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Spectral Signature Studies For Application in Deer Census Using Remote Sensing Techniques

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SPECTRAL SIGNATURE STUDIES FOR APPLICATION IN DEER CENSUS USING REMOTE SENSING TECHNIQUES

by

Maran C. Pate

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Electrical Engineering

Approved:

UTAH STATE UNIVERSITY
Logan, Utah

1979

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Maran C. Pate

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ABSTRACT

Spectral Signature Studies For Application in Deer Census Using Remote Sensing Techniques

by

Maran C. Pate, Master of Science

Utah State University, 1979

Major Professor: Dr. Clair Wyatt
Department: Electrical Engineering

This study was performed to determine the spectral signatures of deer and their natural background elements for censusing purposes. Consideration was given to atmospheric transmittance, acceptable flying weather, and terrain. Possible spectral bands between 0.3 and 14.0 μm were obtained (over a pathlength of 1500 feet at an altitude of 5000 feet) based upon atmospheric transmittance using the LOWTRAN 3B computer program. They are: 0.30 - 1.33, 1.49 - 1.79, 2.00 - 2.50, 3.00 - 3.16, 3.38 - 4.10, 4.59 - 5.05, and 8.00 - 13.33 μm, for transmittance greater than 75%. Weather conditions are favorable for flying and taking data on the average of 2 days per week (in areas near Salt Lake City) throughout the winter months. Measurements were obtained of the spectral reflectance and spectral emissivity of deer hide, sands, soils, sagebrush, and other natural winter habitat elements. The results of these measurements indicate that all the biological samples tested emit blackbody radiation; that is, the emissivity is approximately unity and there are no unique spectral signatures. The reflected spectra in the region 0.5 to 1.1 μm contains considerable unique spectra, including chlorophyll absorption at 0.66 μm, that might be useful in designing a multispectral classifier.

(85 pages)

INTRODUCTION

Nature of the Problem

In recent years there has been an increasing interest in wildlife populations. Society in general, and biologists, in particular, are concerned about the effects which modern civilization has on wildlife habitat. Furthermore, it is important for wildlife managers to know the size of populations in order to make sound management decisions.

A number of techniques have been employed with varying success to estimate the size of deer populations. Some methods used include ground surveys and stripcounts, aerial census, pellet counts, spotlight surveys, browse surveys, hunter kill and success results, and counting shed antlers.

Wolfe (1976) pointed out inherent weaknesses in several of the techniques used. He states, "...browse surveys appear mainly to provide hindsight and reflect cumulatively events and conditions of the past more adequately than those in the time the surveys are conducted." A problem with aerial and ground counts of deer is that "...they can only serve as an index to the general population trend over a relatively long period of time." Politics also seems to play a role in the usefulness of hunter kill results. "Current harvest data alone do not allow an accurate determination of mule deer populations, particularly on a statewide basis, due to more variable and restrictive seasons applied under present management practices." Some techniques have been discarded as inadequate, but others have been kept and used as the most adequate to date in terms of information gained in exchange for effort expended. However, no single method has proved satisfactory. A further discussion of current limitations and capabilities in deer censusing is given in the literature (Wolfe, 1976).

Previous Work

Efforts to estimate the size of deer populations in recent years have moved in the direction of electronic censusing. The possibility of using the thermal infrared regions has been considered by several researchers, e.g., Marble (1967), Carneggie (1968), Croon et al. (1968), McCullough et al. (1969), Graves et al. (1972), Parker (1972), Parker and Driscoll (1972), Isakson et al. (1975).

The concept of a warm-blooded animal standing out from a colder inanimate background seems to be the most appealing reason for investigating the thermal infrared. The peak radiant power (heat) emitted from many animals is in a region where the atmosphere has a high transmittance (8.0 - 14.0 μm). Carneggie (1968) investigating livestock censusing stated:

> Animals can be imaged particularly well at night when the heat from their bodies is in contrast to the cool night-time temperatures of background material such as soil and grass. Animals can also be imaged during the daytime, when temperature differences are detectable between the animals and its background.

Animals lying in shadows are readily seen on thermal infrared imagery.

There are several areas where previous investigators agree and some areas needing further clarification. The results of the literature review performed can be divided into four categories: 1. spectral bands investigated, 2. thermal contrast measured, 3. environmental conditions, and 4. censusing capabilities.

Spectral bands investigated

Parker (1972) used a 8.0 - 13.0μm band and was able to obtain census data at 500 feet but not at 1000 feet using penned deer and antelope. One set of measurements was conducted under "idealistic" conditions (small, open, snow-covered pens with no foliage) and another set was obtained under more natural conditions (large enclosure with some foliage, and snow-covered terrain).

McCullough et al. (1969) investigated three bands (3.5 - 5.5μm, 3.5 - 14.0 μm, and 8.0 - 14.0μm) and obtained results indicating the 8.0 - 14.0μm region is the best. The censusing conditions included three groups of penned animals; one having an open snow-covered pen, one located in a deciduous forest after leaf fall, and one located among evergreens. The animals in the evergreens were not detectable without a priori information.

A third group (Graves et al. 1972) investigated three bands (3.0 - 4.0μm, 3.0 - 5.0μm, 3.0 μ 14.0μm) and found the short wavelength bands gave the best results during the warm summer months and the broadband detector gave the best results during the winter. Their best results overall came from the shorter wavelength region. The results of a study (Barhydt et al., 1970) to determine the optimum spectral region for infrared scanning show that "At very short range [several thousand yards] essentially equivalent performance can be obtained in either the 3.0 - to 5.5 μm region or in the 8 - to 14 μm region." The author also points out that haze tends to make the longer wavelengths more favorable while high humidity tends to make the shorter wavelengths more favorable.

It appears from the literature that the differing results (concerning which wavelength region is best) may have been obtained more because of local or statistical differences than from large inherent differences in the bands investigated.

Thermal contrast measured

Several research groups have conducted outdoor winter temperature measurements. McCullough et al. (1969) reported an apparent temperature differential of about 7°C between deer and a snow background with an air temperature of 4°C. Parker (1972) found a mean temperature differential of 7.7°C between deer and background. He concluded that the actual difference at any time may be much less than the average. Parker (1972) and Marble (1967) both indicate that the temperature measurements of deer etc. are highly variable. The thermal contrast may be defined by

$$\text{thermal contrast} = \frac{T_{\text{deer}} - T_{\text{snow}}}{T_{\text{snow}}}$$

and is approximately 3% for Parker's measurements. A recent analysis of Parker's data (Wyatt et al., 1979) indicates that deer could be successfully detected with snow cover background, however, a thermal scanner would exhibit large errors in detecting deer when the probability of snow-free objects is greater than the probability of deer.

Environmental conditions

"Experience has shown that meteorological conditions during thermal data collection are extremely important to the quality of the output" (Isakson et al., 1975). The fact that the detectability of a target is related to the time of day, season, and altitude is probably due to the interaction with the meteorological conditions. Wind, rain, haze, frost or dew on an animal's back are conditions which seem to hinder infrared detection.

Moen and Jacobsen (1974), Parker (1972), Marble (1967) and others generally agree that the following conditions are beneficial in obtaining thermal census data:

1. level topography,
2. snow covered terrain (for winter censusing),
3. low atmospheric moisture (no rain, etc.),
4. no temperature inversions,
5. little or no wind.

There is some disagreement as to whether daytime flights are better than night flights and whether a clear sky or a high overcast sky is better for obtaining infrared data. Solar radiation, during the day, causes the radiant temperatures of grass, soil, and snow etc., to vary considerably. A clear sky during the night and a high overcast sky during the day tend to produce a more uniform background.

Censusing capabilities

To date no investigator has been able to obtain good thermal infrared census data of deer from more than 500 feet elevation. Nearly "ideal" conditions were used to obtain the existing data. Both Graves' (1972) and Parker's (1972) attempts to detect deer above 500 feet were unsuccessful. Researchers have obtained distinguishable livestock data at altitudes of 1000 feet and higher (Graves et al. 1972, Shilin et al. 1971). Apparently livestock can be detected at significantly higher altitudes than deer because of their larger size.

Objectives

The objectives of this work are to:

1. perform a literature review to determine what progress in censusing has been made,
2. determine candidate spectral bands for censusing based upon the atmosphere transmittance,

3. determine the average number of days available for surveying deer ranges using light aircraft, and
4. determine the spectral radiation "signatures" of deer and its wintertime background in the laboratory in the thermal emission and reflective bands.

Significance of This Work

The success of any discrimination system depends upon utilization of the statistical properties of both the target and the background. The purpose of this study is to investigate the spectral properties (signatures) of deer and background in both emitted and reflected radiation; including the ultraviolet (UV), visible, and infrared (IR) regions. A characterization of the deer and background elements is necessary before a workable, efficient censusing system can be designed or constructed. The samples measured were deer-hide, tree barks, foliage from brushes and trees obtained from the wintertime deer habitat, and various sand and soil samples. A list of the samples measured is given in Appendix A.

FUNDAMENTALS OF TARGET DISCRIMINATION

Introduction

Target discrimination is a problem of detecting and characterizing a target based upon the sensor response to electromagnetic radiation in the presence of competing background and atmospheric scattering. The radiation incident upon the entrance aperature is a combination of reflected and emitted radiation from the target and the background which has been modified by the atmosphere, as illustrated in Figure 1.

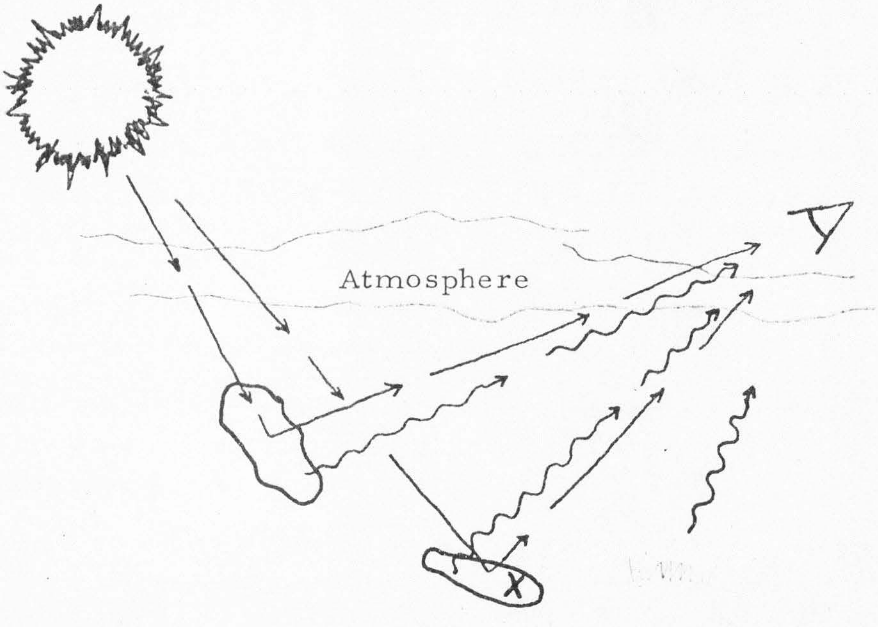

Figure 1. Target discrimination.

Target attributes such as size, shape, temperature, position, and spectral characteristics can be inferred from the radiation measurement in a properly designed experiment. The target radiation (emitted or reflected) is spread over the electromagnetic spectrum and hence cannot be fully utilized or measured by any single detector. The main challenge of discrimination is to find unique properties of the target that can be characterized using remote sensing of electromagnetic radiation. This includes: an examination of the electromagnetic spectrum; consideration of interferring (atmospheric) media; and an understanding of what target parameters can be characterized by remote sensing techniques. Consideration of the above mentioned areas is given in the succeeding text.

Electromagnetic Spectrum

The electromagnetic spectrum can be divided into several regions, depending upon the detection technique employed (see Figure 2).

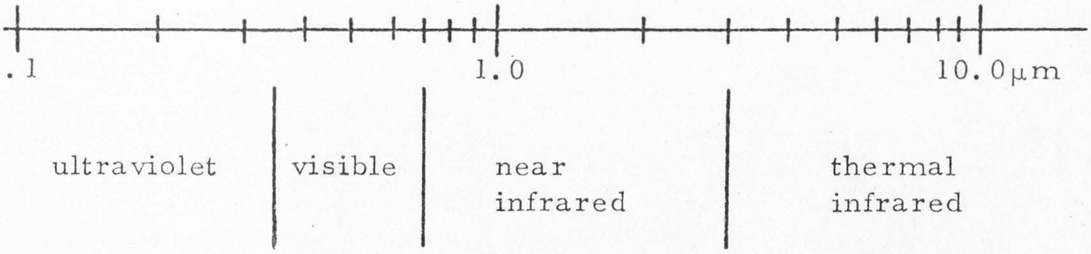

Figure 2. Electromagnetic energy spectrum.

The regions overlap. The micrometer ($\mu m = 10^{-6}$ meters) is a commonly used unit for wavelength to specify a region of the spectrum. The wavelength is defined as the distance between two points in adjacent waves having the same phase.

The continuous spectrum is divided into smaller usable bands because the earth's atmosphere does not transmit radiation at some wavelengths. Atmospheric constituents such as H_2O, CO_2, and CO absorb part of the energy.

Atmospheric Effects

The atmospheric transmission at some wavelengths varies considerably with small changes in humidity. A computer program, LOWTRAN 3B (Selby et al., 1976), was used to calculate the atmospheric transmittance under the expected censusing conditions. The input data used were:

Visibility--5 miles (8.1 km),

Atmospheric Model--Midlattitude Winter,

Spectral range--.3 to 14.0μm (3360 - 710 cm^{-1}, using varying resolution increments),

Atmospheric pathlength--1500 ft (.457 km),

Vertical Atmospheric Path--6500 ft to 5000 ft (1.981 km—1.524 km).

The program output showed that atmospheric humidity and $C0_2$ content are the major factors degrading atmospheric transmission.

The effects of CO_2 for a given altitude, pathlength, and wavelength are essentially constant. Changes in humidity are more variable and can cause significant changes in transmittance at some wavelengths. A summary of the program results is given in Table 1. The results show spectral regions which could be utilized for censusing purposes.

Domains of Characterization

Brown et al. (1975) pointed out, "As remote sensing is used in more varied and comprehensive investigations, it becomes quite obvious how lacking in knowledge we are, in many instances, of some of the basic parameters of our 'targets'."

The response of any remote sensing spectrometer to an incoming noncoherent signal can be described by the equation:

$$R(\lambda) = R_o R(t)\, R(p)\, R(\theta, \phi)\, R_s(\lambda)\, R_i(\lambda)$$

Where $R(\lambda)$ is the sensor responsivity which has the units of volts/flux; R_o is the absolute signal intensity. $R(t)$ is the temporal response (i.e. the sensor response to a time-varying signal); $R(p)$ is the sensor response as a function of the polarization of the incident radiation; $R(\theta, \phi)$ is the sensor field of view (FOV) (i.e. spatial response); $R_s(\lambda)$ is the system relative spectral response throughout the free spectral range of the spectrometer; $R_i(\lambda)$ is the "instantaneous" spectral response resolution function. See Figure 3. Radiometric measurements are considered more fully in Wyatt (1978).

TABLE 1

ATMOSPHERIC TRANSMISSION WINDOWS*

Atmospheric Transmittance (%)	UV, Visible, and Near IR Window Regions (.30 - 2.90μm)				
95	0.50 - 0.93	0.98 - 1.10	1.16 - 1.30	1.52 - 1.75	2.08 - 2.38
90	0.32 - 0.93	0.98 - 1.11	1.16 - 1.32	1.49 - 1.75	2.08 - 2.47
75	0.30 ------------------------------ 1.33			1.49 - 1.79	2.00 - 2.50
50	0.30 ------------------------------ 1.33			1.43 - 1.79	1.96 - 2.50

(%)	IR Window Regions (2.90 - 14.00μm)				
95	X	X	X	8.55 - 9.43	9.62 - 12.42
90	X	X	4.63 - 4.81	8.13 ---------------- 13.07	
75	3.00 - 3.16	3.38 - 4.10	4.59 - 5.05	8.00 ---------------- 13.33	
50	2.90 ---------------- 4.17		4.50 - 5.32	7.55 ---------------- 13.90	

*The data shown were obtained using a "midlattitude winter" atmospheric model with visibility of 5 miles and a vertical pathlength of 1500 feet (6500 feet to 5000 feet altitude).

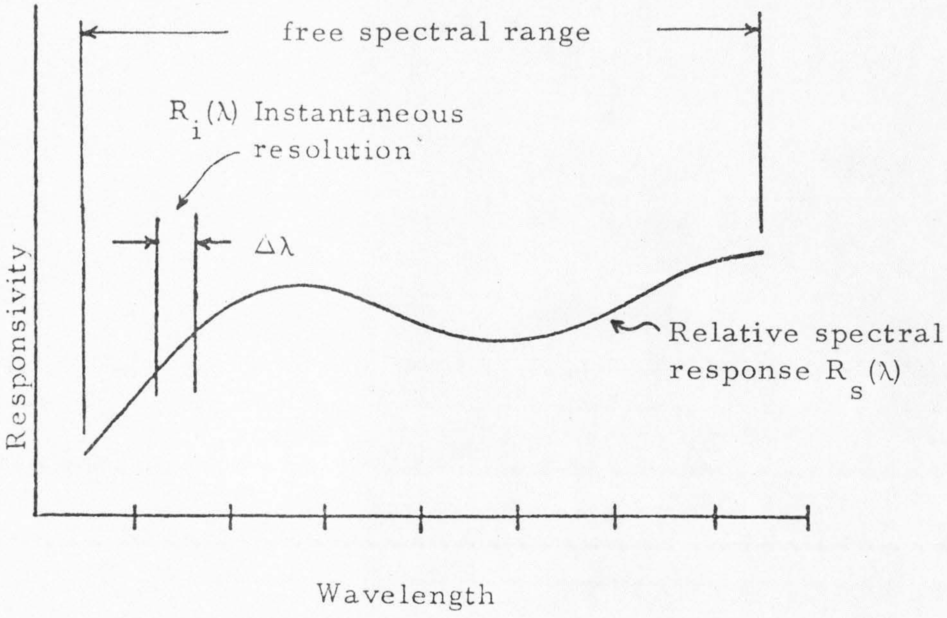

Figure 3. Instantaneous spectral resolution.

The four quantities--$R(t)$, $R(p)$, $R(\theta, \phi)$, and $R_i(\lambda)$--are normalized and dimensionless. These parameters can be considered as independent. The sensor measures the flux which is incident upon the sensor collector. The temporal, polarization, spatial, and spectral properties of the target can be deduced from the sensor response to the target in a properly designed experiment provided that the sensor response has been characterized in those domains. The sensor can also measure the absolute intensity of the radiation or the "contrast" between the target and the background in a properly designed experiment.

Each of these independent parameters may exhibit unique target characteristics and may therefore be utilized in a detection, discrimination, or pattern recognition scheme as follows:

1. Time variation--the target may change position as a function of time;
2. Polarization--the target may reflect and/or emit polarized radiation;
3. Spatial characteristics--unless the target is a gas or fluid it will have a definite spatial shape and orientation in three-dimensional space at any instant of time;
4. Spectral content--every target has spectral characteristics, some of which may form a unique "signature" over a wavelength interval.
5. Target to background contrast--the target may exhibit an intensity contrast to the background.

Time variation

Many targets of interest change position with time. Such is the case with deer. It has been possible in some military applications involving time-varying targets to store the incoming radiation from a scene and then compare the stored data with that taken at some later time. The changes in radiance of the two scenes indicate the presence of the (mobile) target. While such an approach works well for tracking high-speed objects, time variation of the deer and its background may be too similar to be useful. It is necessary to characterize a targets background in order to determine when the target has moved. At the present time, the background has not been characterized sufficiently to discriminate between background changes and target movements.

Polarization

Emitted and reflected energy may have polarization characteristics. The degree of polarization of electromagnetic energy is given by the equation:

$$\rho = \frac{I_{(max)} - I_{(min)}}{I_{(max)} + I_{(min)}}$$

Where $I_{(max)}$ and $I_{(min)}$ are the maximum and minimum values of intensity as measured by a polarimeter.

There seems to be a lack of material on polarization in the infrared region. In a government sponsored study (Beard, 1976), 3100 document titles were extracted using a computer search and retrieval system. Two-hundred thirty of those extracted plus 40 additional documents not on the computer system were selected for inclusion in the survey. From the total of 270 documents included, only one was listed as having polarization as a discrimination criterion. It appears from the scarcity of literature in general that polarization in the thermal infrared is still relatively undeveloped. Polaroid lenses and filters are used extensively in the visible region and in the near infrared. Polarization characteristics are not considered in this project.

Spatial characteristics

The spatial characteristics of wildlife constitute additional information which may be used to discriminate for censusing purposes.

When scanning or imaging wildlife, the FOV of the instrument functions as a spatial filter and should be matched to the target. The spatial target characteristics which can be measured include size, shape, and three-dimensional extent. The spatial parameters are linearly related to time for a sensor that scans uniformly.

The size of a target can be obtained from a single scan or line-transect. The shape and size can be obtained only if the scanner data can be arranged into a raster to obtain a "picture" of the scene. Pattern correlations can be calculated by comparing the target data to some standard pattern. Three-dimensional characterization of a remote target requires the use of a stereoscopic system. Correlations can be performed in two, three or more dimensions but the addition of each dimension increases the complexity. Considerable effort has been spent developing computer techniques to utilize the spatial information of target scenes (Marshall 1969, Tanguay 1969). The spatial profiles of deer and other wildlife may not be unique because background objects such as rocks, trees, patches of soil, etc. can have similar spatial characteristics. A deer's spatial characteristic, by itself, is probably not adequate for discrimination purposes. However, the spatial distribution of the deer can be used along with other parameters to improve the discrimination.

Spectral content

All known naturally occurring materials emit and/or reflect radiation that exhibits characteristics over the range from the UV to the thermal IR. The spectra may be continuous or discontinuous depending upon the reflection, absorption, and emission characteristics of the material. The degree of uniqueness is a measure of information content.

The "spectral signature" of a target is the distribution of flux as a continuous function of wave length. The spectral signature can be considered as a multidimensional vector, where each component of the vector is a resolved component of the spectrum. Data processing techniques are used to perform a spectral feature selection procedure, based upon a hierarchial cluster analysis, to determine which features provide the best target characterization. A classification scheme based upon a single feature would degenerate to the "target contrast" case; while a multispectral system would utilize more complex techniques of pattern recognition. Band selection for a target contrast scheme has been based upon the signal-to-noise ratio (SNR) for detectors.

Target-to-background contrast

The absolute signal intensity of a target is highly variable and difficult to predict. Changes in solar illumination cause the signal intensity from the target to become erratic. Measurements of absolute intensity tend to characterize the environmental conditions rather than unique target features. Attempts have been made (Earing (1969), Kriegler (1969) to obtain measurements that are independent of the absolute intensity and which are more characteristic of the target rather than of the environment. This includes thermal contrast and multispectral ratioing techniques. Measuring the target-to-background contrast reduces the data variability considerably. Using ratioing techniques, ideally it would be possible to find spectral bands which give consistant target/background measurements, regardless of variability in the illumination.

Signal-to-Noise-Ratio

Thermal contrast is a possibility for discrimination in the thermal IR region (3.0 - 14.0 μm), if a target and background are essentially "blackbody" in nature. Barhydt (Barhydt et al. 1970) outlines a technique to obtain the optimum spectral band using a background-noise-limited (thermal-imaging) system based upon the signal-to-noise-ratio. The idea is that if there is no spectral information; i.e. the emission is blackbody, then the only information in the emission is that of thermal contrast and an appropriate selection basis for a band is one that yields the maximum signal-to-noise ratio. The optimum band is obtained when the function

$$I = \frac{\int_0^\infty T_F(\lambda)\, T_a(\lambda)\, R_d(\lambda)\, \frac{\partial W_\lambda}{\partial T} \lambda d\lambda}{\left(\int_0^\infty T_F(\lambda)\, Q_\lambda d\lambda \right)^{\frac{1}{2}}}$$

is maximized where

λ = wavelength

$T_F(\lambda)$ = filter transmittance as a function of wavelength

$T_a(\lambda)$ = atmospheric transmittance as a function of wavelength

$R_d(\lambda)$ = normalized detector response as a function of wavelength

W_λ = Planck's spectral radiant-emittance function

T = temperature

Q_λ = Planck's photon spectral distribution.

All wavelength dependent parameters must be included to obtain the optimum solution. A computer program was written to find an iterative solution using a target temperature of 295 K (22 C) and a differential increment of 0.1 μm. For the sake of simplicity, the filter characteristics $T_F(\lambda)$ were assumed to be unity in the region from 3.0 - 14.0 μm and zero everywhere else. The results of the LOWTRAN 3B program provided the values of $T_a(\lambda)$. Linear approximations of two sets of detector characteristics (InSb 3.0 - 5.5 μm, HgCdTe 5.5 - 14.0 μm) were used for $R_d(\lambda)$ as shown in Figure 4.

In the short wavelength IR region (3.0 - 6.0 μm), the optimum spectral band is 3.0 to 5.2 μm while in the long wavelength region (6.0 - 14.0 μm) the optimum is 7.5 - 13.2 μm. The 7.5 - 13.2 μm band was the overall optimum by a factor of four.

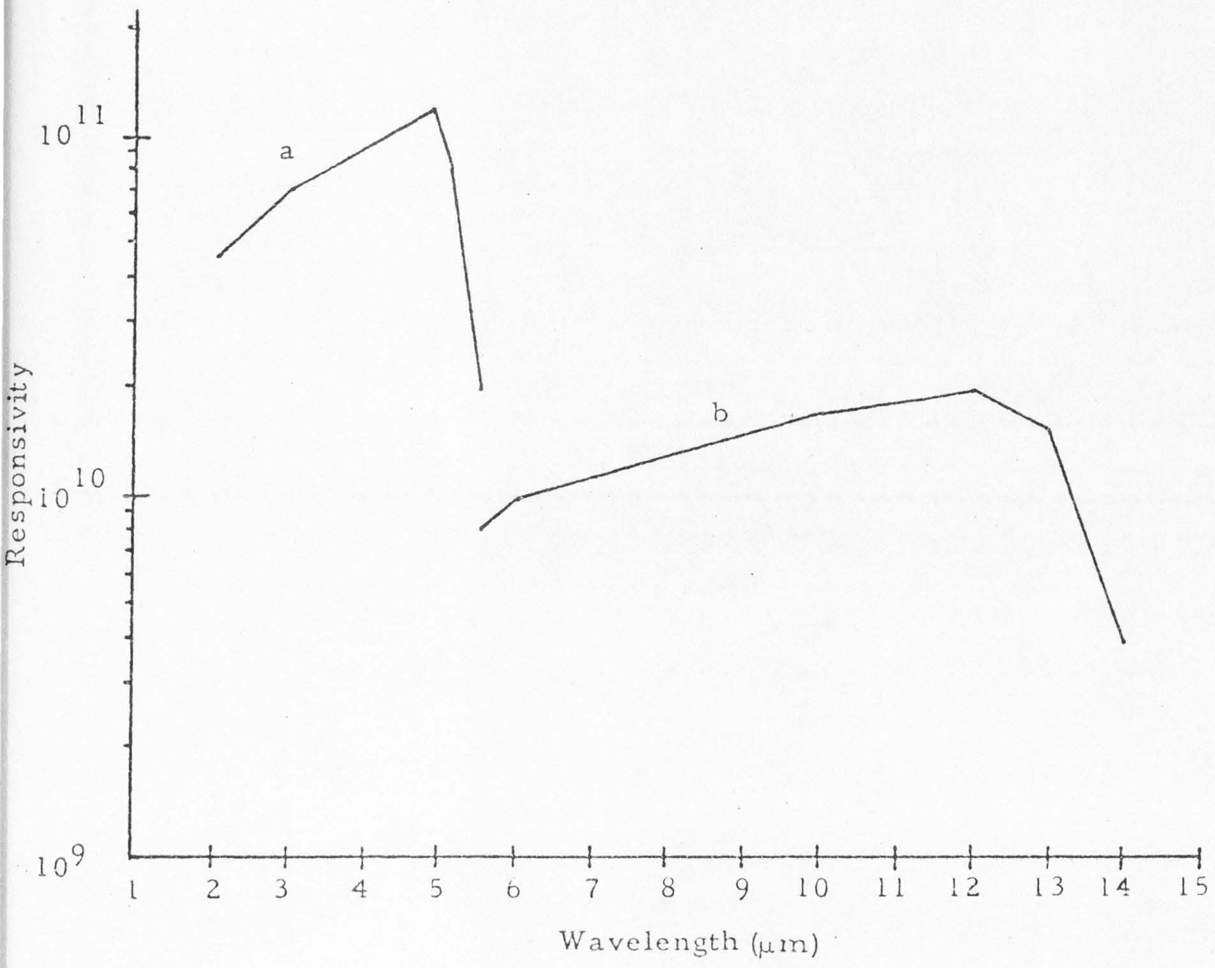

Figure 4. Linear approximations of detector responses.
a) InSb b) HgCdTe

Operational Aspects

The feasibility of utilizing light aircraft for an operational deer censusing system in the state of Utah is dependent upon the climatic conditions. Also, previous studies have indicated that diffuse overcast conditions are best for daytime measurements. Meteorological data for the Salt Lake International Airport were used to determine the number of acceptable days for operational censusing since that is the only site for which a statistical data set is available.

The minimum requirements used to select censusing days were

1. visibility of 5 miles or greater,
2. totally overcast sky at 8:00 a.m.,
3. cloud ceiling of at least 1500 ft (above ground level),
4. days between January 1st and March 31st.

Using a minimum cloud ceiling level of 1500 feet gives the maximum number of censusing days possible at areas near Salt Lake City. To obtain a more conservative estimate, a check was made using a minimum cloud ceiling of 5500 feet. A 5500 feet ceiling at the airport (4,220 ft. altitude) gives a sufficiently high cloud cover to allow censusing up to altitudes of approximately 8500 feet. The results found using the upper and lower extremes, are shown in Table 2. The data indicate that there is an average of 25 to 34 censusing days available per year. Approximately two days per week are available throughout the winter months for censusing.

TABLE 2

CENSUSING DAYS AVAILABLE *

Month	Cloud ceiling (ft)	Censusing days per month
January	≥ 5500	8.00
	≥ 1500	10.50
February	≥ 5500	7.50
	≥ 1500	19.67
March	≥ 5500	10.00
	≥ 1500	14.00
Total number of census days per year		25.50 - 34.17

* Based upon statistical data for a 6 year period

EXPERIMENTAL MEASUREMENTS

Methods and Instrumentation

Reflection bands

Reflectance measurements from the ultraviolet (0.21 μm) through the near infrared (2.6 μm) were made using a Beckman Model DK-2A Ratio Recording Spectrophotometer with an integrating sphere attachment. The integrating sphere has two sample viewports for a 100% reflectance (reference) sample and the data sample (see Figure 5). The samples are mounted in a vertical plane; thus loose pieces of the samples (sand, leaves, etc.) must be properly secured. Samples were

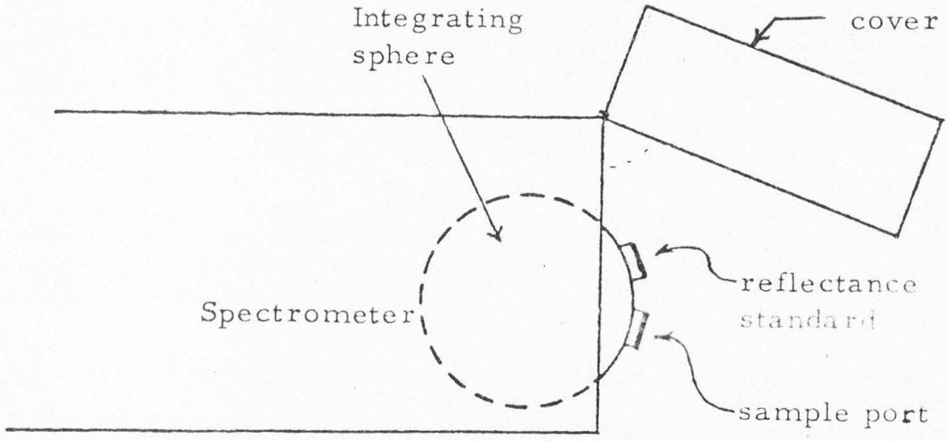

Figure 5. Beckman spectroreflectormeter integrating sphere arrangement (Top view).

attached to a 2-inch-square matboard, using Elmers Glue-All. A sample of the glue was analyzed to determine if its spectra was present in any of the sample data (see Figure 6). Some sand samples were adversely affected in the 1.5 - 2.6μm region; so these measurements were repeated using a special sample chamber equipped with a glass window. The effect of the window was evaluated by measuring a 100% reference sample with and without the glass. The glass lowered the apparent sample reflectance by 10 - 15% and appropriate corrections were made. The effect of the glue was removed by this method as is illustrated in Figure 7. The reflectance spectra obtained are shown in Appendix B.

All of the samples measured in the ultraviolet (UV) region (0.21 - 0.35μm) exhibited very low reflectance values which decreased with decreasing wavelength. Elmers Glue-All showed the highest reflectance value (25% at 0.35μm). Some of the silica sands, and Juniper bark showed reflectance values near 17%. All of the other samples measured, including deer hide, had reflectance values less than 10%; consequently, the UV data are not considered useful for censusing.

Infrared emission bands

Measurements made in the thermal IR (emission) region of the spectrum are referenced to a blackbody. The emissivity of a sample is defined as the ratio of the radiant energy emitted by a sample $\phi_s(\lambda)$,

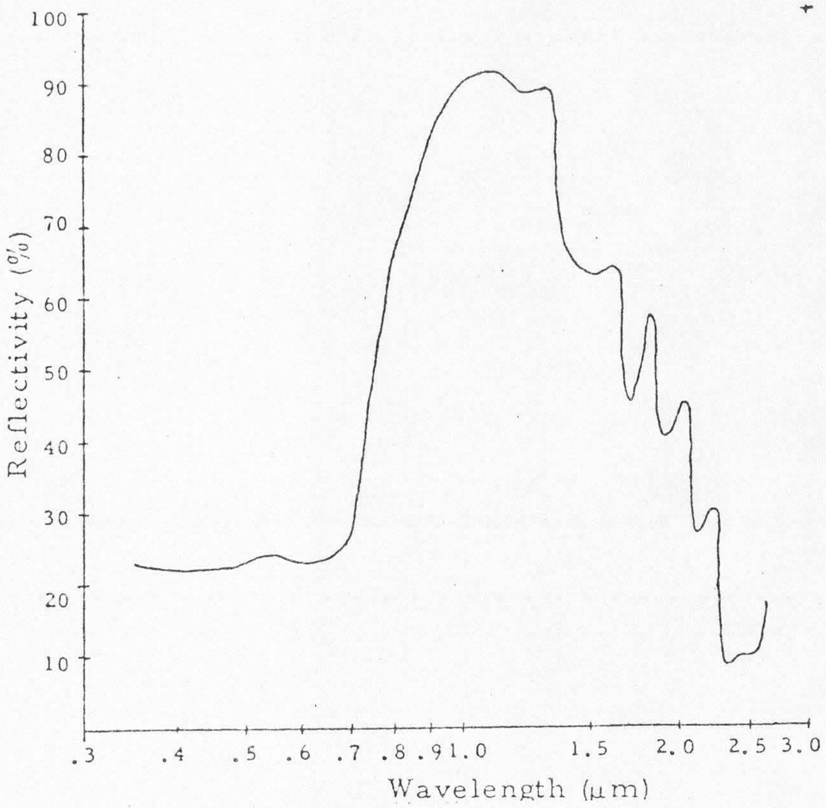

Figure 6. Elmers Glue-All reflectance spectra.

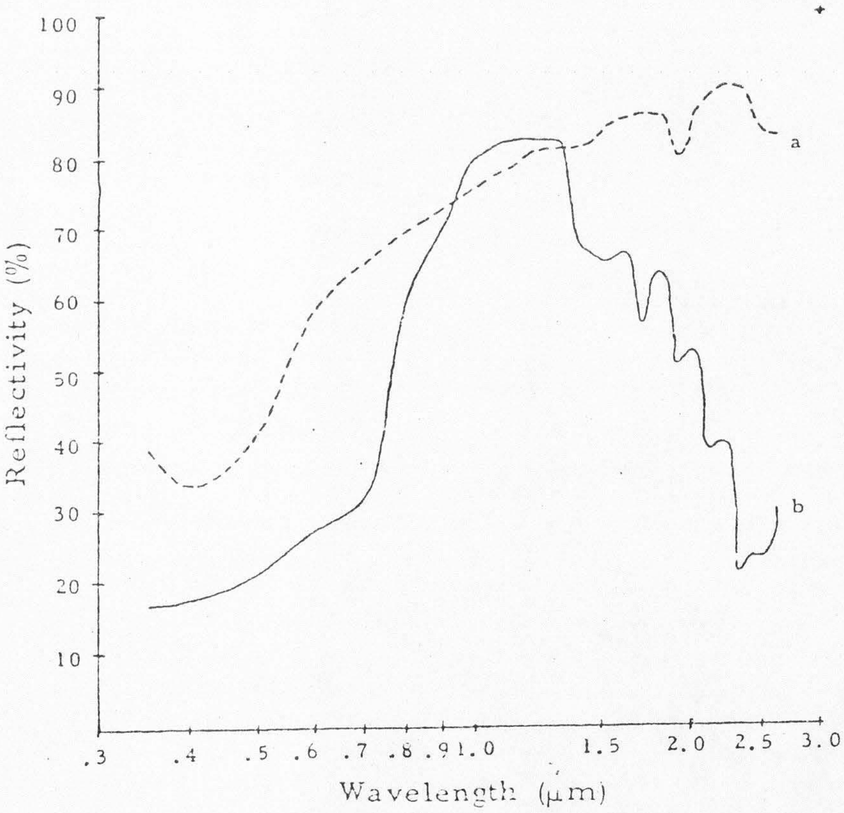

Figure 7. Sand no. 2 (silica) reflectance spectra. a. sample using glass holder b. glued sample.

to that of the radiant energy emitted by a blackbody $\phi_{bb}(\lambda)$ at the same temperature (T).

$$\text{sample emissivity } \epsilon_s = \frac{\phi_s(\lambda)}{\phi_{bb}(\lambda)}$$

The energy radiated by the sample and the blackbody is a function of wavelength, temperature, and emissivity. Accurate temperature and spectral measurements are required for absolute emissivity measurements which theoretically can vary from zero to unity. Practically, such measurements are not easily obtained because of stray radiation. The emissivity $\epsilon(\lambda)$ and reflectivity $r(\lambda)$ of an opaque object are related (Wolfe, 1965, Jamieson, 1963) by the equation:

$$\epsilon(\lambda) + r(\lambda) = 1$$

If a sample is surrounded by objects near the same temperature, the sum of the emitted and reflected energy can be unity. Thus, the apparent emmissivity measured will be in error unless steps are taken to shield the sample or to evaluate the reflected radiation (see Brown and Young, 1975).

Another measurement problem arises because the spectrometer used to measure the emission of objects at, or near ambient temperatures must generally have a cooled baffle. This results in the rapid cooling of the sample by radiation coupling to the cold baffle. The sample can be maintained at a constant temperature in at least four ways as indicated in the literature (Brown and Young, 1975):

1. by heating the sample substrate,
2. by irradiating the sample with energy outside the spectral region of interest,
3. by convection using a warm (non-interferring) gas,
4. by thermal soaking the sample at the desired temperature and then allowing only a short exposure to the spectrometer.

Heating the sample substrate will not work effectively for biological samples having low, variable, or unknown thermal conductivities. The other three methods are possibilities. We used method 3 as discussed in detail below.

A number of infrared circular-variable filter (CVF) spectrometers have been designed, developed, and fabricated at Utah State University (USU) Electro-Dynamics Laboratories to measure the overhead spectral radiance of the atmospheric emission. Two general categories of spectrometers are available: short wavelength infrared (SWIR) liquid-nitrogen cooled systems; and long wavelength infrared (LWIR) liquid-helium cooled systems. Each type was used on this project.

A SWIR CVF spectrometer was used to make spectral measurements in the 3.0 - 5.4μm region. The system is composed of a rotating interference filter (CVF), a drive motor and a position reference generator, optics section, detector, and accompanying electronics preamplifier. The CVF is composed of two 180^{o} filter segments which provide a continuous spectral scan from 2.0 to 5.4μm at a rate of two scans per second. The filter is cooled to liquid nitrogen temperature (77.4 K, − 201 C), using a special conductive bearing designed at USU. The entire optical section is also cooled to achieve enhanced detector response characteristics of such low background conditions. The drive-motor and reference generator provide synchronization pulses to correlate the filter scan position with the wavelength. The cold optics and baffle limit the field-of-view, reject off-axis radiation, and focus the incoming signal on the indium antimonide (InSb) detector. The peak wavelength ($5.3\mu m$) noise equivalent spectral radiance of the system is 1.93×10^{-10} ($W\ cm^{-2}\ sr^{-1}\ \mu m^{-1}$). The electronic amplifiers condition the signal and provide several outputs at different gain factors (see Figure 8). The resolution of the unmodified CVF spectrometer with the scan position and wavelength is shown in Table 3. A more complete description of the SWIR system is given in the literature (Wyatt et al. 1977).

A LWIR CVF spectrometer was used to make spectral measurements in the 7.0 - $14.0\mu m$ region. The basic sections of the LWIR system are similar to the SWIR system in function. The germanium filter half covers wavelengths from 6.5 - $13.0\mu m$ and the irtran-6 half covers from 12.5 - $23.0\mu m$. The arsenic doped silicon detector provides a peak wavelength noise equivalent spectral radiance sensitivity (at $22\mu m$) better than 1×10^{-11} ($W\ cm^{-1}\ sr^{-1}\ \mu m^{-1}$). The resolution and scan position of the unmodified instrument are shown in Table 4.

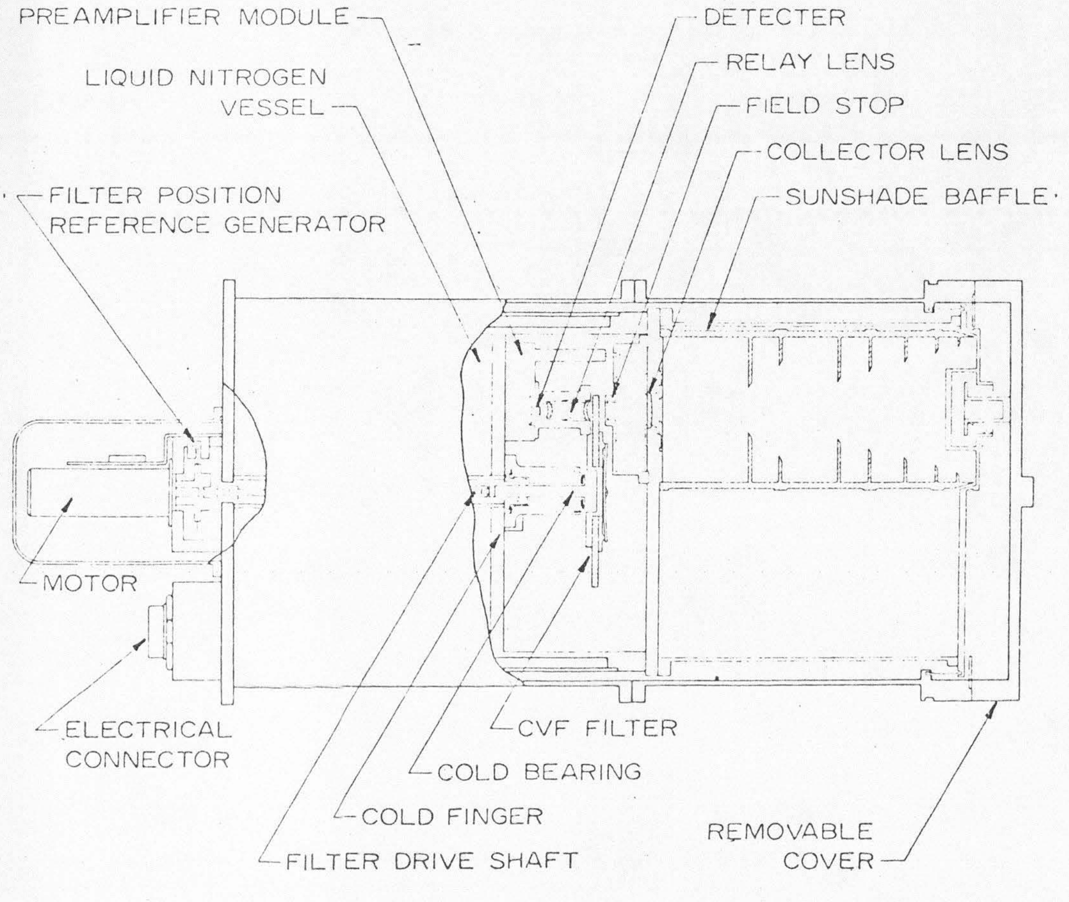

Figure 8. SWIR CVF spectrometer layout (After Wyatt, 1977).

TABLE 3

UNMODIFIED SWIR CVF SPECTROMETER RESOLUTION

Wavelength (μm)	Bandwidth (%)	% of Scan
1.918	1.74	0.0
2.155	1.81	7.0
2.491	2.71	15.3
2.831	1.52	23.6
3.172	1.57	31.9
3.49	1.61	40.3
3.75	1.72	48.6
3.01	1.23	51.4
3.41	1.26	58.3
3.90	1.20	66.7
4.39	1.19	75.0
4.89	1.27	83.3
5.38	1.25	91.7
5.78	1.27	98.6

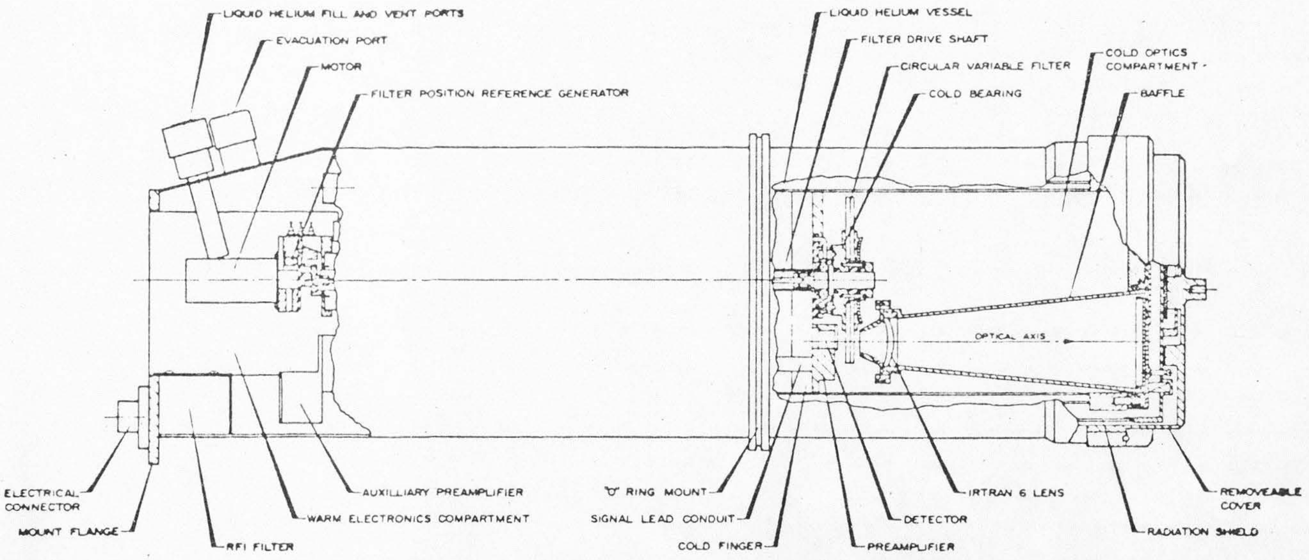

Figure 9. LWIR CVF spectrometer layout (After Wyatt, 1975).

TABLE 4

RESOLUTION OF UNMODIFIED LWIR CVF SYSTEM

Wavelength (μm)	Bandwidth (%)	% of Scan
7	4.20	1.01
8	3.75	8.75
9	3.38	16.50
10	3.10	24.24
11	2.86	31.98
12	2.67	39.72
13	4.29	50.91
14	4.18	54.80
16	3.86	62.56
18	3.62	70.32
20	3.42	78.09
22	3.23	85.85

The LWIR system is shown in Figure 9, and described more completely in the literature (Wyatt, 1975).

The two CVF spectrometers used to measure ambient temperature objects were originally designed to be flown under conditions of high altitude vacuum to measure upper atmospheric emissions. Two instrument modifications were required to perform laboratory measurements. 1. A vacuum cover with a transparent window had to be placed in front of the normally exposed optics section of each instrument. 2. The ambient temperature sample radiation incident on the spectrometer detector had to be reduced to prevent saturation of the sensitive circuitry. The signal reduction was accomplished by placing a cryogenically cooled pinhole aperture in front of the collecting aperture. Addition of the small aperture resulted in the resolution of the spectrometer approaching the theoretical limit. The modified SWIR and LWIR systems have a resolution of 1.0% or better throughout their spectral ranges.

Results

Reflection

All reflectance samples measured show at least a 10% spectral difference from deer over some portion of the visible--near infrared spectrum. Dry Aspen leaves, fallen log bark, and soil provide the spectra most similar to the deer spectra. Even such background elements as log bark and soil which are difficult to distinguish in the visible region have spectra significantly different from deer in the near IR (see Figure 10). Soils differ from deer by 15-20% in some regions and rotten log bark differs by as much as 35% in places. Aspen leaves (Figure 11) differ by at least 10% in regions from 0.7 - 0.9 μm and 1.4 - 1.8 μm.

Background elements containing chlorophyll show absorption near 0.675 μm and an abrupt rise in reflectivity around 0.7 μm. The pine spectra measured (Figure 12) shows the same features and compares favorably with such spectra reported by others (Heller, 1968, Kalensky and Wilson, 1975). The most prevalent background elements expected (other than soil or snow) on deer ranges are juniper and sagebrush. Figures 13 and 14 show their spectra contrasted with deer. Reflectance differences of 25% or better are shown around 0.8 μm. Snow (Figure 15) exhibits the greatest spectral difference from deer spectra which amounts to 50% in both the visible and near infrared.

Emission (thermal IR)

The CVF spectrometer was mounted on a bench in a vertical position with the optics aimed downward so that the samples and blackbodies could be handled easily. The spectrometer output was simultaneously displayed on an oscilloscope and recorded. The scattering of ambient radiation and emission of the IR vacuum window were evaluated by measuring the system response $V_w(\lambda)$ to a 77K blackbody. The reference blackbody response $V_B(\lambda)$ and the sample response $V_s(\lambda)$ were also measured and utilized in the relationship:

$$\epsilon(\lambda) = \frac{V_s(\lambda) - V_w(\lambda)}{V_B(\lambda) - V_w(\lambda)}$$

Reflection of ambient radiation from the sample is greatly reduced since it is exposed primarily to the cold and absorbing baffle as illustrated in Figure 16. Thd 318K (45 C) reference blackbody was an I. R. Industries model 463. All samples measured were also heated to 318k (45 C) using preheated dry nitrogen gas. The sample temperature was measured using a calibrated bead thermister at the nitrogen gas exit. The samples were heated until stable temperature readings were

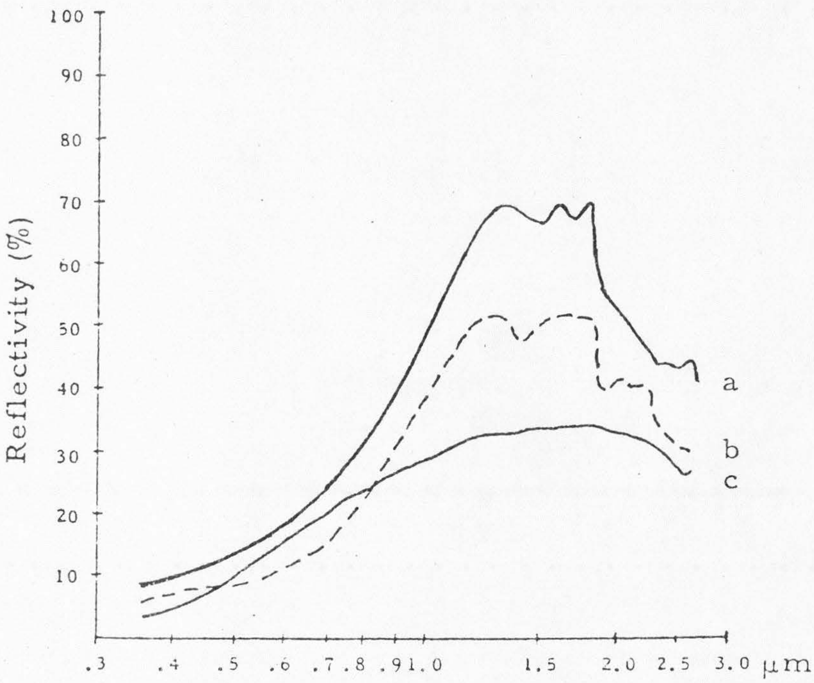

Figure 10. Reflection data. a. deer hide, b. fallen logbark, c. soil no. 2.

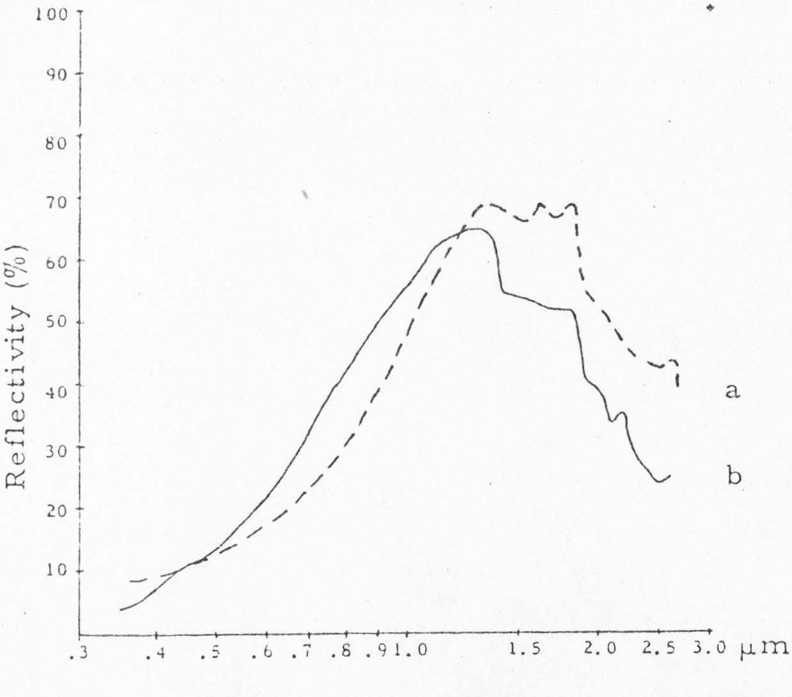

Figure 11. Reflection data. a. deer hide, b. dry aspen leaves.

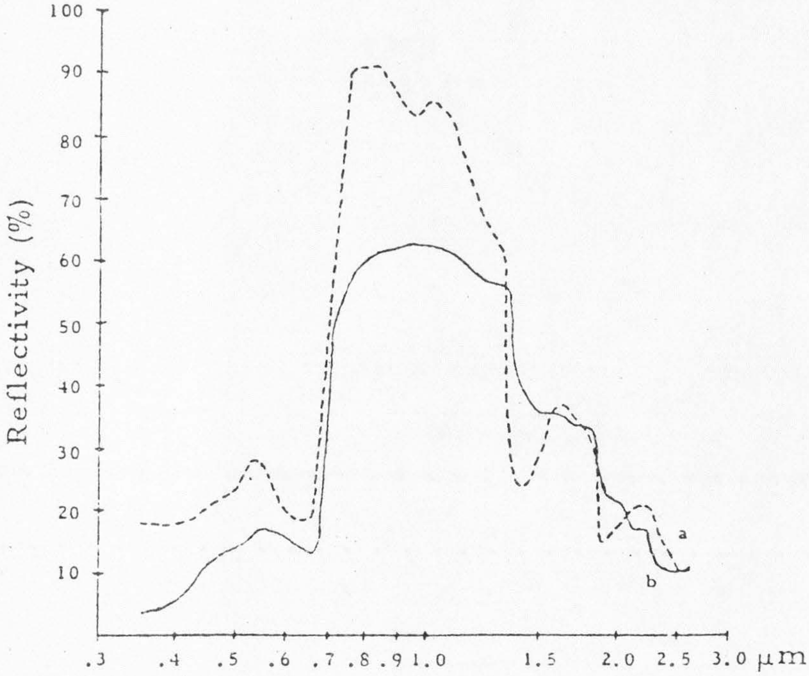

Figure 12. Reflection data. a. Fresh Limber Pine Needles. b. Dry Pine Needles

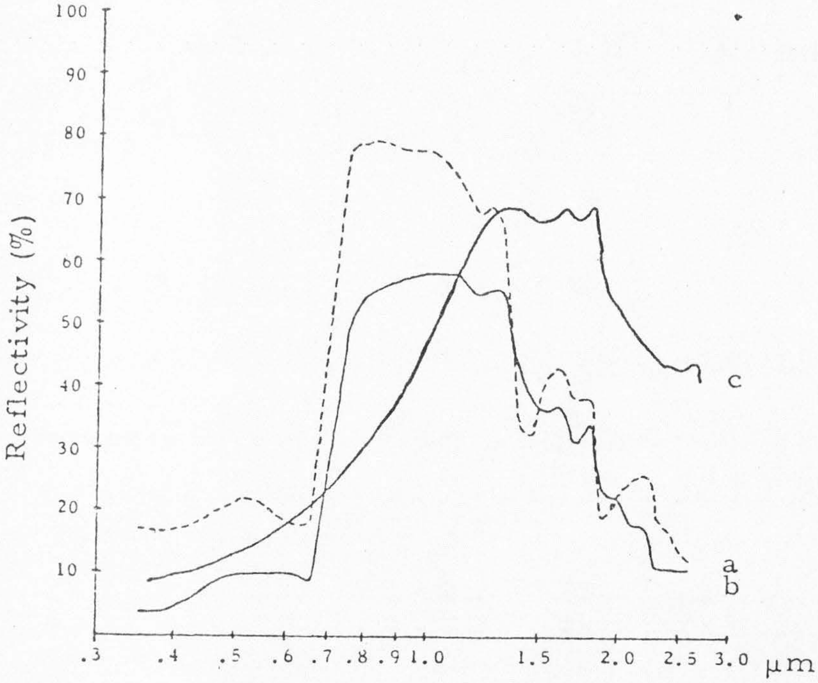

Figure 13. Reflection data. a. fresh juniper (no. 1), b. dry juniper (no. 1), c. deer hide.

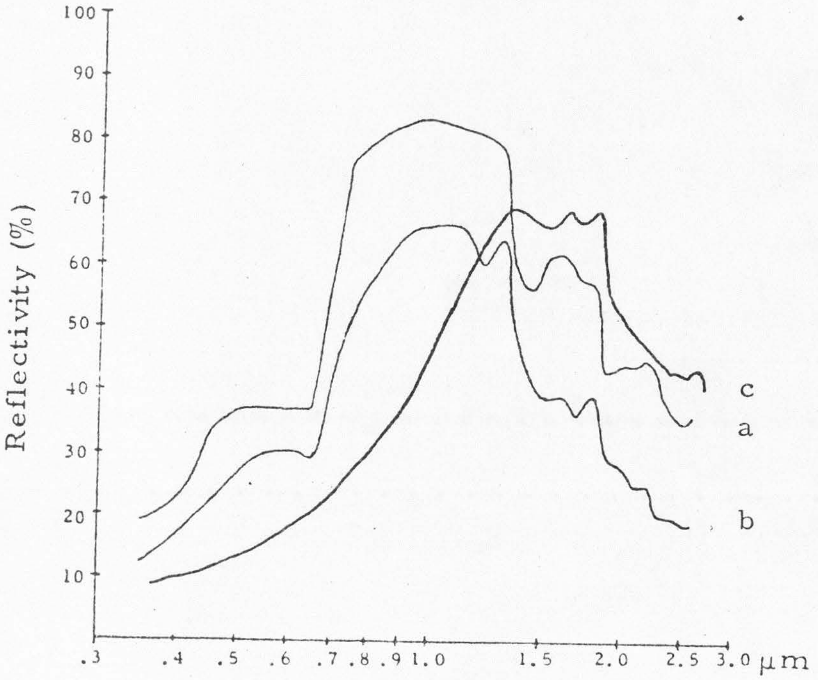

Figure 14. Reflection data. a. fresh sagebrush leaves, b. dry sagebrush leaves, c. deer hide.

Figure 15. Reflection data. a. new snow, b. old snow. (Copied from Journal of Applied Meteorology Vol. 7, No. 4, August 1968, pp. 702-707).

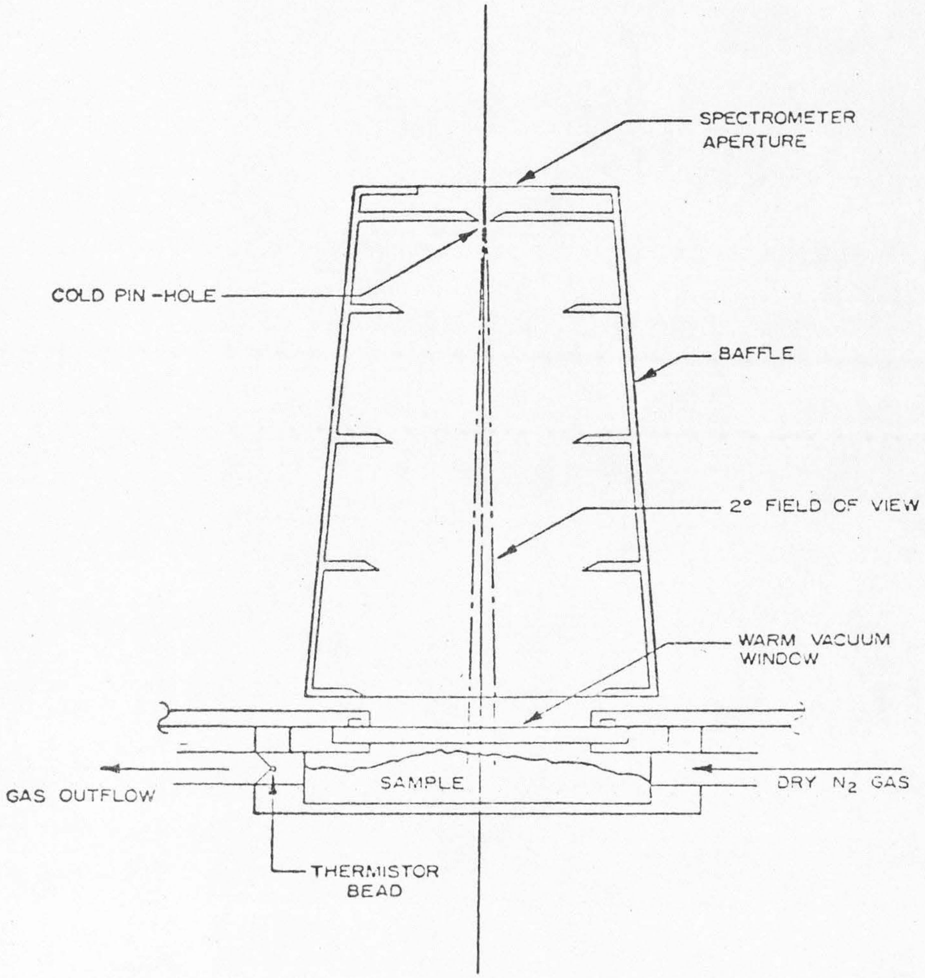

Figure 16. CVF spectrometer baffle and sample holder.

obtained. Multiple scans were recorded on an FM data recorder then processed using a Tektronix 4051 graphics terminal and A/D converter. Several averaged data scans (for the SWIR and LWIR systems) obtained before the data was reduced are shown in Figures 17 and 18.

The objective of the measurements is to discover the presence of existing spectral emissivity features rather than to obtain the absolute spectral emissivity. Nevertheless the temperature was maintained as accurately as possible and was measured by converting the resistance values of the thermister to degrees (see Appendix F). The deviations in the temperature from 318 k (45 C) are shown in Table 5 and are the extremes of all measurements used. The thermal emission data are given in Appendixes C and D. The emissivity of all biological samples

TABLE 5

SAMPLE TEMPERATURE DEVIATION*

	Resistance (KΩ)	Equivalent Temperature (^{o}C)	Deviation (^{o}C)
	2.65	45.0	----
SWIR	2.60	45.5	max + .5
	2.76	43.8	min − 1.2
LWIR	2.60	45.5	max + .5
	2.66	44.9	min − .1

*Deviation is defined as the departure of the temperature from 45 C.

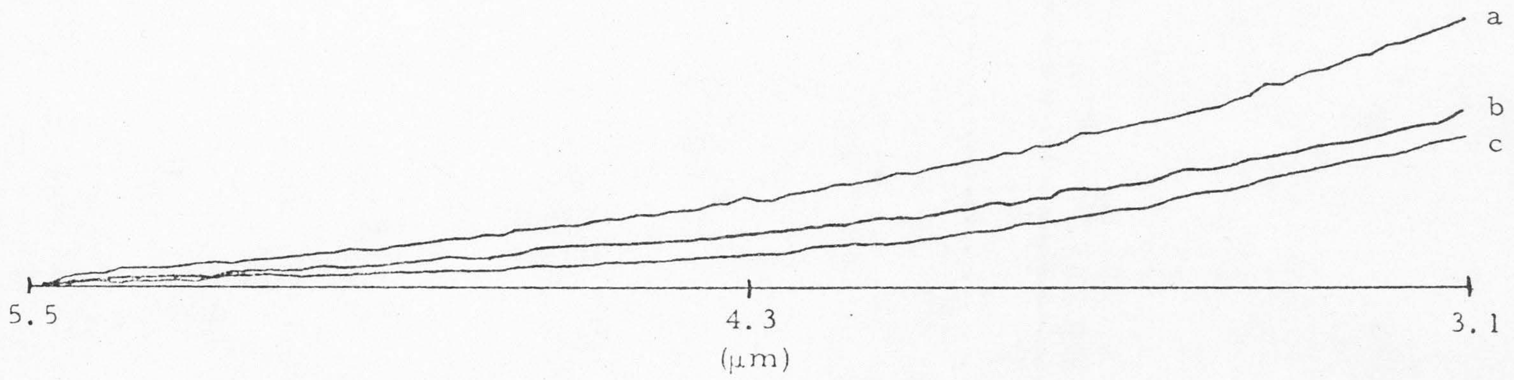

Figure 17. SWIR emission data. a. warm blackbody, b. deerhide, c. crushed fused quartz.

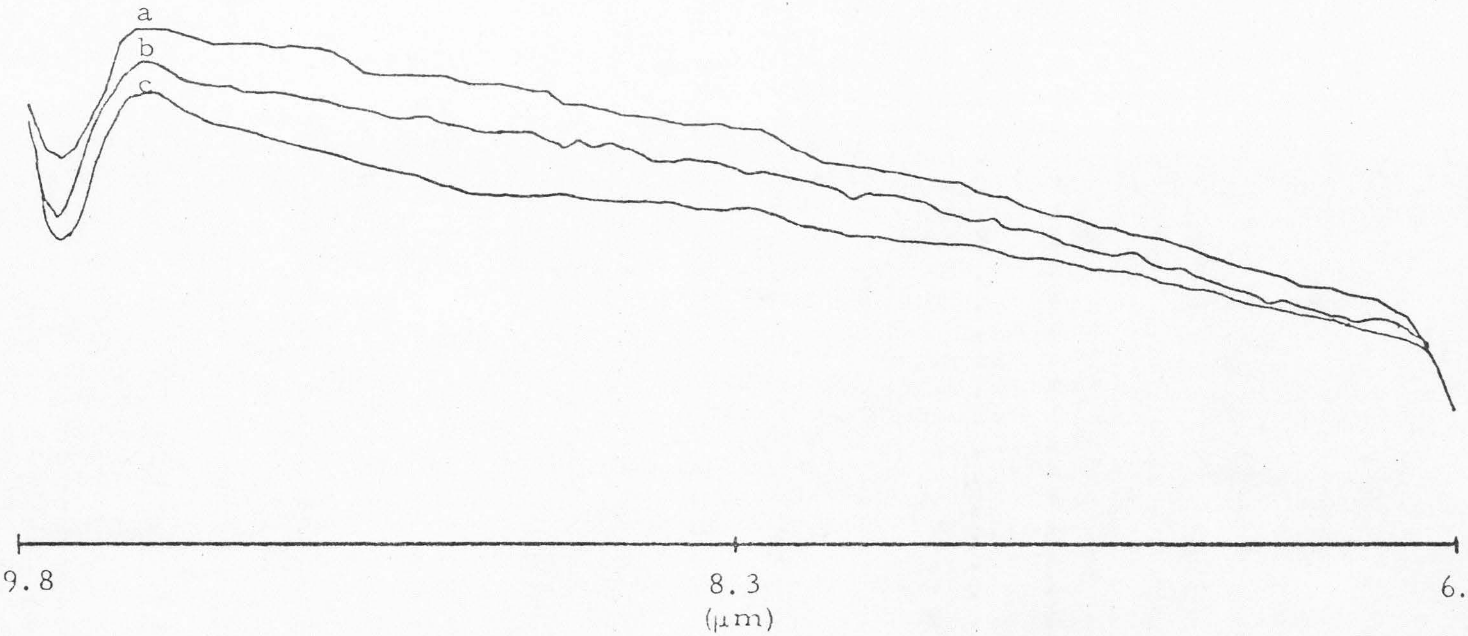

Figure 18. LWIR emission data. a. warm blackbody, b. deerhide, c. crushed fused quartz

exhibit a relatively uniform response as shown in Figures 19, 21, and 22 for deer and log. The spectrum of gypsum (Figure 23), quartz (Figure 24), and silica (Figure 20) exhibit features that appear in the literature, e.g., Lyon (1965) and Brown and Young (1975). Some of the silicate spectra obtained (0.5 - 6.0μm) compare favorably with data obtained by Hovis (1966). His data are reflective, but can be converted to emissivity using the relation $\epsilon(\lambda) = 1 - r(\lambda)$ which provides a good comparison for thermal data over a comparable wavelength region.

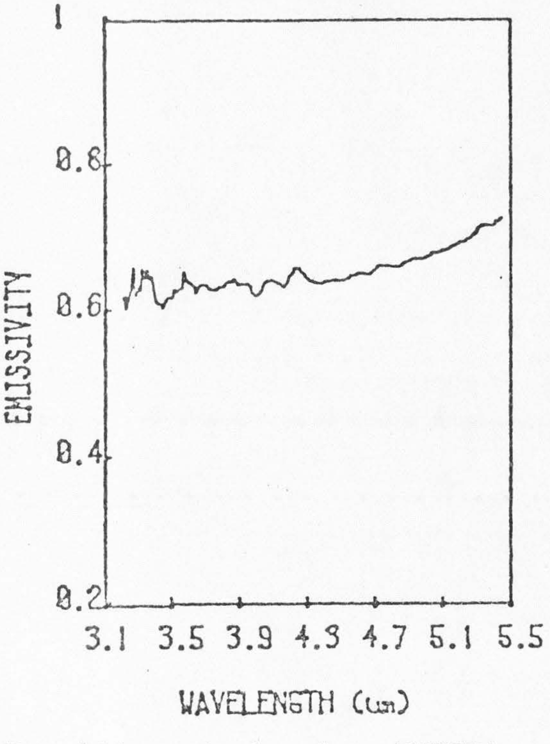

Figure 19. Deerhide emission data (SWIR).

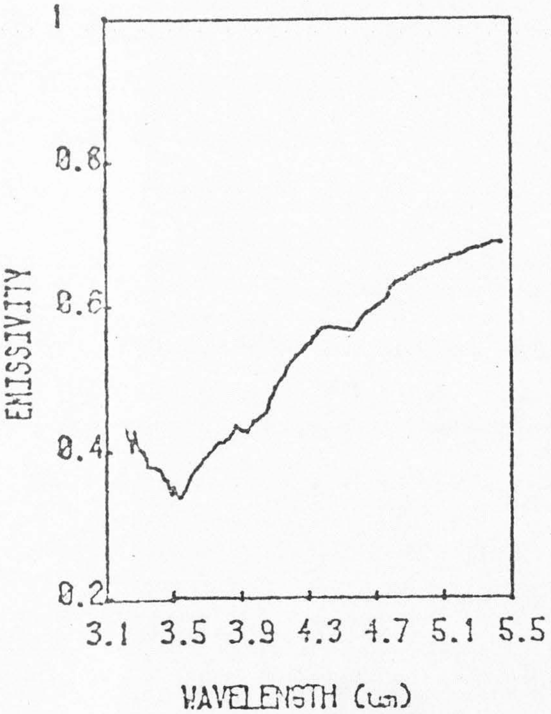

Figure 20. Silica, sand no. 2 (SWIR)

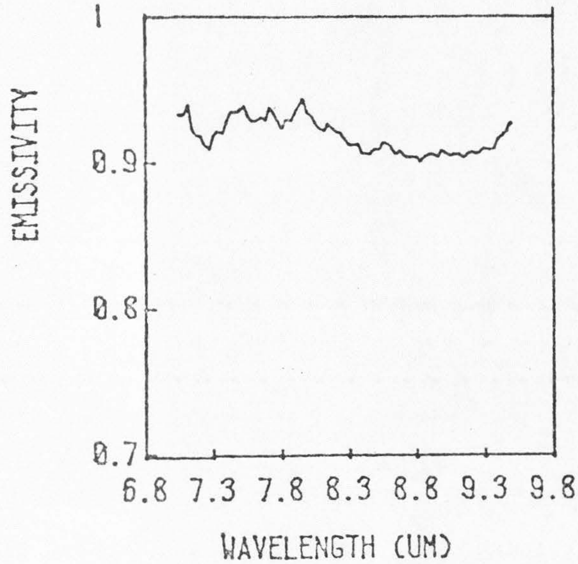

Figure 21. Deerhide emission data (LWIR).

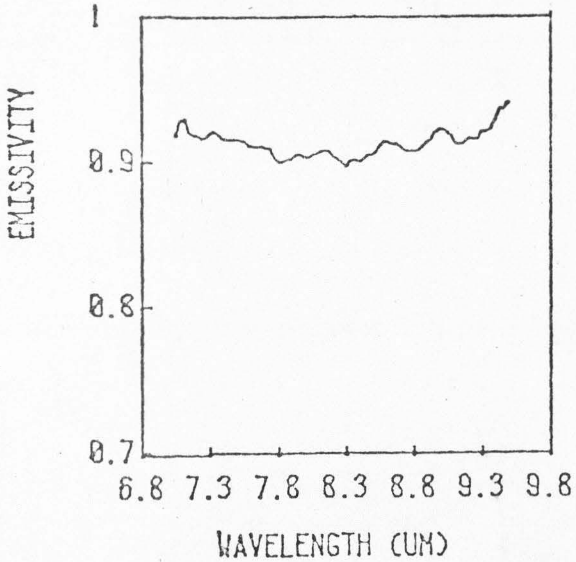

Figure 22. Rotten log bark (LWIR).

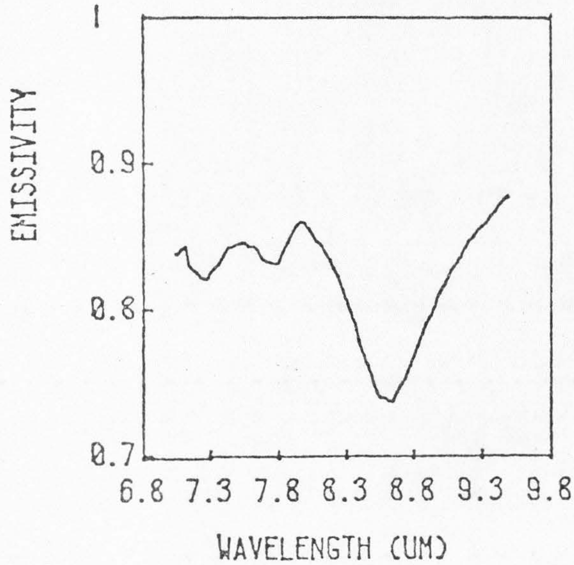

Figure 23. Gypsum (LWIR).

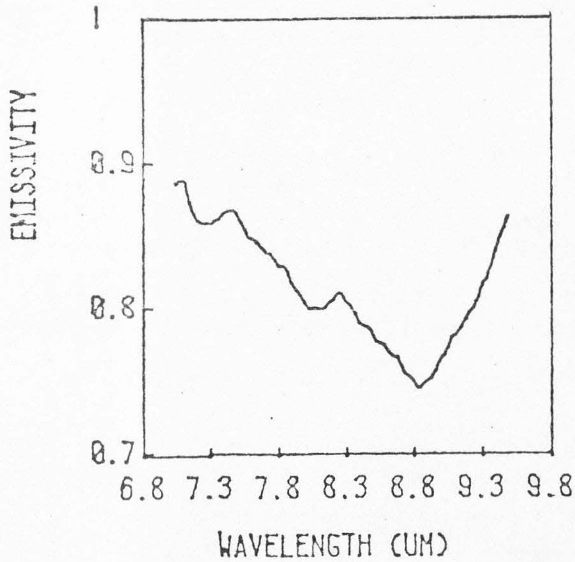

Figure 24. Crushed fused quartz (LWIR).

CONCLUSIONS AND RECOMMENDATIONS

Summary

The results of the study performed can be summarized as follows:

1. The reflective visible and near infrared (0.35 - 2.6 μm) contains substantially more spectral information than any other region investigated in this study, i.e. there is a substantial departure at selected wavelengths from the spectra of the illuminating source and between various samples. Most background elements exhibit at least 10% difference from that of deer over some portion of the near IR (0.70 - 2.6 μm), and at least 5% spectral difference in some portion of the visible region (0.35 - 0.70 μm).
2. The optimum thermal contrast band for obtaining census data, based upon signal-to-noise ratio and utilizing the LOWTRAN 3B atmospheric transmittance calculations, is 7.5 - 13.2 μm.
3. The reflective contrast (relative difference) between deer and snow at 0.6 μm (see Figures 14 and 15) is 50% which compares favorably with the 3% contrast obtained for the thermal bands.

4. The thermal IR spectra obtained of deer and its native background elements (except silicate and gypsum materials) exhibit essentially "blackbody" characteristics in the 3.0 - 10.0 μm region.
5. There is an average of 25 to 34 totally overcast days each winter suitable for light aircraft censusing in areas near Salt Lake City (at altitudes from 5,000 to 8,500 feet).

Recommendations

A field data sample should be obtained. Using a spectrometer equipped with a bore-sighted telescope that could be aimed, would provide spectral signatures as a continuous representation of the reflectance of deer, snow, trees, and brush in a suitably controlled field test program. A relatively large data set, representative of varying environmental conditions would be required. Data analysis would consist of: 1. a feature selection study to determine the wavelengths most effective in discriminating between deer and background; 2. the designing and testing of a multispectral classifier to determine the feasibility of deer census using the reflectance bands. Such a study, conducted in the 0.7 to 2.6 μm region, should yield favorable results, particulary in discriminating between deer, snow and any plant that exhibits the chlorophyll absorption characteristic.

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APPENDIXES

Appendix A

Samples Measured

TABLE 6

SAMPLES MEASURED

	Measurements*						
Samples Measured	1	2	3	4	5	6	7
bark, aspen	X	X	X				
bark, fallen log	X	X				X	
bark, juniper	X						
bark, rotten log	X	X				X	X
bitter brush	X	X					
deer hide	X	X	X			X	X
douglas fir (needles)				X			
juniper (foliage)	X	X		X	X	X	X
leaves, aspen (dead, dry)	X	X					
leaves, maple (dead, dry)	X	X	X			X	X
limber pine (needles)	X	X	X	X	X		
mahogany, curly leafed	X	X		X	X		
quartz (crushed, fused)						X	X
rabbit brush	X	X	X			X	X
sagebrush (dry)		X					
sagebrush (fresh)	X			X	X	X	X
sand no. 1 (gray/white) **	X	X	X				
sand no. 2 (flesh colored) **	X	X		X	X		X
sand no. 3 (yellow) **	X	X		X	X		
sand no. 4 (pale red) **	X	X		X	X		
sand no. 5 (flat red) **	X	X		X	X		
sand no. 6 (light orange) **	X	X		X	X		
sand no. 7 (green) **	X	X		X	X		
sand no. 8 (light orange) **	X	X		X	X		
sand no. 9 (yellow/orange) **	X	X		X	X		
sand no. 10 (tan) **	X			X	X		
sand no. 11 (red silica) **				X	X	X	X
sand no. 12 (white gypsum) **				X	X	X	X
soil no. 1	X	X				X	X
soil no. 2	X	X					
soil no. 3	X	X					
tumbleweed	X	X					
Equipment Measurements							
aluminum sample holder						X	
blackbody, cold (77^{o}K)						X	X
blackbody, warm (300^{o}K, room temp)							X
blackbody, warm (318^{o}K, 45^{o}C)						X	X
Elmers Glue-All	X	X	X				

* 1) 0.21 - 0.36 μm; 2) 0.35 - 0.75 μm; 3) 0.50 - 2.60 μm;
4) 0.35 - 0.75 μm; 5) 0.50 - 2.60 μm; 6) 6.8 - 9.8 μm;
7) 3.1 - 5.5 μm

** A mineralogal analysis of sand samples is given in Appendix E.

Appendix B

Reflection Data

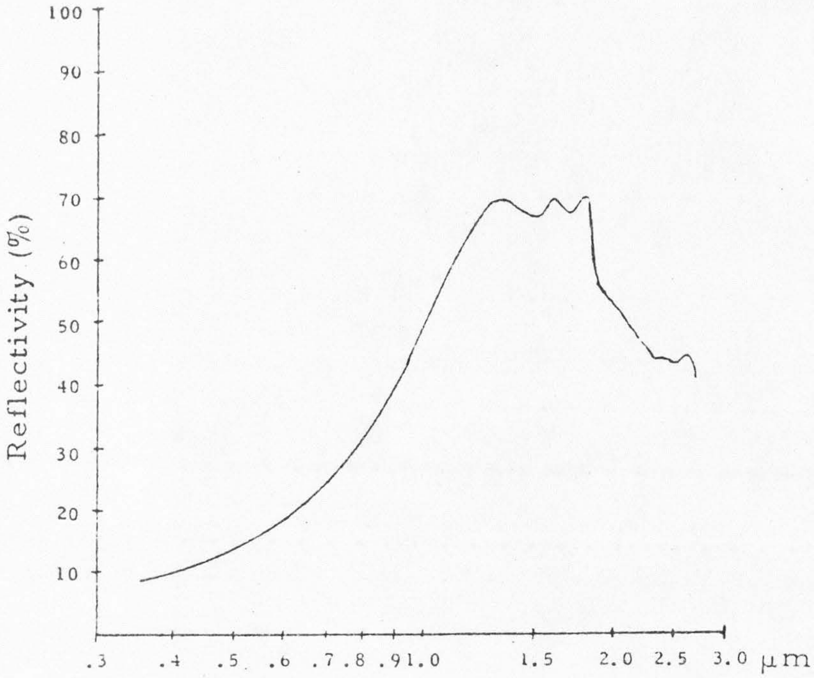

Figure 25. Deer hide reflection data.

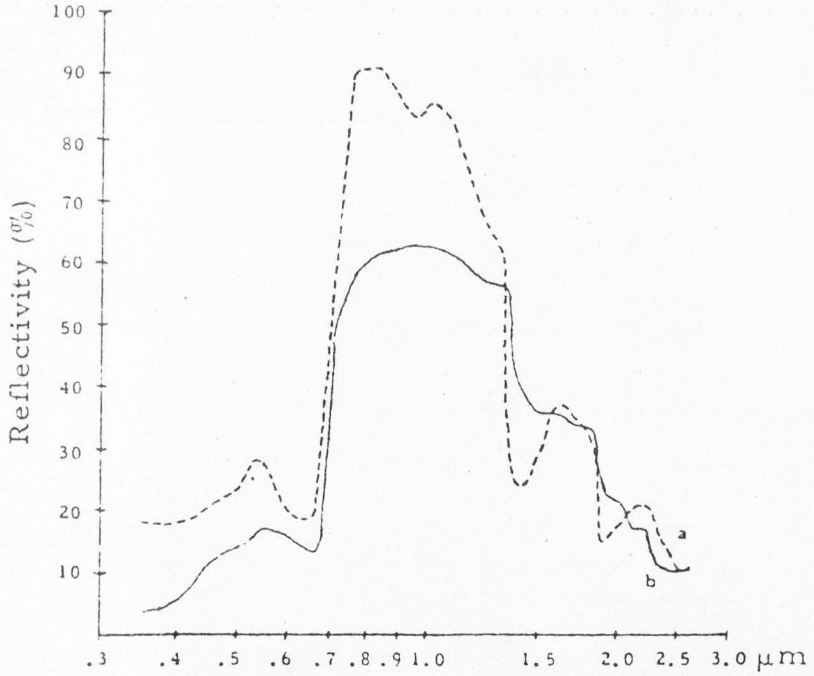

Figure 26. Reflection data. a. Fresh Limber Pine Needles b. Dry Pine Needles

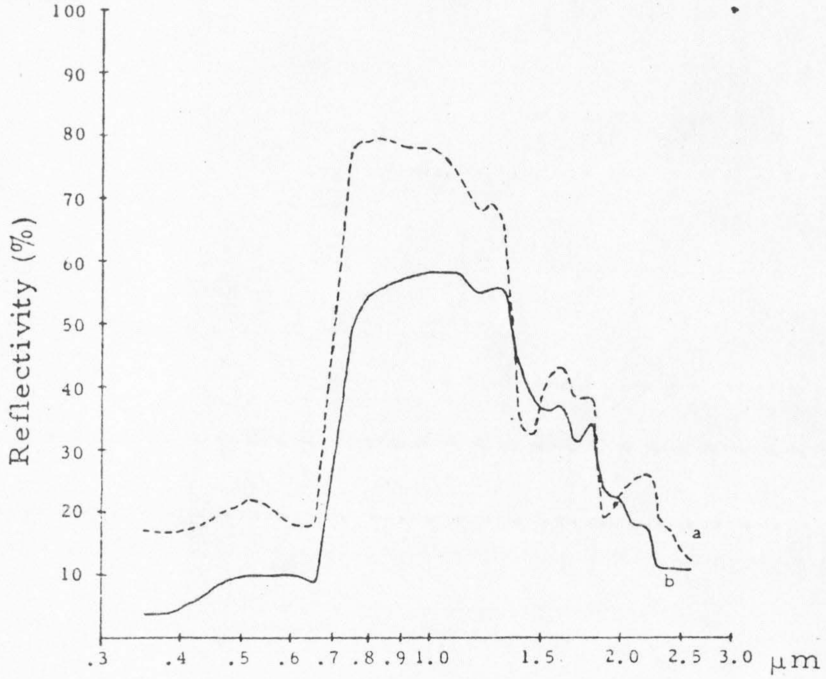

Figure 27. Reflection data. a. Fresh Juniper no. 1, b. Dry Juniper no. 1.

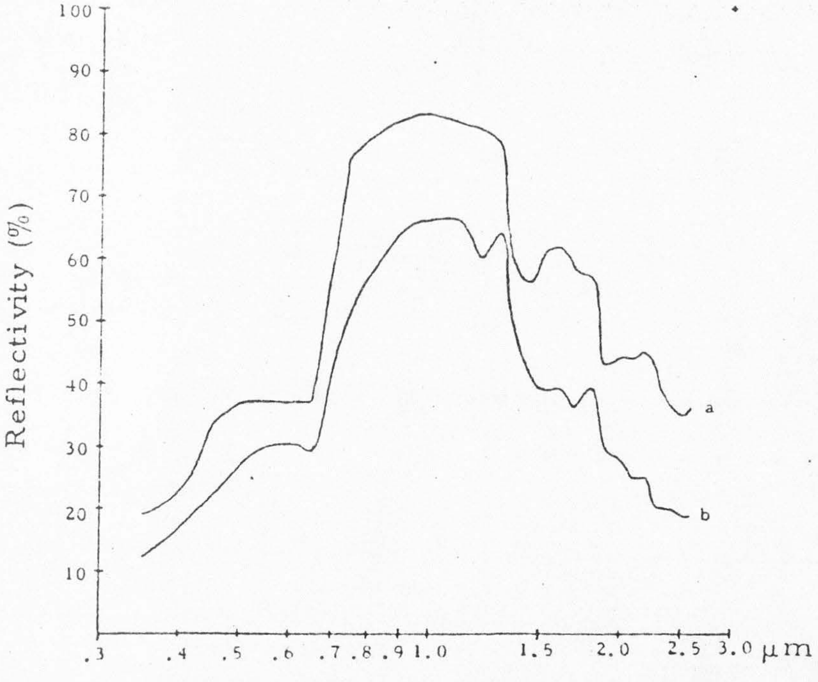

Figure 28. Reflection data. a. Fresh Sagebrush Leaves. b. Dry Sagebrush Leaves.

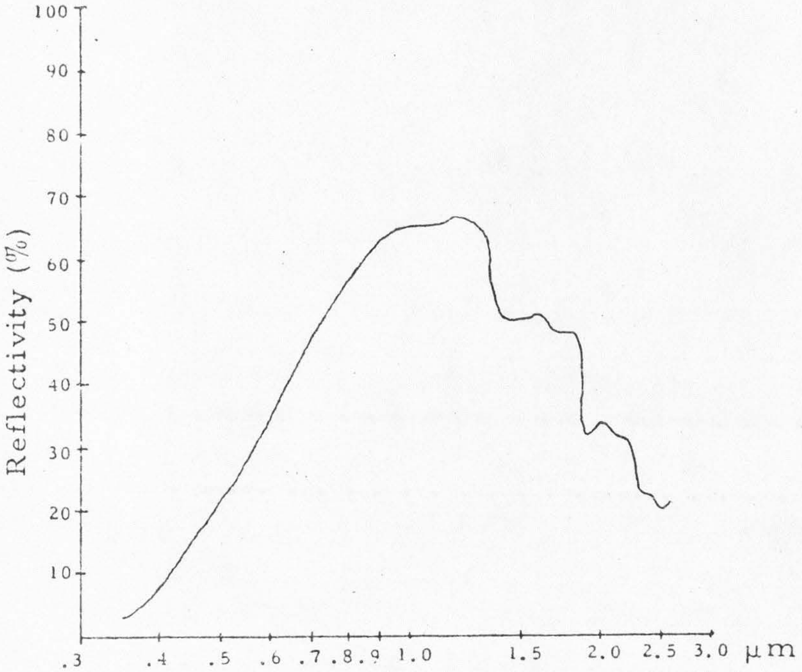

Figure 29. Rabbit brush.

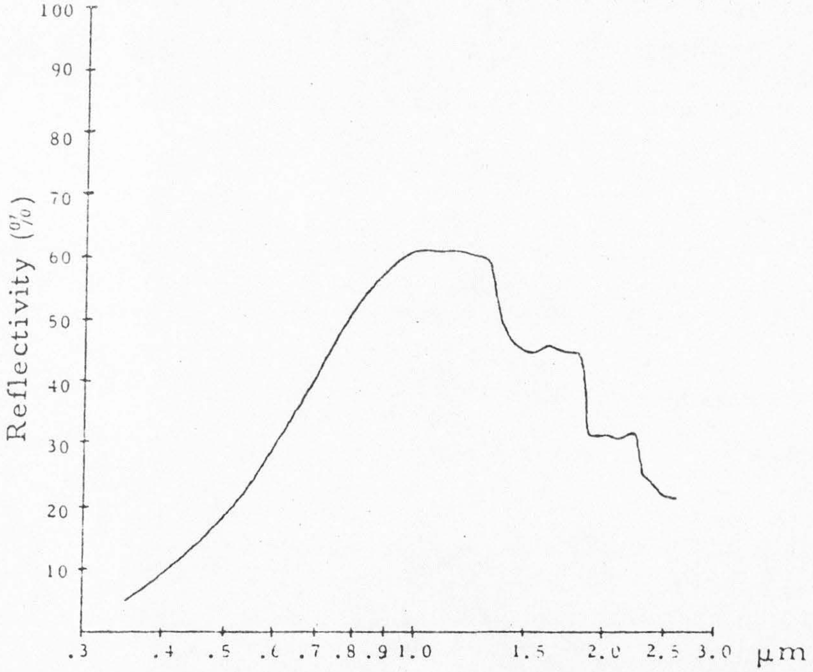

Figure 30. Tumbleweed.

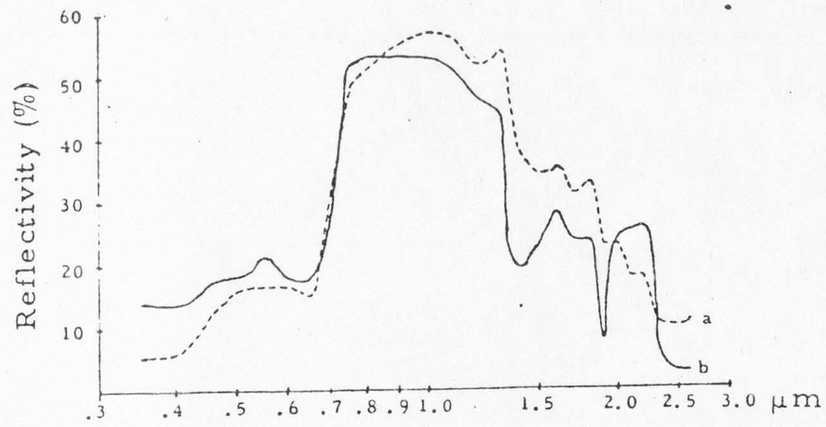

Figure 31. Reflection data. a. Dry Juniper no. 2. b. Fresh Juniper no. 2.

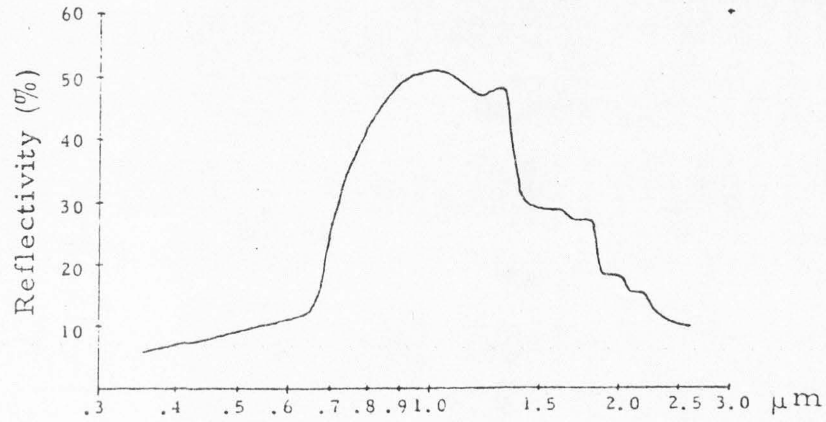

Figure 32. Bitter brush.

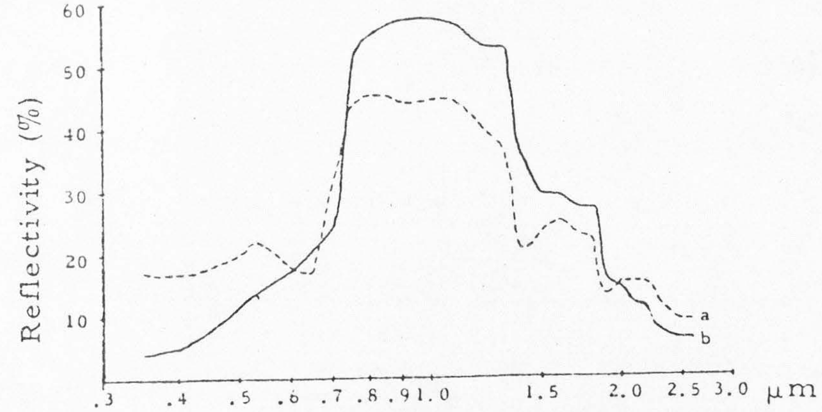

Figure 33. Reflection data. a. Fresh Douglas Fir. b. Curly Leafed Mahogany.

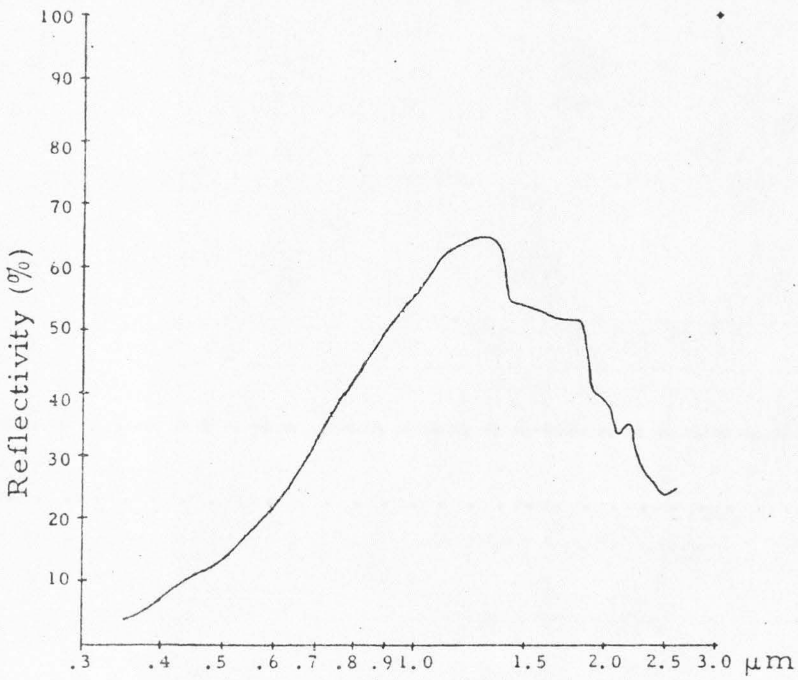

Figure 34. Dry Aspen leaves.

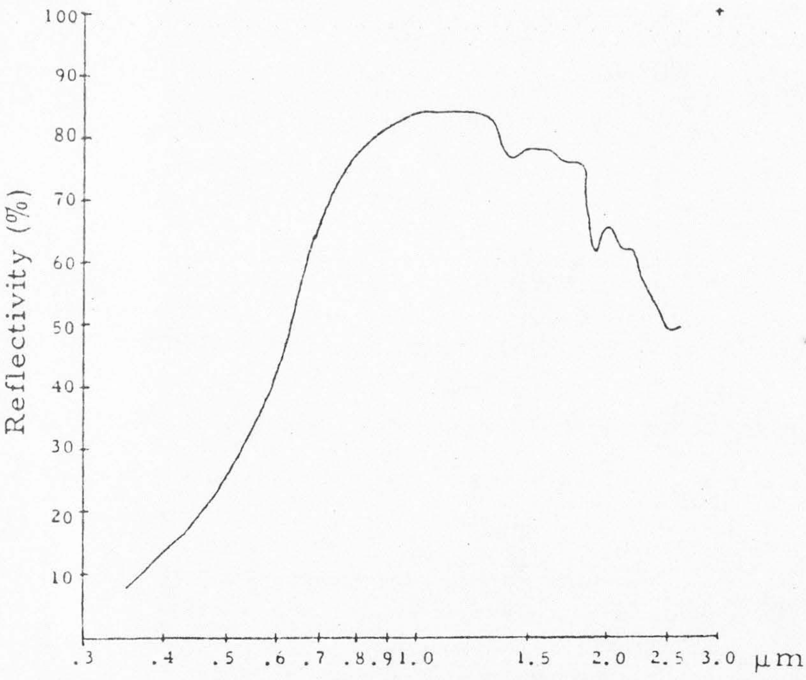

Figure 35. Dry Maple leaves.

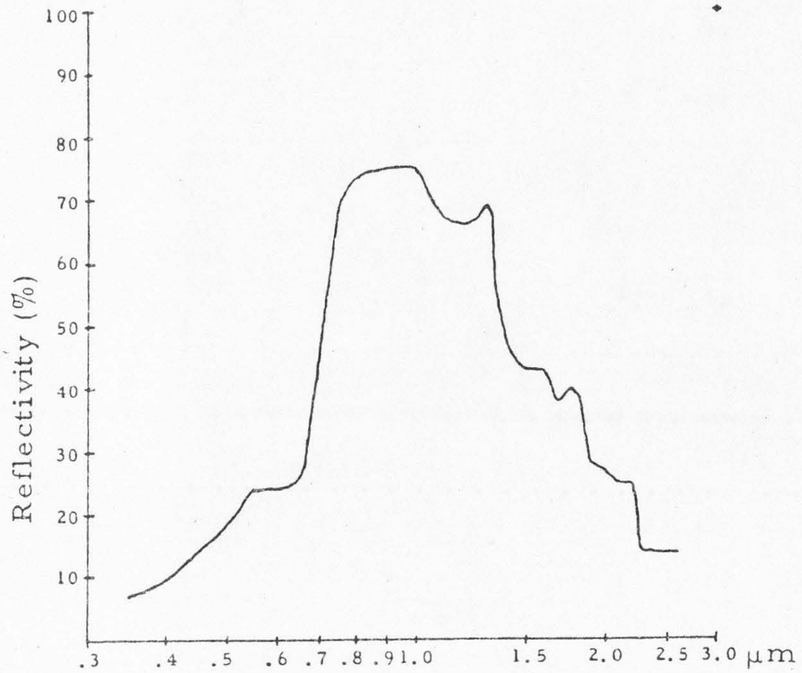

Figure 36. Aspen bark.

Figure 37. Juniper bark.

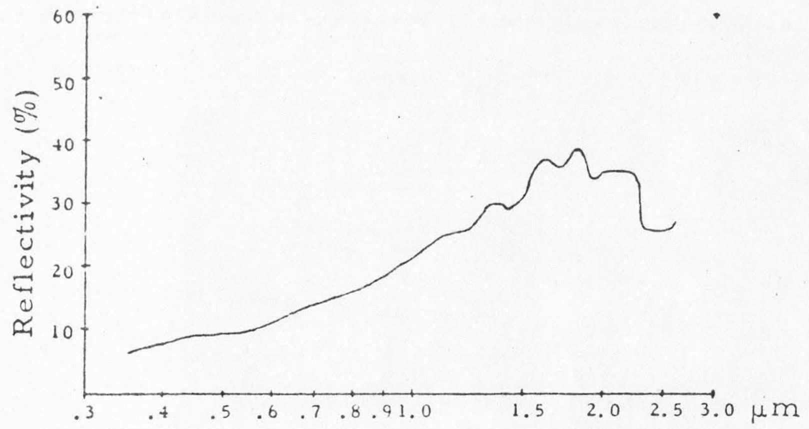

Figure 38. Apple tree bark.

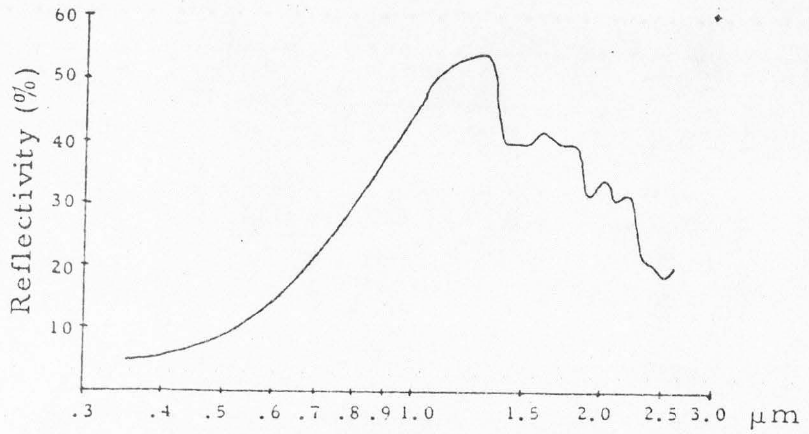

Figure 39. Rotten log bark.

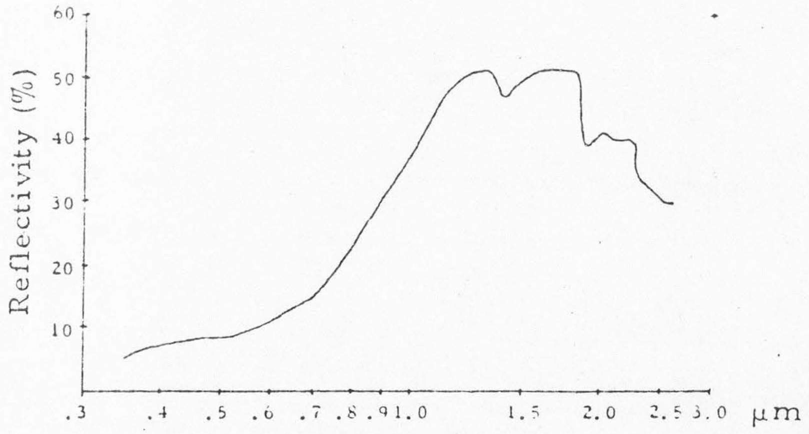

Figure 40. Fallen log bark.

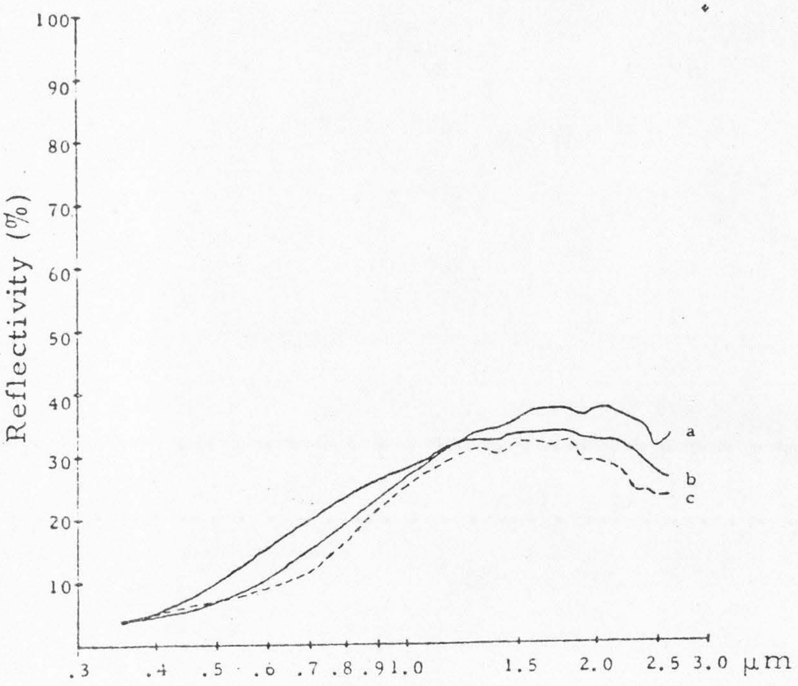

Figure 41. Reflection data. a. Soil no. 1, b. Soil no. 2, c. Soil no. 3 (glued)

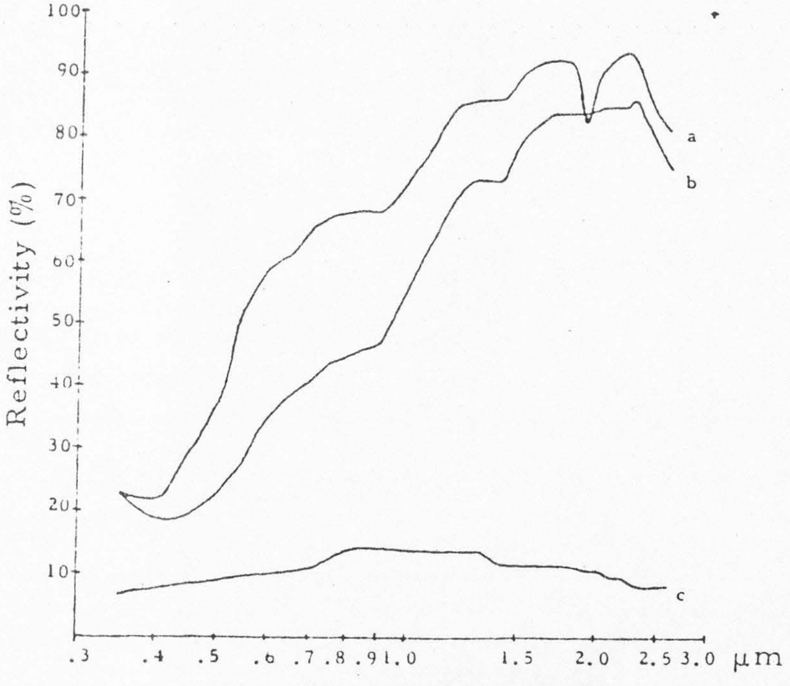

Figure 42. Reflection data. a. Sand no. 3, b. Sand no. 4, c. Sand no. 1.

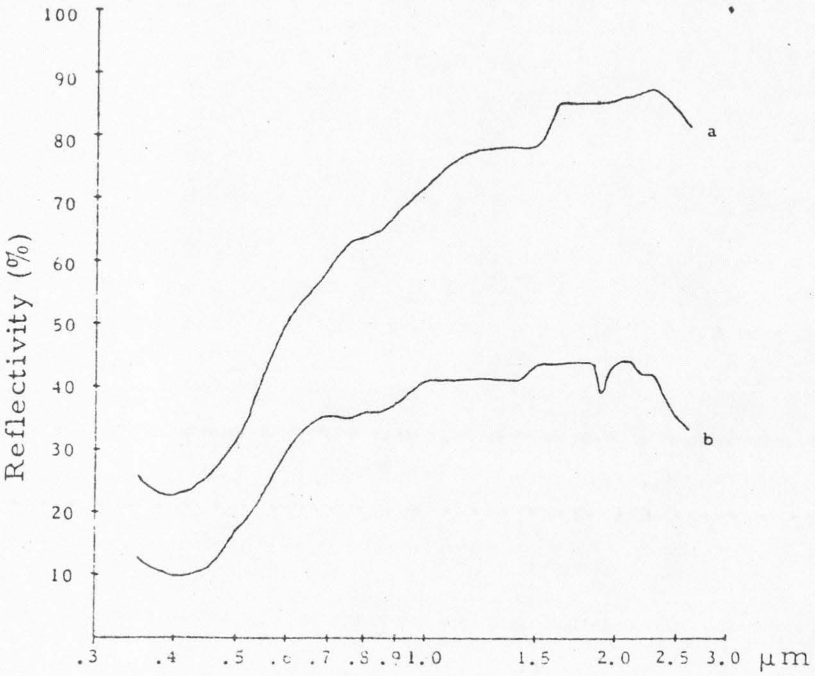

Figure 43. Reflection data. a. Sand no. 5, b. Sand no. 6.

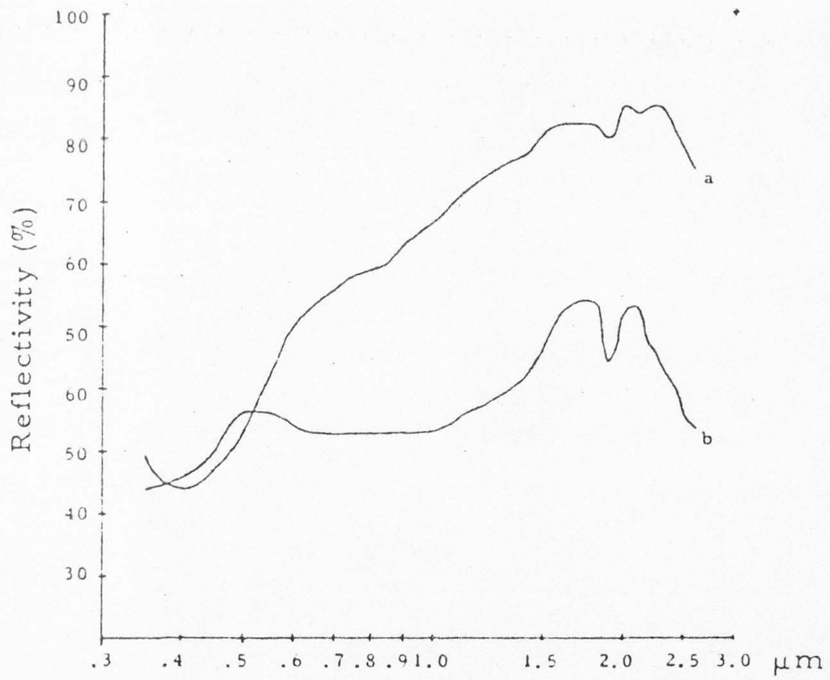

Figure 44. Reflection data. a. Sand no. 7, b. Sand no. 8

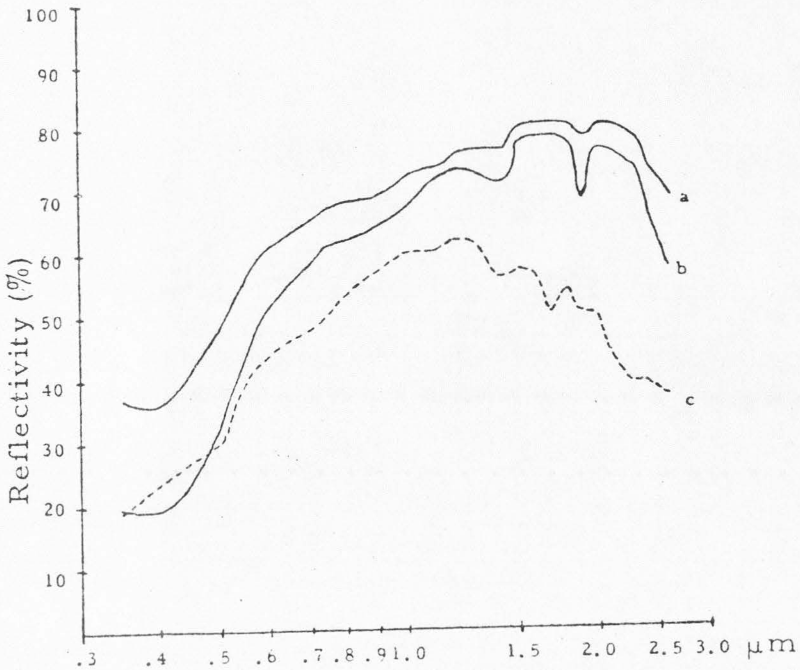

Figure 45. Reflection data. a. Sand no. 10, b. Sand no. 9, c. Sand no. 10 (glued)

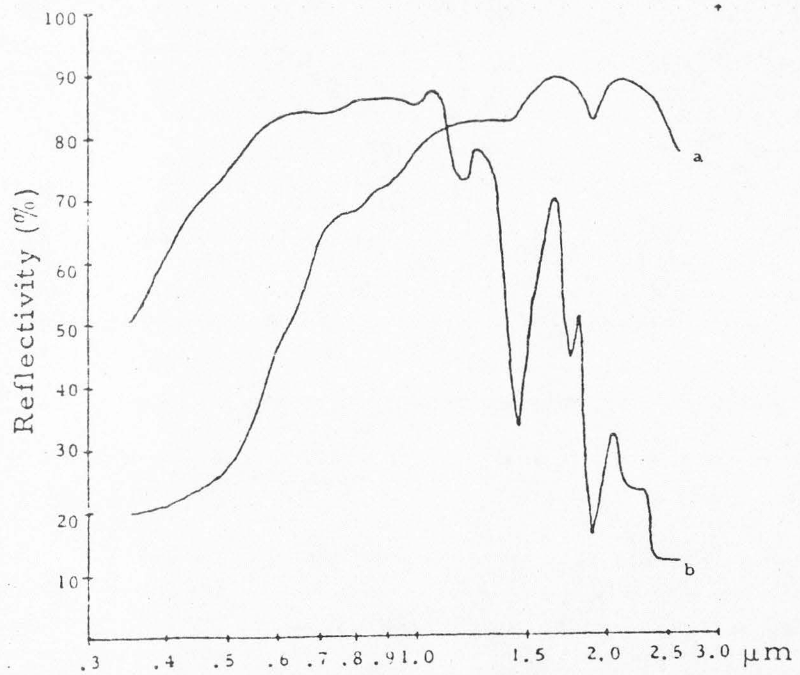

Figure 46. Reflection data. a. Sand no. 11, b. Sand no. 12.

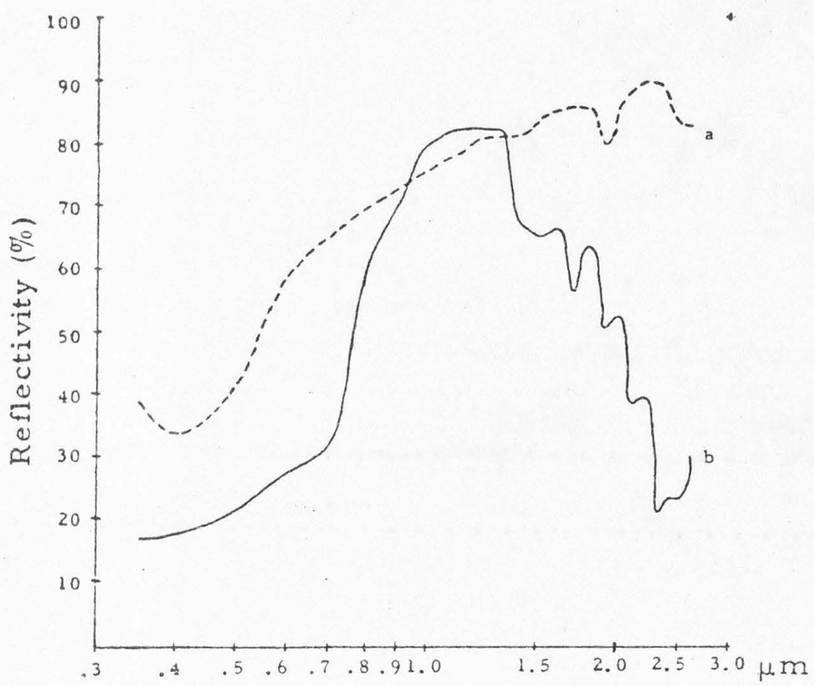

Figure 47. Reflection data. a. Sand no. 2, b. Sand no. 2 (glued)

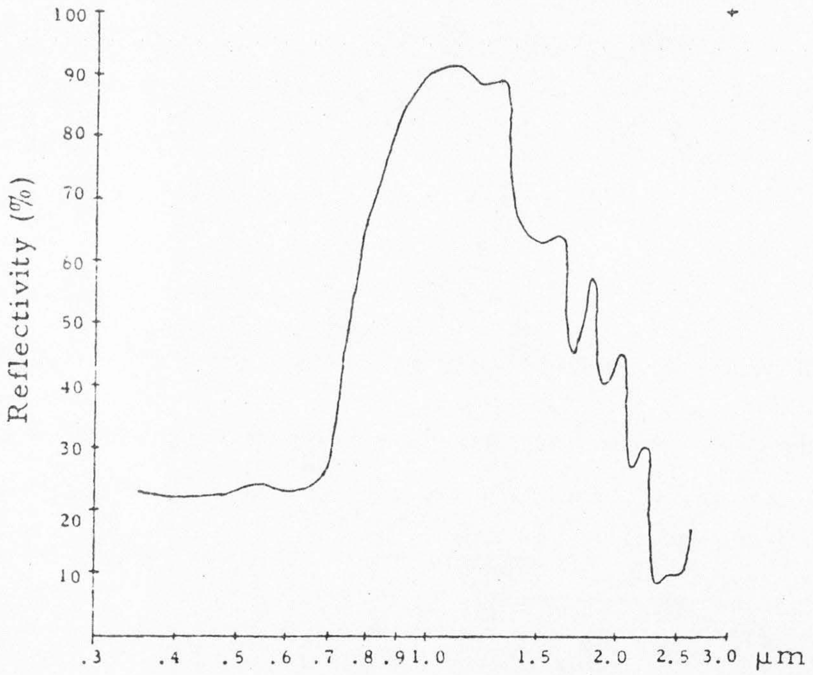

Figure 48. Dry Elmers Glue-All.

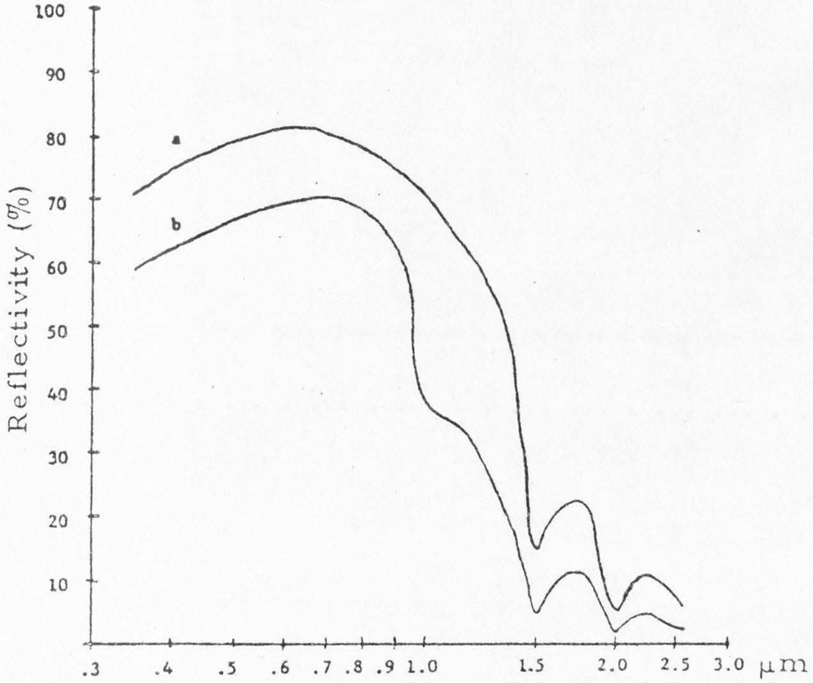

Figure 49. Reflection data. a. New snow, b. Old snow. (Copied from Journal of Applied Meteorology Vol. 7, No. 4, August 1968, pp. 702-707)

Appendix C

SWIR Data

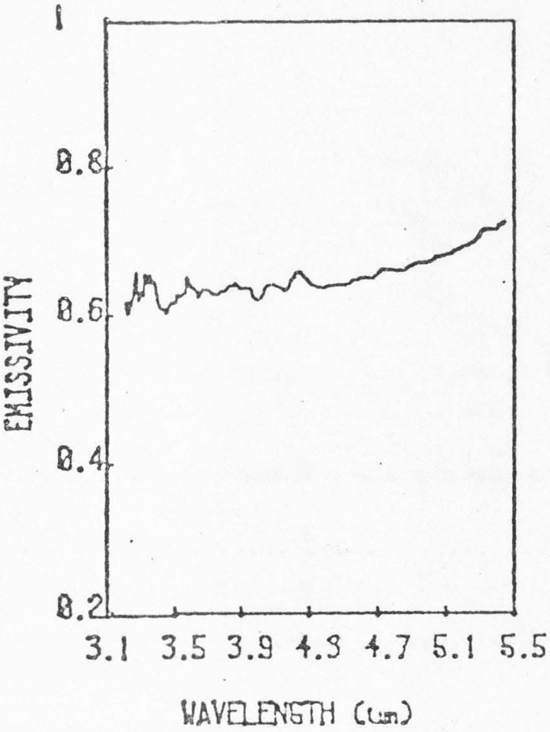

Figure 50. Deer hide emission data (SWIR).

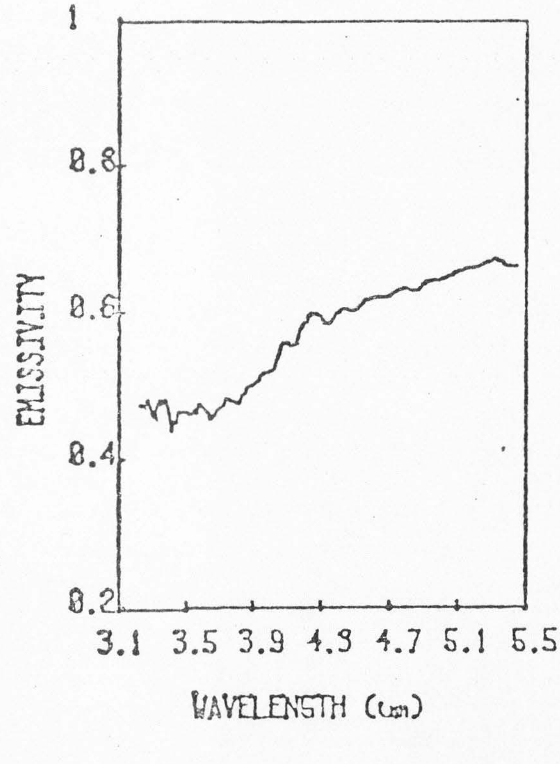

Figure 51. Gypsum, Sand no. 12 (SWIR).

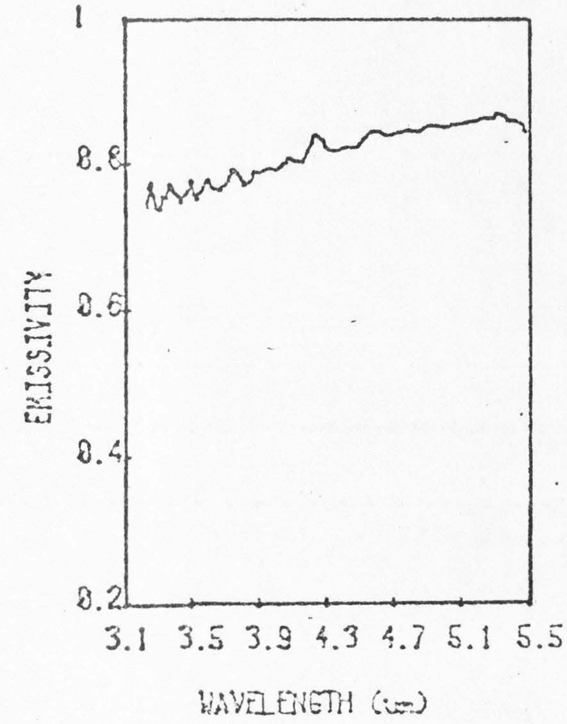

Figure 52. Juniper (SWIR).

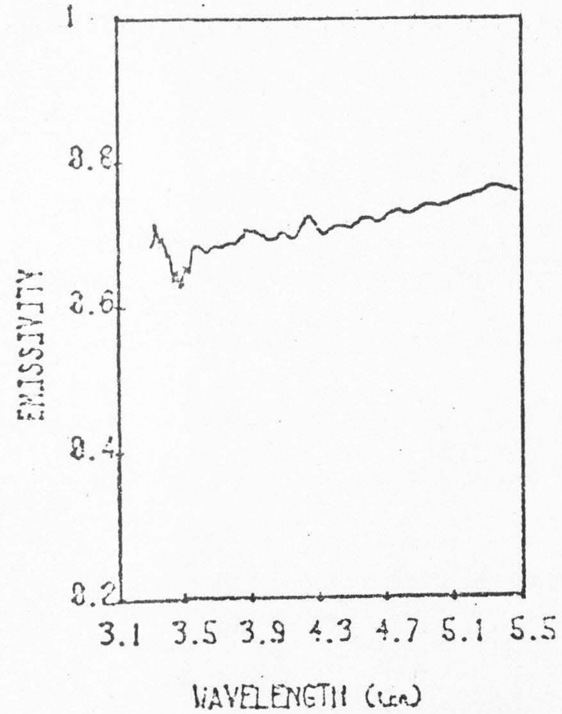

Figure 53. Rotten log bark (SWIR).

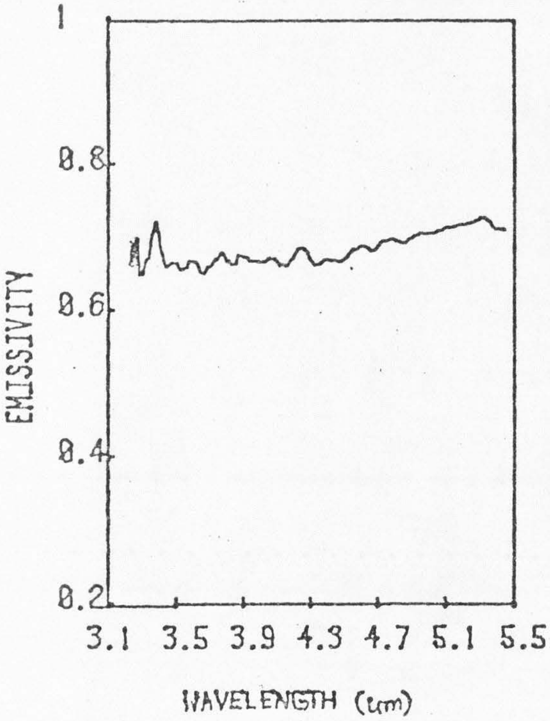

Figure 54. Dry Maple leaves (SWIR).

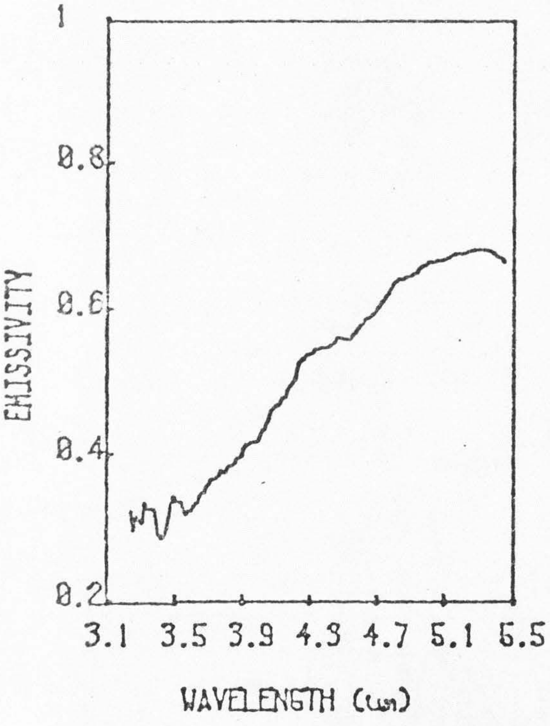

Figure 55. Crushed fused quartz (SWIR).

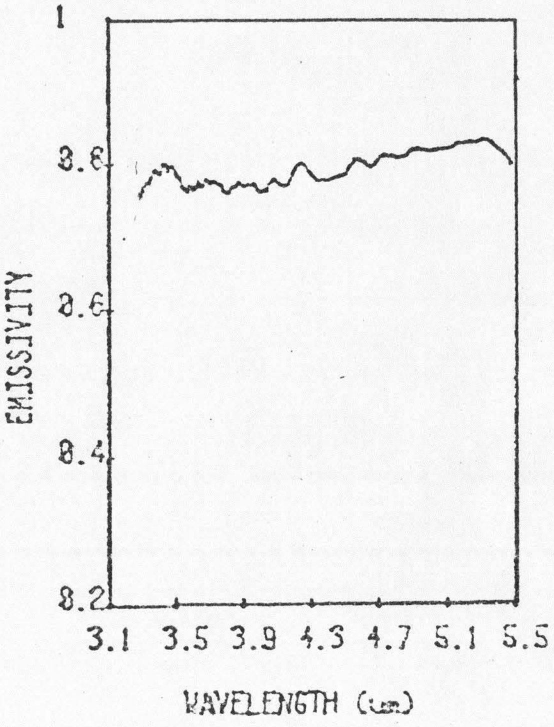

Figure 56. Sagebrush (SWIR).

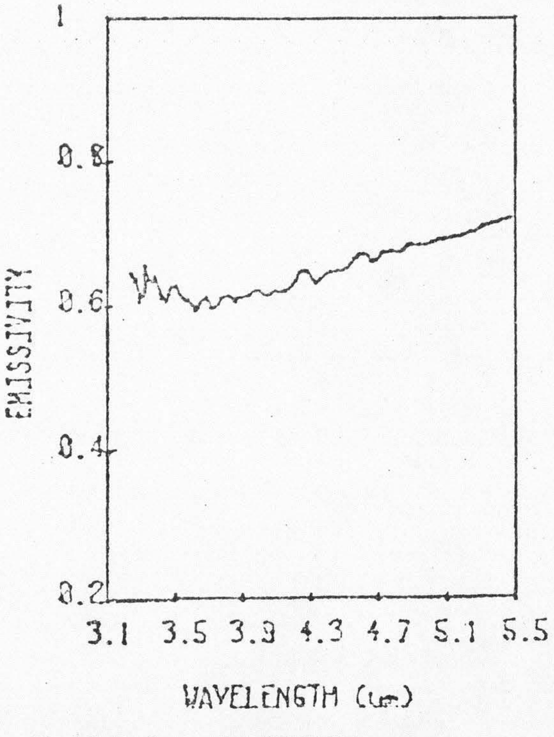

Figure 57. Rabbit brush (SWIR).

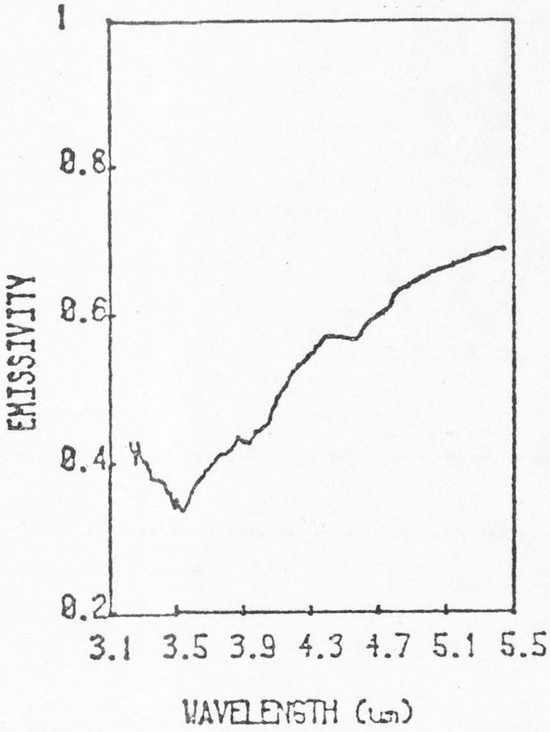

Figure 58. Silica, Sand no. 2 (SWIR).

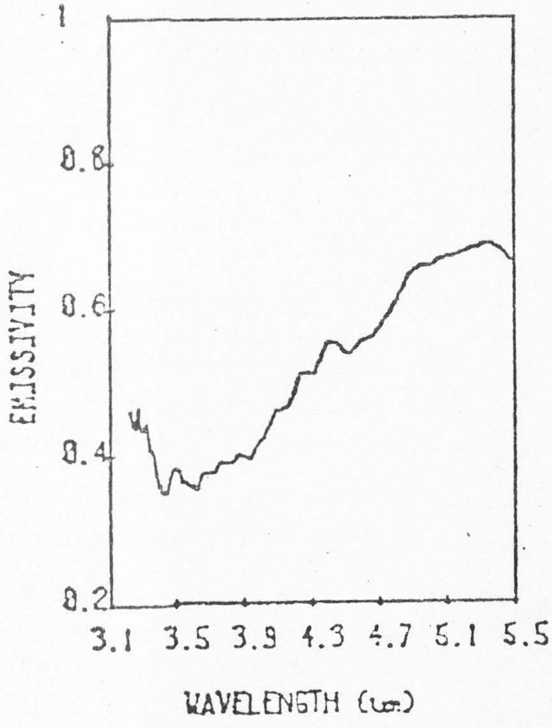

Figure 59. Silica, Sand no. 11 (SWIR).

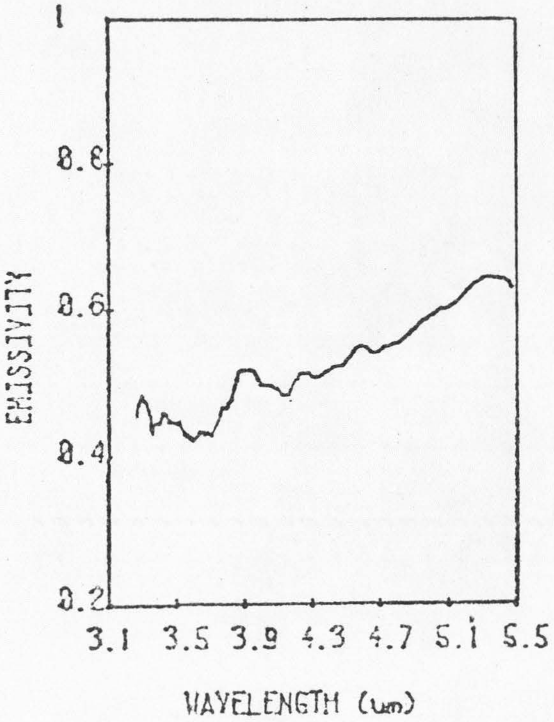

Figure 60. Soil no. 1 (SWIR).

Appendix D

LWIR Data

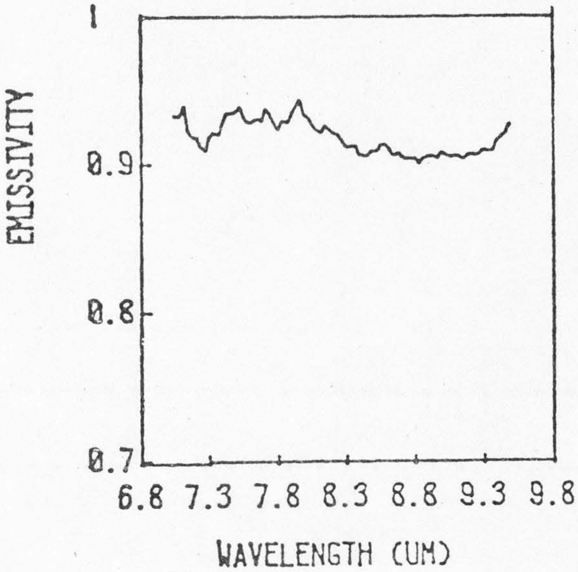

Figure 61. Deer hide emission data (LWIR).

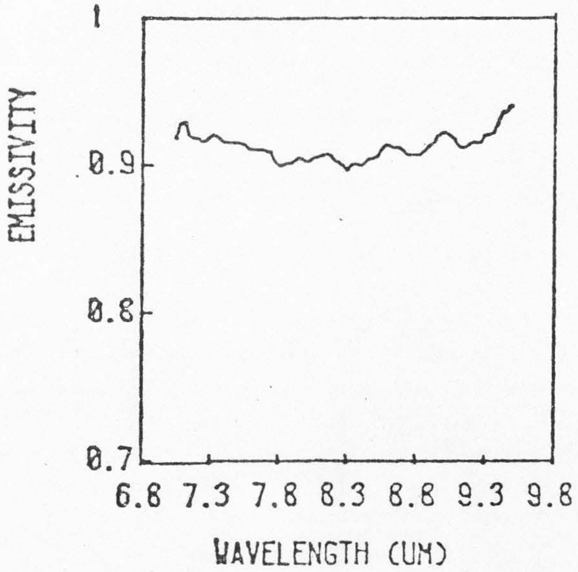

Figure 62. Rotten log bark (LWIR).

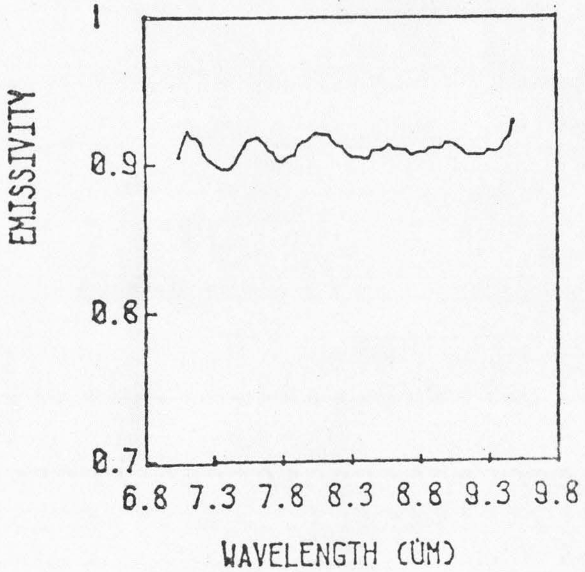

Figure 63. Juniper foliage (LWIR).

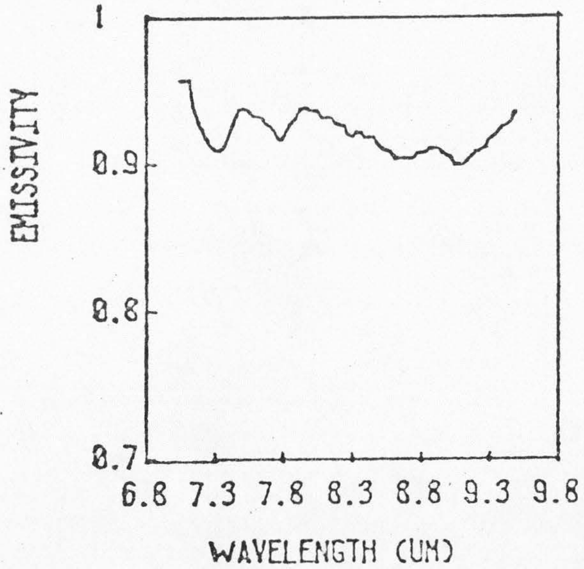

Figure 64. Sagebrush (LWIR).

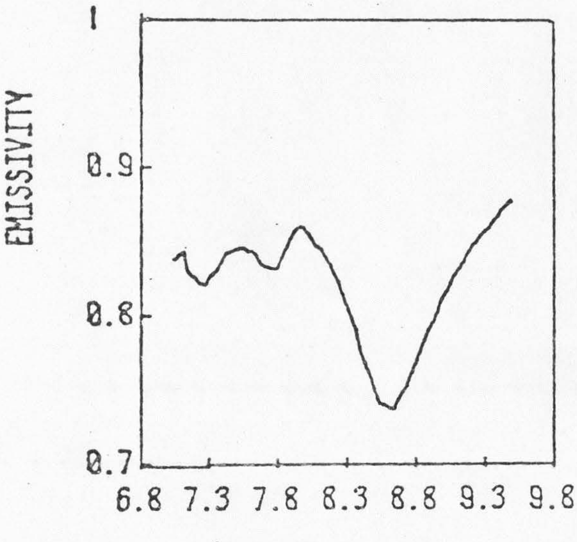

Figure 65. Gypsum, Sand no. 12 (LWIR).

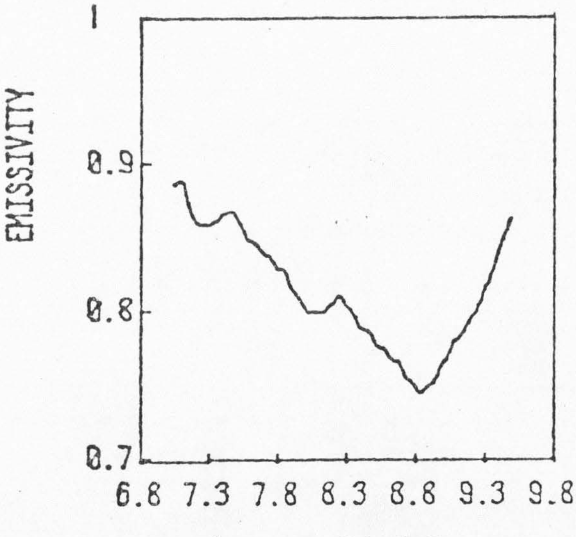

Figure 66. Crushed fused quartz (LWIR).

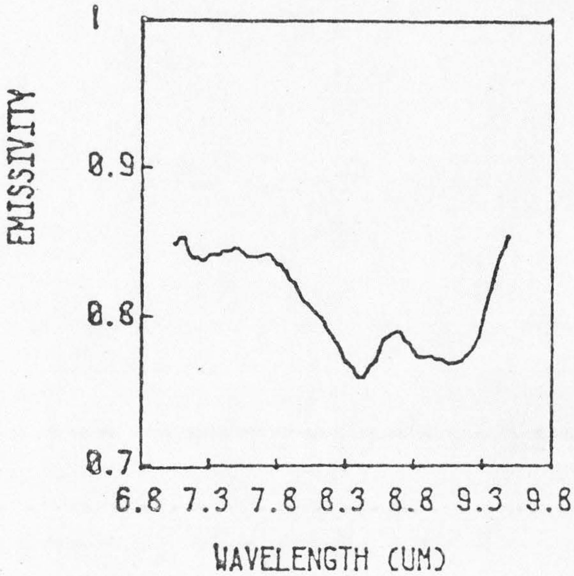

Figure 67. Sand no. 11 (LWIR).

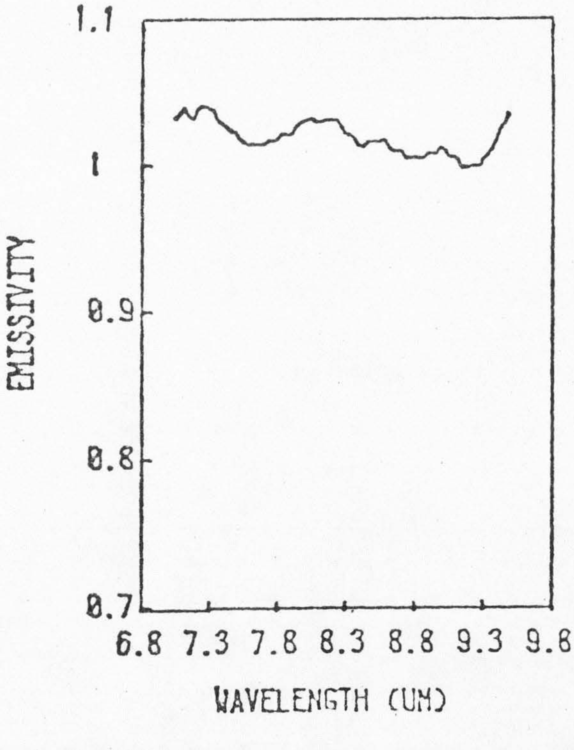

Figure 68. Rabbit brush (LWIR).

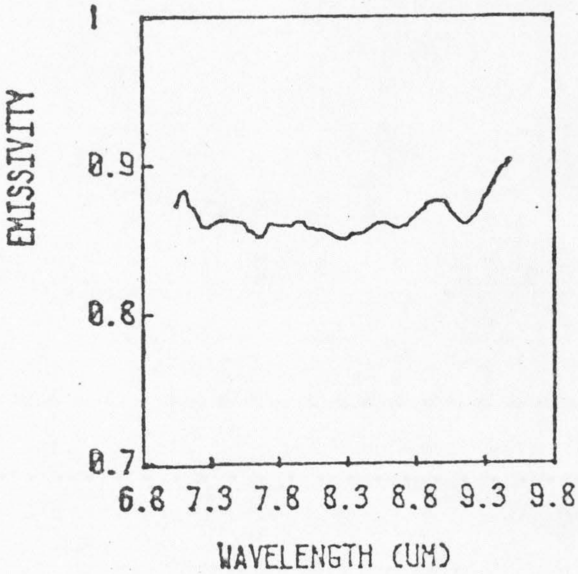

Figure 69. Soil no. 1 (LWIR).

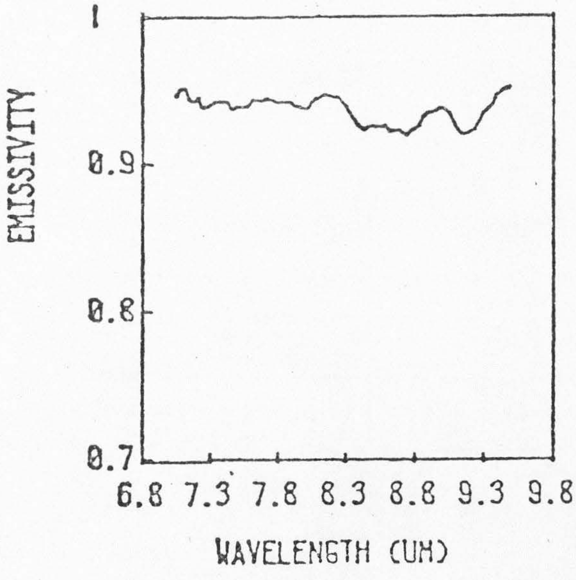

Figure 70. Dry Maple leaves (LWIR).

Appendix E

Mineralogical Analysis

A mineralogical analysis by x-ray diffraction was made of the sand samples to help correlate any salient minerallic features with the reflection and emission data. The samples were analyzed as follows.

Each sample was powdered to pass a 115 mesh sieve. The sample was then spread uniformly on a glass slide which had been lightly coated with Vaseline.

Analysis conditions:

Copper tube; Kα radiation; nickel filter; scan speed: 2° 20/min.; chart speed: 1 inch/min.; copper tube operated at 35 kv., 16 ma.; scintillation detector; time constant: 3; Krystalloflex-4 x-ray generator.

TABLE 7

MINERALOGICAL ANALYSIS

Sand Sample No.	Mineralogy*
1	subequal amounts of quartz and feldspar
2	quartz
3	quartz, trace of feldspar
4	quartz, some calcite, trace of feldspar
5	quartz, some dolomite
6	quartz, trace of feldspar
7	quartz, calcite, dolomite, feldspar, some clay minerals such as illite and some smectite group
8	quartz, trace of feldspar (?)
9	quartz, trace of feldspar
10	quartz, some feldspar, trace of dolomite?
11	quartz, some feldspar
12	gypsum, some quartz

* The chemical composition of the principal minerals is as follows: quartz - $Si0_2$; calcite - $CaCO_3$; dolomite - $(CaMg)C0_3$; gypsum - $CaSO_4 \cdot 2H_20$ feldspar - silicate minerals, composition varies widely.

Appendix F

Thermister Calibration

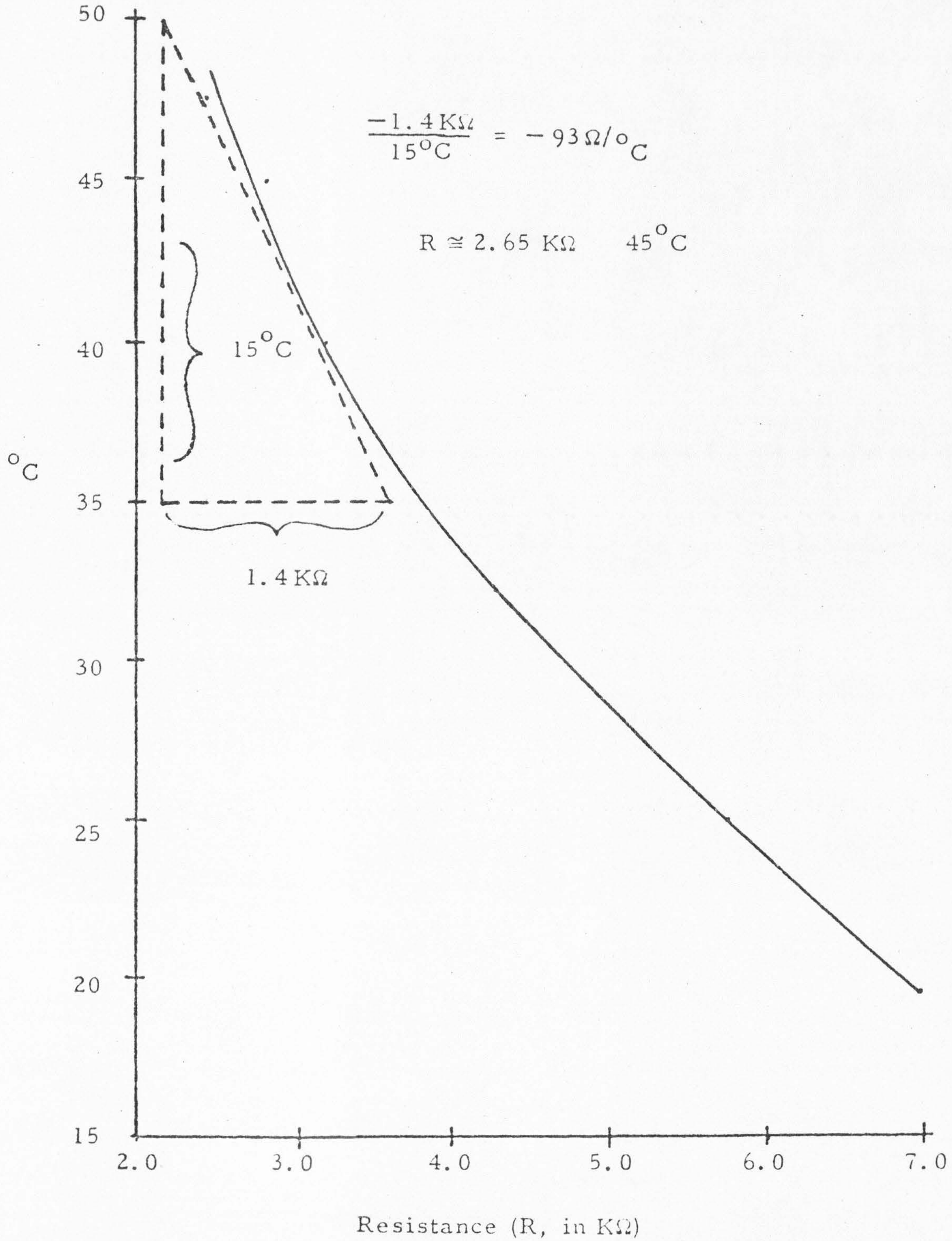

Figure 71. Thermister calibration.