Willson

JET PROPULSION LABORATORY *California Institute of Technology • 4800 Oak Grove Drive, Pasadena, California 91103*

January 9, 1970
Refer to: 371-RCW:yc

Dr. M. P. Thekaekara
Code 322
N.A.S.A.
Goddard Space Flight Center
Greenbelt, Md. 20771

Dear Dr. Thekaekara:

I am enclosing copies of JPL TR's 32-1365 and 32-1426 * per your request. Due to an improved knowledge of the attenuation of the upper atmosphere for solar radiation, a minor change has been made in the solar constant value reported in TR 1365. The correct value, along with its uncertainty is 138.7 ± 2.0 mw/cm$^2$.

The solar constant value quoted above was the result of only the first of two high altitude measurements carried out on balloons with Active Cavity Radiometers. The second measurement took place in August, 1969, at an altitude of 36 km. and produced a solar constant value of 137.6 ± 2.0 mw/cm$^2$. Your figure for my results in the questionnaire should be amended to equal the average of these two or

$$Ho = 138.2 \pm 2.0 \text{ mw/cm}^2$$

The following is a summary of my reasons for weighting the various solar constant values. They are numbered in order to appearance.

1. This experiment was carried out under advantageous circumstances (i.e., zero air mass) but contained many sources of error not treated in the literature on it. There are two major systematic errors:

   A) The device was calibrated on the IPS which has been shown (JPL TR-32-1365) to contain an absolute error of -2.2%.

   B) No correction was allowed for the difference in transmission of the instrument's quartz windows for the solar spectrum at the calibration site (Table Mountain, California) and at zero air mass. Measurements of the window's transmissivity yielded a computed correction factor of 1.1%.

   If corrections for the scale error and window transmission are applied to the reported value of 136.0 mw/cm$^2$, the true value becomes: 136.0X (1 + .011 + .022) or

   $$Ho = 140.5 \text{ mw/cm}^2$$

Telephone 354-4321 Twx 213-449-2451

* Not available at present. Will send you a copy when reprinting completed.
Rw

I have some first-hand knowledge of the instrument flown on the X-15 and have discussed the experiment at length with E. Laue. I feel that the quoted uncertainty of $\pm$ .2 mw/cm$^2$ for this measurement is incredibly optimistic.

2. The GSFC cone is a good solar constant measurement device under the proper experimental circumstances. The CV-990, as a solar constant measurement opportunity, has several important shortcomings. The most detrimental factor for this method of deriving a solar constant figure are as follows:

   A) The variable and uncertain properties of the atmosphere above the CV-990 ceiling of 40K ft. produce significant uncertainties in the attenuation of solar radiation.

   B) The instruments view the sun through quartz or other windows whose transmittance is a function of the incident solar spectrum. This spectrum changes with altitude, air mass and meteorological conditions (e.g. water vapor, aerosols, etc.). At the high velocity of the CV-990, the above conditions can vary rapidly, producing window transmittance changes and corresponding uncertainties in the solar irradiance measurement.

   C) The Bougher-Lambert extrapolation is inaccurate and has been shown to underestimate zero air mass solar irradiance in the presence of aerosol scattering.

3. The calibration and repeatability of Hy Cal radiometers have been consistently inaccurate (always low) and unreliable, respectively.

4&5 The Angstroms suffer from the detrimental factors listed for (2) above. Additionally, they are not used as standard detectors, are susceptible to observer bias and error, and contain the systematic IPS error of 2.2%

6. I do not feel it is meaningful to treat the average of values 2-5 independently.

7. The measurements of the TCFM on M. 69 were conducted in ideal experimental circumstances. This instrument, while capable of being used as a standard detector, was not used as such in the Mariner '69 flights. It was used as a relative instrument, calibrated by tests conducted in a vacuum hohlraum. The TCFM has displayed a systematic error, relative to the standard detectors developed by Kendall and myself of -2 to -3 percent in several tests performed at JPL.

8. The Arvesen method obviates some of the window and atmospheric transmittance problems mentioned in (2) above.

9. There are two problems with this experiment. The same two mentioned in (1) above. I would suggest that the systematic errors produce results 3.3% lower than actual. The correct solar constant value based on this experiment should be = 133.8 x 1.033 = 138.2 mw/cm$^2$.

10. The kondratiev instruments are calibrated on the IPS. Their value should be increased by the 2.2% systematic error in the IPS which yields:
    $136 \times 1.022 = 139.0$ mw/cm$^2$.

11. My experiments (the results of which should be amended according to the previous discussion) were carried out under the best measurement conditions possible, short of actually being outside all the sensible atmosphere. The 1968 flight was at 25 km. and the 1969 flight at 36 km. No significant amounts of water vapor or aerosol exist above these altitudes. The only significant selective absorbers remaining are $CO_2$ and $O_3$. Less than 3% attenuation of the zero air mass solar spectrum remains for vertical paths above 25 km., and less than 1% remains above 36 km. The uncertainty of these figures is no greater than 10%, which produces an experimental uncertainty due to atmospheric attenuation of less than ± .3% for the 1968 flight and less than ± .1% for the 1969 flight.

    The largest single source of uncertainty in my measurements was the uncertainty of the radiometer windows' transmittances (± 1%). The Active Cavity Radiometers themselves are capable of measuring the solar constant with an uncertainty of less than ± 0.5%. The total experimental uncertainty quoted of ± 2 mw/cm$^2$ (1.45%) is therefore mostly due to the window transmittance uncertainties. Great care was taken to evaluate the window transmittances and I believe that the ± 1% uncertainty represents the state of the art in such a measurement. Those experiments in your list, notably (1) and (9), that have windows in their optical path, would contain at least the above uncertainty. It would appear from the literature that those authors have been less than thorough in their treatment of this effect, and their actual window uncertainties could be greater than ± 1%.

    The Active Cavity Radiometer balloon flight experiments in 1968 and 1969 represent the only high altitude measurements of the solar constant made by standard detectors. For this reason and others discussed above and in JPL TR-32-1365, I feel that the Solar Constant value of 138.2 ± 2 mw/cm$^2$ is probably the most accurate value presently available.

12-13-15) In spite of the ground base of these experiments, great care was taken to account for atmospheric attenuation. Although this is only partially redeeming, the quality of analytical work is impressive.

14. It would seem these authors can produce any popular result from their data.

15. This figure is a weighted average of many separate experiments. The large weight assigned is more attributable to the large number of experiments it includes rather than the specific merits of any individual measurement of the solar constant.

I will have solar spectral distribution information in the near future but have nothing to contribute at present.

Very truly yours,

Richard C. Willson

Richard C. Willson

Enclosures

~~Laue~~ Table I
Willson

Proposed Values of the Solar Constant ($mW cm^{-2}$)

| Source | Value of the Solar Constant $mW cm^{-2}$ | Estimated error $\pm mW cm^{-2}$ | Relative weight to be given 0 to 10 |
|---|---|---|---|
| High altitude measurements | | | |
| Eppley - JPL, NASA 711, X-15, Drummond et al (1) | 136.0 | 0.2 | 2 |
| GSFC-NASA 711 - Cone (2) | 135.8 | 2.4 | 2 |
| GSFC-NASA 711 - Hy-Cal (3) | 135.2 | 2.2 | 0 - |
| GSFC-NASA 711 - Å - 6618 (4) | 134.3 | 2.6 | 1 |
| GSFC - NASA 711 - Å - 7635 (5) | 134.9 | 4.0 | 1 |
| GSFC-NASA 711 Average - Thekaekara et al. (6) | 135.1 | 2.8 | 0 |
| JPL Mariner - Plamondon (7) | 135.3 | 2.0 | 2 |
| Ames NASA 711 - Carey 14 - Arvesen et al. (8) | 139.0 | 2.8 | 5 |
| U of Denver - Balloon - Murcray et al. (9) | 133.8 | 0.6 | 2 |
| USSR U of Leningrad - Balloon - Kondratyev (letter 4-15-69) (10) | 136.0 | | 2 |
| JPL - Balloon - Willson (11) | 138.2 ~~139.0~~ | 2.0 ~~0.6~~ | 10 |
| Ground based measurements and Revisions of earlier values | | | |
| NRL - Mt Lemmon and Smithsonian - Johnson (12) | 139.5 | 2.8 | 5 |
| AFCRL - Review - Gast (13) | 139.0 | | 5 |
| NBS - Mauna Loa - 3100-5300 Å - Stair + Ellis (14) | 136.0 | 6.8 | 0 |
| Germany - Jungfraujoch 3300-12500 Å - Labs and Neckel (15) | 136.5 | 2.7 | 5 |
| USSR U. of Moscow - Revision - Makarova and Kharitonov (16) | 141.8 | 3.5 | 5 |

Table II

Solar Spectral Irradiance at selected wavelengths and suggested changes.

| Wavelength microns $\lambda$ | Spectral irradiance (NASA TM, GSFC) $W\,cm^{-2}\,\mu^{-1}$ $P_\lambda$ | Cumulative % from 0 to $\lambda$ $D_\lambda$ | Suggested % change in irradiance |
|---|---|---|---|
| 0·345 | 0·1047 | 4·090 | |
| 0·395 | 0·1191 | 8·189 | |
| 0·425 | 0·1705 | 11·83 | |
| 0·455 | 0·2070 | 15·90 | |
| 0·480 | 0·2085 | 19·72 | |
| | | | |
| 0·510 | 0·1882 | 24·07 | |
| 0·540 | 0·1783 | 28·14 | |
| 0·570 | 0·1705 | 31·97 | |
| 0·600 | 0·1646 | 35·72 | |
| 0·640 | 0·1517 | 40·39 | |
| | | | |
| 0·670 | 0·1443 | 43·67 | |
| 0·710 | 0·1344 | 47·80 | |
| 0·750 | 0·1235 | 51·62 | |
| 0·800 | 0·1107 | 55·95 | |
| 0·850 | 0·0988 | 59·83 | |
| | | | |
| 0·900 | 0·0889 | 63·30 | |
| 1·00 | 0·0746 | 69·42 | |
| 1·1 | 0·0592 | 74·37 | |
| 1·2 | 0·0484 | 78·35 | |
| 1·3 | 0·0396 | 81·61 | |
| | | | |
| 1·4 | 0·0336 | 84·32 | |
| 1·6 | 0·0244 | 88·59 | |
| 1·8 | 0·0159 | 91·58 | |
| 2·4 | 0·0064 | 95·85 | |

Kendall & Willson agree within $\frac{1}{4}$%
Plamondon never in the field

JET PROPULSION LABORATORY *California Institute of Technology • 4800 Oak Grove Drive, Pasadena, California 91103*

January 19, 1970

Dr. M. P. Thekaekara, Code 322
Goddard Space Flight Center
Greenbelt, Maryland 20771

Dear Dr. Thekaekara:

Enclosed please find a copy of your requested evaluation chart. This type of evaluation may be useful, but also represents a mild form of tyranny since the careful consideration necessary for such a judgement almost requires that an explanation be made for each entry. Almost every measurement with which this writer has had personal contact possesses flaws of some type. I feel that the Cone Radiometer, if given much additional effort, will eventually provide the correct answer. However, we are still faced with the difficulty of coordinating the results of this instrument with the apparent 2.2% difference between the various cones and the cones and the Ångström's. Also, it is necessary to explain or account for the apparent fact that at JPL the thermal design group and solar cell panel groups have had reasonably good correlation between the space chamber tests and flight thermal results when the irradiance as established by reference to the IPS scale is set to $1400 wm^{-2}$.

One method of establishing a reasonable cross correlation between some of these instruments, would be to chart to actual observed irradiance at 10 km inside the CV990, then the window transmission factor at the CV990 elevation, and the irradiance just outside the aircraft window. This would eliminate the various sundry zero air mass extrapolation techniques (all of which are open to question).

It is hoped the enclosed is not too late to be of use to your effort.

Sincerely yours, Try to clear up disagreement.

Eric

Eric G. Laue

Enclosure

I talked to Laue on 2/25/70. He agrees to 135.3. Says Kendall & Willson agree within $\frac{1}{4}$% on Table Mountain. Plamondon is low. Willson ~~does~~ is getting ready for his oral Physics UCLA for Ph.D.

December 30, 1969

MEMORANDUM

TO: Members of the Committee on "Solar Electromagnetic Radiation

FROM: Matthew P. Thekaekara
Committee Chairman

In continuation of the discussions which were held at the meeting of our committee on 12/5/69, I am writing to request your considered opinion on two points:

1) What are the relative weights to be given to values of the solar constant proposed by different authors?

2) Is the NASA 711 curve adequate? What changes would you suggest?

Solar Constant - Table I gives a listing of values which have been obtained in recent high altitude measurements or those which have been proposed as a result of ground based measurements and revisions of earlier data. Naturally each one of us has his preferences. But the job of this committee is to propose a value which in our combined judgment comes closest to the correct value.

The last column of Table I is left blank. It is for you to fill in. Enter any integer number 0 through 10; 10 for values which should carry maximum weight and 0 for values which need not at all be considered. You may add on the reverse or on a separate sheet any comments you wish to justify the weights you give. In fact, such comments may prove highly valuable. Your comments as also the weights you give will be confidential; if they have to be shown to others, the names will be deleted.

Solar Spectral Irradiance - It was proposed at our last meeting to use the GSFC, NASA 711 Curve (Applied Optics, 8,17 13, 1969) as a starting point, correct it where necessary as indicated by other independent measurements, normalize the corrected curve to the value of the solar constant which we will have derived.

In Table II are given the irradiance values at 24 wavelengths. These are from the NASA 711 curve. The wavelengths are not equispaced on the micron scale but they are more or less equispaced on the mW $cm^{-2}$ scale. The solar energy between two consecutive wavelengths is approximately four percent of the total energy.

The fourth column is left blank. Please enter your suggestion for change if any. Indicate the value in percentage. Thus, for example, an entry -1.2 in the third column would mean that you would reduce the NASA 711 value by 1.2%.

I am also enclosing four other tables. These are to supplement the intercomparison charts which were sent to you as enclosure 2 on October 30. Please note that these curves and tables are not normalized to the same value of the solar constant. The values (in mW $cm^{-2}$) are 136.5 for Labs and Neckel, 139.6 for Johnson, 136.0 for Stair and Ellis and 135.1 for NASA 711. The NASA 711 values were obtained by taking a weighted average of the data of all our spectral irradiance instruments and then reducing them by 0.1 percent so that the area under curve is 135.1 mW $cm^{-2}$.

You are probably aware of the preliminary findings of Dr. Kostkowski that the spectral irradiance values of the NBS lamps are too high by a small amount (See Charles Duncan's Report, Enclosure 4 of October 20, page 5, line 22). Dr. Kostkowski's measurements are in the range below 0.85μ. Should the NASA 711 values be corrected in accordance with these findings? A yes or no vote is requested.

NOT YET

I am enclosing two copies each of Tables I and II, one for your files and the other to be returned to me with your reply. Handwritten answers will be quite adequate. Please reply soon, on or before January 9, 1970.

Best wishes of the season.

M P Thekaekara

M. P. Thekaekara
Code 322,
Goddard Space Flight Center
Greenbelt, Maryland 20771

# Table I — Lane

## Proposed Values of the Solar Constant ($mW\,cm^{-2}$)

| Source | Value of the Solar Constant $mW\,cm^{-2}$ | Estimated error $\pm mW\,cm^{-2}$ | Relative weight to be given 0 to 10 | $P_i w_i$ |
|---|---|---|---|---|
| *High altitude measurements* | | | | |
| Eppley - JPL, NASA 711, X-15, Drummond et al | 136.0 | ~~0.2~~ 2.3 | 7 | |
| GSFC-NASA 711 - Cone | 135.8 | 2.4 | 4 | |
| GSFC-NASA 711 - Hy-Cal | 135.2 | 2.2 | 3 | |
| GSFC-NASA 711 - Å-6618 | 134.3 | 2.6 | 5 | |
| GSFC-NASA 711 - Å-7635 | 134.9 | 4.0 | 5 | |
| GSFC-NASA 711 Average - Thekaekara et al. | 135.1 | 2.8 | 0 | |
| JPL Mariner - Plamondon | 135.3 | 2.0 | ~~4~~ 4 | |
| Ames NASA 711 - Carey 14 - Arvesen et al. | 139.0 | 2.8 | 6 | 834.0 |
| U of Denver - Balloon - Murcray et al. | 133.8 | 0.6 | 4 | |
| USSR U of Leningrad - Balloon - Kondratyev (letter 4-15-69) | 136.0 | | 5 | |
| JPL - Balloon - Willson | 139.0 | ~~0.6~~ 2.5 | 8 | 1112.0 |
| *Ground based measurements and Revisions of earlier values* | | | | |
| NRL - Mt Lemmon and Smithsonian - Johnson | 139.5 | 2.8 | 6 | 837.0 |
| AFCRL - Review - Gast | 139.0 | | 6 | 834.0 |
| NBS - Mauna Loa - 3100-5300 Å - Stair + Ellis | 136.0 | 6.8 | 5 | ~~834~~ 0 |
| Germany - Jungfraujoch 3300-12500A - Labs and Neckel | 136.5 | 2.7 | 8 | |
| USSR U. of Moscow - Revision - Makarova and Kharitonov | 141.8 | 3.5 | NO VALUE 0 | |

$$\frac{\sum P_i w_i}{\sum w_i} = \frac{10392.2}{76} = 136.7$$

If all values > 139 are given $w = 0$, $\frac{\sum P_i w_i}{\sum w_i} = \frac{6775.2}{50} = 135.50$

E. S. L.

Table II

Solar Spectral Irradiance at selected wavelengths and suggested changes.

| Wavelength microns $\lambda$ | Spectral irradiance (NASA 711, GSFC) $W\,cm^{-2}\,\mu^{-1}$ $P_\lambda$ | Cumulative % from 0 to $\lambda$ $D_\lambda$ | Suggested % change in irradiance |
|---|---|---|---|
| 0.345 | 0.1047 | 4.090 | |
| 0.395 | 0.1191 | 8.189 | |
| 0.425 | 0.1705 | 11.83 | |
| 0.455 | 0.2070 | 15.90 | |
| 0.480 | 0.2085 | 19.72 | |
| | | | |
| 0.570 | 0.1882 | 24.07 | |
| 0.540 | 0.1783 | 28.14 | |
| 0.570 | 0.1705 | 31.97 | |
| 0.600 | 0.1646 | 35.72 | |
| 0.640 | 0.1517 | 40.39 | |
| | | | |
| 0.670 | 0.1443 | 43.67 | |
| 0.710 | 0.1344 | 47.80 | |
| 0.750 | 0.1235 | 51.62 | |
| 0.800 | 0.1107 | 55.95 | |
| 0.850 | 0.0988 | 59.83 | |
| | | | |
| 0.900 | 0.0889 | 63.30 | |
| 1.00 | 0.0746 | 69.42 | |
| 1.1 | 0.0592 | 74.37 | |
| 1.2 | 0.0484 | 78.35 | |
| 1.3 | 0.0396 | 81.61 | |
| | | | |
| 1.4 | 0.0336 | 84.32 | |
| 1.6 | 0.0244 | 88.59 | |
| 1.8 | 0.0159 | 91.58 | |
| 2.4 | 0.0064 | 95.85 | |

THIS REQUIRES MORE STUDY THAN THE AVAILABLE TIME.

E.b.J.

JET PROPULSION LABORATORY California Institute of Technology • 4800 Oak Grove Drive, Pasadena, California 91103

April 8, 1970
REFER TO: 371-RCW:jr

Dr. Mathew P. Thekakara
% NASA Goddard
Greenbelt, Md., 20771

Dear Dr. Thekakara:

At the December meeting of the IES Solar Constant Subcommittee meeting it was carefully explained that the results of the "Willson" balloon flights, the "Plamondon" TCFM Mariner data, and the Epply/JPL X-15 flights were under careful study by a group at JPL. Therefore at the time of the December meeting, insofar as JPL was concerned, all data from these experiments was to be regarded as very preliminary.

For the same reasoning, the three JPL committee members were reluctant to commit themselves on the subsequent questionaire. Nevertheless, at your insistence, appropriate responses were prepared. This participation has been on a cooperative basis, and at no time were we informed that we would be bound to concur unanimously with the results of this survey. Particularly, since we were not provided with the results of the survey and a description of the method used in arriving at the highly publicized value.

It is our opinion that it would be indeed a strange situation if 10 reasonably qualified persons would have an identical opinion of the validity of the method, let alone the resultant value. We still maintain that even a weighted evaluation does not establish a physical constant. History is replete with examples wherein this method has been proven wrong, and indeed has led to supression of the search for the actual value.

Since we feel that there are still some unexplained divergencies, we hope that you will regard this as a minority report of the committee.

Sincerely,

J M Kendall Sr.
J. M. Kendall, Sr.

Eric G. Laue
E. G. Laue

Richard C. Willson
R. C. Willson