NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

OFFICE OF THE ADMINISTRATOR

November 26, 1974

MEMORANDUM

TO: E/Associate Administrator for Applications

FROM: AAD/Deputy Associate Administrator

SUBJECT: Measurement of Solar Constant

To confirm my verbal request of November 22, will you please prepare a brief report by December 15 on the status of our program to measure the solar constant and the global radiation balance of the earth. I would like to know the status of the instrumentation under development; the accuracy you expect to attain; the spacecraft on which the instrument is likely to fly; and the earliest that instrument can be flown.

Will you consult with Dr. Hinners and incorprate any plans that OSS may have which bear on this question.

I understand that present plans call for a flight in the early 80's of an instrument capable of 0.1 - 0.2 per cent accuracy. Would you indicate what would be required to advance that date, i.e., what is pacing the development--funding level, technical problems or the proper spacecraft?

John E Naugle
John E. Naugle

cc: A/Dr. Fletcher
AA/Dr. Petrone
S/Dr. Hinners

Action Copy to ER ✓
Info Copy to E
ED
ED-M

Rec'd in Code E 11/26
Control Number E-993
Suspense Date 12/3
Prepare Reply for Signature of E

ER 993

MEASUREMENT OF THE SOLAR CONSTANT *

I. SOLAR CONSTANT, PRESENT STATUS

The currently accepted value of the solar constant is 1353 Wm^{-2}. This value is based on nine independent determinations, all made from high altitude research aircraft, balloons and spacecraft. Seven of these were derived from NASA sponsored research, including one from the Mariner 6 and 7 spacecraft; the other two were from series of balloon flights of the University of Denver (U.S. Air Force sponsored) and of the University of Leningrad, U.S.S.R.

This value of the solar constant has been accepted as the standard by the American Society of Testing and Materials (1974 ASTM Book of Standards, Part 41) and is being submitted by ASTM for formal adoption by the ISO (International Standards Organization). The ASTM standard includes also the extraterrestrial solar spectral irradiance (table and spectral curve). The spectral data are based mainly on the measurements made by a GSFC research team on board the Convair 990. The solar constant/spectrum values had earlier been adopted as NASA Space Vehicles Design Criteria (NASA SP-8005, May 1971).

Prior to these values originating from NASA sponsored research, the solar flux data widely accepted in the U.S. and abroad were those proposed in 1954 by F. S. Johnson of the Naval Research Laboratory. The NRL value of the solar constant was 3.2 percent higher and the two spectral curves show wide differences, up to ± 15 percent in certain wavelength ranges.

The nine values on which the ASTM standard is based range from 1338 Wm^{-2} to 1368 Wm^{-2}. The stated uncertainty of the standard is ± 1.5 percent, or ± 21 Wm^{-2}. The differences between investigators are due to errors caused

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* Draft prepared by M.P.Thekaekara at the request of Hqrs, Code ER, in response to Dr. Naugle's Memo of 11/26/74

by the atmosphere above the instrument, differences between radiation scales and possibly also variations in the solar constant itself. The uncertainties in the solar spectral distribution are considerable greater (in the order of ± 5 percent in the visible and near infrared range).

II. GLOBAL RADIATION BALANCE OF THE EARTH, PRESENT STATUS

NASA effort in the measurement of outgoing radiant flux from the Earth has been considerably greater than in the measurement of incoming solar flux. Both the Earth albedo and the planet radiation of the Earth have been measured from several of the satellites. The global radiation balance is obtained by subtracting the outgoing flux integrated over the whole globe and for different seasons of the year from the incoming solar flux. The incoming solar flux was assumed to be 1396 Wm^{-2} (the NRL value) for the earlier satellite determinations of the radiation budget. NASA SP-8067, which deals with this topic, cites from an early publication by Von der Haar the following figures for global radiation balance: (all units in Wm^{-2}) Incident solar, 349 (which is ¼ of 1396, the NRL value); reflected solar, 105; Earth planet radiation, 230 which gives a balance of 14 (349 - 105 - 230 = 14). The balance reduces from 14 to 3 if the new value of solar constant, 1353, is used; the incident solar flux is 338 instead of 349. This implies considerably less heating of the Earth than the earlier estimate.

One major finding of the satellite measurements of Earth-reflected solar radiation was to reduce the value of the Earth albedo to about 30%. Previous estimates of the Earth albedo were 34% or higher.

Considerable work has been done also in the U.S.S.R., mainly by Kondratyev and his co-workers at the U. of Leningrad, on the outgoing radiant flux of the Earth-atmosphere system.

The measurement of the spectral distribution of the Earth-albedo and Earth-emitted IR has been attempted with filter radiometers in relatively wide spectral bands. No detailed, high resolution spectral studies have been made from satellites. Spectral scans of the Earth albedo on certain locations have been made from research aircraft.

In all these earlier studies the data on incoming solar flux were taken from other sources, the solar spectral curves of NRL or that of the ASTM standard. No attempt has been made to determine simultaneously the incoming and outgoing fluxes and the spectral distribution of these fluxes. The ERB experiment of Nimbus F will be the first satellite experiment to measure also the solar flux, but this experiment does not provide for detailed spectral measurements. There are a few filter channels which isolate relatively wide bands of the spectrum. The need for simultaneous measurement of incident solar and Earth emitted fluxes has been pointed out by several workers in this field, in particular by Raschke and Bandeen, and by Von der Haar.

III. INSTRUMENTATION UNDER DEVELOPMENT

1) THE ERB EXPERIMENT OF NIMBUS F. The instrument has been built and is ready for integration. A few problems have developed during the testing and substitution of the engineering model for the flight model is under consideration. The spacecraft will be Nimbus F due for launch in the third quarter of CY 1975. The detectors in the solar channels are wire-wound Eppley thermopiles. The expected accuracy is ± 1% for the solar constant. Inaccuracies of the order of 5 to 20% are possible in the filter channels; this estimate is based on the scatter of values obtained from Eppley filter radiometers flown on CV 990, RB57 and X-15. Transmittance curves of interference filters are liable to change due to degradation in space and the computation of filter factors requires prior knowledge of

the solar spectrum.

2) THE ELECTRIC SATELLITE PYRHELIOMETER (ESP) is a total radiation detector. Its development has been approved under the AAFE program. The principal investigator is Hickey of Eppley. The objective is to measure the solar constant and the solar flux filtered through three broad bands and four narrow (500 Ångströms) bands. The proposal aims at an absolute accuracy of one percent or better and a precision of 0.2% or better (related to repeatability) over a two-year period. Spacecraft for which the instrument is designed are EOS, SEOS and Shuttle. The main feature of the detector is that it is a combination of the PACRAD, an absolute radiometer developed at JPL, and the wire-wound thermopile developed at Eppley.

3) ABSOLUTE CAVITY RADIOMETERS. Three models of absolute cone radiometers have been developed at the Jet Propulsion Laboratory under NASA sponsorship, the TCFM (Temperature Control Flux Monitor) by Plamondon, the PACRAD (Primary Absolute Cavity Radiometer) by Kendall and the ACR (Active Cavity Radiometer) by Willson. The TCFM was flown on Mariner 6 and 7. PACRAD is intended primarily for use in the laboratory and several instruments of this type have been distributed by JPL and by Eppley. The ACR has been flown on balloons for measurement of the solar constant. All these instruments operate on the principle of electrical substitution. radiant energy is received on the inside of a blackened cone and the electrical power which is supplied to a coil of wire wound outside the cone to produce an equal rise in temperature is measured. Thus, the radiant flux is equated to absolute electrical units, volt and ampere; hence the name absolute radiometers. Other types of cavity radiometers have been developed independently by Fröhlich at Davos, Geist at NBS, Washington, Gilham at NPL, England and others. Absolute radiometry by electrical substitution is recognized by workers in the field to be essential,

especially because of the uncertainty in the International Pyrheliometric scale, IPS 56, which was set up for the IGY. The IPS was defined arbitrarily in terms of a "standard" instrument, the Ångström pyrheliometer. Recent intercomparisons between Ångström instruments which were all supposed to maintain exactly the IPS have shown that their readings vary within a range of 4%. Absolute cavity radiometers of different models show a considerably smaller spread, of about 0.5%. A cavity radiometer which claims 0.1% absolute accuracy was proposed by West, Hoyt and Sweet under the AAFE program, but was not funded. It is based on a model built at NBS, Boulder, for laser radiometry. The claim of 0.1% accuracy has been questioned. But since its design is significantly different from that of other cavity radiometers, its development is considered to be highly conducive to increasing the degree of confidence in the electrical substitution method.

4) THE GSFC WIRE-WOUND CONE RADIOMETER (THEKAEKARA). This instrument was used for solar constant measurements on board the Convair 990. Other models of the instrument have been built and are in use in the GSFC Space Environment Simulator. Further development is planned for the Shuttle Calibration Facility. Its major advantage over other cavity radiometers is that the coil of wire which supplies the electrical substitution is also the conical receiver for radiant energy. Thus, there is more exact substitution of radient flux for absolute electrical units and errors due to an intervening metal cone and its temperature gradient are eliminated.

5) SOLAR ENERGY MONITOR IN SPACE (SEMIS). The SEMIS is under development by Thekaekara and his co-investigators at GSFC. The objective is to measure the solar constant and solar spectral irradiance with state-of-the-art accuracy and to determine their variability with a precision greater than what is possible for absolute accuracy. State-of-the-art

accuracy is better than 0.5% for total irradiance. For spectral irradiance it is 5% at the two extremes and one to two percent in the visible and near IR. The instrumentation consists of a total irradiance detector and a prism monochromator. A first model has been built and is currently in use in the Space Environment Simulator at GSFC. Another model intended for piggy-back flights on all or almost all routine flights of the U-2 aircraft has been designed and is now being built. The U-2 flights will start in early 1975. An improved model has been proposed for the Solar Maximum Mission Spacecraft, planned for 1978. (This mission is approved as a Phase B start, but no hardware start is approved as yet. Instrument proposals have been reviewed but not selected.) A double SEMIS instrument which can measure both solar flux and Earth-albedo flux and their spectral variation has been proposed for a third Applications Explorer Mission spacecraft. The SMM seems a suitable spacecraft for the SEMIS since it has high pointing stability for the Sun. The AEM is Earth-oriented and the solar experiment would require separate Sun-tracking mechanism (accurate to ± 2.5 degrees).

The SEMIS concept is based on the proven need in the scientific community of accurate knowledge of not only the solar constant but also of the spectral distribution of the solar energy. There is a great deal of rather inconclusive evidence for variations in the solar constant, but apart from the UV below 300 nm, variations in solar spectral irradiance are totally unknown and unexplored. The Earth and ocean surface is not an achromatic absorber nor is the atmosphere a neutral density filter. The Earth-albedo spectrum is very different from that of the solar spectrum. There is no reason to assume that variations in solar spectral irradiance are as small as in the solar constant itself. The absorption by water vapor and ozone, the energy fluxes involved in the global radiation balance and the making of weather and climate, the source and sink mechanisms of atmospheric pollution, the solar irradiance essential for photosynthesis and all plant life, and for photomorphogenic responses like seed and flower development, these and many other problems in the applications area depend more on some specific wavelength ranges of the spectrum than on others. Spacecraft technology requires solar spectral data for studies of surface degradation, solar cell output, thermal balance, etc. Many of the problems in solar physics also require accurate and detailed information on solar spectral irradiance.

Another advantage in making simultaneous measurements of the solar spectrum is that it enhances the level of confidence in the solar constant value. The integral under the spectral curve should give an independent value of the solar constant.

Measurement of the solar constant and the solar spectrum are referred to two absolute but entirely different radiation scales, the former to the AEUS (Absolute Electrical Units Scale) through an absolute detector and the other to the TKTS (Thermodynamic Kelvin Temperature Scale) through spectral irradiance standards. These standards are referred to the TKTS by means of the Planck's equation and the gold point black body.

IV. FUTURE DEVELOPMENT, TECHNICAL PROBLEMS AND FUNDING

According to present plans it would seem that one would have to wait until the early 80's to fly a solar constant experiment which can yield an absolute accuracy of 0.1 to 0.2 percent. All detectors are known to degrade in space. This was specially noticeable in the TCFM on the Mariner 6 and 7. High accuracy cannot be claimed unless the instrument can be retrieved for post-flight calibration. The Space Shuttle of the early 80's will readily permit such calibration. It is also believed that the uncertainties in absolute radiometry will be considerably less by that time.

What is lacking for advancing that date is not spacecraft. Proper spacecraft are available in SMM, AEM, Nimbus and several others. Detector degradation follows an exponential law and such degradation can be detected and can be corrected for by simultaneous measurements from the U-2 or YF12 above half or all of the ozonosphere. Hence, a retrievable experiment package on a spacecraft is not essential to a solar constant/spectrum experiment.

There are technical problems. The margin of uncertainty in absolute radiometry must be made considerably smaller. Funding for this effort has always been at a very low level. The technical problems are not such as cannot be solved by competent manpower and adequate funding. Problems of instrumentation are not as great as that of standard scales of radiometry. Radiance and irradiance, total and spectral, standard detectors and standard sources are of interest to many disciplines, many areas of scientific endeavor. Illumination engineering, radiation biology, atomic and molecular spectroscopy, stellar photometry, high temperature chemistry, weather station data logging, solar energy direct conversion, spacecraft instrumentation and technology -- all have a vital need for absolute radiometry. The approach to the problem must be multidisciplinary. Measurement of the solar constant and solar spectral irradiance with the best attainable accuracy and precision presents one of the greatest challenges to the art and science of radiometry.