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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Memorandum No. 33-312

*Pyrheliometric Comparisons at the
JPL Table Mountain Facility*

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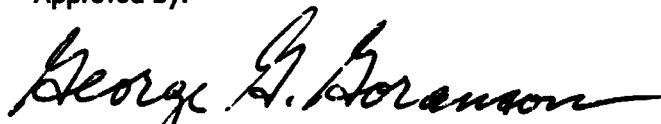
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FOREWORD

The results described herein are based on the work performed jointly by the Eppley Laboratory, Newport, Rhode Island, and the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, and was sponsored by the National Aeronautics and Space Administration under Contract NAS 7-100.

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ABSTRACT

This study concerns a series of comparative measurements of various pyrheliometric instruments which were made using natural sunlight at the JPL Table Mountain Facility. The details shown in this report introduce instrument calibration techniques for flight and surface radiometers. Methods of observation are also described. Responsibility for instrumental comparisons has been left to the participating organizations.

I. INTRODUCTION

An essential aspect of the JPL-Eppley Solar Constant Measurement Experiment¹ is the introduction of instrument calibration techniques for the Flight and Surface Radiometers developed for this project and their evaluation. During 1965 and early in 1966 such calibrations were performed at Newport, Rhode Island, and at Pasadena, California, with the aid of artificial sources of radiant energy. These included high power tungsten-filament lamps and xenon and carbon arcs. It was considered that a logical extension of the laboratory-based studies represented a comparison under conditions of natural sunlight, of the new multi-channel radiometers with precision pyrheliometers, at a high-level location. Therefore, it was decided to undertake a calibration program of this type at the JPL Table Mountain facility,² employing several Ångström electrical-compensation pyr-

heliometers as references. These instruments constitute part of the Eppley group of primary pyrheliometers maintained, in collaboration with Weather Bureau-ESSA, as the United States standards for reproduction of the International Pyrheliometric Scale (IPS). The period April 7-9, 1966 was chosen since operational programs with the radiometers were scheduled for the summer of this year.

Since this was the first such occasion on the West Coast, and after the Smithsonian Institution had ceased to provide such standards (about 1960), that primary pyrheliometers would be available at the Table Mountain site, it was further decided to invite other West Coast organizations concerned with maintaining pyrheliometric standards to participate in the planned comparisons. Advantage was also taken of this opportunity to verify the instrument constants of the two JPL standard Ångström pyrheliometers.

¹See JPL Technical Memorandum No. 33-298.

²Previously the site of the principal solar-constant observing station of the Smithsonian Institution.

II. PRIMARY PYRHELIOMETRIC FACILITIES

The building and related data are described as follows:

1. *Location.* Building TM-2, the JPL Solar Test Facility, at Table Mountain, California, is located at latitude 34.4° N, longitude 117.7° W, and at a 7550-ft altitude.

2. *Primary references.* The Eppley standard Ångström electrical compensation pyrheliometer No. 2028 was checked, on site, against second Eppley standard Ångström pyrheliometer No. 518—agreement to within $\pm 0.2\%$. On return to the Eppley Laboratory, these two pyrheliometers were compared with a

third working standard—Ångström pyrheliometer No. 162, the principal instrument of the primary group—and the agreement was also good to within 0.25%.

3. *Readout instrumentation.* The Eppley control unit No. 2311 was used; it incorporates a potentiometrically referenced precision millimeter, which is checked frequently to better than 0.1%.

4. *Auxiliary reference pyrheliometers.* The JPL Ångström pyrheliometers (Eppley model) 6550 and 6551, with Eppley control unit modified to read electrical current with a digital voltmeter referenced potentiometrically, were used.

5. *Observers.* The observers were A. J. Drummond of Eppley Laboratory and J. Gatewood of Jet Propulsion Laboratory.

III. STANDARD MEASUREMENT SERIES

Table 1 records comparative data covering solar radiation intensities, using Ångström compensating pyrheliometers.

Table 1. Solar radiation data from tested pyrheliometers

Date, 1966	Time, PST	Solar radiation intensities ^a		
		^b cal cm ⁻² min ⁻¹	mw cm ⁻²	w ft ⁻²
April 7	1100-1121	1.490	103.9	96.5
	1205-1217	1.408	98.1	91.2
April 8	0821-0838	1.379	96.1	89.3
	0850-0910	1.405	97.9	91.0
	0923-0935	1.411	98.3	91.4
	0940-1000	1.418	98.8	91.8 JPL
	1010-1030	1.432	99.8	92.7
	1055-1114	1.414	98.5	91.6
	1125-1146	1.412	98.4	91.4
	1200-1220	1.392	97.0	90.1 JPL
	1320-1335	1.424	99.3	92.2
	1345-1400	1.418	98.8	91.8
	1425-1440	1.319	91.9	85.4
	1448-1501	1.156	80.6	74.9
April 9	0940-0955	1.443	100.6	93.4
	1000-1020	1.457	101.5	94.3
	1020-1030	1.464	102.0	94.8
	1038-1053	1.465	102.1	94.9
	1103-1120	1.455	101.4	94.2
	1130-1140	1.441	100.4	93.3
	1148-1158	1.438	100.2	93.1
	1205-1215	1.418	98.8	91.8
	1223-1228	1.416	98.7	91.7

^aÅngström Compensation Pyrheliometer No. 2028 data, and JPL Ångström Compensation Pyrheliometer No. 6550 data corrected to 2028.

^bBasic measurements were in cal cm⁻² min⁻¹, and other values computed with the following conversions:
1 cal(15°) cm⁻² min⁻¹ = 69.7 mw cm⁻² = 64.75 w ft⁻²

IV. TESTS OF SURFACE (E. 3171) AND FLIGHT (E. 3172) RADIOMETERS

The radiometers were mounted, side by side, on an Eppley solar tracking unit. Signal readout (sunlight exposure and screening-thermal zero) was obtained, employing a Leeds and Northrup dc thermocouple amplifier and strip-chart millivolt potentiometric recorder assembly. This system was checked with an Eppley precision voltage reference (accuracy 0.1%). The accuracy of the radiometer reference (total flux) channels was established to within 0.5%, IPS as standard. Relatively, mutual consistency, in general, of all 12 channels

of each radiometer, was indicated to be of the order of 1%, as judged by the Table Mountain and the Newport basic tungsten-optical bench examinations. Figure 1 shows the overall test setup at the TM-2 (SCME³ radiometers are on the extreme right). Figure 2 is a closeup of the primary Angstrom compensation pyrheliometers and associated instrumentation. Figure 3 shows readout instrumentation for the SCME.

³Solar Constant Measurement Experiment.

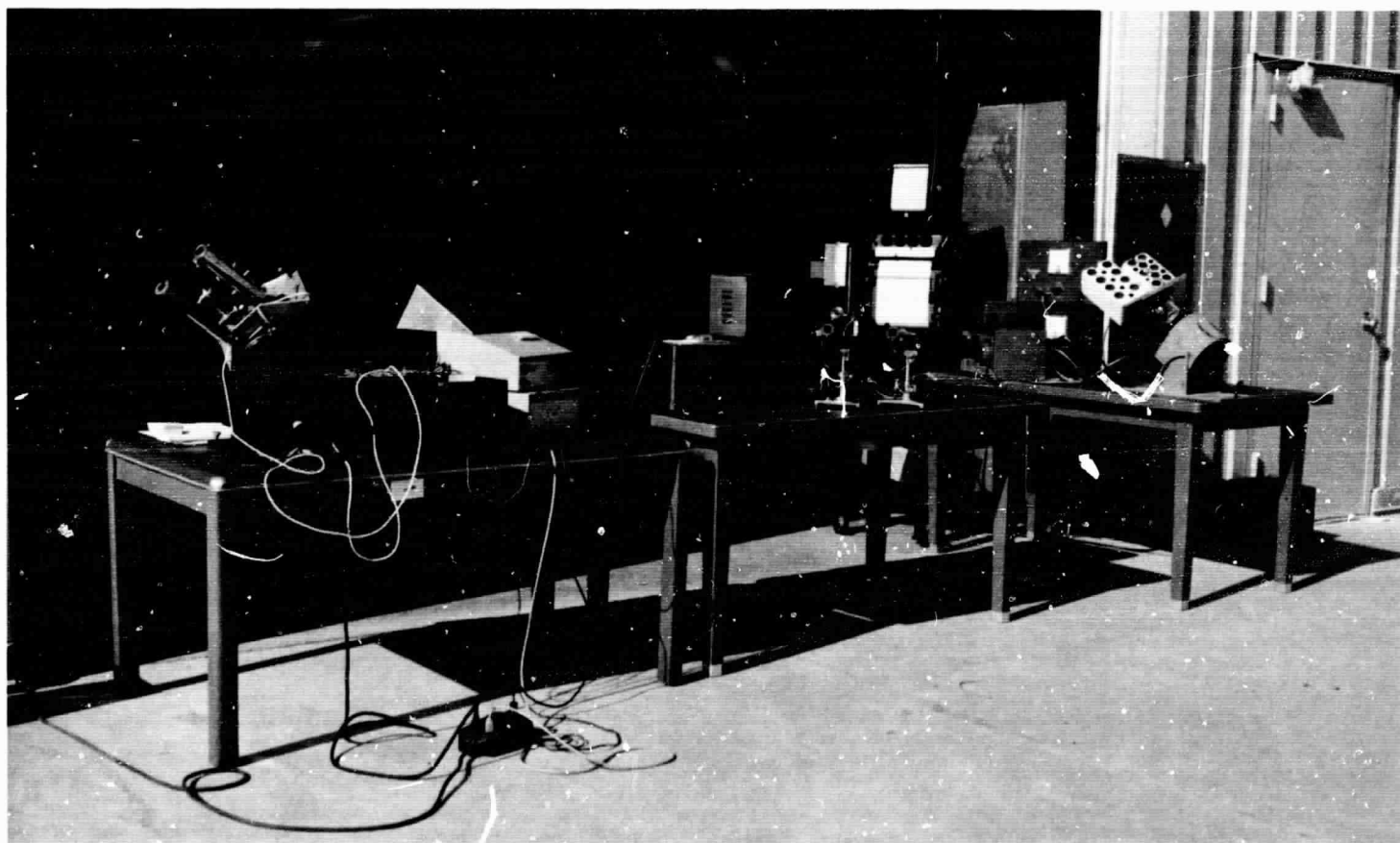


Fig. 1. JPL TM-2 overall solar irradiance test setup



Fig. 2. Primary working standard pyrhelimeters

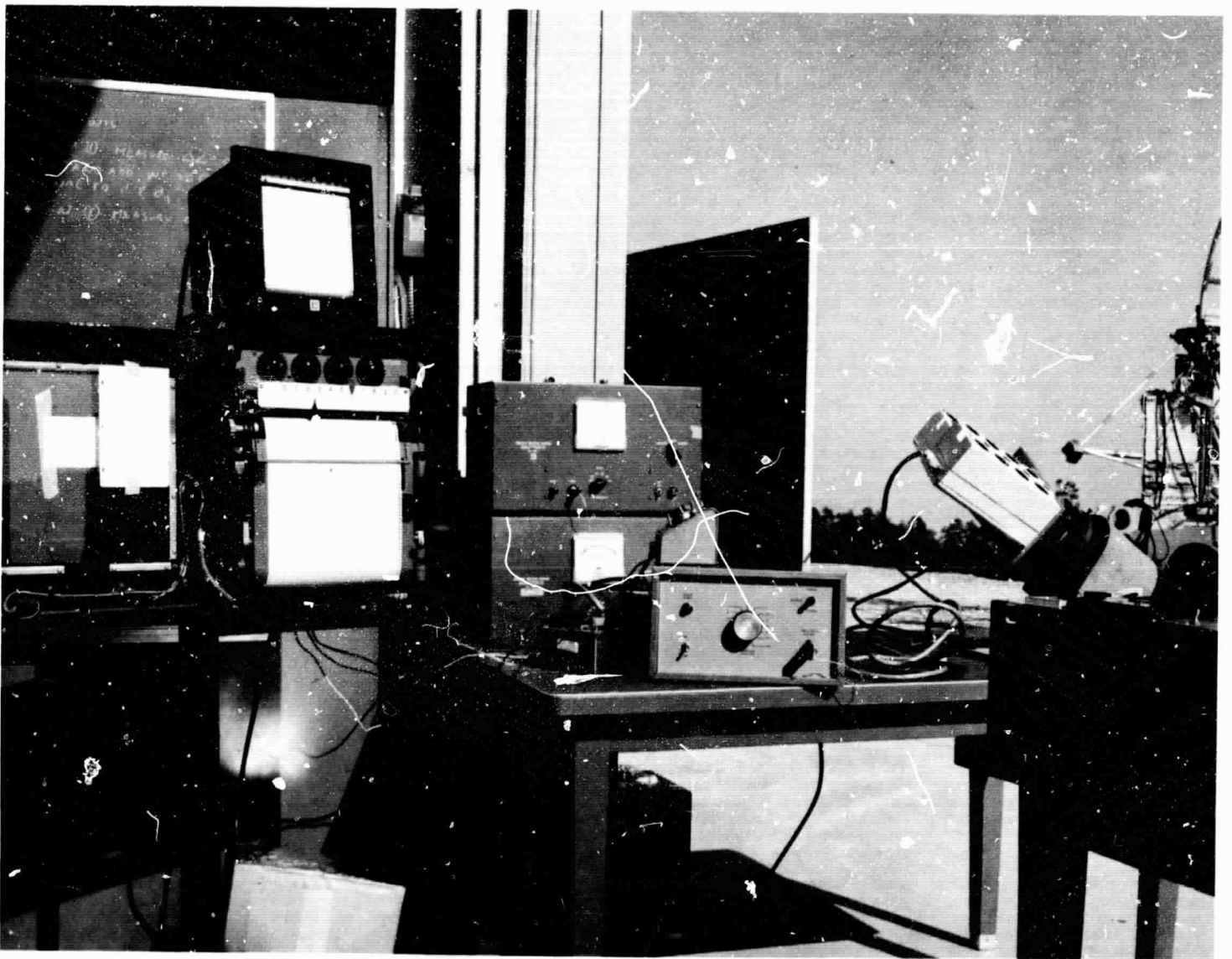


Fig. 3. SCME signal readout equipment

V. CONCURRENT TESTS

In addition to the two primary JPL Ångström pyrheliometers¹ mentioned above, there were three Eppley normal incidence pyrheliometers (No. 5183, 5185, and 5196) recording at the Solar Test Facilities.

At the Industrial Users' Site, which is approximately ½-mi west and at a 300-ft lower elevation, the following pyrheliometric measuring equipment was operated:

1. Aerospace Controls Corporation
Eppley MKV 7132
Hycal 14718
Hycal 17597

Hycal 17599
Hycal 17600
Hycal 17601
Hycal 17602

2. Hoffman Electronics Corporation
Eppley 180° pyrheliometer (pyranometer) 2957
3. Spectrolab, Division of Textron Industries (Fig. 5)
Heliotek normal incidence pyrheliometer E.3907
Spectrolab normal incidence pyrheliometer E.4897
Spectrolab TRW Mod DR-2 212
Spectrolab TRW Mod DR-2 252
Boeing TRW Mod DR-2 253
Boeing TRW Mod DR-2 152

¹The JPL Ångström instrument is shown in Fig. 4.

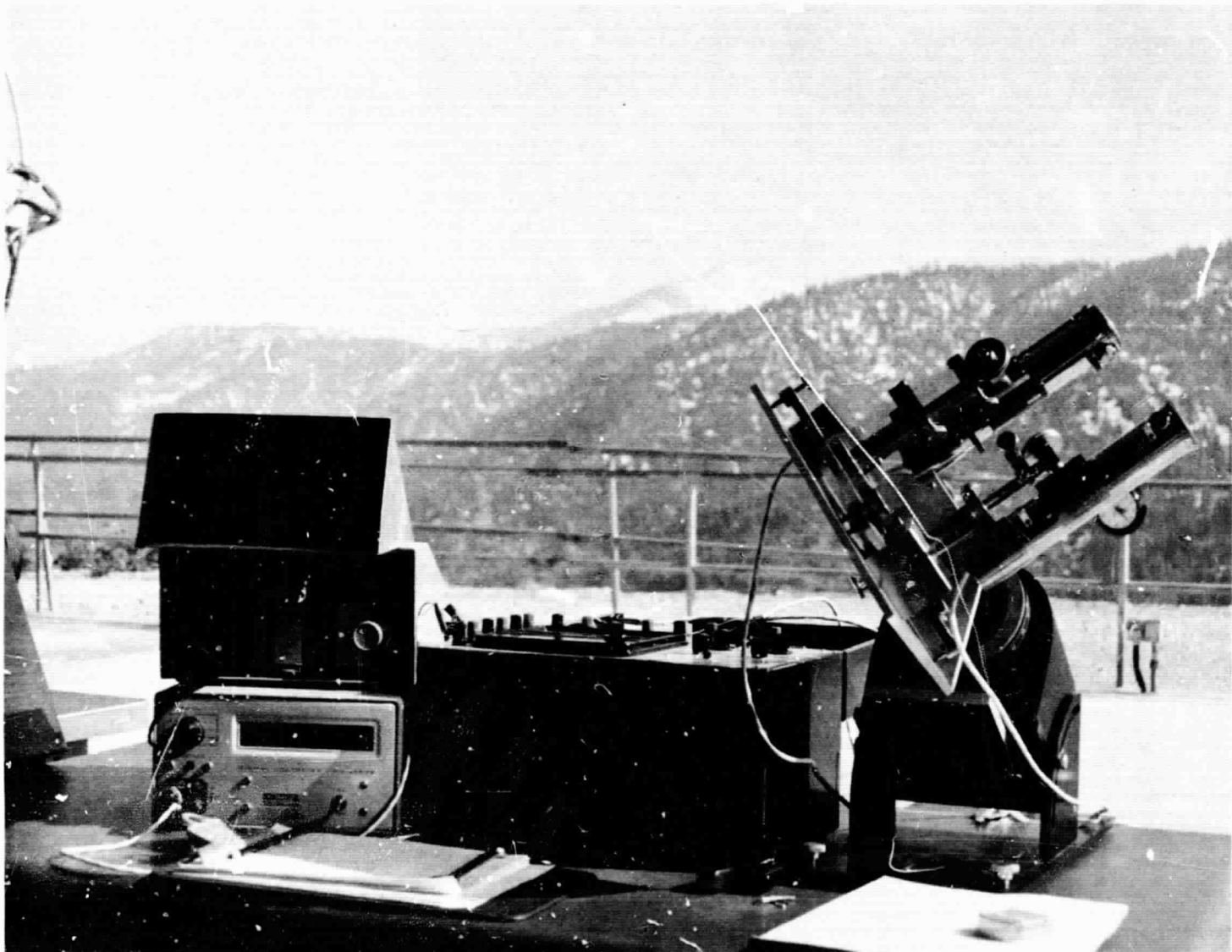


Fig. 4. JPL Ångström measurement equipment

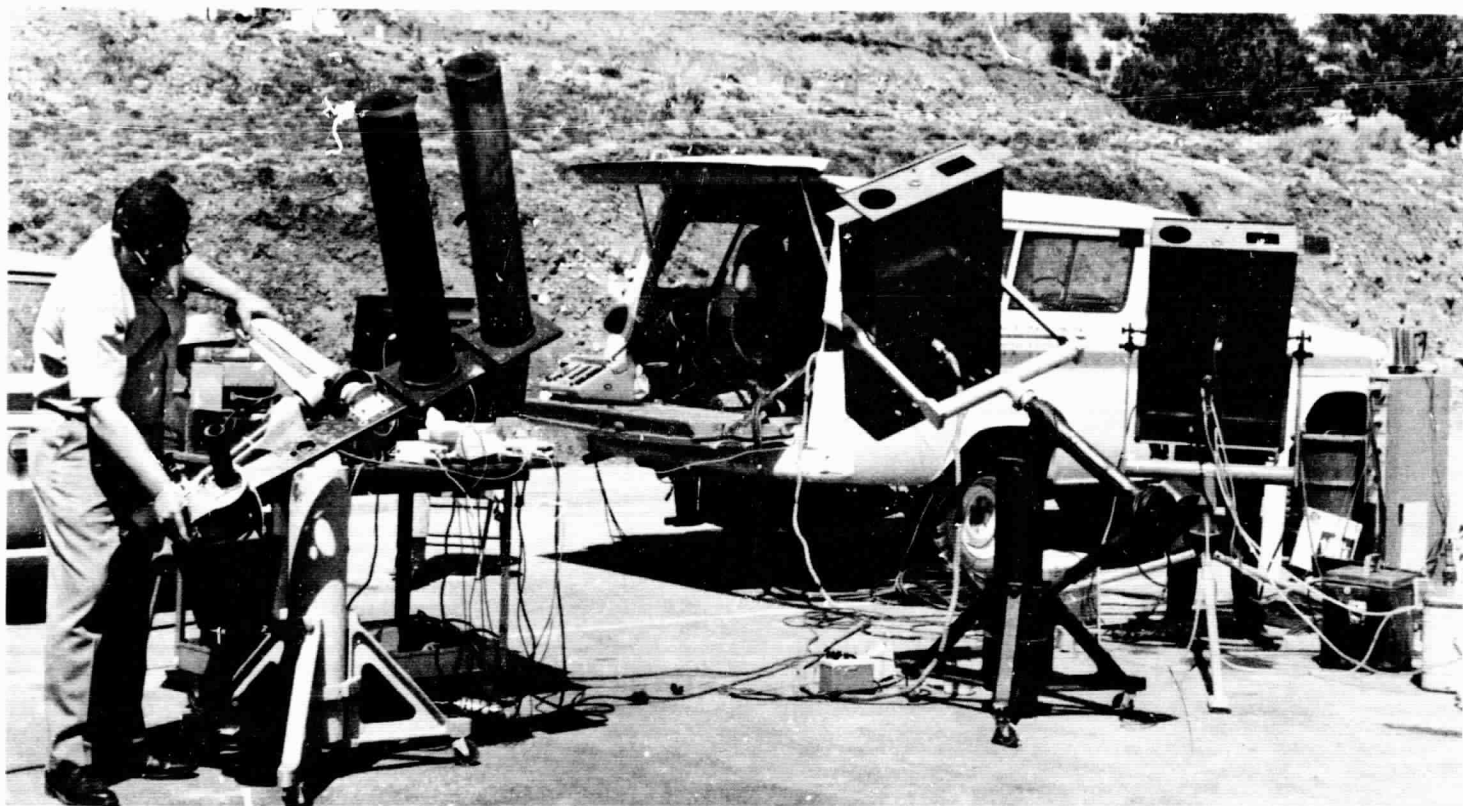


Fig. 5. Arrangement

VI. SUMMARY

Responsibility for redetermination of pyrliometer calibration was left with relevant organizations. The JPL-Eppley facility was intended solely as a source of absolute radiometric reference.

In the interpretation of the standard values tabulated above, it should be emphasized that the effective aperture angle (i.e., total field of view) of the Eppley model of the Ångström electrical compensation pyrliometer is 5.0 deg. In pyrliometer comparisons with the Sun as

the source, where the highest accuracy is desired, consideration must be given to the circumsolar sky radiation⁵. In attempting to correct the measurement of the direct intensity for standard instrument aperture condition, not only must the aperture angle be taken into account, but also atmospheric turbidity conditions (i.e., molecular and aerosol scattering).

⁵Ångström, A., and Rhode, B., "Pyrliometric measurements with special regard to the circumsolar sky radiation," *Tellus*, 18, 1966, pp. 25-33.

ACKNOWLEDGMENTS

The cooperation of Earle Ivie, JPL Table Mountain manager, and Charles Powell, manager of the Solar Test Facility, aided greatly in accomplishing this calibration study.