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RRA RADIATION RESEARCH ASSOCIATES
Fort Worth, Texas 76104

# SCATTERING AND REFLECTANCE OF LIGHT FROM AIRBORNE LASER SYSTEMS

by
Dave G. Collins and Michael B. Wells

Contract No. F19628-67-C-0298

Project No. 7621
Task No. 762107
Work Unit No. 76210701

Scientific Report No. 4

15 June 1968

Contract Monitor
Robert W. Fenn
Optical Physics Laboratory





Prepared
for

AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
OFFICE OF AEROSPACE RESEARCH
UNITED STATES AIR FORCE
BEDFORD, MASSACHUSETTS 01730



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Dave G. Collins and Michael B. Wells

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1506 West Terrell Avenue
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SCATTERING AND REFLECTANCE OF LIGHT
FROM AIRBORNE LASER SYSTEMS

Dave G. Collins and Michael B. Wells

ABSTRACT

The LITE-I Monte Carlo program was used to predict the ground reflected and atmospheric scattered components of the scattered light from airborne laser systems received at collimated receivers located at the same altitude as the laser system and focused on the ground area illuminated by the direct radiation from the laser system. Lasers emitting light with wavelengths of 0.5145, 1.06, 3.507 and 10.6 microns were considered at different altitudes in two model atmospheres. The first atmosphere was a clear atmosphere having a ground level meteorological range of 25 km. The second atmosphere was identical to the first above 1.5 km but below 1.5 km the aerosol content was increased to reduce the ground level meteorological range to 5 km. The ground reflected component of the scattered light entering the receiver for all four wavelengths was taken to be the sum of the direct radiation incident on the ground and reflected to the receiver plus the single scattered radiation incident upon the ground area illuminated by the direct radiation and then reflected to the receiver. For the 3.507 and 10.6 micron lasers the atmospheric scattered component at the receiver in both atmospheres is composed almost entirely of single scattered light, but for the 0.5145 and 1.06 micron lasers the single scattered irradiance seriously underpredicts the atmospheric scattered component for lookangles greater than just a few degrees.

## FOREWORD

This report was prepared by Radiation Research Associates, Inc., Fort Worth, Texas, under Contract No. F19628-67-C-0298.

The contract is under the technical direction of Dr. Robert W. Fenn of the Air Force Cambridge Research Laboratories, L. G. Hanscom Field, Bedford, Massachusetts.

Mr. Michael B. Wells of Radiation Research Associates, Inc., was principal investigator. Mr. Dave G. Collins was the principal mathematician and programmer. In addition, Mr. J. D. Marshall, Mr. J. M. Newell, and Mrs. Frances Hopper contributed to the program. Dr. Fredric E. Volz of AFCRL provided valuable consultation on the atmospheric description. Mr. Karekin Agazarian was very helpful in checking out the computer programs at AFCRL and in performing all the computer runs.

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# I. INTRODUCTION

The amounts of the electromagnetic radiation originating from an airborne laser system that are reflected from the ground and scattered within the air into a collimated receiver located at the same altitude as the airborne laser system have been computed for two model atmospheres. Laser sources emitting radiation with wavelengths of 0.5145, 1.06, 3.507, and 10.6 microns and directed vertically downward were located within the atmospheres at 300, 1500, 6000, 9000 and 18000 meters altitude. At each source altitude, collimated receivers were placed at various horizontal ranges. These receivers were focused upon the area of ground surface illuminated by the direct radiation from the source.

The ground surface was considered to be a Lambert type surface for which the ground albedo was varied from 0.0 to 0.9. A detailed description of the two model atmospheres used in the calculations is given in Section II.

The relative amounts of the ground reflected and air scattered radiation received by the collimated receivers were evaluated through the use of the LITE-I Monte Carlo program (Ref. 1) and a single scattering analysis that is discussed in Section II. The results of the calculations are also presented and discussed in Section III.

The two model atmospheres used in this study differed only in the aerosol content at altitudes below 1.5 km. The temperature and water vapor distributions with respect to pressure for the model atmospheres are shown in Table I. These data were obtained from July 1966 soundings in Saigon (Ref. 2). The atmospheric pressures were related to altitudes by assuming that the pressure variation with altitude was the same as that given for the tropical $15^{o}$ North latitude atmosphere in the AFCRL Handbook of Geophysics and Space Environments (Ref. 3). The Rayleigh scattering cross sections for wavelengths of 0.5145, 1.06, 3.507, and 10.6 microns were computed for the atmospheric density and pressure profiles given as a function of altitude in Table I using the equations reported by Penndorf (Ref. 4).

The aerosol scattering and total cross sections and aerosol phase functions for each of the four wavelengths as well as for 0.55 micron wavelength light were computed by use of the machine procedures described in Ref. 5 for the Haze C aerosol size distribution given by Deirmendjian for a continental haze (Ref. 6). A real refractive index of 1.50 was assumed for the aerosols for 0.5145, 0.55 and 1.06 micron wavelength light, and complex refractive indices of 1.50-0.007i and 1.47-0.1i were assumed for the 3.507 and 10.6 micron wavelengths. The computed aerosol scattering coefficients per particle as a function of wavelength were normalized at 0.55 microns to the aerosol scattering coefficient computed for atmospheres with ground level meteorological ranges of 25 km and 5 km to give the magnitudes of the aerosol cross section at ground level as a function of wavelength.

For the first atmosphere, the aerosol cross sections for each wavelength were assumed to vary with altitude according to the profile given by Elterman for a model clear standard atmosphere (Ref. 7). For the second atmosphere, the aerosol profile above one and a half kilometers was taken to be identical to that for

TABLE I

TEMPERATURE, PRESSURE, AND WATER VAPOR DISTRIBUTIONS VERSUS ALTITUDES

| ALTITUDE (KM) | TEMPERATURE (DEG.K) | PRESSURE (MB.) | WATER VAPOR (PREC.CM) |
|---|---|---|---|
| 0.000+00 | 3.005+02 | 1.01325+03 | 2.15+00 |
| 1.000+00 | 2.940+02 | 9.04134+02 | 1.50+00 |
| 2.000+00 | 2.883+02 | 8.04790+02 | 1.06+00 |
| 3.000+00 | 2.830+02 | 7.14754+02 | 7.30-01 |
| 4.000+00 | 2.775+02 | 6.33206+02 | 4.80-01 |
| 5.000+00 | 2.715+02 | 5.59266+02 | 3.12-01 |
| 6.000+00 | 2.656+02 | 4.92402+02 | 1.98-01 |
| 7.000+00 | 2.603+02 | 4.32099+02 | 1.22-01 |
| 8.000+00 | 2.546+02 | 3.77918+02 | 7.50-02 |
| 9.000+00 | 2.484+02 | 3.29330+02 | 4.25-02 |
| 1.000+01 | 2.412+02 | 2.85890+02 | 1.88-02 |
| 1.100+01 | 2.325+02 | 2.47214+02 | 4.20-03 |
| 1.200+01 | 2.238+02 | 2.12859+02 | 1.17-03 |
| 1.300+01 | 2.152+02 | 1.82451+02 | 4.10-04 |
| 1.400+01 | 2.066+02 | 1.55637+02 | 1.84-04 |
| 1.500+01 | 2.011+02 | 1.32109+02 | 9.30-05 |
| 1.600+01 | 1.963+02 | 1.11548+02 | 6.10-05 |
| 1.700+01 | 1.948+02 | 9.37040+01 | 4.70-05 |
| 1.800+01 | 1.988+02 | 7.88798+01 | 4.00-05 |
| 1.900+01 | 2.027+02 | 6.66272+01 | 3.70-05 |
| 2.000+01 | 2.067+02 | 5.64623+01 | 3.55-05 |
| 2.100+01 | 2.107+02 | 4.80069+01 | 3.57-05 |
| 2.200+01 | 2.146+02 | 4.09413+01 | 3.75-05 |
| 2.300+01 | 2.170+02 | 3.50059+01 | 4.15-05 |
| 2.400+01 | 2.192+02 | 2.99734+01 | 4.80-05 |
| 2.500+01 | 2.214+02 | 2.57079+01 | 5.10-05 |
| 2.600+01 | 2.236+02 | 2.02859+01 | 6.00-05 |
| 2.700+01 | 2.258+02 | 1.89993+01 | 6.50-05 |
| 2.800+01 | 2.279+02 | 1.63701+01 | 6.90-05 |
| 2.900+01 | 2.301+02 | 1.41247+01 | 7.20-05 |
| 3.000+01 | 2.323+02 | 1.22061+01 | 7.20-05 |
| 3.100+01 | 2.345+02 | 1.05624+01 | 7.20-05 |
| 3.200+01 | 2.366+02 | 9.15227+00 | 7.10-05 |
| 3.300+01 | 2.388+02 | 7.94080+00 | 6.80-05 |
| 3.400+01 | 2.410+02 | 6.89953+00 | 6.50-05 |
| 3.500+01 | 2.431+02 | 6.00237+00 | 6.30-05 |
| 3.600+01 | 2.453+02 | 5.22906+00 | 5.80-05 |
| 3.700+01 | 2.475+02 | 4.56029+00 | 5.50-05 |
| 3.800+01 | 2.497+02 | 3.98236+00 | 5.10-05 |
| 3.900+01 | 3.518+02 | 3.48221+00 | 4.70-05 |
| 4.000+01 | 2.540+02 | 3.04839+00 | 4.30-05 |
| 4.100+01 | 2.562+02 | 2.97127+00 | 3.90-05 |
| 4.200+01 | 2.583+02 | 2.34404+00 | 3.50-05 |
| 4.300+01 | 2.605+02 | 2.05886+00 | 3.10-05 |
| 4.400+01 | 2.627+02 | 1.81056+00 | 2.80-05 |
| 4.500+01 | 2.648+02 | 1.59389+00 | 2.50-05 |
| 4.600+01 | 2.670+02 | 1.40478+00 | 2.20-05 |
| 4.700+01 | 2.691+02 | 1.23937+00 | 2.00-05 |
| 4.800+01 | 2.702+02 | 1.09438+00 | 1.80-05 |
| 4.900+01 | 2.702+02 | 0.96645+00 | 2.60-05 |
| 5.000+01 | 2.702+02 | 0.85359+00 | 1.40-05 |

the first atmosphere, but below one and a half kilometers, the aerosol distribution was assumed to be constant with altitude. The aerosol size distribution below 1.5 kilometers was still considered to be defined by the Model C aerosol size distribution, but the concentration was increased to reduce the ground level meteorological range to 5 km.

The variation of the attenuation coefficients with altitude in the Model Atmosphere with a ground level meteorological range of 25 km is shown in Tables II, III, IV and V for wavelengths of 0.5145μ, 1.0648μ, 3.507μ, and 10.6μ, respectively. Only the aerosol attenuation coefficient for altitudes below 1.5 kilometers were changed for the second atmosphere. For 0.5145μ wavelength light the only significant absorption process was ozone absorption. An interpolation on the ozone cross sections listed by Elterman (Ref. 7) for wavelengths on either side of 0.5145 micron wavelength gave the data listed in Table II. Machine calculations of the water vapor absorption coefficient versus temperature and pressure, taking into account the contributions from lines lying ±50 wavenumbers on either side of 1.0648 microns, were furnished by Dr. R. F. Calfee (Ref. 8). These data are listed versus altitude in Table III where the relation between altitude and pressure was assumed to be that given for the 15° N tropical atmosphere in Reference 3. For the 3.507 and the 10.6 micron wavelengths, absorption by aerosol particles becomes significant. For the 3.507μ wavelength, the absorption by $CO_2$ was considered to be negligible, but for the 10.6 micron wavelength, the $CO_2$ absorption coefficient derived by Long (Ref. 9) was used. Water vapor absorption coefficients for both the 3.057 and 10.6 micron wavelengths were taken from data reported by Goody (Ref. 10). For 10.6 microns the variation of the water vapor absorption coefficient with altitude was assumed to depend only on the water vapor density, but for the 3.507 micron wavelength the water vapor absorption coefficient was also assumed to vary with the square root of the pressure as a function of altitude.

TABLE II

CROSS SECTIONS VERSUS ALTITUDE FOR 0.5145μ WAVELENGTH LIGHT ($KM^{-1}$)

| ALTITUDE (KM) | RAYLEIGH SCATTERING | AEROSOL SCATTERING | OZONE ABSORPTION |
|---|---|---|---|
| 0.000+00 | 0.145-01 | 0.153+00 | 0.182-03 |
| 0.100+01 | 0.132-01 | 0.677-01 | 0.167-03 |
| 0.200+01 | 0.120-01 | 0.292-01 | 0.150-03 |
| 0.300+01 | 0.109-01 | 0.122-01 | 0.128-03 |
| 0.400+01 | 0.989-02 | 0.554-02 | 0.116-03 |
| 0.500+01 | 0.896-02 | 0.246-02 | 0.113-03 |
| 0.600+01 | 0.809-02 | 0.846-03 | 0.111-03 |
| 0.700+01 | 0.728-02 | 0.307-03 | 0.114-03 |
| 0.800+01 | 0.654-02 | 0.108-03 | 0.117-03 |
| 0.900+01 | 0.586-02 | 0.384-04 | 0.144-03 |
| 0.100+02 | 0.523-02 | 0.199-04 | 0.179-03 |
| 0.110+02 | 0.465-02 | 0.185-04 | 0.235-03 |
| 0.120+02 | 0.412-02 | 0.169-04 | 0.318-03 |
| 0.130+02 | 0.364-02 | 0.185-04 | 0.433-03 |
| 0.140+02 | 0.320-02 | 0.199-04 | 0.490-03 |
| 0.150+02 | 0.281-02 | 0.323-04 | 0.509-03 |
| 0.160+02 | 0.245-02 | 0.523-04 | 0.528-03 |
| 0.170+02 | 0.208-02 | 0.570-04 | 0.569-03 |
| 0.180+02 | 0.172-02 | 0.615-04 | 0.624-03 |
| 0.190+02 | 0.142-02 | 0.692-04 | 0.730-03 |
| 0.200+02 | 0.118-02 | 0.661-04 | 0.842-03 |
| 0.210+02 | 0.988-03 | 0.631-04 | 0.942-03 |
| 0.220+02 | 0.827-03 | 0.615-04 | 0.100-02 |
| 0.230+02 | 0.699-03 | 0.584-04 | 0.101-02 |
| 0.240+02 | 0.592-03 | 0.400-04 | 0.993-03 |
| 0.250+02 | 0.503-03 | 0.276-04 | 0.926-03 |
| 0.260+02 | 0.428-03 | 0.199-04 | 0.836-03 |
| 0.270+02 | 0.364-03 | 0.185-04 | 0.725-03 |
| 0.280+02 | 0.311-03 | 0.169-04 | 0.630-03 |
| 0.290+02 | 0.266-03 | 0.153-04 | 0.548-03 |
| 0.300+02 | 0.227-03 | 0.146-04 | 0.463-03 |
| 0.310+02 | 0.195-03 | 0.000+00 | 0.407-03 |
| 0.320+02 | 0.167-03 | 0.000+00 | 0.349-03 |
| 0.330+02 | 0.144-03 | 0.000+00 | 0.298-03 |
| 0.340+02 | 0.124-03 | 0.000+00 | 0.247-03 |
| 0.350+02 | 0.107-03 | 0.000+00 | 0.221-03 |
| 0.360+02 | 0.924-04 | 0.000+00 | 0.185-03 |
| 0.370+02 | 0.799-04 | 0.000+00 | 0.155-03 |
| 0.380+02 | 0.691-04 | 0.000+00 | 0.129-03 |
| 0.390+02 | 0.599-04 | 0.000+00 | 0.111-03 |
| 0.400+02 | 0.520-04 | 0.000+00 | 0.954-04 |
| 0.410+02 | 0.452-04 | 0.000+00 | 0.781-04 |
| 0.420+02 | 0.393-04 | 0.000+00 | 0.608-04 |
| 0.430+02 | 0.342-04 | 0.000+00 | 0.477-04 |
| 0.440+02 | 0.298-04 | 0.000+00 | 0.381-04 |
| 0.450+02 | 0.261-04 | 0.000+00 | 0.295-04 |
| 0.460+02 | 0.228-04 | 0.000+00 | 0.228-04 |
| 0.470+02 | 0.199-04 | 0.000+00 | 0.181-04 |
| 0.480+02 | 0.175-04 | 0.000+00 | 0.143-04 |
| 0.490+02 | 0.155-04 | 0.000+00 | 0.114-04 |
| 0.500+02 | 0.137-04 | 0.000+00 | 0.954-05 |

TABLE III

CROSS SECTIONS VERSUS ALTITUDE FOR 1.0648μ WAVELENGTH LIGHT ($KM^{-1}$)

| ALTITUDE (KM) | RAYLEIGH SCATTERING | AEROSOL SCATTERING | WATER VAPOR ABSORPTION |
|---|---|---|---|
| 0.000+00 | 0.780-03 | 0.772-01 | 0.184-03 |
| 0.100+01 | 0.711-03 | 0.339-01 | 0.989-04 |
| 0.200+01 | 0.647-03 | 0.146-01 | 0.556-04 |
| 0.300+01 | 0.585-03 | 0.615-02 | 0.306-04 |
| 0.400+01 | 0.531-03 | 0.278-02 | 0.161-04 |
| 0.500+01 | 0.481-03 | 0.123-02 | 0.858-05 |
| 0.600+01 | 0.434-03 | 0.424-03 | 0.445-05 |
| 0.700+01 | 0.391-03 | 0.154-03 | 0.223-05 |
| 0.800+01 | 0.351-03 | 0.542-04 | 0.108-05 |
| 0.900+01 | 0.314-03 | 0.193-04 | 0.501-06 |
| 0.100+02 | 0.281-03 | 0.100-04 | 0.178-06 |
| 0.110+02 | 0.250-03 | 0.928-05 | 0.327-07 |
| 0.120+02 | 0.221-03 | 0.850-05 | 0.766-08 |
| 0.130+02 | 0.195-03 | 0.928-05 | 0.225-08 |
| 0.140+02 | 0.172-03 | 0.100-04 | 0.846-09 |
| 0.150+02 | 0.151-03 | 0.162-04 | 0.362-09 |
| 0.160+02 | 0.131-03 | 0.262-04 | 0.198-09 |
| 0.170+02 | 0.112-03 | 0.285-04 | 0.129-09 |
| 0.180+02 | 0.924-04 | 0.308-04 | 0.932-10 |
| 0.190+02 | 0.765-04 | 0.347-04 | 0.747-10 |
| 0.200+02 | 0.636-04 | 0.331-04 | 0.621-10 |
| 0.210+02 | 0.530-04 | 0.316-04 | 0.535-10 |
| 0.220+02 | 0.444-04 | 0.308-04 | 0.487-10 |
| 0.230+02 | 0.375-04 | 0.293-04 | 0.456-10 |
| 0.240+02 | 0.318-04 | 0.200-04 | 0.460-10 |
| 0.250+02 | 0.270-04 | 0.138-04 | 0.428-10 |
| 0.260+02 | 0.230-04 | 0.100-04 | 0.443-10 |
| 0.270+02 | 0.196-04 | 0.928-05 | 0.425-10 |
| 0.280+02 | 0.167-04 | 0.850-05 | 0.400-10 |
| 0.290+02 | 0.142-04 | 0.772-05 | 0.374-10 |
| 0.300+02 | 0.122-04 | 0.733-05 | 0.338-10 |
| 0.310+02 | 0.104-04 | 0.000+00 | 0.300-10 |
| 0.320+02 | 0.900-05 | 0.000+00 | 0.269-10 |
| 0.330+02 | 0.774-05 | 0.000+00 | 0.231-10 |
| 0.340+02 | 0.666-05 | 0.000+00 | 0.201-10 |
| 0.350+02 | 0.575-05 | 0.000+00 | 0.176-10 |
| 0.360+02 | 0.496-05 | 0.000+00 | 0.147-10 |
| 0.370+02 | 0.429-05 | 0.000+00 | 0.127-10 |
| 0.380+02 | 0.371-05 | 0.000+00 | 0.107-10 |
| 0.390+02 | 0.322-05 | 0.000+00 | 0.902-11 |
| 0.400+02 | 0.279-05 | 0.000+00 | 0.761-11 |
| 0.410+02 | 0.242-05 | 0.000+00 | 0.631-11 |
| 0.420+02 | 0.211-05 | 0.000+00 | 0.521-11 |
| 0.430+02 | 0.184-05 | 0.000+00 | 0.418-11 |
| 0.440+02 | 0.160-05 | 0.000+00 | 0.352-11 |
| 0.450+02 | 0.140-05 | 0.000+00 | 0.287-11 |
| 0.460+02 | 0.122-05 | 0.000+00 | 0.230-11 |
| 0.470+02 | 0.107-05 | 0.000+00 | 0.194-11 |
| 0.480+02 | 0.943-06 | 0.000+00 | 0.160-11 |
| 0.490+02 | 0.833-06 | 0.000+00 | 0.213-11 |
| 0.500+02 | 0.736-06 | 0.000+00 | 0.100-11 |

TABLE IV

CROSS SECTIONS VERSUS ALTITUDE FOR 3.507μ WAVELENGTH LIGHT ($KM^{-1}$)

| ALTITUDE (KM) | RAYLEIGH SCATTERING | AEROSOL SCATTERING | AEROSOL ABSORPTION | WATER VAPOR ABSORPTION |
|---|---|---|---|---|
| 0.000+00 | 0.644-05 | 0.217-01 | 0.172-02 | 0.131+00 |
| 0.100+01 | 0.587-05 | 0.954-02 | 0.757-03 | 0.867-01 |
| 0.200+01 | 0.535-05 | 0.412-02 | 0.326-03 | 0.579-01 |
| 0.300+01 | 0.483-05 | 0.170-02 | 0.137-03 | 0.375-01 |
| 0.400+01 | 0.439-05 | 0.781-03 | 0.620-04 | 0.232-01 |
| 0.500+01 | 0.397-05 | 0.347-03 | 0.275-04 | 0.142-01 |
| 0.600+01 | 0.359-05 | 0.119-03 | 0.947-05 | 0.845-02 |
| 0.700+01 | 0.323-05 | 0.434-04 | 0.344-05 | 0.487-02 |
| 0.800+01 | 0.290-05 | 0.152-04 | 0.121-05 | 0.280-02 |
| 0.900+01 | 0.260-05 | 0.542-05 | 0.430-06 | 0.148-02 |
| 0.100+02 | 0.232-05 | 0.281-05 | 0.223-06 | 0.611-03 |
| 0.110+02 | 0.206-05 | 0.261-05 | 0.207-06 | 0.127-03 |
| 0.120+02 | 0.183-05 | 0.239-05 | 0.189-06 | 0.329-04 |
| 0.130+02 | 0.161-05 | 0.261-05 | 0.207-06 | 0.107-04 |
| 0.140+02 | 0.142-05 | 0.281-05 | 0.223-06 | 0.442-05 |
| 0.150+02 | 0.124-05 | 0.456-05 | 0.361-06 | 0.206-05 |
| 0.160+02 | 0.108-05 | 0.737-05 | 0.585-06 | 0.124-05 |
| 0.170+02 | 0.925-06 | 0.803-05 | 0.637-06 | 0.874-06 |
| 0.180+02 | 0.763-06 | 0.868-05 | 0.688-06 | 0.684-06 |
| 0.190+02 | 0.632-06 | 0.976-05 | 0.774-06 | 0.581-06 |
| 0.200+02 | 0.525-06 | 0.932-05 | 0.739-06 | 0.515-06 |
| 0.210+02 | 0.438-06 | 0.890-05 | 0.706-06 | 0.475-06 |
| 0.220+02 | 0.367-06 | 0.868-05 | 0.688-06 | 0.461-06 |
| 0.230+02 | 0.310-06 | 0.824-05 | 0.653-06 | 0.473-06 |
| 0.240+02 | 0.263-06 | 0.564-05 | 0.447-06 | 0.504-06 |
| 0.250+02 | 0.223-06 | 0.390-05 | 0.309-06 | 0.496-06 |
| 0.260+02 | 0.190-06 | 0.281-05 | 0.223-06 | 0.542-06 |
| 0.270+02 | 0.161-06 | 0.261-05 | 0.207-06 | 0.545-06 |
| 0.280+02 | 0.138-06 | 0.239-05 | 0.189-06 | 0.537-06 |
| 0.290+02 | 0.118-06 | 0.217-05 | 0.172-06 | 0.520-06 |
| 0.300+02 | 0.101-06 | 0.206-05 | 0.163-06 | 0.484-06 |
| 0.310+02 | 0.866-07 | 0.000+00 | 0.000+00 | 0.449-06 |
| 0.320+02 | 0.744-07 | 0.000+00 | 0.000+00 | 0.413-06 |
| 0.330+02 | 0.639-07 | 0.000+00 | 0.000+00 | 0.369-06 |
| 0.340+02 | 0.550-07 | 0.000+00 | 0.000+00 | 0.328-06 |
| 0.350+02 | 0.474-07 | 0.000+00 | 0.000+00 | 0.297-06 |
| 0.360+02 | 0.410-07 | 0.000+00 | 0.000+00 | 0.255-06 |
| 0.370+02 | 0.354-07 | 0.000+00 | 0.000+00 | 0.226-06 |
| 0.380+02 | 0.306-07 | 0.000+00 | 0.000+00 | 0.196-06 |
| 0.390+02 | 0.266-07 | 0.000+00 | 0.000+00 | 0.169-06 |
| 0.400+02 | 0.230-07 | 0.000+00 | 0.000+00 | 0.144-06 |
| 0.410+02 | 0.200-07 | 0.000+00 | 0.000+00 | 0.122-06 |
| 0.420+02 | 0.174-07 | 0.000+00 | 0.000+00 | 0.103-06 |
| 0.430+02 | 0.152-07 | 0.000+00 | 0.000+00 | 0.856-07 |
| 0.440+02 | 0.132-07 | 0.000+00 | 0.000+00 | 0.725-07 |
| 0.450+02 | 0.115-07 | 0.000+00 | 0.000+00 | 0.608-07 |
| 0.460+02 | 0.101-07 | 0.000+00 | 0.000+00 | 0.502-07 |
| 0.470+02 | 0.885-08 | 0.000+00 | 0.000+00 | 0.428-07 |
| 0.480+02 | 0.779-08 | 0.000+00 | 0.000+00 | 0.362-07 |
| 0.490+02 | 0.668-08 | 0.000+00 | 0.000+00 | 0.302-07 |
| 0.500+02 | 0.607-08 | 0.000+00 | 0.000+00 | 0.249-07 |

TABLE V

CROSS SECTIONS VERSUS ALTITUDES FOR 10.6 WAVELENGTH LIGHT ($KM^{-1}$)

| ALTITUDE (KM) | RAYLEIGH SCATTERING | AEROSOL SCATTERING | AEROSOL ABSORPTION | WATER VAPOR ABSORPTION | CO2 ABSORPTION |
|---|---|---|---|---|---|
| 0.000+00 | 0.771-07 | 0.436-02 | 0.543-02 | 0.159+00 | 0.632-01 |
| 0.100+01 | 0.704-07 | 0.191-02 | 0.238-02 | 0.111+00 | 0.478-01 |
| 0.200+01 | 0.641-07 | 0.827-03 | 0.103-02 | 0.784-01 | 0.375-01 |
| 0.300+01 | 0.579-07 | 0.347-03 | 0.433-03 | 0.540-01 | 0.303-01 |
| 0.400+01 | 0.526-07 | 0.157-03 | 0.195-03 | 0.355-01 | 0.247-01 |
| 0.500+01 | 0.476-07 | 0.698-04 | 0.869-04 | 0.231-01 | 0.207-01 |
| 0.600+01 | 0.430-07 | 0.239-04 | 0.298-04 | 0.147-01 | 0.157-01 |
| 0.700+01 | 0.387-07 | 0.872-05 | 0.108-04 | 0.903-02 | 0.123-01 |
| 0.800+01 | 0.348-07 | 0.306-05 | 0.381-05 | 0.555-02 | 0.921-02 |
| 0.900+01 | 0.311-07 | 0.109-05 | 0.135-05 | 0.314-02 | 0.680-02 |
| 0.100+02 | 0.278-07 | 0.565-06 | 0.704-06 | 0.139-02 | 0.550-02 |
| 0.110+02 | 0.247-07 | 0.524-06 | 0.653-06 | 0.318-03 | 0.480-02 |
| 0.120+02 | 0.219-07 | 0.480-06 | 0.598-06 | 0.866-04 | 0.410-02 |
| 0.130+02 | 0.193-07 | 0.524-06 | 0.653-06 | 0.303-04 | 0.380-02 |
| 0.140+02 | 0.170-07 | 0.565-06 | 0.704-06 | 0.136-04 | 0.374-02 |
| 0.150+02 | 0.149-07 | 0.916-06 | 0.114-05 | 0.688-05 | 0.380-02 |
| 0.160+02 | 0.130-07 | 0.148-05 | 0.184-05 | 0.451-05 | 0.400-02 |
| 0.170+02 | 0.110-07 | 0.161-05 | 0.201-05 | 0.348-05 | 0.420-02 |
| 0.180+02 | 0.914-08 | 0.174-05 | 0.217-05 | 0.296-05 | 0.440-02 |
| 0.190+02 | 0.757-08 | 0.196-05 | 0.244-05 | 0.274-05 | 0.450-02 |
| 0.200+02 | 0.629-08 | 0.187-05 | 0.233-05 | 0.263-05 | 0.469-02 |
| 0.210+02 | 0.525-08 | 0.178-05 | 0.222-05 | 0.264-05 | 0.480-02 |
| 0.220+02 | 0.439-08 | 0.174-05 | 0.217-05 | 0.278-05 | 0.490-02 |
| 0.230+02 | 0.371-08 | 0.165-05 | 0.206-05 | 0.307-05 | 0.500-02 |
| 0.240+02 | 0.315-08 | 0.113-05 | 0.141-05 | 0.355-05 | 0.510-02 |
| 0.250+02 | 0.267-08 | 0.783-06 | 0.976-06 | 0.377-05 | 0.514-02 |
| 0.260+02 | 0.227-08 | 0.565-06 | 0.704-06 | 0.444-05 | 0.510-02 |
| 0.270+02 | 0.194-08 | 0.524-06 | 0.653-06 | 0.481-05 | 0.490-02 |
| 0.280+02 | 0.165-08 | 0.480-06 | 0.598-06 | 0.511-05 | 0.460-02 |
| 0.290+02 | 0.141-08 | 0.436-06 | 0.543-06 | 0.533-05 | 0.430-02 |
| 0.300+02 | 0.121-08 | 0.413-06 | 0.515-06 | 0.533-05 | 0.410-02 |
| 0.310+02 | 0.103-08 | 0.000+00 | 0.000+00 | 0.533-05 | 0.360-02 |
| 0.320+02 | 0.891-09 | 0.000+00 | 0.000+00 | 0.525-05 | 0.300-02 |
| 0.330+02 | 0.766-09 | 0.000+00 | 0.000+00 | 0.502-05 | 0.250-02 |
| 0.340+02 | 0.660-09 | 0.000+00 | 0.000+00 | 0.481-05 | 0.200-02 |
| 0.350+02 | 0.569-09 | 0.000+00 | 0.000+00 | 0.466-05 | 0.120-02 |
| 0.360+02 | 0.491-09 | 0.000+00 | 0.000+00 | 0.429-05 | 0.500-03 |
| 0.370+02 | 0.424-09 | 0.000+00 | 0.000+00 | 0.407-05 | 0.000+00 |
| 0.380+02 | 0.367-09 | 0.000+00 | 0.000+00 | 0.377-05 | 0.000+00 |
| 0.390+02 | 0.318-09 | 0.000+00 | 0.000+00 | 0.348-05 | 0.000+00 |
| 0.400+02 | 0.276-09 | 0.000+00 | 0.000+00 | 0.318-05 | 0.000+00 |
| 0.410+02 | 0.240-09 | 0.000+00 | 0.000+00 | 0.289-05 | 0.000+00 |
| 0.420+02 | 0.209-09 | 0.000+00 | 0.000+00 | 0.259-05 | 0.000+00 |
| 0.430+02 | 0.182-09 | 0.000+00 | 0.000+00 | 0.229-05 | 0.000+00 |
| 0.440+02 | 0.158-09 | 0.000+00 | 0.000+00 | 0.207-05 | 0.000+00 |
| 0.450+02 | 0.138-09 | 0.000+00 | 0.000+00 | 0.185-05 | 0.000+00 |
| 0.460+02 | 0.121-09 | 0.000+00 | 0.000+00 | 0.163-05 | 0.000+00 |
| 0.470+02 | 0.106-09 | 0.000+00 | 0.000+00 | 0.143-05 | 0.000+00 |
| 0.480+02 | 0.933-10 | 0.000+00 | 0.000+00 | 0.133-05 | 0.000+00 |
| 0.490+02 | 0.824-10 | 0.000+00 | 0.000+00 | 0.118-05 | 0.000+00 |
| 0.500+02 | 0.728-10 | 0.000+00 | 0.000+00 | 0.104-05 | 0.000+00 |

The normalized aerosol phase functions for each of the four wavelengths are shown in Figs. 1 through 4. Although the normalized aerosol phase functions are almost identical over a larger position of the scattering angle range, the scattering angles where the largest differences appear are those near 0 and 180 degrees. The phase functions shown in Figs. 1 through 4 are normalized so that an integration over solid angle gives a value of 1.0.

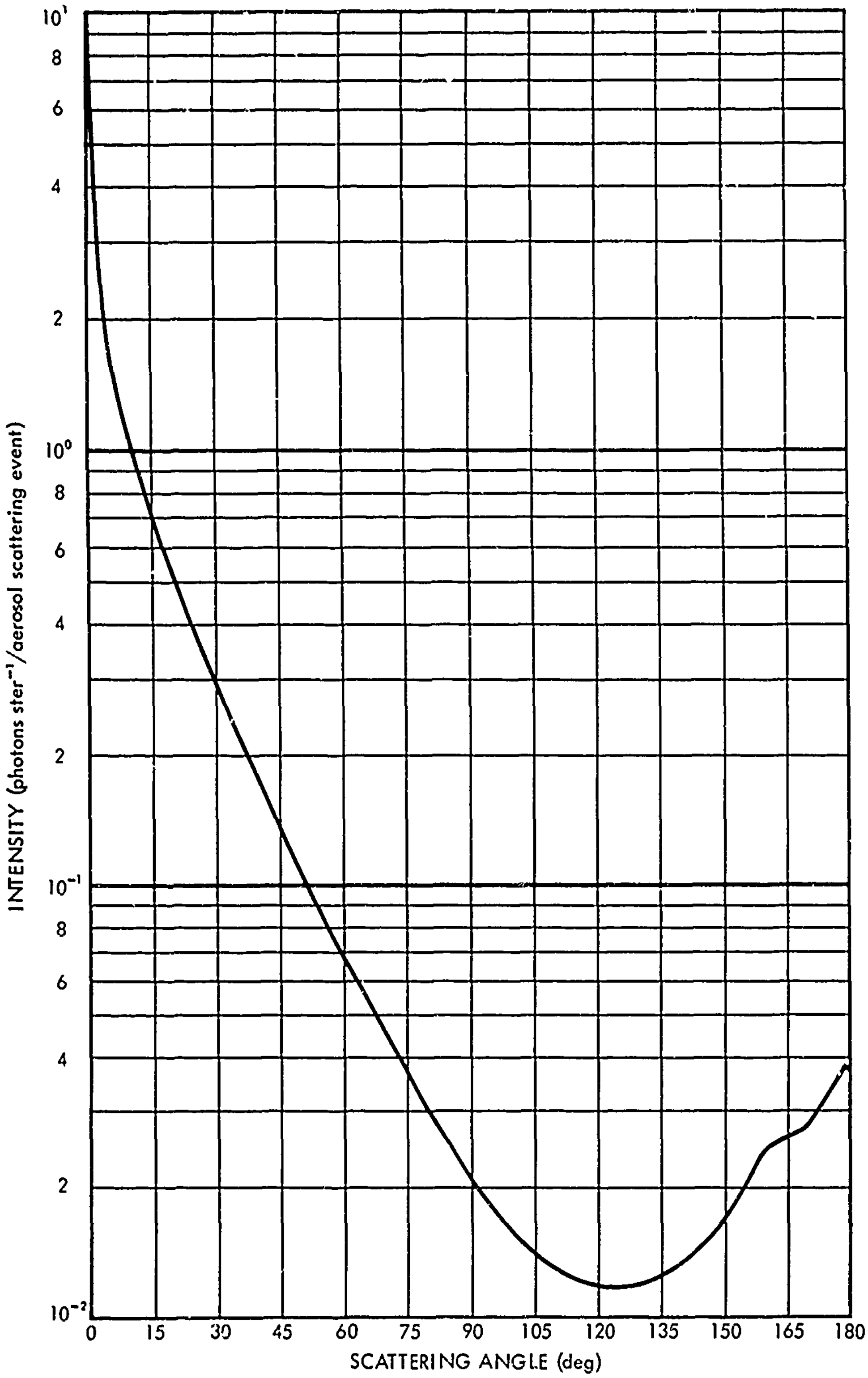


Fig. 1. Haze C Model Aerosol Phase Function for 0.5145 Micron Wavelength Light: Index of Refraction = 1.50 - 0.0i

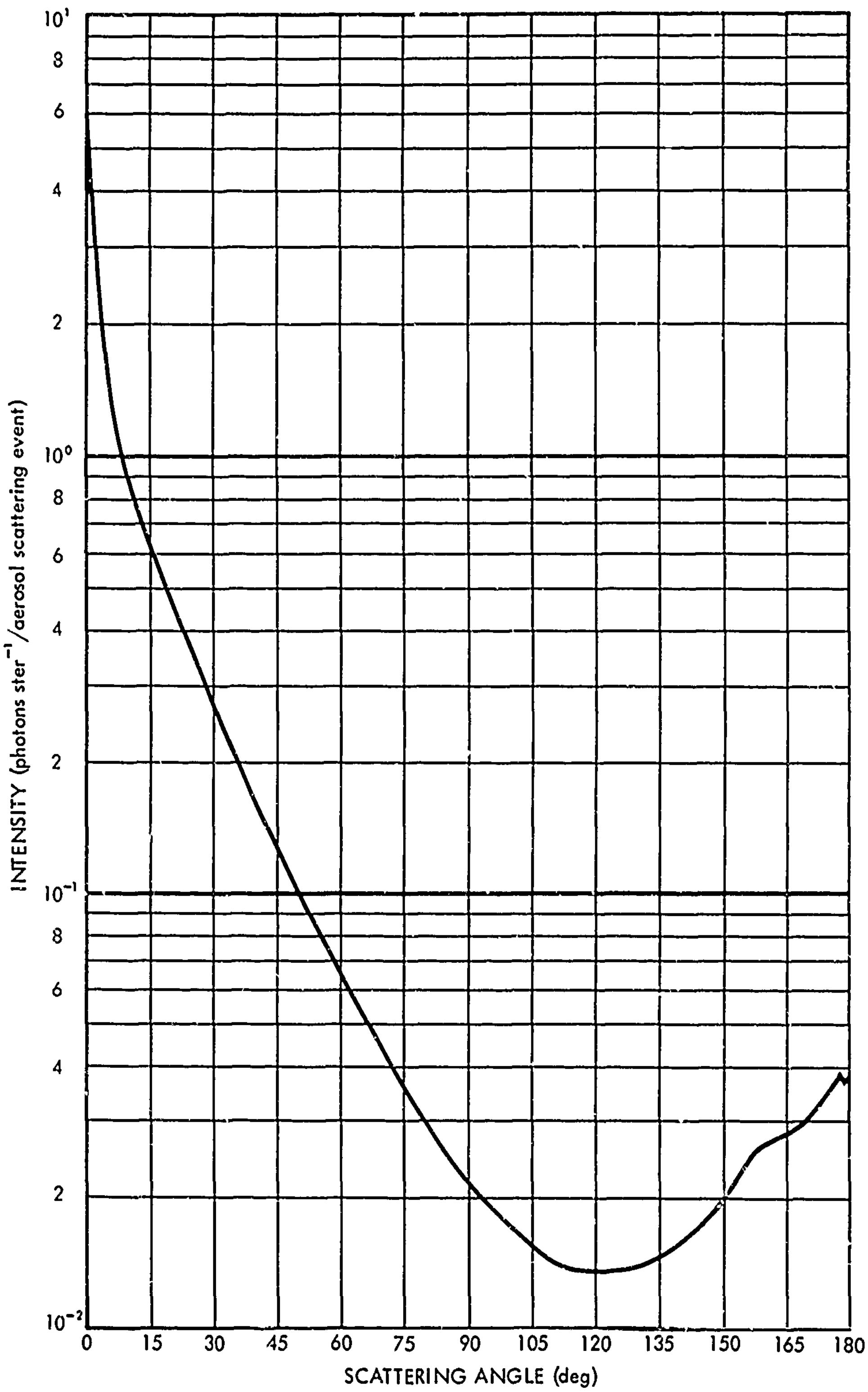


Fig. 2. Haze C Model Aerosol Phase Function for 1.06 Micron Wavelength Light: Index of Refraction = 1.50 - 0.0i

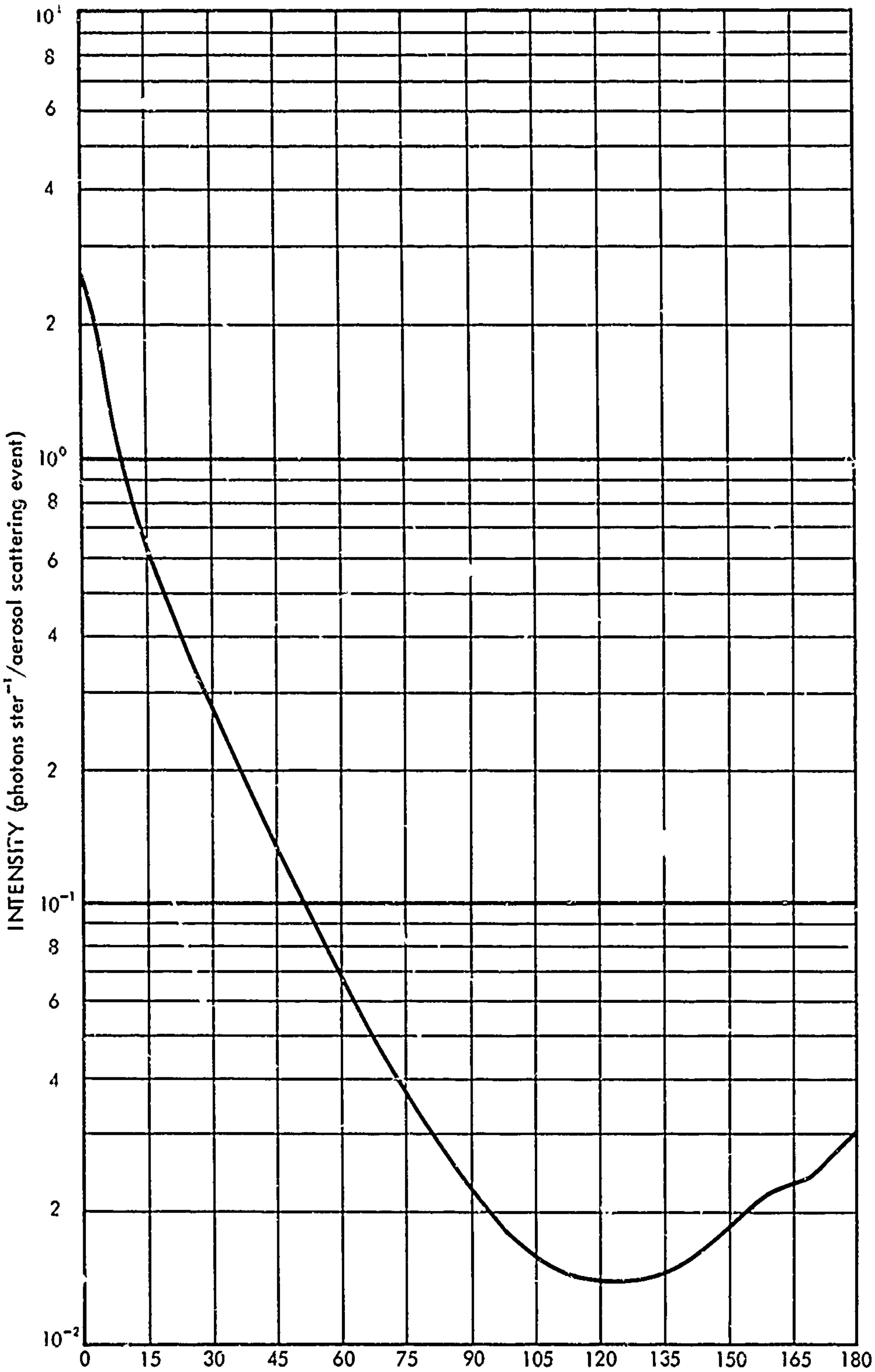


Fig. 3. Haze C Model Aerosol Phase Function for 3.507 Micron Wavelength Light: Index of Refraction = 1.50 - 0.007i

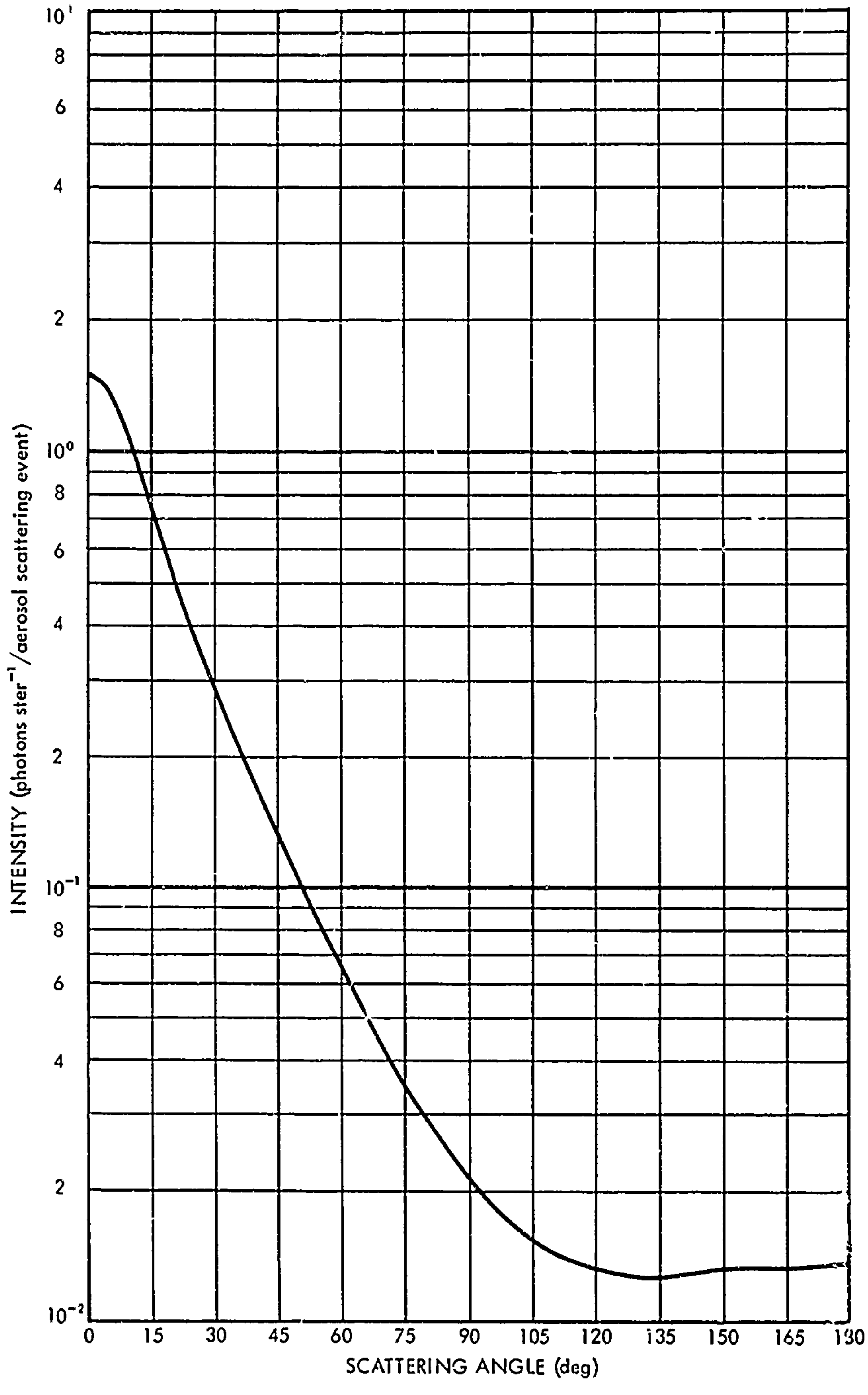


Fig. 4. Haze C Model Aerosol Phase Function for 10.6 Micron Wavelength Light. Index of Refraction = 1.47 - 0.1i

## III. PATH RADIANCES AND GROUND REFLECTANCES

The LITE-I program was used to compute the irradiance at collimated receivers located at the source altitude and focused on the ground area illuminated by the direct radiation from laser sources shining vertically downward from altitudes ranging from 300 to 18000 meters. Figure 5 illustrates the problem geometry. The same source receiver positions were considered for the two model atmospheres discussed in Section II. Source altitudes of 300, 1500, 6000, 9000 and 18000 meters were considered in the calculations for the 0.5145 and 1.06 micron wavelengths. A source altitude of 18000 meters was the only one considered for the 3.507 and the 10.6 micron wavelengths. The laser beam is emitted in a cone with an apex angle of $\varepsilon = 0.1$ radians.

### 3.1 LITE-I Calculations

Tables VI through X list the results of the LITE-I calculation of the scattered light irradiance at the collimated receivers as a function of the order of reflection and lookangle for each source altitude and wavelength. The lookangle is defined as the angle between a vertical axis through the receiver position and the axis of the collimated receiver where the receiver is oriented to view the area of ground surface illuminated by the direct radiation from the source. The irradiances listed in Tables VI through X were computed for a Lambert type surface having an albedo of 0.9. The irradiances for a ground albedo of 0.9 may be converted to irradiances for other values of the ground albedo by multiplying the irradiances for the nth order of reflection by the factor $(\alpha/0.9)^n$ where $\alpha$ is the new albedo and n is the order of reflection.

### 3.2 Components from First Order Reflection

The irradiances recorded in Tables VI through X for the zero order of reflection are due to light undergoing scattering within the atmosphere without reflecting from the ground surface. The

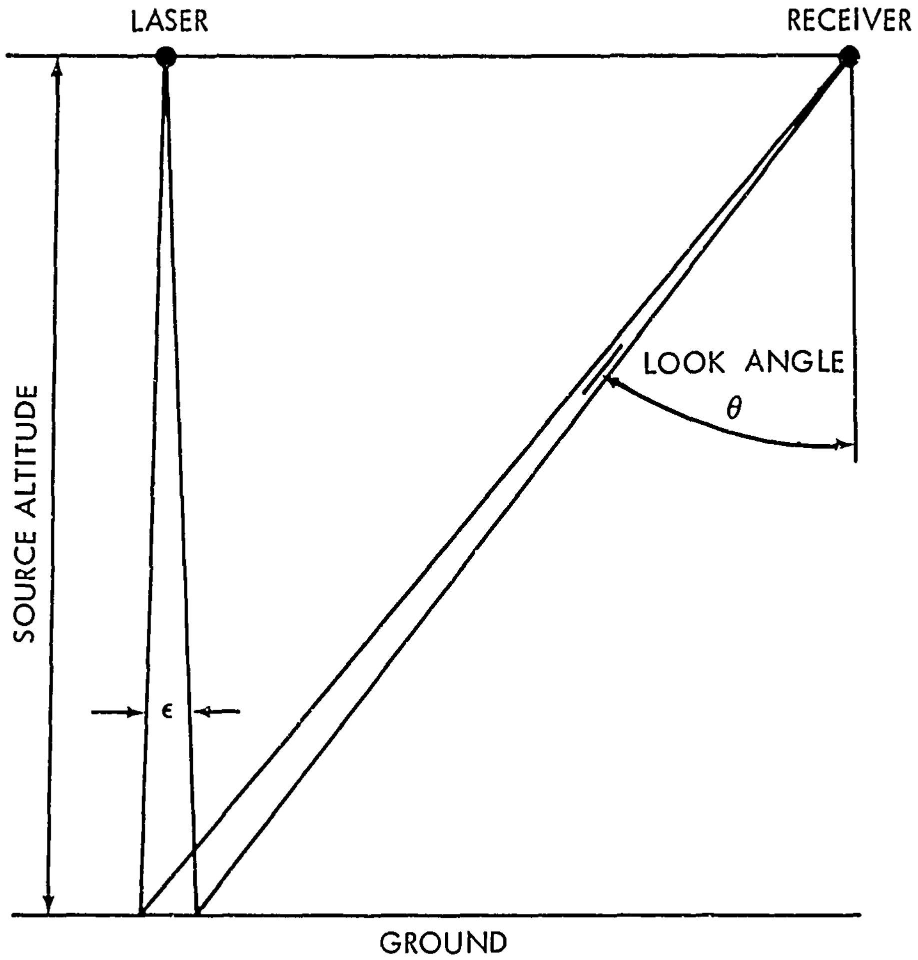


Fig. 5. Airborne Laser System and Collimated Receiver Geometry

TABLE VI

SCATTERED IRRADIANCE VERSUS ORDER OF REFLECTION FOR 0.5145 MICRON LASER IN 25 KILOMETER VISIBILITY ATMOSPHERE, GROUND ALBEDO = 0.9

| ALTITUDE (METERS) | LOOKANGLE (DEGREES) | ORDER OF REFLECTION 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|
| | | IRRADIANCE (PHOTONS $M^{-2}$ /SOURCE PHOTON) | | | | |
| 300 | 0 | 4.087-06 | 2.955-06 | 8.252-10 | 0.000+00 | 0.000+00 |
| | 45 | 1.818-10 | 1.038-06 | 2.378-10 | 0.000+00 | 0.000+00 |
| | 70 | 1.171-11 | 1.106-07 | 3.420-11 | 0.000+00 | 0.000+00 |
| 1500 | 0 | 3.533-06 | 9.641-08 | 9.578-11 | 0.000+00 | 0.000+00 |
| | 45 | 2.452-11 | 3.239-08 | 3.886-11 | 0.000+00 | 0.000+00 |
| | 70 | 1.972-12 | 2.880-09 | 3.553-12 | 4.686-15 | 0.000+00 |
| 6000 | 0 | 1.334-07 | 5.263-09 | 2.707-11 | 3.177-13 | 0.000+00 |
| | 45 | 7.137-12 | 1.697-09 | 9.986-12 | 1.066-13 | 8.428-16 |
| | 70 | 4.666-13 | 1.306-10 | 8.003-13 | 8.090-15 | 2.048-18 |
| 9000 | 0 | 1.060-07 | 2.340-09 | 2.002-11 | 4.691-13 | 2.042-15 |
| | 45 | 4.658-12 | 7.532-10 | 7.055-12 | 1.667-13 | 4.052-16 |
| | 70 | 2.463-13 | 5.469-11 | 5.200-13 | 1.127-14 | 1.488-17 |
| 18000 | 0 | 1.164-08 | 5.776-10 | 8.244-12 | 2.015-13 | 3.209-15 |
| | 45 | 2.452-12 | 1.843-10 | 3.001-12 | 8.196-14 | 2.893-15 |
| | 70 | 1.306-13 | 1.313-11 | 2.090-13 | 5.927-15 | 2.256-16 |

TABLE VII

SCATTERED IRRADIANCE VERSUS ORDER OF REFLECTION FOR 0.5145 MICRON LASER IN 5 KILOMETER VISIBILITY ATMOSPHERE, GROUND ALBEDO = 0.9

| ALTITUDE (METERS) | LOOKANGLE (DEGREES) | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|
| | | ORDER OF REFLECTION IRRADIANCE (PHOTONS $M^{-2}$/SOURCE PHOTON) | | | | |
| 300 | 0 | 3.774-05 | 2.038-06 | 8.488-10 | 0.000+00 | 0.000+00 |
| | 45 | 4.712-10 | 6.601-07 | 6.586-10 | 0.000+00 | 0.000+00 |
| | 70 | 3.832-11 | 5.058-08 | 4.078-11 | 0.000+00 | 0.000+00 |
| 1500 | 0 | 3.074-05 | 1.545-08 | 1.103-10 | 0.000+00 | 0.000+00 |
| | 45 | 2.210-11 | 3.193-09 | 2.938-11 | 2.644-13 | 0.000+00 |
| | 70 | 4.911-13 | 5.463-11 | 6.177-13 | 4.434-15 | 0.000+00 |
| 6000 | 0 | 3.271-07 | 1.459-09 | 5.343-11 | 2.472-12 | 0.000+00 |
| | 45 | 2.050-11 | 3.371-10 | 1.674-11 | 6.812-13 | 0.000+00 |
| | 70 | 6.100-13 | 5.146-12 | 2.042-13 | 4.543-15 | 0.000+00 |
| 9000 | 0 | 1.155-07 | 7.497-10 | 3.428-11 | 2.738-12 | 0.000+00 |
| | 45 | 1.917-11 | 1.946-10 | 8.167-12 | 3.387-13 | 1.823-14 |
| | 70 | 5.404-13 | 3.128-12 | 2.199-13 | 5.947-15 | 9.267-15 |
| 18000 | 0 | 7.324-09 | 2.567-10 | 1.816-11 | 1.372-12 | 5.426-14 |
| | 45 | 1.127-11 | 6.905-10 | 6.507-12 | 2.846-13 | 1.617-14 |
| | 70 | 3.830-13 | 1.451-12 | 1.337-13 | 1.001-14 | 3.196-16 |

TABLE VIII

SCATTERED IRRADIANCE VERSUS ORDER OF REFLECTION FOR 1.06 MICRON LASER IN 25 KILOMETER VISIBILITY ATMOSPHERE, GROUND ALBEDO = 0.9

| ALTITUDE (METERS) | LOOKANGLE (DEGREES) | ORDER OF REFLECTION 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|
| | | IRRADIANCE (PHOTONS $M^{-2}$ /SOURCE PHOTON) | | | | |
| 300 | 0 | 1.300-06 | 3.063-06 | 5.127-10 | 0.000+00 | 0.000+00 |
| | 45 | 3.279-11 | 1.083-06 | 1.915-10 | 0.000+00 | 0.000+00 |
| | 70 | 1.789-12 | 1.192-07 | 2.027-11 | 0.000+00 | 0.000+00 |
| 1500 | 0 | 2.062-07 | 1.126-07 | 5.772-11 | 1.489-13 | 3.061-14 |
| | 45 | 1.464-11 | 3.933-08 | 2.674-11 | 5.553-14 | 1.059-14 |
| | 70 | 9.455-13 | 3.961-09 | 2.512-12 | 5.239-15 | 1.069-15 |
| 6000 | 0 | 1.254-09 | 6.837-09 | 1.445-11 | 4.303-14 | 0.000+00 |
| | 45 | 3.093-12 | 2.343-09 | 5.580-12 | 2.099-14 | 3.746-17 |
| 9000 | 0 | 2.037-10 | 3.068-09 | 9.403-12 | 2.091-14 | 1.268-15 |
| | 45 | 2.543-12 | 1.055-09 | 3.789-12 | 8.118-15 | 4.199-16 |
| | 70 | 1.976-13 | 1.019-10 | 3.529-13 | 8.439-16 | 4.189-17 |
| 18000 | 0 | 2.437-11 | 7.879-10 | 4.706-12 | 4.877-14 | 2.359-16 |
| | 45 | 1.086-12 | 2.720-10 | 1.859-12 | 2.115-14 | 1.952-16 |
| | 70 | 8.026-14 | 2.653-11 | 1.732-13 | 2.417-15 | 8.145-18 |

TABLE IX

SCATTERED IRRADIANCE VERSUS ORDER OF REFLECTION FOR 1.06 MICRON LASER IN 5 KILOMETER VISIBILITY ATMOSPHERE, GROUND ALBEDO = 0.9

| ALTITUDE (METERS) | LOOKANGLE (DEGREES) | ORDER OF REFLECTION 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|
| | | IRRADIANCE (PHOTONS $M^{-2}$ /SOURCE PHOTON) | | | | |
| 300 | 0 | 1.218-05 | 2.545-06 | 2.298-09 | 0.000+00 | 0.000+00 |
| | 45 | 3.018-10 | 8.509-07 | 1.034-09 | 0.000+00 | 0.000+00 |
| | 70 | 2.643-11 | 7.891-08 | 1.037-10 | 0.000+00 | 0.000+00 |
| 1500 | 0 | 1.481-05 | 4.111-08 | 2.655-10 | 3.421-12 | 0.000+00 |
| | 45 | 3.196-11 | 1.154-08 | 9.399-11 | 9.222-13 | 0.000+00 |
| | 70 | 1.059-12 | 5.015-10 | 3.300-12 | 1.270-13 | 0.000+00 |
| 6000 | 0 | 8.380-09 | 3.382-09 | 6.670-11 | 3.046-12 | 2.167-13 |
| | 45 | 1.511-11 | 9.705-10 | 2.060-11 | 1.266-12 | 7.766-14 |
| | 70 | 8.143-13 | 3.962-11 | 8.730-13 | 8.799-14 | 2.514-15 |
| 9000 | 0 | 3.520-10 | 1.662-09 | 4.727-11 | 2.545-12 | 1.369-13 |
| | 45 | 1.855-11 | 4.895-10 | 1.636-11 | 1.231-12 | 6.142-14 |
| | 70 | 6.454-13 | 2.156-11 | 7.217-13 | 3.887-14 | 2.941-15 |
| 18000 | 0 | 7.544-11 | 5.086-10 | 1.998-11 | 1.305-12 | 3.635-14 |
| | 45 | 8.423-12 | 1.609-10 | 7.021-12 | 4.094-13 | 1.447-14 |
| | 70 | 4.354-13 | 7.521-12 | 4.280-13 | 2.358-14 | 9.289-16 |

TABLE X

SCATTERED IRRADIANCE VERSUS LOOKANGLE FOR 3.507 AND 10.6 MICRON LASERS AT 18000 METERS IN 25 KILOMETER VISIBILITY ATMOSPHERE

GROUND ALBEDO = 0.9

| WAVELENGTH (MICRONS) | LOOKANGLE (DEGREES) | ORDER OF REFLECTION 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|
| | | IRRADIANCE (PHOTONS $M^{-2}$/SOURCE PHOTON) | | | | |
| | | 25 KILOMETER VISIBILITY ATMOSPHERE | | | | |
| 3.507 | 0 | 2.067-12 | 4.599-10 | 5.339-13 | 4.000-16 | 0.000+00 |
| | 45 | 1.543-13 | 1.424-10 | 1.778-13 | 1.374-16 | 0.000+00 |
| | 70 | 9.564-15 | 9.721-12 | 1.214-14 | 1.266-17 | 0.000+00 |
| 10.6 | 0 | 4.020-12 | 2.147-10 | 4.715-14 | 0.000+00 | 0.000+00 |
| | 45 | 1.188-14 | 5.699-11 | 1.342-14 | 0.000+00 | 0.000+00 |
| | 70 | 4.299-16 | 2.228-12 | 5.400-16 | 0.000+00 | 0.000+00 |
| | | 5 KILOMETER VISIBILITY ATMOSPHERE | | | | |
| 3.507 | 0 | 1.733-11 | 3.488-10 | 5.384-12 | 1.005-13 | 1.127-14 |
| | 45 | 2.083-12 | 1.014-10 | 1.866-12 | 3.037-14 | 3.975-15 |
| | 70 | 9.169-14 | 4.574-12 | 8.051-14 | 1.514-15 | 1.424-17 |
| 10.6 | 0 | 1.021-12 | 1.800-10 | 3.196-13 | 2.286-15 | 0.000+00 |
| | 45 | 1.414-13 | 4.582-11 | 9.068-14 | 7.207-16 | 0.000+00 |
| | 70 | 3.616-15 | 1.489-12 | 3.020-15 | 2.257-17 | 0.000+00 |

irradiances recorded for the other orders of reflection were not separated into a ground reflected component and an atmospheric scattered component however, an attempt has been made to separate the irradiances recorded for the first and second orders of reflection into these components.

The basic assumption made in evaluating components of the irradiances for the first order of reflection is that the ground reflected component is composed entirely of the reflected direct radiation plus the reflected single scattered irradiance that scatters at a sufficiently small angle such that it is incident upon the ground surface subtended by the collimated receivers. The direct radiation reflected into each collimated receiver and the single scattered radiation that is reflected from the ground surface subtended by the collimated receivers are listed in the columns headed by DR and SCR in Tables XI through XV for a ground albedo of 0.9. The validity of the assumption that the ground reflected component of the LITE-I calculated irradiances for first order reflection is made up entirely of the reflected direct and single scattered radiation may be checked by comparing the single scattered reflected to the direct reflected. If the single scattered reflected is only a small fraction of the direct reflected, then the reflection of radiation which scatters more than once in the atmosphere before the first reflection will be negligible. This is the case for all but the higher altitudes in the 5 kilometer visibility atmosphere in which case the assumption may cause an under-prediction of the reflected radiation by as much as 30 per cent.

The irradiances reflected directly from the ground after undergoing a first order reflection are shown in the columns headed by TR1 in Tables XI through XV. These irradiances were obtained by adding the direct and single scattered reflected components. The columns headed by AS1 list the atmosphere scattered component of

TABLE XI

GROUND REFLECTED AND ATMOSPHERIC SCATTERED COMPONENTS OF 0.5145 MICRON LASER LIGHT IN 25 KILOMETER VISIBILITY ATMOSPHERE BEFORE SECOND ORDER REFLECTION FROM GROUND SURFACE WITH ALBEDO = 0.9

| ALT | LA | DR | SCR | TR1 | AS1 | ASO | TAS |
|---|---|---|---|---|---|---|---|
| 300 | 0 | 2.95-06 | 2.23-08 | 2.97-06 | 0.00&00 | 4.09-06 | 4.09-06 |
| | 45 | 1.03-06 | 7.50-09 | 1.04-06 | 0.00&00 | 1.82-10 | 1.82-10 |
| | 70 | 1.10-07 | 8.28-10 | 1.11-07 | 0.00&00 | 1.17-11 | 1.17-11 |
| 1500 | 0 | 9.27-08 | 2.20-09 | 9.49-08 | 1.51-09 | 3.53-06 | 3.54-06 |
| | 45 | 3.09-08 | 6.70-10 | 3.16-08 | 8.17-10 | 2.45-11 | 8.42-10 |
| | 70 | 2.76-09 | 4.85-11 | 2.81-09 | 7.11-11 | 1.97-12 | 7.30-11 |
| 6000 | 0 | 4.71-09 | 4.03-10 | 5.11-09 | 1.50-10 | 1.33-07 | 1.34-07 |
| | 45 | 1.49-09 | 1.25-10 | 1.61-09 | 8.20-11 | 7.14-12 | 8.91-11 |
| | 70 | 1.13-10 | 9.74-12 | 1.23-10 | 7.94-12 | 4.66-13 | 8.40-12 |
| 9000 | 0 | 1.99-09 | 2.14-10 | 2.20-09 | 1.36-10 | 1.06-07 | 1.06-07 |
| | 45 | 6.30-10 | 6.75-11 | 6.98-10 | 5.57-11 | 4.66-12 | 6.04-11 |
| | 70 | 4.64-11 | 4.94-12 | 5.13-11 | 3.35-12 | 2.46-13 | 3.60-12 |
| 18000 | 0 | 4.65-10 | 6.73-11 | 5.32-10 | 4.53-11 | 1.16-08 | 1.17-08 |
| | 45 | 1.44-10 | 2.02-11 | 1.64-10 | 2.01-11 | 2.45-12 | 2.26-11 |
| | 70 | 1.01-11 | 1.45-12 | 1.16-11 | 1.58-12 | 1.31-13 | 1.71-11 |

ALT - ALTITUDE (METERS)
LA - LOOKANGLE (DEGREES)
DR - DIRECT RADIATION REFLECTED INTO COLLIMATED RECEIVER
SCR - SINGLE SCATTERED RADIATION REFLECTED INTO COLLIMATED RECEIVER
TR1 - TOTAL FIRST ORDER REFLECTION (DB + SCR)
AS1 - ATMOSPHERIC SCATTERED COMPONENT AFTER 1ST ORDER REFLECTION
ASO - ATMOSPHERIC SCATTERED COMPONENT BEFORE ANY REFLECTION OCCURS
TAS - TOTAL ATMOSPHERIC SCATTERED COMPONENT (AS1 + ASO) RESULTING FROM 0 AND FIRST ORDER REFLECTIONS BY GROUND SURFACE

REFLECTED AND SCATTERED IRRADIANCES ARE GIVEN IN UNITS OF PHOTONS M $^{-2}$/SOURCE PHOTON

TABLE XII

GROUND REFLECTED AND ATMOSPHERIC SCATTERED COMPONENTS OF 0.5145 MICRON LASER LIGHT IN 5 KILOMETER VISIBILITY ATMOSPHERE BEFORE SECOND ORDER REFLECTION FROM GROUND SURFACE WITH ALBEDO = 0.9

| ALT | LA | DR | SCR | TR1 | AS1 | ASO | TAS |
|---|---|---|---|---|---|---|---|
| 300 | 0 | 1.93-06 | 7.95-08 | 2.01-06 | 2.80-08 | 3.77-05 | 3.77-05 |
| | 45 | 6.16-07 | 2.55-08 | 6.42-07 | 1.86-08 | 4.71-10 | 1.90-08 |
| | 70 | 4.79-08 | 1.96-09 | 4.99-08 | 6.80-10 | 3.83-11 | 7.18-10 |
| 1500 | 0 | 1.04-08 | 2.17-09 | 1.26-08 | 2.88-09 | 3.07-05 | 3.07-05 |
| | 45 | 2.22-09 | 4.40-10 | 2.66-09 | 5.33-10 | 2.21-11 | 5.55-10 |
| | 70 | 3.84-11 | 7.91-12 | 4.63-11 | 8.30-12 | 4.91-13 | 8.79-12 |
| 6000 | 0 | 5.32-10 | 3.09-10 | 8.41-10 | 6.18-10 | 3.27-07 | 3.27-07 |
| | 45 | 1.07-10 | 6.20-11 | 1.69-10 | 1.66-10 | 2.05-11 | 1.86-10 |
| | 70 | 1.58-12 | 9.20-13 | 2.50-12 | 2.64-12 | 6.10-13 | 3.25-12 |
| 9000 | 0 | 2.26-10 | 1.67-10 | 3.93-10 | 3.56-10 | 1.16-07 | 1.16-07 |
| | 45 | 4.54-11 | 3.40-11 | 7.94-11 | 1.15-10 | 1.92-11 | 1.34-10 |
| | 70 | 6.47-13 | 4.76-13 | 1.12-12 | 2.00-12 | 5.40-13 | 2.55-12 |
| 18000 | 0 | 5.26-11 | 5.25-11 | 1.05-10 | 1.52-10 | 7.32-09 | 7.48-09 |
| | 45 | 1.04-11 | 1.07-11 | 2.11-11 | 4.80-11 | 1.13-11 | 5.92-11 |
| | 70 | 1.40-13 | 1.40-13 | 2.80-13 | 1.17-12 | 3.83-13 | 1.55-12 |

ALT - ALTITUDE (METERS)
LA - LOOKANGLE (DEGREES)
DR - DIRECT RADIATION REFLECTED INTO COLLIMATED RECEIVER
SCR - SINGLE SCATTERED RADIATION REFLECTED INTO COLLIMATED RECEIVER
TR1 - TOTAL FIRST ORDER REFLECTION (DB + SCR)
AS1 - ATMOSPHERIC SCATTERED COMPONENT AFTER 1ST ORDER REFLECTION
ASO - ATMOSPHERIC SCATTERED COMPONENT BEFORE ANY REFLECTION OCCURS
TAS - TOTAL ATMOSPHERIC SCATTERED COMPONENT (AS1 + ASO) RESULTING FROM 0 AND FIRST ORDER REFLECTIONS BY GROUND SURFACE

REFLECTED AND SCATTERED IRRADIANCES ARE GIVEN IN UNITS OF PHOTONS $M^{-2}$/SOURCE PHOTON

TABLE XIII

GROUND REFLECTED AND ATMOSPHERIC SCATTERED COMPONENTS OF 1.06 MICRON LASER LIGHT IN 25 KILOMETER VISIBILITY ATMOSPHERE BEFORE SECOND ORDER REFLECTION FROM GROUND SURFACE WITH ALBEDO = 0.9

| ALT | LA | DR | SCR | TR1 | AS1 | ASO | TAS |
|---|---|---|---|---|---|---|---|
| 300 | 0 | 3.07-06 | 1.08-08 | 3.08-06 | 0.00E00 | 1.30-06 | 1.30-06 |
| | 45 | 1.08-06 | 3.80-09 | 1.08-06 | 0.00E00 | 3.28-11 | 3.28-11 |
| | 70 | 1.19-07 | 4.20-10 | 1.19-07 | 0.00E00 | 1.79-12 | 1.79-12 |
| 1500 | 0 | 1.11-07 | 1.68-09 | 1.13-07 | 0.00E00 | 2.06-07 | 2.06-07 |
| | 45 | 3.71-08 | 5.70-10 | 3.76-08 | 1.73-09 | 1.46-11 | 1.74-09 |
| | 70 | 3.88-09 | 5.90-11 | 3.94-09 | 2.15-11 | 9.46-13 | 2.24-11 |
| 6000 | 0 | 6.49-09 | 2.61-10 | 6.75-09 | 8.60-11 | 1.25-09 | 1.34-09 |
| | 45 | 2.20-09 | 8.60-11 | 2.29-09 | 5.64-11 | 3.09-12 | 5.95-11 |
| | 70 | 2.13-10 | 8.60-12 | 2.22-10 | 4.40-12 | 2.85-13 | 4.68-12 |
| 9000 | 0 | 2.87-09 | 1.44-10 | 3.01-09 | 5.40-11 | 2.04-10 | 2.58-10 |
| | 45 | 9.72-10 | 2.50-11 | 9.97-10 | 5.81-11 | 2.54-12 | 6.06-11 |
| | 70 | 9.36-11 | 4.72-12 | 9.83-11 | 3.57-12 | 1.98-13 | 3.77-12 |
| 18000 | 0 | 7.16-10 | 4.80-11 | 7.64-10 | 2.39-11 | 2.44-11 | 4.83-11 |
| | 45 | 2.42-10 | 1.60-11 | 2.58-10 | 1.40-11 | 1.09-12 | 1.51-11 |
| | 70 | 2.34-11 | 1.57-12 | 2.49-11 | 1.63-12 | 8.03-14 | 1.71-12 |

ALT - ALTITUDE (METERS)
LA - LOOKANGLE (DEGREES)
DR - DIRECT RADIATION REFLECTED INTO COLLIMATED RECEIVER
SCR - SINGLE SCATTERED RADIATION REFLECTED INTO COLLIMATED RECEIVER
TR1 - TOTAL FIRST ORDER REFLECTION (DB + SCR)
AS1 - ATMOSPHERIC SCATTERED COMPONENT AFTER 1ST ORDER REFLECTION
ASO - ATMOSPHERIC SCATTERED COMPONENT BEFORE ANY REFLECTION OCCURS
TAS - TOTAL ATMOSPHERIC SCATTERED COMPONENT (AS1 + ASO) RESULTING FROM 0 AND FIRST ORDER REFLECTIONS BY GROUND SURFACE

REFLECTED AND SCATTERED IRRADIANCES ARE GIVEN IN UNITS OF PHOTONS $M^{-2}$/SOURCE PHOTON

TABLE XIV

GROUND REFLECTED AND ATMOSPHERIC SCATTERED COMPONENTS OF 1.06 MICRON LASER LIGHT IN 5 KILOMETER VISIBILITY ATMOSPHERE BEFORE SECOND ORDER REFLECTION FROM GROUND SURFACE WITH ALBEDO = 0.9

| ALT | LA | DR | SCR | TR1 | AS1 | ASO | TAS |
|---|---|---|---|---|---|---|---|
| 300 | 0 | 2.46-06 | 4.79-08 | 2.51-06 | 3.80-08 | 1.22-05 | 1.22-05 |
| | 45 | 8.31-07 | 1.61-08 | 8.47-07 | 3.90-09 | 3.02-10 | 4.20-09 |
| | 70 | 7.78-08 | 1.51-09 | 7.93-08 | 0.00+00 | 2.64-11 | 2.64-11 |
| 1500 | 0 | 3.65-08 | 3.53-09 | 4.00-08 | 1.11-09 | 1.48-05 | 1.48-05 |
| | 45 | 9.90-09 | 9.60-10 | 1.09-08 | 6.81-10 | 3.20-11 | 7.13-10 |
| | 70 | 4.39-10 | 4.26-11 | 4.82-10 | 1.99-11 | 1.06-12 | 2.09-11 |
| 6000 | 0 | 2.13-09 | 5.98-10 | 2.73-09 | 6.54-10 | 8.38-09 | 9.03-09 |
| | 45 | 5.76-10 | 1.55-10 | 7.31-10 | 2.40-10 | 1.51-11 | 2.55-10 |
| | 70 | 2.41-11 | 6.76-12 | 3.09-11 | 8.72-12 | 8.14-13 | 9.53-12 |
| 9000 | 0 | 9.45-10 | 3.37-10 | 1.28-09 | 3.80-10 | 3.52-10 | 7.32-10 |
| | 45 | 2.55-10 | 8.90-11 | 3.44-10 | 1.46-10 | 1.86-11 | 1.64-10 |
| | 70 | 1.06-11 | 3.80-12 | 1.44-11 | 7.16-12 | 6.45-13 | 7.81-12 |
| 18000 | 0 | 2.35-10 | 1.13-10 | 3.48-10 | 1.61-10 | 7.54-11 | 2.36-10 |
| | 45 | 6.35-11 | 3.10-11 | 9.45-11 | 6.64-11 | 8.42-12 | 7.48-11 |
| | 70 | 2.65-12 | 1.27-12 | 3.92-12 | 3.60-12 | 4.35-13 | 4.03-12 |

ALT - ALTITUDE (METERS)
LA - LOOKANGLE (DEGREES)
DR - DIRECT RADIATION REFLECTED INTO COLLIMATED RECEIVER
SCR - SINGLE SCATTERED RADIATION REFLECTED INTO COLLIMATED RECEIVER
TR1 - TOTAL FIRST ORDER REFLECTION (DB + SCR)
AS1 - ATMOSPHERIC SCATTERED COMPONENT AFTER 1ST ORDER REFLECTION
ASO - ATMOSPHERIC SCATTERED COMPONENT BEFORE ANY REFLECTION OCCURS
TAS - TOTAL ATMOSPHERIC SCATTERED COMPONENT (AS1 + ASO) RESULTING FROM 0 AND FIRST ORDER REFLECTIONS BY GROUND SURFACE

REFLECTED AND SCATTERED IRRADIANCES ARE GIVEN IN UNITS OF PHOTONS $M^{-2}$/SOURCE PHOTON

TABLE XV

GROUND REFLECTED AND ATMOSPHERIC SCATTERED COMPONENTS OF 3.507 AND 10.6 MICRON LASER AT 18000 METERS IN 25 AND 5 KILOMETER VISIBILITY ATMOSPHERES, GROUND ALBEDO = 0.9

| WL | LA | DR | SCR | TR1 | AS1 | ASO | TAS |
|---|---|---|---|---|---|---|---|
| | | 25 KILOMETER VISIBILITY ATMOSPHERE | | | | | |
| | 0 | 5.03-10 | 3.81-13 | 4.60-10 | 0.00+00 | 2.07-12 | 2.07-12 |
| 3.507 | 45 | 1.55-10 | 1.22-13 | 1.42-10 | 0.00+00 | 1.54-13 | 1.54-13 |
| | 70 | 1.06-11 | 8.20-15 | 9.72-12 | 0.00+00 | 9.56-15 | 9.56-15 |
| | 0 | 2.41-10 | 8.55-13 | 2.14-10 | 0.00+00 | 4.02-12 | 4.02-12 |
| 10.6 | 45 | 6.39-11 | 2.32-13 | 5.70-11 | 0.00+00 | 1.19-14 | 1.19-14 |
| | 70 | 2.51-12 | 8.87-15 | 2.23-12 | 0.00+00 | 4.30-16 | 4.30-16 |
| | | 5 KILOMETER VISIBILITY ATMOSPHERE | | | | | |
| | 0 | 2.78-10 | 5.68-11 | 3.48-10 | 1.32-11 | 1.73-11 | 3.05-11 |
| 3.507 | 45 | 7.60-11 | 1.59-11 | 1.01-10 | 9.10-13 | 2.08-12 | 2.99-12 |
| | 70 | 3.33-12 | 6.77-13 | 4.57-12 | 5.63-13 | 9.17-14 | 6.55-13 |
| | 0 | 1.86-10 | 7.92-12 | 1.80-10 | 0.00+00 | 1.02-12 | 1.02-12 |
| 10.6 | 45 | 4.69-11 | 2.05-12 | 4.58-11 | 0.00+00 | 1.41-13 | 1.41-13 |
| | 70 | 1.51-12 | 6.43-14 | 1.49-12 | 0.00+00 | 3.62-15 | 3.62-15 |

WL - WAVELENGTH(μ)
LA - LOOKANGLE (DEGREES)
DR - DIRECT RADIATION REFLECTED INTO COLLIMATED RECEIVER
SCR - SINGLE SCATTERED RADIATION REFLECTED INTO COLLIMATED RECEIVER
TR1 - TOTAL FIRST ORDER REFLECTION (DB + SCR)
AS1 - ATMOSPHERIC SCATTERED COMPONENT AFTER 1ST ORDER REFLECTION
ASO - ATMOSPHERIC SCATTERED COMPONENT BEFORE ANY REFLECTION OCCURS
TAS - TOTAL ATMOSPHERIC SCATTERED COMPONENT (AS1 + ASO) RESULTING FROM 0 AND FIRST ORDER REFLECTIONS BY GROUND SURFACE

REFLECTED AND SCATTERED COMPONENTS ARE GIVEN IN UNITS OF PHOTONS $M^{-2}$ /SOURCE PHOTON the first order reflection intensities This component was obtained by subtracting the total reflected radiation from the LITE-I computed component for the first order of reflection. The columns headed by ASO list the LITE-I computed irradiances for the zero order of reflection. These data were added to the atmosphere scattered component of the radiation scattering from first order reflections to give the atmospheric scattered component listed in the columns under the heading TAS.

The sums of the components of the irradiance resulting from first order reflection of the direct beam and the single scattered radiation for the 3.507 and 10.6 micron wavelength lasers, as given in Table XV, for the 18000 meters altitudes were larger than the LITE-I computed irradiances for single order reflection for all cases except that for the 3.507 micron wavelength laser in the second atmosphere. This is an indication that the atmosphere scattered portion of the LITE-I computed irradiances resulting from first order reflection is negligible in comparison with the component resulting from the direct beam reflecting from the ground surface. Since the atmospheric scattered portion of the LITE-I computed first order reflected irradiances is expected to become less significant with decreasing altitudes, it was decided that single scattering and single reflection calculations would provide sufficient information to evaluate the atmospheric scattered and ground reflected irradiances for the 3.507 and 10.6 micron wavelength lasers at the lower altitudes in the two atmospheres.

### 3.3 Components from Second Order Reflection

The irradiances at the collimated receivers due to second order reflection and scattering in the atmosphere after second order reflection are, in general, somewhat smaller than the ground reflected and atmosphere scattered components determined for the zero and first order reflection. In some cases, however, the irradiances received after second order reflection are sufficiently large to contribute to either the ground reflected or atmospheric scattered component. An attempt was made, therefore, to separate the LITE-I calculated irradiances for second order reflection into ground reflected and atmospheric scattered components.

To separate the LITE-1 calculated irradiances for second order reflection into ground reflected and atmospheric scattered components, it was observed that the direct radiation plus the single scattered radiation reflected from the ground surface subtended by source and receiver collimators, GRF1, composed almost all of the irradiance, GR1, reflected directly to the receivers from the entire ground surface for first order reflection. These two groups of irradiances are shown in Tables XVI through XIX for the 0.5145 and 1.06 micron wavelength lasers at the various altitudes and lookangles considered in the LITE-I calculations.

The photon flux, $N_n$, reflected from the area on the ground surface illuminated by the laser beam that results from photons undergoing their $n^{th}$ order of reflection from that area is proportional to the photon flux, $N_{n-1}$, previously reflected from that area. The ratio $N_n/N_{n-1}$ is independent of the placement of the source and receiver. It is dependent only on the absorption and scattering properties of the atmosphere and the albedo of the ground area illuminated by the laser beam. Since the direct attenuation from the ground surface area illuminated by the laser beam to a receiver position is the same for all orders of reflection, the ground reflected portion of the LITE-I calculated irradiance at the receiver for second order reflections should have the same distribution with altitude and lookangle as does the ground reflected component of the LITE-I calculated irradiance for the first order reflection. Therefore, if the ground reflected component of the LITE-I calculated irradiance for second order reflection is known for any receiver, it may be determined for all other receivers.

TABLE XVI

GROUND REFLECTED AND ATMOSPHERIC SCATTERED COMPONENTS FROM FIRST AND SECOND ORDER REFLECTION OF 0.5145 MICRON LASER LIGHT IN 25 KILOMETER VISIBILITY ATMOSPHERE, GROUND ALBEDO = 0.9

| ALT | LA | GRF1 | GR1 | GRF2 | AS2 | GRT | AST |
|---|---|---|---|---|---|---|---|
| 300 | 0 | 2.97-06 | 3.00-06 | 7.84-10 | 4.12-11 | 2.97-06 | 4.09-06 |
| | 45 | 1.04-06 | 1.06-06 | 2.74-10 | 0.00+00 | 1.04-06 | 1.82-10 |
| | 70 | 1.11-07 | 1.14-07 | 2.93-11 | 4.90-12 | 1.11-07 | 1.66-11 |
| 1500 | 0 | 9.49-08 | 1.03-07 | 2.51-11 | 7.07-11 | 9.49-08 | 3.54-06 |
| | 45 | 3.16-08 | 3.49-08 | 8.35-12 | 3.05-11 | 3.16-08 | 8.73-10 |
| | 70 | 2.81-09 | 3.20-09 | 7.42-13 | 2.81-12 | 2.81-09 | 7.58-11 |
| 6000 | 0 | 5.11-09 | 5.60-09 | 1.35-12 | 2.57-11 | 5.11-09 | 1.34-07 |
| | 45 | 1.61-09 | 1.82-09 | 4.25-13 | 9.56-12 | 1.61-09 | 9.87-11 |
| | 70 | 1.23-10 | 1.42-10 | 3.25-14 | 7.68-13 | 1.23-10 | 9.17-12 |
| 9000 | 0 | 2.20-09 | 2.42-09 | 5.81-13 | 1.94-11 | 2.20-09 | 1.06-07 |
| | 45 | 6.98-10 | 7.74-10 | 1.84-13 | 6.89-12 | 6.98-10 | 6.72-11 |
| | 70 | 5.13-11 | 5.90-11 | 1.36-14 | 5.06-13 | 5.13-13 | 4.11-12 |
| 18000 | 0 | 5.32-10 | 5.71-10 | 1.41-13 | 8.10-12 | 5.32-10 | 1.17-08 |
| | 45 | 1.64-10 | 1.80-10 | 4.33-14 | 2.96-12 | 1.64-10 | 2.56-11 |
| | 70 | 1.16-11 | 1.29-11 | 3.06-15 | 2.06-13 | 1.16-11 | 1.92-12 |

ALT - ALTITUDE (METERS)
LA - LOOKANGLE (DEGREES)
GRF1 - DIRECT AND SINGLE SCATTERED RADIATION REFLECTED INTO COLLIMATED RECEIVER
GR1 - SINGLE ORDER REFLECTED RADIATION INTO UNCOLLIMATED RECEIVER
GRF2 - REFLECTED RADIATION AT COLLIMATED RECEIVER DUE TO SECOND ORDER REFLECTION
AS2 - ATMOSPHERIC SCATTERED CONTRIBUTION AFTER SECOND ORDER REFLECTION
GRT - TOTAL GROUND REFLECTED COMPONENT AT COLLIMATED RECEIVER
AST - TOTAL ATMOSPHERIC SCATTERED COMPONENT AT COLLIMATED RECEIVER (ASO + AS1 + AS2) RESULTING FROM 0, FIRST, AND SECOND ORDER REFLECTIONS FROM GROUND SURFACE

REFLECTED AND SCATTERED IRRADIANCES ARE GIVEN IN UNITS OF PHOTONS $M^{-2}$/SOURCE PHOTON

TABLE XVII

GROUND REFLECTED AND ATMOSPHERIC SCATTERED COMPONENTS FROM FIRST AND SECOND ORDER REFLECTION OF 0.5145 MICRON LASER LIGHT IN 5 KILOMETER VISIBILITY ATMOSPHERE, GROUND ALBEDO = 0.9

| ALT | LA | GRF1 | GR1 | GRF2 | AS2 | GRT | AST |
|---|---|---|---|---|---|---|---|
| 300 | 0 | 2.01-06 | 2.27-06 | 6.78-10 | 1.71-10 | 2.01-06 | 3.77-05 |
| | 45 | 6.42-07 | 7.60-07 | 2.16-10 | 4.43-10 | 6.42-07 | 1.94-08 |
| | 70 | 4.99-08 | 6.27-08 | 1.68-11 | 2.40-11 | 4.99-08 | 7.42-10 |
| 1500 | 0 | 1.26-08 | 2.47-08 | 4.25-12 | 1.06-10 | 1.26-08 | 3.07-05 |
| | 45 | 2.66-09 | 6.62-09 | 8.96-13 | 2.85-11 | 2.66-09 | 5.84-10 |
| | 70 | 4.63-11 | 2.11-10 | 1.56-14 | 6.02-13 | 4.63-11 | 9.39-12 |
| 6000 | 0 | 8.41-10 | 1.57-09 | 2.83-13 | 5.31-11 | 8.41-10 | 3.07-07 |
| | 45 | 1.69-10 | 3.50-10 | 5.70-14 | 1.67-11 | 1.69-10 | 2.03-10 |
| | 70 | 2.50-12 | 5.86-12 | 8.42-16 | 2.04-13 | 2.50-12 | 3.45-12 |
| 9000 | 0 | 3.93-10 | 6.75-10 | 1.32-13 | 3.41-11 | 3.93-10 | 1.16-07 |
| | 45 | 7.94-11 | 1.43-10 | 2.68-14 | 8.14-12 | 7.94-11 | 1.42-10 |
| | 70 | 1.12-12 | 2.34-12 | 3.78-16 | 2.20-13 | 1.12-12 | 3.77-12 |
| 18000 | 0 | 1.05-10 | 1.63-10 | 3.54-14 | 1.81-11 | 1.05-10 | 7.49-09 |
| | 45 | 2.11-11 | 3.33-11 | 7.11-15 | 6.50-12 | 2.11-11 | 6.57-11 |
| | 70 | 2.80-13 | 5.07-13 | 9.43-17 | 1.34-13 | 2.80-13 | 1.68-12 |

ALT - ALTITUDE (METERS)
LA - LOOKANGLE (DEGREES)
GRF1 - DIRECT AND SINGLE SCATTERED RADIATION REFLECTED INTO COLLIMATED RECEIVER
GR1 - SINGLE ORDER REFLECTED RADIATION INTO UNCOLLIMATED RECEIVER
GRF2 - REFLECTED RADIATION AT COLLIMATED RECEIVER DUE TO SECOND ORDER REFLECTION
AS2 - ATMOSPHERIC SCATTERED CONTRIBUTION AFTER SECOND ORDER REFLECTION
GRT - TOTAL GROUND REFLECTED COMPONENT AT COLLIMATED RECEIVER
AST - TOTAL ATMOSPHERIC SCATTERED COMPONENT AT COLLIMATED RECEIVER (ASO + AS1 + AS2) RESULTING FROM 0, FIRST, AND SECOND ORDER REFLECTIONS FROM GROUND SURFACE

REFLECTED AND SCATTERED IRRADIANCES ARE GIVEN IN UNITS OF PHOTONS $M^{-2}$/SOURCE PHOTON

TABLE XVIII

GROUND REFLECTED AND ATMOSPHERIC SCATTERED COMPONENTS FROM FIRST AND SECOND ORDER REFLECTION OF 1.06 MICRON LASER LIGHT IN 25 KILOMETER VISIBILITY ATMOSPHERE, GROUND ALBEDO = 0.9

| ALT | LA | GRF1 | GR1 | GRF2 | AS2 | GRT | AST |
|---|---|---|---|---|---|---|---|
| 300 | 0 | 3.08-06 | 3.08-06 | 5.00-10 | 1.27-11 | 3.08-06 | 1.30-06 |
| | 45 | 1.08-06 | 1.09-07 | 1.75-10 | 1.65-11 | 1.08-06 | 3.44-11 |
| | 70 | 1.19-07 | 1.21-07 | 1.93-11 | 9.70-13 | 1.19-07 | 2.76-12 |
| 1500 | 0 | 1.13-07 | 1.16-07 | 1.84-11 | 3.93-11 | 1.13-07 | 2.06-07 |
| | 45 | 3.76-08 | 4.04-08 | 6.10-12 | 2.06-11 | 3.76-08 | 1.76-09 |
| | 70 | 3.94-09 | 4.14-09 | 6.40-13 | 1.87-12 | 3.94-09 | 2.43-11 |
| 6000 | 0 | 6.75-09 | 6.99-09 | 1.09-12 | 1.34-11 | 6.75-09 | 1.35-09 |
| | 45 | 2.29-09 | 2.39-09 | 3.72-13 | 5.21-12 | 2.29-09 | 6.47-11 |
| | 70 | 2.22-10 | 2.33-10 | 3.61-14 | 5.31-13 | 2.22-10 | 5.21-12 |
| 9000 | 0 | 3.01-09 | 3.11-09 | 4.89-13 | 8.91-12 | 3.01-09 | 2.66-10 |
| | 45 | 9.97-10 | 1.06-09 | 1.62-13 | 3.63-12 | 9.97-10 | 6.42-11 |
| | 70 | 9.83-11 | 1.03-10 | 1.60-14 | 3.37-13 | 9.83-11 | 4.11-12 |
| 18000 | 0 | 7.64-10 | 7.77-10 | 1.24-13 | 4.58-12 | 7.64-10 | 5.29-11 |
| | 45 | 2.58-10 | 2.64-10 | 4.19-14 | 1.82-12 | 2.58-10 | 1.69-11 |
| | 70 | 2.49-11 | 2.56-11 | 4.04-15 | 1.62-13 | 2.49-11 | 1.87-12 |

ALT - ALTITUDE (METERS)
LA - LOOKANGLE (DEGREES)
GRF1 - DIRECT AND SINGLE SCATTERED RADIATION REFLECTED INTO COLLIMATED RECEIVER
GR1 - SINGLE ORDER REFLECTED RADIATION INTO UNCOLLIMATED RECEIVER
GRF2 - REFLECTED RADIATION AT COLLIMATED RECEIVER DUE TO SECOND ORDER REFLECTION
AS2 - ATMOSPHERIC SCATTERED CONTRIBUTION AFTER SECOND ORDER REFLECTION
GRT - TOTAL GROUND REFLECTED COMPONENT AT COLLIMATED RECEIVER
AST - TOTAL ATMOSPHERIC SCATTERED COMPONENT AT COLLIMATED RECEIVER (ASO + AS1 + AS2) RESULTING FROM 0, FIRST, AND SECOND ORDER REFLECTIONS FROM GROUND SURFACE

REFLECTED AND SCATTERED IRRADIANCES ARE GIVEN IN UNITS OF PHOTONS $M^{-2}$/SOURCE PHOTON

TABLE XIX

GROUND REFLECTED AND ATMOSPHERIC SCATTERED COMPONENTS FROM FIRST AND SECOND ORDER REFLECTION OF 1.06 MICRON LASER LIGHT IN 5 KILOMETER VISIBILITY ATMOSPHERE, GROUND ALBEDO = 0.9

| ALT | LA | GRF1 | GR1 | GRF2 | AS2 | GRT | AST |
|---|---|---|---|---|---|---|---|
| 300 | 0 | 2.51-06 | 2.66-06 | 1.91-09 | 3.88-10 | 2.51-06 | 1.22-05 |
| | 45 | 8.47-07 | 9.20-07 | 6.44-10 | 3.90-10 | 8.47-07 | 4.59-09 |
| | 70 | 7.93-08 | 8.77-08 | 6.02-11 | 4.35-11 | 7.93-08 | 6.99-11 |
| 1500 | 0 | 4.00-08 | 5.56-08 | 3.04-11 | 2.35-10 | 4.00-08 | 1.48-05 |
| | 45 | 1.09-08 | 1.68-08 | 8.28-12 | 8.57-11 | 1.09-08 | 7.99-10 |
| | 70 | 4.82-10 | 9.01-10 | 3.66-13 | 2.93-12 | 4.82-12 | 2.38-11 |
| 6000 | 0 | 2.73-09 | 3.63-09 | 2.06-12 | 6.46-11 | 2.73-09 | 9.09-09 |
| | 45 | 7.31-10 | 1.01-09 | 5.56-13 | 2.00-11 | 7.31-10 | 2.75-10 |
| | 70 | 3.09-11 | 4.41-11 | 2.35-14 | 8.50-13 | 3.09-11 | 1.04-11 |
| 9000 | 0 | 1.28-09 | 1.62-09 | 1.68-12 | 4.56-11 | 1.28-09 | 7.78-10 |
| | 45 | 3.44-10 | 4.48-10 | 2.61-13 | 1.61-11 | 3.44-10 | 1.80-10 |
| | 70 | 1.44-11 | 1.90-11 | 1.09-14 | 7.11-13 | 1.44-11 | 8.52-12 |
| 18000 | 0 | 3.48-10 | 4.11-10 | 2.64-13 | 1.97-11 | 3.48-10 | 2.56-10 |
| | 45 | 9.45-11 | 1.12-10 | 7.18-14 | 6.95-12 | 9.45-11 | 8.18-11 |
| | 70 | 3.92-12 | 4.67-12 | 2.98-15 | 4.25-13 | 3.92-12 | 4.46-12 |

ALT - ALTITUDE (METERS)
LA - LOOKANGLE (DEGREES)
GRF1 - DIRECT AND SINGLE SCATTERED RADIATION REFLECTED INTO COLLIMATED RECEIVER
GR1 - SINGLE ORDER REFLECTED RADIATION INTO UNCOLLIMATED RECEIVER
GRF2 - REFLECTED RADIATION AT COLLIMATED RECEIVER DUE TO SECOND ORDER REFLECTION
AS2 - ATMOSPHERIC SCATTERED CONTRIBUTION AFTER SECOND ORDER REFLECTION
GRT - TOTAL GROUND REFLECTED COMPONENT AT COLLIMATED RECEIVER
AST - TOTAL ATMOSPHERIC SCATTERED COMPONENT AT COLLIMATED RECEIVER (ASO + AS1 + AS2) RESULTING FROM 0, FIRST, AND SECOND ORDER REFLECTIONS FROM GROUND SURFACE

REFLECTED AND SCATTERED IRRADIANCES ARE GIVEN IN UNITS OF PHOTONS $M^{-2}$/SOURCE PHOTON

It was assumed that the ratio of the ground reflected component to the second order reflection component of the irradiance at the collimated receiver for the zero lookangle and the 300 meters altitude was equal to the ratio of the total integrated intensity at the receiver resulting from radiation reflected directly to the receiver from the entire ground surface due to second order reflection to the total integrated intensity from second order reflection. Under this assumption the ground reflected components for the zero lookangle and the 300 meters altitude collimated receiver were determined to be $7.84 * 10^{-10}$ and $6.78 * 10^{-10}$ photons $m^{-2}$/source photon for the 0.5145 micron laser in the 25 kilometer and the 5 kilometer visibility atmospheres respectively and $5.00 * 10^{-10}$ and $1.91 * 10^{-9}$ photons $m^{-2}$/ source photon for the 1.06 micron laser in the two atmospheres. The second order ground reflected component, GRF2, as shown in Tables XVI through XIX for the other altitudes and lookangles was determined by normalizing the distribution of the first order reflection component to the second order reflection component for the zero lookangle and 300 meters altitude. The difference between the LITE-I calculated total second order reflection irradiance and the ground reflected component, GRF2, was taken to be the atmospheric scattered portion, AS2, of the second order reflection data. This component is also shown in Tables XVI through XIX. Also shown in Tables XVI through XIX are the total ground reflected component, GRT, and the atmospheric scattered component, AST, through two orders of reflection. This data is plotted in Figures 6 through 17 for a ground albedo of 0.9.

## 3.4 Conversion to Different Albedos

The atmospheric scattered and the ground reflected components through the second order of reflection for a ground albedo of 0.9 are summarized in Tables XX and XXI. The atmospheric scattered component for a given wavelength, altitude, lookangle, and for a ground albedo of 0.9 is the sum of the data listed under the headings $AS_c$, $AS_1$, and $AS_2$. The ground reflected component for a ground albedo of 0.9 is the sum of the two values listed under the headings $R_1$ and $R_2$. The data listed in Tables XX and XXI for a ground albedo of 0.9 may

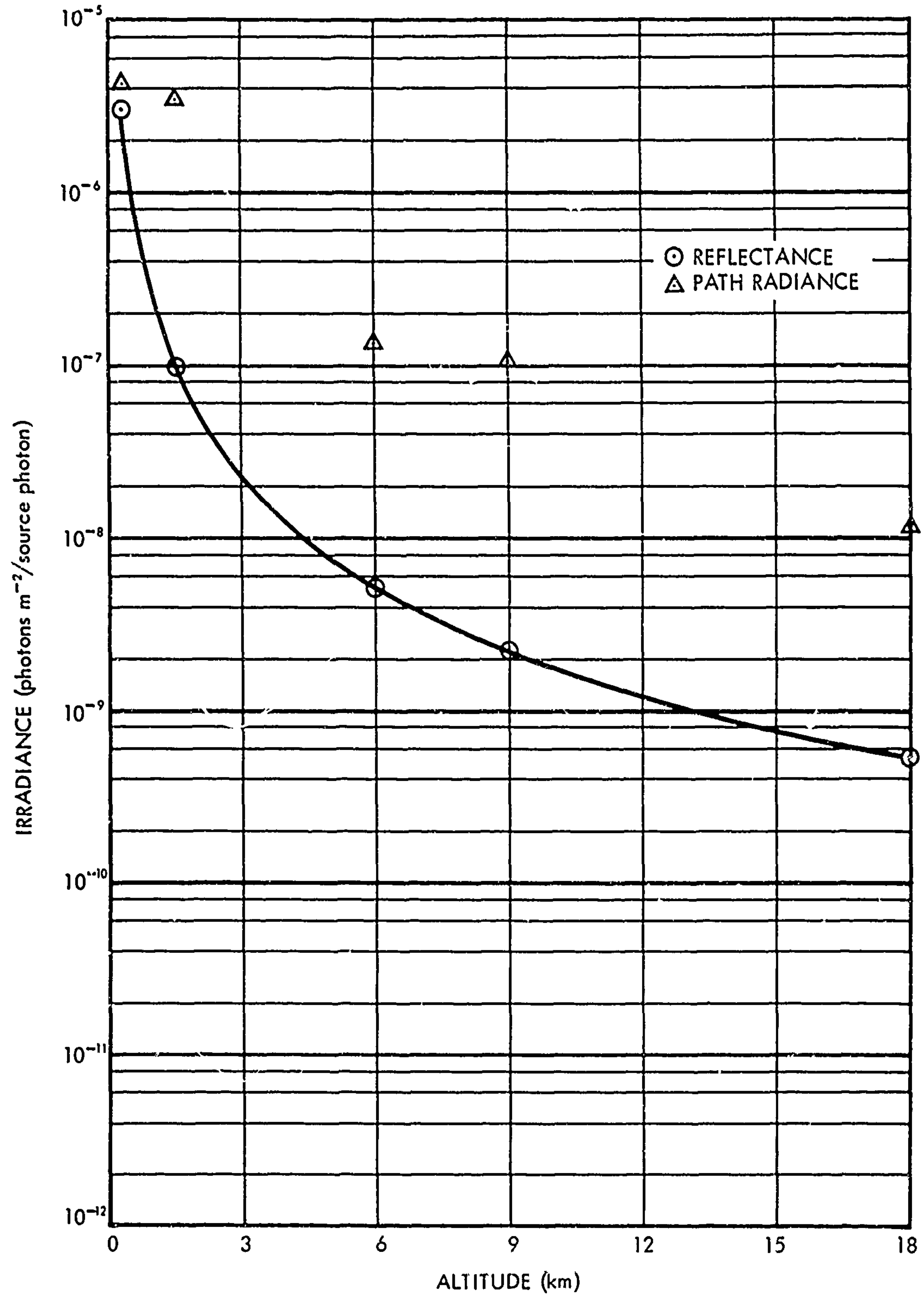


Fig. 6. Reflectance and Path Radiance for 0.5145 Micron Wavelength Laser in a 25 Kilometer Visibility Atmosphere for a 0° Look Angle: Ground Albedo = 0.9

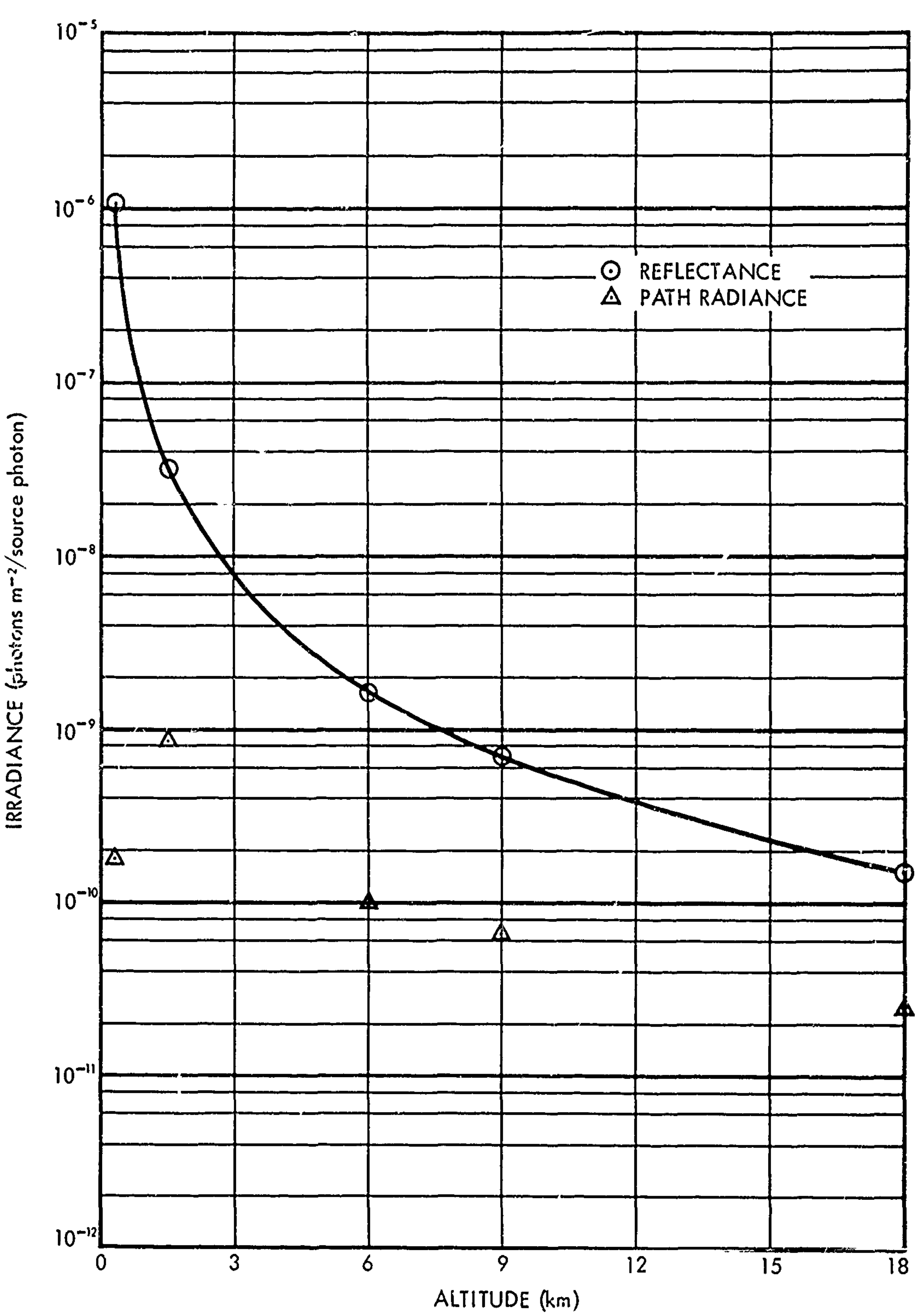


Fig. 7. Reflectance and Path Radiance for 0.5145 Micron Wavelength Laser in a 25 Kilometer Visibility Atmosphere for a 45° Look Angle: Ground Albedo = 0.9

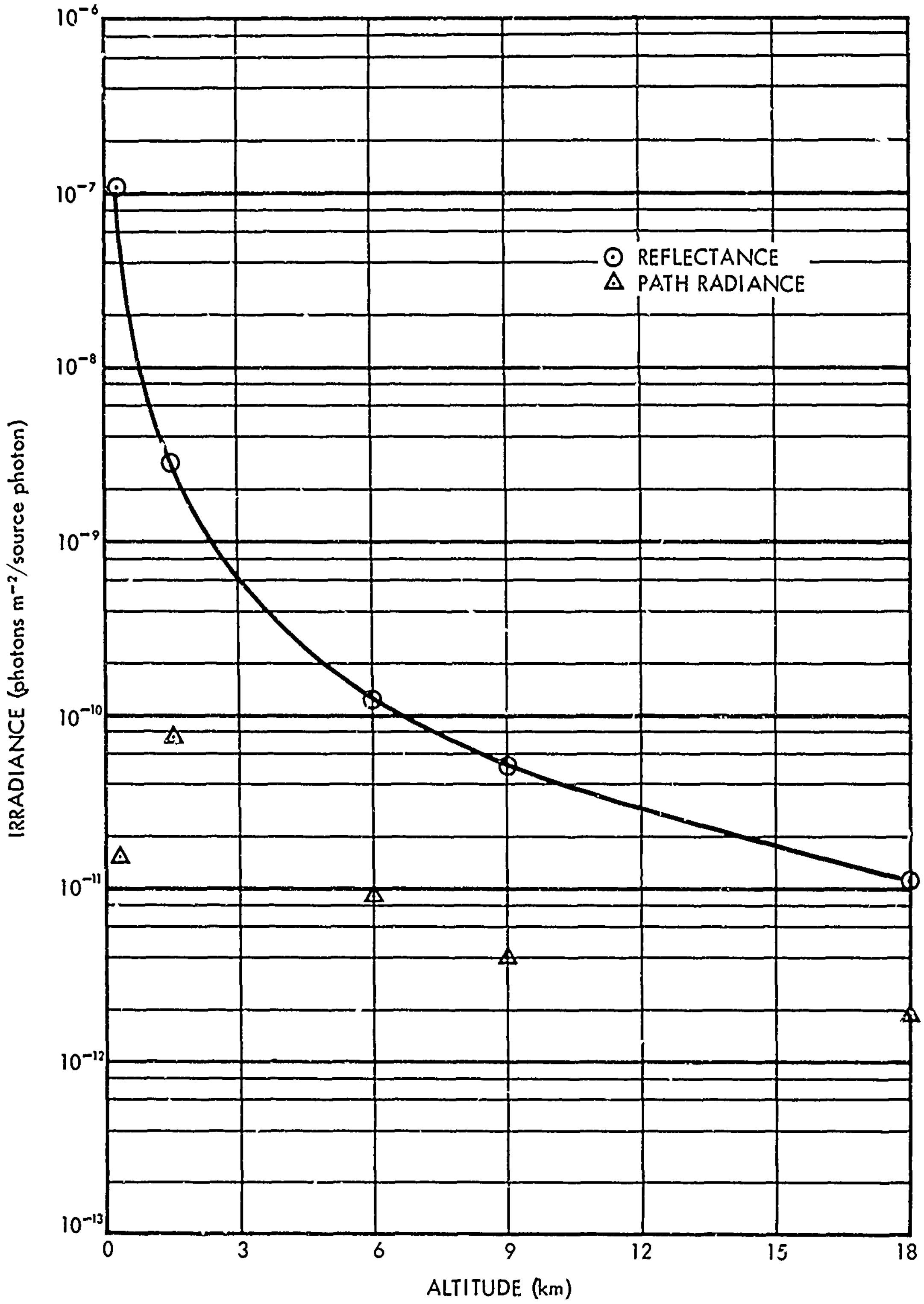


Fig. 8. Reflectance and Path Radiance for 0.5145 Micron Wavelength Laser in a 25 Kilometer Visibility Atmosphere for a 70° Look Angle: Ground Albedo = 0.9

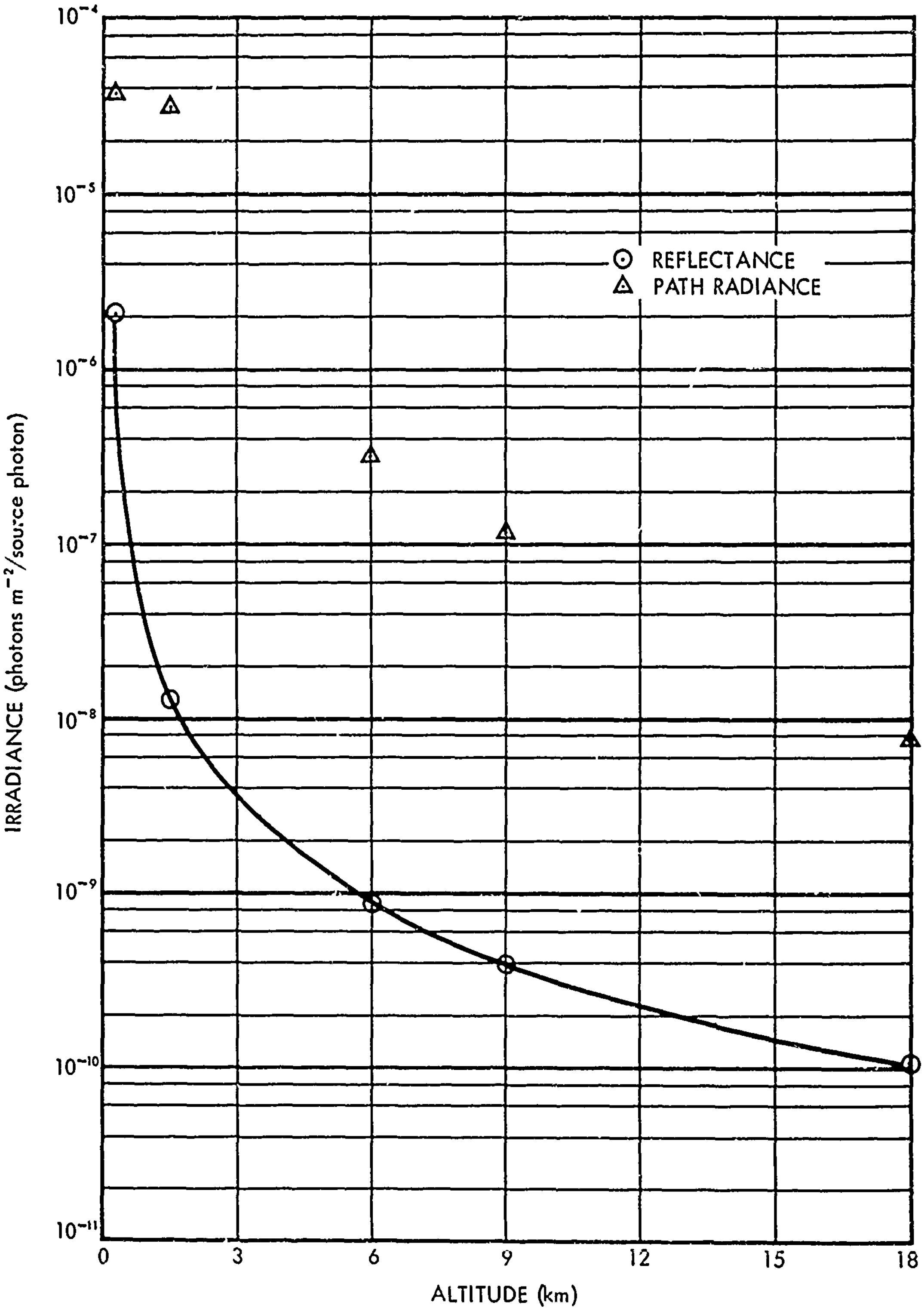


Fig. 9. Reflectance and Path Radiance for a 0.5145 Micron Wavelength Laser in a 5 Kilometer Visibility Atmosphere for a 0° Look Angle: Ground Albedo = 0.9

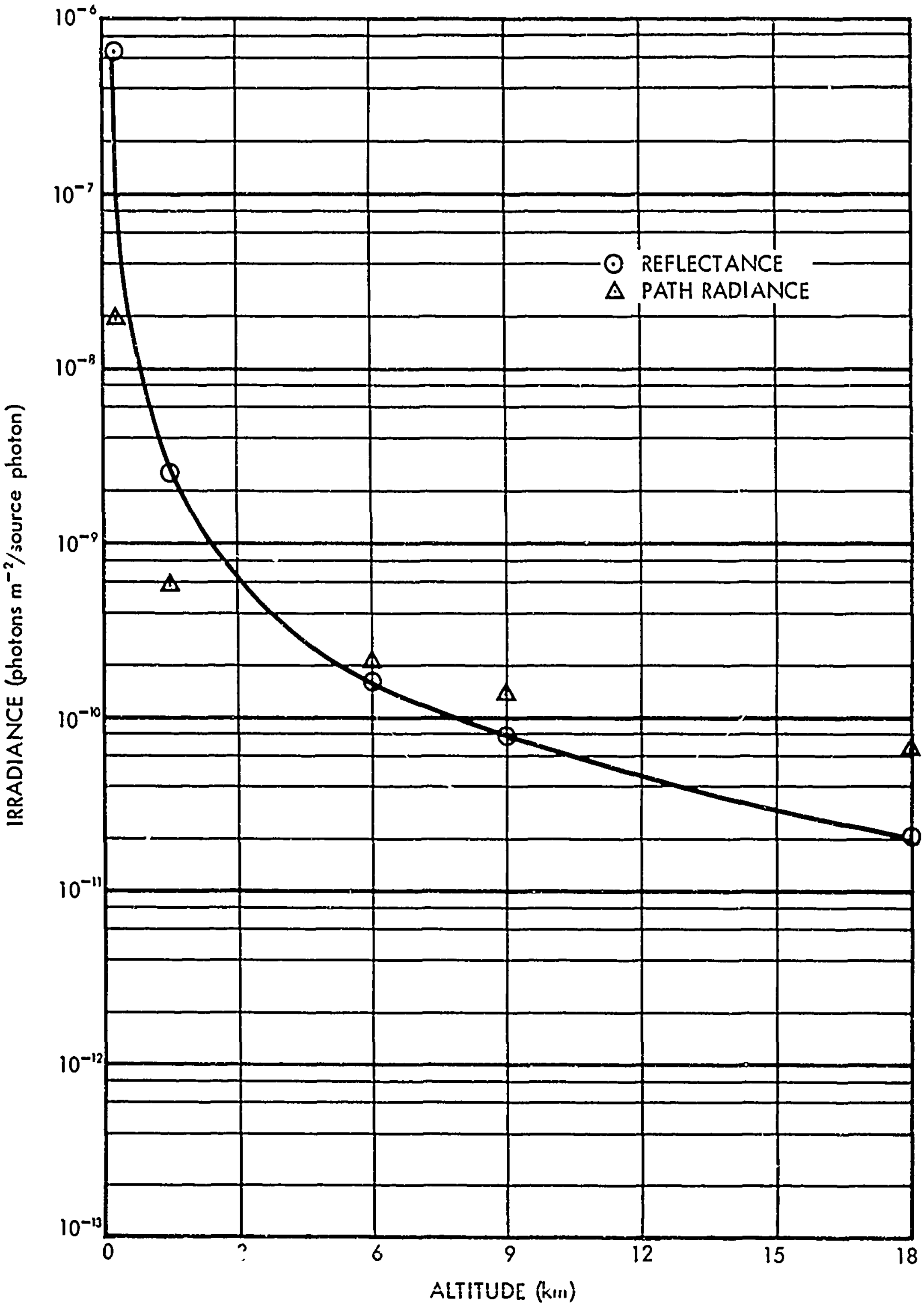


Fig. 10. Reflectance and Path Radiance for a 0.5145 Micron Wavelength Laser in a 5 Kilometer Visibility Atmosphere for a 45° Look Angle: Ground Albedo = 0.9

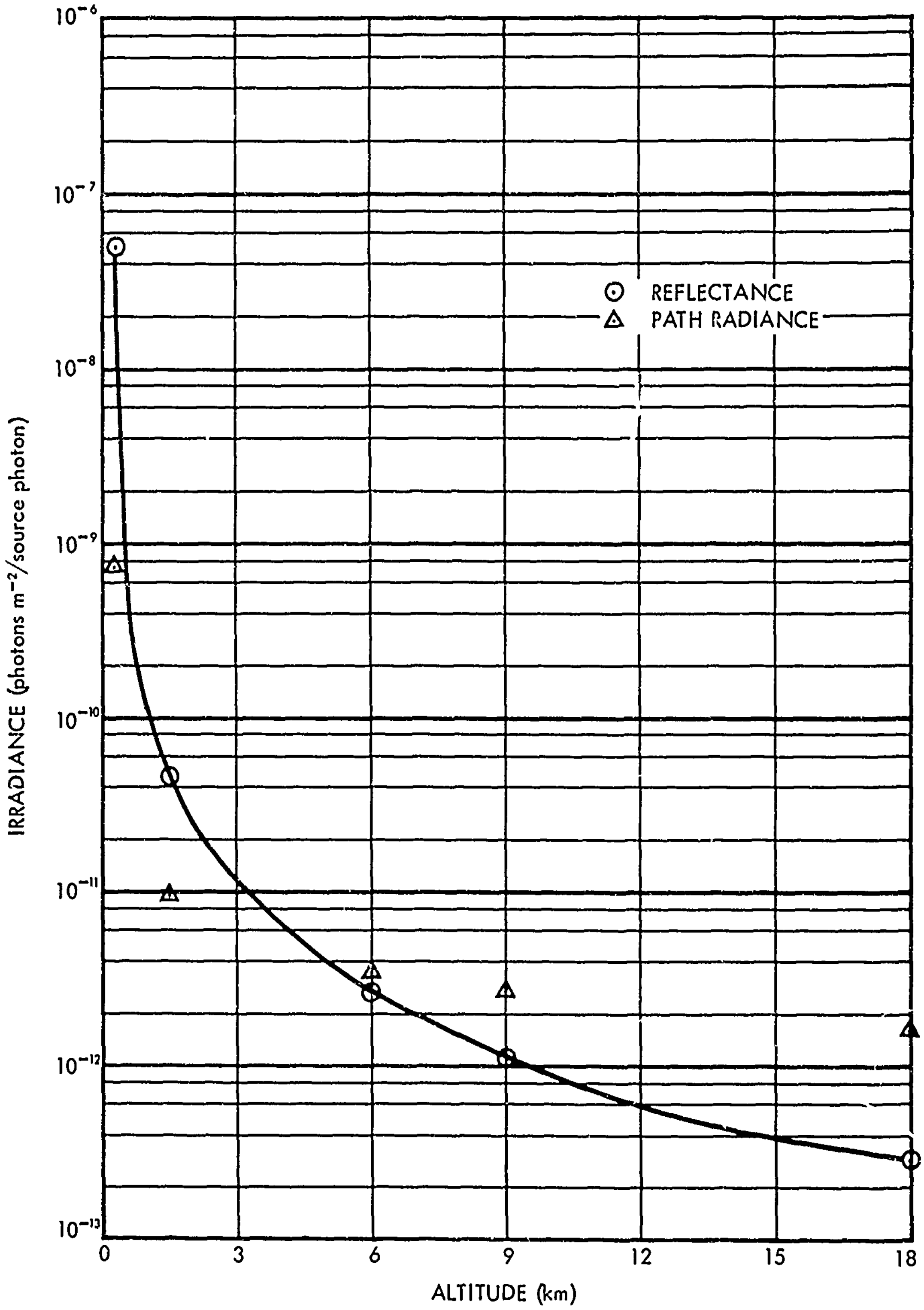


Fig. 11. Reflectance and Path Radiance for a 0.5145 Micron Wavelength Laser in a 5 Kilometer Visibility Atmosphere for a 70° Look Angle: Ground Albedo = 0.9

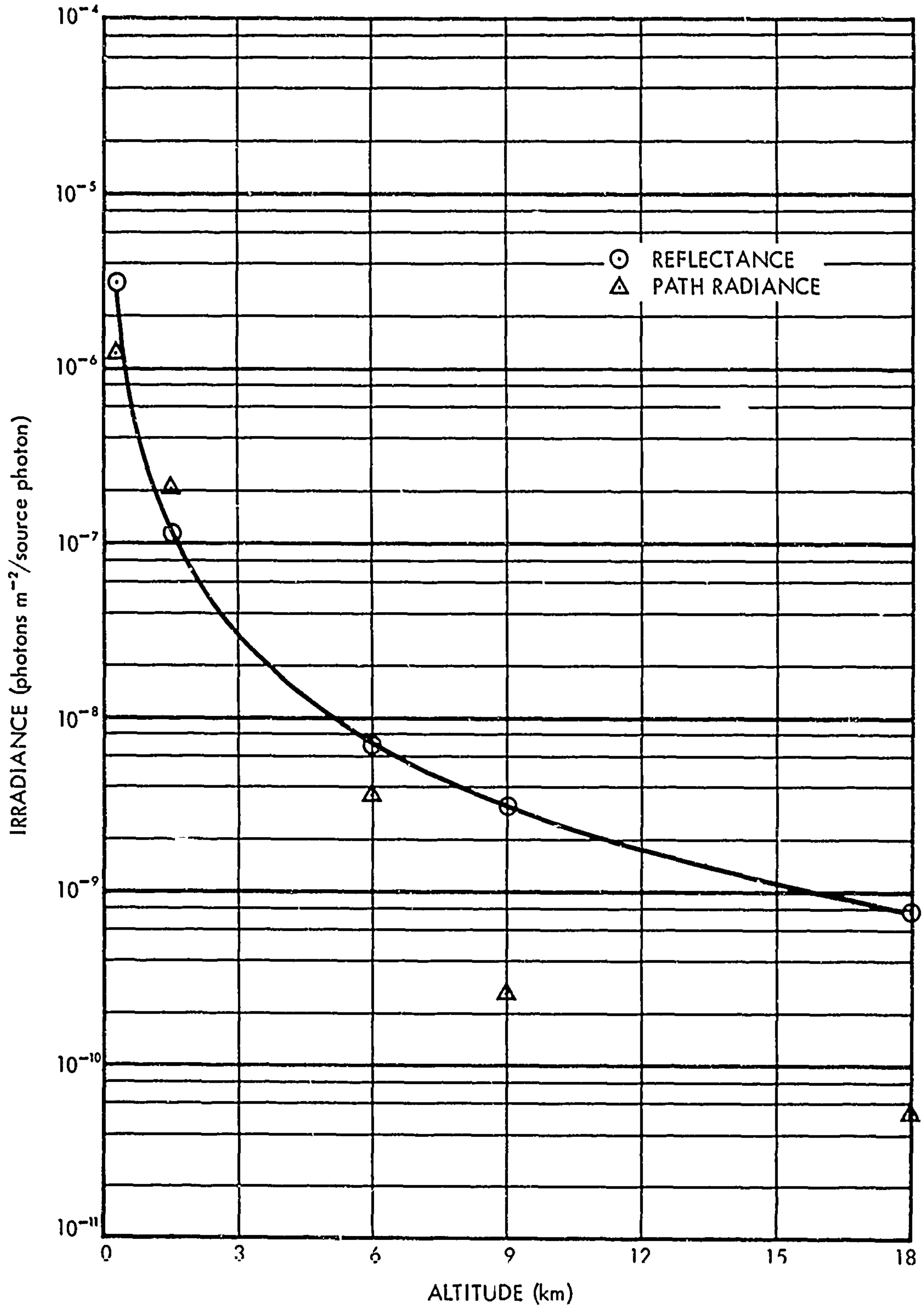


Fig. 12. Reflectance and Path Radiance for a 1.06 Micron Wavelength Laser in a 25 Kilometer Visibility Atmosphere for a 0° Look Angle: Ground Albedo = 0.9

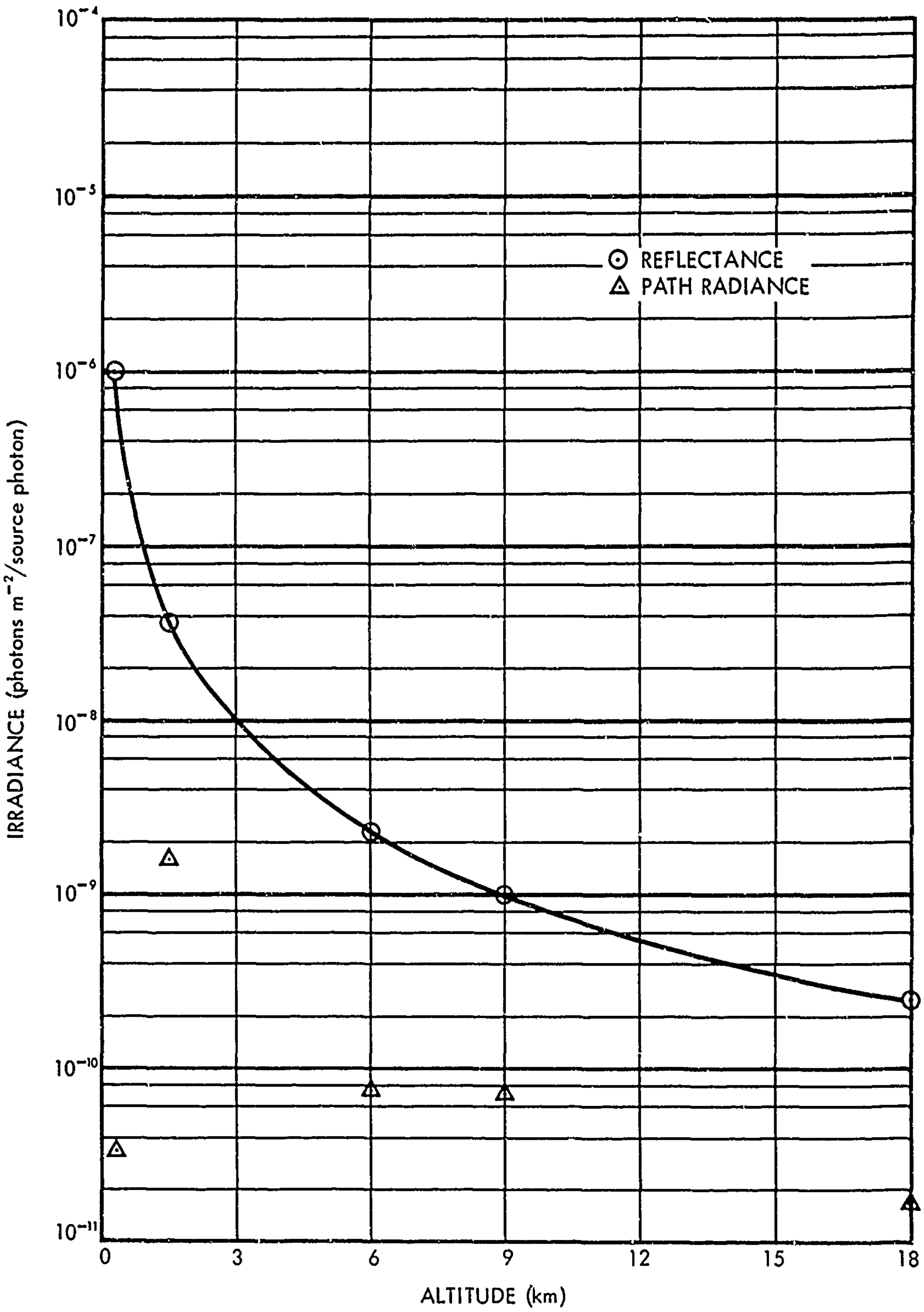


Fig. 13. Reflectance and Path Radiance for a 1.06 Micron Wavelength Laser in a 25 Kilometer Visibility Atmosphere for a 45° Look Angle: Ground Albedo = 0.9

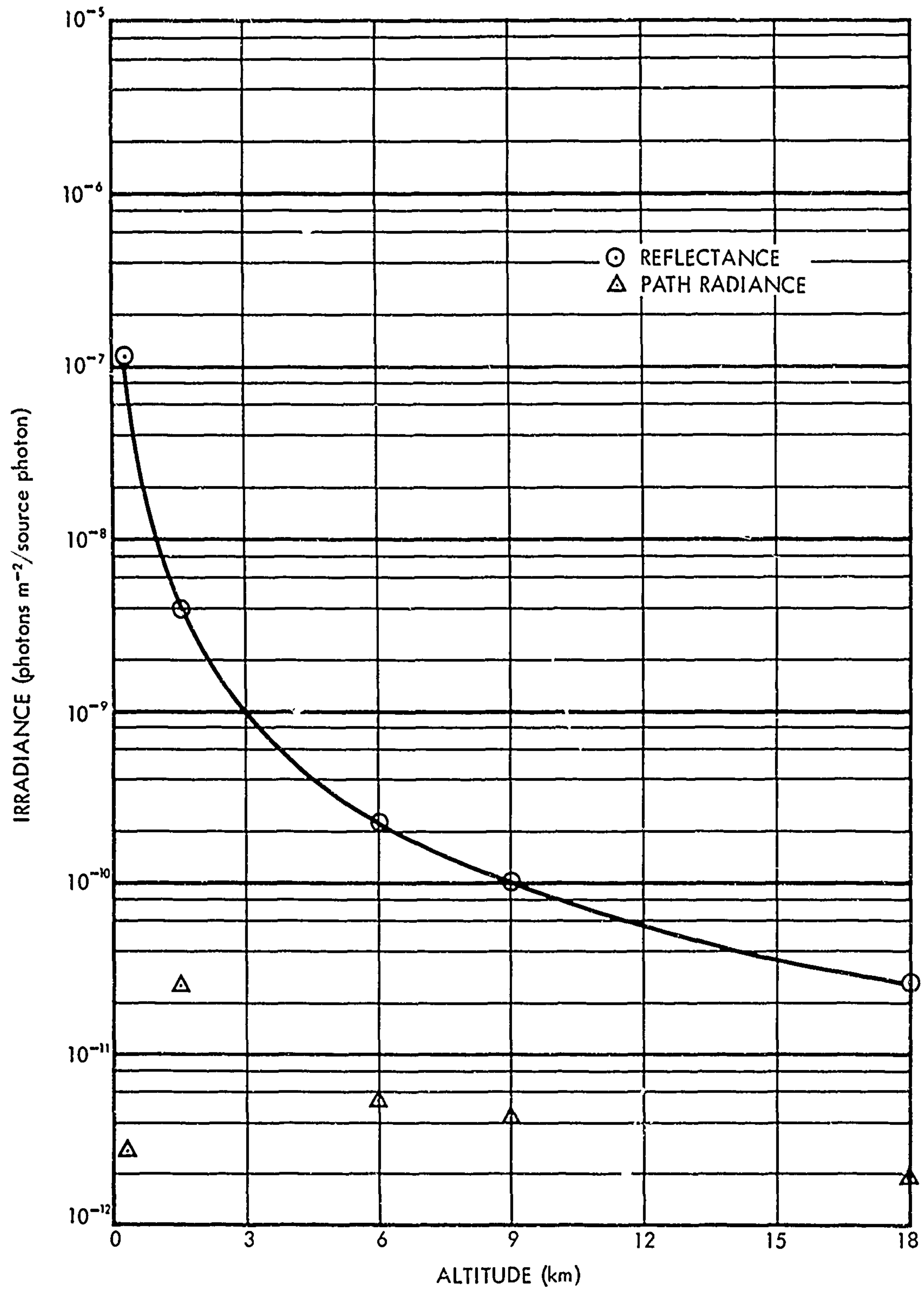


Fig. 14. Reflectance and Path Radiance for a 1.06 Micron Wavelength Laser in a 25 Kilometer Visibility Atmosphere for a 70° Look Angle: Ground Albedo = 0.9

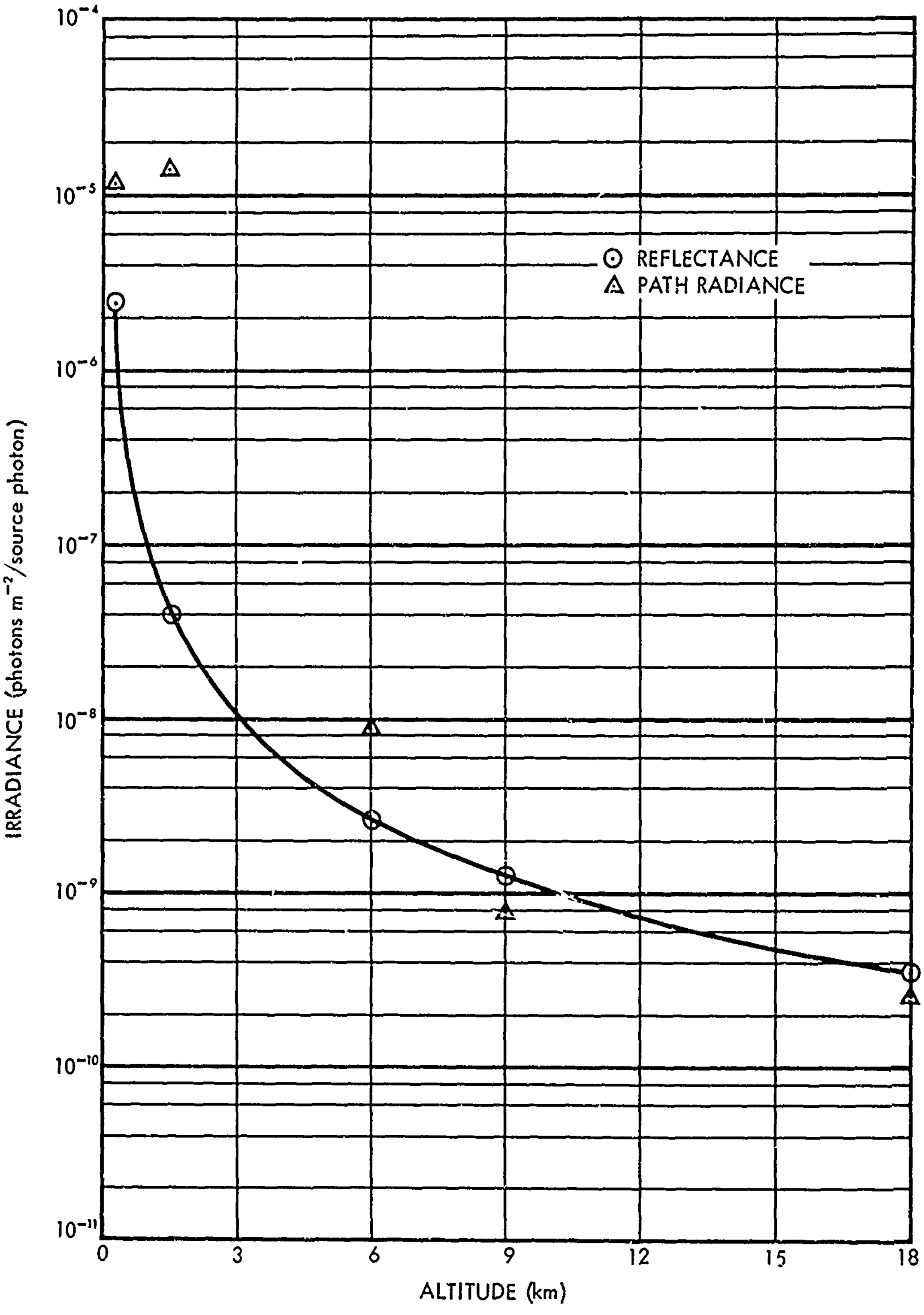


Fig. 15. Reflectance and Path Radiance for a 1.06 Micron Wavelength Laser in a 5 Kilometer Visibility Atmosphere for a 0° Look Angle: Ground Albedo = 0.9

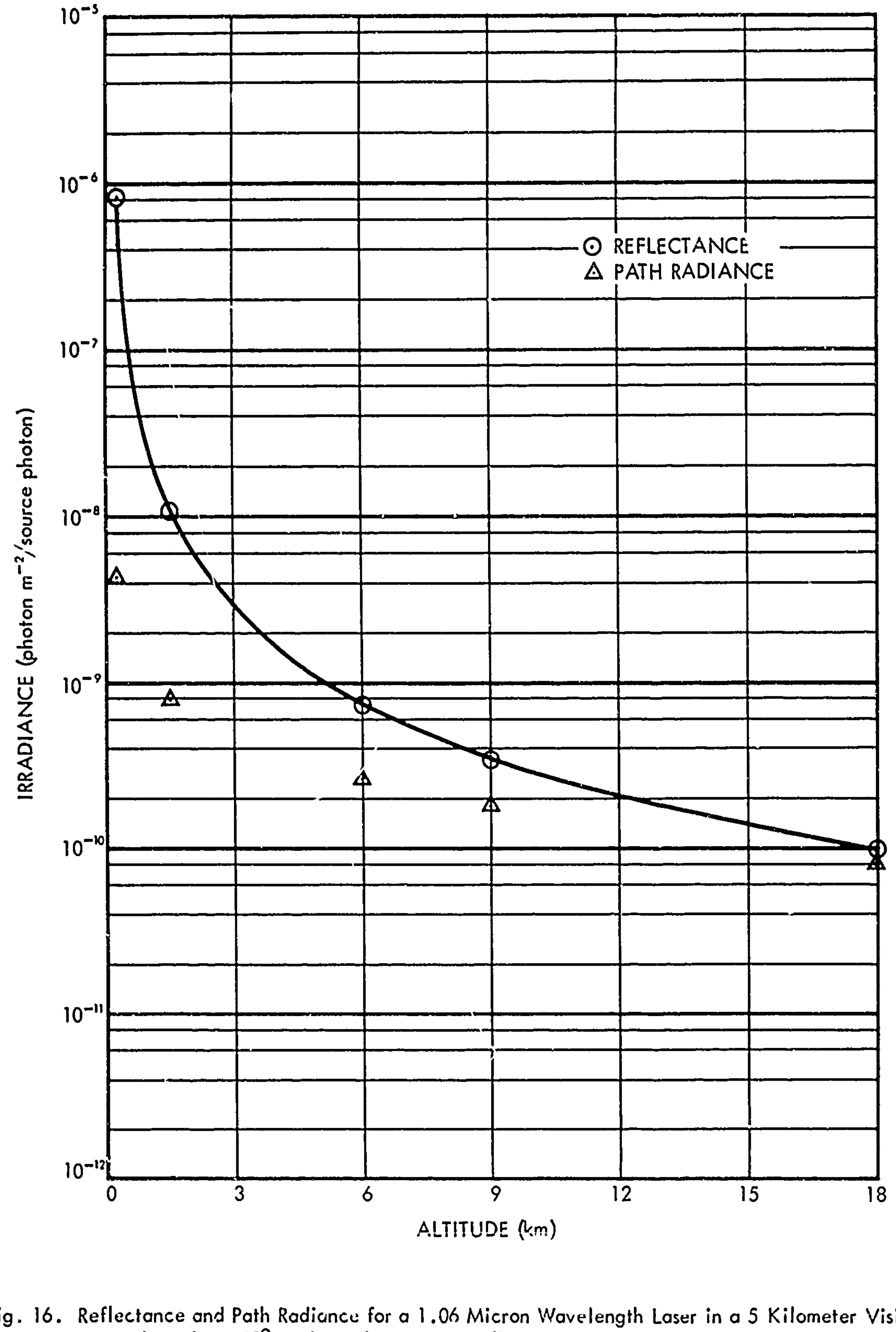


Fig. 16. Reflectance and Path Radiance for a 1.06 Micron Wavelength Laser in a 5 Kilometer Visibility Atmosphere for a 45° Look Angle: Ground Albedo = 0.9

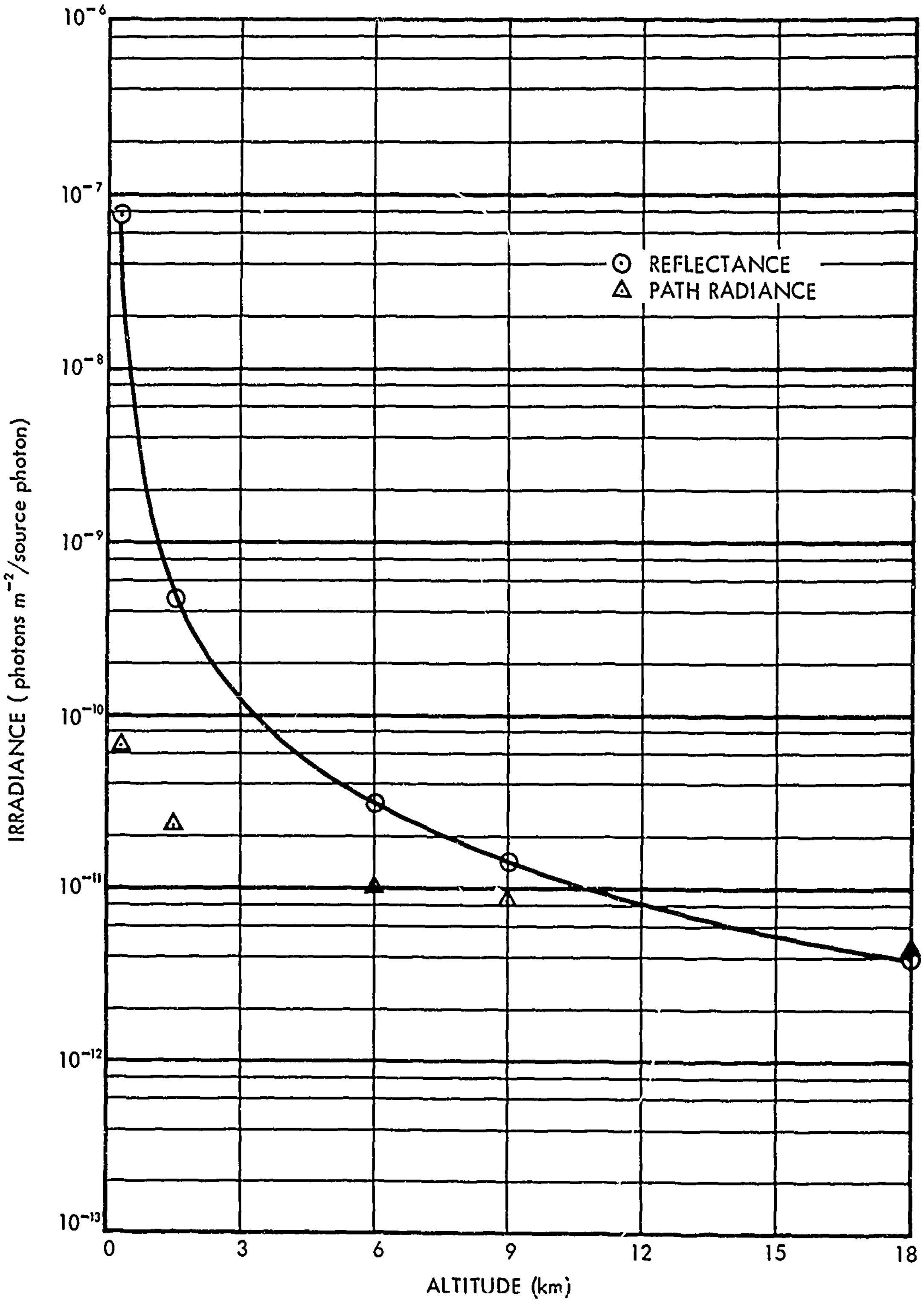


Fig. 17. Reflectance and Path Radiance for a 1.06 Micron Wavelength Laser in a 5 Kilometer Visibility Atmosphere for a 70° Look Angle: Ground Albedo = 0.9

TABLE XX

ATMOSPHERIC SCATTERED AND GROUND REFLECTED COMPONENTS OF SCATTERED IRRADIANCE VERSUS ORDER OF REFLECTION FOR 25 KILOMETER VISIBILITY ATMOSPHERE FOR 0.9 GROUND ALBEDO

| WL | LA | $AS_0$ | $AS_1$ | $AS_2$ | $R_1$ | $R_2$ |
|---|---|---|---|---|---|---|
| | | ALTITUDE 300 METERS | | | | |
| 0.5145 | 0 | 4.09-06 | 0.00+00 | 4.12-11 | 2.97-06 | 7.84-10 |
| | 45 | 1.82-10 | 0.00-00 | 0.00&00 | 1.04-06 | 2.74-10 |
| | 70 | 1.17-11 | 0.00+00 | 4.90-12 | 1.11-07 | 2.93-11 |
| | | ALTITUDE 1500 METERS | | | | |
| | 0 | 3.53-06 | 1.51-09 | 7.07-11 | 9.49-08 | 2.51-11 |
| | 45 | 2.45-11 | 8.17-10 | 3.05-11 | 3.16-08 | 8.35-12 |
| | 70 | 1.97-12 | 7.11-11 | 2.81-12 | 2.81-09 | 7.42-13 |
| | | ALTITUDE 6000 METERS | | | | |
| | 0 | 1.33-07 | 1.50-10 | 2.57-11 | 5.11-09 | 1.35-12 |
| | 45 | 7.14-12 | 8.20-11 | 9.56-12 | 1.61-09 | 4.25-13 |
| | 70 | 4.66-13 | 7.94-12 | 7.68-13 | 1.23-10 | 3.25-14 |
| | | ALTITUDE 9000 METERS | | | | |
| | 0 | 1.06-07 | 1.36-10 | 1.94-11 | 2.20-09 | 5.81-13 |
| | 45 | 4.66-12 | 5.57-11 | 6.89-12 | 6.98-10 | 1.84-13 |
| | 70 | 2.46-13 | 3.35-12 | 5.06-13 | 5.13-11 | 1.36-14 |
| | | ALTITUDE 18000 METERS | | | | |
| | 0 | 1.16-08 | 4.53-11 | 8.10-12 | 5.32-10 | 1.41-13 |
| | 45 | 2.45-12 | 2.01-11 | 2.96-12 | 1.64-10 | 4.33-14 |
| | 70 | 1.31-13 | 1.58-12 | 2.06-13 | 1.16-11 | 3.06-15 |

TABLE XX (CONTINUED)

| WL | LA | $AS_o$ | $AS_1$ | $AS_2$ | $R_1$ | $R_2$ |
|---|---|---|---|---|---|---|
| | | ALTITUDE 300 METERS | | | | |
| 1.06 | 0 | 1.30-06 | 0.00+00 | 1.27-11 | 3.08-06 | 5.00-10 |
| | 45 | 3.28-11 | 0.00+00 | 1.65-11 | 1.08-06 | 1.75-10 |
| | 70 | 1.79-12 | 0.00+00 | 9.70-13 | 1.19-07 | 1.93-11 |
| | | ALTITUDE 1500 METERS | | | | |
| | 0 | 2.06-07 | 0.00+00 | 3.93-11 | 1.13-07 | 1.84-11 |
| | 45 | 1.46-11 | 1.73-09 | 2.06-11 | 3.76-08 | 6.10-12 |
| | 70 | 9.46-13 | 2.15-11 | 1.87-12 | 3.94-09 | 6.40-13 |
| | | ALTITUDE 6000 METERS | | | | |
| | 0 | 1.25-09 | 8.60-11 | 1.34-11 | 6.75-09 | 1.09-12 |
| | 45 | 3.09-12 | 5.64-11 | 5.21-12 | 2.29-09 | 3.72-13 |
| | 70 | 2.85-13 | 4.40-12 | 5.31-13 | 2.22-10 | 3.61-14 |
| | | ALTITUDE 9000 METERS | | | | |
| | 0 | 2.04-10 | 5.40-11 | 8.91-12 | 3.01-09 | 4.89-13 |
| | 45 | 2.54-12 | 5.81-11 | 3.63-12 | 9.97-10 | 1.62-13 |
| | 70 | 1.98-13 | 3.57-12 | 3.37-13 | 9.83-11 | 1.60-14 |
| | | ALTITUDE 18000 METERS | | | | |
| | 0 | 2.44-11 | 2.39-11 | 4.58-12 | 7.64-10 | 1.24-13 |
| | 45 | 1.09-12 | 1.40-11 | 1.82-12 | 2.58-10 | 4.19-14 |
| | 70 | 8.03-14 | 1.63-12 | 1.62-13 | 2.49-11 | 4.04-15 |

TABLE XX (CONTINUED)

| WL | LA | $AS_0$ | $AS_1$ | $AS_2$ | $R_1$ | $R_2$ |
|---|---|---|---|---|---|---|
| | | ALTITUDE 300 METERS | | | | |
| 3.507 | 0 | 2.63-09 | 0.00+00 | 0.00+00 | 3.27-06 | 0.00+00 |
| | 45 | 2.33-11 | 0.00+00 | 0.00+00 | 1.14-06 | 0.00+00 |
| | 70 | 1.94-12 | 0.00+00 | 0.00+00 | 1.22-07 | 0.00+00 |
| | | ALTITUDE 1500 METERS | | | | |
| | 0 | 3.30-10 | 0.00+00 | 0.00+00 | 1.01-07 | 0.00+00 |
| | 45 | 3.38-12 | 0.00+00 | 0.00+00 | 3.35-08 | 0.00+00 |
| | 70 | 2.34-13 | 0.00+00 | 0.00+00 | 2.95-09 | 0.00+00 |
| | | ALTITUDE 6000 METERS | | | | |
| | 0 | 2.41-11 | 0.00+00 | 0.00+00 | 4.66-09 | 0.00+00 |
| | 45 | 5.65-13 | 0.00+00 | 0.00+00 | 1.44-09 | 0.00+00 |
| | 70 | 3.19-14 | 0.00+00 | 0.00+00 | 1.01-09 | 0.00+00 |
| | | ALTITUDE 9000 METERS | | | | |
| | 0 | 9.71-12 | 0.00+00 | 0.00+00 | 2.01-09 | 0.00+00 |
| | 45 | 3.56-13 | 0.00+00 | 0.00+00 | 6.23-10 | 0.00+00 |
| | 70 | 2.01-14 | 0.00+00 | 0.00+00 | 4.27-11 | 0.00+00 |
| | | ALTITUDE 18000 METERS | | | | |
| | 0 | 2.07-12 | 0.00+00 | 0.00+00 | 4.60-10 | 0.00+00 |
| | 45 | 1.54-13 | 0.00+00 | 0.00+00 | 1.42-10 | 0.00+00 |
| | 70 | 9.56-15 | 0.00+00 | 0.00+00 | 9.72-12 | 0.00+00 |

TABLE XX (CONTINUED)

| WL | LA | $AS_o$ | $AS_1$ | $AS_2$ | $R_1$ | $R_2$ |
|---|---|---|---|---|---|---|
| | | ALTITUDE 300 METERS | | | | |
| 10.6 | 0 | 2.45-10 | 0.00+00 | 0.00+00 | 3.13-06 | 0.00+00 |
| | 45 | 3.87-12 | 0.00+00 | 0.00+00 | 1.08-06 | 0.00+00 |
| | 70 | 3.45-13 | 0.00+00 | 0.00+00 | 1.12-07 | 0.00+00 |
| | | ALTITUDE 1500 METERS | | | | |
| | 0 | 2.77-11 | 0.00+00 | 0.00+00 | 8.30-08 | 0.00+00 |
| | 45 | 4.63-13 | 0.00+00 | 0.00+00 | 2.63-08 | 0.00+00 |
| | 70 | 3.02-14 | 0.00+00 | 0.00+00 | 1.97-12 | 0.00+00 |
| | | ALTITUDE 6000 METERS | | | | |
| | 0 | 1.59-12 | 0.00+00 | 0.00+00 | 2.69-09 | 0.00+00 |
| | 45 | 5.09-14 | 0.00+00 | 0.00+00 | 7.31-10 | 0.00+00 |
| | 70 | 2.05-15 | 0.00+00 | 0.00+00 | 3.33-11 | 0.00+00 |
| | | ALTITUDE 9000 METERS | | | | |
| | 0 | 5.95-13 | 0.00+00 | 0.00+00 | 1.05-09 | 0.00+00 |
| | 45 | 2.92-14 | 0.00+00 | 0.00+00 | 2.83-10 | 0.00+00 |
| | 70 | 1.10-15 | 0.00+00 | 0.00+00 | 1.18-11 | 0.00+00 |
| | | ALTITUDE 18000 METERS | | | | |
| | 0 | 4.02-12 | 0.00+00 | 0.00+00 | 2.14-10 | 0.00+00 |
| | 45 | 1.19-14 | 0.00+00 | 0.00+00 | 5.70-11 | 0.00+00 |
| | 70 | 4.30-16 | 0.00+00 | 0.00+00 | 2.23-12 | 0.00+00 |

WL - WAVELENGTH ($\mu$)
LA - LOOKANGLE (DEGREES)
AS - ATMOSPHERIC SCATTERED COMPONENT BEFORE ANY REFLECTION OCCURS
AS - ATMOSPHERIC SCATTERED COMPONENT AFTER SINGLE ORDER REFLECTION
AS - ATMOSPHERIC SCATTERED COMPONENT AFTER SECOND ORDER REFLECTION
R - GROUND REFLECTION FROM FIRST ORDER REFLECTION
R - GROUND REFLECTION FROM SECOND ORDER REFLECTION

THE UNITS FOR IRRADIANCE ARE PHOTONS $M^{-2}$/SOURCE PHOTON

TABLE XXI

ATMOSPHERIC SCATTERED AND GROUND REFLECTED COMPONENTS OF SCATTERED IRRADIANCE VERSUS ORDER OF REFLECTION FOR 5 KILOMETER VISIBILITY ATMOSPHERE FOR 0.9 GROUND ALBEDO

| WL | LA | $AS_0$ | $AS_1$ | $AS_2$ | $R_1$ | $R_2$ |
|---|---|---|---|---|---|---|
| ALTITUDE 300 METERS | | | | | | |
| 0.5145 | 0 | 3.77-05 | 2.80-08 | 1.71-10 | 2.01-06 | 6.78-10 |
| | 45 | 4.71-10 | 1.86-08 | 4.43-10 | 6.42-07 | 2.16-10 |
| | 70 | 3.83-11 | 6.80-10 | 2.40-11 | 4.99-08 | 1.68-10 |
| ALTITUDE 1500 METERS | | | | | | |
| | 0 | 3.07-05 | 2.88-09 | 1.06-10 | 1.26-08 | 4.25-12 |
| | 45 | 2.21-11 | 5.33-10 | 2.85-11 | 2.66-09 | 8.96-13 |
| | 70 | 4.91-13 | 8.30-12 | 6.02-13 | 4.63-11 | 1.56-14 |
| ALTITUDE 6000 METERS | | | | | | |
| | 0 | 3.27-07 | 6.18-10 | 5.31-11 | 8.41-10 | 2.83-13 |
| | 45 | 2.05-11 | 1.66-10 | 1.67-11 | 1.69-10 | 5.70-14 |
| | 70 | 6.10-13 | 2.64-12 | 2.04-13 | 2.50-12 | 8.42-16 |
| ALTITUDE 9000 METERS | | | | | | |
| | 0 | 1.16-07 | 3.56-10 | 3.41-11 | 3.93-10 | 1.32-13 |
| | 45 | 1.92-11 | 1.15-10 | 8.14-12 | 7.94-11 | 2.68-14 |
| | 70 | 5.40-13 | 2.00-12 | 2.20-13 | 1.12-12 | 3.78-16 |
| ALTITUDE 18000 METERS | | | | | | |
| | 0 | 7.32-09 | 1.52-10 | 1.81-11 | 1.05-10 | 3.54-14 |
| | 45 | 1.13-11 | 4.80-11 | 6.50-12 | 2.11-11 | 7.11-15 |
| | 70 | 3.83-13 | 1.17-12 | 1.34-13 | 2.80-13 | 9.43-17 |

TABLE XXI (CONTINUED)

| WL | LA | $AS_o$ | $AS_1$ | $AS_2$ | $R_1$ | $R_2$ |
|---|---|---|---|---|---|---|
| | | ALTITUDE 300 METERS | | | | |
| 1.06 | 0 | 1.22-05 | 3.80-08 | 3.88-10 | 2.51-06 | 1.91-09 |
| | 45 | 3.02-10 | 3.90-09 | 3.90-10 | 8.47-07 | 6.44-10 |
| | 70 | [illegible].64-11 | 0.00+00 | 4.35-11 | 7.93-08 | 6.02-11 |
| | | ALTITUDE 1500 METERS | | | | |
| | 0 | 1.48-05 | 1.11-09 | 2.35-10 | 4.00-08 | 3.04-11 |
| | 45 | 3.20-11 | 6.81-10 | 8.57-11 | 1.09-08 | 8.28-12 |
| | 70 | 1.06-12 | 1.99-11 | 2.93-12 | 4.82-10 | 3.66-13 |
| | | ALTITUDE 6000 METERS | | | | |
| | 0 | 8.38-09 | 6.54-10 | 6.46-11 | 2.73-09 | 2.06-12 |
| | 45 | 1.51-11 | 2.40-10 | 2.00-11 | 7.31-10 | 5.56-13 |
| | 70 | 8.14-13 | 8.72-12 | 8.50-13 | 3.09-11 | 2.35-14 |
| | | ALTITUDE 9000 METERS | | | | |
| | 0 | 3.52-10 | 3.80-10 | 4.56-11 | 1.28-09 | 1.68-12 |
| | 45 | 1.86-11 | 1.46-10 | 1.61-11 | 3.44-10 | 2.61-13 |
| | 70 | 6.45-13 | 7.16-12 | 7.11-13 | 1.44-11 | 1.09-14 |
| | | ALTITUDE 18000 METERS | | | | |
| | 0 | 7.54-11 | 1.61-10 | 1.97-11 | 3.48-10 | 2.64-13 |
| | 45 | 8.42-12 | 6.64-11 | 6.95-12 | 9.45-11 | 7.18-14 |
| | 70 | 4.35-13 | 3.60-12 | 4.25-13 | 3.92-12 | 2.98-15 |

TABLE XXI (CONTINUED)

| WL | LA | $AS_o$ | $AS_1$ | $AS_2$ | $R_1$ | $R_2$ |
|---|---|---|---|---|---|---|
| | | ALTITUDE 300 METERS | | | | |
| 3.507 | 0 | 2.32-08 | 0.00+00 | 0.00+00 | 2.93-06 | 0.00+00 |
| | 45 | 1.81-10 | 0.00+00 | 0.00+00 | 1.00-06 | 0.00+00 |
| | 70 | 1.38-11 | 0.00+00 | 0.00+00 | 9.80-08 | 0.00+00 |
| | | ALTITUDE 1500 METERS | | | | |
| | 0 | 3.01-09 | 0.00+00 | 0.00+00 | 5.83-08 | 0.00+00 |
| | 45 | 1.52-11 | 0.00+00 | 0.00+00 | 1.70-08 | 0.00+00 |
| | 70 | 6.61-13 | 0.00+00 | 0.00+00 | 9.65-10 | 0.00+00 |
| | | ALTITUDE 6000 METERS | | | | |
| | 0 | 1.70-10 | 0.00+00 | 0.00+00 | 2.89-09 | 0.00+00 |
| | 45 | 2.85-12 | 0.00+00 | 0.00+00 | 7.89-10 | 0.00+00 |
| | 70 | 9.51-14 | 0.00+00 | 0.00+00 | 3.55-11 | 0.00+00 |
| | | ALTITUDE 9000 METERS | | | | |
| | 0 | 6.59-11 | 0.00+00 | 0.00+00 | 1.28-09 | 0.00+00 |
| | 45 | 1.95-12 | 0.00+00 | 0.00+00 | 3.50-10 | 0.00+00 |
| | 70 | 6.23-14 | 0.00+00 | 0.00+00 | 1.54-11 | 0.00+00 |
| | | ALTITUDE 18000 METERS | | | | |
| | 0 | 1.73-11 | 1.32-11 | 0.00+00 | 3.48-10 | 0.00+00 |
| | 45 | 2.08-12 | 9.10-13 | 0.00+00 | 1.01-10 | 0.00+00 |
| | 70 | 9.17-14 | 5.63-13 | 0.00+00 | 4.57-12 | 0.00+00 |

TABLE XXI (CONTINUED)

| WL | LA | $AS_o$ | $AS_1$ | $AS_2$ | $R_1$ | $R_2$ |
|---|---|---|---|---|---|---|
| | | | ALTITUDE 300 METERS | | | |
| 10.6 | 0 | 2.26-09 | 0.00+00 | 0.00+00 | 2.98-06 | 0.00+00 |
| | 45 | 3.26-11 | 0.00+00 | 0.00+00 | 1.02-06 | 0.00+00 |
| | 70 | 2.80-12 | 0.00+00 | 0.00+00 | 1.02-07 | 0.00+00 |
| | | | ALTITUDE 1500 METERS | | | |
| | 0 | 3.14-10 | 0.00+00 | 0.00+00 | 6.45-08 | 0.00+00 |
| | 45 | 3.12-12 | 0.00+00 | 0.00+00 | 1.93-08 | 0.00+00 |
| | 70 | 1.65-13 | 0.00+00 | 0.00+00 | 1.20-09 | 0.00+00 |
| | | | ALTITUDE 6000 METERS | | | |
| | 0 | 1.17-11 | 0.00+00 | 0.00+00 | 2.10-09 | 0.00+00 |
| | 45 | 3.73-13 | 0.00+00 | 0.00+00 | 5.52-10 | 0.00+00 |
| | 70 | 1.15-14 | 0.00+00 | 0.00+00 | 2.07-11 | 0.00+00 |
| | | | ALTITUDE 9000 METERS | | | |
| | 0 | 4.17-12 | 0.00+00 | 0.00+00 | 8.39-10 | 0.00+00 |
| | 45 | 2.27-13 | 0.00+00 | 0.00+00 | 2.15-10 | 0.00+00 |
| | 70 | 6.35-15 | 0.00+00 | 0.00+00 | 7.41-12 | 0.00+00 |
| | | | ALTITUDE 18000 METERS | | | |
| | 0 | 1.02-12 | 0.00+00 | 0.00+00 | 1.80-10 | 0.00+00 |
| | 45 | 1.41-13 | 0.00+00 | 0.00+00 | 4.58-11 | 0.00+00 |
| | 70 | 3.62-15 | 0.00+00 | 0.00+00 | 1.49-12 | 0.00+00 |

WL - WAVELENGTH (μ)
LA - LOOKANGLE (DEGREES)
AS - ATMOSPHERIC SCATTERED COMPONENT BEFORE ANY REFLECTION OCCURS
AS - ATMOSPHERIC SCATTERED COMPONENT AFTER SINGLE ORDER REFLECTION
AS - ATMOSPHERIC SCATTERED COMPONENT AFTER SECOND ORDER REFLECTION
R - GROUND REFLECTION FROM FIRST ORDER REFLECTION
R - GROUND REFLECTION FROM SECOND ORDER REFLECTION

THE UNITS FOR IRRADIANCE ARE PHOTONS /SOURCE PHOTON be utilized to compute the atmospheric scattered component and the ground reflected component for a different background albedo with the following relationships

$$PR(\alpha) = AS_o + AS_1\ (\alpha/0.9) + AS_2(\alpha/0.9)^2 \qquad (1)$$

and

$$GR(\alpha) = R_1(\alpha/0.9) + R_2(\alpha/0.9)^2 \qquad (2)$$

where $PR(\alpha)$ is the atmospheric scattered component for the new background albedo $\alpha$, $GR(\alpha)$ is the ground reflected component for the new background albedo and the parameters $AS_o$, $AS_1$, $AS_2$, $R_1$ and $R_2$ are values listed in Tables XX or XXI for a particular combination of atmosphere, wavelength, altitude and lookangle.

If the area of the ground surface being illuminated has a different albedo from the surrounding background, equations 1 and 2 should be modified as follows:

$$PR(\alpha') = AS_o + AS_1(\alpha'/0.9) + AS_2(\alpha'/0.9)(\alpha/0.9) \qquad (3)$$

$$GR(\alpha') = R_1(\alpha'/0.9) + R_2(\alpha'/0.9)^2 \qquad (4)$$

where $\alpha'$ is the albedo of the illuminated area and $\alpha$ is the background albedo. In equation 4, the albedo, $\alpha'$, of the illuminated area is used because the nonreflected light incident on the ground surface is almost all incident on the area illuminated by the direct radiaiton from the source and the only portion of the second order reflected light seen by a collimated receiver is that reflected from the illuminated area. In equation 3, the atmospheric scattered light that has been reflected once is due to reflection from the illuminated area, but that which has been reflected twice, more than likely, was reflected the second time from the background area not illuminated by the direct radiation from the source.

If the albedo for the area illuminated by the direct radiation from the source has a reflection distribution other than the distribution for a Lambert type surface, the following equation should be utilized to compute the reflectance rather than equation 4:

$$GR(\alpha'(\theta)) = R_1\ (\alpha'(\theta)/(0.9\cos\theta/\pi)) + R_2\ (\alpha'/0.9)\ (\alpha'(\theta)/(0.9\cos\theta/\pi)) \quad (5)$$

where $\alpha'(\theta)$ is the differential albedo evaluated at the look-angle $\theta$.

If the 1.06 micron wavelength laser were located at 6000 meters in the 5 kilometer visibility atmosphere with a background albedo of 0.1 but with the illuminated area having a total albedo of 0.7 and differential albedo of 0.05 in the direction of the 45 degree lookangle, then the atmospheric scattered component would be:

$$\begin{aligned} PR(0.7) &= 1.51*10^{-11} + 2.40*10^{-10} *(0.7/0.9) \\ &\quad + 2.00*10^{-11}(0.7/0.9)(0.1/0.9) \\ &= 1.51*10^{-11} + 1.867*10^{-10} + 1.73*10^{-12} \\ &= 2.04*10^{-10}(\text{photons m}^{-2}/\text{source photon}) \end{aligned}$$

and the reflected component would be:

$$\begin{aligned} GR(0.05) &= 7.31*10^{-10}(0.05/(0.9*0.70711/3.1416) + \\ &\quad 5.56*10^{-13}\ (0.7/0.9)(0.05/(0.9*0.70711/3.14159) \\ &= 7.31*10^{-10}\ (.2483) + 5.56*10^{-13}(0.0193) \\ &= 1.815*10^{-10} + 1.073*10^{-14} \\ &\doteq 1.815*10^{-10}\ (\text{photons m}^{-2}/\text{source photon}) \end{aligned}$$

## 3.5 Single Scattering and Reflection

In Tables XI through XV the direct radiation reflected to each receiver was computed with the expression:

$$DR(\alpha) = (\alpha\cos\theta/\pi r^2)\exp(-T(hs)(1 + \sec\theta)) \quad (6)$$

where T(hs) is the optical distance from the ground to the source-receiver altitude hs, $\theta$ is the lookangle of the receiver, $\alpha$ is the ground albedo and r is the slant distance from the illuminated area to the receiver position. The reflection of the single scattered radiation incident upon the ground area illuminated by the direct radiation was computed with the expression:

$$SCR(\alpha) = (\alpha\cos\theta/\pi r^2)\ \exp(-T(hs)(1+\sec\theta)) *$$

$$2\pi\int_0^{hs}\sigma_a(h)\int_0^{\theta_h} f_a(\theta')\sin\theta' d\theta' dh + 2\pi\int_0^{hs}\sigma_r(h)\int_0^{\theta_h} f_r(\theta')\sin\theta' d\theta' dh, \qquad (7)$$

where $\sigma_a(h)$ and $\sigma_r(h)$ are the aerosol and Rayleight scattering cross sections as a function of altitude, $f_a(\theta')$ and $f_r(\theta')$ are the aerosol and Rayleigh phase functions and $\theta_h$ is the angle whose tangent is the radius of the illuminated ground area divided by the altitude of the single scattering event.

In addition to computing the ground reflected component of the scattered irradiance as shown above, single scattering calculations were performed to investigate the possibility of computing the atmospheric scattered component with a single scattering method.

The single scattered component was computed with the expression:

$$ss = \int_0^{hs} \exp(-T(hs)-T(h))(1+\sec\theta_1))\ [(\sigma_a(h)P_a(180-\theta_1)$$

$$+ \sigma_R(h)\ P_R(180-\theta_1))/((hs-h)\sec\theta_1)^2]dh \qquad (8)$$

where T(hs) is the optical distance from the ground to the source-receiver altitude, T(h) is the optical distance from the ground to the single scattering center, h is the height of the scattering center, hs is the height of the source and receiver, and $\theta_1$ is the angle between the vertical axis through the scattering center and the line joining the collision center with the receiver. The single scattering calculations illustrates the difficulty in computing the atmospheric scattered component when the source and receiver are located at the same position. For the other receiver positions, the denominator of equation 8 approaches a finite non-zero value as h approaches hs, but for the receiver located at the source position, the denominator approaches zero as h approaches hs. The single scattered irradiance at the collimated receiver for the 0.5145 micron wavelength laser located at 9000 meters in the clear atmosphere is plotted versus lookangle in Fig. 18. This figure shows the typical sharp increase as the receiver position approaches the source position. The total atmospheric scattered components of the irradiance at the collimated receiver as computed by LITE-I for the three lookangles of 0, 45, and 70 degrees are compared in Fig. 18 with the single scattering calculations. It is noted that the single scattered irradiance underpredicts the atmospheric scattered component for the 45 and 70 degree lookangles. This comparison is typical of that observed for both the 0.5145 and 1.06 micron lasers at all altitudes in both the clear and hazy atmospheres. Thus, a single scattering analysis would greatly underestimate the atmospheric scattered component at the large lookangles for lasers in the visible and near-infrared region. For the 3.507 and 10.6 micron wavelength lasers the single scattered component at 18000 meters compares more favorably with the atmospheric scattered component and thus the assumption was made that it was unnecessary to compute the multiple scattered and reflected irradiances for the other source receiver altitudes. Tables XXII and XXIII give the results of the single scattering calculations as a function of lookangle and altitude for each wavelength for the two different atmospheres. The accuracy with which single scattering calculation predicts the atmospheric scattered component may be evaluated by comparing the values in Tables XXII and XXIII for a given wavelength, lookangle, and altitude with the sum of the three air scattered components for the same parameters in Tables XX or XXI.

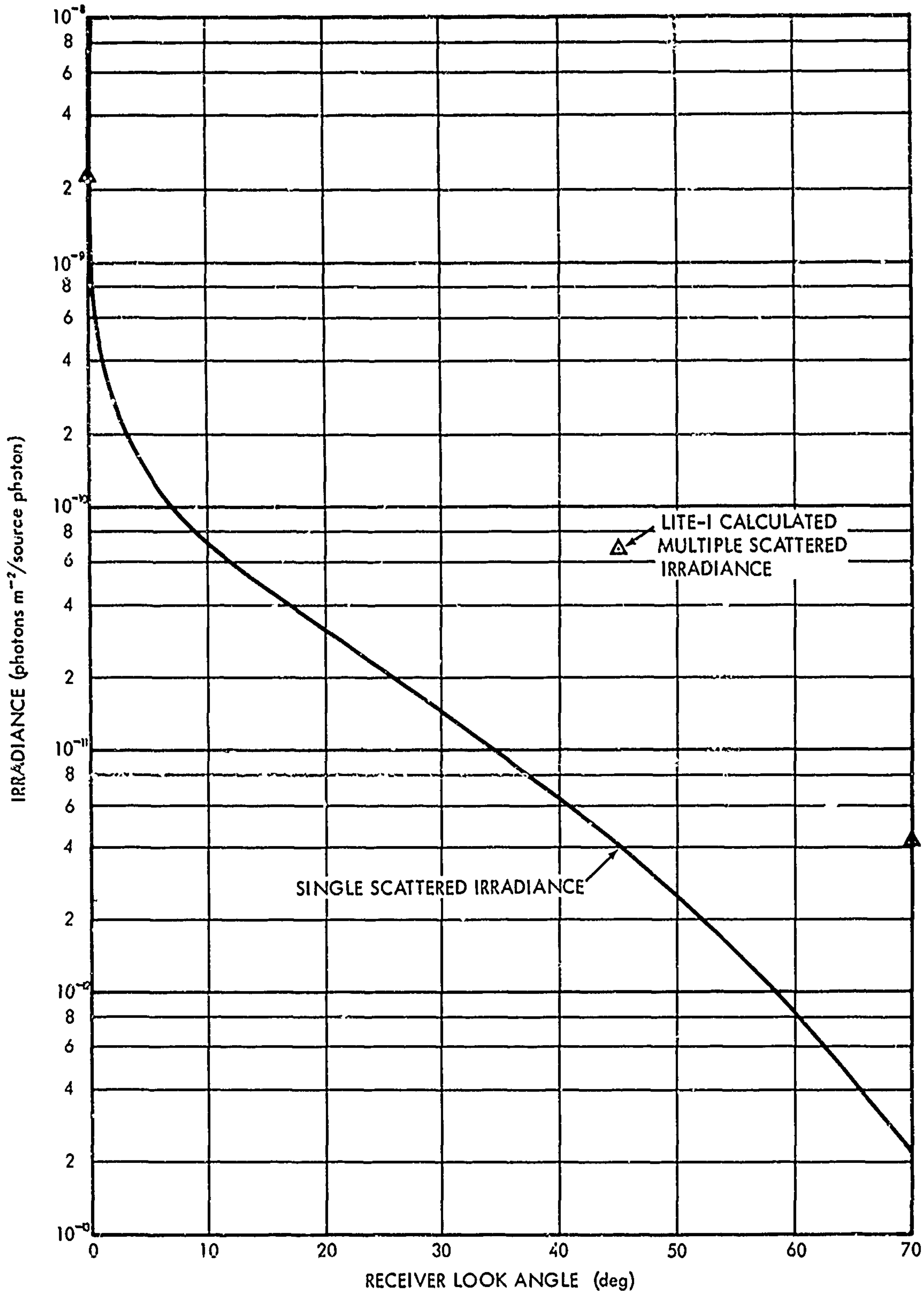


Fig. 18. Single and Multiple Scattered Components of the Atmospheric Scattered Irradiance at 9000 Meters Altitude versus Receiver Look Angle for a 0.5145 Micron Wavelength Laser in the Model Clear Atmosphere

TABLE XXII

SINGLE AIR SCATTERED IRRADIANCE VERSUS WAVELENGTH, ALTITUDE, AND LOOKANGLE FOR AIRBORNE LASER SYSTEM IN A 25 KILOMETER VISIBILITY ATMOSPHERE

| ALT | LA | WAVELENGTH (μ) | | | |
|---|---|---|---|---|---|
| | | 0.5145 | 1.06 | 3.507 | 10.6 |
| 300 | 2 | 3.09-08 | 1.26-08 | 2.63-09 | 2.95-10 |
| | 6 | 9.15-09 | 3.74-09 | 7.98-10 | 8.02-11 |
| | 12 | 3.93-09 | 1.63-09 | 3.47-10 | 3.79-11 |
| | 25 | 1.19-09 | 4.89-10 | 1.26-10 | 1.45-11 |
| | 45 | 2.33-10 | 9.15-11 | 2.33-11 | 3.87-12 |
| | 60 | 6.04-11 | 2.46-11 | 6.38-12 | 1.12-12 |
| | 70 | 1.75-11 | 7.01-12 | 1.94-12 | 3.05-13 |
| | 85 | 2.48-13 | 1.36-13 | 2.96-14 | 4.31-15 |
| 1500 | 2 | 4.29-09 | 1.26-09 | 3.30-10 | 2.77-11 |
| | 6 | 1.37-09 | 3.74-09 | 1.13-10 | 1.00-11 |
| | 12 | 6.06-10 | 1.63-09 | 5.14-11 | 4.83-12 |
| | 25 | 1.85-10 | 4.89-10 | 1.89-11 | 1.85-12 |
| | 45 | 3.49-11 | 1.59-11 | 3.38-12 | 4.63-13 |
| | 60 | 8.45-12 | 4.18-12 | 8.64-13 | 1.19-13 |
| | 70 | 2.20-12 | 1.18-12 | 2.34-13 | 3.02-14 |
| | 85 | 1.14-14 | 1.41-14 | 1.19-15 | 6.31-17 |
| 6000 | 2 | 5.16-10 | 1.59-10 | 2.41-11 | 1.59-12 |
| | 6 | 2.17-10 | 8.86-11 | 1.36-11 | 9.09-13 |
| | 12 | 1.08-10 | 4.95-11 | 7.52-12 | 5.20-13 |
| | 25 | 3.56-11 | 1.77-11 | 3.15-12 | 2.17-13 |
| | 45 | 6.69-12 | 3.51-12 | 3.65-13 | 5.09-14 |
| | 60 | 1.53-12 | 9.25-13 | 1.34-13 | 1.09-14 |
| | 70 | 3.63-13 | 2.59-13 | 3.19-13 | 2.05-15 |
| | 85 | 7.64-16 | 2.36-15 | 4.45-17 | 2.50-19 |

TABLE XXII (CONTINUED)

| ALT | LA | WAVELENGTH (μ) 0.5145 | 1.06 | 3.507 | 10.6 |
|---|---|---|---|---|---|
| 9000 | 2 | 2.51-10 | 6.77-11 | 9.71-12 | 5.95-13 |
| | 6 | 1.15-10 | 4.43-11 | 6.70-12 | 4.23-13 |
| | 12 | 6.14-11 | 2.77-11 | 4.18-12 | 2.73-13 |
| | 25 | 2.14-11 | 1.08-11 | 1.90-12 | 1.22-13 |
| | 45 | 4.12-12 | 2.26-12 | 3.56-13 | 2.92-14 |
| | 60 | | 6.03-13 | 8.53-14 | 6.14-15 |
| | 70 | 2.18-13 | 1.72-13 | 2.01-14 | 1.10-15 |
| | 85 | | 1.54-15 | 2.54-17 | 8.39-20 |
| 18000 | 2 | 7.41-11 | 1.57-11 | 1.99-12 | 1.08-13 |
| | 6 | 3.82-11 | 1.18-11 | 1.72-12 | 1.02-13 |
| | 12 | 2.24-11 | 8.70-12 | 1.32-12 | 8.39-14 |
| | 25 | 8.86-12 | 4.17-12 | 7.51-13 | 4.63-14 |
| | 45 | 1.83-12 | 1.00-12 | 1.62-13 | 1.24-14 |
| | 60 | | 2.83-13 | 4.11-14 | 2.67-15 |
| | 70 | 9.52-14 | 8.26-14 | 9.95-15 | 4.71-16 |
| | 85 | | 7.59-16 | 1.28-17 | 2.54-20 |

ALT - ALTITUDE (METERS)
LA - LOOKANGLE (DEGREES)

IRRADIANCE IS GIVEN IN UNITS OF PHOTONS $M^{-2}$ /SOURCE PHOTON

TABLE XXIII

SINGLE AIR SCATTERED IRRADIANCE VERSUS WAVELENGTH, ALTITUDE, AND LOOKANGLE FOR AIRBORNE LASER SYSTEM IN A 5 KILOMETER VISIBILITY ATMOSPHERE

| ALT | LA | WAVELENGTH (μ) 0.5145 | 1.06 | 3.507 | 10.6 |
|---|---|---|---|---|---|
| 300 | 2 | 1.07-07 | 6.20-08 | 2.32-08 | 2.26-09 |
| | 6 | 2.76-08 | 4.70-08 | 6.65-09 | 7.08-10 |
| | 12 | 1.10-08 | 7.03-09 | 2.82-09 | 3.28-10 |
| | 25 | 3.02-09 | 2.03-09 | 1.01-09 | 1.24-10 |
| | 45 | 5.04-10 | 3.59-10 | 1.81-10 | 3.26-11 |
| | 60 | 1.19-10 | 9.07-11 | 4.79-11 | 9.32-12 |
| | 70 | 2.99-11 | 2.52-11 | 1.38-11 | 2.80-12 |
| | 85 | 7.62-14 | 1.81-13 | 1.28-13 | 2.84-14 |
| 1500 | 2 | 6.65-09 | 6.80-09 | 3.01-09 | 3.14-10 |
| | 6 | 1.09-09 | 1.50-09 | 7.35-10 | 8.57-11 |
| | 12 | 3.62-10 | 5.69-10 | 2.91-10 | 3.74-11 |
| | 25 | 8.19-11 | 1.49-10 | 9.72-11 | 1.33-11 |
| | 45 | 9.50-12 | 2.20-11 | 1.52-11 | 3.12-12 |
| | 60 | 1.23-12 | 4.11-12 | 3.22-12 | 7.37-13 |
| | 70 | 1.21-13 | 7.17-13 | 6.61-13 | 1.65-13 |
| | 85 | 6.15-20 | 7.24-17 | 2.68-16 | 1.16-16 |
| 6000 | 2 | 9.11-10 | 5.68-10 | 1.70-10 | 1.17-11 |
| | 6 | 5.32-10 | 4.33-10 | 1.41-10 | 1.07-11 |
| | 12 | 1.80-10 | 2.03-10 | 7.31-11 | 6.23-12 |
| | 25 | 2.51-11 | 4.28-11 | 2.05-11 | 1.88-12 |
| | 45 | 2.30-12 | 5.69-12 | 2.85-12 | 3.73-13 |
| | 60 | 2.63-13 | 1.01-12 | 5.40-13 | 7.09-14 |
| | 70 | 2.29-14 | 1.68-13 | 9.51-14 | 1.15-14 |
| | 85 | 4.53-21 | 1.27-17 | 1.03-17 | 4.65-19 |

TABLE XXIII (CONTINUED)

| ALT | LA | WAVELENGTH (μ) 0.5145 | 1.06 | 3.507 | 10.6 |
|---|---|---|---|---|---|
| 9000 | 2 | 4.06-10 | 2.27-10 | 6.59-11 | 4.17-12 |
| | 6 | 2.35-10 | 1.80-10 | 5.63-11 | 3.90-12 |
| | 12 | 1.54-10 | 1.40-10 | 4.63-11 | 3.52-12 |
| | 25 | 2.18-11 | 3.28-11 | 1.48-11 | 1.22-12 |
| | 45 | 1.71-12 | 4.08-12 | 1.95-12 | 2.27-13 |
| | 60 | 1.84-13 | 7.09-13 | 3.61-13 | 4.12-14 |
| | 70 | 1.54-14 | 1.17-13 | 6.23-14 | 6.35-15 |
| | 85 | 2.46-21 | 8.59-18 | 6.00-18 | 1.55-19 |
| 18000 | 2 | 1.08-11 | 5.09-11 | 1.45-11 | 8.44-13 |
| | 6 | 6.38-11 | 4.22-11 | 1.28-11 | 8.19-13 |
| | 12 | 4.19-11 | 3.40-11 | 1.08-11 | 7.57-13 |
| | 25 | 1.91-11 | 1.97-11 | 8.01-12 | 5.82-13 |
| | 45 | 1.32-12 | 2.59-12 | 1.16-12 | 1.19-13 |
| | 60 | 1.19-13 | 4.19-13 | 2.04-13 | 2.02-14 |
| | 70 | 8.99-15 | 6.69-14 | 3.43-14 | 2.94-15 |
| | 85 | 9.81-22 | 4.68-18 | 3.17-18 | 4.87-20 |

ALT - ALTITUDE (METERS)
LA - LOOKANGLE (DEGREES)

IRRADIANCE IS GIVEN IN UNITS OF PHOTONS M $^{-2}$/SOURCE PHOTON

# IV. CONCLUSIONS

The atmospheric scattered component of the scattered irradiance received from an airborne laser system can be greatly reduced if the source and receiver are separated horizontally so that the lookangle is in the order of 5 degrees or larger. At lookangles near zero, even a small increase in the horizontal separation distance can greatly reduce the atmospheric scattered component.

For the wavelengths in the visible and near infrared regions, the light scattered within the atmosphere after reflecting from the ground surface contributes more to the irradiance at the collimated receivers for large lookangles than does the light scattered in the atmosphere before reflecting from the ground surface.

For the 3.507 and 10.6 micron wavelength lasers, a single scattering calculation predicts the atmospheric scattered component within the statistical accuracy of the Monte Carlo calculation of the multiple scattered irradiance at the collimated receivers.

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**13 ABSTRACT**

The LITE-I Monte Carlo program was used to predict the ground reflected and atmospheric scattered components of the scattered light from airborne laser systems received at collimated receivers located at the same altitude as the laser system and focused on the ground area illuminated by the direct radiation from the laser system. Lasers emitting light with wavelengths of 0.5145, 1.06, 3.507 and 10.6 microns were considered at different altitudes in two model atmospheres. The first atmosphere was a clear atmosphere having a ground level meteorological range of 25 km. The second atmosphere was identical to the first above 1.5 km but below 1.5 km the aerosol content was increased to reduce the ground level meteorological range to 5 km. The ground reflected component of the scattered light entering the receiver for all four wavelengths was taken to be the sum of the direct radiation incident on the ground and reflected to the receiver plus the single scattered radiation incident upon the ground area illuminated by the direct radiation and then reflected to the receiver. For the 3.507 and 10.6 micron lasers the atmospheric scattered component at the receiver in both atmospheres is composed almost entirely of single scattered light, but for the 0.5145 and 1.06 micron lasers the single scattered irradiance seriously underpredicts the atmospheric scattered component for lookangles greater than just a few degrees.

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| Light Scattering | | | | | | |
| Reflectance | | | | | | |
| Visibility | | | | | | |
| Model Atmosphere | | | | | | |
| Albedo | | | | | | |
| Backscattering | | | | | | |

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