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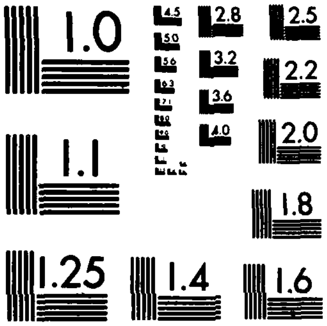

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A STUDY OF ATMOSPHERIC TRANSMISSION IN THE WAVELENGTH REGIONS OF 0.35 um to 14um

Raymond Cammilleri
Casey Ko Neil Jenkins
Laurence Caretto
Timothy W. Fox

California State University Northridge
School of Engineering and Computer Science

FINAL REPORT
AUGUST 1983

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EDWARDS AIR FORCE BASE, CALIFORNIA
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE

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This report has been reviewed
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This report documents a study of low altitude atmospheric radiation transmission conducted by a student-faculty team at California State University, Northridge, School of Engineering. The report was generated under a contract issued by the Air Force Flight Test Center at Edwards Air Force Base. A simple computer program, LARTAP, has been developed. The simplicity of the program makes it easy to modify to suit users requirements. Should detailed testing be required to improve program accuracy, currently available instrumentation has been evaluated. It has also been suggested that a technique

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involving direct measurement of radiation transmission and utilization of a numerical filtering technique may provide a more accurate model of atmospheric transmission at a test site.

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ABSTRACT

The following report documents a study of low altitude atmospheric radiation transmission conducted by a student-faculty team at California State University, Northridge, School of Engineering. The report was generated under a contract issued by the Air Force Flight Test Center at Edwards Air Force Base. A simple computer program, LARTAP, has been developed. The simplicity of the program makes it easy to modify to suit users requirements. Should detailed testing be required to improve program accuracy, currently available instrumentation has been evaluated. It has also been suggested that a technique involving direct measurement of radiation transmission and utilization of a numerical filtering technique may provide a more accurate model of atmospheric radiation transmission at a test site.

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INTRODUCTION

As radiation technology becomes more and more a part of our defense capabilities, the need arises to be able to understand and predict the effects of the earth's atmosphere on radiation transmission. The need is especially great for the low altitude regions of the earth's atmosphere because many systems are being designed to operate in this region. Particular examples of such systems are Forward Looking Infrared (FLIR) Lasers, Low Light Level Television, and Night Vision Goggles.

The Air Force Flight Test Center (AFFT Edwards Air Force Base (Edwards AFB) requires such knowledge to evaluate sensors in the visible through infrared spectrum. In order to acquire this knowledge AFFTC issued a contract to the School of Engineering at California State University, Northridge (CSUN).

CSUN was to evaluate the transmission of radiation in the atmosphere of the earth. The radiation of interest was in the wavelenth region of 0.35 um to 14 um. The atmosphere of interest was from an altitude of 0.0 km (AGL) to an altitude of 0.7 km (AGL), with a maximum altitude of 5 km (ASL). CSUN was also to identify atmospheric components that effect the transmission of radiation in the aforementioned wavelength region.

The contract was carried out at CSUN through the use of a student Design Clinic. A Design Clinic is an independent study course offered at CSUN where students work under the guidance of faculty members on contracts issued to the School of Engineering. The faculty and student team that worked on this contract is listed on the title page as authors.

The project began with a literature search. The first goal of the literature search was to acquire and understand the theoretical equations that describe the transmission of radiation in the earth's atmosphere. The second goal of the literature search was to investigate the atmospheric components affecting the transmission of radiation. The final goal of the literature search was to evaluate presently existing computer software that modeled the transmission of radiation in the earth's atmosphere.

Currently, the most comprehensive computer program that models transmission of radiation in the earth's atmosphere is LOWTRAN. LOWTRAN is a product of Air Force Geophysics Laboratory at Hanscom AFB, Massachusetts. This program was first developed in the mid-1970's and several modified versions have been released since that time.

Unfortunately, the LOWTRAN computer code is extremely complicated. This complication posed a problem since AFFTC had expressed a need for a computer program that could be used at a test site. It was determined that LOWTRAN could not be used to satisfy this need. However, LOWTRAN contains an extremely comprehensive empirical data base. Thus CSUN developed a new computer program, LARTAP, that is much simpler than LOWTRAN, however the new computer program still utilizes the same empirical data base as LOWTRAN. Preliminary test runs of LARTAP have shown agreement with LOWTRAN. However, it is suggested that further testing be done to compare LARTAP to actual test data.

CSUN has also evaluated the AFFTC test equipment to assess the capability of AFFTC to measure atmospheric components that affect radiation transmission. The equipment existing at AFFTC is more than adequate to support the current version of LARTAP. However, should the need arise for more comprehensive measurements, suggestions are made for possible acquisitions.

Finally, suggestions are made for possible future work. As was mentioned previously, more testing needs to be performed to verify the LARTAP computer program. One of the short comings of both LARTAP and LOWTRAN is the inability to handle the possible affects of solar radiation. It is suggested that a model be developed to account for this affect. The resulting model could easily be incorporated in LARTAP.

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SECTION I

BASIC CONCEPTS IN RADIATION TRANSMISSION

If a source emits radiation into a medium (such as the atmosphere of the earth) then the intensity of the emitted radiation will be changed by the medium. The situation is presented qualitatively in figure 1. The radiative intensity from the source of interest is changed through four mechanisms. Radiation may be absorbed, radiation may be scattered out of the line of sight, radiation may be emitted and radiation from sources other than the one of interest may be scattered into the line of sight.

It is demonstrated in reference 1 that the change in radiative intensity of wavelength λ, along some path S through a medium is given by the following differential equation.

$$\frac{dI}{ds} = a I_b - aI - \sigma I + \frac{\sigma}{4\pi} \int_{4\pi} \Phi I^* \, d\omega \qquad (1)$$

where:

S - path

I - monochromatic radiative intensity at S

I_b - blackbody intensity using the temperature of the medium at S and wavelength

a - absorption coefficient of the medium at S and

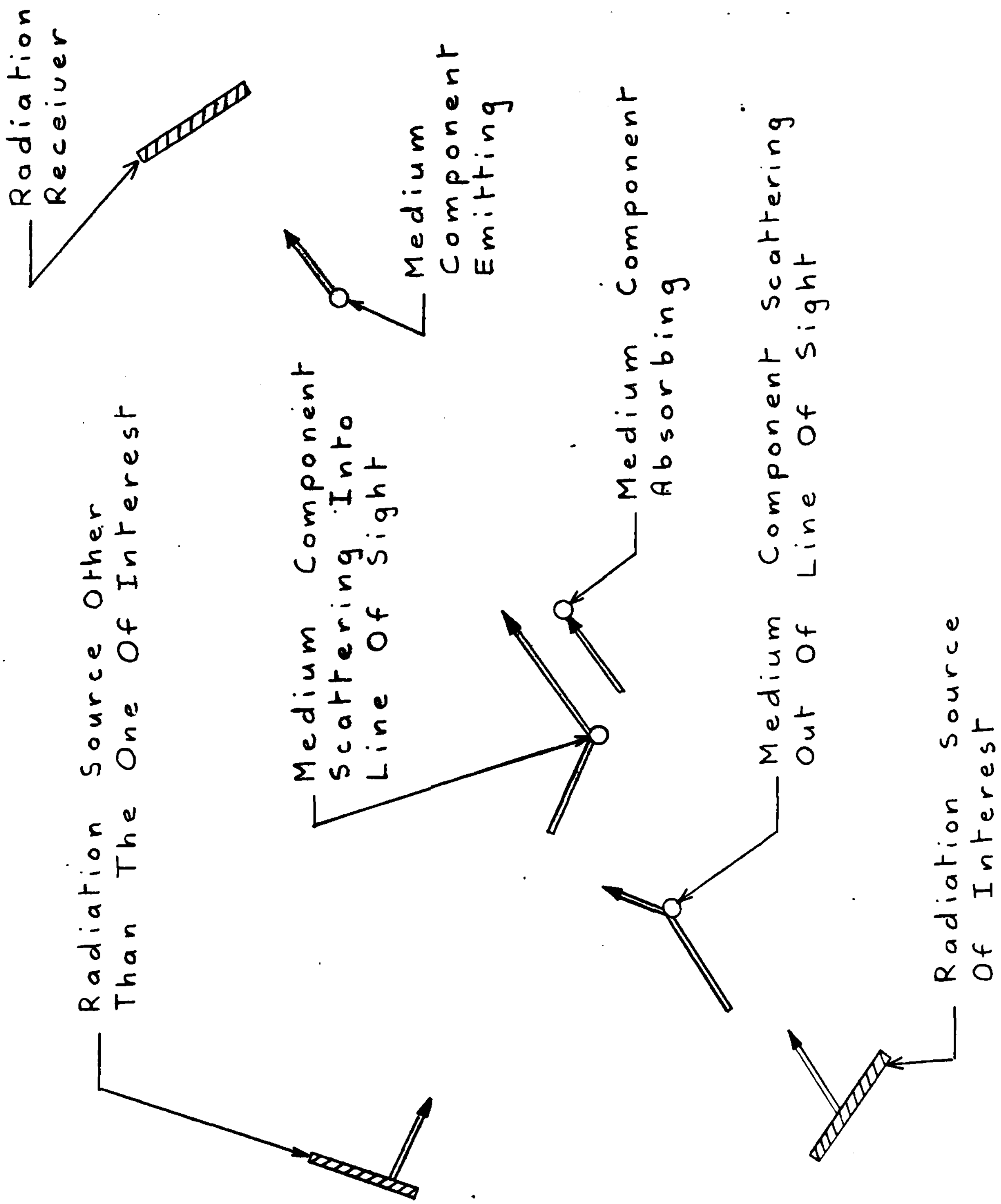
σ - scattering coefficient of the medium at S and

w - solid angle

Φ - *phase function of scattering*

I^* - radiative intensity along S from sources other than the one

FIGURE 1
How a Medium Affects Radiation



of Interest.

The first term to the right of the equal sign accounts for emission by the medium. Note that Kirkoff's Law has been invoked in the derivation of equation (1) since the absorption coefficient is used in the emission term. The second and third terms account for attenuation due to the absorption and scattering out of the line of sight, respectively. The fourth term accounts for the scattering of radiation from sources other than the one of interest into the line of sight.

The scattering coefficient and phase function in the fourth term may be interpreted qualitatively as follows. The scattering coefficient determines the total amount of radiation from sources other than the one of interest that is scattered. The phase function accounts for the proportion of radiation that is scattered into the line of sight. A good example of I* source of radiation would be solar intensity.

Unfortunately, in order to properly evaluate the last term in equation (1) it would be necessary to know the local intensity along the line of sight from all possible radiative sources around and in the region of the medium under consideration. This is quite a formidable task. Briefly it involves transforming equation (1) into an integro-partial-differential equation. Then this equation is solved for an intensity field function that may be evaluated at any point in the region of the medium under consideration. In general this integro-partial-differential equation may be solved only by a numerical technique such as finite element.

Thus in the interest of simplicity the last term of equation (1) was dropped. It should be pointed out, however, that for a line of sight that extends from the surface of the earth upwards I* source term resulting from the scattering of solar radiation may be quite significant. It is felt that a future effort should be undertaken to find a simplified method to model this effect.

Dropping the last term, equation (1) may be written as:

$$\frac{dI}{ds} + \epsilon I = aI_b \qquad (2)$$

where:

$\epsilon = \alpha + a$ - extinction coefficient

Equation (2) is a linear, ordinary differential equation which has the following solution.

$$I_L = I_o \, e^{-\int_0^L \epsilon(u)\,du} + \int_0^L I_b(s^*)\, a(s^*)\, e^{-\int_{s^*}^L \epsilon(u)\,du} \, ds^* \qquad (3)$$

where I_L and I_o are the following Dirichlet boundary conditions.

I_o - monochromatic intensity at the source of interest.

I_L - monochromatic intensity at a point a distance L along S.

Equation (3) may be interpreted qualitative as follows. Consider the case where the medium is cold such that $I_b \approx 0$, then equation (3) would reduce to:

$$I_L = I_o \, e^{-\int_0^L \epsilon(u)\,du}$$

Thus the exponential with an integral augument represents the attenuation of the intensity I_o along the line of sight extending from 0 to L. This exponential with an integral augument defines the transmittance of the path from 0 to L. Note that the transmittance will vary from zero to one.

The second term is a little more complicated. Consider a differential path length at S* some where along S between 0 and L. Over this differential path length dS* radiation will be emitted by the medium. The exact amount is given by $I_b(S^*)a(S^*)dS^*$. However, this amount will be attenuated between S* and L where the transmittance is given by:

$$e^{-\int_{s^*}^{L} \epsilon(u)\,du}$$

Summing all the contributions from every dS* between 0 and L gives the second term in equation (3).

Equation (3) may be written as follows:

$$I_L = I_0\, e^{-\int_0^L \epsilon(u)\,du} + \int_0^L \frac{I_b(s^*)\, e^{-\int_{s^*}^{L} \epsilon(u)\,du}}{e^{-\int_{s^*}^{L} a(u)\,du}} \; \frac{d\left[e^{-\int_{s^*}^{L} a(u)\,du}\right]}{d s^*} \, d s^* \qquad (4\,a$$

Define τ_a and τ_ϵ as follows:

$$\tau_\epsilon(x,y) = e^{-\int_x^y \epsilon(u)\,du} \qquad \tau_a(x,y) = e^{-\int_x^y a(u)\,du} \qquad (4b)$$

Then equation (4) may be written as:

$$I_L = I_0\, \tau_\epsilon(0,L) + \int_0^L \frac{I_b(s^*)\;\; \tau_\epsilon(s^*,L)}{\tau_a(s^*,L)} \; \frac{d\,\tau(s^*,L)}{d\,s^*} \, d\,s^* \qquad (5$$

At first glance it may appear that equation (5) is more complicated than equation (3), however, the numerical analogue of equation (5) will prove to be very convenient for evaluating I_L with a computer program. The numerical analogue of equation (5) is:

$$I_L = I_o \, \tau_e(0, L) + \sum_{i=1}^{n-1} \left\{ \left[\frac{I_b(s^*_{i+1}) \, \tau_e(s^*_{i+1}, L)}{\tau_a(s^*_{i+1}, L)} + \frac{I_b(s^*_i) \, \tau_e(s^*_i, L)}{\tau_a(s^*_i, L)} \right] \frac{1}{2} \times \left[\tau_a(s^*_{i+1}, L) - \tau_a(s^*_i, L) \right] \right\} \tag{6}$$

where the path from 0 to L has been divided into n-1 distances of $(s^*_{i+1} - s^*_i)$.

SECTION II

RADIATION PROPERTIES OF GASES AND PARTICLES

In section I the concepts of absorption, emission and scattering were introduced. The purpose of this section is to discuss these concepts in more detail. However, before discussing the microscopic effects producing these three phenomenon it is helpful to review the continuous matter assumption.

Equation (1) assumes continuity of matter in the following sense. A macroscopic differential volume of matter contains an infinite number of molecules; such that, in equilibrium although the microscopic states of the molecules are continuously changing, the macroscopic state of the matter in dV is the time average of the continuously changing microscopic states of the molecules within dV.

In order to understand absorption, emission and scattering it is necessary to utilize Quantum Mechanics. From a Quantum Mechanical point of view the radiative transfer problem becomes one of determining the characteristics of photons. In particular the local number density, energy distribution and direction of motion. If these three characteristics are known then the macroscopic quantity, intensity, may be determined. Any or all of these characteristics are altered by interactions between the photons and the medium components (atoms, molecules and particulates).

Absorption occurs when a photon encounters a component of the medium and is absorbed thereby increasing the energy of that component. Emission occurs when a component emits a photon thereby decreasing the energy of that component. Scattering occurs when a photon encounters a component of the medium and the direction of motion of the photon is changed.

According to Quantum Mechanics a single medium component may exist in any one of a number of accessible energy states. This concept is displayed in figure 2. The ground state is the lowest energy level that a medium component may have. The ionization state is the energy required to ionize the medium component. In figure 2, two other accessible energy states are shown between ground and ionization. For an actual medium component there may be any number of accessible energy states between ground and ionization.

Consider a single gas molecule that has accessible energy states as shown in figure 2. According to Quantum Mechanics the energy of a photon is $h\nu$ where h is Planck's Constant and ν is frequency. Thus in order for this gas molecule to move from energy state E_1 to energy state E_2 it must absorb a photon of the following frequency.

$$\nu = \frac{E_2 - E_1}{h}$$

If there were no interaction between molecules and no other effects the absorption coefficient for a large number of these gas molecules would be a single vertical line at frequency ν. The magnitude of the absorption coefficient would depend of the number of gas molecules within the medium at energy level E_1. However, in the case of a real gases collisions between molecules cause the accessible states displayed in figure 2 to shift. Thus for a real gas the absorption coefficient is a distribution around frequency ν. The spread of the distribution depends on the number of molecules experiencing a collision. The number of gas molecules experiencing a

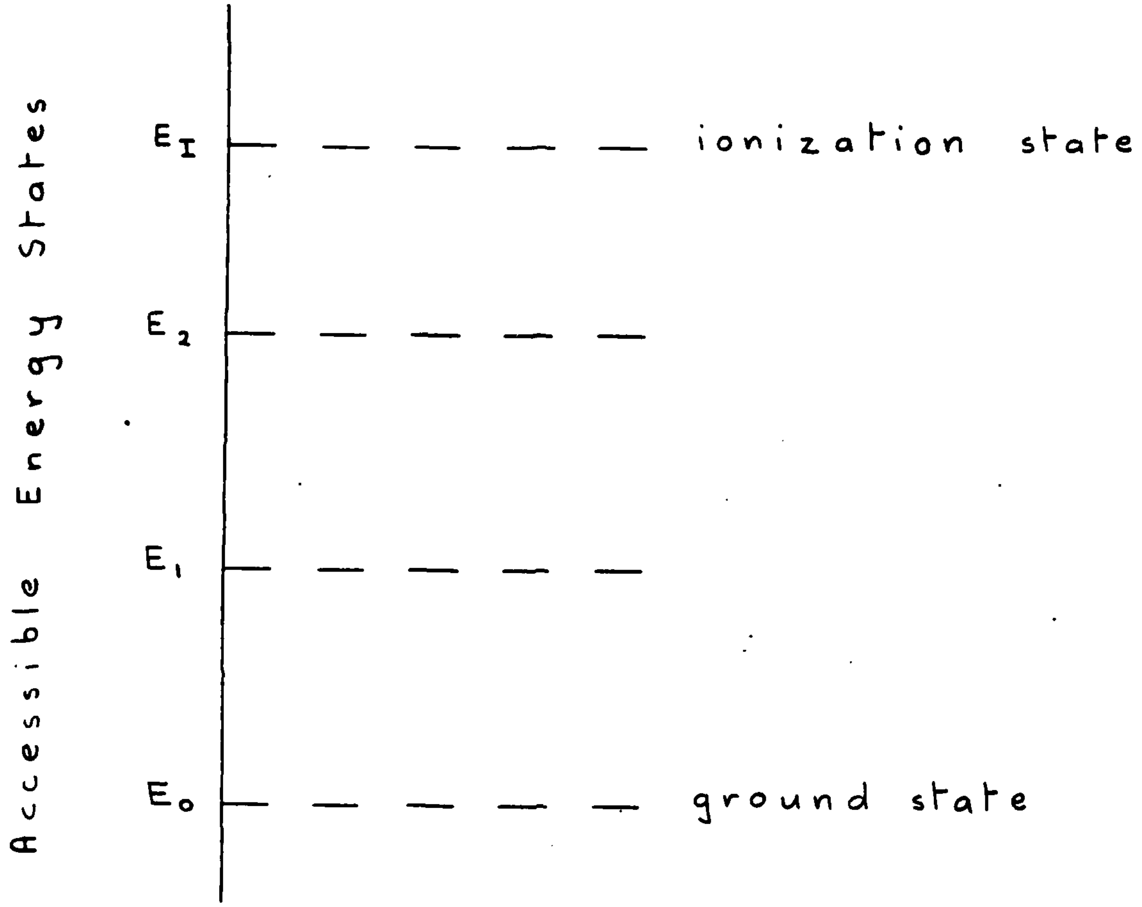


FIGURE 2

Schematic of Accessible Energy States of a Medium Component collision is related to pressure. As was previously mentioned the magnitude of the absorption coefficient at frequency ν depends on the number of molecules in energy state E_1. This number is dependent on the density and temperature of the gas.

Thus the following conclusions can be drawn about the absorption coefficient of a gas. First, the absorption coefficient will depend on the local thermodynamic state of the gas. Second, the absorption coefficient for a gas is a strong function of incident radiation frequency. The principles presented thus far are displayed in figure 3.

Finally, if the schematic displayed in figure 2 were for a real gas, then a plot of absorption coefficient versus all frequencies would appear as three distributions of the type displayed in figure 3. These distributions would be centered at the following frequencies:

$$\nu_1 = \frac{E_1 - E_0}{h} \qquad \nu_2 = \frac{E_2 - E_0}{h} \qquad \nu_3 = \frac{E_2 - E_1}{h}$$

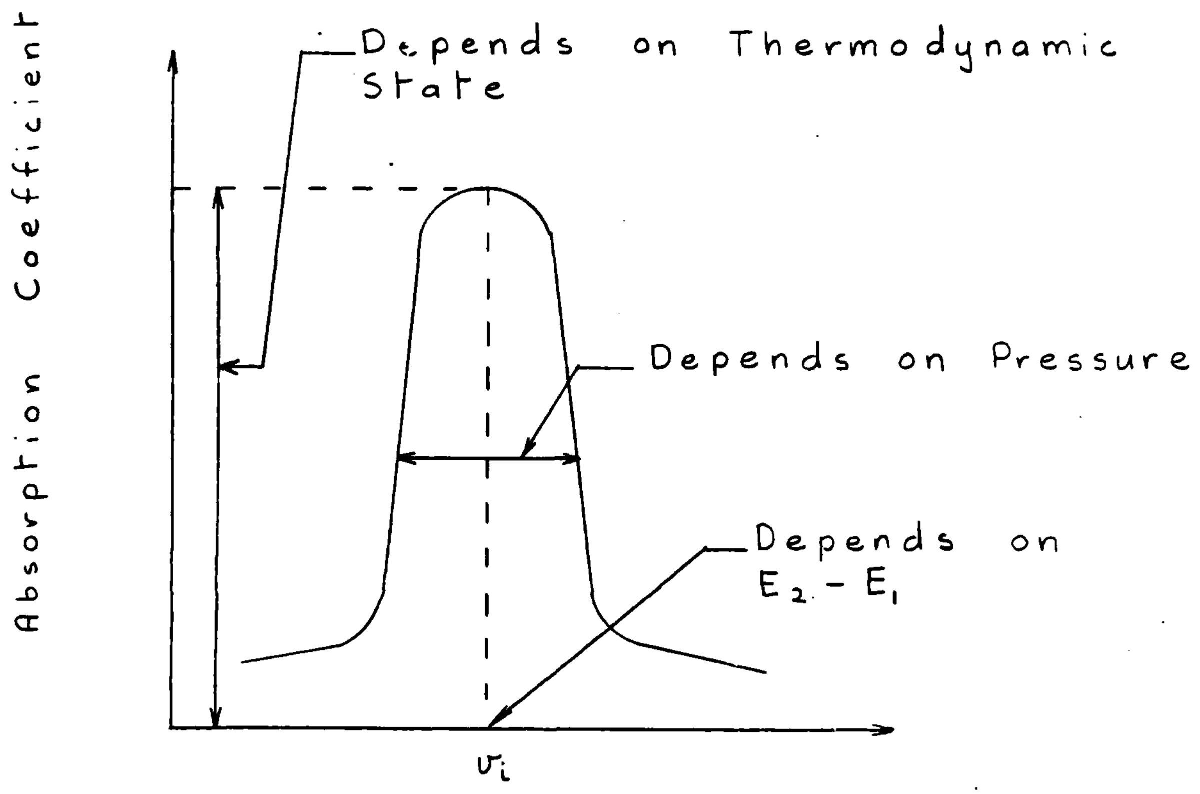
The relative magnitude of the absorption coefficient at each of these frequencies would depend of the thermodynamic state of the gas.

Attention is now turned to the medium components that are referred to as particulates or aerosols. These components are solid particles that are suspended in the gaseous components of the medium. Examples of particulates are dust particles, water droplets, etc.

It is important to note at this point the size of particulates and how it relates to the continuum assumption discussed at the

FIGURE 3

Absorption Coefficient of a Gas



Frequency of Incident Radiation

beginning of this section. In order to treat the particulates using a continuum equation such as equation (1), it must be assumed that the dimensions of the problem under consideration are large enough such that a differential volume dV contains a large number of particulates.

Where as a gas exhibits an absorption coefficient that is a strong function of frequency, particulates tend to exhibit absorption coefficients that are somewhat smoother functions of frequency. The reason is that a particulate is composed of a number of closely interacting molecules. Figure 2 for such particulates becomes a continuum of accessible states. Thus the molecular collision-pressure relationship that is significant for gas has essentially been carried to an extreme in the case of particulates resulting in a smoothing of the frequency dependence.

The absorption coefficient for particulates also depends on the thermodynamic state of each particle since this is related to the energy state of each molecule comprising the particle. However this dependence is negligible.

Thus the absorption coefficient for particulates in the medium is a function of frequency and particle density. The density dependence is expanded to include particulate size distribution, since larger particles will tend to absorb more radiation than a smaller particle. This is due simply to the larger cross-section presented to the incident radiation by larger particles.

If a photon encounters a molecule and the energy of the photon is such that the molecule cannot absorb it, then that photon will be scattered into a different direction as a result of the collision.

In the case of particulates the scattering phenomenon is complicated by the fact that when a photon encounters a particulate it encounters the surface molecules of the structure. Thus it is these molecules that determine the resulting motion of the photon. For example, a photon may encounter a surface molecule that scatters the photon toward a molecule on the same particulate that finally absorbs this photon.

As can be seen by this last example the mechanism that govern scattering can get quite complicated. However, scattering coefficients of molecules and particulates exhibit the same dependence characteristics as the absorption coefficients.

SECTION III

RADIATION MODEL

Given the tools developed in sections I & II it is now possible to formulate a mathematical model to analyze the transmission of thermal radiation through the earth's atmosphere. Such a model has been developed by C.S.U.N. in the form of a computer program. This section documents this computer program.

The model was designed to function under the following constraints. The radiation to be considered by the model is in the wavelength range from 0.25 um to 25 um. The region of the atmosphere to be considered extends from ground level to an altitude of 0.7 km above ground level with a maximum of 5 km above sea level.

The objective of the computer program is to evaluate equation (6) of section I. From the information presented in section II it can be concluded that the absorption and extinction coefficients will be a function of the local thermodynamic state of the atmosphere and the frequency of the incident radiation. In general the thermodynamic state of the atmosphere will vary in all directions, however, for this report it is assumed only to be a function of altitude measured vertically to the earth.

The atmosphere is composed of a large number of components. It is assumed that the total absorption coefficient of the atmosphere is the summation of the absorption coefficients of each of the components:

$$a_{TOT} = \sum_{i=1}^{n} a_i$$

This assumption is also made for the total scattering coefficient:

$$\alpha_{TOT} = \sum_{i=1}^{n} \alpha_i$$

This implies that the total extinction coefficient as defined in section I is:

$$\epsilon_{TOT} = \sum \epsilon_i$$

These assumptions lead to the following conclusions concerning τ_a and τ_ϵ as defined in section I.

$$\tau_{\epsilon TOT}(x, y) = \left[\tau_{\epsilon_1}(x,y)\right]\left[\tau_{\epsilon_2}(x,y)\right] \cdot \cdot \cdot \left[\tau_{\epsilon_n}(x,y)\right] \qquad (7a)$$

$$\tau_{a TOT}(x, y) = \left[\tau_{a_1}(x,y)\right]\left[\tau_{a_2}(x,y)\right] \cdot \cdot \cdot \left[\tau_{a_n}(x,y)\right] \qquad (7b)$$

Also, based on the above assumptions and definitions in section I, τ_{a_i} and τ_{ϵ_i} for atmospheric component i are functions of path length, the thermodynamic state of component i along that path length and the frequency of the incident radiation.

Thus if empirical data were obtained to establish functional relationships for τ_{a_i} and τ_{ϵ_i}, then these relationships and equation (6) would provide the desired result. This is exactly the approach that was taken in formulating the model developed at C.S.U.N.

Fortunately, the required empirical data has already been obtained for use in a computer program known LOWTRAN. This computer program was developed by the Geophysics Laboratory in Cambridge, Mass. The objective of LOWTRAN is to solve problems similar to the one considered in this report. The obvious question now arises as to why it was necessary to develop a new program?

The answer to this question lies in the fact that LOWTRAN was developed to handle problems more general than the one under consideration in this report. The consequence of this generality is complication. Thus by developing a new model and extracting the pertinent data from LOWTRAN as required, C.S.U.N. was able to develop a simpler computer program that was geared only to the problem at hand.

According to LOWTRAN documentation (reference 2), $\tau_{a_i}(x,y)$ and $\tau_{\epsilon_i}(x,y)$ may be expressed as follows:

$$\text{function}\left[C_{\nu_i}(\nu)\int_x^y w_i(h)\,ds\right] \tag{8}$$

where:

ν - frequency

C_{ν_i} - spectral coefficient for component i

h - altitude measured vertically from the ground

s - path (x to y)

ω_i - absorber or scattering amount of component i

There is an assumption that needs to be made in order to utilize the empirical data from LOWTRAN. The assumption is related to the fact that equation (6) from section I applies only for radiation of a discrete frequency. Unfortunately, it is virtually impossible to obtain the required empirical data at discrete frequencies. The data obtained for LOWTRAN was acquired by instruments that essentially obtained the average values of τ_a and τ_s over a narrow band of frequencies. Thus in order to utilize equation (6) the assumption must be made that this equation is also valid over a narrow band of frequencies.

LOWTRAN provided data for the following atmospheric components:

H_2O, O_2, CO_2, CH_4, N_2O, CO, O_3, N_2

and also five general categories of particulates (aerosols)

1. Maritime
2. Urban
3. Rural
4. Advection Fog
5. Radiation Fog

The components CO_2, CH_4, N_2O, CO, and O_2 were lumped as one component which is referred to as the uniformly mixed gases. The absorber amount for this component is given by:

$$\omega = \frac{P}{1013.0} \quad \frac{273.15}{T} \left[\frac{P}{1013.0} \sqrt{\frac{273.15}{T}} \right]^{0.75}$$

where:

P - local total pressure (mb)

T - local temperature (K°)

For incident radiation having a wavelength in the region of 4 um, N_2 molecules experiencing a collision provide a continuum of accessible energy states which are capable of absorbing radiation in this region. This effect is considered by the program and the absorber amount is given by:

$$W = 0.8 \left[\frac{P}{1013.0}\right]^{2} \left[\frac{273.15}{T}\right]^{3/2}$$

where:

P - local total pressure (mb)

T - local pressure (K°)

The atmospheric component H_2O is treated as three separate components in order to artificially account for three separate absorption characteristics. The first characteristic involves the standard type of gaseous absorption that was discussed in section II. The absorber amount for this component is given by:

$$W = 0.1 \; W_{H2} \left[\frac{P}{1013.0} \sqrt{\frac{273.15}{T}}\right]^{0.9}$$

where:

P - local total pressure (mb)

T - local temperature (K°)

W_{H2} - local density of H_2O (gm/m^3)

The other two absorption characteristics attributed to H_2O involve continuum absorption. The two continuums are in the wavelength regions of 3.5 um to 4.2 um and 8 vm to 11 um. Unfortunately, theoretical explanations for the existence of these two regions of continuum absorption does not presently exist. However they are accounted for, and the absorber amounts are calculated as follows:

8.0 um to 11.0 um

$$W = W_{HZ} \left\{ P_{H_2O} \; EXP \left[6.08 \left(\frac{296}{T} - 1 \right) \right] + 0.002 \left(P - P_{H_2O} \right) \right\}$$

where:

P_{H_2O} - local partial pressure of H_2O (atm.)

P - local total pressure (atm.)

T - local temperature (K)

W_{HZ} - local density of H_2O gm/cm - km

3.5 um to 4.2 um

$$W = W_{HZ} \left[P_{H_2O} + 0.12 \left(P - P_{H_2O} \right) \right] EXP \left[4.56 \left(\frac{296}{T} - 1 \right) \right]$$

where nomenclature and units are the same as 8.0 um to 11.0 um region.

The atmospheric component O_3 is treated as two separate components in order to artificially account for two separate absorption characteristics. The first O_3 component accounts for the standard type of gaseous absorption that was discussed in section II. This component will be referred to as Ozone I.R. Where the I.R. refers to infrared. The absorber amount is given as follows:

$$W = 46.67 \, W_{OZ} \left[\frac{P}{1013.0} \sqrt{\frac{273.15}{T}} \right]^{0.4}$$

where:

P - local total pressure (mb)

T - local temperature (K)

W_{OZ} - density of O_3 (gm/m)

The second O_3 component accounts for the absorption of photons by the electronic structure of the O_3 molecule. This type of absorption was not discussed in section II because it would have required a complete dissertation in Quantum Mechanics. Briefly, absorption at the electronic level of molecules is associated with high frequency incident radiation which is referred to as ultraviolet (U.V.) (1 um to 0.01 um). The absorber amount is given as follows:

$$W = 46.6667\ W_{oz}$$

where:

W_{oz} - density of O_3 (gm/m^3)

According to the LOWTRAN documentation, the total effect of scattering by the molecular atmospheric components discussed thus far can be lumped together. The scattering amount is given as follows:

$$W = \frac{P}{1013.0} \ \frac{273.15}{T}$$

where:

P - local total pressure (mb)

T - local temperature (K°)

The spectral coefficients for each of the attenuation components discussed thus far are presented in figure 4 to figure 11. In these figures the independent spectral quantity is the wave number (η) and it is defined as follows:

$$\eta = 1.0/\lambda$$

where λ is the wavelength. Thus a wave number of $\eta\ cm^{-1}$ is equivalent

FIGURE 4
UNIFORMILY MIXED GASES

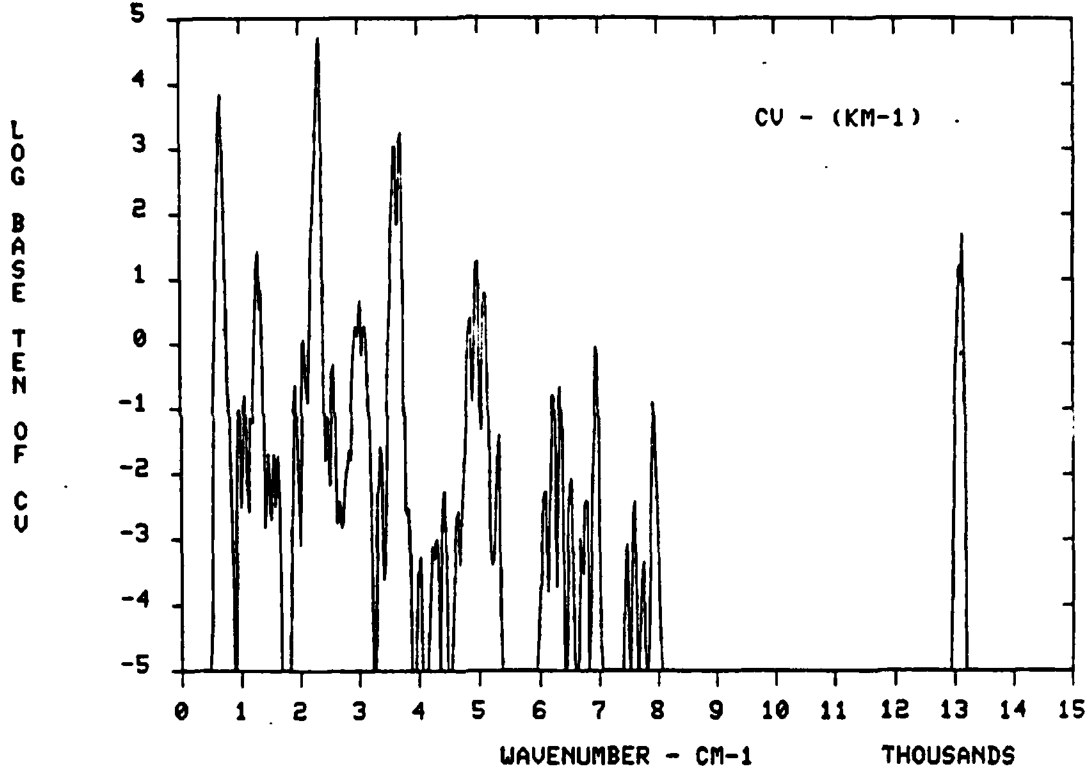


FIGURE 5
NITROGEN CONTINUUM (4 UM)

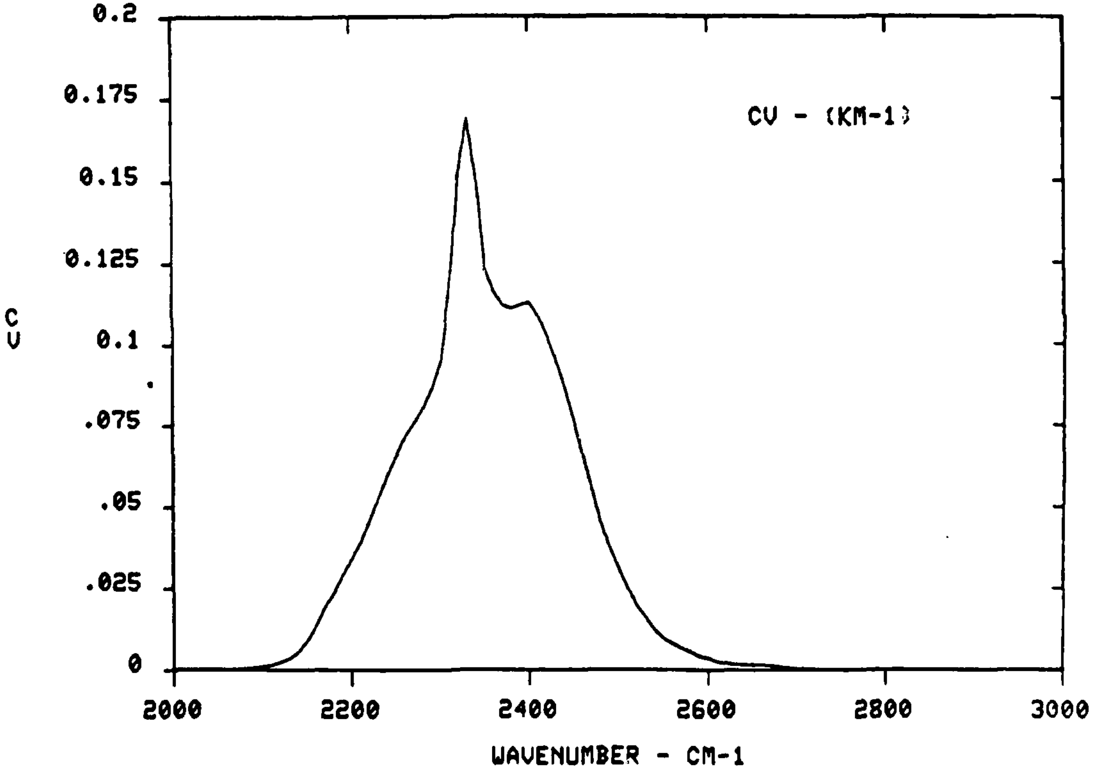


FIGURE 6
H2O GAS

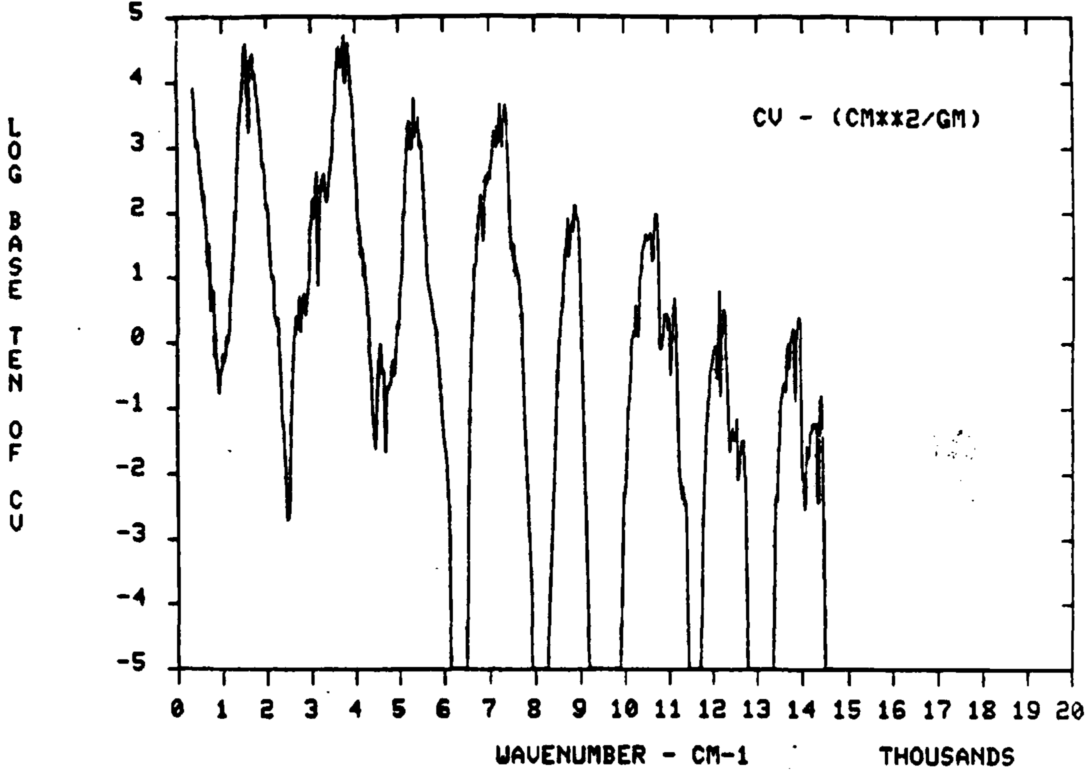


FIGURE 7
H2O CONTINUUM (8 UM TO 11 UM)

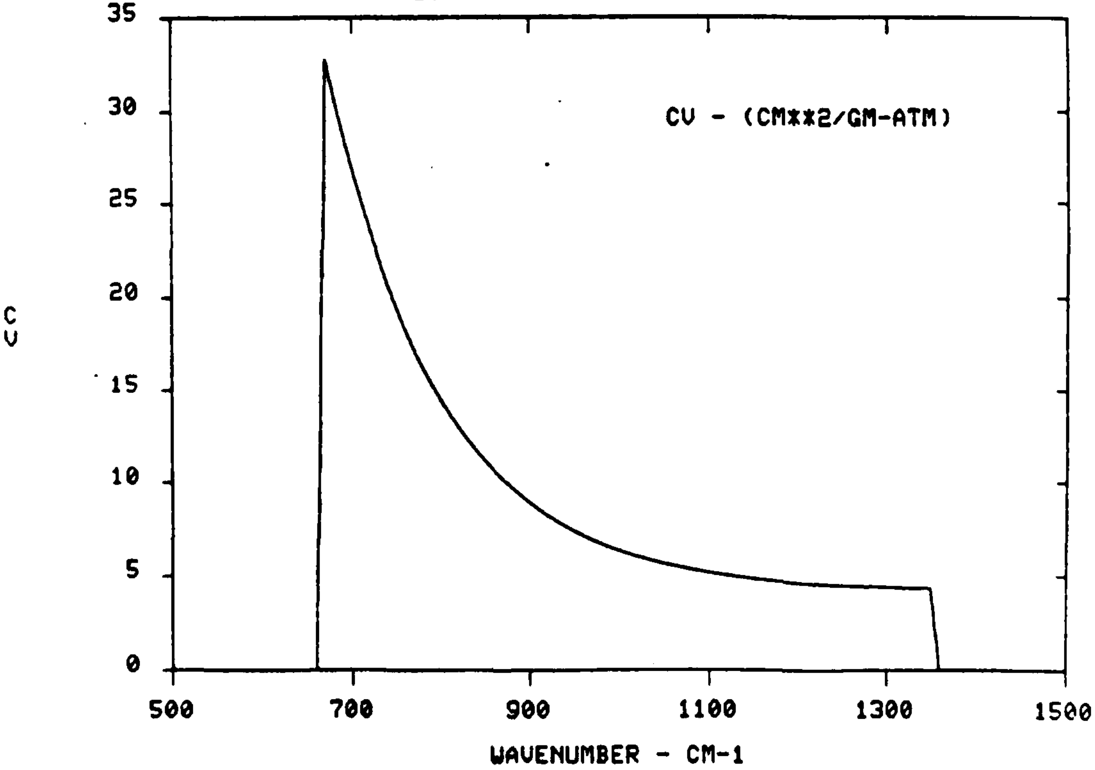


FIGURE 8
H2O CONTINUUM (3.5 UM TO 4.2 UM)

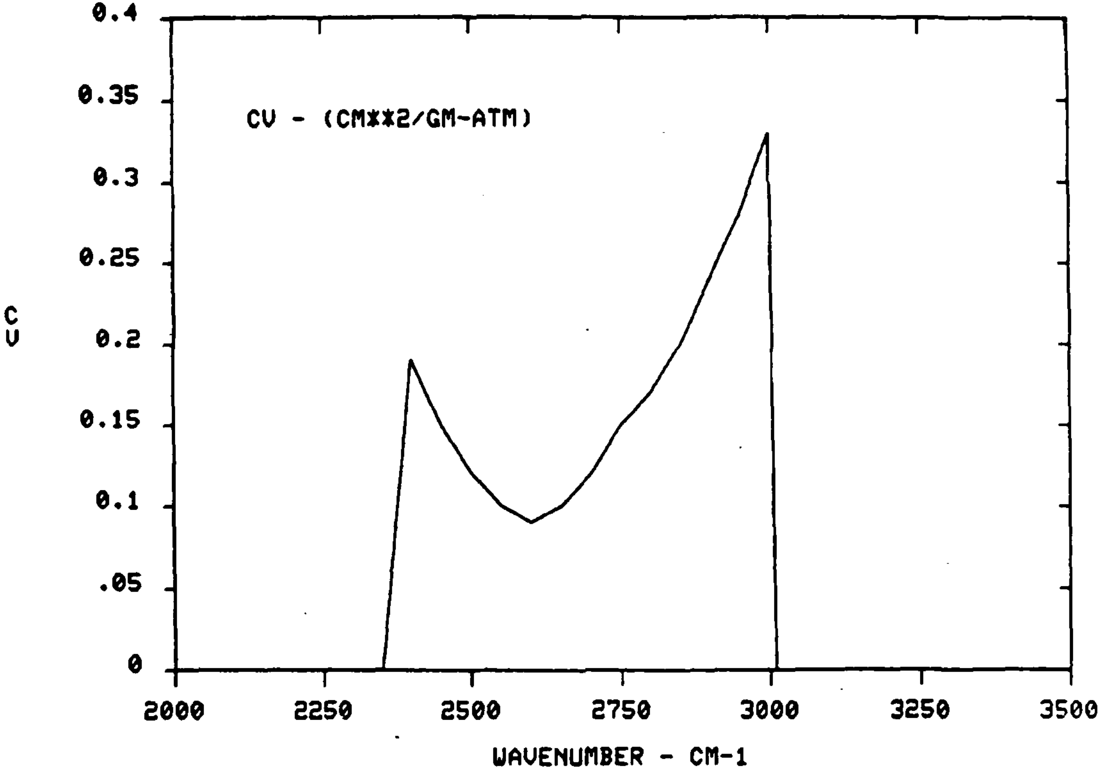


FIGURE 9
OZONE I.R. REGION

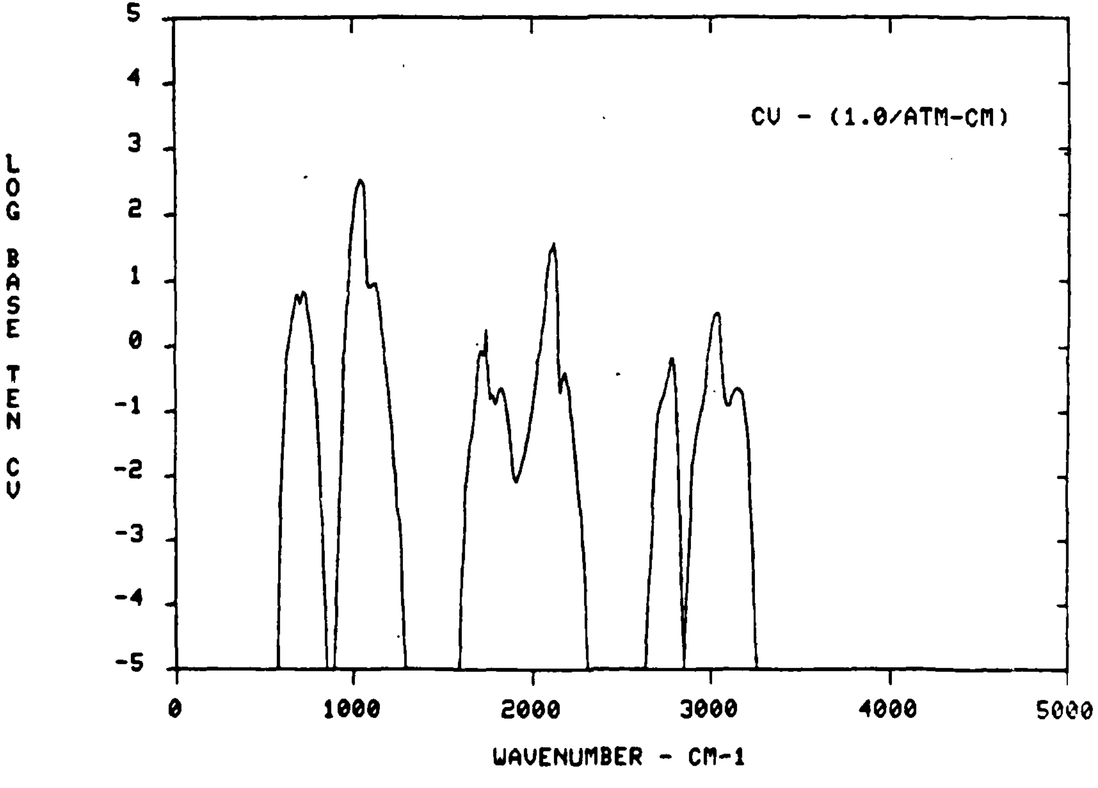


FIGURE 10
OZONE U.V. REGION

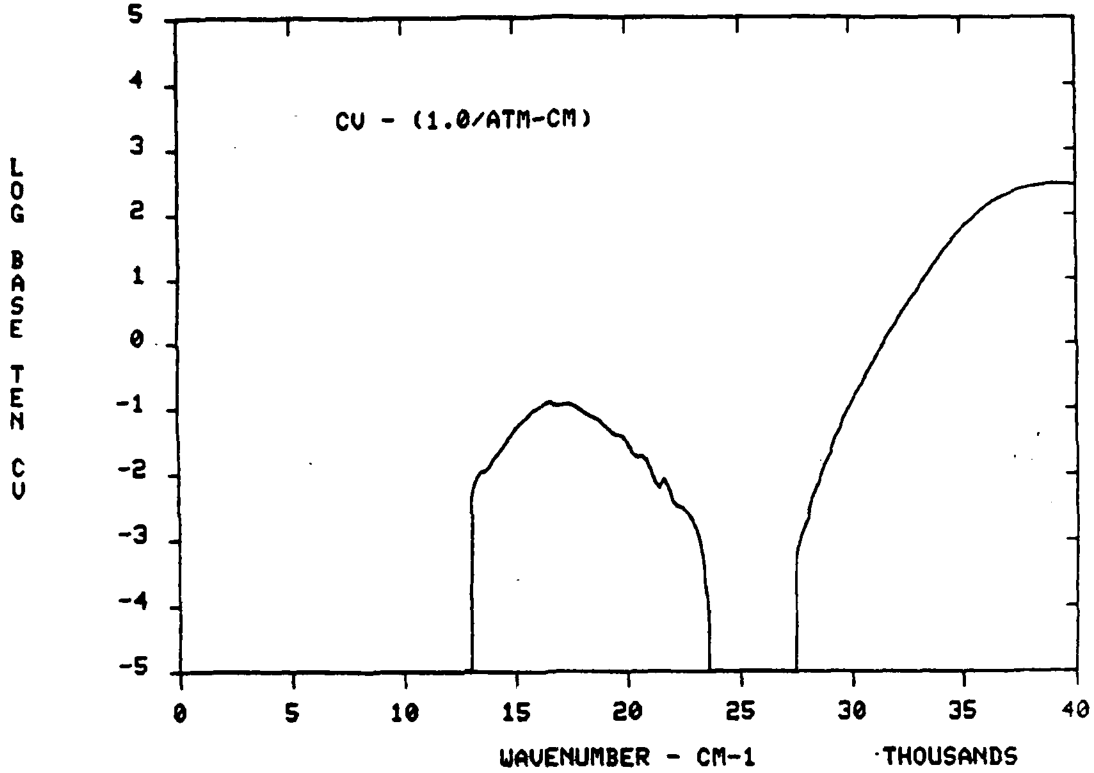
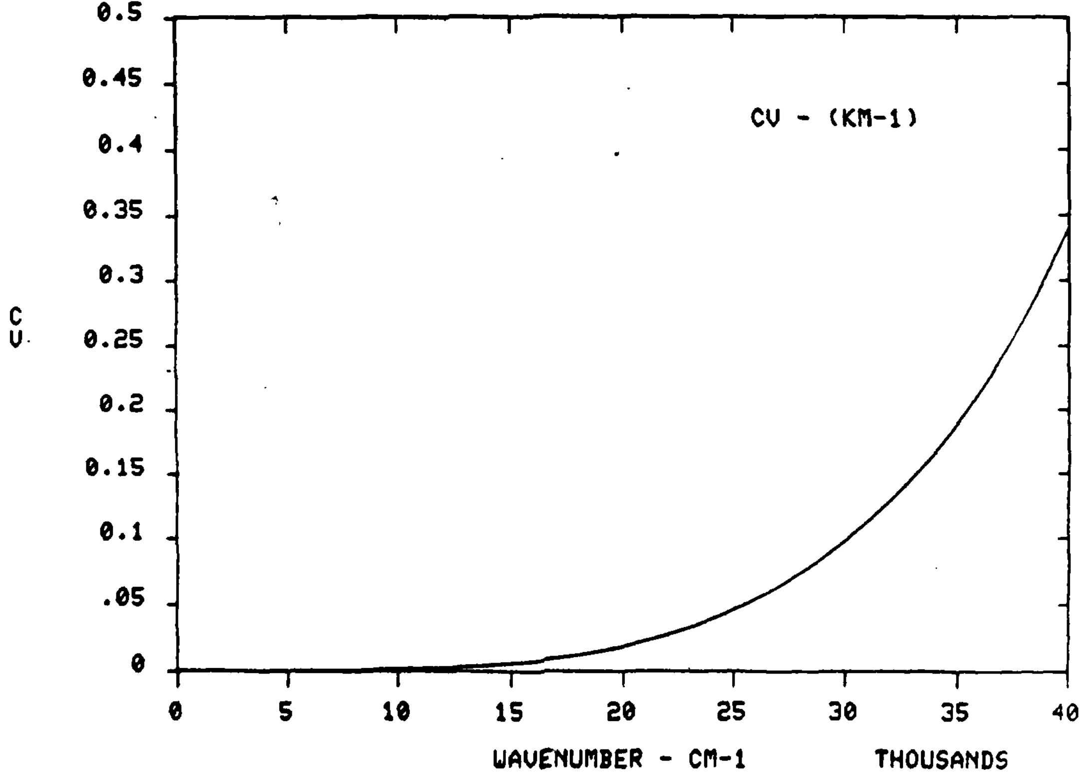


FIGURE 11
MOLECULAR SCATTERING



to a wavelength of:

$$\lambda = \frac{10^4}{\eta} \text{ um}$$

It is worthwhile to note that all of the thermodynamic properties required to evaluate each W_i are functions of h. Thus each W_i is a function of h.

As was mentioned earlier, LOWTRAN provided empirical data for five general categories of particulates (aerosols). They are as follows:

1. Maritime
2. Urban
3. Rural
4. Advection Fog
5. Radiation Fog

The Maritine category applies to oceanic regions and coast line areas. The particulates result from sea salt particles which are produced by the evaporation of sea spray droplets.

The Urban category applies to industrial and urban areas where the majority of particulates result from combustion processes.

The Rural category is intended to represent the aerosol conditions found in continental areas which are not directly influenced by urban particulate sources.

When the air becomes nearly saturated with water vapor, fog can form. Saturation of the air can occur as a result of two different processes; the mixing of air masses with different temperatures (advection fog) or by cooling of the air to the point where the temperature approaches the dew point (radiation fog). It should be mentioned that a cloud cover is nothing more than a fog that does not contact the ground.

Based on the information presented in section II, the extinction and absorption coefficients for particulates are a function of particulate concentration, size distribution and frequency of incident radiation. The spectral and size distribution data was obtained from LOWTRAN for the five categories of particulates. This data is presented in figure 15 through figure 24. The particle size distribution for each of the five categories of particulates was obtained empirically. It only remains to account for variations in particulate concentration. Note that in each case the data has been normalized such that the extinction coefficient is one at a wavelength of 0.55 um. The reason is to incorporate the particulate concentration utilizing a quantity called the Meterological Range (V). The quantity V is the distance required for the radiant intensity of some source to drop to 2% of the original source intensity at a wavelength of 0.55 um. If the source intensity is such that emission by the particulates is negligable, then

$$\tau_\varepsilon(0,V) = 0.02 = e^{-VB}$$

or

$$B = \frac{3.912}{V}$$

where

B - particulate extinction coefficient at 0.55 um (km^{-1}).

The obvious question arises as to the effect of other atmospheric components on B. The answer lies in the specified wavelength of 0.55 um, which is approximately equal to a wave number of 18000 cm^{-1}.

By reviewing figure 4 through figure 11 it can be seen that the only atmospheric components affecting $\tau_\epsilon(0,V)$ at 0.55 um are O_3 and molecular scattering. The concentration of O_3 at low altitudes is virtually negligible. It was only considered in this model for completeness. Also the effect of molecular scattering at 0.55 um is negligible. Thus the quantity V depends on the particulate concentration.

The reason for normalizing the particulate data to an extinction coefficient of one at 0.55 um should now be obvious. By measuring or estimating a value of V and selecting the appropriate particulate category, the extinction and absorption coefficients at any other wavelength may be calculated as follows:

$$a_i = \frac{3.912}{V} C_{\sigma a_i}(\lambda, \omega_{Hz})$$

$$\epsilon_i = \frac{3.912}{V} C_{\sigma \epsilon_i}(\lambda, \omega_{Hz})$$

where:

λ - wavelength

ω_{Hz} - H_2O density

V - meterological range

$C_{\sigma a}$ and $C_{\sigma\epsilon}$ are presented in figure 15 through figure 24.

Note that $C_{\sigma a}$ and $C_{\sigma\epsilon}$ are functions of the H_2O density. This is shown in the figures by relative humidity. The reason for this functional relationship is that the H_2O molecules tend to accrete to

FIGURE 15
MARITIME PARTICULATE

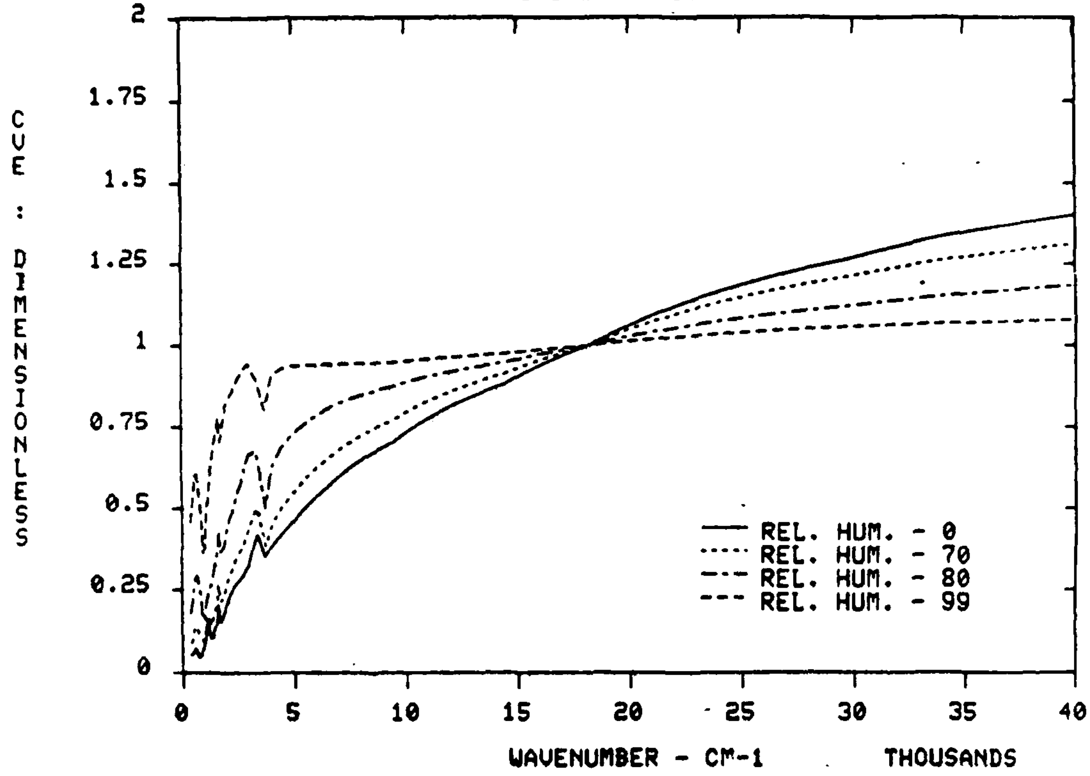


FIGURE 16
MARITIME PARTICULATE

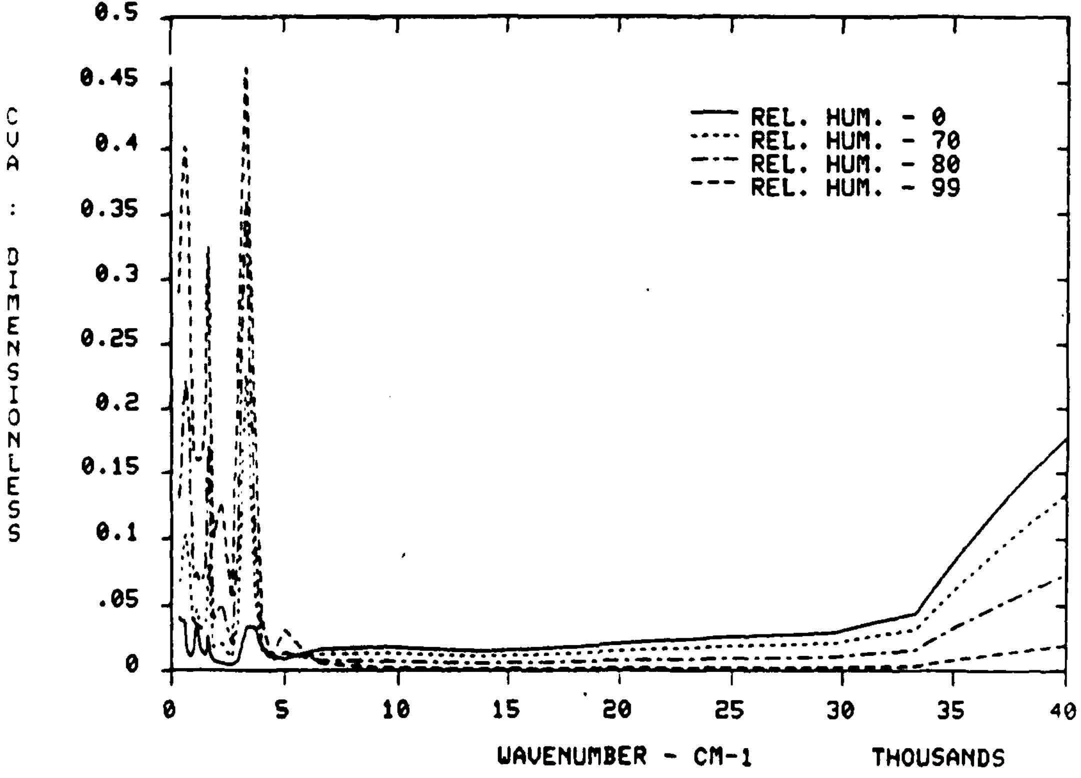


FIGURE 17
URBAN PARTICULATE

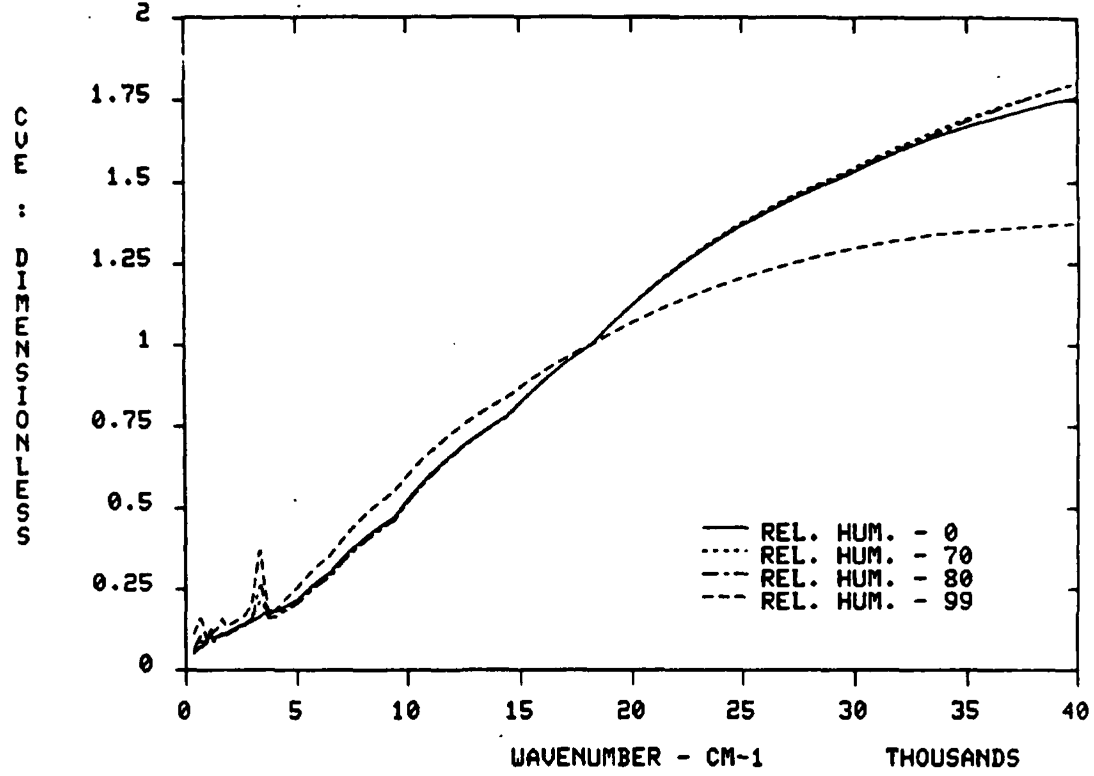


FIGURE 18
URBAN PARTICULATE

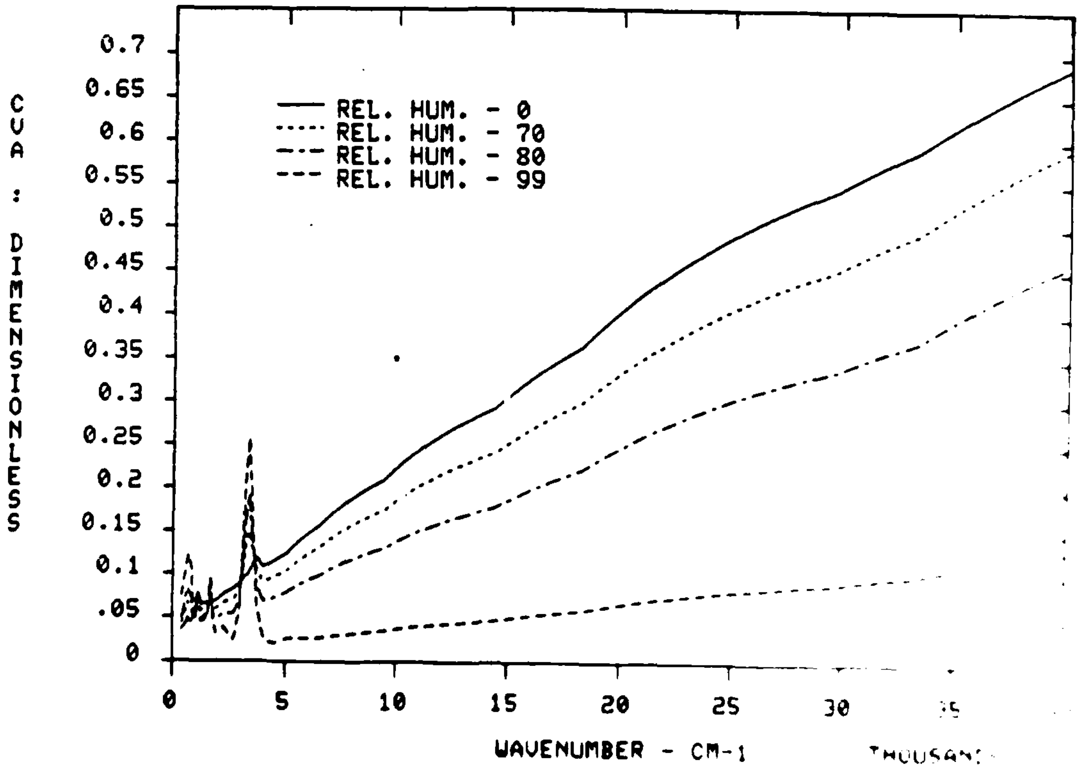


FIGURE 19
RURAL PARTICULATE

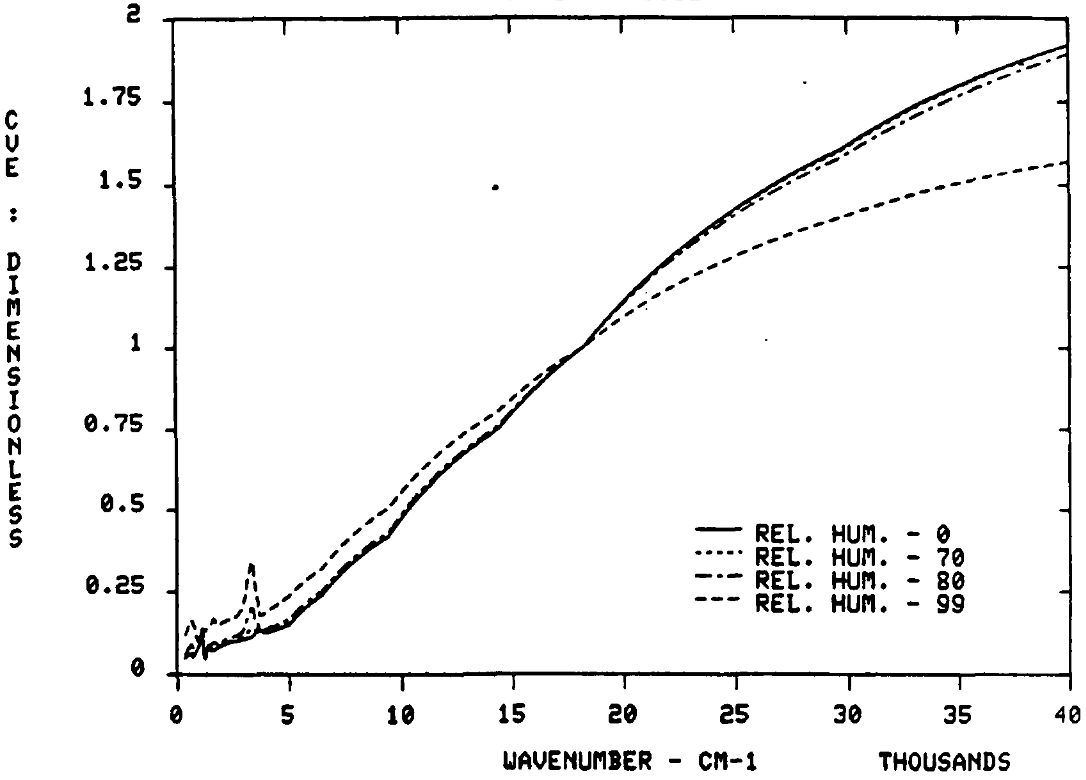


FIGURE 20
RURAL PARTICULATE

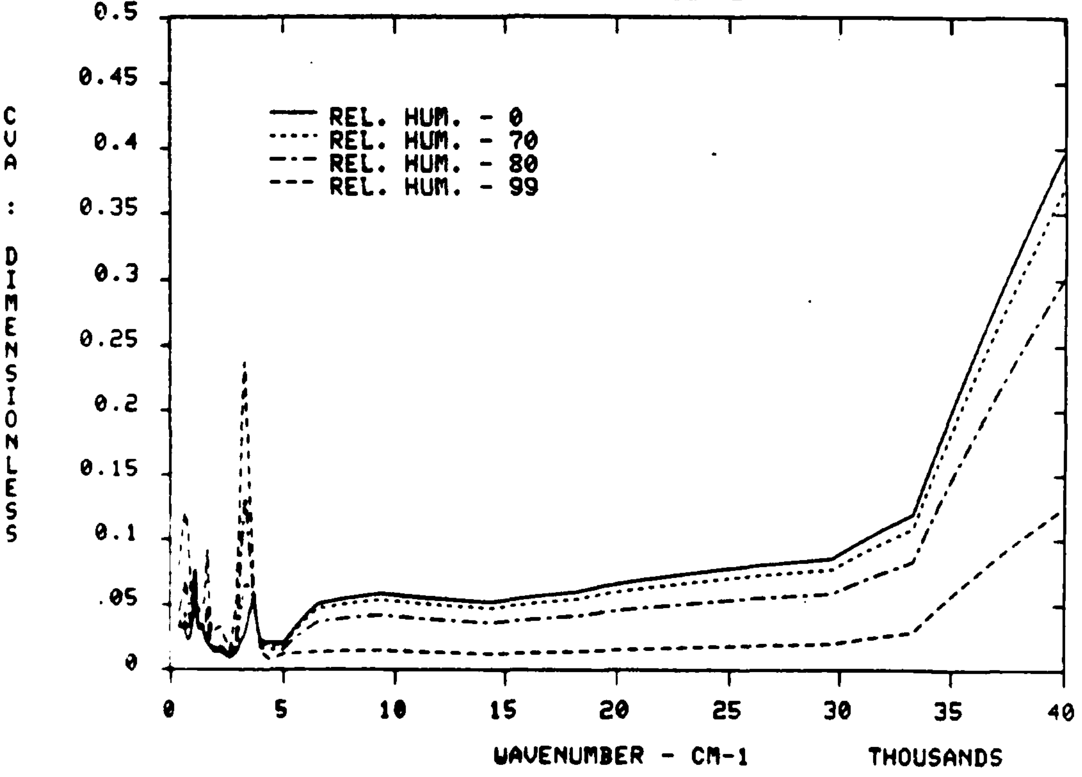


FIGURE 21
ADVECTION FOG

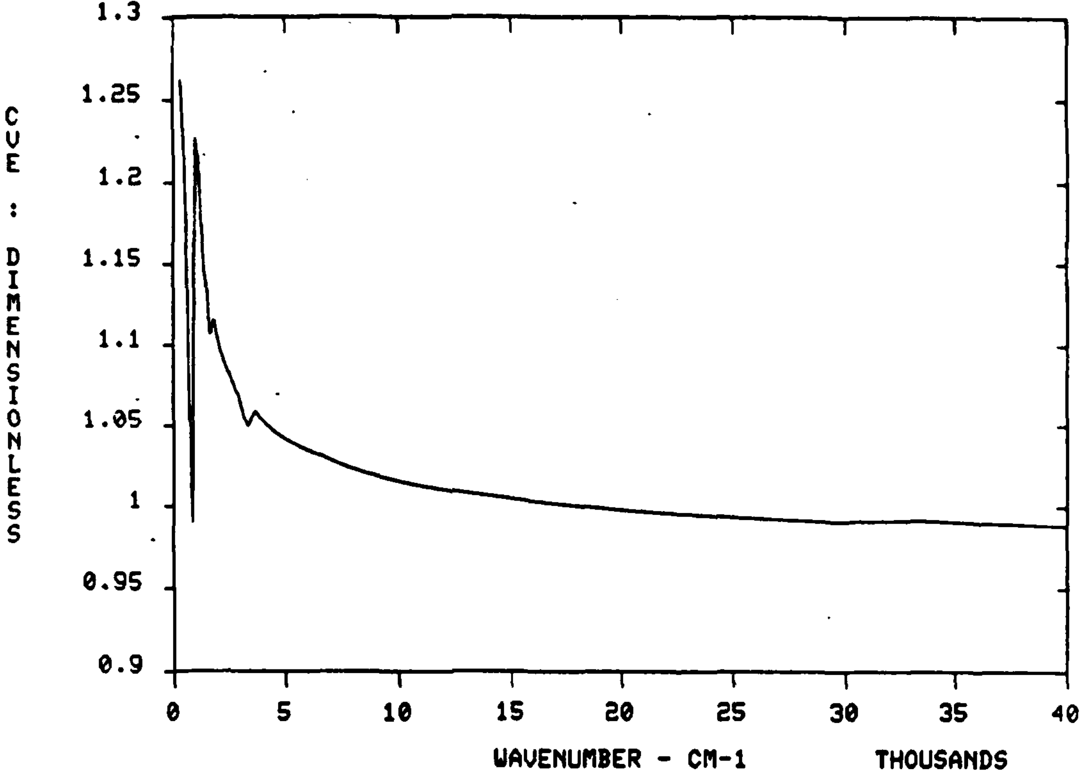


FIGURE 22
ADVECTION FOG

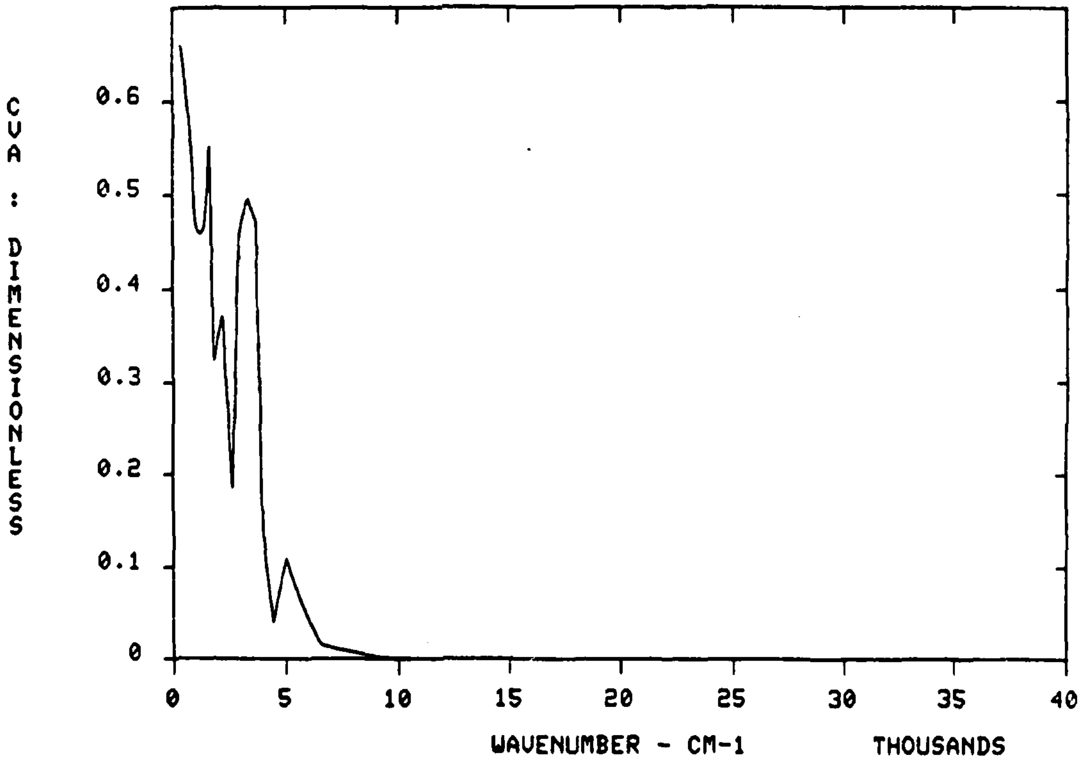


FIGURE 23
RADIATION FOG

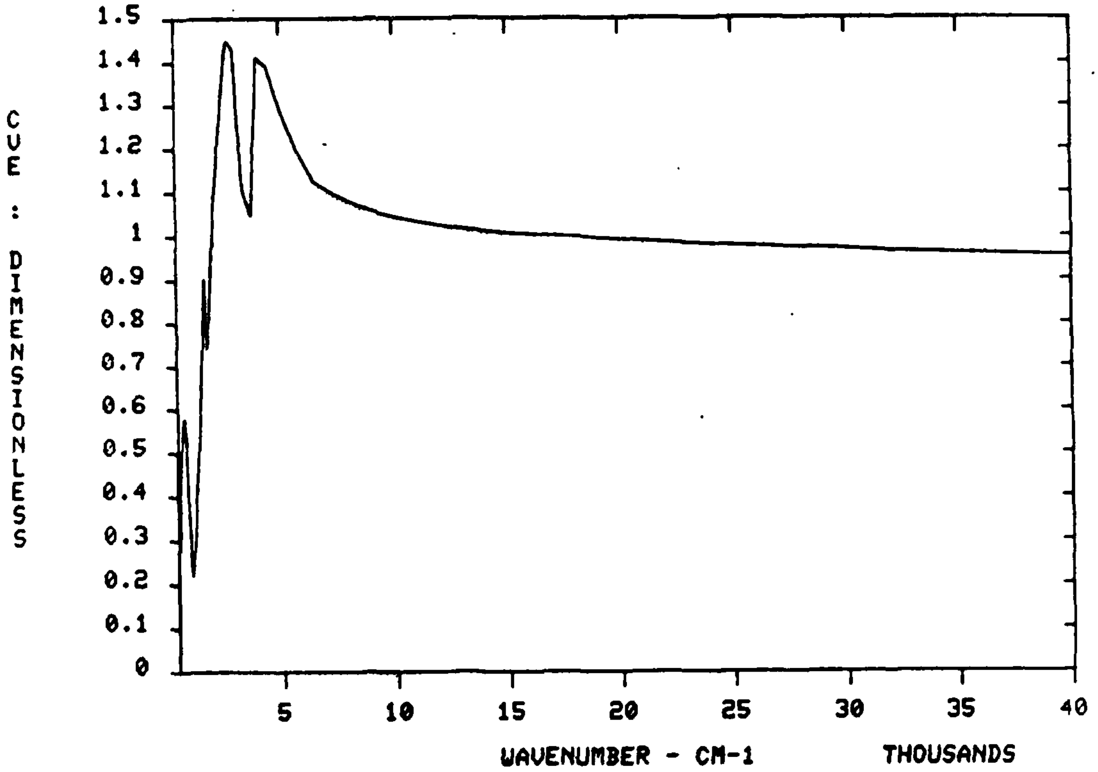
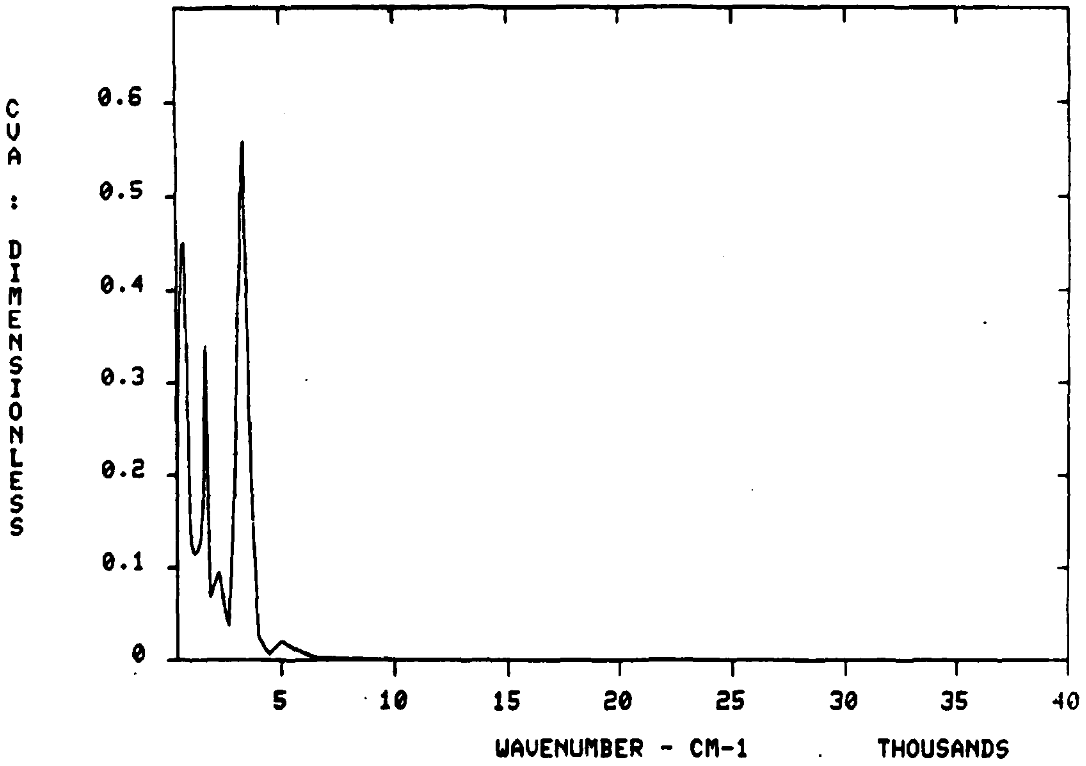


FIGURE 24
RADIATION FOG



the surface of the particulates. Thus the incident photons encounter H_2O molecules. The higher W_{HZ} the more accretion takes place.

It is worth mentioning some more information about the fog models. For thick fogs (clouds) where V is less than 200m the extinction coefficient is virtually independent of wavelength. These conditions are modeled best by the advection fog. For moderate fogs 200 m $< V <$ 1000 m the radiation fog should be used. For thin fogs, 1 km $< V <$ 2 km a maritine, urban or rural particulate model should be used with a 99% relative humidity.

Utilizing equation 4b from section I and the above equations for the particulate absorption and extinction coefficient, $\tau_a(x,y)$ and $\tau_\epsilon(x,y)$ for a particulate atmospheric component may be expressed as follows:

$$\text{function}\left[\int_x^y C_{\nu i}(\nu, W_{HZ})\; W_i(h)\, ds\right]$$

where

$$W_i(h) = \frac{3.912}{V}$$

W_{HZ} - shows the dependence of the spectral coefficient on the H_2O density (relative humidity)

ν - frequency

$C_{\nu i}(\nu, W_{HZ})$ - from figure 14 through figure 24. (extinction and absorption)

h - altitude

The spectral coefficient for a particulate atmospheric component is part of the integrand due to its dependence on H_2O density which is dependent of h. This is in contrast to the equivalent expression for molecular atmospheric components (see equation 8). The above equation can be placed in the same form as equation 8 by evaluating the spectral coefficient at the average H_2O density between x and y. Then $\tau_{a_i}(x,y)$ and $\tau_{\epsilon_i}(x,y)$ for the particulate atmospheric component may be expressed as follows:

$$\text{function}\left[C\nu_i(\nu, \overline{W_{HZ}})\int_x^y W_i(h)\,ds\right] \tag{9}$$

where

$$\overline{W_{HZ}} = \frac{W_{HZ}(x) + W_{HZ}(y)}{2}$$

Based on the data presented thus far in this section it is now possible to evaluate the following term for each of the atmospheric components

$$K_i = C\nu_i(\nu)\int_x^y W_i(h)\,ds$$

All that remains is to know the functional relationship between $\tau_{\epsilon_i}(x,y)$, $\tau_{a_i}(x,y)$, and K_i.

For the Uniformily Mixed Gases

$$\tau_\epsilon = \tau_a = EXP\left[-0.0689\,K^{0.555}\right] \tag{10}$$

For the Nitrogen Continuum

$$\tau_\epsilon = \tau_a = EXP\left[-K\right] \tag{11}$$

For the H_2O

$$\tau_\epsilon = \tau_a = EXP\left[-0.0689\,K^{0.555}\right] \tag{12}$$

For the H_2O Continuum (8.0 um to 11.0 um)

$$\tau_\epsilon = \tau_a = EXP\left[-K\right] \tag{13}$$

For the H_2O Continuum (3.5 um to 4.2 um)

$$\tau_\epsilon = \tau_a = EXP\left[-K\right] \tag{14}$$

For the O_3 I.R. Region

$$\tau_\epsilon = \tau_a = EXP\left[-0.0643\ K^{0.666}\right] \tag{15}$$

For the O_3 U.V. Region

$$\tau_\epsilon = \tau_a = EXP\left[-K\right] \tag{16}$$

For Molecular Scattering

$$\tau_\epsilon = EXP\left[-K\right] \tag{17}$$

$$\tau_a = 0.0 \tag{18}$$

For Particulates

$$\tau_\epsilon = EXP\left[-K_\epsilon\right] \tag{19}$$

$$\tau_a = EXP\left[-K_a\right] \tag{20}$$

Note that for a particulate component there are two values for K where K_a is obtained by evaluating equation (9) for absorption and K_ϵ is obtained by evaluating equation (9) for extinction.

Consider the situation depicted in figure 25, where

h_1 - altitude of point x

h_2 - altitude of point y

$T(h_1)$ - temperature at h_1

$T(h_2)$ - temperature at h_2

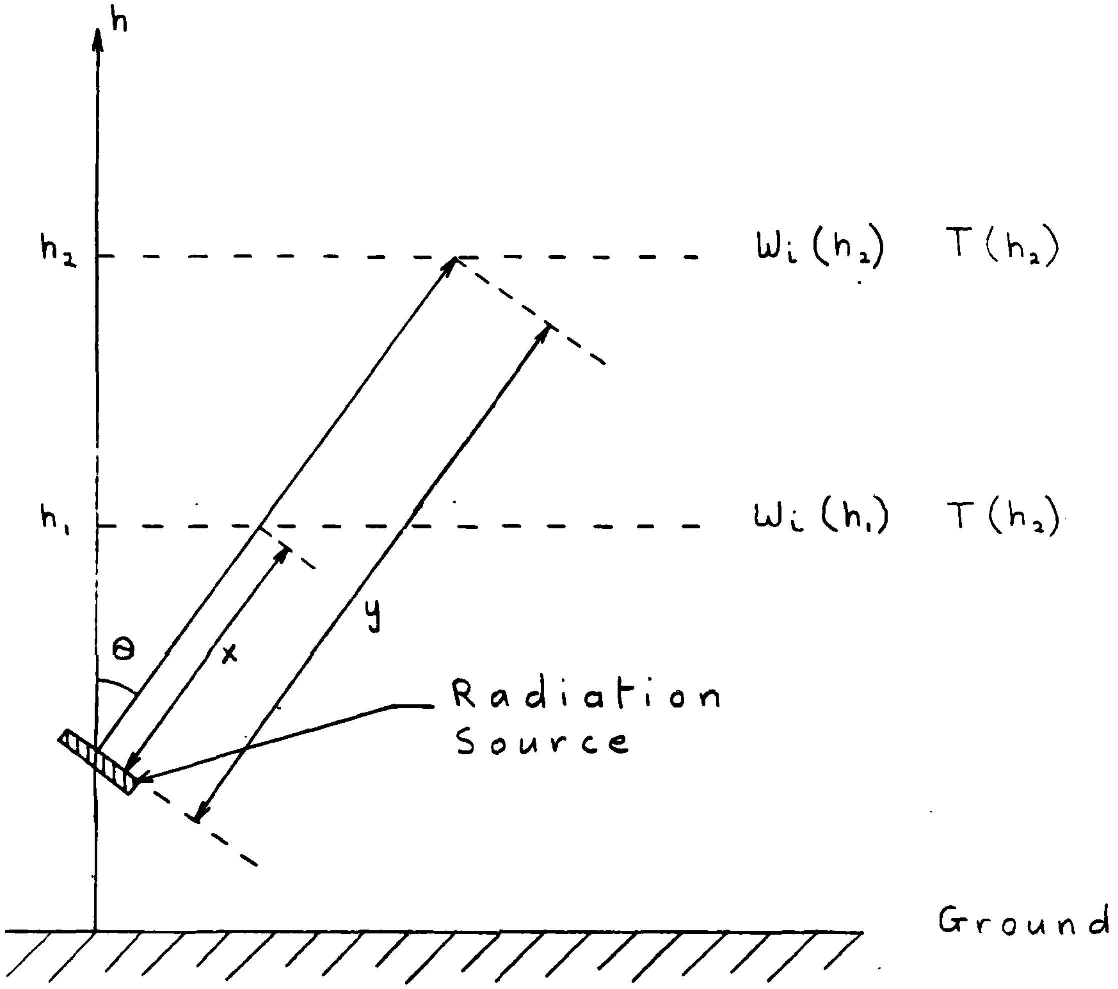
$W_i(h_1)$ - absorber amount of component i at h_1

$W_i(h_2)$ - absorber amount of component i at h_2

thus

$$ds = \frac{dh}{\cos\theta}$$

FIGURE 25
Sample Configuration



and

$$C_{v_i}(v)\int_x^y W_i(h)\,ds = \frac{C_{v_i}(v)}{\cos\theta}\int_x^y W_i(h)\,dh$$

assume that $W_i(h)$ is a semi-log function of altitude, then

$$W_i(h) = W_i(h_1)\left[\frac{W_i(h_2)}{W_i(h_1)}\right]^{\frac{h-h_1}{h_2-h_1}}$$

$$C_{v_i}(v)\int_x^y W_i(h)\,dh = \frac{\left[W_i(h_2) - W_i(h_1)\right]\left[y - x\right]\ C_{v_i}(v)}{\log_e\left[\frac{W_i(h_2)}{W_i(h_1)}\right]}$$

as $h_1 \rightarrow h_2$

$$C_{v_i}(v)\int_x^y W_i(h)\,dh \longrightarrow W_i(h_1)\left[y - x\right]\ C_{v_i}(v)$$

from the last two expressions and equations (10) through (20) it is possible to evaluate equations (7a) and (7b) for $\tau_{e_{TOT}}(x,y)$ and $\tau_{a_{TOT}}(x,y)$. Thus equation (6) of section I can now be evaluated where $T(h_1)$ and $T(h_2)$ would be used in the black body function. The quantity n for the numerical analogue of the emission integral in equation (6) would be 2 for this particular example, and also note that in general.

$$\tau_{\epsilon_{TOT}}(y,y) = 1.0$$

$$\tau_{a_{TOT}}(y,y) = 1.0$$

The above has been a simplified example of how the computer program operates. This example is simplified in the sense that only two points were used to evaluate the numerical analogue of the emission integral. The actual computer program will use more points. A listing of the computer program is presented in Appendix A. The program is well commented with intent of being self-documenting.

SECTION IV

USERS GUIDE

Sections I, II, and III provide the theoretical basis for the computer program LARTAP. The objective of this section is to provide the user with a guide of how to use the current version of LARTAP. The word, current, is significant because one of the major guidelines utilized during the development of LARTAP was that the program be simple. The objective of this simplicity was to allow for easy modification. Thus, the program may be tailored with little effort to accommodate any project that requires the analysis of low altitude radiation transmission.

In order to use LARTAP the user must place the required program inputs in a disk file. This is accomplished by utilizing the editor on the user's computer. The disk file must be named DATA. On each line of the file the user must specify the numerical data as presented in the following paragraphs. The program utilizes free format read statements. Thus each numerical value must be followed by a comma except for the last piece of data on a line.

On line 1 of the file DATA, 3 values must be specified, as follows:

MODEL, GRASL, NPTS

MODEL - An integer that determines the default atmospheric thermodynamic data to be used if the user desires. The uses of MODEL will become apparent when one enters the data for line 3. The possible value of MODEL are:

MODEL	Default Atmospheric Model
1	Tropical
2	Midlatitude Summer
3	Midlatitude Winter
4	Subarctic Summer
5	Subarctic Winter
6	1962 U.S. Standard

Further documentation of these atmospheric models can be found in reference 2.

GRASL - A real number that specifies the local ground altitude measured relative to sea level in kilometers.

NPTS - An integer that specifies the number of points to be entered after, and including, line 3 to define the thermodynamic state of the atmosphere as a function of altitude. Note the larger NPTS, the more accurate the results given by LARTAP. A good value for NPTS would be 10.

On line 2 of the file DATA, 3 values must be specified, as follows:

HI, SMAX, ANGLE

HI - A real number that specifies the altitude of the radiative source measured relative to the local ground altitude (GRASL) in kilometers.

SMAX - A real number that specifies the distance from the source to the observer along a straight line between the source and the observer, in kilometers.

ANGLE - A real number that specifies the angle between a vertical line and the line between the source and the observer, in degrees. This variable is represented in Figure 25 of Section III by the angle θ.

On line 3 through line 3+NPTS the user specifies the thermodynamic state of the atmosphere as a function of altitude. On each of these lines, the user must specify the following data:

ZGR, P, T, RH, WO, VIS, IHA

ZGR - A real number that specifies the altitude, in kilometers, relative to ground level at which the rest of the data on the line is measured.

P - A real number that specifies the total atmospheric pressure, in millibars, at altitude ZGR. A value of -1000. will cause a use of default data as specified by the value of MODEL.

T - A real number that specifies the atmospheric temperature, in degrees C, at altitude ZGR. A value of -1000. will cause a use of default data as specified by the value of MODEL.

RH - A real number that specifies the relative humidity of the atmosphere, in percent, at altitude of ZGR. A value of -1000.

will cause a use of default data as specified by the value of MODEL.

WO - A real number that specifies the density of ozone in the atmosphere, in grams per cubic meter, at altitude ZGR. A value of -1000. will cause a use of default data as specified by the value of MODEL.

VIS - A real number that specifies the value of the meterological range, in kilometers, at altitude ZGR. A value of -1000. will cause a use of default value as specified by the value of IHA.

IHA - An integer that specifies the type of particulate in the atmosphere region between ZGR and the next specified altitude above ZGR. The possible values of IHA are as follows:

IHA	Type
0	No particulates present
1	Rural with a default meterological range of 23 km
2	Rural with a default meterological range of 5 km
3	Maritime with a default meterological range of 23 km
4	Maritime with a default meterological range of 5 km
5	Urban with a default meterological range of 5 km
8	Advection Fog with a default meterological range of 0.5 km
9	Radiation Fog with a default meterological range of 0.5 km

The Rural type is intended to represent the particulate conditions found in continental areas which are not directly influenced by urban particulate sources.

The Maritime type applies to oceanic regions and coast line areas. The particulates result from sea-salt particles, [illegible] produced by the evaporation of sea-spray droplets.

The Urban type applies to industrial and urban areas where the majority of particulates result from combustion processes.

When the atmosphere becomes nearly saturated with water vapor, fog can form. Saturation of the air can occur as a result of two different processes; the mixing of air masses with different temperatures (advection fog) or by cooling of the air to the point where its temperature approaches the dew-point (radiation fog).

For thick fogs where V is less than 200m the extinction coefficient is virtually independent of wave length. These conditions are modeled best by the advection fog. For moderate fogs, 200m V 1000m, the radiation fog should be used. For thin fogs, 1km V 2km, a maritime, urban or rural particulate model should be used with a 99% relative humidity.

It should be mentioned that a cloud is nothing more than a thick fog that does not contact the ground.

Since the density of ozone at low altitudes is quite low it is suggested that no special effort be undertaken to measure ozone density. However, for completeness, it is recommended that ozone be included utilizing one of the program default model capabilities.

In order for LARTAP to operate correctly, NPTS must have a value of at least two. This means that the thermodynamic state of the atmosphere must be specified at a minimum of two altitudes, (two values of ZGR). These two altitudes have to bound the atmospheric region of interest. For example ZGR = 0.0 and ZGR = 0.7 where 0.0 represents the minimum altitude of interest relative to ground level [illegible] represents the maximum altitude of interest relative to ground level.

The output from the current version of LARTAP is in the form of three disk files. The names of the disk files are WAVN, TRAS, and RADA. The file WAVN contains the wave numbers for the spectral region studied by LARTAP. WAVN contains one wave number on each line of the file. The file TRAS contains the transmittance for the atmospheric configuration specified in DATA. TRAS contains one value of transmittance on each line. The value of transmittance on a particular line of TRAS corresponds to the wave number on the same line in WAVN. The file RADA contains the intensity of radiation emitted by the atmosphere between the source and the observer for the atmospheric configuration specified in DATA. The value of emitted intensity on a particular line in RADA corresponds to the wave number on the same line in WAVN.

The spectral region studied by the current version of LARTAP is from a wave number of 350 cm to a wave number of 40,000 cm in increments of 10 cm .

In table I, five sample input data files are presented. Each of the five sample data files shown in table I is preceded by a title indicating the values of HI, SMAX, and ANGLE for that particular data file. These titles are not part of the data files. LARTAP output for these five sample data files is presented graphically in figure 26 through figure 40.

The program also requires seven other input data files. These files are not controlled by the user. They supply the necessary spectral data that was discussed in section III. The reasons for storing this spectral data in files is as follows.

In order to facilitate this possible conversion of this program to a micro-computer for use in the field, it was determined that the large spectral data based would have to be stored in peripheral equipment. Thus these seven spectral data files were incorporated to emulate such peripheral equipment.

TABLE 1 - SAMPLE DATA FILES

H1=1.0 KM SMAX=1.0 KM ANGLE=0 DEGREES

```
1,0.000,5
1.0,1.0,0.000
0.000, -1000.0, -1000.0, -1000.0, -1000.0, -1000.0, 0
0.500, -1000.0, -1000.0, -1000.0, -1000.0, -1000.0, 0
1.000, -1000.0, -1000.0, -1000.0, -1000.0, -1000.0, 0
1.500, -1000.0, -1000.0, -1000.0, -1000.0, -1000.0, 0
2.000, -1000.0, -1000.0, -1000.0, -1000.0, -1000.0, 0
```

H1=1.0 KM SMAX=1.0 KM ANGLE=60 DEGREES

```
1,0.000,5
1.0,1.0,60.000
0.000, -1000.0, -1000.0, -1000.0, -1000.0, -1000.0, 0
0.500, -1000.0, -1000.0, -1000.0, -1000.0, -1000.0, 0
1.000, -1000.0, -1000.0, -1000.0, -1000.0, -1000.0, 0
1.500, -1000.0, -1000.0, -1000.0, -1000.0, -1000.0, 0
2.000, -1000.0, -1000.0, -1000.0, -1000.0, -1000.0, 0
```

H1=1.0 KM SMAX=1.0 KM ANGLE=90 DEGREES

```
1,0.000,5
1.0,1.0,90.000
0.000, -1000.0, -1000.0, -1000.0, -1000.0, -1000.0, 0
0.500, -1000.0, -1000.0, -1000.0, -1000.0, -1000.0, 0
1.000, -1000.0, -1000.0, -1000.0, -1000.0, -1000.0, 0
1.500, -1000.0, -1000.0, -1000.0, -1000.0, -1000.0, 0
2.000, -1000.0, -1000.0, -1000.0, -1000.0, -1000.0, 0
```

H1=1.0 KM SMAX=1.0 KM ANGLE=120 DEGREES

```
1,0.000,5
1.0,1.0,120.000
0.000, -1000.0, -1000.0, -1000.0, -1000.0, -1000.0, 0
0.500, -1000.0, -1000.0, -1000.0, -1000.0, -1000.0, 0
1.000, -1000.0, -1000.0, -1000.0, -1000.0, -1000.0, 0
1.500, -1000.0, -1000.0, -1000.0, -1000.0, -1000.0, 0
2.000, -1000.0, -1000.0, -1000.0, -1000.0, -1000.0, 0
```

TABLE 1 (CONTINUED)

H1=1.0 KM SMAX=1.0 KM ANGLE=180 DEGREES

```
1,0.000,5
1.0,1.0,180.000
0.000, -1000.0, -1000.0, -1000.0, -1000.0, -1000.0, 0
0.500, -1000.0, -1000.0, -1000.0, -1000.0, -1000.0, 0
1.000, -1000.0, -1000.0, -1000.0, -1000.0, -1000.0, 0
1.500, -1000.0, -1000.0, -1000.0, -1000.0, -1000.0, 0
2.000, -1000.0, -1000.0, -1000.0, -1000.0, -1000.0, 0
```

FIGURE 26
H1=1 KM RANGE=1 KM ANGLE=0 DEGREES

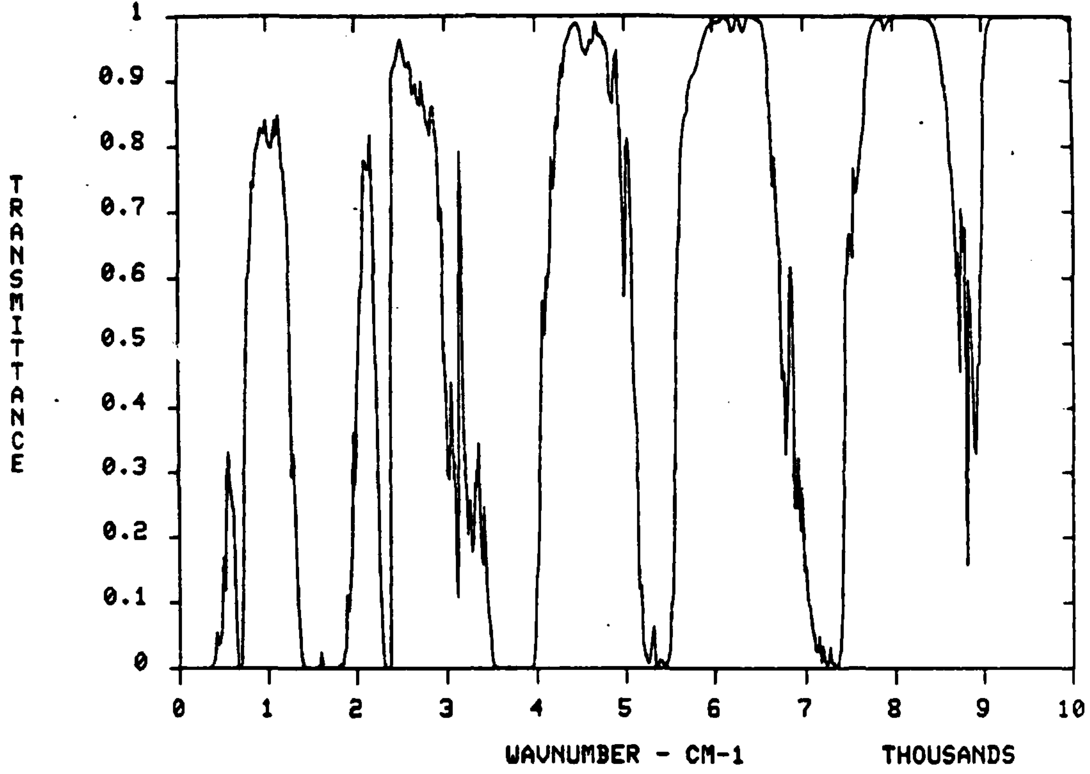


FIGURE 27
H1=1 KM RANGE=1 KM ANGLE=0 DEGREES

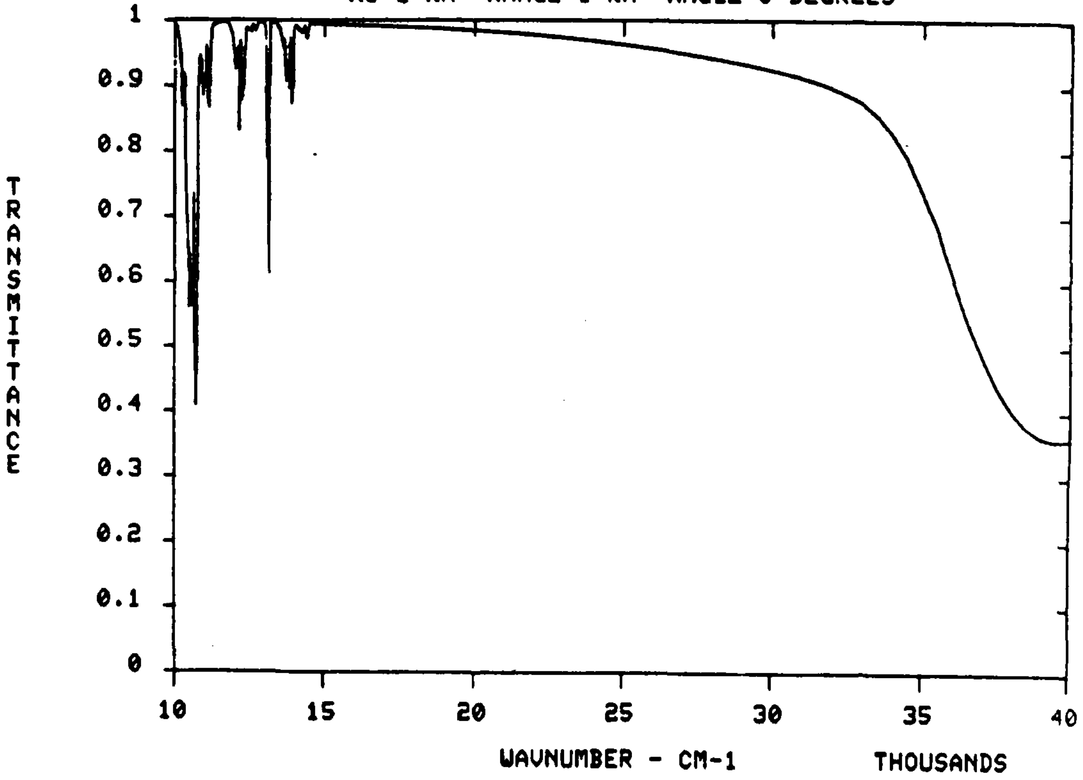


FIGURE 28
H1=1 KM RANGE=1 KM ANGLE=0 DEGREES

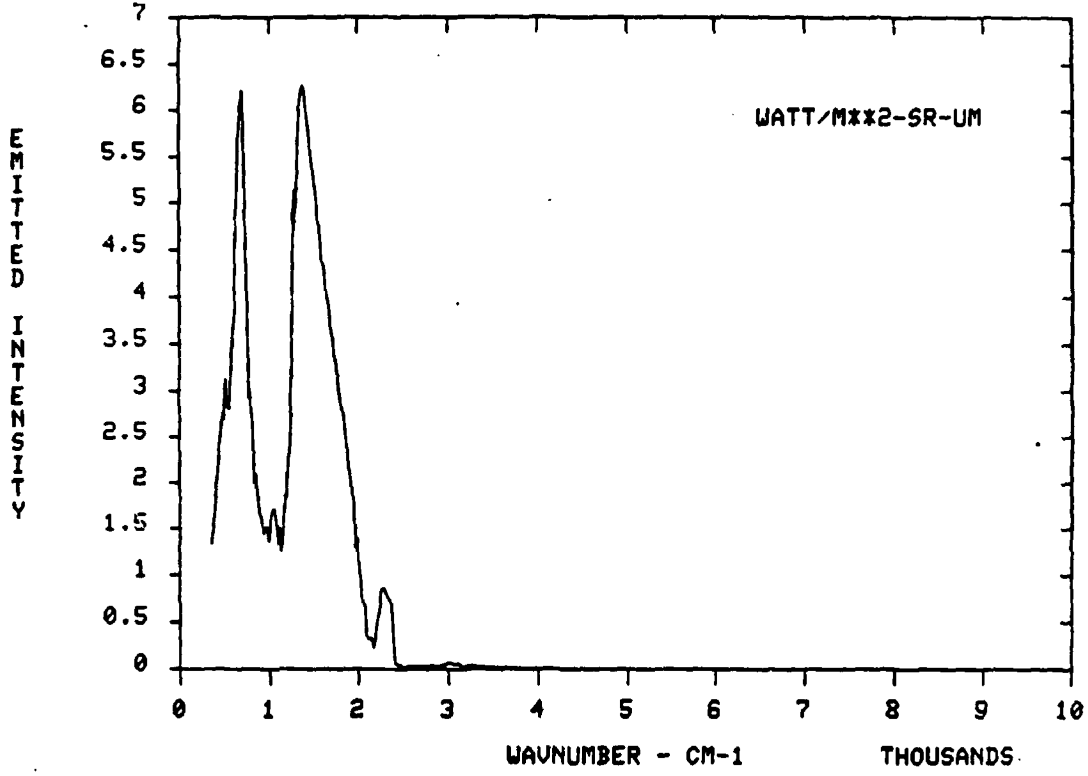


FIGURE 29
H1=1 KM RANGE=1 KM ANGLE=60 DEGREES

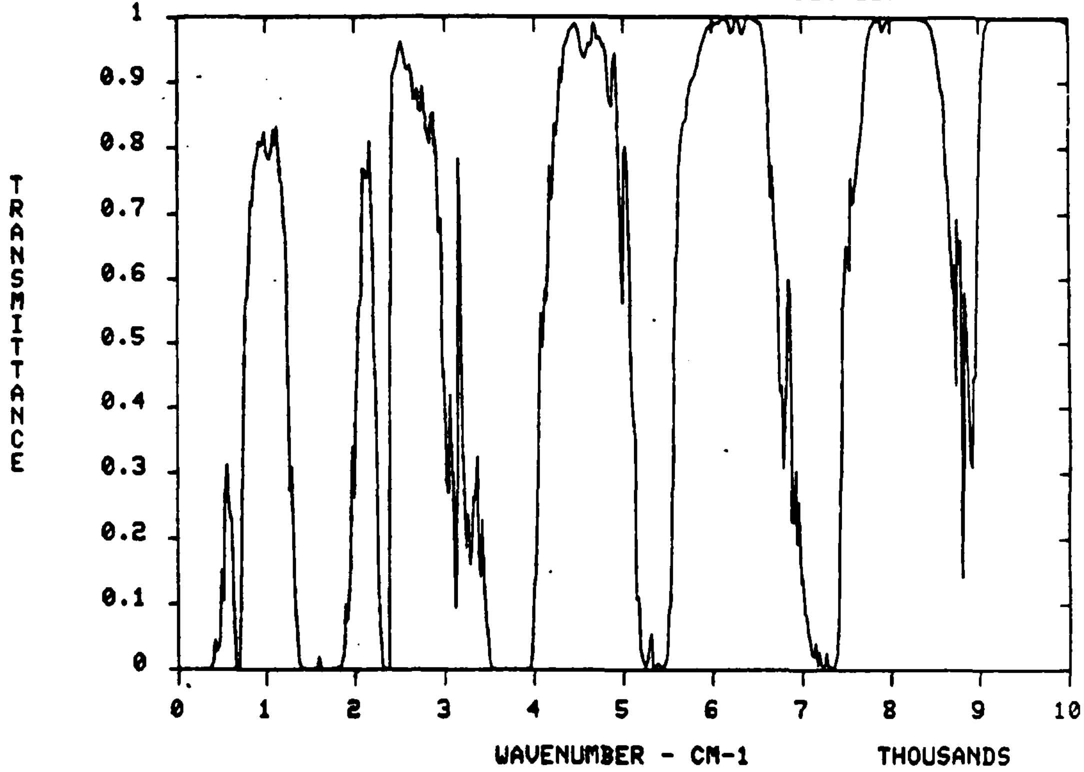


FIGURE 30
H1=1 KM RANGE=1 KM ANGLE=60 DEGREES

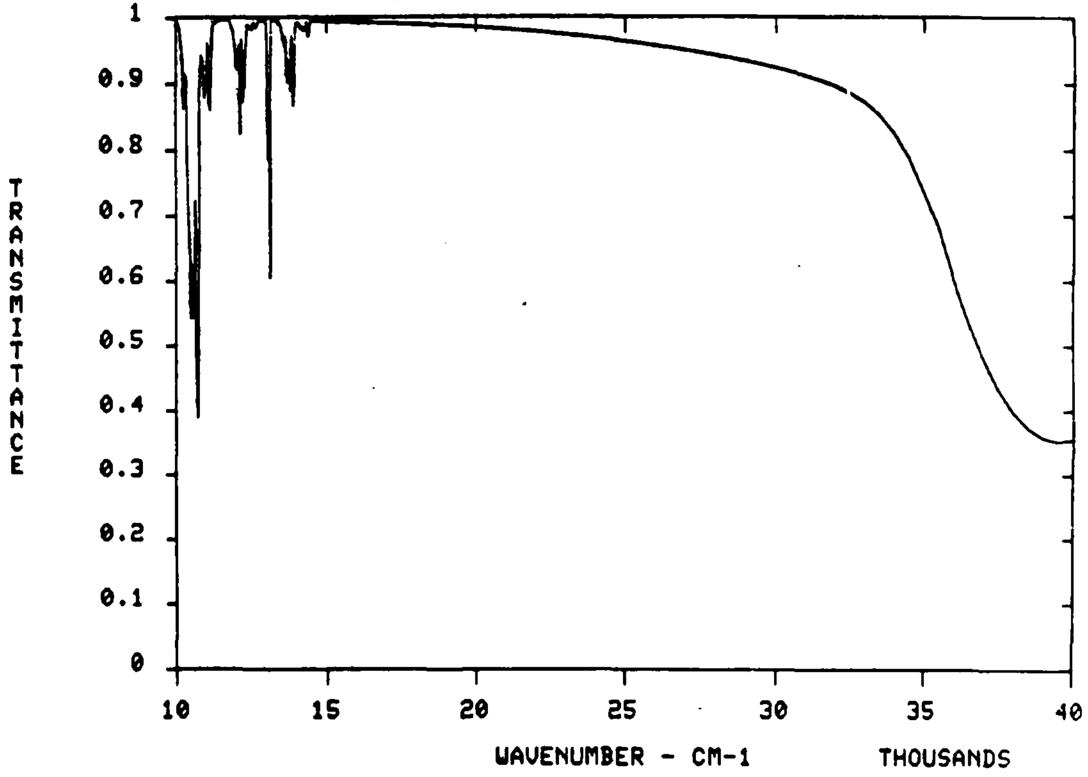


FIGURE 31
H1=1 KM RANGE=1 KM ANGLE=60 DEGREES

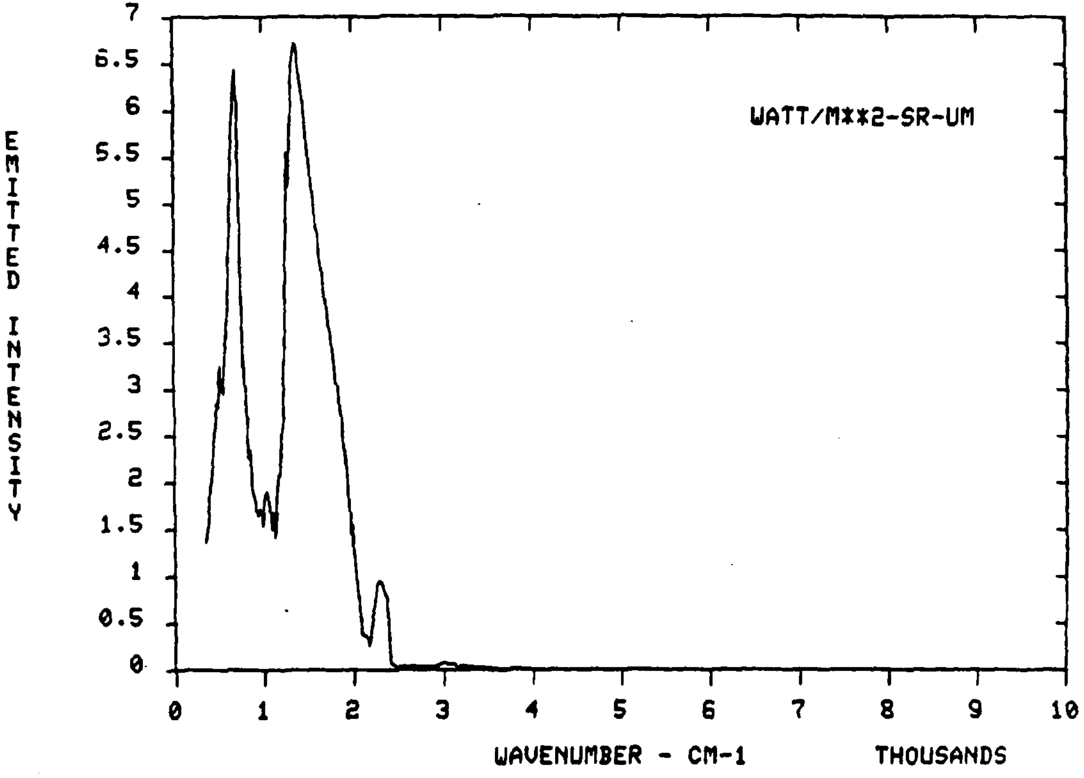


FIGURE 32
H1=1 KM RANGE=1 KM ANGLE=90 DEGREES

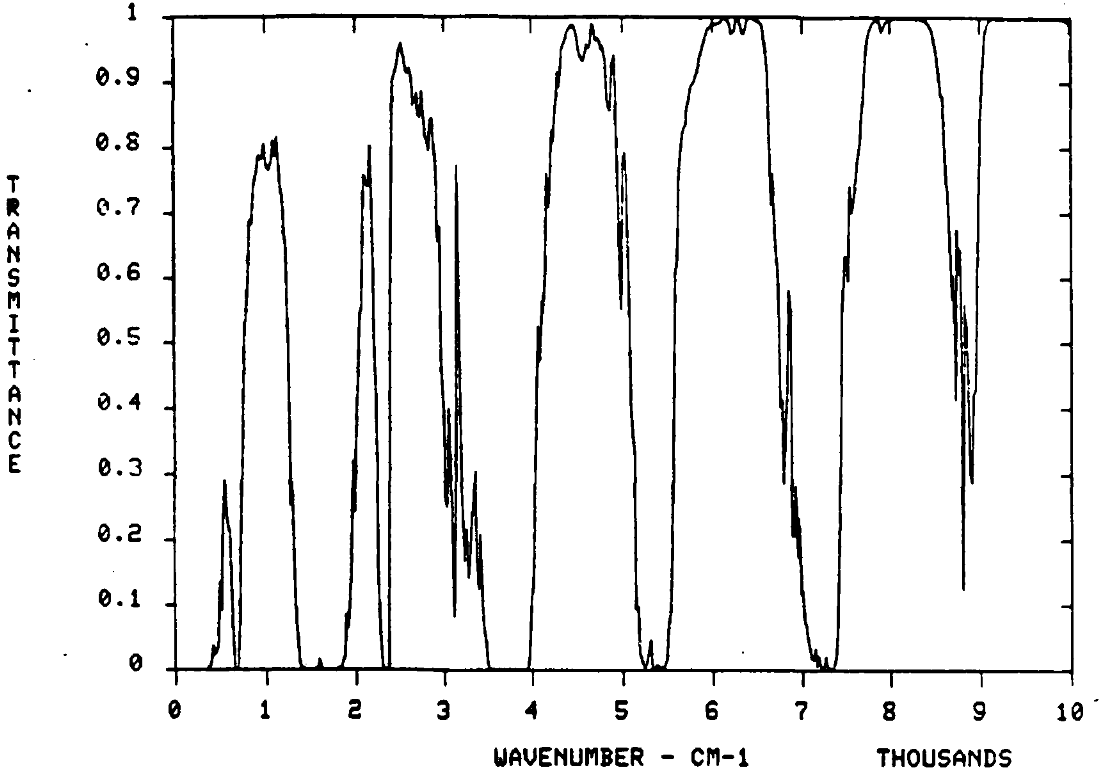
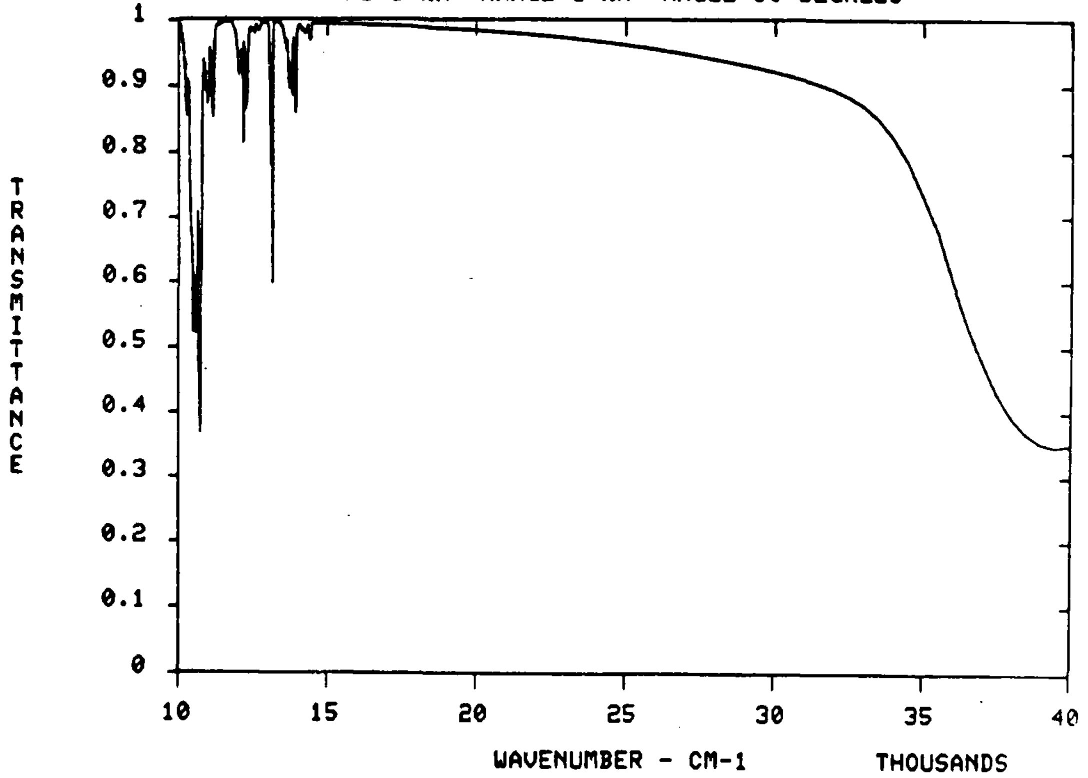


FIGURE 33
H1=1 KM RANGE=1 KM ANGLE=90 DEGREES



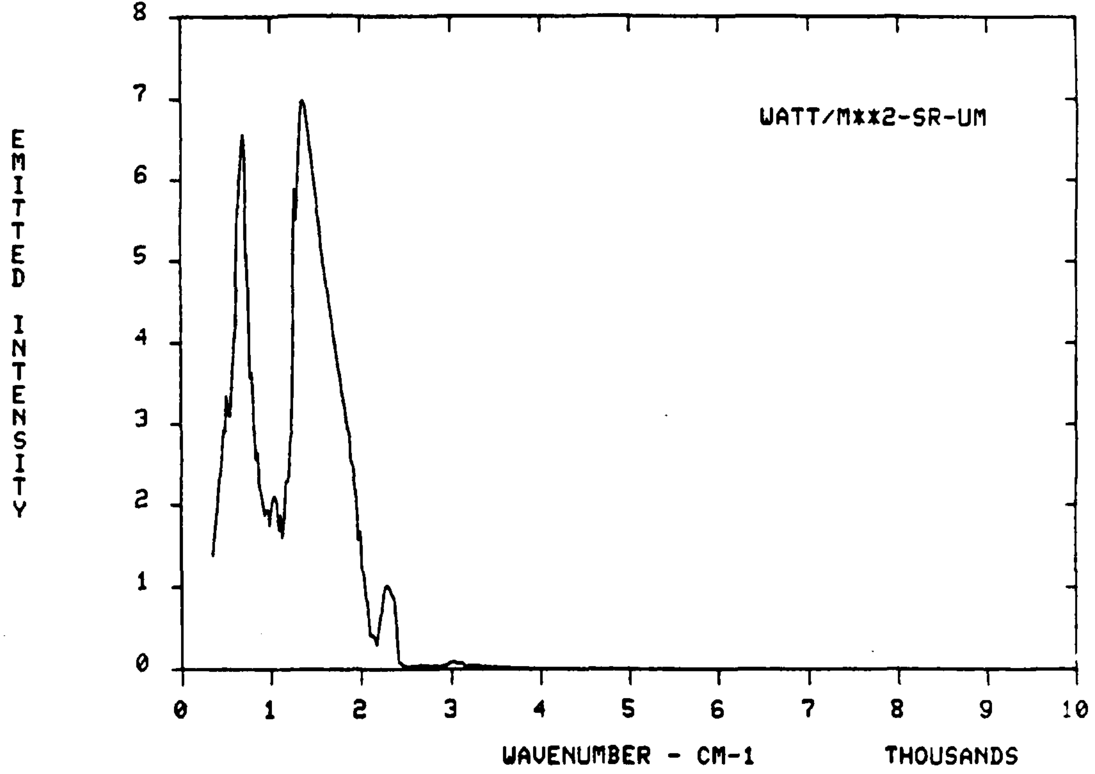


FIGURE 34
H1=1 KM RANGE=1 KM ANGLE=90 DEGREES

FIGURE 35
H1=1 KM RANGE=1 KM ANGLE=120 DEGREES

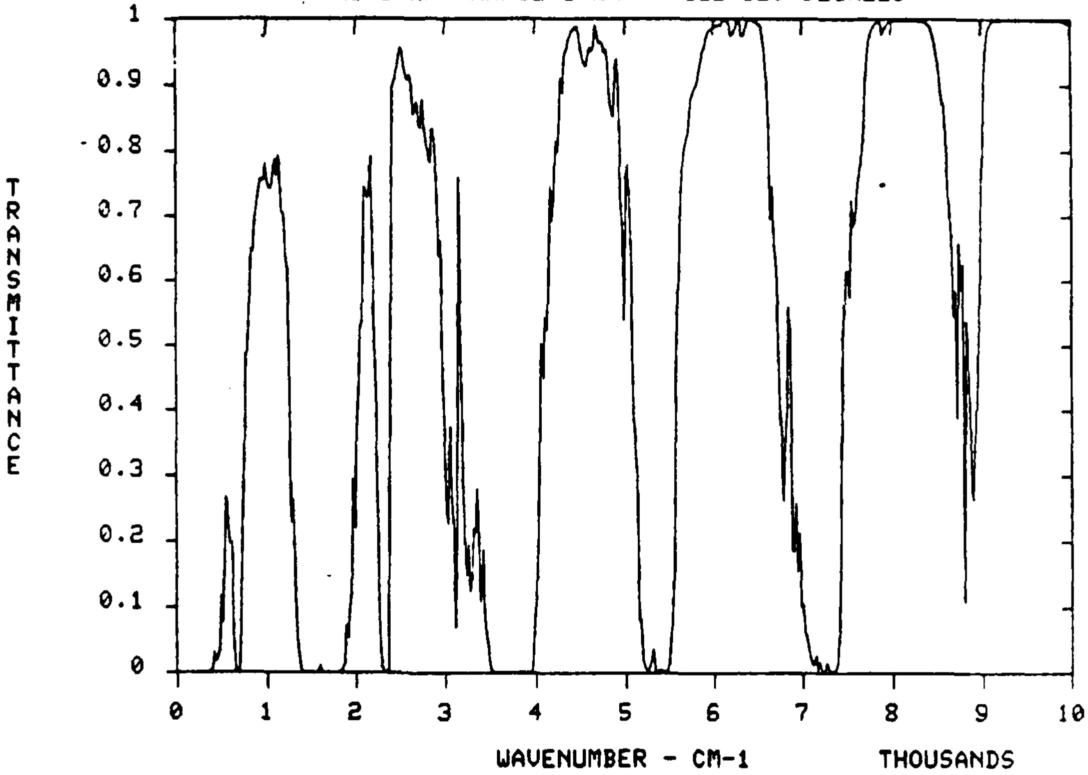


FIGURE 36
H1=1 KM RANGE=1 KM ANGLE=120 DEGREES

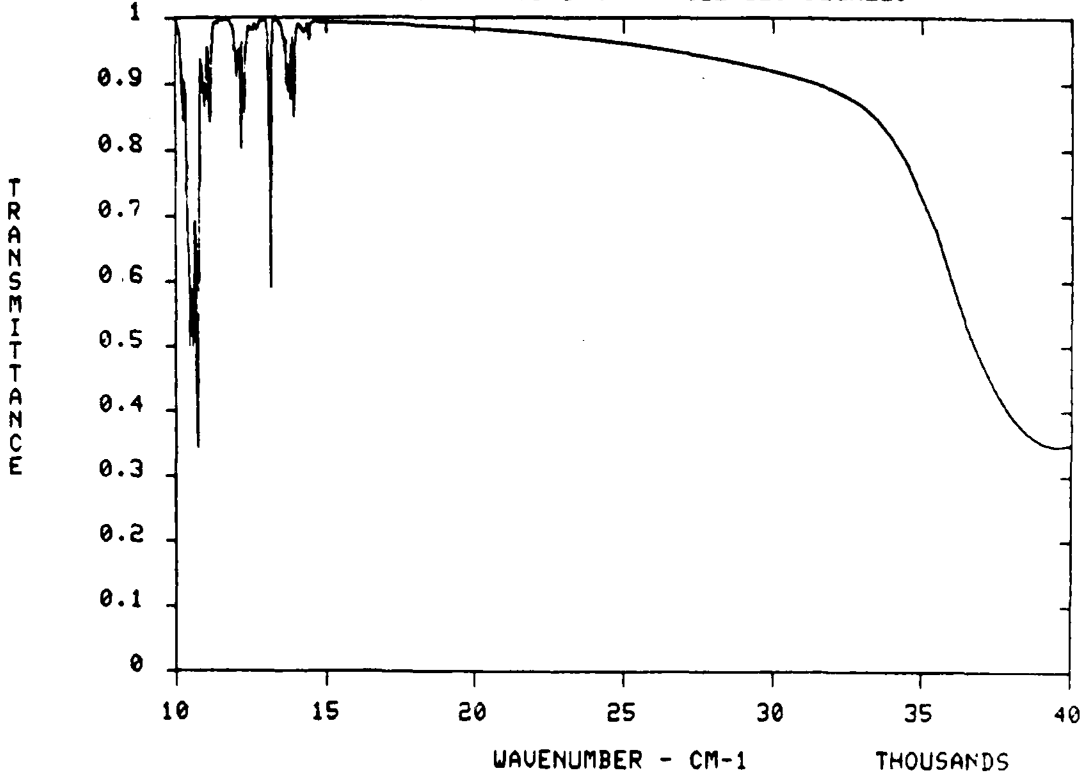


FIGURE 37
H1=1 KM RANGE=1 KM ANGLE=120 DEGREES

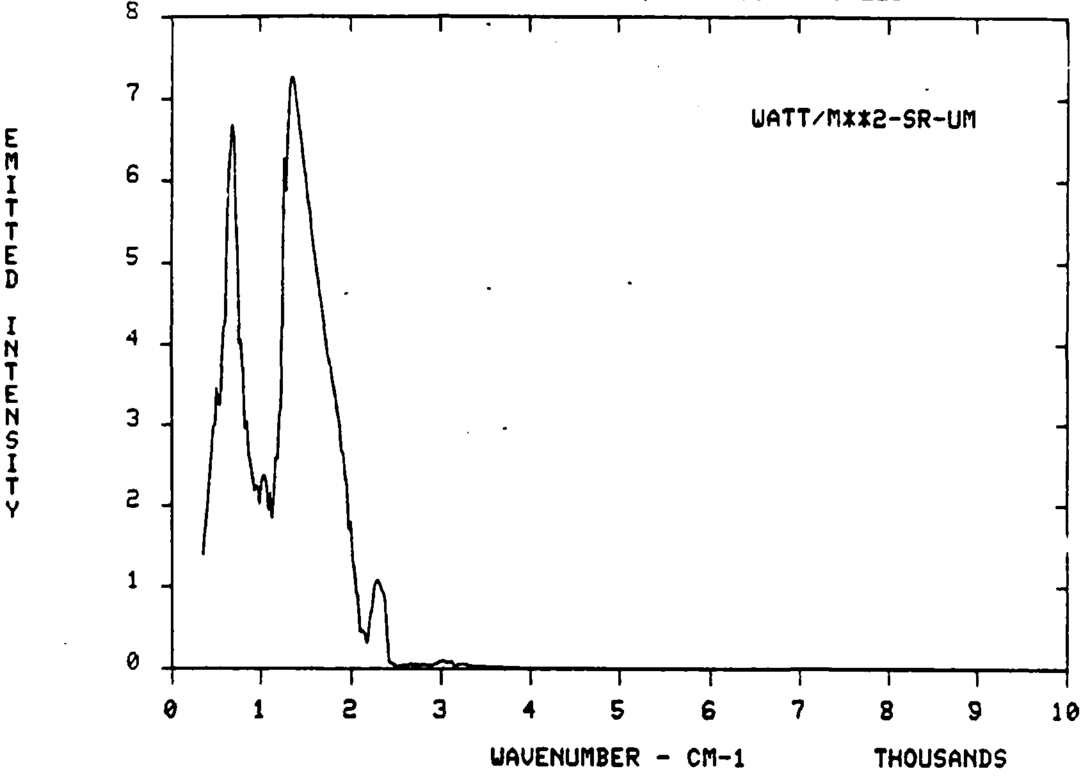


FIGURE 38
H1=1 KM RANGE=1 KM ANGLE=180 DEGREES

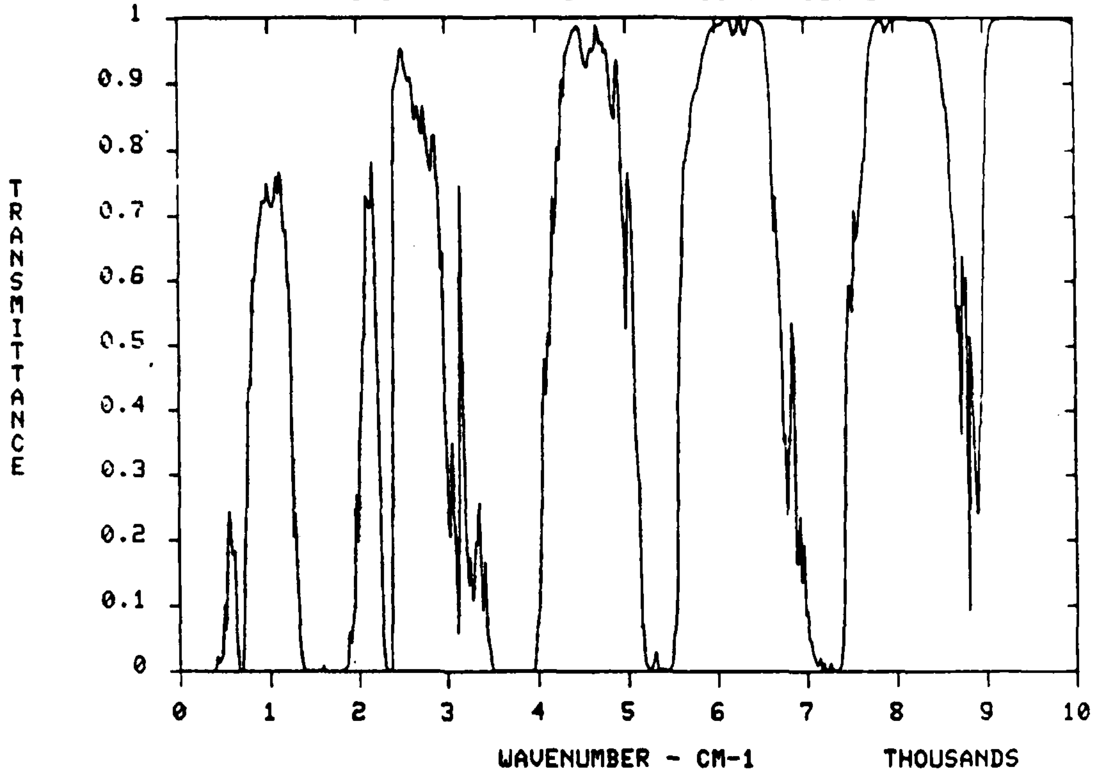


FIGURE 39
H1=1 KM RANGE=1 KM ANGLE=180 DEGREES

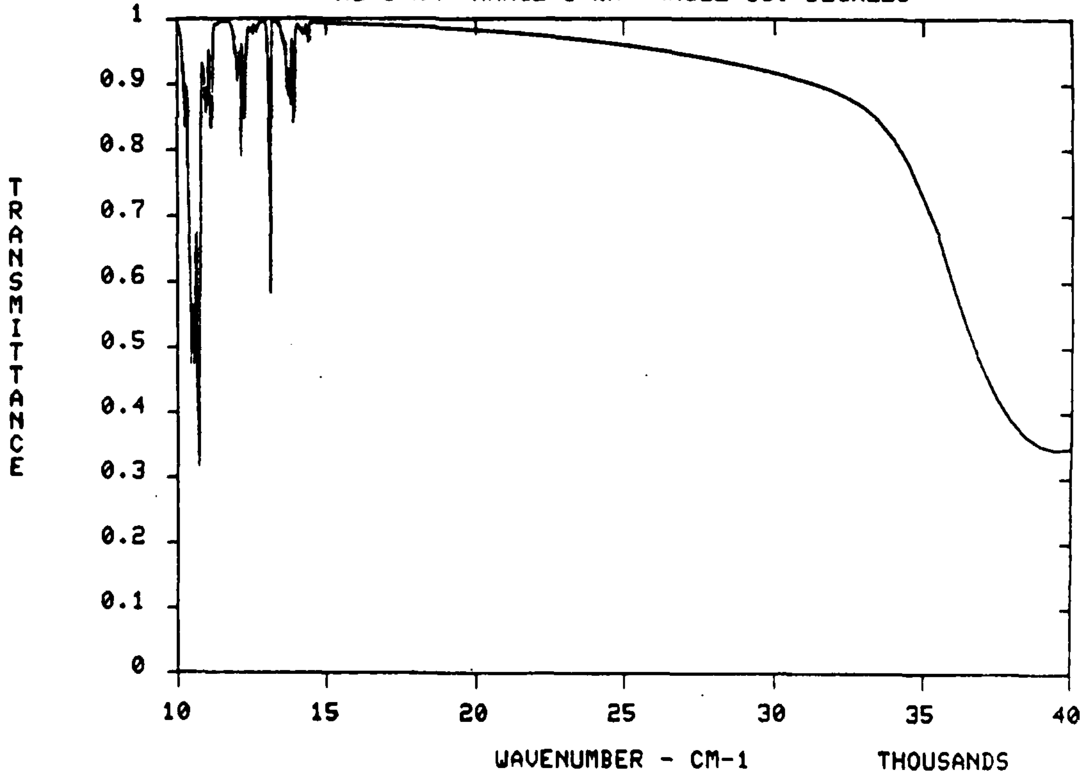
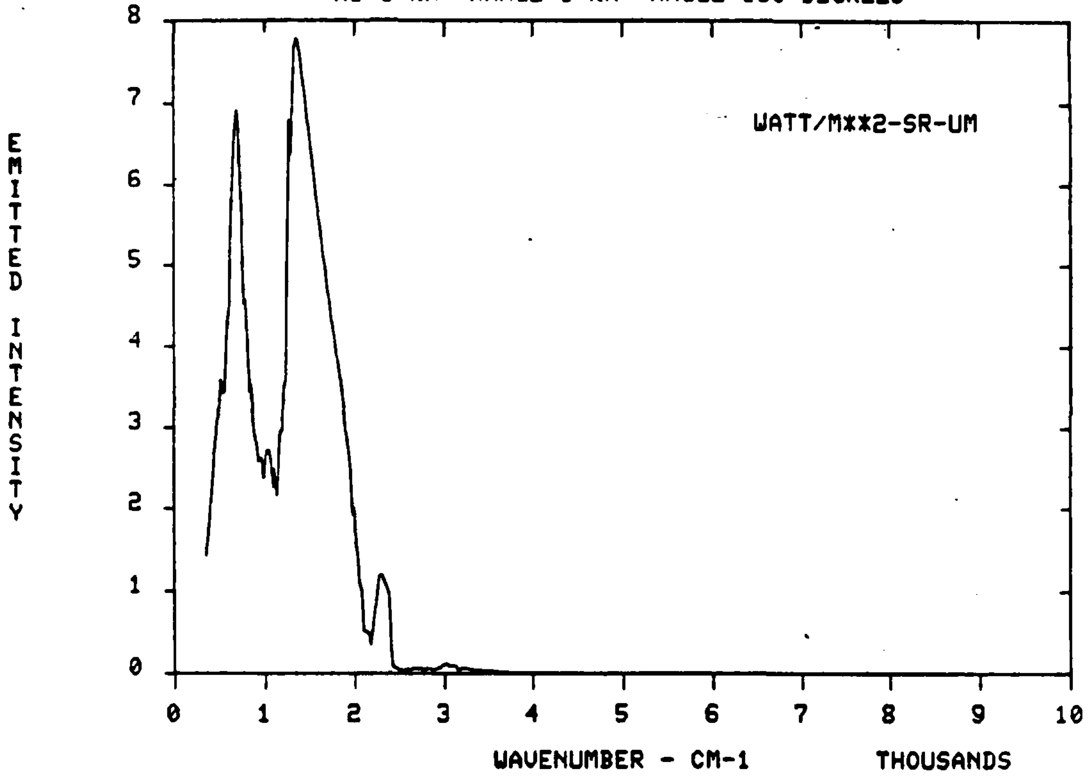


FIGURE 40
H1=1 KM RANGE=1 KM ANGLE=180 DEGREES



SECTION V

SUMMARY OF RADIATION INSTRUMENTS

It can be concluded from section IV that in order to support the current version of LARTAP, it is necessary to make four measurements. These four measurements are pressure, temperature, relative humidity and meterological range. As was discussed in section IV, since the density of ozone at low altitudes is small. It is suggested that no special effort be made to measure ozone density. However, for completeness, it is recommended that ozone be included utilizing one of the program default model capabilities.

The pressure measurement can be made utilizing a barometer. The temperature and relative humidity measurements can be made utilizing an AN/TMQ-11 Temperature Dew Point. Finally, the meterological range measurement can be made utilizing an AN/GMQ-10 Transmissometer. This instrumentation is available at most AFB installations.

The atmospheric components that effect radiation transmission are H_2O, O_2, CO_2, CH_4, N_2O, CO, O_3, N_2 and particulates. The question now arises as to how each of these components is accounted for by the four required measurements. The H_2O component is accounted for by the relative humidity measurement. The O_3 component would ordinarily be accounted for by direct measurement, however, as was just discussed it is recommended that default data be utilized so no measurement is necessary. The other gaseous components and the particulate component are accounted for by the use of two assumptions. First, in order to account for the remaining gaseous components it is assumed that the mole fraction concentration of each of these components is a world wide constant. Secondly, as was discussed in section III, by assuming standard size distributions, the particulate component can be accounted for by utilizing the meterological range. These two assumptions are inherent in the data base obtained from LOWTRAN for use in LARTAP. According to reference 2 these assumptions are valid for the intended uses of LOWTRAN. However, LARTAP will be used by AFFTC at Edwards AFB where, state of the art, radiation systems are being tested. Thus the question arises as to the accuracy of these assumptions for the intended uses of LARTAP. This question can only be answered by comparing results predicted by LARTAP with those obtained from test data. Should disagreement arise then the LARTAP data base would have to be expanded through detailed testing and more detailed measurements would have to be taken to support LARTAP.

CSUN has surveyed the equipment available at Edwards AFB to determine the currently existing capability to support such a detailed testing program. The present inventory at Edwards AFB contained instrumentation to measure H_2O, O_3, and CO concentrations. The following is an outline of this instrumentation.

IMQ - 11:

This is standard equipment at most AFB installations capable of indicating relative or absolute water content of the air.

Monitor Labs 8410: Ozone Analyzer

The concentration of ozone is measured by a chemiluminescent detector. The ozone sample and ethylene are mixed in a reaction chamber. The ozone reacts with the ethylene to form activated aldehyde. The aldehyde then emits infrared with an intensity directly proportional to the ozone concentration.

Full Scale Ranges - 0.1, 0.5, 1.0, 5.0, 10.0 ppm.

Precision - ± 0.339% full-scale

Minimum Sensitivity - 2 ppb.

Monitor Labs 8310 - Carbon Monoxide Analyzer:

Ambient air is pumped in and split into two paths. One path flows through a sample cell where an infrared beam's intensity is measured. The higher the CO content, the greater the attenuation of the IR beam. The second flow path travels through a catalytic converter, which changes all the CO to CO_2, and then flows to a second sample cell. This second cell is used as a reference, and the difference in the IR attenuations is used to display the CO concentration.

Full Scale Ranges - 50, 100 ppm.

Precision - ± 0.1 ppm.

Minimum Sensitivity - 0.1 ppm.

Edwards AFB also has a good support instrument available in the following:

Monitor Labs 9300: Data Logger

This instrument is a general purpose, microprocessor controlled, data logger. Analog inputs are attached to any of the 40 channels, where the signal is digitized and stored. The data flow is programmed via the front key board. Standard features include: English language programming with alpha-numeric display, auto-ranging on input voltages, thermocouple printout, and alarm conditions. Optimal features available are: alarm relay panel, external recording devices, special order conversion tables, and programmable alarms.

No. of Channels - 40

Channel Voltage Ranges - 10.000V, 3.000V, 300.00mV, 30.000mV.

Input Impedance - 100 Meg ohm

Channel Scan Rate - 1 sec. to 999 hrs.

Printer Scan Rate - 1 sec. to 999 hrs.

Optional External Recording Devices -

- Teletype
- Serial Terminals and Printers
- Paper Tape Punches
- Incremental Mag. Tape
- Synchronous Mag. Tape with read after write data check

Alarms - Channel Overrange (exceeds full scale)

Thermocouple burned out (open channel)

In an effort to complete the required capability, instrument manufacturers were contacted. CSUN was able to acquire information concerning instruments capable of measuring CO_2 concentrations, CH_4 concentrations and particulate concentrations (and size distribution). The following is a summary of this instrumentation.

Monitor Labs 3300/3400: Carbon Monoxide/Dioxide Meter

This instrument utilizes a single beam infrared source in conjunction with a mechanical chopper. The 3300 is single component and 3400 dual component.

Full Scale Range CO_2 - 400 ppm.

Full Scale Range Co - 1000 ppm.

Precision - ±1%

Price 3300/3400 - $2,975/$4,500

Beckman Model 400: Hydrocarbon Analyzer

This meter was chosen because of its sensitivity to low Hydrocarbon concentrations and its compatibility with the Monitor Labs Data

Logger. The Model 400 measures hydrocarbons utilizing flame ionization detection. The sample is injected into a burning hydrocarbon flame where the hydrocarbons become ionized. A voltage is applied between the burner jet and a collection plate that results in ion migration. The induced current is proportional to the hydrocarbon concentration.

*Full Scale Range - 1, 10, 100, 1000 ppm.

Precision - ±1% of full scale

Output - 10mV, 100mV, 1V, 5V (selectable)

Price - $4,600

Recommended Accessories:

Part No.	Description	Price
630779	Air Pump	$ 410
630157	Auto Fuel Shut-off	$ 145
	Solinoid for Shut-off	$ 57

*With pure hydrogen fuel accessory

It is possible to obtain more detailed measurements of hydrocarbons by using a gas chromatograph. The chromatograph can break down the different hydrocarbon component, but such an instrument must be designed for the particular tests, and chromatographs are in the $20,000 price range.

Various particle-sizing instruments were evaluated for measuring particulate concentration and size distribution. Those capable of measuring particles of size less than 10 micrometers with reasonable accuracy and ease ot operation were selected. Those instruments found to satisfy these requirements are presented below.

Anderson Samplers Inc.: Low-Pressure Impactor

The Anderson LPI utilizes the well-known inertial impactor principle of the particles in the gas flow; the higher inertia of the heavier phase can cause the particle trajectories to differ from the gas flow streamlines. By staging plates with nozzles of decreasing diameter, size differentiation is obtained; as the gas velocity increases, successively smaller particles will impact on the dish beneath the nozzle. The collected particles are transported to the laboratory for analysis.

The price of the complete system is $4,875. The disadvantage is accuracy may be lost unless extreme care is exercised in handling and transporting the collected particles.

California Measurements Inc.: Aerosol Particle Analyzer Model PC-2

The PC-2 is a 10 stage cascade impactor with quartz crystal microbalance mass monitors in each stage. It utilizes the inertial impactor principle as in the Anderson L.P.I., however, the PC-2 processes a list of special features which make it most attractive for its accuracy and ease of operation. The most prominent of its features is the employment of highly sensitive piezo electric crystal mass monitor in each stage which provides real time mass concentration information. The adhesive coated surface of the crystals retain the samples for further evaluation.

Other features include built-in crystal saturation indicator and built-in sample time stopwatch.

The estimated price for the complete system $15,000.

CONCLUSION

As infrared radiation technology becomes more and more a part of our defense capabilities, the need arises to be able to understand and predict the effects of the earth's atmosphere on the transmission of infrared radiation. The need is especially great for the low altitude regions of the earth's atmosphere.

LOWTRAN offers one possible solution to this problem. However, as LOWTRAN has evolved it has become a very complicated computer program. Thus a new program, LARTAP, has been developed. LARTAP utilizes the large empirical data base from LOWTRAN, however, this new program is geared specifically towards low altitude radiation problems, thus the resulting computer code is much simpler than LOWTRAN.

The net result is that LARTAP offers a good starting point for the development of any computer program to support a project that requires information concerning low altitude radiation transmission.

One of the specific goals of this project was to attempt to make LARTAP a tool that could be used in the field to provide analysis capability at a test site. This would require the conversion of the program to a micro-computer. In order to accomplish this conversion, the large empirical data base utilized by LARTAP would have to be stored on peripheral equipment. Thus in the current version of LARTAP this data base has been stored in disk files to emulate such peripheral equipment.

A short coming of both LOWTRAN and LARTAP is the neglect of scattering into the line of sight of radiation from sources other than the one of interest. It is felt that this could be quite significant for the scattering of solar radiation. It is suggested that an effort should be under taken to model this effect. The resulting model could easily be incorporated into LARTAP.

It is suggested that the LARTAP program be tested. If the program should not agree with test data then detailed testing would have to be performed to modify the data base of LARTAP.

Although the primary concern of this project has been the modeling of radiation transmission, CSUN has also considered the possibility of direct measurement of radiation transmission at a test site.

More direct techniques of measuring radiation transmission can be accomplished by using a radiometer. A wide range radiometer, such as the Molectron PR200, (see table 2), is sensitive from the ultraviolet to the far infrared ranges. By using interchangeable filters, the proper frequency range can be obtained.

For example, the radiometer is mounted on a GMD-2 Balloon Tracker to track a radiation source that is rising through the atmosphere on a balloon. The light source has to be stable and also flash on and off so that changing background radiation can be measured.

The measurements from this test could be combined with the theory of sections I and II of this report utilizing a numerical filtering technique. The result would be an accurate model of radiation transmission at the test site.

In conclusion, a simple computer program, LARTAP, has been developed. This program needs to be tested. The simplicity of the program makes it easy to modify to suit users requirements. Should detailed testing be required to improve program accuracy, currently available instrumentation has been evaluated. It has also been suggested that a technique involving direct measurement of radiation transmission and utilization of a numerical filter may provide a more accurate model of atmospheric radiation transmission at a test site.

TABLE 2

Molectron PR200 Pyroelectric Radiometer

Detector Type - Circular lithium tantalate pyroelectric crystal

Spectral Range - 0.2 to 20 μm ±3%

0.2 to 40 μm ±5%

40 to 500 μm uncalibrated

Ranges (Full Scale) - 2 μW, 20 μW, 200 μW, 2 mW, 20 mW, 200 mW/cm

System Response Time -

Full Scale Range	Fast Response	Slow Response
2 μW	10 sec.	100 sec.
20 μW	3 sec.	100 sec.
200 μW	2 sec.	100 sec.
2,20,200 mW	1 sec.	100 sec.

Absolute Maximum Irradiance - 50 Watts/cm

Price - $3,350

REFERENCES

1. Siegel, R. and Howell J.R.; Thermal Radiation Heat Transfer; Hemisphere Publishers; 1981.
2. Atmospheric Transmittance/Radiance: Computer Code LOWTRANS; Environmental Research Papers, No. 697; AFGL-TR-80-0067; 1980.
3. Chandrasekhar, S.; Radiative Transfer; Dover Publications; 1960.
4. Hudson, R.D., Jr.; Infrared System Engineering; John Wiley and Sons; 1969.
5. Goody, R.M.; Atmospheric Radiation; Oxford, Clarendon Press; 1964.
6. Zuev, V.E.; Propagation of Visible and Infrared Radiation in the Atmosphere; John Wiley and Sons; 1974.

APPENDIX A

Listing of Computer Program

```
C
C            LOW ALTITUDE RADIATION TRANSMISSION ANALYSER PROGRAM
C                              L. A. R. T. A. P.
C            MAIN DRIVER PROGRAM
      COMMON /BLK1/ ZGR(20),P(20),T(20),RH(20),WH(20),WO(20),VIS(20)
      COMMON /BLK2/ H1      , ANGLE     , SMAX
      COMMON /BLK3/ IHA(20), NPTS
      COMMON /SPEC1/ C1ARR(2580),C2ARR(1575),C3ARR(540),C4ARR(133)
      COMMON /SPEC2/ C7ARR(280,5), C8ARR(102,2) ,C9ARR(131)
      DIMENSION W1(10), W2(10), REL(20), WLAY(20,10), CVE(10), CVA(10)
      DIMENSION EXTN(20,10), ABSP(20,10), EMIS(20)
      DIMENSION TEMP(20), TRANE(20), TRANA(20)
      DIMENSION IHAZ(20)
C            OPEN OUTPUT FILES
      OPEN(UNIT=6,FILE='WAVN')
      OPEN(UNIT=7,FILE='TRAS')
      OPEN(UNIT=8,FILE='RADA')
C            READ SPECTRAL DATAFILES
      OPEN(UNIT=31,FILE='C1FILE')
      OPEN(UNIT=32,FILE='C2FILE')
      OPEN(UNIT=33,FILE='C3FILE')
      OPEN(UNIT=34,FILE='C4FILE')
      OPEN(UNIT=37,FILE='C7FILE')
      OPEN(UNIT=38,FILE='C8FILE')
      OPEN(UNIT=40,FILE='C9FILE')
C            H2O SPECTRAL DATA
      DO 31 I=1,2580
      READ(31,*) C1ARR(I)
  31  CONTINUE
C            UNIFORM GASES SPECTRAL DATA
      DO 32 I=1,1575
      READ(32,*) C2ARR(I)
  32  CONTINUE
C            OZONE I.R.  SPECTRAL DATA
      DO 33 I=1,540
      READ(33,*) C3ARR(I)
  33  CONTINUE
C            N2 SPECTRAL DATA
      DO 34 I=1,133
      READ(34,*) C4ARR(I)
  34  CONTINUE
C            AEROSOL SPECTRAL DATA
      DO 37 I=1,280
      READ(37,*) C7ARR(I,1),C7ARR(I,2),C7ARR(I,3),C7ARR(I,4),C7ARR(I,5)
  37  CONTINUE
C            OZONE U.V.  SPECTRAL DATA
      DO 38 I=1,102
      READ(38,*) C8ARR(I,1),C8ARR(I,2)
  38  CONTINUE
C            H2O CONTINUUM (4 UM) SPECTRAL DATA
      DO 39 I=1,131
      READ(40,*) C9ARR(I)
  39  CONTINUE
```

```
C           DATA INITIALIZE
      CALL PROPUT
C           CALCULATE COMPONENT AMOUNT INTEGRALS
      LY=0
      S1=0.000
C           CALCULATE COMPONENT AMOUNTS AT START OF PATH
      CALL EQUABS(S1,IHAZE1,W1,REL1,TEM1)
C           INTEGRAL EVALUATION LOOP
  100 LY=LY+1
      S2=SMAX+1.0E-04
C           CHECK FOR HORIZONTAL PATH
      IF (ANGLE .GT. 89.5 .AND. ANGLE .LT. 90.5) GO TO 120
C           FIND CLOSEST DATA POINT -  DEFAULT IS SMAX
      DO 110 I=1,NPTS
      DSMIN=S2-S1
      TEST=((ZGR(I)-H1)/COS(ANGLE*3.14159/180.0))-S1
      IF (TEST .GT. 0.0001 .AND. TEST .LT. DSMIN) S2=TEST+S1
  110 CONTINUE
C           CALCULATE COMPONENT AMOUNT INTEGRALS FOR LAYER LY
  120 CALL EQUABS(S2,IHAZE2,W2,REL2,TEM2)
      DO 130 I=1,9
      WLAY(LY,I)=(W2(I)+W1(I))*(S2-S1)/2.0
      IF (W1(I) .EQ. 0.000 .OR. W2(I) .EQ. 0.000) GO TO 130
      AUG=W2(I)/W1(I)
      WLAY(LY,I)=W1(I)*(S2-S1)
      IF (AUG .GT. 0.99 .AND. AUG .LT. 1.01) GO TO 130
      WLAY(LY,I)=(W2(I)-W1(I))*(S2-S1)/ALOG(AUG)
  130 CONTINUE
C           CALCULATE AVERAGE RELATIVE HUMIDITY FOR LAYER LY
      REL(LY)=(REL1+REL2)/2.0
C           DETERMINE AEROSOL TYPE FOR LAYER LY
      IF (ANGLE .LE. 90.0) IHAZ(LY)=IHAZE1
      IF (ANGLE .GT. 90.0) IHAZ(LY)=IHAZE2
C           STORE TEMPERATURE FOR EMISSION CALCULATION
      TEMP(LY)=TEM1
C           INCREMENT DATA
      S1=S2
      REL1=REL2
      IHAZE1=IHAZE2
      TEM1=TEM2
      DO 250 I=1,9
      W1(I)=W2(I)
  250 CONTINUE
C           CHECK FOR END OF PATH
      IF (S2 .LT. SMAX) GO TO 100
      LYTOT=LY+1
C           STORE TEMPERATURE AT SMAX
      TEMP(LYTOT)=TEM2
C           SPECTRAL LOOP
      DO 400 IV=350,40000,10
C           PATH INDEPENDENT SPECTRAL COEFFICIENTS
      CALL C1DTA(CVE(1),IV)
      CVA(1)=CVE(1)
      CALL C2DTA(CVE(2),IV)
```

```
      CVA(2)=CVE(2)
      CALL C3DTA(CVE(3),IV)
      CVA(3)=CVE(3)
      CALL C4DTA(CVE(4),IV)
      CVA(4)=CVE(4)
      CALL C5DTA(CVE(5),IV)
      CVA(5)=CVE(5)
      CALL C6DTA(CVE(6),IV)
      CVA(6)=0.000
      CALL C8DTA(CVE(8),IV)
      CVA(8)=CVE(8)
      CALL C9DTA(CVE(9),IV)
      CVA(9)=CVE(9)
C            ZERO EXTINCTION AND ABSORPTION ARRAYS
      DO 265 J=1,9
      EXTN(LYTOT,J)=0.000
      ABSP(LYTOT,J)=0.000
 265  CONTINUE
C            CALCULATE TRANSMITTANCES FROM EACH LAYER TO OBSERVER
C            NOTE - WORK FROM OBSERVER BACK TO SOURCE
      I=LYTOT
      DO 300 K=1,LYTOT
C            CALCULATE TRANSMITTANCE AT WAVENUMBER IV (EXTINCTION)
C            H2O
      TRANE(I)=1.00/EXP(0.0689*EXTN(I,1)**0.555)
C            UNIFORM GASES
      TRANE(I)=TRANE(I)/EXP(0.0689*EXTN(I,2)**0.555)
C            OZONE I.R.
      TRANE(I)=TRANE(I)/EXP(0.0643*EXTN(I,3)**0.666)
C            N2 CONTINUUM
      TRANE(I)=TRANE(I)/EXP(EXTN(I,4))
C            H2O CONTINUUM (10 UM)
      TRANE(I)=TRANE(I)/EXP(EXTN(I,5))
C            MOLECULAR SCATTERING
      TRANE(I)=TRANE(I)/EXP(EXTN(I,6))
C            AEROSOL
      TRANE(I)=TRANE(I)/EXP(EXTN(I,7))
C            OZONE U.V.
      TRANE(I)=TRANE(I)/EXP(EXTN(I,8))
C            H2O CONTINUUM (4 UM)
      TRANE(I)=TRANE(I)/EXP(EXTN(I,9))
C            CALCULATE TRANSMITTANCE AT WAVENUMBER IV (ABSORPTION)
C            H2O
      TRANA(I)=1.00/EXP(0.0689*ABSP(I,1)**0.555)
C            UNIFORM GASES
      TRANA(I)=TRANA(I)/EXP(0.0689*ABSP(I,2)**0.555)
C            OZONE I.R.
      TRANA(I)=TRANA(I)/EXP(0.0643*ABSP(I,3)**0.666)
C            N2 CONTINUUM
      TRANA(I)=TRANA(I)/EXP(ABSP(I,4))
C            H2O CONTINUUM (10 UM)
      TRANA(I)=TRANA(I)/EXP(ABSP(I,5))
C            MOLECULAR SCATTERING
      TRANA(I)=TRANA(I)/EXP(ABSP(I,6))
```

```
C                AEROSOL
      TRANA(I)=TRANA(I)/EXP(ABSP(I,7))
C                OZONE U.V.
      TRANA(I)=TRANA(I)/EXP(ABSP(I,8))
C                H2O CONTINUUM (4 UM)
      TRANA(I)=TRANA(I)/EXP(ABSP(I,9))
      I=I-1
      IF (I .EQ. 0) GO TO 325
C                AEROSOL SPECTRAL COEFFICIENTS
      CALL C7DTA(CVE(7),CVA(7),IV,REL(I),IHAZ(I))
C                CALCULATE EXTINCTION-ABSORPTION COFFICIENTS
C                FROM BEGINNING OF LAYER I TO OBSERVER
      DO 275 J=1,9
      EXTN(I,J)=EXTN(I+1,J)+CVE(J)*WLAY(I,J)
      ABSP(I,J)=ABSP(I+1,J)+CVA(J)*WLAY(I,J)
  275 CONTINUE
  300 CONTINUE
C                CALCULATE EMISSION ALONG PATH
  325 DO 350 I=1,LYTOT
      EMIS(I)=PLAN(TEMP(I),IV)
  350 CONTINUE
C                CALCULATE RADIANCE FOR PATH
      RADI=0.000
      DO 375 I=1,LY
      DRAD=(EMIS(I+1)*TRANE(I+1)/TRANA(I+1))+(EMIS(I)*TRANE(I)/TRANA(I
      RADI=RADI+DRAD*(TRANA(I+1)-TRANA(I))/2.0
  375 CONTINUE
C                PRINT RESULTS
      WRITE(6,1000) IV
      WRITE(7,1000) TRANE(1)
      WRITE(8,1000) RADI
  400 CONTINUE
 1000 FORMAT(1PE12.5)
      STOP
      END
```

```
C
C** PROPUT ***********************************************************
C
      SUBROUTINE PROPUT
C            DATA PROCESSING AND INPUT ROUTINE
      COMMON /BLK1/ ZGR(20),P(20),T(20),RH(20),WH(20),WO(20),VIS(20)
      COMMON /BLK2/ H1    , ANGLE    , SMAX
      COMMON /BLK3/ IHA(20), NPTS
C            OPEN INPUT DATA FILE
      OPEN(UNIT=5,FILE='DATA')
C            DEFINE CONSTANTS
      RV=4.6150E-03
C            PROGRAM CONTROL DATA
      READ(5,*) MODEL,GRASL,NPTS
      READ(5,*) H1,SMAX,ANGLE
      DO 100 I=1,NPTS
      READ(5,*) ZGR(I),P(I),T(I),RH(I),WO(I),VIS(I),IHA(I)
C            CONVERT TEMPERATURE TO ABSOLUTE
      T(I)=T(I)+273.15
C            CHECK AND SET DEFAULT DATA
      IF (P(I)  .LT.  -500.0) CALL PRMOD(ZGR(I)+GRASL,MODEL,P(I))
      IF (T(I)  .LT.  -500.0) CALL TEMOD(ZGR(I)+GRASL,MODEL,T(I))
      IF (RH(I) .LT.  -500.0) CALL WHMOD(ZGR(I)+GRASL,MODEL,WH(I))
      IF (WO(I) .LT.  -500.0) CALL WOMOD(ZGR(I)+GRASL,MODEL,WO(I))
C            DETERMINE WATER DENSITY
      TA=273.15/T(I)
      IF (RH(I) .LT.  -500.0) GO TO 50
      RHSAT=FCT(TA)
      RHO=0.01*RH(I)
      DN=1.0-(1.0-RHO)*RHSAT*RV*T(I)/P(I)
      WH(I)=RHSAT*RHO/DN
      GO TO 100
C            CALCULATE RELATIVE HUMIDITY
 50   RHOSTR=P(I)/(RV*T(I))
      RH(I)=100.0*(WH(I)/FCT(TA))*((RHOSTR-FCT(TA))/(RHOSTR-WH(I)))
 100  CONTINUE
      RETURN
      END
```

```
C
C** PRMOD *****************************************************
C
      SUBROUTINE PRMOD(Z,M,P)
C           PRESSURE MODEL DATA ROUTINE
      DIMENSION ZD(6),PD(6,6)
C           ALTITUDE
      DATA
     * ZD(1)   , ZD(2)   , ZD(3)   , ZD(4)   , ZD(5)   , ZD(6)
     * 0.0     , 1.0     , 2.0     , 3.0     , 4.0     , 5.0
C           PRESSURE MODEL 1
      DATA
     * PD(1,1) , PD(1,2) , PD(1,3) , PD(1,4) , PD(1,5) , PD(1,6
     * 1.013E+03, 9.040E+02, 8.050E+02, 7.150E+02, 6.330E+02, 5.590E
C           PRESSURE MODEL 2
      DATA
     * PD(2,1) , PD(2,2) , PD(2,3) , PD(2,4) , PD(2,5) , PD(2,6
     * 1.013E+03, 9.020E+02, 8.020E+02, 7.100E+02, 6.280E+02, 5.540E
C           PRESSURE MODEL 3
      DATA
     * PD(3,1) , PD(3,2) , PD(3,3) , PD(3,4) , PD(3,5) , PD(3,6
     * 1.018E+03, 8.973E+02, 7.897E+02, 6.938E+02, 6.081E+02, 5.313E
C           PRESSURE MODEL 4
      DATA
     * PD(4,1) , PD(4,2) , PD(4,3) , PD(4,4) , PD(4,5) , PD(4,6
     * 1.010E+03, 8.960E+02, 7.929E+02, 7.000E+02, 6.160E+02, 5.410E
C           PRESSURE MODEL 5
      DATA
     * PD(5,1) , PD(5,2) , PD(5,3) , PD(5,4) , PD(5,5) , PD(5,6)
     * 1.013E+03, 8.878E+02, 7.775E+02, 6.798E+02, 5.932E+02, 5.158E
C           PRESSURE MODEL 6
      DATA
     * PD(6,1) , PD(6,2) , PD(6,3) , PD(6,4) , PD(6,5) , PD(6,6)
     * 1.013E+03, 8.986E+02, 7.950E+02, 7.012E+02, 6.166E+02, 5.405E
C           SEMI-LOG INTERPOLATION
      DO 10 I=2,6
      L=I
      IF (Z .LT. ZD(L)) GO TO 12
 10   CONTINUE
 12   FAC=(Z-ZD(L-1))/(ZD(L)-ZD(L-1))
      P=PD(M,L-1)*(PD(M,L)/PD(M,L-1))**FAC
C           RETURN
      RETURN
      END
```

```
C
C** TEMOD *****************************************************************
C
      SUBROUTINE TEMOD(Z, M, T)
C              TEMPERATURE MODEL DATA ROUTINE
      DIMENSION ZD(6), TE(6, 6)
C              ALTITUDE
      DATA
     * ZD(1)     , ZD(2)     , ZD(3)     , ZD(4)     , ZD(5)     , ZD(6)     /
     * 0.0       , 1.0       , 2.0       , 3.0       , 4.0       , 5.0       /
C              TEMPERATURE MODEL 1
      DATA
     * TE(1, 1)  , TE(1, 2)  , TE(1, 3)  , TE(1, 4)  , TE(1, 5)  , TE(1, 6)  /
     * 3. 000E+02, 2. 940E+02, 2. 880E+02, 2. 840E+02, 2. 770E+02, 2. 700E+02/
C              TEMPERATURE MODEL 2
      DATA
     * TE(2, 1)  , TE(2, 2)  , TE(2, 3)  , TE(2, 4)  , TE(2, 5)  , TE(2, 6)  /
     * 2. 940E+02, 2. 900E+02, 2. 850E+02, 2. 790E+02, 2. 730E+02, 2. 670E+02/
C              TEMPERATURE MODEL 3
      DATA
     * TE(3, 1)  , TE(3, 2)  , TE(3, 3)  , TE(3, 4)  , TE(3, 5)  , TE(3, 6)  /
     * 2. 722E+02, 2. 687E+02, 2. 652E+02, 2. 617E+02, 2. 557E+02, 2. 497E+02/
C              TEMPERATURE MODEL 4
      DATA
     * TE(4, 1)  , TE(4, 2)  , TE(4, 3)  , TE(4, 4)  , TE(4, 5)  , TE(4, 6)  /
     * 2. 870E+02, 2. 820E+02, 2. 760E+02, 2. 710E+02, 2. 660E+02, 2. 600E+02/
C              TEMPERATURE MODEL 5
      DATA
     * TE(5, 1)  , TE(5, 2)  , TE(5, 3)  , TE(5, 4)  , TE(5, 5)  , TE(5, 6)  /
     * 2. 570E+02, 2. 590E+02, 2. 559E+02, 2. 527E+02, 2. 477E+02, 2. 409E+02/
C              TEMPERATURE MODEL 6
      DATA
     * TE(6, 1)  , TE(6, 2)  , TE(6, 3)  , TE(6, 4)  , TE(6, 5)  , TE(6, 6)  /
     * 2. 881E+02, 2. 816E+02, 2. 751E+02, 2. 687E+02, 2. 622E+02, 2. 557E+02/
C              SEMI-LOG INTERPOLATION
      DO 10 I=2, 6
      L=I
      IF (Z .LT. ZD(L)) GO TO 12
   10 CONTINUE
   12 FAC=(Z-ZD(L-1))/(ZD(L)-ZD(L-1))
      T=TE(M, L-1)*(TE(M, L)/TE(M, L-1))**FAC
C              RETURN
      RETURN
      END
```

```
C
C** WHMOD **************************************************************
C
      SUBROUTINE WHMOD(Z,M,WH)
C            WATER DENSITY MODEL DATA ROUTINE
      DIMENSION ZD(6),WHD(6,6)
C            ALTITUDE
      DATA
     * ZD (1)   , ZD (2)   , ZD (3)   , ZD (4)   , ZD (5)   , ZD (6)   /
     * 0.0      , 1.0      , 2.0      , 3.0      , 4.0      , 5.0      /
C            WATER DENSITY MODEL 1
      DATA
     * WHD(1,1) , WHD(1,2) , WHD(1,3) , WHD(1,4) , WHD(1,5) , WHD(1,6) /
     * 1.900E+01, 1.300E+01, 9.300E+00, 4.700E+00, 2.200E+00, 1.500E+00/
C            WATER DENSITY MODEL 2
      DATA
     * WHD(2,1) , WHD(2,2) , WHD(2,3) , WHD(2,4) , WHD(2,5) , WHD(2,6) /
     * 1.400E+01, 9.300E+00, 5.900E+00, 3.300E+00, 1.900E+00, 1.000E+00/
C            WATER DENSITY MODEL 3
      DATA
     * WHD(3,1) , WHD(3,2) , WHD(3,3) , WHD(3,4) , WHD(3,5) , WHD(3,6) /
     * 3.500E+00, 2.500E+00, 1.800E+00, 1.200E+00, 6.600E-01, 3.800E-01/
C            WATER DENSITY MODEL 4
      DATA
     * WHD(4,1) , WHD(4,2) , WHD(4,3) , WHD(4,4) , WHD(4,5) , WHD(4,6) /
     * 9.100E+00, 6.000E+00, 4.200E+00, 2.700E+00, 1.700E+00, 1.000E+00/
C            WATER DENSITY MODEL 5
      DATA
     * WHD(5,1) , WHD(5,2) , WHD(5,3) , WHD(5,4) , WHD(5,5) , WHD(5,6) /
     * 1.200E+00, 1.200E+00, 9.400E-01, 6.800E-01, 4.100E-01, 2.000E-01/
C            WATER DENSITY MODEL 6
      DATA
     * WHD(6,1) , WHD(6,2) , WHD(6,3) , WHD(6,4) , WHD(6,5) , WHD(6,6) /
     * 5.900E+00, 4.200E+00, 2.900E+00, 1.800E+00, 1.100E+00, 6.400E-01/
C            SEMI-LOG INTERPOLATION
      DO 10 I=2,6
      L=I
      IF (Z .LT. ZD(L)) GO TO 12
 10   CONTINUE
 12   FAC=(Z-ZD(L-1))/(ZD(L)-ZD(L-1))
      WH=WHD(M,L-1)*(WHD(M,L)/WHD(M,L-1))**FAC
C            RETURN
      RETURN
      END
```

```
C
C** WOMOD ***************************************************************
C
      SUBROUTINE WOMOD(Z,M,WO)
C            OZONE DENSITY MODEL DATA ROUTINE
      DIMENSION ZD(6),WOD(6,6)
C            ALTITUDE
      DATA
     * ZD (1)    , ZD (2)    , ZD (3)    , ZD (4)    , ZD (5)    , ZD (6)
     * 0.0       , 1.0       , 2.0       , 3.0       , 4.0       , 5.0
C            OZONE DENSITY MODEL 1
      DATA
     * WOD(1,1) , WOD(1,2) , WOD(1,3) , WOD(1,4) , WOD(1,5) , WOD(1,6)
     * 5.600E-05, 5.600E-05, 5.400E-05, 5.100E-05, 4.700E-05, 4.500E-0
C            OZONE DENSITY MODEL 2
      DATA
     * WOD(2,1) , WOD(2,2) , WOD(2,3) , WOD(2,4) , WOD(2,5) , WOD(2,6)
     * 6.000E-05, 6.000E-05, 6.000E-05, 6.200E-05, 6.400E-05, 6.600E-0
C            OZONE DENSITY MODEL 3
      DATA
     * WOD(3,1) , WOD(3,2) , WOD(3,3) , WOD(3,4) , WOD(3,5) , WOD(3,6)
     * 6.000E-05, 5.400E-05, 4.900E-05, 4.900E-05, 4.900E-05, 5.800E-0
C            OZONE DENSITY MODEL 4
      DATA
     * WOD(4,1) , WOD(4,2) , WOD(4,3) , WOD(4,4) , WOD(4,5) , WOD(4,6)
     * 4.900E-05, 5.400E-05, 5.600E-05, 5.800E-05, 6.000E-05, 6.400E-0
C            OZONE DENSITY MODEL 5
      DATA
     * WOD(5,1) , WOD(5,2) , WOD(5,3) , WOD(5,4) , WOD(5,5) , WOD(5,6)
     * 4.100E-05, 4.100E-05, 4.100E-05, 4.300E-05, 4.500E-05, 4.700E-0
C            OZONE DENSITY MODEL 6
      DATA
     * WOD(6,1) , WOD(6,2) , WOD(6,3) , WOD(6,4) , WOD(6,5) , WOD(6,6)
     * 5.400E-05, 5.400E-05, 5.400E-05, 5.000E-05, 4.600E-05, 4.600E-0
C            SEMI-LOG INTERPOLATION
      DO 10 I=2,6
      L=I
      IF (Z .LT. ZD(L)) GO TO 12
   10 CONTINUE
   12 FAC=(Z-ZD(L-1))/(ZD(L)-ZD(L-1))
      WO=WOD(M,L-1)*(WOD(M,L)/WOD(M,L-1))**FAC
C            RETURN
      RETURN
      END
```

```
C
C** EQUABS ************************************************************
C
      SUBROUTINE EQUABS(S,IHAZE,W,RHZ,TZ)
C             CALCULATES COMPONENT AMOUNTS
      COMMON /BLK1/ ZGR(20),P(20),T(20),RH(20),WH(20),WO(20),VIS(20)
      COMMON /BLK2/ H1     , ANGLE    , SMAX
      COMMON /BLK3/ IHA(20), NPTS
      DIMENSION W(10), VSB(9)
C             DETERMINE ALTITUDE
      Z=H1+S*COS(ANGLE*3.14159/180.0)
C             DETERMINE DATA ARRAY LOCATION
      DO 100 I=2,NPTS
      L=I
      IF (Z .LT. ZGR(L)) GO TO 110
 100  CONTINUE
C             DETERMINE FACTOR
 110  FAC=(Z-ZGR(L-1))/(ZGR(L)-ZGR(L-1))
C             PRESSURE AT Z
      PZ=P(L-1)*(P(L)/P(L-1))**FAC
C             TEMPERATURE AT Z
      TZ=T(L-1)*(T(L)/T(L-1))**FAC
C             WATER DENSITY AT Z
      WHZ=WH(L-1)*(WH(L)/WH(L-1))**FAC
C             OZONE DENSITY AT Z
      WOZ=WO(L-1)*(WO(L)/WO(L-1))**FAC
C             RELATIVE HUMIDITY
      RHZ=RH(L-1)*(RH(L)/RH(L-1))**FAC
C             SET AEROSOL
      IHAZE=IHA(L-1)
      VISZ=VIS(L-1)
C             EQUIVALENT AEROSOL AMOUNT
      W(7)=0.0000
      IF (IHAZE .EQ. 0) GO TO 150
      DATA
     * VSB(1),VSB(2),VSB(3),VSB(4),VSB(5),VSB(6),VSB(7),VSB(8),VSB(9)/
     * 23.0  , 5.0  ,23.0  , 5.0  , 5.0  ,50.0  ,23.0  , 0.2  , 0.5  /
      IF (VISZ .LT. -500.0) VISZ=VSB(IHAZE)
      W(7)=3.912023/VISZ
C
 150  PA=PZ/1013.0
      TA=273.15/TZ
C             SET EQUIVALENT AMOUNTS
      D=0.1*WHZ
      X=PA*TA
      PT=PA*SQRT(TA)
C             EQUIVALENT H2O AMOUNT
      W(1)=D*PT**0.9
C             EQUIVALENT CO2 N2O AND ETC.  AMOUNT
      W(2)=X*PT**0.75
C             EQUIVALENT N2 AMOUNT
      W(4)=0.8*PT*X
C
      PPW=4.560E-05*D*TZ
```

```
      TS1=296.0/TZ
C             EQUIVALENT H2O CONTINUUM AMOUNT (10 UM)
      W(5)=D*PPW*EXP(6.08*(TS1-1.0))+0.002*D*(PA-PPW)
C             EQUIVALENT H2O CONTINUUM AMOUNT (4 UM)
      W(9)=D*(PPW+0.12*(PA-PPW))*EXP(4.56*(TS1-1.0))
C             EQUIVALENT MOLECULAR SCATTERING AMOUNT
      W(6)=X
C             EQUIVALENT OZONE AMOUNT (U.V. REGION)
      W(8)=46.6667*WOZ
C             EQUIVALENT OZONE AMOUNT (I.R. REGION)
      W(3)=W(8)*PT**0.4
      RETURN
      END
```

```
C
C** FCT ******************************* ******************************
C
      FUNCTION FCT(A)
C            FUNCTION
      FCT=A*EXP(18.9766-14.9595*A-2.43882*A*A)
      RETURN
      END
```

```
C
C** PLAN *************************************************************
C
      FUNCTION PLAN(T, IV)
C            PLANCK BLACKBODY FUNCTION
      XLAM=1 0E+04/IV
      C1=0. 59544E+08
      C2=14388. 000
      AUG=C2/(XLAM*T)
      PLAN=2. 0*C1/((XLAM**5)*(EXP(AUG)-1. 0))
      RETURN
      END
```

AD-A135 721 A STUDY OF ATMOSPHERIC TRANSMISSION IN THE WAVELENGTH 2/2
REGIONS OF 035 MICR..(U) CALIFORNIA STATE UNIV
NORTHRIDGE SCHOOL OF ENGINEERING AND CO..
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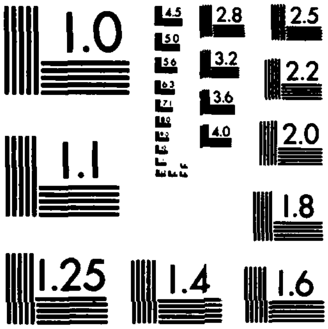

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

```
C
C** C1DTA ************************************************************
C
      SUBROUTINE C1DTA(C1,IV)
C            DETERMINE WATER VAPOR SPECTRAL COEFFICIENT
      COMMON /SPEC1/ C1ARR(2580),C2ARR(1575),C3ARR(540),C4ARR(133)
      COMMON /SPEC2/ C7ARR(280,5), C8ARR(102,2) ,C9ARR(131)
      I=0
      C1=0.000
      IF (IV .GE.   350 .AND. IV .LE.  9195) I=(IV-350)/5+1
      IF (IV .GE.  9875 .AND. IV .LE. 12795) I=(IV-9875)/5+1771
      IF (IV .GE. 13400 .AND. IV .LE. 14520) I=(IV-13400)/5+2356
      IF (I .EQ. 0) RETURN
      C1=10.000**C1ARR(I)
      RETURN
      END
```

```
C
C** C2DTA *************************************************************
C
      SUBROUTINE C2DTA(C2,IV)
C            DETERMINE UNIFORM MIXED GASES SPECTRAL COEFFICIENT
      COMMON /SPEC1/ C1ARR(2580),C2ARR(1575),C3ARR(540),C4ARR(133)
      COMMON /SPEC2/ C7ARR(280,5), C8ARR(102,2) ,C9ARR(131)
      I=0
      C2=0.000
      IF (IV .GE.   500 .AND. IV .LE.  8070) I=(IV-500)/5+1
      IF (IV .GE. 12950 .AND. IV .LE. 13245) I=(IV-12950)/5+1516
      IF (I .EQ. 0) RETURN
      C2=10.0**C2ARR(I)
      RETURN
      END
```

```
C
C** C3DTA ************************************************************
C
      SUBROUTINE C3DTA(C3,IV)
C            OZONE I. R. SPECTRAL COEFFICIENT
      COMMON /SPEC1/ C1ARR(2580),C2ARR(1575),C3ARR(540),C4ARR(133)
      COMMON /SPEC2/ C7ARR(280,5), C8ARR(102,2) ,C9ARR(131)
      I=0
      C3=0.000
      IF (IV .GE.   575 .AND.  IV .LE.   3270) I=(IV-575)/5+1
      IF (I .EQ.  0) RETURN
      C3=10.000**C3ARR(I)
      RETURN
      END
```

```
C
C** C4DTA *****************************************************************
C
      SUBROUTINE C4DTA(C4,IV)
C            NITROGEN CONTINUUM SPECTRAL COEFFICIENT
      COMMON /SPEC1/ C1ARR(2580),C2ARR(1575),C3ARR(540),C4ARR(133)
      COMMON /SPEC2/ C7ARR(280,5), C8ARR(102,2) ,C9ARR(131)
      I=0
      C4=0.000
      IF (IV .GE.  2080 .AND. IV .LE.  2740) I=(IV-2080)/5+1
      IF (I .EQ. 0) RETURN
      C4=C4ARR(I)
      RETURN
      END
```

```
C
C** C5DTA ************************************************************
C
      SUBROUTINE C5DTA(C5,IV)
C               WATER VAPER CONTINUUM (10UM) SPECTRAL COEFFICIENT
      C5=0.0000
      IF (IV .GE. 670 .AND. IV .LE. 1350) GO TO 50
      RETURN
 50   V=IV
      C5=4.18+5578.0*EXP(-7.87E-03*V)
      RETURN
      END
```

```
C
C** C6DTA **************************************************************
C
      SUBROUTINE C6DTA(C6, IV)
C             MOLECULAR SCATTERING SPECTRAL COEFFICIENT
      C6=0.000
      IF (IV .GE. 4000) GO TO 50
      RETURN
   50 V=IV
      C6=V**4/(9.26799E+18-1.07123E+09*V**2)
      RETURN
      END
```

```
C
C** C7DTA **************************************************************
C
      SUBROUTINE C7DTA(C7E,C7A,IV,RH,IHAZE)
C             DETERMINE AEROSOL SPECTRAL COEFFICIENT
      COMMON /SPEC1/ C1ARR(2580),C2ARR(1575),C3ARR(540),C4ARR(133)
      COMMON /SPEC2/ C7ARR(280,5), C8ARR(102,2) ,C9ARR(131)
      DIMENSION RHZONE(4)
      DATA
     * RHZONE(1), RHZONE(2), RHZONE(3), RHZONE(4)/
     *     0.000,     70.000,     80.000,     99.000/
C             CHECK FOR NO AEROSOL
      C7A=0.000
      C7E=0.000
      IF (IHAZE .EQ. 0) RETURN
C             DETERMINE DEPENDENT VARIABLES
      V=IV
      Y=1.0E+04/V
      X=100.0-RH
C             CHECK FOR FOGS
      IF (IHAZE .EQ. 8 .OR. IHAZE .EQ. 9) GO TO 1000
C             DETERMINE DATAFILE COLUMN
      DO 100 K=2,4
      J=K
      IF (RH .LT. RHZONE(J)) GO TO 110
  100 CONTINUE
  110 X1=100.0-RHZONE(J-1)
      X2=100.0-RHZONE(J)
C             ALLOW FOR WAVELENGTH IN FIRST COLUMN
      J=J+1
C             DETERMINE EXTINCTION COEFFICIENT
C             DETERMINE TYPE OF AEROSOL
      IF (IHAZE .EQ. 1 .OR. IHAZE .EQ. 2) ISTRT=2
      IF (IHAZE .EQ. 3 .OR. IHAZE .EQ. 4) ISTRT=162
      IF (IHAZE .EQ. 5) ISTRT=82
      IEND=ISTRT+38
C             SET UP WAVELENGTH INTERPOLATION
      DO 200 K=ISTRT,IEND
      I=K
      IF (Y .LT. C7ARR(I,1)) GO TO 210
  200 CONTINUE
C             LOG ON RH AND LINEAR ON WAVELENGTH
  210 Y1=C7ARR(I-1,1)
      Y2=C7ARR(I,1)
      ZA1=C7ARR(I-1,J-1)
      ZA2=C7ARR(I-1,J)
      ZB1=C7ARR(I,J-1)
      ZB2=C7ARR(I,J)
      FACA=ALOG(ZA2/ZA1)/ALOG(X2/X1)
      FACB=ALOG(ZB2/ZB1)/ALOG(X2/X1)
      ZA=ZA1*(X/X1)**FACA
      ZB=ZB1*(X/X1)**FACB
      FAC=(Y-Y1)/(Y2-Y1)
      C7E=FAC*(ZB-ZA)+ZA
```

```
C               DETERMINE ABSORPTION COEFFICIENT
      I=I+40
C               LOG ON RH AND LINEAR ON WAVELENGTH
      Y1=C7ARR(I-1,1)
      Y2=C7ARR(I,1)
      ZA1=C7ARR(I-1,J-1)
      ZA2=C7ARR(I-1,J)
      ZB1=C7ARR(I,J-1)
      ZB2=C7ARR(I,J)
      FACA=ALOG(ZA2/ZA1)/ALOG(X2/X1)
      FACB=ALOG(ZB2/ZB1)/ALOG(X2/X1)
      ZA=ZA1*(X/X1)**FACA
      ZB=ZB1*(X/X1)**FACB
      FAC=(Y-Y1)/(Y2-Y1)
      C7A=FAC*(ZB-ZA)+ZA
      RETURN
C               FOGS
C               DETERMINE EXTINCTION COEFFICIENT
 1000 IF (IHAZE .EQ. 8) J=2
      IF (IHAZE .EQ. 9) J=4
      ISTRT=242
      IEND=ISTRT+38
      DO 1100 K=ISTRT,IEND
      I=K
      IF (Y .LT. C7ARR(I,1)) GO TO 1110
 1100 CONTINUE
 1110 Y1=C7ARR(I-1,1)
      Y2=C7ARR(I,1)
      Z1=C7ARR(I-1,J)
      Z2=C7ARR(I,J)
      FAC=(Y-Y1)/(Y2-Y1)
      C7E=FAC*(Z2-Z1)+Z1
C               DETERMINE ABSORPTION COEFFICIENT
      IF (IHAZE .EQ. 8) J=3
      IF (IHAZE .EQ. 9) J=5
      Y1=C7ARR(I-1,1)
      Y2=C7ARR(I,1)
      Z1=C7ARR(I-1,J)
      Z2=C7ARR(I,J)
      FAC=(Y-Y1)/(Y2-Y1)
      C7A=FAC*(Z2-Z1)+Z1
      RETURN
      END
```

```
C                                                                       
C** C8DTA ***************************************************************
C
      SUBROUTINE C8DTA(C8,IV)
C                 OZONE U.V. SPECTRAL COEFFICIENT
      COMMON /SPEC1/ C1ARR(2580),C2ARR(1375),C3ARR(540),C4ARR(133)
      COMMON /SPEC2/ C7ARR(280,5), C8ARR(102,2) ,C9ARR(131)
      C8=0.000
      IF (IV .GE. 13000 .AND. IV .LE. 24000) GO TO 100
      IF (IV .GE. 27500 .AND. IV .LE. 50000) GO TO 200
      RETURN
C                 13000 CM-1 TO 24000 CM-1
  100 V=IV
      DO 120 I=2,56
      N=I
      IF (V .LT. C8ARR(N,1)) GO TO 130
  120 CONTINUE
      N=56
  130 FAC=(C8ARR(N-1,2)-C8ARR(N,2))/(C8ARR(N-1,1)-C8ARR(N,1))
      C8=FAC*(V-C8ARR(N-1,1))+C8ARR(N-1,2)
      RETURN
C                 27500 CM-1 TO 50000 CM-1
  200 V=IV
      DO 220 I=58,102
      N=I
      IF (V .LT. C8ARR(N,1)) GO TO 230
  220 CONTINUE
      N=102
  230 FAC=(C8ARR(N-1,2)-C8ARR(N,2))/(C8ARR(N-1,1)-C8ARR(N,1))
      C8=FAC*(V-C8ARR(N-1,1))+C8ARR(N-1,2)
      RETURN
      END
```

```
C
C** C9DTA *************************************************************
C
      SUBROUTINE C9DTA(C9,IV)
C             WATER VAPOR CONTINUUM (4UM) SPECTRAL COEFFICIENT
      COMMON /SPEC1/ C1ARR(2580),C2ARR(1575),C3ARR(540),C4ARR(133)
      COMMON /SPEC2/ C7ARR(280,5), C8ARR(102,2) ,C9ARR(131)
      I=0
      C9=0.000
      IF (IV .GE.  2350 .AND. IV .LE.  3000) I=(IV-2350)/5+1
      IF (I .EQ. 0) RETURN
      C9=C9ARR(I)
      RETURN
      END
```

FILM

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