RE-ORDER NO. 64-759

FINAL TECHNICAL REPORT

DUMMY MOCK-UP PHASE

SOLAR SPECTRAL MEASUREMENT PROGRAM

(JPL CONTRACT NO. 950929)

This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, sponsored by the National Aeronautics and Space Administration under Contract NAS7-100.

Prepared for

The Jet Propulsion Laboratory,
4800 Oak Grove Drive,
Pasadena, California.

28 December 1964

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A. J. Drummond

Project Director

28 December 1964

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1. INTRODUCTION

The requirements of the subject contract did not call specifically for a Final Technical Report at this stage, but it was considered advisable, for the sake of continuity should the contract be extended to more active phases, to prepare a report presenting all test data assembled during the Dummy Mock-up phase. Likewise, the filter development work undertaken since the submission of the Final Technical Report on the Design Study is summarized here (this includes the relevant essential material of Progress Reports Nos. 2, 3 and 4 covering the period August - December 1964).

The construction work accomplished during the Dummy Mock-up phase of the contract included two single-channel modules (assembled principally to facilitate carrying out of the overlapping portions of the Eppley and JPL test programs) and the mock-up unit. Initially, the latter included two operational channels for test purposes. However, as the contract requirements called for the supply of 12 lens-filter-detector assemblies, the dummy mock-up in its final form incorporated all such assemblies: this was considered to be more convenient to JPL rather than simply supplying the separate components. Relative sensitivity determinations (employing tungsten-filament and mercury-arc sources) were made of all 12 channels in the mock-up. Detailed drawings of the mock-up have also been supplied to JPL.

2. DESIGN AND CONSTRUCTION OF THE DUMMY MOCK-UP

2.1 General

The single-channel modules were constructed of aluminum anodized similar in shape to the channels in the mock-up. Each incorporated a filter-lens-detector assembly. As this is not a contract requirement, no drawings appear in this Report (but working sketches are available).

The dummy mock-up was constructed from a solid block of magnesium finished through application of the Dow 19 process, and painted white (baked enamel). Ten of the channels contain filters (eight narrow bandpass type and two broad bandpass type - See Table I); eight channels are fitted with quartz lenses and two with quartz discs; all 12 channels have thermopile detectors of similar construction but not similar sensitivity. Teflon rings are employed as shock rings, at the suggestion of JPL.

TABLE I Wavelength intervals (in mμ) of the 12 channels in the dummy mock-up

Channel	Filter No.	Wavelength limits (mμ)
1	8	1300-2000
2	7	500- 600
3	5	500- 600
4	6	450- 500
5	Quartz	200-4000
6	OG1	535+
7	RG8	697+
8	Quartz	200-4000
9	4	400- 450
10	3	350- 400
11	2	310- 390
12	1	300- 350

Photographs of the general view, detail of the mock-up and the assemblies for two of the component channels are included here as Figs. 1-4. Drawings of the mock-up assembly and details constitute Figs. 5-7.

2.2 Geometry

The single-channel modules are conical in shape; the channels of the mock-up are cylindrical (for ease of manufacture). Tests have shown the channel configuration to be of little importance. The four channels of the mock-up without lenses were designed to a 15° aperture (total) angle. Those channels with lenses have a smaller limiting aperture.

2.3 Components

2.3.1 Detectors

The basic construction principles of the thermopile detectors have been discussed in the Final Technical Report on the Design Study. Certain further improvements have evolved during the period covered by this second contract phase (but constitute part of the Eppley Laboratory's own supported research and development program - if required, the Laboratory is prepared to discuss these developments but it is felt that the present moment is too early for useful discussions). The highest sensitivity obtained so far for the very fast model of detector without receiver is about 4 mv per cal cm^{-2} min^{-1}, in vacuum, with a response time (1/e signal) approaching 0.2 second. The somewhat slower and larger model with receiver has reached a sensitivity level of 9 mv per cal cm^{-2} min^{-1} in vacuum (1/e response 1 second).

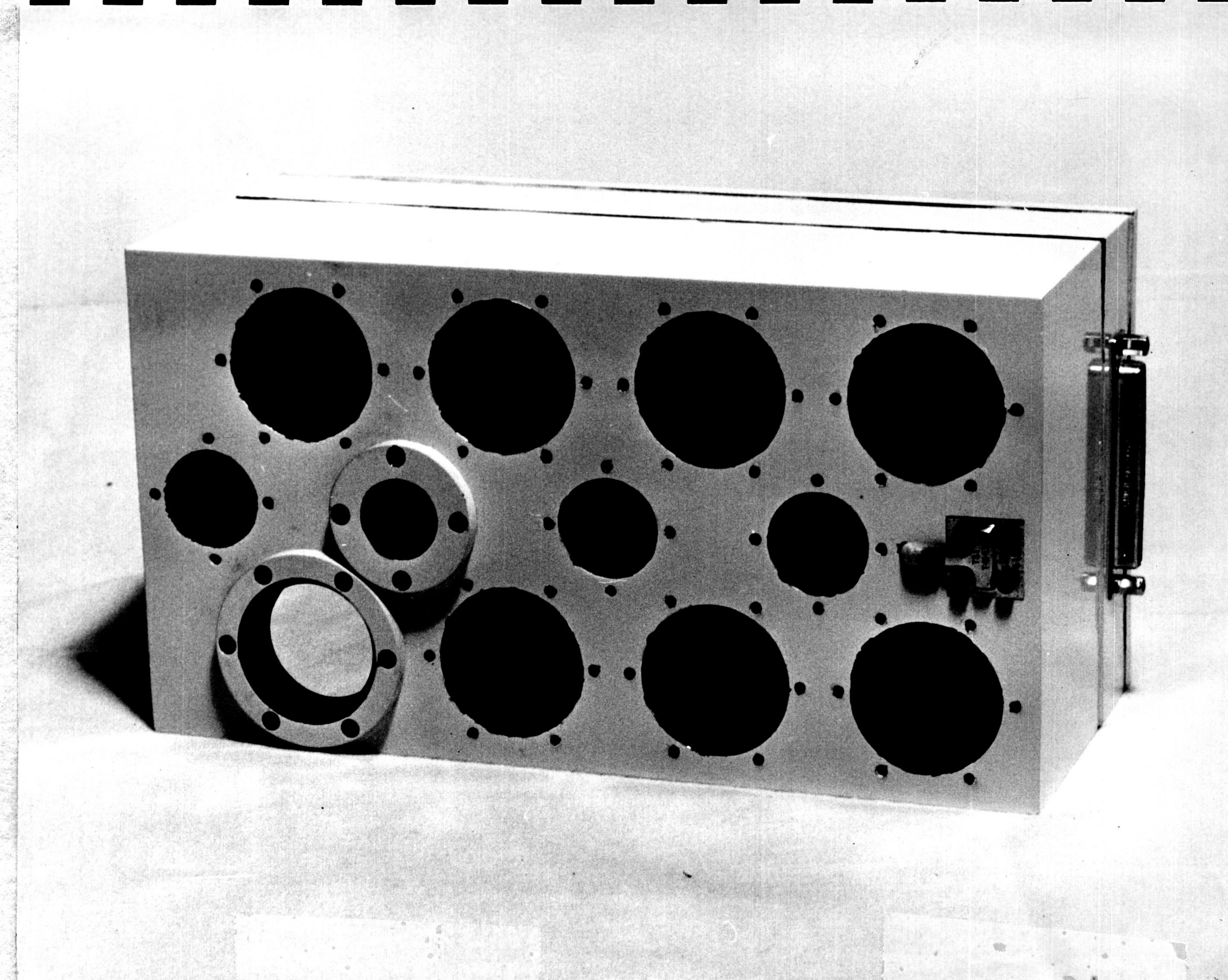


Fig. 1 General view of dummy mock-up (with two channels assembled)

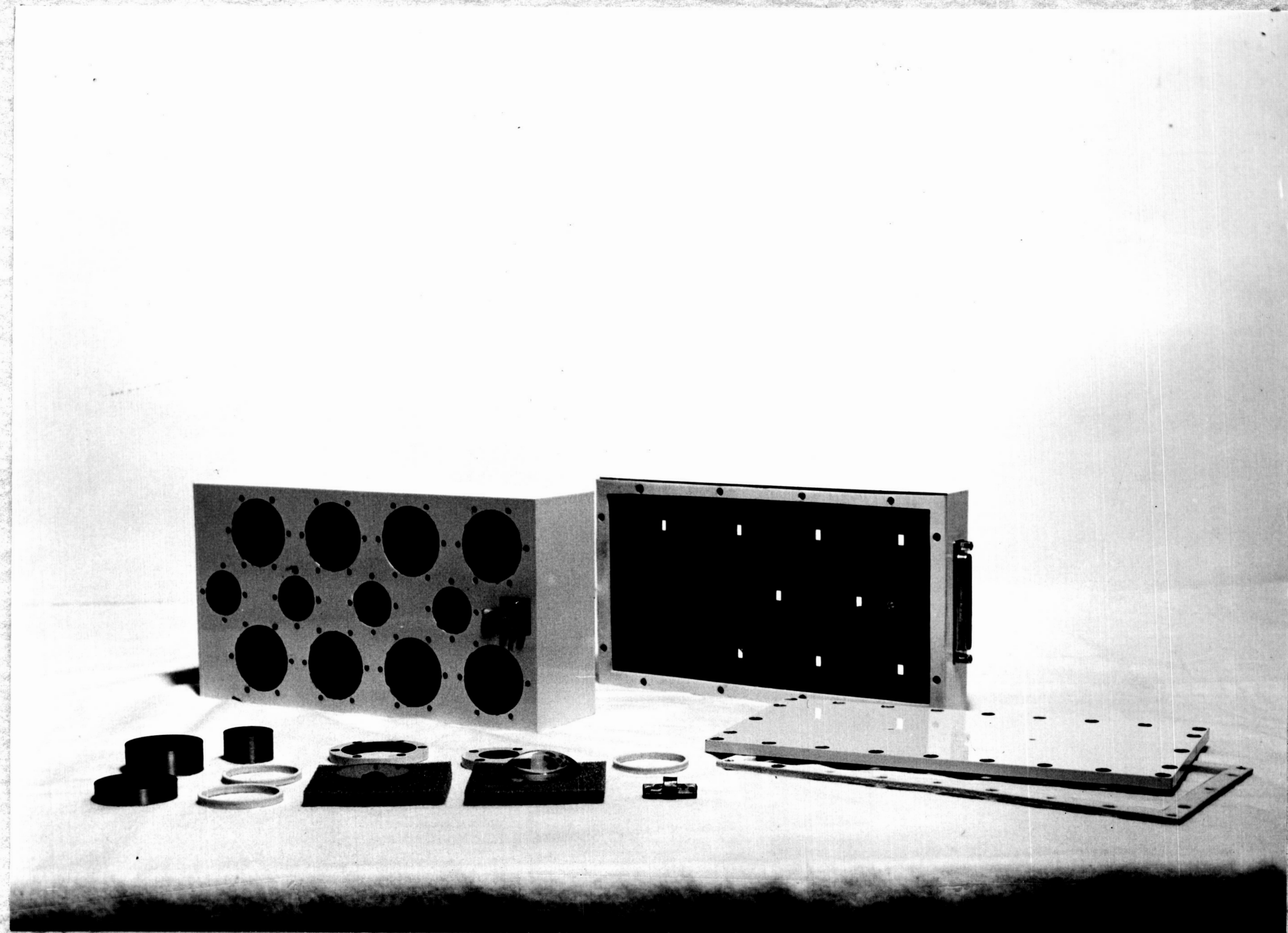


Fig. 2 Detail of mock-up (front view)

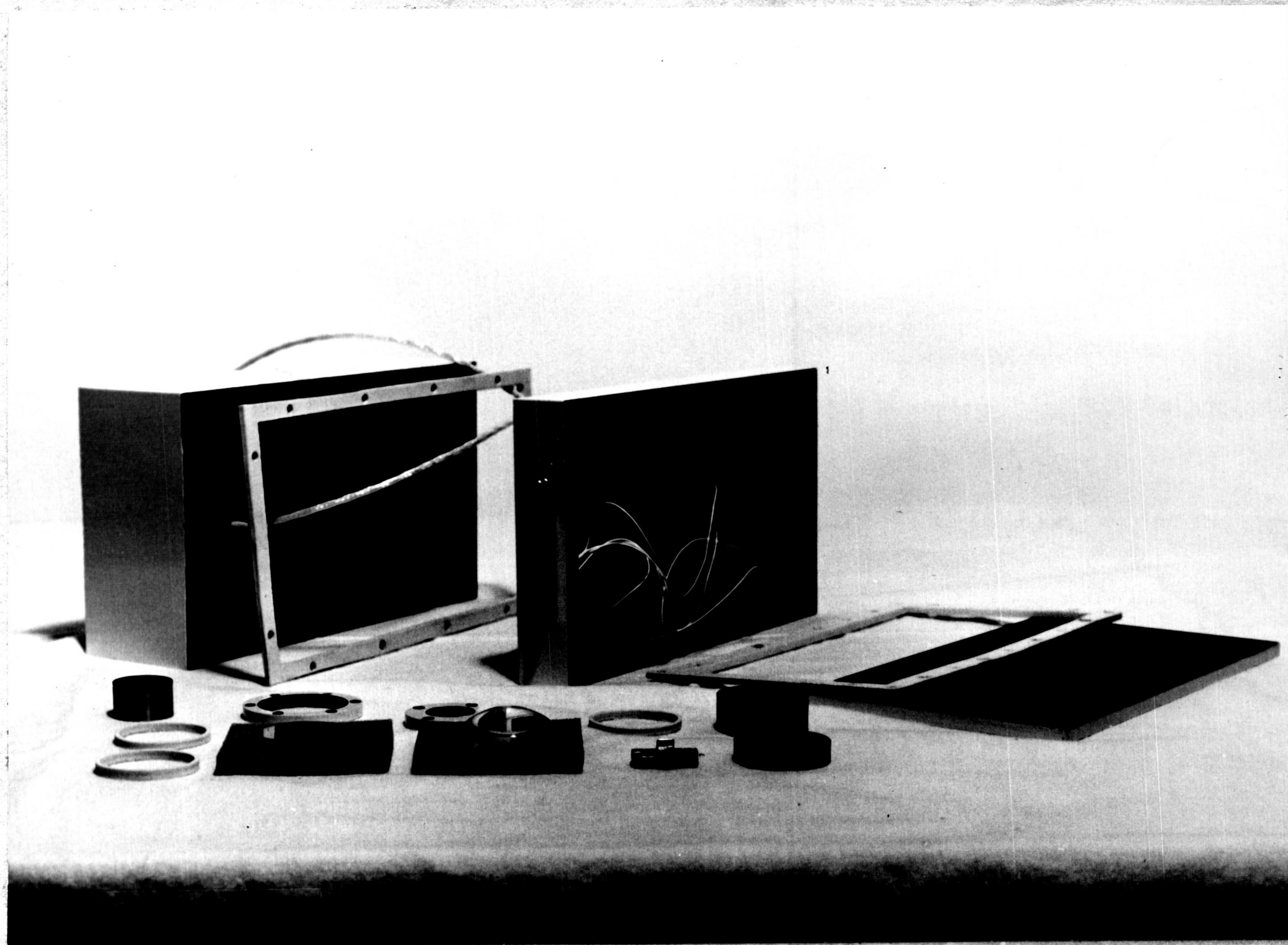


Fig. 3 Detail of mock-up (rear view)

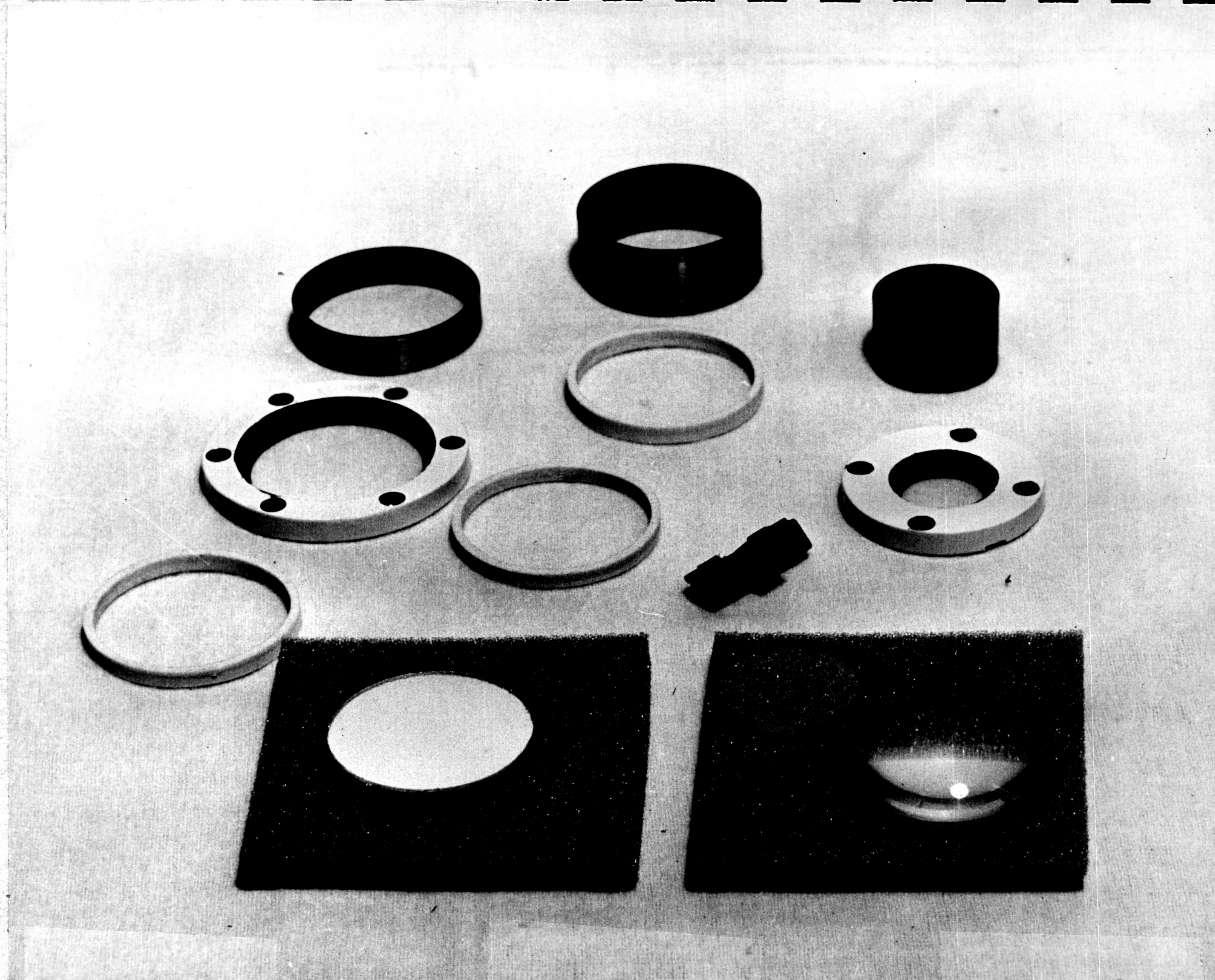


Fig. 4 Assemblies for two component channels of mock-up

2.3.2 Lenses

The type of lens (all common) was described in the previous Report. It will be sufficient to recall here that the material is high-grade crystal quartz and the shape plano-convex.

2.3.3 Filters

Two types of filter are employed, viz. sharp cutoff broad bandpass and interference narrow bandpass. As mentioned above, the wavelength limits of the ten filters in the mock-up are listed in Table I. Curves showing the transmittance of the narrow bandpass filters inserted in the mock-up are reproduced at the end of this Report as Figs. 17 (a)-(d). Since this Report contains a section on the continuance of the parallel filter development program (See Section 7), no reference will be made to the improvements which have been accomplished, except to state that a very significant feature has emerged, namely, the encapsulation of the narrow bandpass filters in an entirely closed quartz container. No epoxy is necessary, so the light beam only traverses layers of quartz and metals and/or dielectrics. Apart from solving the solarization problem, the new filter production technique results in waterproofing and maximum freedom from mechanical and thermal shock effects. All narrow bandpass filters in the mock-up are of this design.

3. TEST PROGRAM AT EPPLEY

3.1 Mechanical (vibration)

The two single channel modules and the dummy mock-up with two operational channels were tested as described in the previous Report. The vibration table, with the mock-up in position, is shown in Fig. 8. In the case of the modules and one of the mock-up channels, the system comprised narrow bandpass filter, lens, teflon spacers and thermopile unit: in the case of the second mock-up channel, the thermopile unit was covered only by a quartz plate. A "g" value of at least 15 was simulated in all instances (modules: displacement of 0.125 inch at a frequency of 47 c/s - mock-up: displacement of 0.2 inch at a frequency of 38 c/s). The test period was 10-15 minutes continuous. The test source of irradiance was a 5000-watt, tungsten-filament, projector-type lamp (forced ventilated and water-cooled for stability of output). At the positions chosen on the optical bench, the radiant flux density ranged from about 50-60 mw cm^{-2} (i.e. 0.7-0.85 cal cm^{-2} min^{-1}). Thermopile emf was measured on a precision Eppley (White-type) potentiometer. The divergence between each set of similar data (i.e. before, as compared with after shock test) is generally within the accuracy realizable in the experiment, viz. ±1 per cent.

The results of the module tests are given in Table II and those of the mock-up tests in Table III.

3.2 Solarization

The equipment employed in this test comprised the Eppley small solar simulator (of which the bell jar with cold shroud is on loan from JPL): it is illustrated in Figs. 9-12.

The radiation source used was a H400-E1 General Electric mercury arc. This lamp with the outer glass envelope (i.e. quartz envelope) removed was positioned so that the arc discharge was approximately at the center of a 60-inch focal length ellipsoidal mirror. Measurements with a thermopile at the approximate second

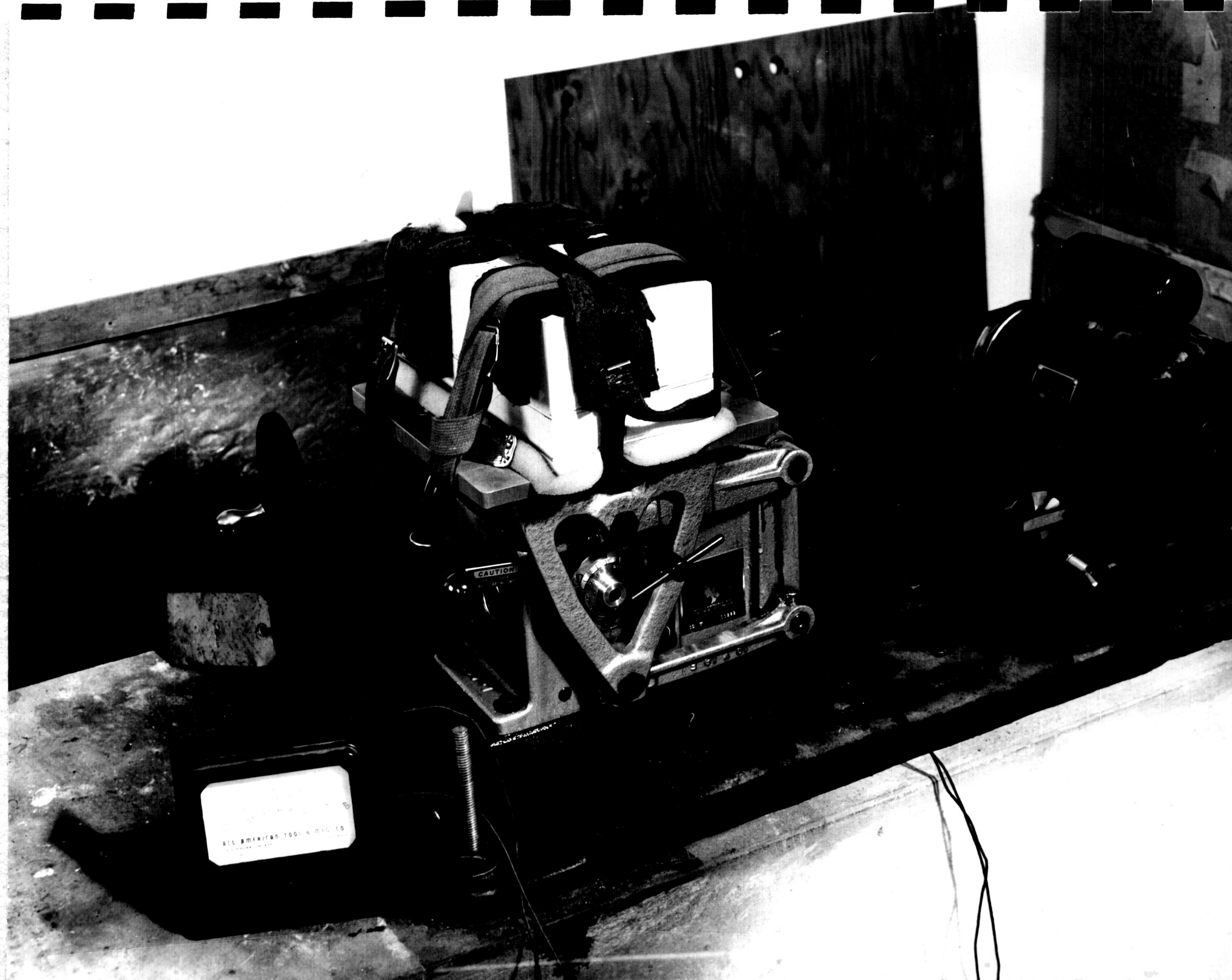


Fig. 8 Photograph showing mechanical shock (vibration) test at Newport

Fig. 9 General view of Eppley small solar simulator

Fig. 10 The cold shroud of the Eppley solar simulator

Fig. 11 Location of dummy mock-up during solarization environmental test

Fig. 12 Ultra-violet solarization test in operation

TABLE II <u>Results of the mechanical shock (vibration) tests, at Newport, of the two single-channel modules</u>

Module No.	Vibration Test Before	After (1)	After (2)
	mv	mv	mv
1	0.022	0.023	
2	0.098	0.097_5	0.099

TABLE III <u>Results of (a) mechanical shock, (b) UV solarization and (c) thermal shock tests, at Newport of two channels (one filtered and the other unfiltered) in the dummy mock-up</u>

Channel No.	Vibration Test Before	After (1)	After (2)
	mv	mv	mv
4(filtered)	0.100	0.101	0.100
7(unfiltered)	1.38	1.37	1.36_5

	UV Solarization Test Before	After
	mv	mv
4	0.100	0.100

	Thermal Shock Test Before	After
	mv	mv
4	0.100	0.101
7	1.38	1.36_5

focus indicated a radiation flux at the test location of approximately 150 mw cm^{-2}. From the manufacturer's catalogue data, approximately 20 per cent of this output appears to be in the ultra-violet region. As about 7 per cent of the extraterrestrial solar radiation is in the UV, this test exceeds in severity (by about x3) the actual flux to be expected in X-15 flight conditions. The period of continuous exposure was 10 hours.

At the start of the tests, a vacuum of approximately 5×10^{-4} torr was obtained. After the cold walls and traps of the vacuum system were chilled, with liquid nitrogen, the pressure decreased to 5×10^{-5} torr, and thereafter to slightly lower values, reaching 1×10^{-5} at the end.

A small hole in the shroud wall allowed the filtered channel No. 4 to be irradiated. Throughout, the temperatures of the shroud and the mock-up were monitored; in conditions of equilibrium the respective values were -177 and -86° C.

As will be seen from Table III, no significant change occurred in the sensitivity of this channel. Figs. 13 and 14 further demonstrate the absence of solarization in this (blue) filter. The two curves of transmittance are identical within the performance of the spectrophotometer as used in these tests.

3.3 Thermal

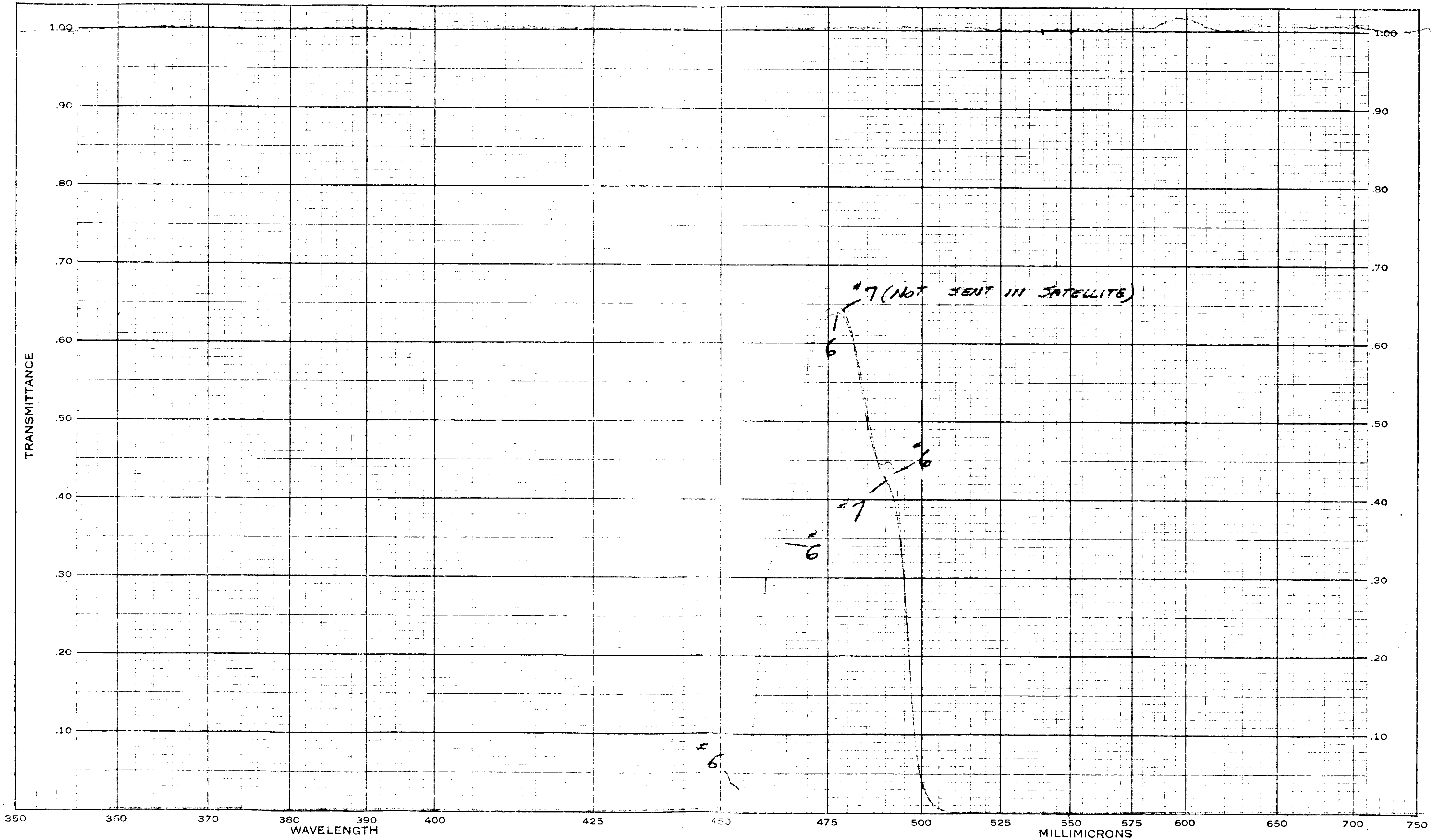
This test was undertaken by placing the mock-up inside a temperature environmental chamber and cycling the temperature as rapidly as the system would permit. Over a period of three hours, the relevant values were +105, -70 and +100° C. No mechanical change was observed in the mock-up, although the white paint had yellowed

SAMPLE
SOLVENT
CONC.
CELL

SPECTRACORD
THE PERKIN-ELMER CORP.

SERIAL NO. J.P.L SAT. FILTERS
SLIT #4750-6 & #4750-7
SCANNING TIME
DATE 11/10/64

VIS. 2038



F. 13 Spectrophotometric examination of the narrow bandpass filter (No. 6: nominal 450-500 mμ limits) used in the solarization test - prior to UV exposure in the environmental system

SAMPLE
SOLVENT
CONC.
CELL

SPECTRACORD
THE PERKIN-ELMER CORP.

SERIAL NO. J.P.L. SAT. FILTER
SLIT #7750-6 AFTER
SCANNING TIME 6 hr U.V. & VAC & COLD WALLS
DATE 11/13/64

VIS. 2038

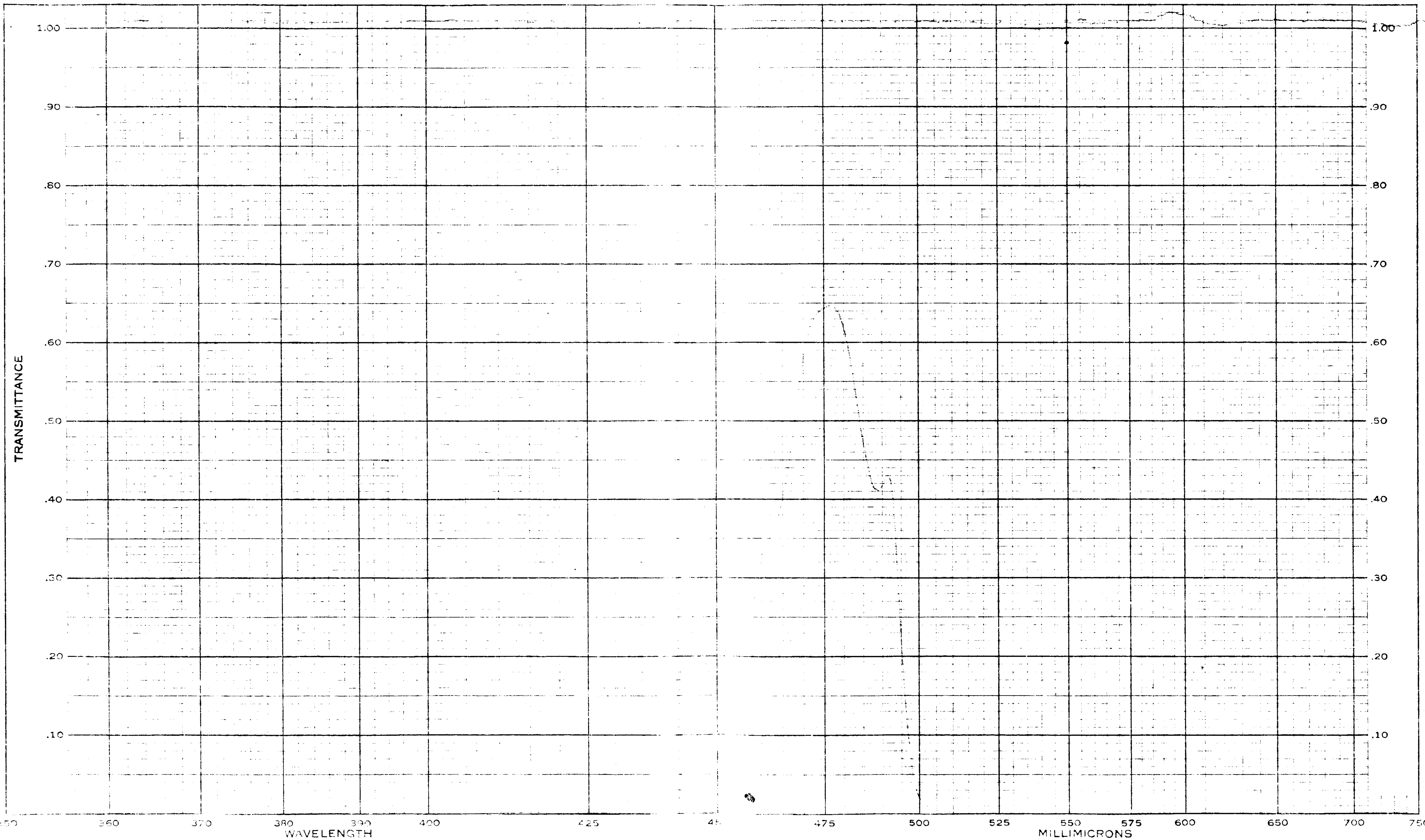


Fig. 14 Spectrophotometric examination of the narrow bandpass filter (No. 6: nominal 450-500 mμ limits) used in the solarization test - after such exposure (10 hours continuous at UV flux level in excess of that for solar exposure at the earth's outer atmospheric limit) noticeably. The data of Table III indicate that the sensitivity of each channel was unaffected. Fig. 15 illustrates the method.

4. TEST PROGRAM AT JPL

It was learned, from JPL, that no adverse test results had been obtained. It is not the purpose of this Report to discuss such tests.

5. FINAL ASSEMBLY OF DUMMY MOCK-UP

On completion of the JPL test program, carried out subsequently to that at Newport, all channels of the mock-up were assembled, for operational use at JPL, in accordance with arrangement detailed in Table IV (See also Fig. 5).

6. DETERMINATION OF CHANNEL SENSITIVITY OF DUMMY MOCK-UP

6.1 Relative sensitivity

This was determined on the same optical bench as was used in the test program (Section 3) - See Fig. 16. In addition to the 5000 watt tungsten lamp, the mercury (quartz envelope) arc employed in the solarization test (Section 3) was utilized as the source to irradiate the three UV channels. The results of this determination are contained in Table IV and are only valid for these exposure conditions.

6.2 Recommendations for absolute sensitivity

In the previous Report a section (No. 5) dealt with the fundamental radiometric references, the normal calibration procedures in precision radiometry, and the group of primary and transfer standards available at the Eppley Laboratory. In September of

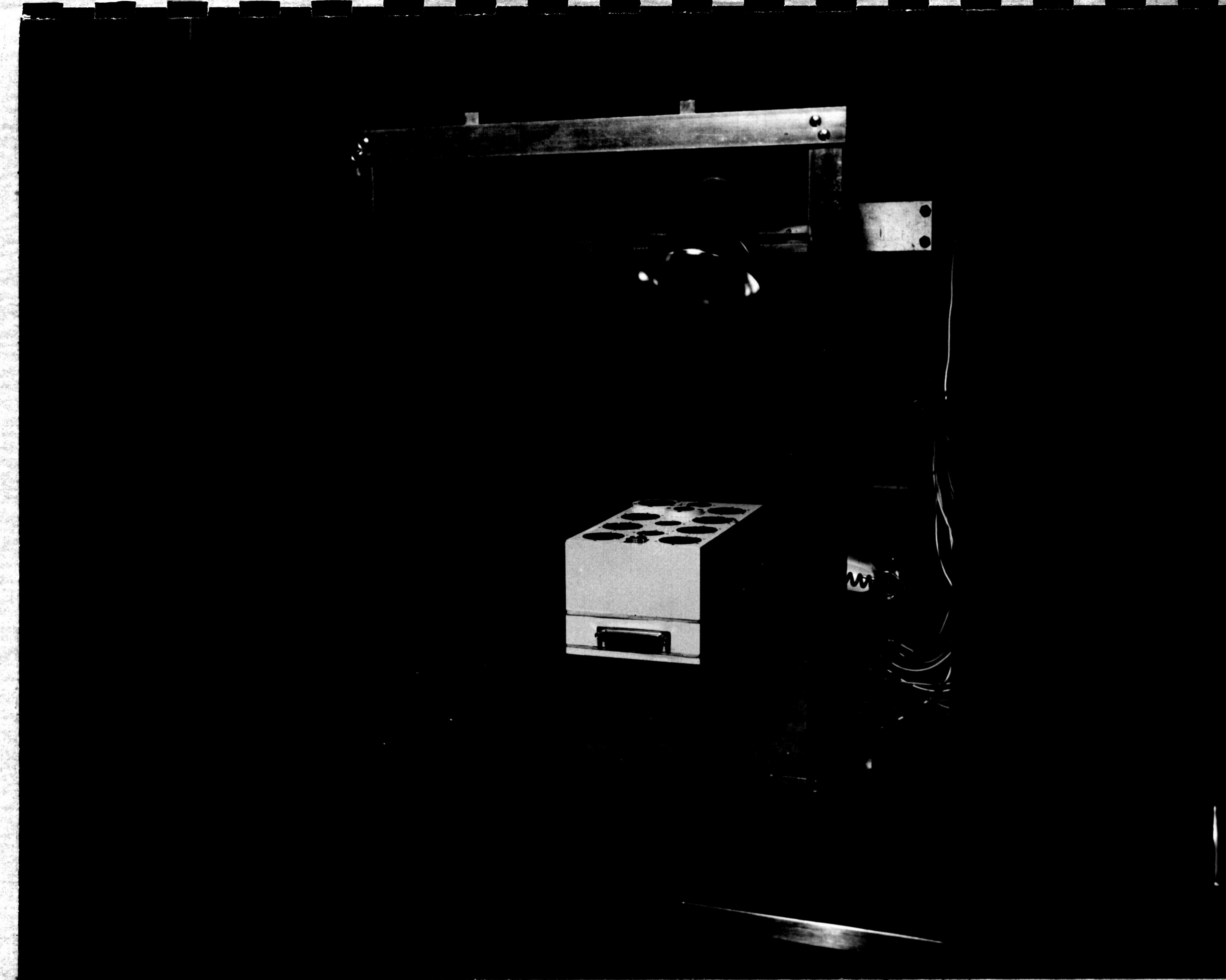


Fig. 15 Thermal shock test of mock-up (constant radiation source in a temperature chamber)

Fig. 16 Instrumentation for the determination of mock-up channel sensitivity (with respect to a tungsten source)

SAMPLE
SOLVENT
CONC.
CELL

SPECTRACORD
THE PERKIN-ELMER CORP.

SERIAL NO. JPL FILTERS
SLIT FOR SATELLITE
SCANNING TIME
DATE DEC 3, 1964

U.V. 2037

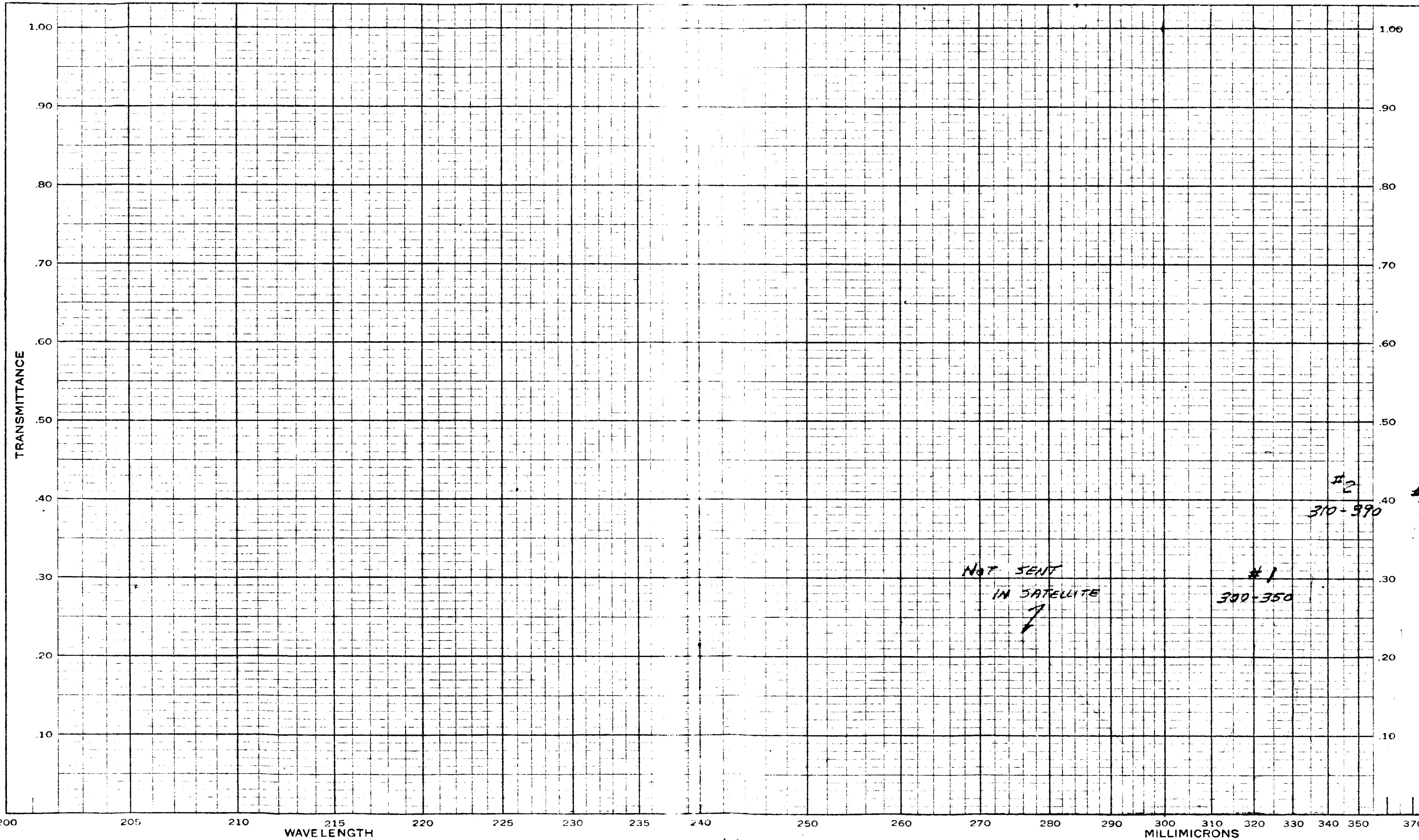


Fig. 17 (a) Transmittance of the narrow bandpass filters inserted in the mock-up (Continued)

SAMPLE
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SPECTRACORD
THE PERKIN-ELMER CORP.

SERIAL NO. JPL FILTERS
SLIT FOR SATELLITE
SCANNING TIME
DATE DEC. 18 1964

VIS. 2038

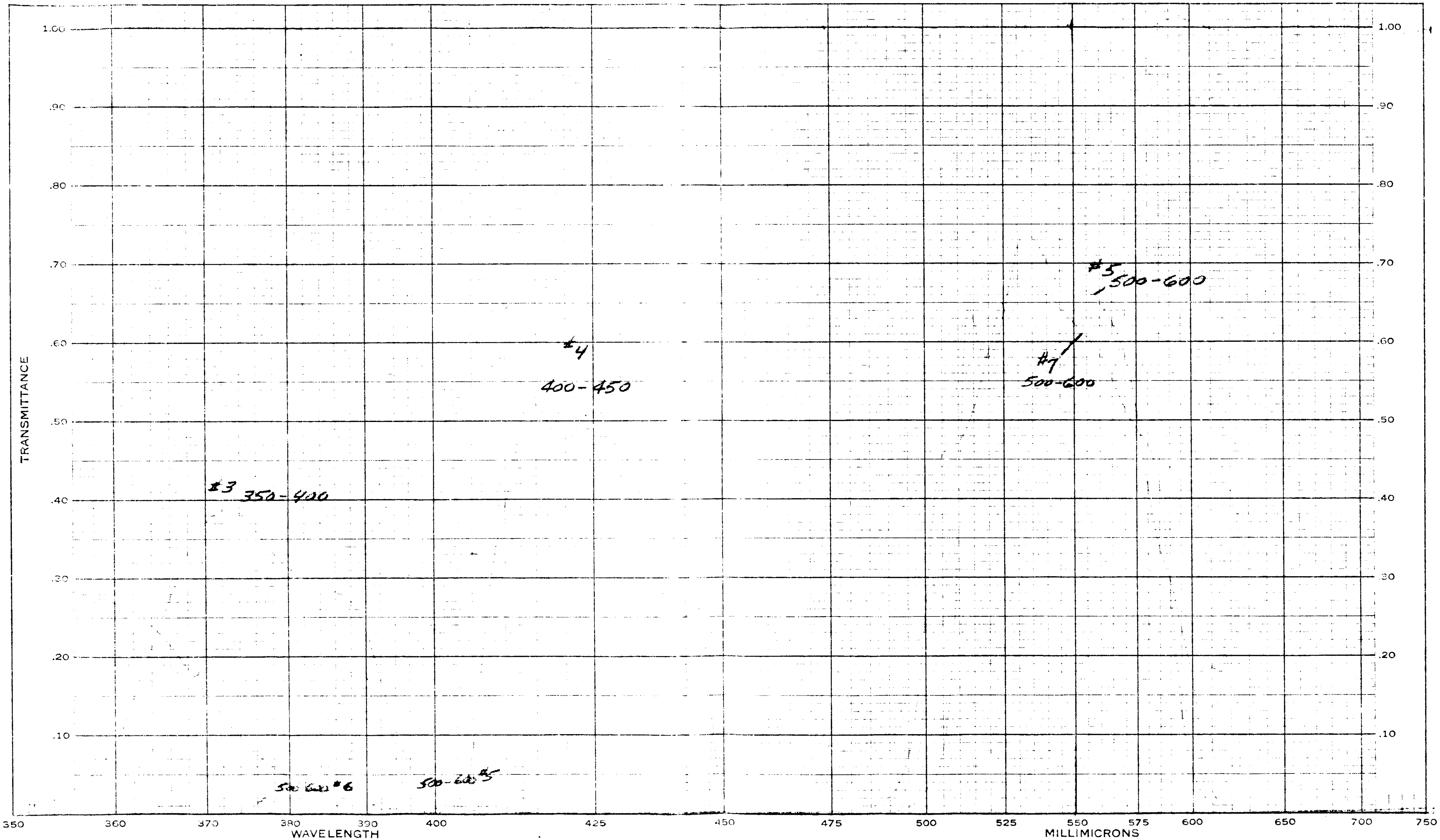

Fig. 17 (b) Transmittance of the narrow bandpass filters inserted in the mock-up (Continued)

SAMPLE
SOLVENT
CONC.
CELL

SPECTRACORD
THE PERKIN-ELMER CORP.

SERIAL NO. U.P. SAT FILTERS
SLIT #4750-6 & #4750-7
SCANNING TIME
DATE 11/10/64

VIS. 2038

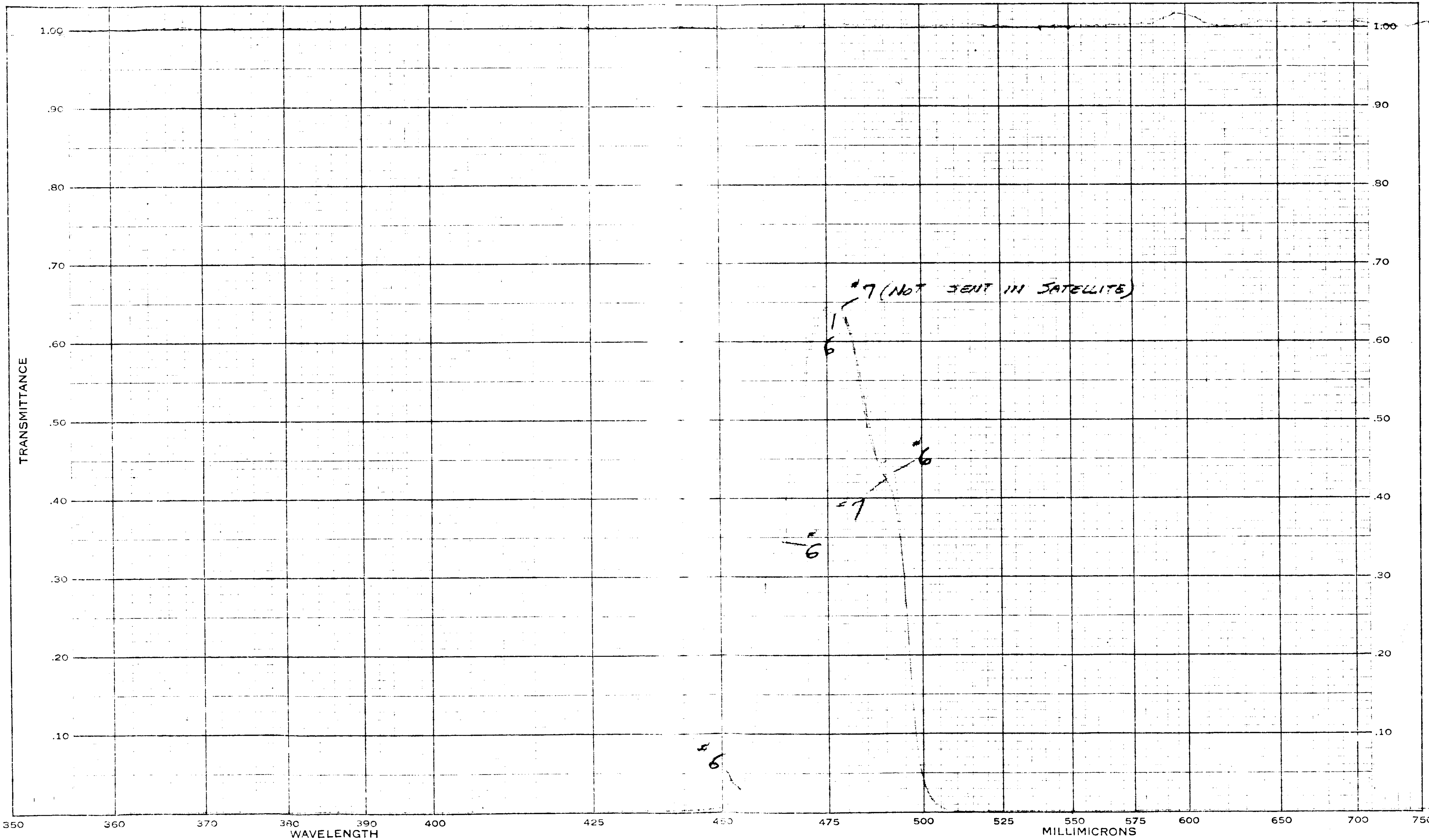

Fig. 17 (c) Transmittance of the narrow bandpass filters inserted in the mock-up (Continued)

SAMPLE

SOLVENT

CONC.

CELL

SPECTRACORD

THE PERKIN - E MER CORP.

SERIAL NO. JPL FILTERS

SLIT FOR SATELLITE

SCANNING TIME

DATE DEC. 18 1964

NIR 2039

#3 1500-2300

TRANSMITTANCE

1.00 .90 .80 .70 .60 .50 .40 .30 .20 .10

WAVELENGTH

MILLIMICRONS

600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1800 1900 2000 2100 2200 2300 2400 2500 2600 2700 2800

Fig. 17 (d) Transmittance of the narrow bandpass filters inserted in the mock-up

TABLE IV Results of relative sensitivity determination of all 12 channels of the dummy mock-up

Channel No.	Connector Pins +	Connector Pins -	Filter No.	Lens	Output mv
1	3	4	8	Yes	5.70
2	5	6	7	"	0.958
3	8	7	5	"	1.10
4	10	9	6	"	0.086
5	26	25	Quartz	No	1.64
6	24	23	OG1	"	1.72
7	21	22	RG8	"	1.05
8	19	20	Quartz	"	1.84
9	11	12	4	Yes	0.075
10	14	13	3	"	0.207
11	15	16	2	"	0.258
12	17	18	1	"	0.072

N.B. 1. Channels 1-9 were tested using the 5000 watt tungsten source operated at 110.0 v and with its emission limited by quartz: mean intensity 59.6 mw cm^{-2}.

2. Channels 10-12 were tested using the 400 watt mercury arc (quartz envelope): mean intensity 52 mw cm^{-2}.

this year one of these primary working standards was verified, in Switzerland, during the second International Pyrheliometric Comparisons.

However, the absolute calibration of such a 12-channel detector radiometer, as described in this Report, is by no means a "normal-type calibration". For a determination of this nature, it is recommended that several different approaches be attempted, at least for the highly wavelength selective narrow bandpass channels. These could well include the following energy sources:

(a) high-intensity carbon arc, stabilized and operated without and with a series of filters identical to those in the radiometer under test;

(b) the sun at Newport (during high solar elevation in summer months), also considering filter as well as total flux techniques;

(c) the sun at the JPL test site at Table Mountain or at the Air Force site at Sacramento Peak;

(d) the sun as observed during conventional aircraft test flight(s).

7. FILTER DEVELOPMENT

The objective of this section of the Report is to describe the work undertaken in continuance of that initiated in July 1964 and discussed in the previous Report. Essentially, included here are:

(A) a review of the theoretical background of single and Fabry-Perot etalon interference-type filters;

(B) a report on the measured characteristics of a series of such filters produced for the purpose of demonstrating the "trade-offs" which must be made in obtaining the most satisfactory filter for any desired band;

(C) a similar report on the second phase of this production study;

(D) a brief report on the developed method to produce narrow band-pass interference filters intended to be free from effects of solarization, to be waterproof and to be highly resistant to mechanical and thermal shock (See also Section 2.3.3 of this Report).

In considering the theoretical review, it should be borne in mind that the mathematics alone do not embrace the complete picture, since all of the filter types which are theoretically possible are not practical from a fabrication standpoint.

A. In general, an ideal optical bandpass filter for use with a spectrally flat detector must satisfy the following conditions.

(1) The passband must be rectangular in shape and exhibit 100 per cent internal transmission for all radiation within preassigned wavelength limits.

(2) The rejection region must extend sufficiently to cover the total bandwidth of the detector within the emission region of the source. The rejection must be complete.

(3) The substrates and materials used in the manufacture and assembly must not deteriorate as a result of indefinite exposure to UV or cosmic radiation.

(4) The complete assembled filter must withstand mechanical shock equal to a single piece of glass of the same dimensions.

(5) The filter must not deteriorate due to temperature changes resulting from alternate exposure to extremely hot sources and extremely cold background.

(6) The filter must not be a radiation emitter. It must perfectly reflect all radiation not transmitted.

The above features will be discussed in the order of their listing. First of all, those bandpass filters which have the best chance of meeting the above conditions are interference filters of the Fabry-Perot type. The theory of such filters is basically that of the Fabry-Perot interferometer. This instrument consists of two semi-transparent, highly reflecting plates separated by a predetermined spacing. The transmitted intensity is given by the Airy summation formula as

$$I = \frac{(1-R)^2}{(1-R)^2+4R \sin^2 d/2} \qquad (1)$$

where R = reflectance (0 to 1),

d = retardation between successive beams,

$d/2$ = optical spacing between the plates.

We see that I_{max}, no absorption, equals one, regardless of the value of R. I_{min} is a strong function of R only. The fringe width ($I_{max}/2$) is a function of both R and d/2.

$$I_{max} = \frac{(1-R)^2}{(1-R)^2} \text{ and } I_{min} = \frac{(1-R)^2}{(1+R)^2} \qquad (2)$$

corresponding to $\sin^2 d/2$ equal to zero and one respectively. Rewriting (1) we have,

$$I = \frac{(1-R)^2}{(1-R)^2} \cdot \frac{1}{\frac{1+4R \sin^2 d/2}{(1-R)^2}} \qquad (3)$$

and $$I = \frac{I_{max}}{1+F \sin^2 d/2} \qquad (4)$$

where $F = 4R/(1-R)^2$.

The value of F determines the bandwidth for a fixed value of phase retardation d. The trigonometric function ($\sin^2 d/2$) determines the shape.

Now d, the phase retardation between beams, is

$$d = \frac{2\pi(2\ N\ S\ \mathrm{Cos}\ \phi)}{\lambda} \qquad (5)$$

where ϕ is the angle of refraction in the spacer material,
S is the physical separation of the plates,
N is the index of refraction of the spacer material,
λ is any wavelength of concern.

Equation (5) may be rewritten in terms of order of spacer and optical thickness as,

$$d = \frac{2\pi M\ \lambda_o\ \mathrm{Cos}\ \phi}{\lambda} \qquad (6)$$

where λ_o is the wavelength of the bandwidth under study and M is an integer, 1, 2, 3, etc.

Then $d/2 = \dfrac{M\ \pi\ \lambda_o\ \mathrm{Cos}\ \phi}{\lambda}$, and

$$d/2 = \frac{M\ \pi\ \lambda_o}{\lambda}, \text{ for normal incidence.} \qquad (7)$$

At the wavelength showing maximum transmittance $\sin^2 d/2 = 0$ (4) and $d/2 = M\pi$. To satisfy this condition $\cos\phi = \lambda/\lambda_o$. In practice ϕ is not measured readily. Instead the exterior incident angle is measured and the angular effect calculated from Snell's law, viz.

$$\sin\phi = \frac{\sin i}{N},$$

$$\sin^2\phi = \frac{\sin^2 i}{N^2},$$

$$\cos^2\phi = 1 - \frac{\sin^2 i}{N^2},$$

or $$\cos\phi = \frac{\sqrt{N^2 - \sin^2 i}}{N} = \frac{\lambda i}{\lambda o} \tag{8}$$

where λi is the wavelength position of the band when viewed at an angle of incidence i, and λo is its position when viewed at normal incidence.

Let us now return to the task of calculating the width and shape of the band for various values of reflectivity (R). We will do this for normal incidence using (2), (4) and (7). The wavelength span between the points Tmax/2 is commonly called the halfwidth. It is convenient to specify other widths such as 1/10, 1/100, etc., in terms of the 1/2 width. Substituting the value of d/2 from (7) in (4), we have at the 1/2 width

$$\frac{I_{max}}{I} = 2 = 1 + F \sin^2 M \pi \lambda o/\lambda. \tag{9}$$

The results of applying the formula are shown below.

Reflection Coef. R	I min (in %)	F	$\sqrt{F}$	$\sqrt{1/F}$	$\sin^{-1}\frac{1}{\sqrt{F}}$	1/2 Bandwidth (1st Order M=1)
0.3	29.0	2.45	1.56	.638	39.6°	0.46λo
0.4	18.0	4.4	2.1	.477	28.5	0.32
0.5	11.0	8.0	2.83	.353	20.8	0.23
0.6	6.2	15	3.87	.258	15.0	0.17
0.7	3.1	31	5.57	.179	10.3	0.13
0.8	1.2	80	8.95	.112	6.4	0.072
0.85	.66	151	12.3	.081	4.7	0.049
0.90	.28	360	19.0	.053	3.0	0.033
0.92	.17	575	24.0	.040	2.3	0.027
0.94	.10	1040	33.0	.031	1.75	0.019
0.96	.04	2400	49.0	.02	1.17	0.012
0.98	.01	9800	99.0	.01	.58	0.007
0.99	.003	40,000	199	.005	.28°	0.002λo

The 1/2 bandwidth in the last column is shown as a fraction of λ_o, the center wavelength being of the first order band. Bands of higher order are narrower with widths equal to the first order half band divided by the order number M. It is apparent from the above that the contrast ratio, I max/I min, is relatively large only for very narrow bands. In comparison with the ideal filter the band shape leaves something to be desired. For instance, the 1/10 bandwidth (I max/10) is three times the 1/2 width; the 1/100 bandwidth is over nine times the 1/2 width.

The contrast ratio and bandwidth are clearly dependent. The principle we use to lessen this dependence is that of using two or more interferometers of low contrast in series. Effectively, the resulting spectrogram is the product of the individual curves. The bandwidth is defined by the narrowest individual passband and the background transmission is the product of all. The passbands exhibit sharp cut-off slopes and broad tops. If one were to actually mount a series of Fabry-Perot interferometers, as described, the interplay of multiple reflections would cause a marked departure from the expected product. By depositing this multiple interferometer on one side of one substrate, using thin films in place of massive interferometer plates, the phase relation for all beams is properly controlled and the result is as stated above. In practice, the bandwidth requirement determines the characteristics of the elemental F-P interferometer; the contrast requirement determines the number of interferometers to be deposited. Desirable results are achieved unless absorption in the materials used becomes appreciable, as is the case for most UV filters.

Let us now consider the problem of excluding radiation at wavelength points outside of the band. From the formulae already given, I min can never be zero no matter how many F-P periods are used. However, the rejection can be made sufficiently small to be of secondary significance only.

Eppley thermopiles are broadband and respond to the total optical spectrum. In making isolation filters, it is essential to integrate the background transmission over the total bandwidth of the detector. The choice of substrate can help a great deal. Glass absorbs outside of the band 340-3000 mμ and quartz absorbs outside of the band 180-5000 mμ. We need not concern ourselves with wavelengths beyond these points.

For the sake of discussion, let us assume a spectrally flat source as well as detector and assign a signal to noise ratio, S/N, of 100.

Then, S/N = area under the passband divided by the area under the rejection region.

The maximum allowable transmission (T) at any wavelength outside of the passband is

$$T = (\text{Filter baseline bandwidth} \times T \text{ average})/(5000 \times S/N)$$

For a baseline bandwidth of 50 mμ and an average band transmission (T) of 10 per cent, T must be 0.001 per cent - and optical density of 5.

B. Based upon the principles outlined above, the characteristics of the first series of filters fabricated to match the spectral bands outlined in the previous Report are presented in Table V. It must be realized that the preceding discussion was based on a single interferometer layer and that successive applications of this technique are necessary to determine the characteristics of the completed multilayer filter.

In the table, filter number (T-1) is a simple three-layer (al-dielectric-al) F-P etalon. (T-2) is a double filter (AL-die-AL-die-AL). (T-3), (T-4) and (T-5) each consist of a triple etalon. In each case, the filters are 1st order with the aluminum layers approximately equal in thickness. The interference thickness monitoring was carried out at a wavelength of 275 mμ. (T-3), (T-4) and (T-5) exhibit sufficient rejection and represent an attempt to reproduce the same characteristics.

TABLE V Spectral transmission characteristics of a series of narrow bandpass filters peaking in the UV region (Development I)

Wavelength (μ)	Transmission as Percentage T-1	T-2	T-3	T-4	T-5
0.20	18	0.90	-	-	-
.21	22	1.0	-	0.06	0.10
.22	27	1.3	0.05	0.10	0.30
.23	33	1.7	0.10	0.20	0.70
.24	41	2.9	0.25	0.60	3.5
.25	48	5.5	0.70	2.2	16
.26	52	12	3.5	5.5	33
.27	52	24	14	24	29
.28	48	33	23	26	22
.29	42	31	20	21	14
.30	36	24	13	13	6.0
.31	29	13	6.0	5.0	1.8
.32	24	7.0	1.7	1.4	0.50
.33	20	3.2	0.48	0.46	0.20
.34		1.7	0.15	0.16	0.090
.35	13	0.90	0.056	0.058	0.038
.36		0.60	0.024	0.023	0.020
.37		0.35	0.011	0.014	0.010
.38	8.0	0.23	0.006	0.007	0.006
.39		0.16			
.40	6.0	0.11	0.0023	0.003	0.003
.41		0.085	0.0014	0.0018	0.0016
.42		0.065		0.0009	0.0009
.43		0.058	0.0004		
.44		0.050	0.0003		
.45	3.0	0.033	0.0002	0.0002	0.0002
.50	2.0	0.009	-	-	-
.55	1.5	0.007	-	-	-
.60	1.0	0.005	-	-	-
.70	1.0				
.80	1.0				
0.90	1.0				
1.00	<1.0				

C. Although quartz was selected as the substrate and cover plate of all filters the materials used in the actual fabrication do absorb in certain spectral regions. The materials used in making filters with passbands at wavelengths of 1.6 μ and longer consist of germanium and silicon monoxide. Germanium strongly absorbs energy of wavelengths shorter than about 1.5 μ. Filters lying between 0.4 and 1.6 μ are made using zinc sulphide, cryolite and silver. For these filters, zinc sulphide absorbs energy of wavelengths shorter than 0.39 μ. In the region 0.31 to 0.40 μ lead chloride, cryolite and silver are used, and in this case lead chloride absorbs strongly energy of wavelengths shorter than 0.30 μ. In the region 0.20 to 0.30 μ aluminum and cryolite are used. The absorption for filters located in this region is characteristic of aluminum metal.

One of the problems in filter making, is that of ensuring the necessary rejection outside of the passband. Without the aid of absorption glass it is necessary to build into the filter the necessary rejection, preferably by reflection. Procedures carried out to date gave a high degree of rejection but somewhat at the expense of band shape, and in some cases, band transmission itself. Improvement in design and control are called for in each of the spectral regions using different materials.

Perhaps a modification is in order wherein an absorption glass is used as a separate piece, placed between the detector and quartz primary filter. The following spectrographic data, given in Table VI suggests the possibility.

If, for instance, only light of wavelength shorter than .3 μ solarizes, then the combination of filter plus absorption

TABLE VI Spectral transmission characteristics of a series of narrow bandpass filters peaking in the UV region (Development II)

Wavelength (μ)	Transmission as Percentage: Filter without absorption glass	Transmission as Percentage: Filter with Schott UG-11 in series
0.28	2.0	1.5
.29	5.0	3.0
.30	11.0	7.0
.31	24.0	18.0
.32	47.0	38.0
.33	62.0	51.0
.34	59.0	49.0
.35	52.0	43.0
.36	48.0	36.0
.37	38.0	19.0
.38	25.0	11.0
.39	16.0	0.6
.40	9.0	0.05
.42	3.0	<0.01
.45	1.0	<0.01
.50	0.3	<0.01
.60	0.2	<0.01
.70	0.1	<0.01
.80	0.06	<0.01
0.90	0.03	<0.01
1.00	0.01	<0.01

glass might prove to be a filter superior to one designed to perform the necessary rejection without such absorption.

D. The primary purpose of the filter development program initiated under this contract was that of examining the various techniques of manufacture and providing a necessary set of bandpass filters suitable for use in space. To minimize solarization, the decision was made to use only quartz substrates, and to eliminate the use of organic laminating materials, such as thermo-setting plastic and epoxy. The use of absorption glass ordinarily used as an aid in reducing secondary transmission was also negated for the same reason.

To meet the above requirements, it was necessary to find a means of edge sealing the several substrates comprising each filter. This was done by clamping the substrates together and epoxy laminating a quartz ring onto the edges. Though this technique proved quite satisfactory, improvement is necessary to avoid the condition of epoxy being pulled into the small space between the elements by surface tension. This, in effect, is an encapsulation of the filter. Tests have shown this arrangement to be completely waterproof, to be able to withstand severe shock and (in the preliminary experiments) to be free from the effects of solarization.

8. DETECTOR SIGNAL OPTICAL AMPLIFICATION

The questions of lens choice and lens testing was elaborated upon in the previous Report.

The tests of the lenses performed during this phase were of two types. The first consisted of the measurement of focal lengths, to assure the manufacturer's ability to meet and to reproduce the desired specifications. The second consisted of preliminary usage tests using one of the single-channel modules.

The lenses were ordered to specifications which were considered preliminary. The manufacturer was to supply specimens which had a power of close to 20 diopters with a diameter of 1.5 inches. The circle of confusion, at the focal point, for an infinitely distant source was specified at 0.06 inch diameter maximum.

The repeatability of manufacture was checked using a normal optical bench method for determining focal length. The focal lengths were found to be 5.58 ± 0.10 cm (white light) for the eight lenses tested. These lenses were assigned serial numbers 4-11. This focal length corresponds to a power of approximately 18 diopters.

A short series of tests were made while the single-channel modules (1.25 inch lens diameter) were available. These tests were mainly angular scan tests to indicate how critical is the angular position, and were conducted with no filter in place. Measurements were made radiometrically using detector No. 3 to aid in deciding the lens position for use during the shock tests. The 5000 watt tungsten-filament lamp was used as source. These preliminary investigations indicate that angular position, with the present channel arrangement, appears to be critical to 1 or 2° in reproducing detector output. This is clearly a matter which would require further close study before finalizing the channel arrangement in a fully operational model of the radiometer.

9. RECOMMENDATIONS FOR CONTRACT CONTINUANCE

These may be summarized as follows:

(a) the high degree of success achieved in thermopile detector development where fast response, good sensitivity (with freedom from temperature dependence) and robustness are paramount requirements;

(b) the distinct improvement in narrow bandpass filter fabrication, as evidenced especially in increased filter transmission in the ultraviolet and visible regions (but further filter development is desirable especially with regard to filter shape) and in the realization of completely sealed units capable of withstanding solarization, moisture ingress and severe shock;

(c) the completely successful performance of the modules and the dummy mock-up in the Eppley and JPL test programs to date;

(d) the rapid current development of the employment and interpretation of filter techniques in precision radiometry;

(e) the present state of the art in radiometer calibration, at high flux levels and in vacuum.

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