperature. The assembly also contains an emissivity correction control setting that is used to obtain true temperature on nonblackbody surfaces. The IR thermometer can be operated on regular a-c power or on a portable a-c power supply. A typical system is shown in Figure C-1.

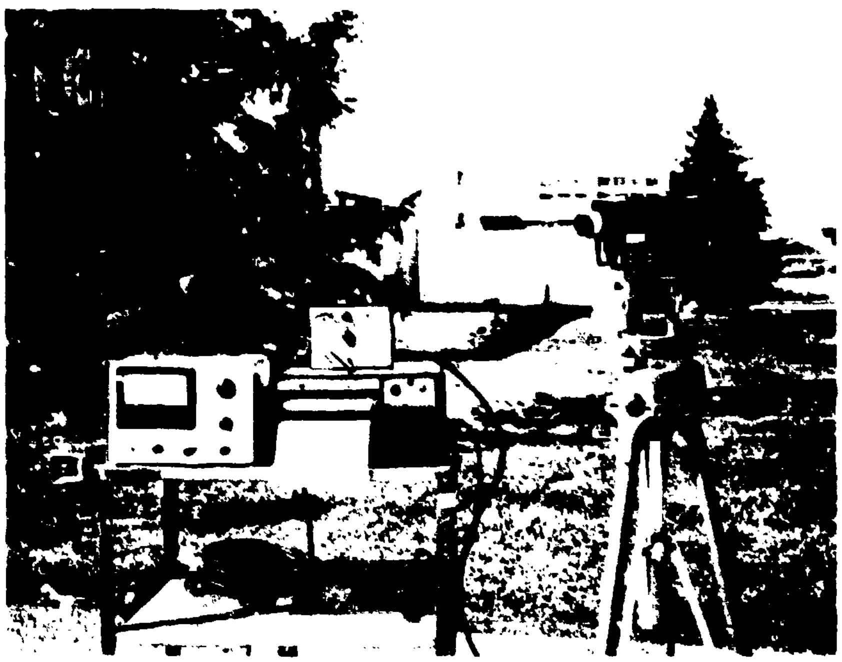

Figure C-1. IR Thermometer, Oscillographic Recorder, and Timing Generator.

The size of the area measured by the thermometer depends on the distance between the unit and the object under investigation. A measuring spot 6.4 mm in diameter at a distance of 3 to 4.6 meters is typical of most units. The spectral region of the detector is generally narrow band and consistent with the temperature range being measured.

The advantages of using the IR thermometer are the noncontact feature and the fast response of the instrument.

APPENDIX D
IR RADIOMETER

The IR radiometer collects the total IR flux in its field of view in the wavelength of its detector's spectral response. The wavelength of interest can be selected by change of detector or filter. The radiant flux may be displayed in many forms, such as radiant emittance, radiant intensity, or radiance (See Table D-1 for units.), depending on the specific radiometer selected.

The portable, hand-held radiometer illustrated in Figure D-1 measures radiance [milliwatts/(cm^2·steradian)] in the wavelength intervals of 2 to 20, 3 to 5, and 8 to 14 micrometers of the spectrum. The 2 to 20 micrometer region covers the full range of interest in the IR while the 3 to 5 and 8 to 14 micrometer regions cover the atmospheric windows found in nature (Figure D-2).

Figure D-1. Hand-Held Radiometer. (Measures Total Flux in Three Ranges: 2 to 20, 8 to 14, and 3 to 5 Micrometer Spectral Region.)

Table D-1 - Recommended Radiometric Terminology

Symbol	Term	Description	Unit
U	Radiant energy	Energy transferred by electromagnetic waves	Joule
u	Radiant energy density	Radiant energy per unit volume	Joule/cm^3
P	Radiant flux	Rate of transfer of radiant energy	Watt (W)
W	Radiant emittance	Radiant flux emitted per unit area of a source	W/cm^2
Q	Radiant photon emittance	No. of photons emitted per second per unit area	Photon/(sec·cm^2)
J	Radiant intensity	Radiant flux per unit solid angle	W/sr
N	Radiance	Radiant flux per unit solid angle per unit area	W/(cm^2·sr)
H	Irradiance	Radiant flux incident per unit area	W/cm^2
$P\lambda$	Spectral radiant flux	Radiant flux per unit wavelength interval at a particular wavelength	W/μm
$W\lambda$	Spectral radiant emittance	Radiant emittance per unit wavelength interval at a particular wavelength	W/(cm^2·μm)
$Q\lambda$	Spectral radiant photon emittance	Radiant photon emittance per unit wavelength interval at a particular wavelength	Photon/(sec·cm^2·μm)
$J\lambda$	Spectral radiant intensity	Radiant intensity per unit wavelength interval at a particular wavelength	W/(sr·μm)
$N\lambda$	Spectral radiance	Radiance per unit wavelength interval at a particular wavelength	W/(cm^2·sr·μm)
$H\lambda$	Spectral irradiance	Irradiance per unit wavelength interval at a particular wavelength	W/(cm^2·μm)
ϵ	(Radiant) emissivity	Ratio of radiant emittance of a source to that of a blackbody at the same temperature	(Numeric)
α	(Radiant) absorptance	Ratio of absorbed radiant flux to incident radiant flux	(Numeric)
ρ	(Radiant) reflectance	Ratio of reflected radiant flux to incident radiant flux	(Numeric)
τ	(Radiant) transmittance	Ratio of transmitted radiant flux to incident radiant flux	(Numeric)

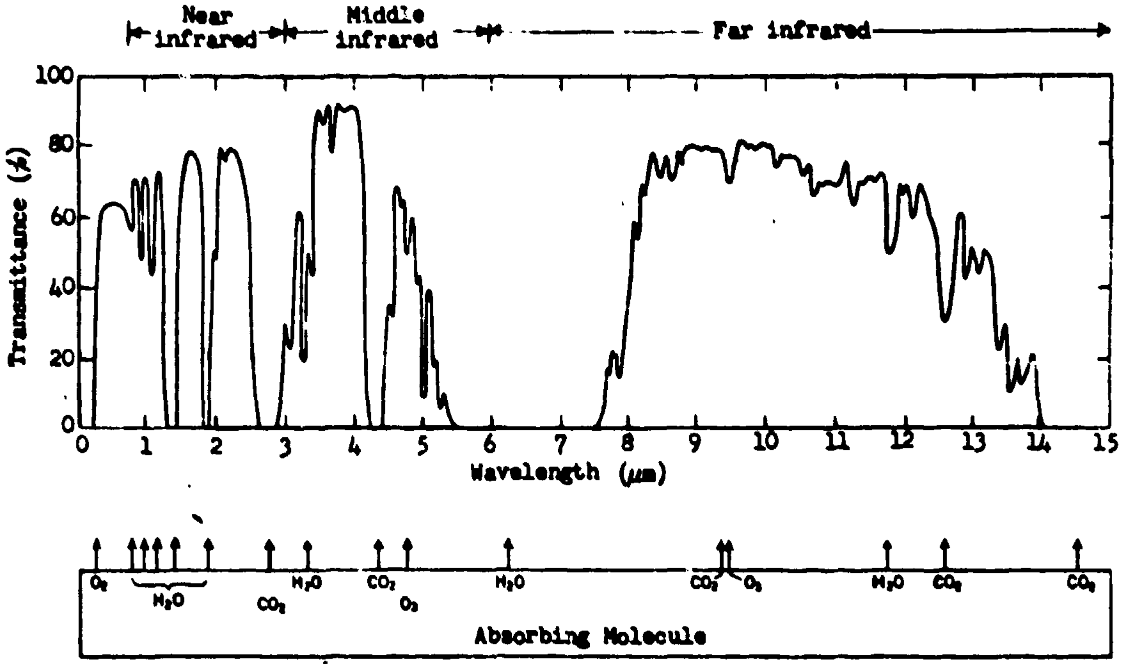

Figure D-2. Transmittance of the Atmosphere for an 1,829-Meter (6,000-Foot) Horizontal Path at Sea Level Containing 17 mm of Precipitable Water.

The significance of the average radiance difference (Paragraph 6.1) is that it represents the energy difference in milliwatts/(cm^2·steradian) between vehicle and background. The total radiance of the vehicle in any view can be determined by adding the background radiance value to the difference for each respective wavelength region. For example, data obtained (Paragraph 5.1.1.2) for a right side view of a vehicle in the 8 to 14 micrometer region, the radiance difference was 1.95 mW/(cm^2·sr); since the background radiance was 4.78 mW/(cm^2·sr), the total radiance of the vehicle would be 6.73 mW/(cm^2·sr).

There are other units and methods of displaying vehicle IR data obtained by radiometry depending on individual test requirements. The technique described in Paragraph 5.1.1 is the most suitable for TECOM testing at Aberdeen Proving Ground with the available instrumentation.

APPENDIX E
COMPUTATION OF RADIANCE FROM AN OBJECT AT A GIVEN TEMPERATURE

Where radiance (N) is to be calculated for a given temperature (T), its value is given as:

$$N = \frac{\varepsilon \sigma T^4}{\pi} = W/(cm^2 \cdot sr)$$

where: ε (emissivity) may range from 0.12 to 0.99μm (See Table E-1 below.)
σ = Stefan-Boltzmann Constant [$5.672 \times 10^{-12} W/(cm^2 \cdot deg^4)$]
T = Temperature of material (°K)

Table E-1 - Emissivities of Various Materials

Material	Emissivities (ε)		
	2 to 20μm	3 to 5μm	8 to 14μm
18-8 Weathered stainless	0.57	0.40	0.49
24-ST Weathered aluminum	.26	—	—
18-8 Polished stainless	.12	—	—
Pinewood	.90	—	—
Cast iron	—	—	—
Oxidized mild sheet steel	—	—	—
Red iron oxide	—	—	—
Soot	—	.99	.99
White enamel	—	—	.90
OD paint (MIL-E-46117)	—	.74	.72
Grass	—	.82	.88
Sand, silt loam	—	.85	.94
Coniferous	—	.96	.97
OD paint (TT-E-529)	.90	—	—
Rubber	.91	—	—
Oxidized paint	.87	—	—