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# SOLAR ULTRAVIOLET RADIATION ON HORIZONTAL, SOUTH/45° AND SOUTH/VERTICAL SURFACES

by R.S. Yamasaki



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## RÉSUMÉ

La résistance aux intempéries de matériaux à base de plastique dépend de leur angle d'exposition à la lumière. Pour analyser le rôle des rayons ultraviolets en fonction de cet angle d'exposition, on a mesuré pendant toute une année à Ottawa le rayonnement ultraviolet incident sur des surfaces horizontales (H) orientées au sud à 45° (S/45) et à 90° (S/V). Pour les matériaux dont la dégradation dépend largement du rayonnement ultraviolet, l'exposition S/45 a conduit à une dégradation moindre de 5 à 13% par rapport à l'exposition H, tandis que
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# SOLAR ULTRAVIOLET RADIATION ON HORIZONTAL, SOUTH/45° AND SOUTH/VERTICAL SURFACES

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## ABSTRACT

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The weatherability of plastic-based materials depends on the exposure angle. To help clarify the contribution of solar "ultraviolet" to this angular dependence, UV radiation incident on surfaces at horizontal (H) position and facing south at 45° (S/45) and 90° (S/V), at Ottawa, Canada, was measured continuously for one year. For materials in which UV plays a dominant role in degradation, the S/45 exposure results in 5 — 13% less degradation than the H exposure, while the S/V exposure results in 37 — 54% less than the H exposure. The proportion of UV in solar radiation increases with a decrease in daily global solar radiation. This relation can be used to estimate the UV radiation at various sites from global solar radiation readings. Median and maximum daily UV levels for each month were determined, to aid development of an accelerated weathering test.

## INTRODUCTION

The dependence of weatherability of plastic-based materials on the exposure angle has been commonly observed (Estevez, 1965; Yamasaki and Blaga, 1982; Gomez, 1977); damage at the horizontal exposure is more severe than at the vertical exposure, facing the equator, by a factor of two or more (Gomez, 1977). This dependence is generally attributed to differences in the amount of solar ultraviolet (UV) radiation incident on surfaces at different angles (Gomez, 1977; Lappin, 1971), even though temperature and moisture conditions also depend on the exposure angle and may have significant effects (Yamasaki and Blaga, 1976; unpublished data). Further, although the effect of exposure angle on the incident UV radiation has been studied, the measurements have either been confined to cloudless days (Yamasaki, 1971) or have been taken continuously but

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have excluded vertical exposure which is important in building applications (Davis et al., 1973).

To help clarify the contribution of UV to the angular dependence of weatherability of plastic-based building materials, a knowledge of the integrated (time) irradiance, or dosage, of solar UV on surfaces at representative exposure angles under service conditions is required. Such information will also aid in the development of an accelerated weathering test by enabling the simulation of adverse microenvironmental conditions for building plastics. This paper, therefore, reports the results of continuous instrumental measurement of UV radiation incident on surfaces at horizontal (H) position and facing south at 45° (S/45) and 90° (S/V), at Ottawa, Canada, for a period of one year.

## EXPERIMENTAL PROCEDURE

Solar UV radiation incident on H, S/45 and S/V surfaces was monitored continuously with an ultraviolet radiometer (Eppley Model TUVR), incor-

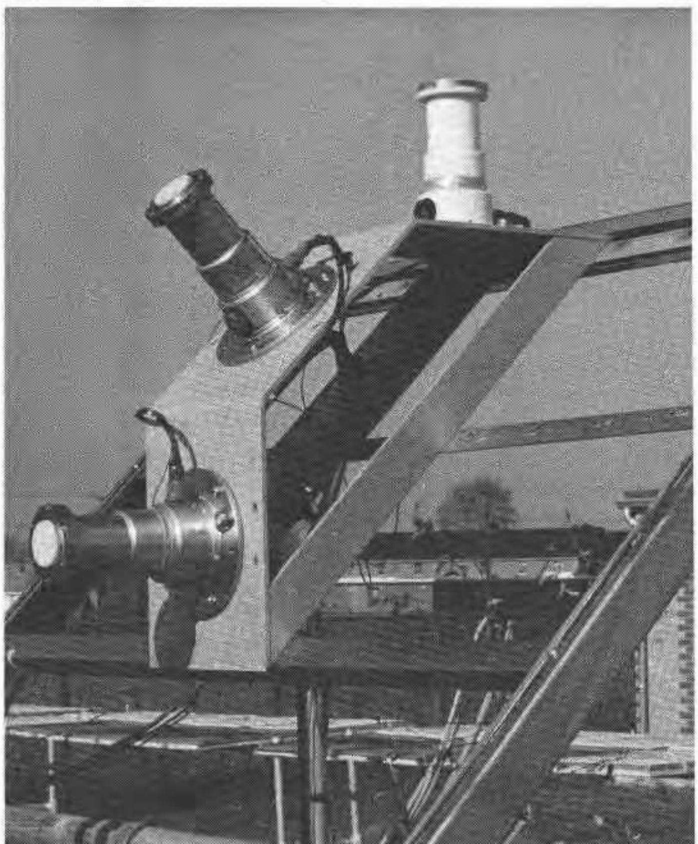

**Fig. 1. Apparatus for measuring solar UV radiation incident on H, S/45 and S/V surfaces.**

porating a selenium barrier-layer photocell with a spectral response between 295 and 385 nm. The radiometers were mounted on an aluminum rack at an average height of 1.8 m from the ground at the Ottawa exposure site (45° 27'N latitude, 75° 37'W longitude, humid continental climate). The apparatus is shown in Fig. 1. Each radiometer was wired to an electronic integrator and a printer (Eppley Model 411—6140) which determined the cumulative total UV radiation, gave hourly printouts and reset itself at midnight. The temperature of each radiometer was monitored with a Type T thermocouple and a data logger (Kaye Model 8200)—tape deck (Cipher) data acquisition system to correct the temperature sensitivity of calibration (—0.1%/1°C). The calibration of each radiometer was checked periodically in the field against a reference radiometer. The readings were taken continuously during the 1981 calendar year.

## RESULTS AND DISCUSSION

### *Total UV radiation on H, S/45 and S/V surfaces during 1981*

The total UV radiation, impinging on these surfaces during 1981 in Ottawa was 206 (H), 197 (S/45) and 131 MJ/m$^2$ (S/V); thus the H:S/45:S/V ratio is 1:0.95:0.63. For a material affected by UV only, the S/45 and S/V exposures should result in 5 and 37% less degradation, respectively, than the H exposure.

### *Monthly level and variation of UV on surfaces*

To assess the effect of surface angle on the seasonal variation in UV, the monthly UV radiation incident on each surface was determined (Fig. 2). The maximum monthly UV on the H surface was 29.2 MJ/m$^2$, for July. The corresponding values for the S/45 and S/V surfaces were lower at 25.5 (July) and 13.9 MJ/m$^2$ (March), respectively, a factor of about 2 between H and S/V surfaces. The UV level on the H surface was highest in spring and summer; from September to March there was little difference in irradiation between the horizontal and S/45 surfaces. The minimum UV levels on all three surfaces were similar at 6.1 (H), 5.8 (S/45) and 5.9 MJ/m$^2$ (S/V); all occurred in December.

Figure 3 illustrates the monthly variations in the S/45 and S/V irradiation as a percent of that on the H surface. It shows that the S/45 surface received 87% (June and July) to 116% (January) of the UV on the H surface, while the S/V surface received less, from 46% (June) to 112% (January). Thus, for a material whose UV degradation becomes dominant at hot summer temperatures, the S/45 and S/V exposures should produce up to 13 and 54% less degradation, respectively, than the H exposure.

The UV radiation on the H surface underwent the greatest seasonal variation, with a range of 23.1 MJ/m$^2$; on the S/45 surface, the variation

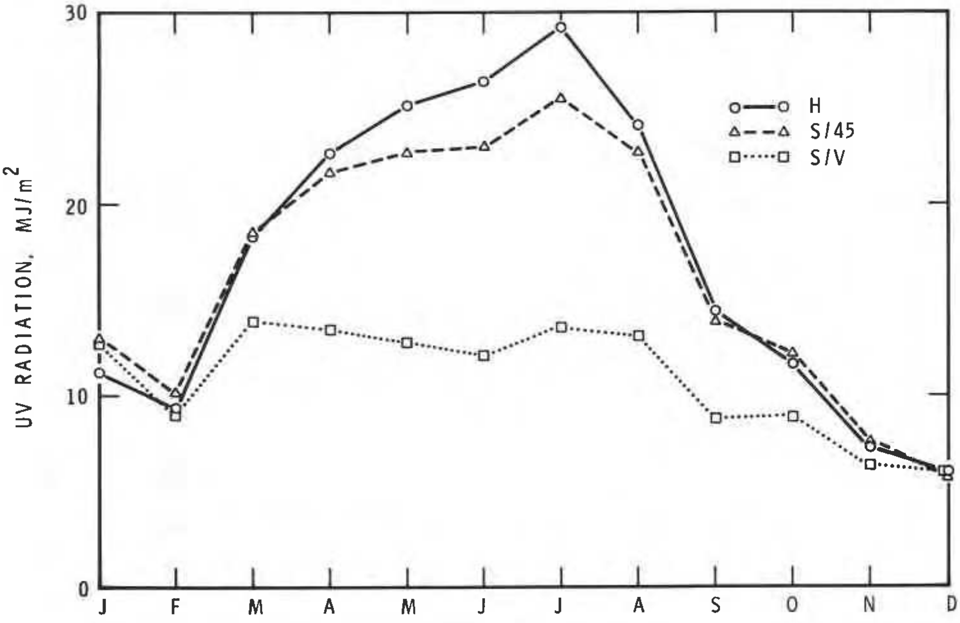


Fig. 2. Monthly UV radiation incident on H, S/45 and S/V surfaces.

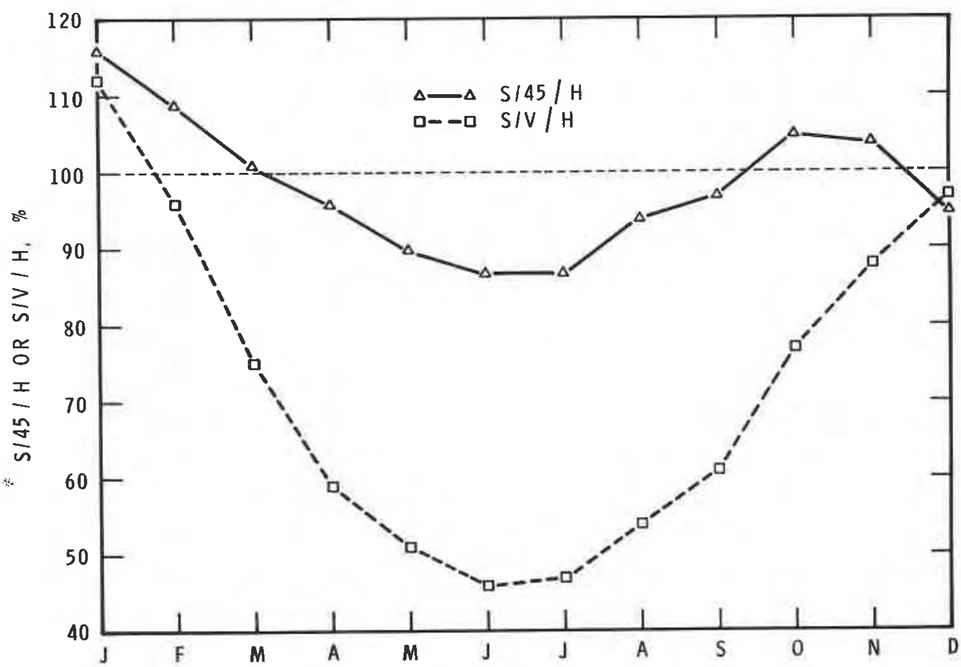


Fig. 3. Relation of monthly UV radiation on S/45 and S/V surfaces to that on H surface.

was 19.7 $MJ/m^2$ and on the S/V surface, 7.7 $MJ/m^2$. The range in UV on the S/V surface was 1/3 that of the H surface.

The change in UV radiation on surfaces may be attributed mainly to seasonal variation in the angular relation between the surface and the sun, (because of similarities of the curves in Fig. 2 to those of maximum UV (Fig. 4), which generally occur on cloudless days). The divergence in the relation, especially in February, March, September and November, is due to the reduction in UV caused by poor weather conditions.

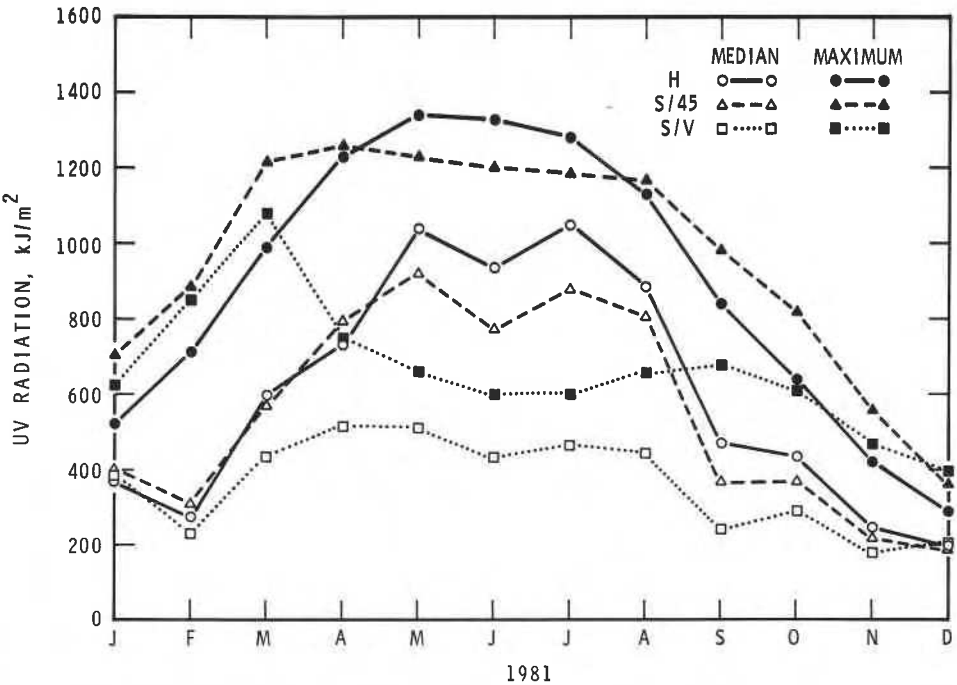


**Fig. 4. Level and variation of median and maximum daily UV radiation on surfaces, monthly basis.**

## *Seasonal distribution of UV on surfaces*

In order to determine the seasonal distribution of UV, monthly UV radiation as percent of the total annual UV radiation was calculated for each exposure angle. Figure 5 shows that for the H surface, monthly UV ranged from 14.2% in July to 3.0% in December, a factor of about 5. For the S/45 surface, the corresponding values were lower at 2.9% (December) and 12.9% (July), and for the S/V surface, 4.5% (December) and 10.6% (March). Further, more than half of the annual UV radiation occurred during the spring-summer period and amounted to 70% on the H surface, 67% on the S/45 surface and 58% on the S/V surface. These explain the general observation that plastics degrade faster in *summer* than in *winter*.

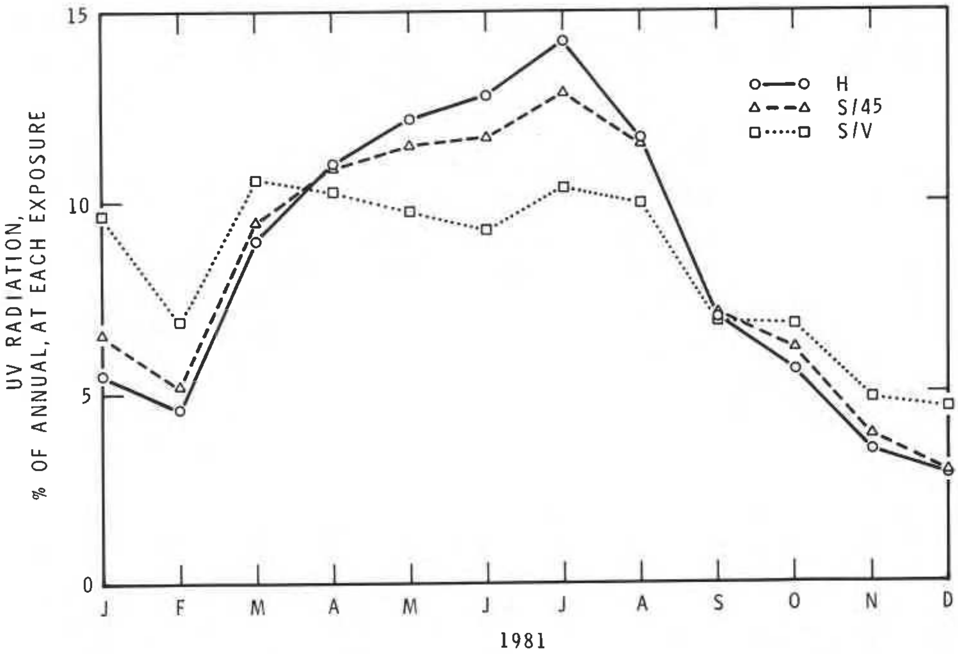


Fig. 5. Seasonal distribution of UV radiation on surfaces.

*Median and maximum daily UV on surfaces for each month*

To help utilize UV results for developing an accelerated weathering test incorporating adverse UV conditions, median and maximum daily UV irradiances were selected for each month to represent average and maximum UV conditions. These are illustrated in Fig. 4. For the H surface, the median daily UV varied from 200 kJ/m$^2$ in December to 1050 kJ/m$^2$ in July for a factor of 5, which is the same factor as for monthly UVs. The corresponding values were 195 kJ/m$^2$ (December) and 920 kJ/m$^2$ (May) for S/45, and 180 kJ/m$^2$ (November) and 515 kJ/m$^2$ (April) for S/V, a factor of 3. The median daily UV on the H surface underwent greatest seasonal variation, as for the monthly UVs, with a range of 850 kJ/m$^2$, which was followed by 725 kJ/m$^2$ and 335 kJ/m$^2$ on the S/45 and S/V surfaces, respectively.

The maximum daily UV measurement gives the upper natural limits for use in accelerated weathering tests; generally, it would occur on cloudless days. This parameter was highest on the H surface at about 1340 kJ/m$^2$ in May and June, while for the S/45 surface the maximum was 1260 kJ/m$^2$ in April. For the S/V surface, the maximum UV was 1080 kJ/m$^2$ in March. The period of maximum daily UV on the H surface was greatest from April to August, and on the S/45 surface, for the rest of the year. The maximum UV values were 22% greater than corresponding median values on the H surface in July and 260% greater in February, reflecting the best and worst months for sunshine. The corresponding values for the S/45 surface were 35% and 285% and for the S/V surface at 29% and 310%.

*Relation between UV content and daily solar radiation*

Since UV is influenced to a greater extent than the rest of the solar spectrum by factors such as cloud cover, haze and moisture (Koller, 1965), the effect of the weather on the UV content of solar radiation was determined. The percent daily UV radiation on the H surface was calculated with reference to total (global) solar radiation readings taken on the roof of a nearby building by the Atmospheric Environment Service of Canada. When percent UV was plotted against daily global solar radiation on a semi-log plot, the results from February to October, although scattered, could be fitted to a straight line (Fig. 6 — representative points only).

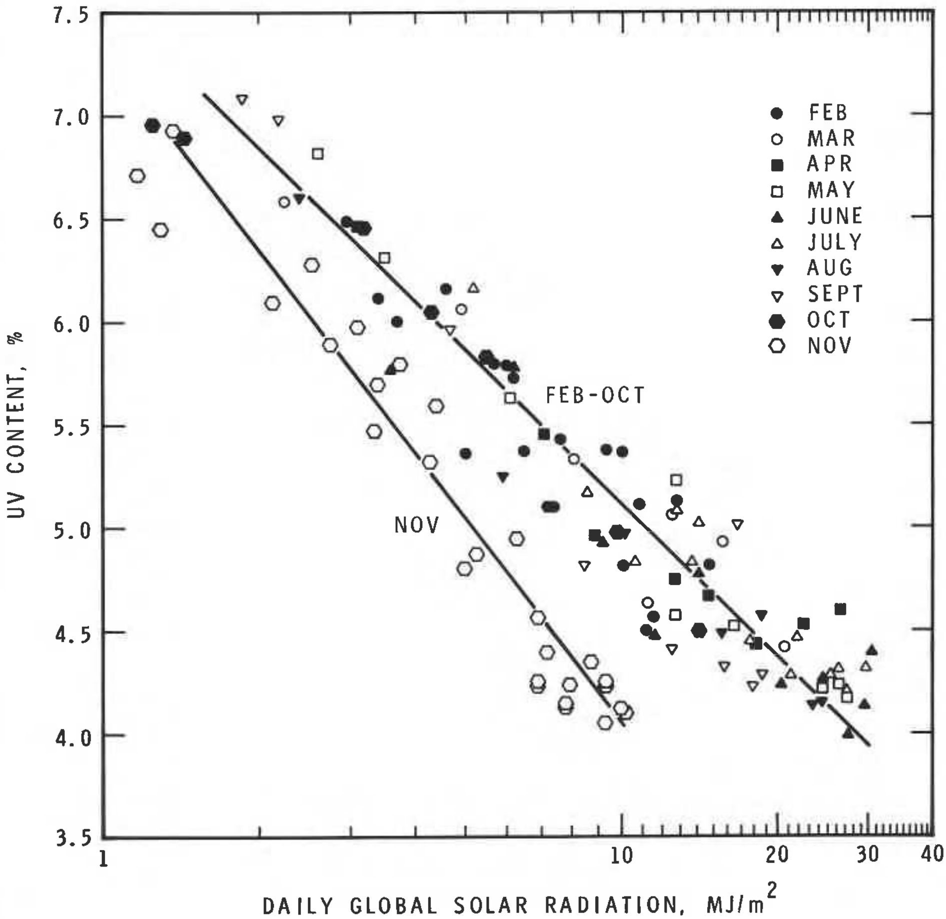


**Fig. 6. Percent UV radiation vs. daily total (global) solar radiation on horizontal surface, February—November 1981.**

November, December and January readings, however, fitted separate monthly straight lines (Figs. 6 and 7); these had greater slopes because of the decrease in the range of daily solar radiation in winter. These relations show that the UV content of 4.0% in February increased to 7.0% in November with a decrease in daily solar radiation; this is probably because of an increase in UV scattering induced by a rise in atmospheric opacity. For December and January, the change in UV content was smaller at 2.7% and 2.0%, respectively.

These relations can be used to estimate the UV radiation at sites located near the same latitude as Ottawa (45°27'N) and with a similar climate (humid continental), since global solar radiation readings are commonly taken at various locations.

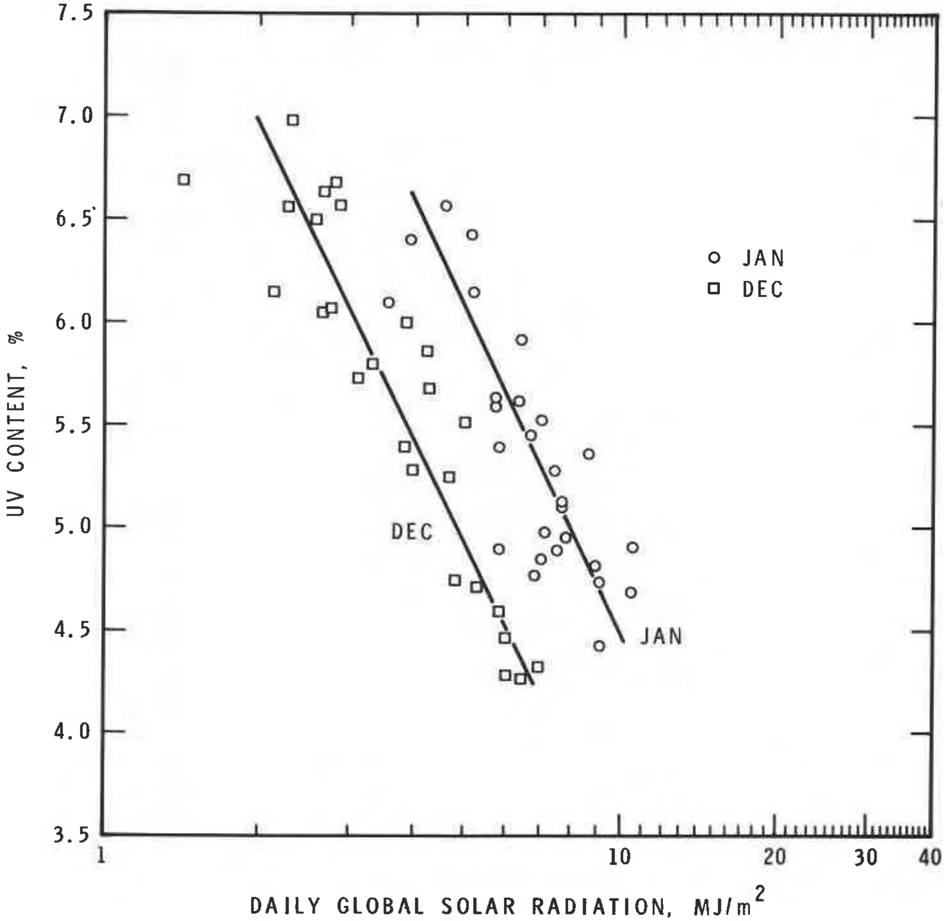


**Fig. 7. Percent UV radiation vs. daily total (global) solar radiation on horizontal surface, January, December 1981.**

*Application of UV information for development of accelerated weathering test*

The knowledge of the behaviour of solar UV incident on surfaces, combined with an understanding of how UV plays a dominant role in degrading plastic-based materials, can be used to identify natural UV conditions that are most deleterious. By simulating these severe conditions and reducing idle time, a rapid but reliable artificial weathering test can be developed. For example, if the dominant degradation mechanism for a material subjected to H exposure is the result of UV radiation at elevated summer temperatures, the median daily UV radiation during July would be selected for the test.

## CONCLUSIONS

(1) Total UV radiation impinging on the H, S/45 and S/V surfaces is 206, 197 and 131 MJ/m$^2$, respectively. Thus, for a material affected by UV only, the S/45 exposure should result in 5% less degradation than for the H exposure while for the S/V exposure, it should be 37% less.

(2) Both the level and seasonal variation of monthly UV radiation are highest on the H surface and lowest on the S/V surface. Monthly and daily UV irradiances are highest on the H surface during spring and summer. Thus, for a material in which UV degradation becomes dominant at hot summer temperatures, the S/45 and S/V exposures should produce up to 13 and 54% less degradation, respectively, than the H exposure.

(3) The UV radiation during the spring-summer period amounts to 70% (H), 67% (S/45) and 58% (S/V) of the annual total UV received by these surfaces.

(4) For a given month the proportion of UV in solar radiation increases (from 4.0 to 7.0%) with decreasing daily global solar radiation. This correlation can be used to estimate the UV radiation at various sites with humid continental climate, at or near 45° latitude from global solar radiation readings.

(5) The median and maximum daily UV values for each month determined in this study, combined with additional information on how UV radiation plays a dominant role in degrading plastics, can be used to identify UV conditions which are most deleterious. By simulating these conditions and reducing idle time, an accelerated weathering test can be developed.

## ACKNOWLEDGEMENTS

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