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DESIGN AND CONSTRUCTION OF A WIDE ANGLE DIFFUSE SOURCE

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by

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INTRODUCTION

A Multispectral Scanner (MSS) has been under development for some time and is now undergoing tests for final calibration. It has four bands, each containing six channels. Thus it has 24 detectors which receive radiation by fiber optics. The scanner is to be flown on the Earth Resources Technology Satellite A (ERTS A). The scanner has an aperture of nine inches. The scanner must be calibrated before it can be flown. Hence an extended source was needed for this purpose.

It has been shown that a spherical integrator makes a satisfactory extended source for the calibration of radiometers (References 1 & 2). A six-foot spherical integrator has been in use by the Earth Observations Branch, Code 652, Goddard Space Flight Center, for a number of years for this purpose. However, this sphere has an exit port which is only 3.5 inches in diameter and thus is not suitable for the calibration of the MSS.

It was therefore a matter of highest priority to design and calibrate an extended source which could be used to calibrate the MSS. For this reason it was proposed to examine the problem for a feasible solution. Two alternatives were considered: (a) a 30 inch spherical integrator with a twelve inch exit port, and/or (b) the use of one hemisphere of the 30 inch spherical integrator in conjunction with a Kodak Ektalite Screen. After some preliminary trials it seemed that the 30 inch sphere would give the most satisfactory results.

THEORY OF THE SPHERICAL INTEGRATOR

The principle of spherical integration which has been discussed elsewhere (References 3 & 4) was proposed by Sumpner in 1892 (Reference 5). He showed that if a source of light is placed inside a hollow sphere which is coated internally with a perfectly diffusing coat, the luminance of any portion of the surface due to the light reflected from the rest of the sphere is everywhere the same and is directly proportional to the total flux emitted by the source.

It is easy to show (Reference 6) that the theoretical expression for this relation in terms of the reflectance ρ of the perfectly diffusing coat of the sphere wall due to an infinite number of reflections is given by

$$\Phi = \frac{F}{4\pi r^2} \frac{\rho}{1-\rho} \tag{1}$$

where Φ is the total radiant flux reaching unit area of the spherical surface by reflection, F the total flux emitted by the source and r the radius of the sphere. In the derivation of equation (1) it is assumed that ρ is constant, that the surface is a perfect diffuser, that the sphere is empty and that it has no ports. As a matter of facts, the reflectance ρ of the coating varies with wavelength. Moreover there is no perfect diffuser so that Lambert's cosine law does not hold accurately. In addition, the sphere has sources, shields and ports, all of which affect the total radiant flux. It has been shown that the error introduced by the finite size of holes and samples may be as much as 25 percent (Reference 7). Moreover, the spectral dependence of the reflection can modify considerably the spectral distribution of the flux streaming from the port of the sphere (Reference 1).

Thus the intensity is increased for wavelengths for which the reflectance is high and decreased for wavelengths for which the reflectance is low. In spite of these uncertainties, one can calibrate the output of the sphere against a known standard for use as an absolute calibration source.

THE SPHERICAL INTEGRATOR

The spherical integrator which has been developed is a nickel-plated sphere of spun aluminum with a diameter of 30 inches. It was spun in the form of two hollow aluminum hemispheres with a one inch flange. These were subsequently nickel plated. The one inch flange makes it possible to bolt the hemispheres together and also mount them on a rigid, movable aluminum frame work (Figure 1). An exit port with a diameter of twelve inches is located at the midpoint of the surface of one of the hemispheres. This port provides ready access to the integrator for calibration purposes.

In order to eliminate any temperature variations which might affect the calibration, the sphere is water cooled by means of nickel-plated copper tubing (3/8 inch ID) which has been wound on the outer surface of the sphere in the form of a spiral. The tubing was soldered along its entire length in order to make good thermal contact. A water pressure switch is interlocked with the

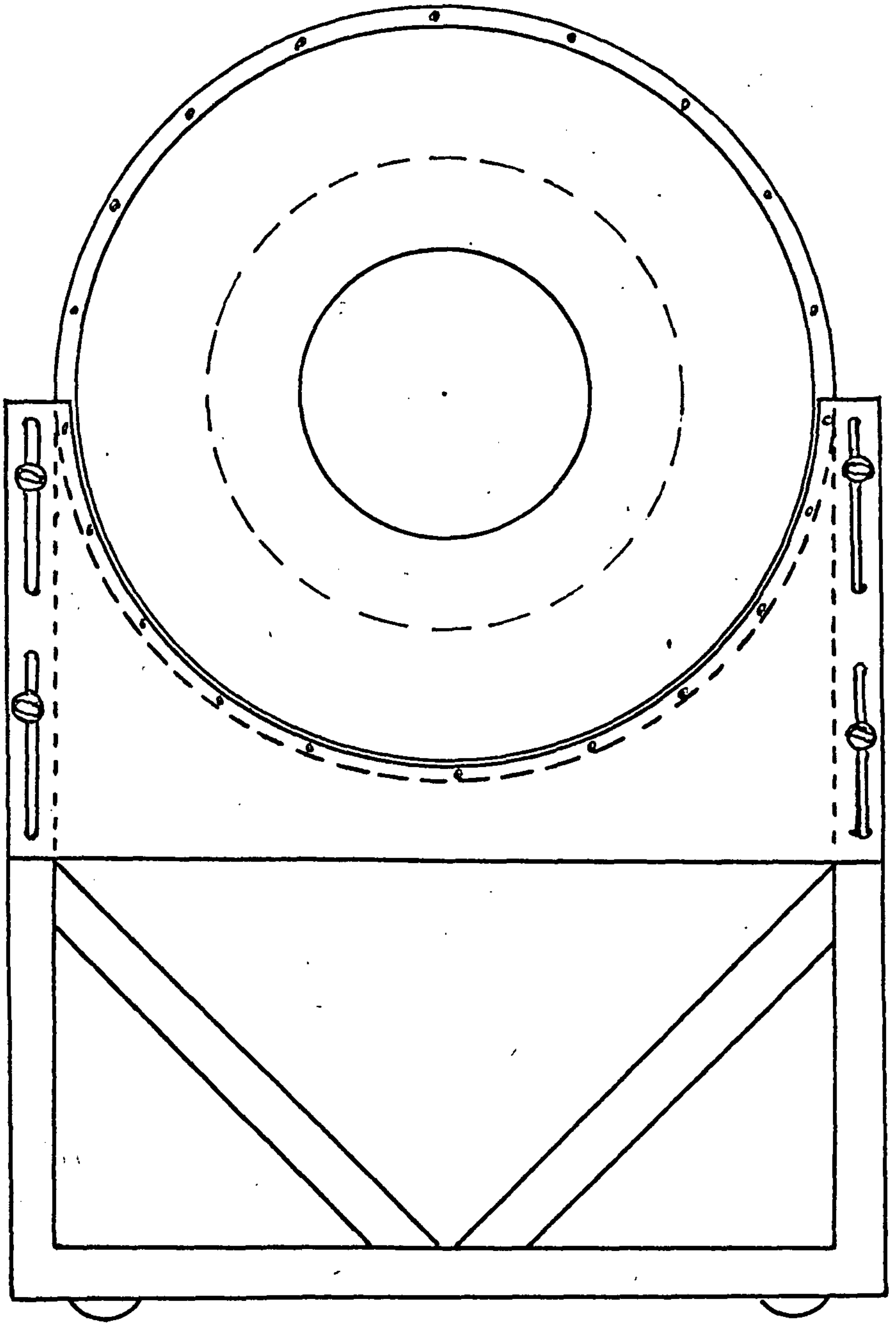


Figure 1. Front view of the 30 inch sphere and support. The height of the sphere is adjustable. The twelve inch port is shown by the circle at the center. The lamps are mounted in the sphere along the dashed circle.

lamp power. The electrical input circuits to the lamps are normally open until the water switch is operated. This assures proper cooling of the sphere whenever the lamps are turned on.

The inner surface of the sphere was sprayed with a number of coats of white sphere paint having a base of finely divided, high purity barium sulfate powder. This paint, in the form in which it was used on the 30 inch sphere, was developed by Michael C. Shai, Code 713, Goddard Space Flight Center. It provides a highly diffusing surface with a greater reflectance than that of smoked magnesium oxide. In addition, it shows little degradation with age in contrast to the well known deterioration of smoked magnesium oxide.

The radiant flux is supplied to the sphere by means of twelve quartz-halogen lamps. The quartz-halogen lamps have several characteristics (References 8 and 9) which make them superior to conventional tungsten lamps. Because of the "transport mechanism" provided by a trace of halogen in the lamp, evaporated tungsten is returned to the filament. In addition, the lamp is more compact due to the resistance of its quartz envelope to higher temperatures.

These lamps are equally spaced around the twelve inch exit port on a circle with a radius of ten inches (shown as a dashed line in figure 1). Small teflon shields, 1.5" x 3", mounted in front of the lamps, prevent the flux of these lamps from reaching the exit port directly.

Near the top and bottom of the sphere there are 1.5 inch diameter holes. A fan is mounted over the hole at top to aid in the circulation of the air inside the sphere in order to maintain a more nearly uniform air temperature in the sphere, in addition to the cooling effect of the water-cooled walls of the sphere.

POWER SUPPLY FOR THE SPHERICAL INTEGRATOR LAMPS

The 45-watt quartz-halogen lamps require a 6.5 ampere current at approximately 6.8 volts. The lamps are operated in three banks of four lamps each. The four lamps in a given bank are in series.

Each bank of four lamps is operated by one of three power supplies. These power supplies are model 590-11 power supplies manufactured by Edgerton, Germeshausen & Grier, Inc. They have been specifically designed for use with various types of standard lamps. They are solid state supplies designed to furnish programmed voltage and rms regulated current in preset combinations at power levels ranging from 2 to 1000 watts (1 to 50 amperes and 2 to 160 volts). The chopper-stabilized square wave current is feed-back regulated within 0.25% rms of the selected digital value for control of the light output within 1%. In the present application, the power supplies are preset to provide a constant current of 6.5 amperes with a maximum available potential of 44 volts.

A switching arrangement allows any one or all of the lamps in a given bank to be turned off. Since there would be a considerable decrease in load in a given bank if one or more lamps in the bank were turned off, each lamp which is turned off is automatically replaced by an equivalent load outside of the sphere. This load consists of a 7.07 ampere, 100 watt Ohmite Dividohm adjustable power resistor adjusted to give a resistance of 1.033 $\pm$ 0.010 ohms. It is located in the control rack so that the dissipated power does not contribute to the total flux in the sphere.

The circuit arrangement provides for constant monitoring of the voltage drop across each lamp separately, by means of a true rms voltmeter. The D.C. output of this meter is fed into a digital voltmeter, which may be read to four significant digits.

This continuous monitoring of the voltage permits the operator to note if and when the resistance of a given lamp begins to change. Since such a change is accompanied by a corresponding change in the lamp output and hence in its intensity, the investigator knows that a particular lamp must be replaced by an equivalent lamp in order to keep the emittance of the sphere constant.

The running time of each lamp is constantly monitored by one of twelve elapsed time meters. This serves as an additional check on the probable condition of each lamp in view of their average life expectancy.

According to information obtained from the General Electric Lamp Division (Reference 10), the initial output of the 45 watt lamp is 640 lumens and decreases to 97% of this at the end of its average life expectancy while operating at constant current. The average life expectancy (the time exceeded by one-half of the lamps) is about 1000 hours.

Theoretically a decrease of one percent in either current or voltage of the lamp will be accompanied by a decrease of two percent in lamp output. It is suggested, therefore, that if the monitored voltage of a given lamp in the sphere varies by 2.5% (provided the power supply has not changed) while maintaining a constant lamp current, the lamp should probably be replaced.

THE SPECTRAL REFLECTANCE OF THE SPHERE PAINT

In the case of the six-foot spherical integrator of the Earth Observations Branch, the diffusing surface was obtained by spraying the inside with several coats of a white paint with a magnesium carbonate base manufactured by the Burch Company. Although this paint has a reflectance of more than 90% in the visible range, it drops rather rapidly in the ultraviolet and the near infrared ranges.

Recently a much more satisfactory paint has come into use. It is composed of high purity barium sulfate pigment suspended in a polyalcohol to facilitate its use in a spray gun and also make it adhere well to the inside wall of the sphere. This paint, used in the 30 inch sphere, was developed by Michael C. Shai, Code 713, Goddard Space Flight Center. The reflectance of this paint was determined by comparing it with freshly smoked magnesium oxide in the range 0.2 micron to 2.5 microns by means of a Cary 14 Double Beam Spectrophotometer. For the range 2.5 microns to 10 microns the reflectance of the paint was compared with a calibrated aluminum mirror as a standard by means of a Cary-White 90 Double Beam Spectrophotometer. The resulting data are given in Table 1 and plotted in Figure 2. The data are shown only for the range 0.25 micron to 3.0 microns since the reflectance drops rapidly beyond 2.5 microns.

Table 1

Spectral Reflectance of $BaSO_4$ Sphere Paint (MS125-4)
(λ in microns)

λ	ρ_λ	λ	ρ_λ	λ	ρ_λ
0.25	0.898	0.70	0.962	2.10	0.859
0.26	0.923	0.75	0.960	2.20	0.867
0.27	0.935	0.80	0.960	2.30	0.853
0.28	0.946	0.90	0.960	2.40	0.850
0.29	0.961	1.00	0.960	2.50	0.826
0.30	0.967	1.10	0.959	2.60	0.802
0.32	0.960	1.20	0.953	2.70	0.727
0.35	0.962	1.30	0.950	2.80	0.368
0.37	0.964	1.40	0.943	2.90	0.225
0.40	0.951	1.50	0.926	3.00	0.208
0.45	0.955	1.60	0.924		
0.50	0.964	1.70	0.921		
0.55	0.960	1.80	0.912		
0.60	0.962	1.90	0.893		
0.65	0.961	2.00	0.876		

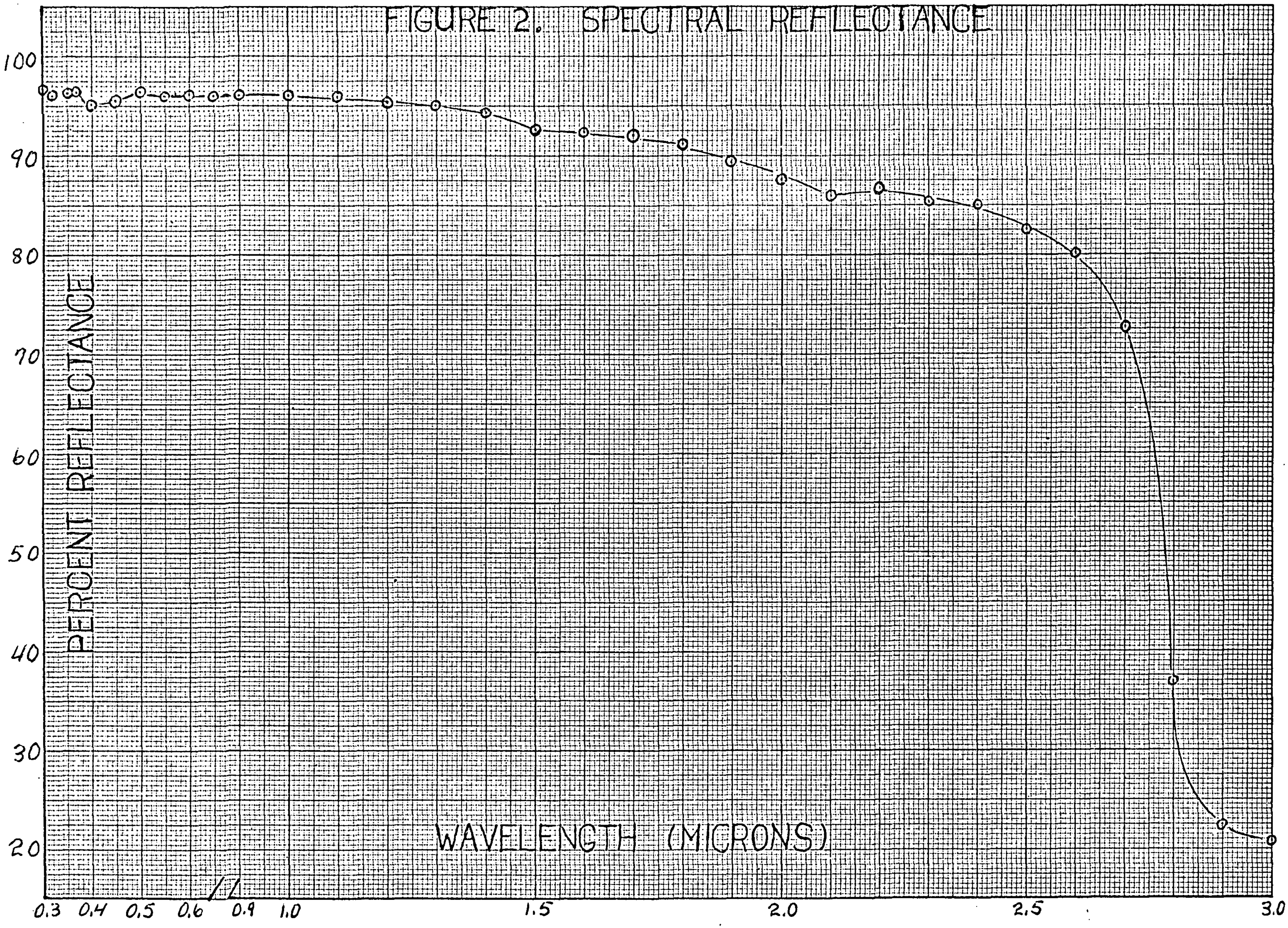


FIGURE 2. SPECTRAL REFLECTANCE
PERCENT REFLECTANCE
WAVELENGTH (MICRONS)
100
90
80
70
60
50
40
30
20
0.3
0.4
0.5
0.6
0.9
1.0
1.5
2.0
2.5
3.0

OPERATING PROCEDURE

Before making any measurements on or with the sphere, the fan, the water and all twelve lamps were turned on. Fifteen minutes were allowed for the sphere to attain equilibrium. This assured repeatable steady state conditions.

When a radiometer is to be calibrated, from one to N lamps will be required, where N+1 lamps would saturate the detector. In this case lamps No. 12, 11, ... N+1 are turned off after steady state conditions have been reached. Thus the operator will start with N lamps. This number is decreased one lamp at a time till only lamp No. 1 is in use. This gives the available range of intensities. It is important to decrease the current through a given lamp slowly when turning it off in order to assure the maximum useful lifetime for a given lamp.

Detailed operating procedures are provided with the control console for the sphere.

RELATIVE SPECTRAL DISTRIBUTION

Since the integrating effect of the sphere is influenced by the spectral dependence of the reflectance, it is necessary to compare the spectral distribution of the output with that from a standard of spectral radiance. Tests have shown that the number of lamps used in the sphere has no effect on the spectral distribution of the output within the limits of experimental accuracy (Reference 1), hence twelve lamps were used to calibrate the sphere in order to get a satisfactory flux intensity.

The measurements of the spectral distribution of the sphere were made with a Perkin-Elmer Double-Pass Monochromator Model 99. The slit of the monochromator was positioned about 8 inches from the port of the spherical integrator. The slit width and gain were held at the smallest values possible in order to have the best resolution possible as well as a minimum amount of noise. For the wavelength range from 0.45 to 2.7 microns a Reeder thermocouple detector with quartz window was used. A photomultiplier detector 1P28 was used in the range from 0.32 to 0.75 microns. The spectral distribution for both ranges was automatically recorded by means of a Leeds and Northrup Speedomax G.

In order to obtain preliminary information on the spectral distribution of the sphere, a run was made and recorded during which the wavelength of the radiation passed by the monochromator was varied continuously. However, the data for the relative spectral distribution of the sphere was obtained by recording a short run at a fixed wavelength setting of the monochromator in order to obtain a reliable average value at said wavelength. This was repeated for additional wavelength settings at every one tenth micron or less from 0.32 micron to 2.70 microns. Whenever it was necessary to change the slit width of the monochromator or the gain of the amplifier in order to obtain a satisfactory deflection, one or two points already recorded were scanned again as a double check on the relative intensity of the sphere at these wavelengths. This procedure was repeated two or three times to obtain the average value of the radiance at each wavelength measured.

In order to get the spectral distribution of the standard of radiance the Eppley Laboratories standard lamps EPI-1154 and EPI-1155 were used. For a given trial one of these lamps was positioned about 2.6 meters in front of the slit of the monochromator and on a line with its axis. The spectral distribution of each lamp was obtained under the same conditions of slit width and amplifier gain as those which were used to get the spectral distribution of the output of the sphere.

The average recorder deflections D_{sr_λ} obtained for the output of the sphere were divided by the corresponding average recorder deflections D_{lr_λ} obtained for each of the standard lamps. This was done at one-tenth micron intervals or less over the entire spectral range which was scanned. This gave the relative ratios of the spectral distribution of the sphere and of a specific lamp. These ratios $k_{r\lambda} = D_{sr\lambda}/D_{lr_\lambda}$ were determined separately for each of the standard lamps used.

ABSOLUTE SPECTRAL DISTRIBUTION

The spherical integrator as a source of radiant flux has a different spectral configuration than that of an approximate point source such as the standard quartz-halogen.lamp. In order to obtain an absolute calibration by comparing the spectral distribution of the sphere with that of the standard lamp it is necessary to eliminate the effects of this difference. Since "the role of a diffusely reflecting surface is to obliterate the past history of the incident radiation" (Reference 11), a 12-inch spherical integrator was mounted on the front of the Perkin Elmer Monochromator. This small sphere consists of two aluminum hemispherical shells painted on the inside with the barium sulfate paint used on the 30" sphere. The two hemispheres were bolted together and rigidly fastened to the monochromator so that a 1.8 cm diameter exit port was centered in front of the monochromator slit. The second hemisphere has a 3.7 cm. diameter entrance port designed (a) to be positioned at the exit port of the thirty inch integrator so that it is on the inside curvature of the thirty inch integrator and thus receive flux from all parts of the large sphere, or (b) so as to be in line with the standard quartz-iodine lamp located at a known distance (about 18 cm) from this port and thus receive the flux from the standard lamp. Using the small sphere in this way, the monochromator alternately saw the flux emitted by the thirty inch integrator or from the standard lamp at a known distance after the flux had been integrated by the small sphere.

Using a given slit width of the monochromator and gain of the recorder a direct comparison was made between the total flux which the small sphere received from the thirty inch integrator and from the standard lamps which had been used to get the relative ratios as described above. This was done using the photomultiplier detector 1P28 at the following wavelengths: 0.50, 0.55, 0.60 microns. This procedure was repated using the Reeder thermocouple detector at the following wavelengths: 1.1, 1.2, 1.3 microns. Each measurement was repeated two or three times.

Let $D_{sa\lambda}$ be the recorder deflection of the monochromator at one of the above-mentioned wavelengths when the small sphere receives flux from the thirty inch integrator, and $D_{la\lambda}$ the deflection at the same wavelength when it receives flux from one of the standard lamps placed at a known distance from the entrance port. Then $k_{a\lambda} = D_{sa\lambda}/D_{la\lambda}$ is the absolute ratio of the flux from the thirty inch integrator to that of the standard lamp at this wavelength. The average value obtained at three wavelengths was chosen as the true value for $k_{a\lambda}$. The absolute ratios for all wavelengths measured was obtained by normalizing the relative ratios $k_{r\lambda}$ to this absolute ratio $k_{a\lambda}$.

CALIBRATION OF THE SPHERICAL INTEGRATOR

When the small sphere, mounted on the monochromator, has its entrance port located at the exit port of the thirty inch integrator, the flux incident on the entrance port is obviously the same flux which is incident on the corresponding portion of the exit port of the thirty inch integrator. Since this flux comes from all parts of the inside surface of the integrator by diffuse reflection, each elemental area of the inside surface of the small sphere receives flux from an equivalent fractional portion of the inside surface of the integrator which is on the line of sight through the port with that of the small sphere. This means that the small sphere receives completely diffuse radiation from the thirty inch integrator.

In order to determine the total flux receivrd by the small sphere, one must evaluate it in terms of the flux incident at the exit port of the integrator which has come from all parts of the diffusing surface of the integrator. Let $F_{s\lambda}$ watts $\cdot$ cm^{-2} $\cdot$ μ^{-1} be diffusely reflected into the solid angle 2π. Then the diffuse spectral radiation in the normal direction is $F_{s\lambda}/\pi$. The spectral radiant flux from the diffusely reflecting surface of the spherical segment of area dA_s which is incident at the effective area of the exit port, and hence of the area A of the entrance port of the small sphere is equal to

$$A\ dW_s = \frac{F_s}{\pi} \times \frac{dA_s \times \cos 1/2\ \theta \times A \cos 1/2\ \theta}{d^2}$$

where d is the distance between the element of area dA_s and the port, and $1/2\ \theta$ is the angle betwen the line of sight propagation from this area and the inner normal to the sphere at the same point on dA_s, as is shown in Figure 3. Since $d = 2r \cos 1/2\ \theta$, and $dA_s = 2\pi r^2 \sin\theta\ d\theta$, the element of spectral radiant power at the entrance port of the small sphere is

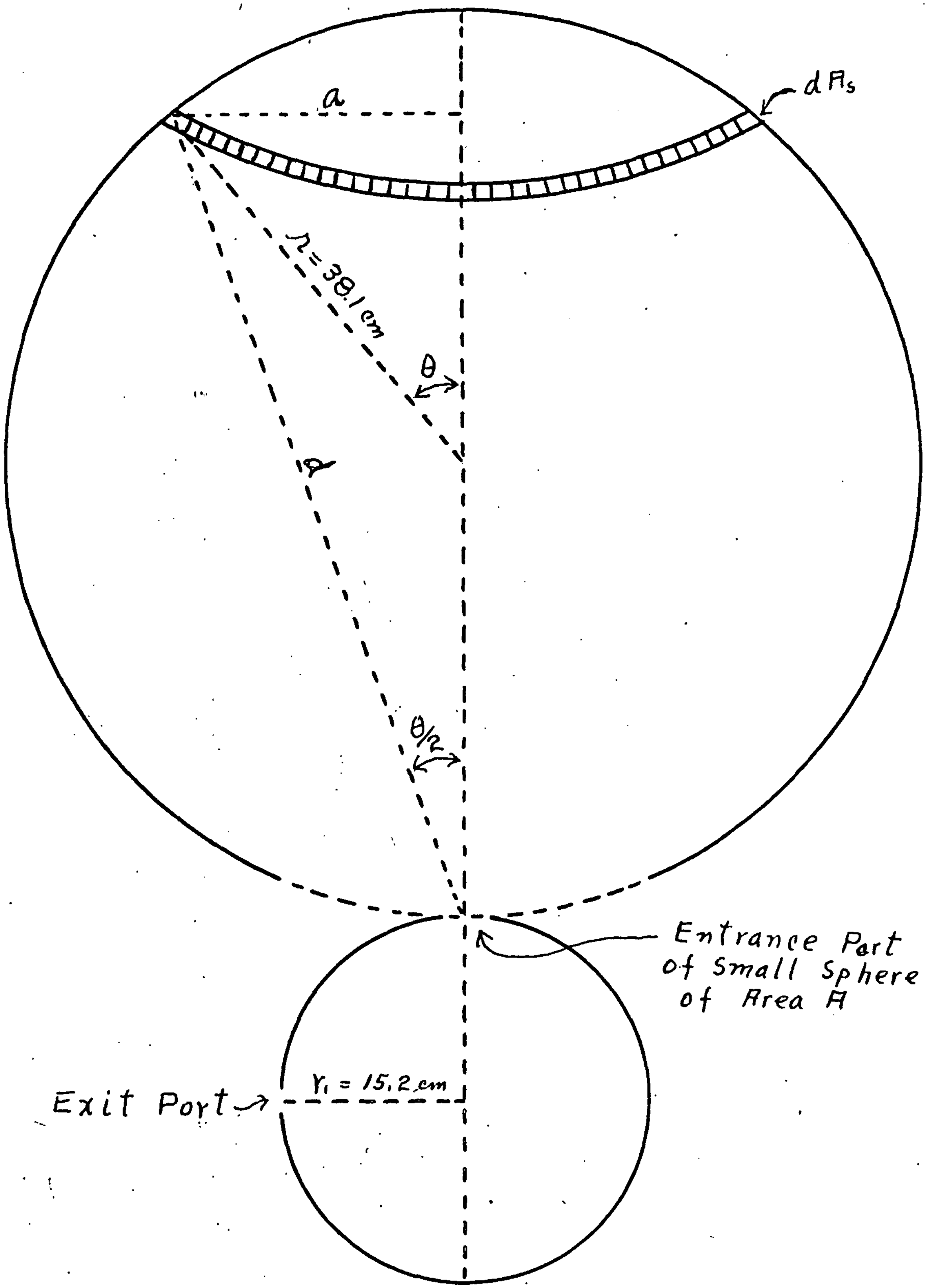


Figure 3. Cross Section of Large and Small Spheres Showing Data Used to Derive Equations 2 and 3.

$$dP_{s\lambda} = A\ dW_{s\lambda} = \frac{F_{s\lambda}}{\pi} \times \frac{2\pi r^2 \sin\theta\ d\theta \cos^2 1/2\ \theta\ A}{4r^2 \cos^2 1/2\ \theta} .$$

Upon simplification this becomes $dP_{s\lambda} = 1/2\ F_{s\lambda}\ A \sin\theta\ d\theta$. Thus the spectral radiant power at the port of the thirty inch integrator and hence at the entrance port of the small sphere is

$$P_{s\lambda} = 1/2\ F_{s\lambda} A \int_o^\theta \sin\theta\ d\theta = 1/2\ F_{s\lambda}\ A(1 - \cos\theta). \quad (2)$$

Since θ varies essentially from 0^o to 156.4^o because of the size of the port and the relative positions of the ports of the two spheres equation (2) becomes

$$P_{s\lambda} = W_{s\lambda}\ A = .958\ F_{s\lambda}\ A \text{ watts/micron} \quad (3)$$

This diffuse flux from the thirty inch integrator was integrated by the small sphere so that the radiant emittance at the exit port of the small sphere is given by equation (1) as

$$W'_{s\lambda} = \frac{W_{s\lambda} A}{4\pi r_1^2} \times \frac{\rho_\lambda}{1-\rho_\lambda} \quad (4)$$

where r_1 is the radius of the small sphere and ρ_λ is the spectral reflectance of the sphere paint. This flux was viewed by the monochromator. The resulting recorder deflection $D_{sa\lambda}$ was proportional to the integrated flux $W'_{s\lambda}$ and hence to the spectral radiant emittance $W_{s\lambda}$ of the thirty inch integrator.

On the other hand when the small sphere, mounted on the monochromator, receives flux from the standard lamp, it comes from approximately a point source. Let $J_{1\lambda}$ watts/steradian/micron be the spectral radiant intensity of the standard quartz-iodine lamp. Then the spectral irradiance per unit area at the port of the small sphere due to the standard lamp is given by

$$H_{1\lambda} = CJ_{1\lambda}/r^2 \quad \text{watts/cm}^2\text{/micron.} \tag{5}$$

where r is the distance from the lamp to the entrance port and C is a correction factor to correct for inverse square failure (Reference 2). The spectral radiant power received by the small sphere from the standard lamp is given by

$$P_{1\lambda} = H_{1\lambda} A \quad \text{watts/micron} \tag{6}$$

where A is the area of the entrance port of the small sphere.

As mentioned previously, the flux received by the small sphere from the thirty inch integrator is diffuse radiation. The flux from the standard lamp, however, comes from approximately a point source and falls on a relatively small area of the inside of the small sphere after which it is diffusely reflected. Thus the flux from the standard lamp only becomes comparable to the diffuse radiation received from the thirty inch integrator after it has undergone a single diffuse reflection. Hence the effective radiant power from the standard lamp which will be integrated by the small sphere is obtained by multiplying equation (6) by the spectral reflectance of the sphere paint ρ_λ so that

$$P_1' = \rho_\lambda \times H_{1\lambda} A \text{ watts/micron.} \tag{7}$$

This effective flux was integrated by the small sphere. Hence the spectral radiant emittance at the exit port of the small sphere which is viewed by the monochromator is found by equation (1) to be

$$W_{1\lambda} = \frac{\rho_\lambda \times H_{1\lambda} A}{4\pi r_1^2} \times \frac{\rho_\lambda}{1-\rho_\lambda} \text{ watts/cm}^2\text{/micron} \tag{8}$$

where r_1 is the radius of the small sphere. The corresponding recorder deflection $D_{1a\lambda}$ was proportional to the emittance $W_{1\lambda}$ and thus to the effective flux $\rho_\lambda \times H_{1\lambda}$ received from the lamp after a single diffuse reflection.

It is therefore possible to compare the spectral radiant emittance which the small sphere received from the thirty inch integrator with the spectral intensity from the standard lamp after a single diffuse reflection in terms of the corresponding deflections of the record as seen by dividing equation (4) by equation (8), or

$$\frac{W'_{s\lambda}}{W_{1\lambda}} = \frac{\dfrac{W_{s\lambda} A}{4\pi\lambda_1^2} \times \dfrac{\rho_\lambda}{1-\rho_\lambda}}{\dfrac{\rho_\lambda H_{1\lambda} A}{4\pi\lambda_1^2} \times \dfrac{\rho_\lambda}{1-\rho_\lambda}} = \frac{W_{s\lambda}}{\rho_\lambda H_{1\lambda}} \tag{9}$$

As stated before, the monochromator deflections are proportional to the intensity of the flux seen by the monochromator if the gain and the slit width are held constant. Hence the absolute ratio of the recorder deflections is equal to the ratio given by equation (9), or

$$k_{a\lambda} = D_{sa\lambda}/D_{la\lambda} = W'_{s\lambda}/W_{l\lambda} = W_{s\lambda}/\rho_\lambda H_{l\lambda}.$$

Thus one obtains

$$W_{s\lambda} = \rho_\lambda \; H_{l\lambda} \; D_{sa\lambda}/D_{la\lambda} \text{ watts/m}^2\text{/micron.} \tag{10}$$

for the spectral radiant emittance of the thirty inch integrator.

Using equation (10) the diffuse spectral emittance of the thirty inch integrator was determined every tenth of a micron or less from 0.32 to 2.7 microns for each standard lamp separately. The resulting data in the case of standard lamp EPI-1155 is given in Table 2. The wavelength is in microns. The second column gives the spectral irradiance of the standard lamp EPI-1155 at 17.7 cm (in milliwatts/cm^2/micron). The third column gives the spectral radiance after a single reflection by the small sphere. The fourth column gives the absolute ratios of the recorder deflections. The fifth column gives the diffuse spectral radiant emittance of the thirty inch integrator when twelve lamps are operating. Table 3 gives the mean spectral radiant emittance of the integrator as determined by means of the standard lamps EPI-1154, and EPI-1155. Figure 3 shows the spectral distribution of the thirty inch integrator at the port as determined by the use of the standard lamps, as well as points on the Johnson curve.

Table 2

SPECTRAL RADIANT EMITTANCE OF SPHERICAL INTEGRATOR BY USE OF LAMP EPI-1155

λ	H_λ	$\rho_\lambda H_\lambda$	$D_{s\lambda a}/D_{1\lambda a}$	$W_{s\lambda}$
.32	2.613	2.509	.4006	1.005
.35	5.927	5.702	.5626	3.208
.37	9.145	8.816	.6178	5.446
.40	15.882	15.104	.7376	11.14
.45	35.04	33.46	.7561	25.30
.50	58.03	55.94	.8281	46.33
.55	84.00	80.64	.8808	71.04
.60	109.4	105.3	.9145	96.26
.65	137.8	132.4	.9373	124.1
.70	160.1	154.0	.9550	147.1
.75	178.2	171.1	.9730	166.4
.80	191.8	184.2	1.026	189.0
.90	199.3	191.3	1.182	226.1
1.00	194.4	186.7	1.072	200.0
1.1	178.3	171.0	1.023	175.0
1.2	164.4	156.7	1.004	157.3
1.3	148.9	141.5	.9817	138.9
1.4	132.8	125.2	.9091	113.8
1.5	117.4	108.7	.7852	85.37
1.6	103.0	95.16	.8010	76.22
1.7	89.26	82.21	.8140	66.92
1.8	77.16	70.37	.7509	52.85
1.9	66.69	59.56	.7097	42.27
2.0	57.95	50.76	.4784	24.29
2.1	50.23	43.15	.5029	21.70
2.2	44.20	38.30	.5101	19.54
2.3	39.33	33.55	.4978	16.70
2.4	35.74	30.38	.4008	12.18
2.5	32.75	27.05	.3274	8.856
2.6	26.90	21.58	.2886	6.228
2.7	23.77	17.28	.2058	3.556

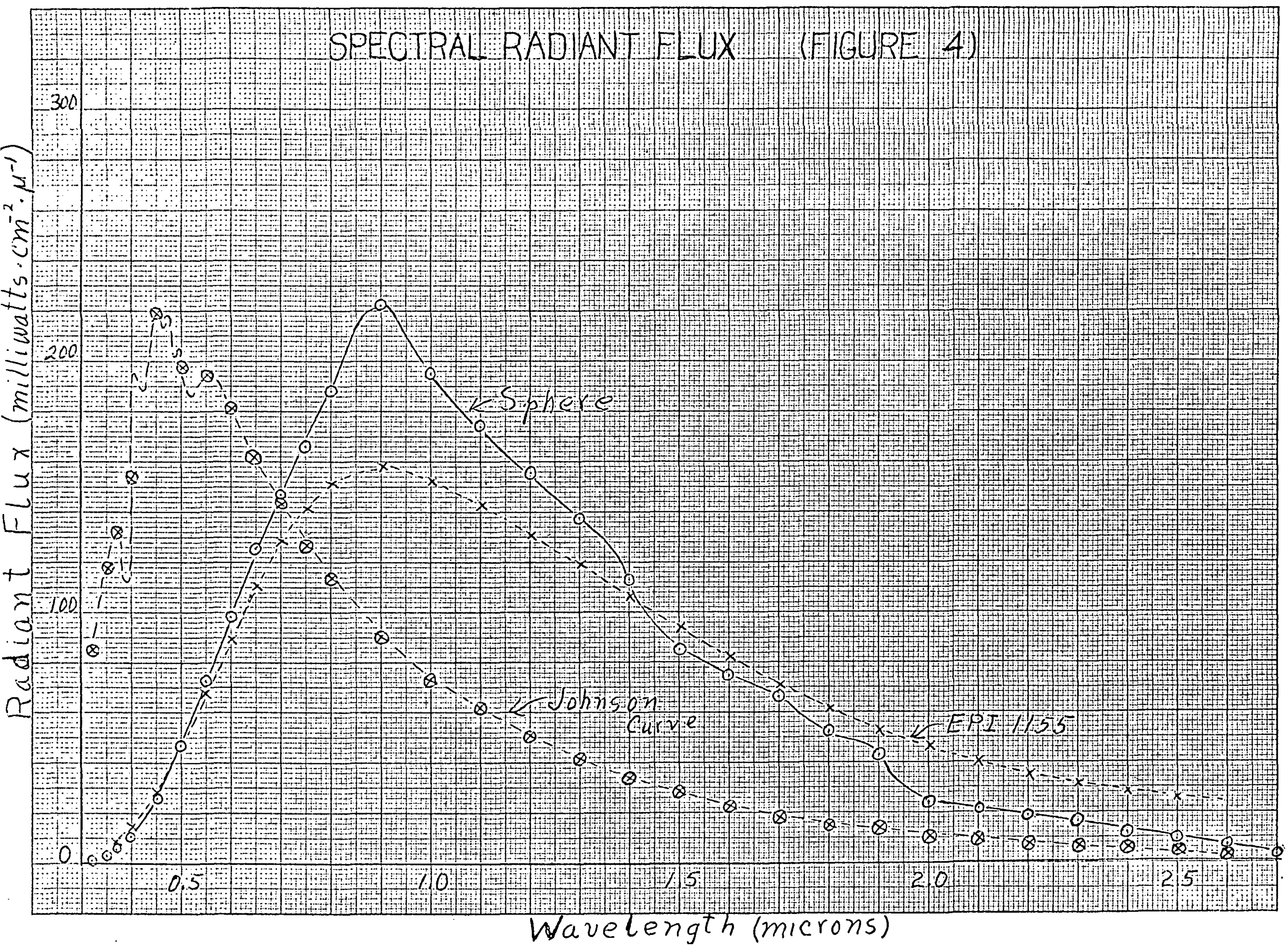
Table 3
SPECTRAL RADIANT EMITTANCE OF
THIRTY-INCH SPHERICAL INTEGRATOR

(λ in microns; W_λ in milliwatts cm^{-2} μ^{-1}; W'_λ in watts m^{-2} μ^{-1} sr^{-1})

λ	W_λ	W'_λ	λ	W_λ	W'_λ
			1.1	173.9	553.5
.32	.920	2.92	1.2	155.2	494.0
.35	2.989	9.51	1.3	136.8	435.4
.37	5.056	16.09	1.4	112.8	359.1
.40	10.49	33.39	1.5	84.51	269.0
.45	25.53	81.26	1.6	75.25	239.5
.50	46.83	149.1	1.7	65.72	209.2
.55	71.65	228.1	1.8	51.90	165.2
.60	97.99	311.9	1.9	41.78	133.0
.65	124.6	396.6	2.0	23.82	75.82
.70	146.6	466.7	2.1	21.35	67.96
.75	165.9	528.0	2.2	19.21	61.15
.80	187.5	596.7	2.3	16.44	52.33
.90	221.6	705.5	2.4	12.10	38.52
1.00	194.6	619.3	2.5	8.820	28.07
			2.6	6.234	19.84
			2.7	3.625	11.54

Table 4
RATIO OF INTENSITY OF N LAMPS TO
12 LAMPS IN SPHERICAL INTEGRATOR

No. of Lamps	$W_{\lambda_n}/W_{\lambda_{12}}$
12	1.0000
11	.9183
10	.8350
9	.7513
8	.6684
7	.5840
6	.5014
5	.4184
4	.3364
3	.2507
2	.1663
1	.0837


SPECTRAL RADIANT FLUX (FIGURE 4)
Radiant Flux (milliwatts·cm⁻²·μ⁻¹)
300
200
100
0
0.5
1.0
1.5
2.0
2.5
Wavelength (microns)
Sphere
Johnson Curve
EPI 1155

INTEGRATOR EMITTANCE VERSUS NUMBER OF LAMPS

In order to use the spherical integrator to calibrate radiometers it is necessary to vary the magnitude of the spectral radiant emittance. To permit such a change in intensity the "source" consists of twelve 45 watt quartz-halogen lamps operating at 6.5 amperes. As stated above, the circuit design permits one to turn on or off any one of the lamps independently. Thus any number of lamps from one to twelve may be used as the source in the integrator.

In order to determine the emittance versus number of lamps, the slit of the monochromator was positioned about 40 cm from the port of the spherical integrator. The monochromator was set for the fixed wavelength 1.2 micron, which is the wavelength at which the thermocouple gave the greatest recorder deflection when the flux came from the quartz-halogen lamp. The slit width and the amplifier gain were the smallest possible in order to have good resolution and low noise and still obtain approximately full scale deflection when 12 lamps were operating in the sphere. This deflection was recorded. Then the lamps were turned off one at a time in order from No. 12, 11, 10, etc. until only lamp No. 1 was operating. The recorder deflection was recorded in each case. This procedure was repeated three times and the average evaluated.

The ratio of the intensity of the integrator emittance versus number of lamps was obtained by dividing the deflection for N lamps by the deflection for 12 lamps. The mean of the ratios for the three trials is given in Table 4. The spectral radiant emittance for ten lamps may be obtained by multiplying the spectral radiant emittance for twelve lamps by the ratio of the intensity of ten lamps to that of twelve lamps and similarly for any number of lamps from one to eleven.

ANALYSIS OF RESULTS

An examination of the spectral curves in Figure 4 reveals several significant facts. First, it will be observed that the peak value of the integrator emittance is 1.41 times the peak value of the irradiance of the standard lamp at 20 cm. Secondly, the maximum intensity of the integrator emittance is located at approximately 0.90μ for the sphere as well as the lamp. Thirdly, for those wavelengths for which the reflectance of the sphere paint is high, the sphere amplifies the emitted power, while for the wavelengths for which the reflectance is low, the emitted power of the sphere is less than that of the source.

A comparison of the spectral distribution of the integrator emittance as determined by the two standard lamps shows that the results are reasonably consistent. The greatest difference at a given wavelength between the two sets of data is usually less than three percent except in the ultraviolet where it is about 15%. The variation between the data for several trials with the same lamp was two percent or less for the absolute calibration data and three percent or less for the relative calibration data. The National Bureau of Standards reports that the calibration of the standard lamps has an uncertainty of 8% in the ultraviolet and one of 3% in the visible and the infrared (Reference 12). The data for the calibration of the sphere which was obtained by the use of the two standard lamps differ by the same order of magnitude.

There are a number of possible sources of error. First, there is some uncertainty in the reflectance of the sphere paint. The recording on the chart may be read to within 0.5%. In reversing the two samples of freshly smoked MgO in the Cary 14 spectrophotometer while determining the reflectance of the sphere paint, the difference in reflectance was found to be less than 0.5% at most points. The data for the reflectance of MgO which has been reported by various observers differ somewhat. It seems to depend on the nature of the surface, the thickness of the layer and the age. Thus the uncertainty in the reflectance of the MgO standard is probably less than 1% in the spectral range where the quartz-Halogen lamp is most intense, while in the near infrared this uncertainty may be as high as 5%.

Secondly, there is a variation in the voltage across the 45 watt lamp in the integrator. This variation has been found to be 1% or less. This would represent a variation in the flux of the lamps and hence of the sphere of about two percent.

Among other sources of error may be mentioned the monochromator slit which may be set within 0.2%. The chart which records the magnitude of the flux at various wavelengths can be read within 0.5%. It has been observed that there may be a decrease in the 0.1 microvolt test signal as shown by the corresponding recorder deflections at the beginning and the end of a run. This change was usually less than 1% when sufficient time was allowed to warm up and stabilize the amplifier and recorder electronics.

The data obtained for the spectral distribution of the sphere and of the standard lamps may vary by a similar percentage. Since the two lamps were used independently and since the differences in the resulting data show some random variation, some of these errors may compensate each other. Thus the overall uncertainty of the data may be of the order of 5% or less. This is more or less the same as the difference between the values of the integrator emittance as obtained by means of the two standard lamps.

ANGULAR DEPENDENCE OF THE RADIANT EMITTANCE OF THE SPHERICAL INTEGRATOR

The MSS has a rocking mirror rotating through 5.9° toward either side of its mean position while scanning the earth. For this reason the radiant emittance of the spherical integrator, which is used as an extended source to calibrate the MSS, ought to be independent of the viewing angle at least within this range of 5.9°. In order to check on the angular dependence, the axis of the Perkin-Elmer monochromator was rotated toward either side of the normal to the port by this amount. When using a thermocouple detector to determine the intensity of the radiation passed by the monochromator in a narrow band at 1.2 microns, the total variation with angle was about 1.25%. Using a 1P28 photomultiplier at a wavelength setting of 0.55 microns the variation with angle was approximately 1.6%. These variations are within probable experimental error. It may be assumed that the radiant emittance of the integrator is independent of angle in the case of the small angular variation of the field of view of the MSS.

CONCLUSIONS

It would seem that the present arrangement of the thirty inch spherical integrator provides a satisfactory extended source for the calibration of detectors in the visible and near infrared. The uncertainty of the calibration is estimated to be at most five percent.

ACKNOWLEDGEMENTS

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TABLES

FIGURES

ADDENDUM

Calibration of the Leiss Double Monochromator

A Research Report on Grant NGR 21-023-001, Supplement No. 1, "Relative Spectral Response of Photodetectors" was submitted in August 1969. The report describes the set-up designed to measure relative spectral response. In this set-up, a Leiss Double Monochromator, borrowed for temporary use from Mr. Charles Duncan, Code 762.4, was used to obtain radiation in a narrow spectral band.

Meanwhile a Leiss Double Monochromator, complete with ultrasil, rock salt and potassium bromide prisms was purchased by the Earth Observations Branch, GSFC, Code 652, for use with this set-up. It was necessary, therefore, to calibrate the three new prisms. This was done by using the procedure reported in the above-mentioned report of August 1969.

Recalibration of the Six Foot Integrating Sphere

The six foot integrating sphere of the Earth Observations Branch, GSFC, Code 652, was calibrated four years ago (Summer of 1967). This was reported in Document X-622-69-195, dated May 1969. Due to the probable change in the reflectance of the sphere paint, it was highly desirable to recalibrate the sphere.

Upon examination it was found that the sphere paint was in good condition while some of the twelve lamps had become somewhat black on the inside of the envelope. For this reason all twelve lamps were replaced by new 200 W quartz-halogen lamps.

The procedure used to calibrate the six foot sphere was the same as that which was used to calibrate the 30-inch sphere and described in the foregoing pages. The calibration for the six foot sphere is given on the next sheet.

A comparison of the new data for the spectral radiant emittance of the sphere with previous values reveals several changes: (a) The maximum emission which occurred at 0.8 microns, now occurs at 0.9 microns, the present value being about 0.6% higher. (b) In the UV and visible the present calibration is lower than previously; and (c) in the infrared the present calibration is higher than it was before. The decrease in the UV may be due to a decrease in the reflectance of the Burch sphere paint during the four years since it was last calibrated. At present there is no explanation for the increase in the infrared part of the spectrum.

SPECTRAL RADIANT EMITTANCE OF SIX-FOOT SPHERICAL INTEGRATOR

(λ in microns; W_λ in milliwatts cm^{-2} μ^{-1}; W'_λ in watts m^{-2} μ^{-1} sr^{-1})

λ	W_λ	W'_λ	λ	W_λ	W'_λ
			1.1	186.7	594.2
.32	.1458	.4641	1.2	148.2	471.7
.35	.6658	2.119	1.3	122.7	390.6
.37	1.535	4.886	1.4	88.80	282.7
.40	4.304	13.70	1.5	43.92	139.8
.45	14.04	44.69	1.6	40.72	129.6
.50	34.88	111.0	1.7	33.31	106.0
.55	66.73	212.4	1.8	20.66	65.77
.60	105.6	336.2	1.9	14.15	45.05
.65	146.8	467.4	2.0	6.624	21.08
.70	183.5	584.0	2.1	5.963	18.98
.75	211.1	672.1	2.2	5.116	16.28
.80	238.7	759.9	2.3	3.124	9.944
.90	264.6	842.4	2.4	1.928	6.137
1.00	213.2	678.6	2.5	1.282	4.081
			2.6	.7489	2.384
			2.7	.4308	1.371

RATIO OF INTENSITY OF N LAMPS TO 12 LAMPS IN SPHERICAL INTEGRATOR

No. of Lamps	$W_{\lambda_n}/W_{\lambda_{12}}$
12	1.0000
11	.9149
10	.8286
9	.7481
8	.6626
7	.5817
6	.4986
5	.4138
4	.3301
3	.2463
2	.1640
1	.08176