LSSA PROJECT
TASK REPORT

AVAILABILITY OF ULTRAVIOLET RADIATION DATA (FOR ENCAPSULATION SYSTEM DESIGN)

FEBRUARY 14, 1977

5101-13

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA
AVAILABILITY OF ULTRAVIOLET RADIATION DATA (FOR ENCAPSULATION SYSTEM DESIGN)

February 14, 1977

Charles Gonzalez

Approved by:

W. F. Carroll, Manager
LSSA Encapsulation Task
To Distribution:

The enclosed report on the availability of ultraviolet data is provided as a supplement to the Battelle Columbus Laboratories report, "Terrestrial Service Environments for Selected Geographic Locations," ERDA/JPL 954328-76/5 written under a contract funded by JPL. This report is not meant to replace the section on UV radiation in the Battelle report, but merely to provide additional information. In fact, this report recommends that for the present time the approach developed by Battelle be used for the purposes of The Encapsulation Task of the Low-Cost Silicon Solar Array Project.

W. F. Carroll, Manager
LSSA Encapsulation Task
This work was performed by the Jet Propulsion Laboratory, California Institute of Technology, under National Aeronautics and Space Administration Contract NAS7-100, for the U. S. Energy Research and Development Administration (ERDA), Division of Solar Energy.

The Low-Cost Silicon Solar Array Project is funded by ERDA and forms part of the ERDA Photovoltaic Conversion Program to initiate a major effort toward the development of low-cost solar arrays.
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SECTION I
INTRODUCTION

The purpose of this report is to review the literature in order to determine the availability and adequacy of Ultraviolet (UV) data which is required to predict the effects of solar UV radiation (< 4000 Å magnitude and spectral distribution) on terrestrial solar cell encapsulants. In addition, the characteristics of UV radiation which affect the amount reaching the Earth's surface will be considered. The parameters and relationships reviewed include: the ratio of the UV (selected bands) intensity to the total surface incident horizontal solar radiation; seasonal and diurnal UV variation; atmospheric conditions—haze, turbidity, smog, ozone; UV variation with solar altitude; UV variation with receiving plane orientation; ground reflectance; ratio of direct-to-diffuse radiation; and anisotropy of sky UV.

Investigators (References 1-1 and 1-2) have found that the degradation of polymers is related to the UV spectrum when outdoor weathering tests are performed, but not to the total solar spectrum. It has also been shown that degradation proceeds faster in summer than in winter. This could be due in part to higher temperatures, but is also probably related to the higher UV which is measured in summer. In any case, the consideration of UV radiation is extremely important in materials testing.

Although numerous measurements have been made of selected UV bands between 2900-4000 Å (UV below 2900 is absorbed by Earth's atmosphere) the actual amount of data usable for the purposes of predicting encapsulant degradation are limited. The difficulty arises when one attempts to correlate these measurements over different spectral ranges made at different times and locations, under various atmospheric conditions, and using different instruments. Attempts to estimate UV radiation will result in large uncertainties. The amount of UV, both absolute and relative, reaching the surface is a function of the time of day, time of year, cloud or haze cover, and air pollution levels. Therefore, measurements made at one location may not correlate with those made at another.

The approach used by the Battelle Columbus Laboratories (Reference 1-3) in performing the analysis for the Low Cost Silicon Solar Array (LSSA) Module Encapsulation Task was to obtain the percentage of the total solar radiation attributed to UV. This was based on measurements by the Smithsonian Radiation Biology Laboratory for Washington, D. C., and Rockville, Maryland (Reference 1-4). The data for Washington were considered to represent an urban area, and those for Rockville a suburban (or non-urban area).

The objective of the Battelle approach is to predict long-term (20-year) UV exposure. Therefore, the difficulties which are encountered when attempting to estimate UV exposure over a short time period become less important. They cannot be eliminated from consideration completely, however. An average value of the ratio of UV percentage of total solar radiation determined in one location may be different from that at another location. For example, two locations may have the same total insolation levels, but may experience different weather patterns in terms of cloudiness such that the total amount of UV received would
be different. It is also possible for two locations to have the same total UV radiation (<4000 Å), but different spectral distributions. Such differences will also be introduced by differences in air pollution levels.

Another consideration, when making estimates of the UV radiation, is that the response of various bands of the UV spectrum to ozone, pollution and atmospheric scattering are different. Also, different polymers respond to different bands in the UV spectrum. This report discusses some of the measurements taken in the past in order to identify the characteristics of UV radiation which are required for developing the methodology needed for predicting the UV exposure at a particular site.
SECTION II
DISCUSSION

A. RELATIONSHIP OF UV RADIATION TO TOTAL INSOLATION—SEASONAL AND DIURNAL EFFECTS

The ratio of the intensity in a selected band in the UV region to the total solar radiation intensity was considered in several studies. One study, performed by the Smithsonian Radiation Biology Laboratory (SRBL), Rockville, Maryland, in Washington, D. C., and Rockville, allows a comparison of UV measurements taken under similar conditions of instrumentation and processing (Reference 1-4). The data were taken in the period 1968-1973.

The total radiation values are broken up spectrally, with the UV being lumped into the radiation below 4000 Å. Figure 2-1 shows the result of plotting the daily percentage of UV (percentage of total insolation) averaged over a given month for Washington, D. C. for 1968 through 1972. A curve is given for each year as well as an average of the monthly averages discussed below. Also plotted on the curve are the average monthly percentages of UV in the spectral band 2900-3150 Å taken by Coblentz (Reference 2-1) in Washington, D. C., for the years 1941-1950. The reader may well question why the smaller spectral band which is a part of a larger one shows a higher percentage. The actual amount of UV reaching the surface in Washington in 1968-1972 may well be lower than that in 1941-1950 due to an increased amount of pollution or change in weather patterns. The differences between earlier measurement techniques and current ones may also account for this occurrence. In other words, it is impossible to determine if the effects were real or not.

Some patterns in UV radiation can be noted by examining relative values. For example, from Figure 2-1 there is a general trend for the UV percentages to be higher in summer and lower in winter. The trend is more pronounced in the Coblentz narrow band data than the SRBL data. This illustrates the fact that lumping all of the UV into the below 4000 Å may not give the results desired if the effects on polymers sensitive to a narrower band are being considered.

Figure 2-2 shows monthly average daily UV percentages for Rockville, Maryland. Figure 2-3 shows daily UV percentages for Washington and Rockville for April, 1972, and gives an indication of the scatter in the data.

However, when long term averages, such as cumulative monthly daily averages are plotted, less scatter is obtained (i.e., data smoothing results). This can be seen in Figure 2-4 for the Washington and Rockville data. The cumulative data begins to converge to a long term value, 4.5% in the case of Rockville, and 2.5% in the case of Washington. This implies that the long term effects would tend to lend themselves to prediction techniques whereas short term would be more difficult.

Singleton and Cook (Reference 2-2) also consider the seasonal variation in UV intensity from data taken in Phoenix, Arizona and Miami, Florida. Figure 2-5 gives the UV (<3500 Å) percentage of the total insolation for a year for Phoenix, while Figure 2-6 gives the same values for Miami. These data also confirm the increase in percentage of UV observed in the summer months.
Figure 2-1. Percent Ultraviolet in Washington, D. C.

Figure 2-2. Percent Ultraviolet in Rockville, MD
Figure 2-3. Daily UV % vs Daily Total Insolation, April 1972, Washington, D. C. vs Rockville, MD

Figure 2-4. Cumulative Percent Ultraviolet Radiation
Figure 2-5. Seasonal Variation in UV Content of Solar Radiation in Phoenix (Taken from Reference 2-2)

Figure 2-6. Seasonal Variation in UV Content of Solar Radiation in Miami (Taken from Reference 2-2)
Searle and Hirt (Reference 2-3) consider both diurnal and seasonal variations of UV intensity as they measured the spectral intensity distribution of sunlight at 30 Å intervals between 2900-4100 Å at Stanford, Connecticut in the years 1957-1959. The field of view of the sensor ranged from 19°2' to 23° 34'. The measurements were made at various hours of the day and seasons of the year, noting sky conditions. Figure 2-7 gives a comparison of daily variation of UV over the seasons of the year showing a steeper variation in summer than in winter. Also shown is the lack of symmetry between the intensities before and after noon. The UV intensity is generally lower in mid-afternoon than at mid-morning. The authors comment that the relationship between UV energy and total solar energy is neither linear nor constant. Table 2-1 summarizes their results.

The highest UV intensities were measured from May to October. In December and January, the total UV intensities are about half as much as the highest summer values; but those in the wavelength region less than 3400 Å are reduced to about 1/3 or 1/4 of their highest values. The drop-off in intensity in the winter is considerably greater in the early morning than at noon.

The seasonal and diurnal affects result from the change in solar altitude and the fact that atmospheric scattering and absorption have a greater effect on the UV than on the total radiation. Therefore, the variations in UV energy at various hours of the day or different months of the year are not reflected by measurements of total sunlight. This was clearly illustrated by two separate measurements in 1958, one on July 10, and one on August 19. At noon the total energy was 1.30 Langley/min on July 10, and 1.25 Langley/min on August 19, whereas the UV energy on the 19th was almost twice that on July 10.

The results of the Searle and Hirt measurements show that the proportion of ultraviolet energy to total sun intensity ranges from less than 1 to 7% depending on the time of day and season. The fraction of short (<3400 Å) to total ultraviolet ranges from 2.5 to 16.5%.

They also state that the UV energy (<4000 Å) is reduced about 50% when haze is moderately heavy. A significant reduction is also caused by haze so slight that it is difficult to discern visually.

Sihoven, et al., (Reference 2-4) took measurements of the solar spectral energy in Miami, Florida from 1954-1956 with a spectroheliometer¹ for comparison with the total solar radiation. The instrument measured the radiation in several bands: 3095-3260 Å; 3410-3630 Å; 3865-4150 Å; and bands above 4150 Å. Total radiation was also measured using a pyroheliometer. Instrumentation was set up to convert the direct radiation measurements to the amount of radiation which would fall on a panel facing south and which was inclined 45°. Table 2-2 shows the percentage of energy in each band (related to the total radiation) for a panel facing south at 45°.

The values in the table are derived from measurements made from February 1954 to February 1955 near Miami.

¹This instrument measures only direct solar radiation.
Figure 2-7. Daily Variation in Intensity of Sunlight at 3050 Å and 5100 Å
(Taken from Reference 2-3)

Daily variation in intensity of sunlight at 3050 Å (—) and 4100 Å (—) on 7 and 9 January 1959 (solar altitude at noon about 22°) and 22 April 1959 (solar altitude at noon about 63°).

Figure 2-7. Daily Variation in Intensity of Sunlight at 3050 Å and 5100 Å (Taken from Reference 2-3) (Continuation 1)
Figure 2-7. Daily Variation in Intensity of Sunlight at 3050 Å and 5100 Å
(Taken from Reference 2-3) (Continuation 2)
Table 2-1. Daily and Seasonal Variation of Ratio of Ultraviolet to Total\textsuperscript{a} Sunlight Intensity. Ratios Intensity 2900-4100 Å/Total Sunlight. (Taken from Reference 2-3)

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Table 2-1. Daily and Seasonal Variation of Ratio of Ultraviolet to Total \(^a\) Sunlight Intensity. Ratios of Ultraviolet Intensity 2900-4100 Å/Total Sunlight. (Taken from Reference 2-3) (Continuation 1)

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\(a\) Measured in Langley/min (gm cal/cm²/min) using a General Electric Radiation Meter. Conversion to \(\mu W = \text{Langley} \times 60 \times 1162.8\).

\(b\) Very slightly hazy.

\(c\) Slightly hazy.

\(d\) Partly cloudy, clear around the sun.

\(e\) High thin clouds.

\(f\) Light scattered clouds.
Table 2-2. UV Percentage of Total Radiation for South-Facing Panel Tilted 45°

<table>
<thead>
<tr>
<th>Band, Å</th>
<th>Percent of Total Solar Radiation</th>
</tr>
</thead>
<tbody>
<tr>
<td>3095 - 3260</td>
<td>0.2</td>
</tr>
<tr>
<td>3410 - 3630</td>
<td>1.1</td>
</tr>
<tr>
<td>3865 - 4150</td>
<td>2.4</td>
</tr>
<tr>
<td>Total</td>
<td>3.7</td>
</tr>
</tbody>
</table>

B. VARIATION OF UV INTENSITY WITH ATMOSPHERIC CONDITIONS

The variation of UV intensity reaching the Earth's surface is also dependent on atmospheric conditions. Several authors have considered this aspect in addition to Searle and Hirt.

Condit and Grum (Reference 2-5) made measurements of the spectral energy distribution of daylight (sunlight plus skylight) in the near ultraviolet (down to about 3200 Å) and visible regions. The measurements were made on planes of different azimuthal orientations at 15° from the vertical as a function of solar altitude for various atmospheric conditions. The plots of relative energy vs wavelength are shown in Figure 2-8 for a variety of sky conditions ranging from clear to heavily overcast sky. The differences in spectra with sky conditions illustrate the difficulty in taking scattered UV measurements and attempting to derive meaningful correlations from them.

Nader and White (Reference 2-6) determined an empirical relationship for UV (3000-3800 Å) incident on a horizontal plane, through unpolluted air:

\[ Y = 8.634 + 36.8X \]

Where \( Y \) = direct + scattered UV radiation in W/m²

\[ X = \cos Z e^{-\sec Z} \]

Where \( Z \) = Zenith angle

and sec \( Z \) is also known as the air mass or the ratio of the length of the vertical path. They found that this relationship for incident UV intensity was obeyed for conditions of no smog, but did not hold for observations made through smog.
Figure 2-8. Spectral Distribution of Energy on a 15° - 0° Plane (Taken from Reference 2-4) Note: 15° - 0° signifies 15° from vertical and 0° azimuth (0° - pointing south)
The horizontal sensor gives a cosine response to all the incident radiation, and the intensity of the direct sunlight together with the skylight is reduced exponentially with increased air mass (expressed as the secant function of the solar Zenith angle, Z). The authors (Nader and White) checked the curve with data taken near Cincinnati (Figure 2-9) and showed a good fit for Z<75°. The authors attribute the divergence beyond this angle to the accuracy with which the low levels of UV can be measured. Figure 2-9 shows a fit obtained with data taken on a smoggy day in Los Angeles for comparison. The Los Angeles data show an increase in UV attenuation with decreasing Zenith angle. A significant decrease occurred at mid-morning at the time of maximum pollutant concentration.

Nader's group made a second set of measurements in Los Angeles (Reference 2-7). Measurements were made in downtown Los Angeles and at Mt. Wilson (5700 ft elevation). The readings were taken on several days which represented the following smog conditions: moderate to heavy; light to moderate; light; and none. These classifications were based on ozone concentration, visibility and eye irritation. The UV measurements which were made did show that ground level UV intensity is dependent on air pollution levels. Figure 2-10 gives a comparison of readings for each of 5 days for different categories of smog for the 3000-3800 Å range. The effect of smog is demonstrated qualitatively. Although the reference provides data for making a quantitative comparison, that was not attempted here. Figure 2-11 gives a comparison of UV spectral levels taken for each of 2 days under different smog levels.

The measurements, taken in the horizontal plane, were made for True Solar Time (TST) which is Pacific Daylight Time less 40 min.

The attenuation in the UV between downtown Los Angeles and Mt. Wilson as evidenced by the measurements, ranged from a mean value of about 14% to a minimum of about 3% for a clear day. On a smoggy day (moderate to heavy), the attenuation ranged from a mean of 38 to peak of 58%. In other words, the attenuation between downtown and Mt. Wilson was a factor of three greater on a smoggy day than a clear day. On the days of maximum attenuation the ozone and NO₂ concentration were 6-10 times those on a nonsmoggy day and visibility was reduced from 25 to 0.5 mi.

Laue (Reference 2-8) took solar insolation (including UV) measurements at Table Mountain and the JPL Edwards Test Station. A comparison of the results is given in Figure 2-12. The graph of the UV intensity shows a drop around mid-afternoon due to dust and smog over Table Mountain.

Swartmen et.al., (Reference 2-9) also have investigated the results of studies of atmospheric pollution on the amount of radiation reaching the surface. In industrial areas, it has been found that the amount of UV radiation is decreased by possibly as much as 40-60% of that which may be found in suburban areas. This loss might possibly be attributed to concentration of SO₂ since it absorbs solar radiation in the troposphere quite strongly in the wavelength range 2900-4000 Å. Shorter wavelengths are more seriously affected by pollution than long wavelengths.

The authors also cite studies showing reductions in sunlight due to pollution of 23% in Houston, Texas, and 16% in Washington, D. C. (the latter over the past half-century).
Figure 2-9. Empirical Relationship of Vertical UV Radiation (3000 - 3800 Å) Intensities with Solar Zenith Angle (Taken from Reference 2-6)

Figure 2-10. Average Incoming (3000 - 3800 Å) Radiation for 30-min Intervals, as Function of Time of Day on Various Days of Smog in Downtown Los Angeles (Taken from Reference 2-7)
Figure 2-11. Average Incoming Radiation in Downtown Los Angeles for 30-min Intervals as a Function of Time (Taken from Reference 2-7)
Figure 2-12. Comparison of Spectral Intensities for Table Mountain and Edwards Test Station (Taken from Reference 2-8)
According to Machta et al., (Reference 2-10) the air mass variation cited above changes the amount of solar radiation differently with each UV wavelength. The decrease in solar radiation with increasing air mass is more rapid at shorter wavelengths than at longer wavelengths. Figure 2-13 taken from the reference illustrates this. The decrease at shortest wavelengths is more rapid than would be expected simply from the increasing length of the air column. The reason for this is the strong absorption by ozone.

C. VARIATION OF UV INTENSITY WITH RECEIVING PLANE ORIENTATION

As cited above, the orientation of the plane receiving the UV intensity is important. Yamasaki (Reference 2-11) measured hourly values of UV (3000-4000 A) intensity as well as that for longer wavelengths for several planar orientations in Ottawa, Canada for the years 1967-1968 (once or twice a month). The planes were oriented in the vertical direction facing south, at 45° facing south, and normal to the sun's rays. The vertical plane is of little interest to us. Figure 2-14 shows some of the results as a function of planar orientation and that the UV spectrum has the largest housey rate of change in intensity in the normal plane when compared to the hourly rate of change of the rest of the solar spectrum. Except for the December-March time period, the highest intensity was measured on the normal plane. The figure also shows that data for the different planes converged in winter and diverged in summer, an indication that orientation is a more important factor in summer. The intensities on a normal plane were lowest in December and highest in August. The contribution of UV to the total intensity was 1 to 5%, from winter to summer, respectively.

D. RELATIONSHIP OF DIRECT AND DIFFUSE COMPONENTS OF SOLAR RADIATION

In order to understand the differences in the absorption and transmission of UV radiation and total solar radiation, the relationship of the direct and diffuse component of solar radiation must be considered. The diffuse component is much richer in UV than the direct component.

The discussion about the significance of diffuse solar radiation is meant to illustrate the difficulty in using generalized average approaches for obtaining the fraction of the UV radiation available. As noted in previous sections, the actual amount of UV incident on a surface depends on the inclination and orientation of the surface, the time of day, time of year, conditions of the sky and the characteristics of the ground near by. These parameters are related differently to the direct and diffuse components.

Bener, of Switzerland, (Reference 2-12) has made numerous measurements of the UV intensity. Among other characteristics, he considered the ratio of the direct solar radiation\(^1\) to the diffuse or sky radiation. His data analysis

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\(^1\)Bener actually compared the vertical component of direct solar radiation with the sky radiation. This component is equivalent to the difference between the total radiation and the sky radiation.
Figure 2-13. Relative UV Intensity at Various Air Masses
(Taken from Reference 2-10)
Figure 2-14. Diurnal and Seasonal Variations in Intensity of UV Band Impinging on S/V, S/45, and L Planes in Ottawa from Data Taken on Clear Days During 1967-1968 (Taken from Reference 2-11)
supported several conclusions, summarized below. The amount of diffuse radiation increases with decreasing wavelength (measurements were made in the range 3300-3700 Å). The diffuse radiation exceeds the direct radiation when the sun is between the horizon and a given elevation, which is wavelength dependent. The exact difference between the two components is a function of elevation. As an example, results obtained at Davos, Switzerland for June, show that the two components become equal at an altitude of 28° for the 3600-3700 Å band. The equivalent altitude for the 3000-3200 Å band is 53°. In fact, the noon values of the direct component exceed those for the diffuse radiation only from May to September. The corresponding period for the wavelength interval 3600-3700 Å extends from February to October. Bener attributes some of the increase of direct radiation over diffuse radiation in the summer to the decrease in the amount of ozone in the atmosphere. The effect is less at lower solar elevations. Figure 2-15 shows the annual variation of the ratio of direct to diffuse radiation for noon as a function of wavelength.

Page (Reference 2-13) performed a theoretical analysis of the relationship of total to diffuse radiation. He was concerned with how this relationship was affected by cloudiness or haze. In general, low values of diffuse radiation are normally associated with sky regions of great clarity and high values with regions of high turbidity or haze.

His analysis supported the conclusion that the maximum diffuse radiation occurs on partly cloudy days and not on clear or overcast days. A decrease in the intensity of the direct beam is accompanied by an appreciable increase in the amount of diffuse radiation available (in a cloudiness range surrounding the point of maximum diffuse radiation).

Actually, the diffuse shortwave radiation on inclined planes is made up of two parts, radiation diffusely scattered from the sky and radiation diffusely reflected from the ground. In addition, the ground albedo increases very appreciably at low angles of incidence.

Morris and Lawrence (Reference 2-14) discuss the question of antisotropy of clear sky diffuse solar radiations. They conclude that sky radiation comes predominantly from some sector of the sky not adjacent to the sun's position. They state that there are few days when only one or the other of the assumptions that diffuse radiation is directional (concentrated around the sun) or that it is isotropic gives good results. The actual situation is more nearly represented by a combination of these effects. They also cite investigators who claim that the sky near the sun has a higher intensity than at 90 or 180° from the sun's azimuthal direction. It is generally held that for an overcast sky there is no azimuthal variation in intensity, except when cloudiness is not uniform or is partially transparent. However, there is disagreement with the isotropic theory from investigators who claim that there is a pronounced anisotropy for overcast skies. The authors conclude that in the majority of cases the isotropic approximation gives unsatisfactory results when used to calculate the diffuse radiation fluxes to an inclined surface. They cite calculations of daily total radiation values with errors up to 22%.

Based on experimental analyses, the authors determined that the clear sky intensity distribution of diffuse radiation can be represented as emission from two superimposed sources. The sources are defined as: 1) the circumsolar...
Figure 2-15. Annual Variation of Direct to Diffuse Ratio of Solar Radiation as a Function of Wavelength (Taken from Reference 2-12)
region centered about the sun and extending radially outward, and 2) the total hemisphere of the sky vault. Because the sun must be the ultimate origin of energy in both cases, these two sources are not completely independent of each other.

The circumsolar region is defined, in terms of the angular distance from the sun, as extending from about 8 to 60 deg. The direct solar component is excluded from this. The hemispherical component is the solar energy scattered throughout the Earth's atmosphere by the particles and components of the atmosphere. The intensity of the former component varies with angular position around the sun only when the air mass has large changes across the whole region. This occurs when the sun is low in the sky. The intensity of the second component varies because of the variation in air mass as seen from the Earth's surface.

The hemispherical diffuse component contributes 43% of the total diffuse radiation energy available; the circumsolar diffuse component contributes 57% of the total diffuse radiation energy. The physical shape of the energy source and the orientation of the receiving surface will determine the quantity of energy that will actually reach the surface. However, the relative magnitude of energy from these two sources remains nearly constant.

Finally, the ratio of the amount of diffuse radiation to the direct, after traversing the atmosphere and its pollutants, was considered by Sprigg and Reifsnyder (Reference 2-15). They simultaneously took measurements of normal incidence solar radiation at two or three levels in the lowest 100 m of the atmosphere in New Haven, Connecticut between February and July, 1971. They also took measurements of certain pollutant indicators such as SO₂, soiling index, suspended particulates, and transmissivity. They measured the total radiation on a roof top. They found that the decreases in total radiation measured at the roof top compared to those at higher levels were significantly less than the corresponding differences in the amount of direct radiation. The mid-morning average decrease in total radiation was 6% compared to 28% in direct radiation. Approximately 75-80% of the radiation depleted in the direct beam was regained at the surface as diffuse radiation. This proportion remained essentially consistent from mid-morning to mid-afternoon, where as the percentage decreases in the direct beam and the diffuse radiation varied directly with Zenith angle.
SECTION III

CONCLUSIONS

In order to predict the effects of weathering on potential encapsulants, the expected exposure to the appropriate UV component of the solar insolation must be determined. Most of the solar insolation data which have been recorded have been total radiation data. Data giving the spectral composition of the UV portion on the surface are not available for many locations.

A literature search has shown that there are some UV data available that may be helpful in predicting the effects of UV radiation (4000 Å) on terrestrial solar cell encapsulants. However, the current data base does not appear to be adequate for formulating predictive methodology in which a user would have much confidence.

The development of accurate tools for predicting UV fluxes will require correlation of the UV with some other relatively well measured quantity. Measurements of the total solar radiation are available for a number of sites for periods of time ranging from several months to in excess of 20 years. Although the solar data have been the subject of a certain amount of controversy because of uncertainties in the measurements, the National Oceanic and Atmospheric Administration is in the process of rehabilitating the data to uncertainties of about 5%. Additionally, new measurement networks are being set up. Therefore, the approach for developing a methodology for predicting the UV environment which appears to have the greatest chance of success is one which relates the UV spectral bands to the total solar radiation.

The difficulties with resorting to a simple formula relating UV to total radiation are discussed above. As was pointed out, a number of parameters must be considered when relating UV intensity to total solar radiation intensity. Although a simplistic formula may be sufficient to estimate total 20-year exposure, it would probably not be accurate enough to use in performing aging studies on encapsulants. Such aging studies would depend on the correlation of accelerated and abbreviated tests with field tests. Therefore, it would be necessary to determine short-term UV exposure at a particular site.

The development of more accurate tools for predicting UV fluxes will require obtaining additional UV spectral measurements which can be correlated with other required parameters. An intermediate approach is to correlate whatever UV data are available with the other parameters which are available after careful consideration of all the data. The probability of being able to develop all of the prediction tools required to represent an adequate number of sites is limited both by the amount of UV data available and by the availability of other data required to develop correlations. However, the results obtained for certain sites may provide for reasonably accurate estimates of the environment.
SECTION IV
RECOMMENDATIONS

It will be necessary to obtain UV measurements which are correlative with other parameters in order to develop the methodology for predicting the expected UV environment at a site. The measurements should be taken at a sufficiently large number of sites to represent both the required extremes in the UV environment and in the environments which may produce synergistic effects with UV radiation. The program for taking measurements should be coordinated by an agency which will be responsible for ensuring standard instrumentation and calibration and the availability of other required data.

UV spectral measurements should be made in the range from atmospheric cutoff (about 2900 Å) to 4000 Å at intervals of about 50 Å or smaller. They should be taken at a location and time so that they are correlative with all or most of the following parameters, depending on the site:

1. Total solar insolation.
2. Some standardized indicators of cloud cover, hazes or turbidity.
3. Atmospheric pollutants which are UV absorbers, e.g., ozone.
4. Site latitude and altitude.
5. Local solar time.
6. Altitude of the sun (can be determined from standard tables based on time of day and time of year).
7. Reflectance characteristics of near-by surfaces, especially ground surfaces.
8. Inclination and orientation of the plane on which measurements are being made if they are planar.

The above parameters are those which would be used in developing a methodology for predicting the UV environment. In addition to this, environmental measurements should be taken of those environments which will produce synergistic effects with UV radiation. This should include those air pollutants which have a potential for degrading materials such as NOX, SO2, ozone and other oxidents, and temperature.

A minimum of one complete year of data is required to ensure an adequate seasonal representation. Until such an effort can be undertaken, the methodology presented in the Battelle Study Report (Reference 1-3) should form the basis for the purposes of the LSSA Project.
REFERENCES


