Devices & Services Co.

D&S TECHNICAL NOTE 82-1

SOLAR SPECTRUM REFLECTOMETER UPDATES AND DESIGN MODIFICATIONS

ABSTRACT

A modification to the design of the SSR measurement head is described that improves the accuracy of measurements on specular materials and allows measurement of second surface reflectors up to 0.25 inches thick. The modification provides more uniform illumination of the sample in the specular direction, and minimizes clipping of the specular reflection from a second surface mirror by the edges of the measurement port. In addition to these design modifications, detector weightings have been calculated for an Air Mass zero measurement spectrum.

INTRODUCTION

The D&S Model SSR Solar Spectrum Reflectometer provides a single measurement of hemispherical solar reflectance. A tungsten-halogen lamp illuminates the sample to be measured and reflected radiation is measured at an angle of 20 degrees. As shown in Figure 1, a collimator with baffles restricts the view of detectors to the 3/4" diameter sample port. The solar measurement spectrum is achieved by measuring the reflected radiation with four detectors covering different wavelength ranges and combining the outputs to produce a good fit to the solar spectrum. Gain adjustments for each detector allow the user to select the air mass, to fit other spectra or to measure reflectance for the individual detectors.

Rather than attempt to generate a collimated source and measure the radiation reflected into all directions, the sample is diffusely illuminated and the reflected radiation measured in a single direction. A reciprocity relationship between directional-hemispherical and hemispherical-directional reflectance requires that these two reflectance values be equal if the hemispherical source is uniform in all directions (diffuse). As a practical matter, a diffuse source can only be approximated. For example, the presence of the collimator in the SSR measurement head unavoidably decreases the light intensity from that direction.

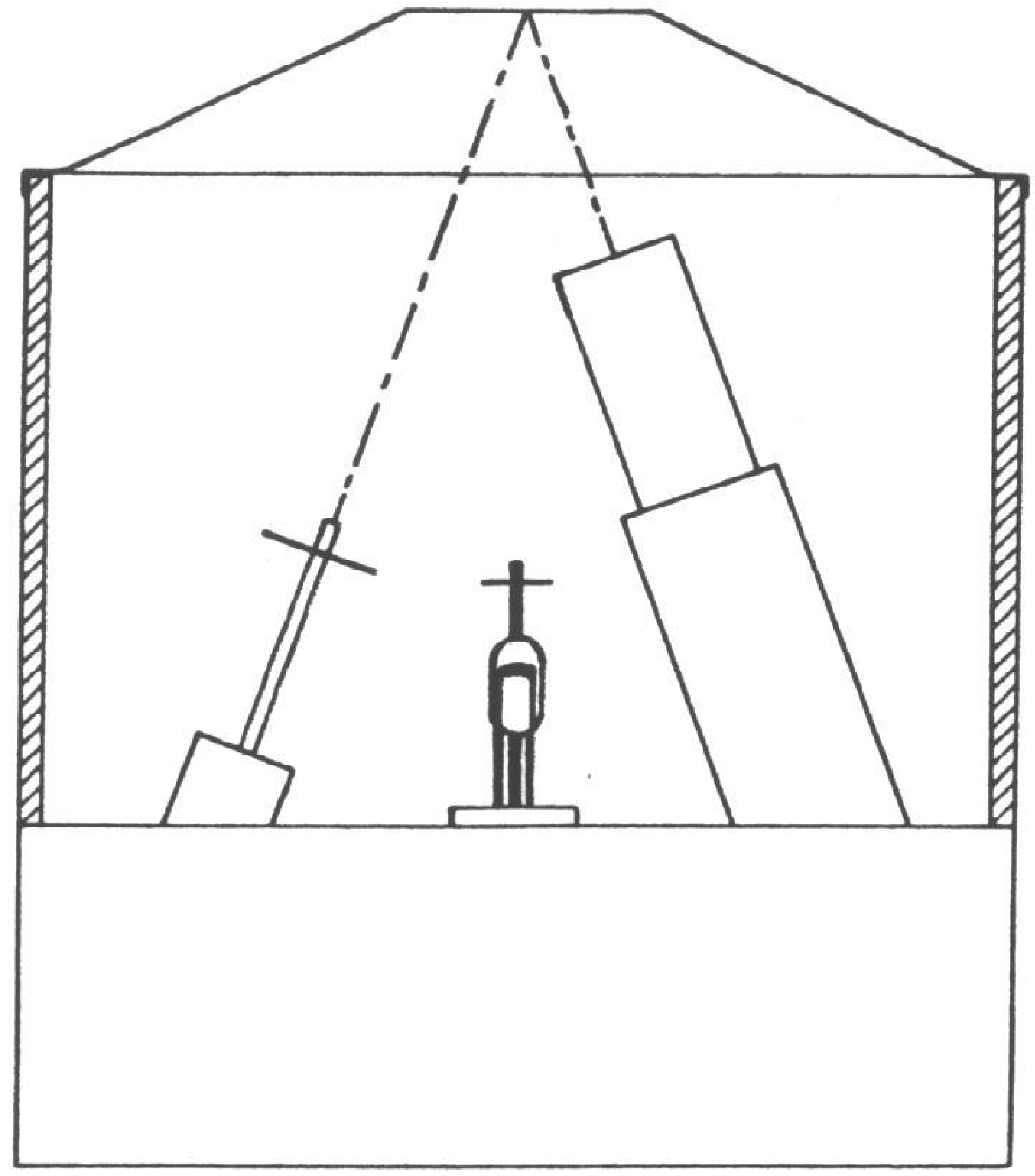


Figure 1. Original Configuration of SSR Measurement Head

In the original instrument design, two additional features were added to decrease errors due to nonuniform illumination. One was a shade directly between the lamp and the port to prevent direct illumination of the sample, and the other was an adjustable target located in the area of the chamber from which the specular component of reflection originates (Figure 1). By moving this target up and down, it is possible to adjust the relative amount of light intensity in the specular direction compared to the average intensity striking the port. Making this adjustment, the SSR reads reflectance accurately for both specular and diffuse materials. Because most materials exhibit primarily specular and diffuse components of reflection, only minor errors result from the nonideal illumination once the target is properly set (see D&S Technical Note 79-16).

SSR DESIGN MODIFICATIONS

This method of adjustment works well for flat diffuse materials, first surface mirrors and very thin second surface reflectors. For thick second surface reflectors, some difficulties with this configuration were encountered (Alan R. Mahoney, "Solar Hemispherical Reflectometer Modification for Second Surface Mirror Measurements," Sandia Report SAND82-0934, May 1982). Figure 2 illustrates the path of reflected light for a specular second surface reflector. It was found that, due to the shifting of the reflected beam, a portion of the second surface is shaded by the edge of the port. The intensity coming from the specular direction also changes because the specular reflection comes from a slightly different portion of the chamber. In addition, due to the small size of the target, each of the four detectors was affected to a different degree since the area of view is not identical. The first of these difficulties, shading of the sample, prohibits measurement of thick second surface mirrors without making large corrections that would vary from one instrument to another. The nonuniformity of illumination in the specular direction causes small discrepancies between diffuse, first surface specular and second surface reflectors.

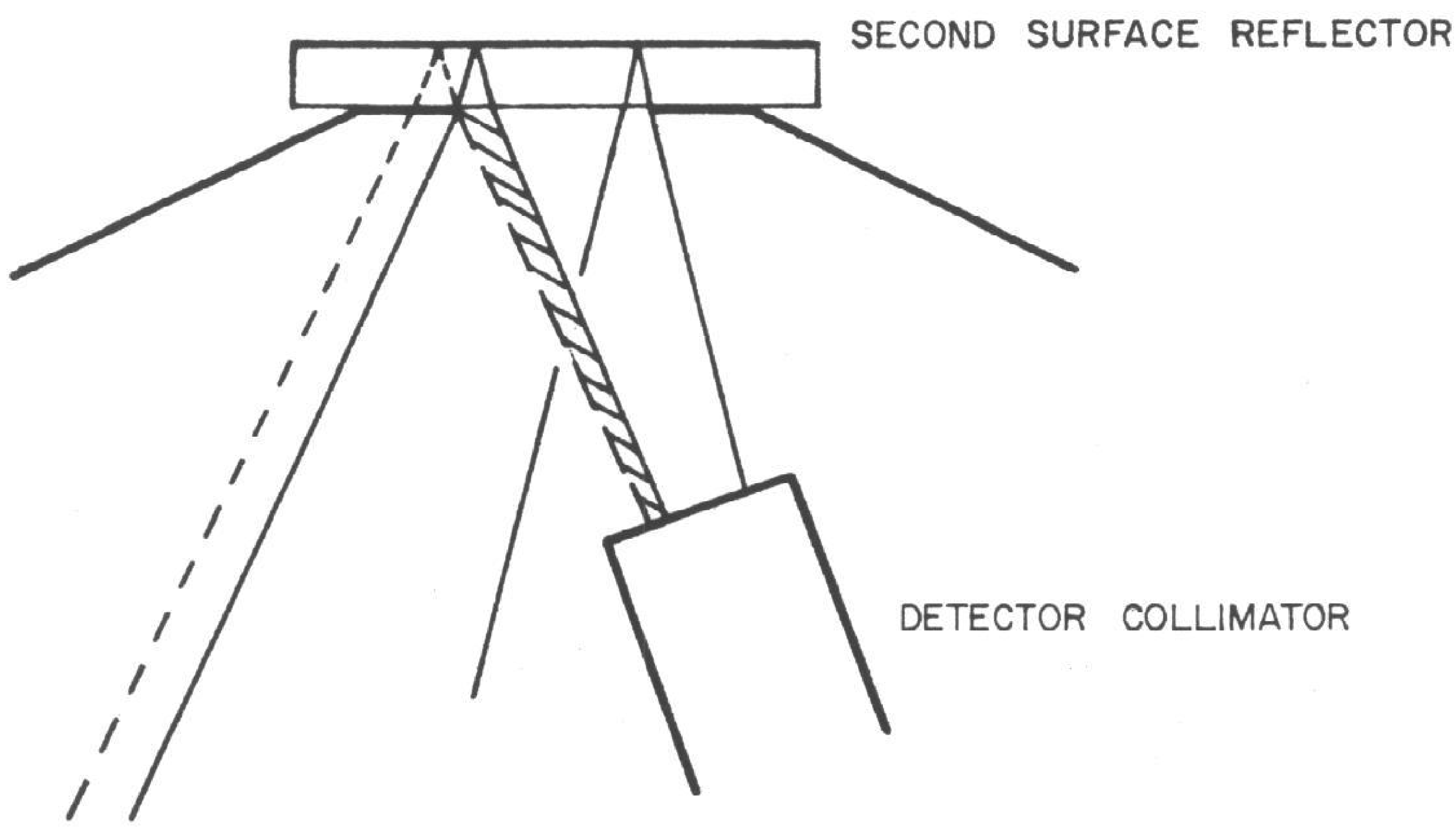


Figure 2. Shading of Second Surface Mirror by Measurement Port

The above referenced Sandia Report describes modifications to the SSR that minimize errors for second surface reflectors. First, the size of the measurement port was increased to 1.16" to eliminate the sample shading. In addition, the target size was increased to encompass the majority of the detector view in the specular direction and a diffuser was placed over the lamp to ensure that the enlarged target was illuminated uniformly. These changes allow the SSR to be used for second surface reflectors up to 0.250" thick.

As a result of this work and some additional experimentation, we have developed a design modification that allows the use of the reflectometer to measure second surface mirrors (up to 0.25") and that improves the accuracy of measurement on specular materials. The new configuration is shown in Figure 3. The port size has been increased to 1.0" diameter and the collimator has been moved off center to prevent shading for second surface reflectors. The target has been eliminated and the shade is now mounted on the lamp assembly. The intensity in the specular direction is adjusted by moving the entire lamp assembly up or down. Moving the lamp up decreases the relative intensity in the specular direction. By removing the target, the detectors now view (in the specular direction) a large uniformly illuminated area on the back of the wall.

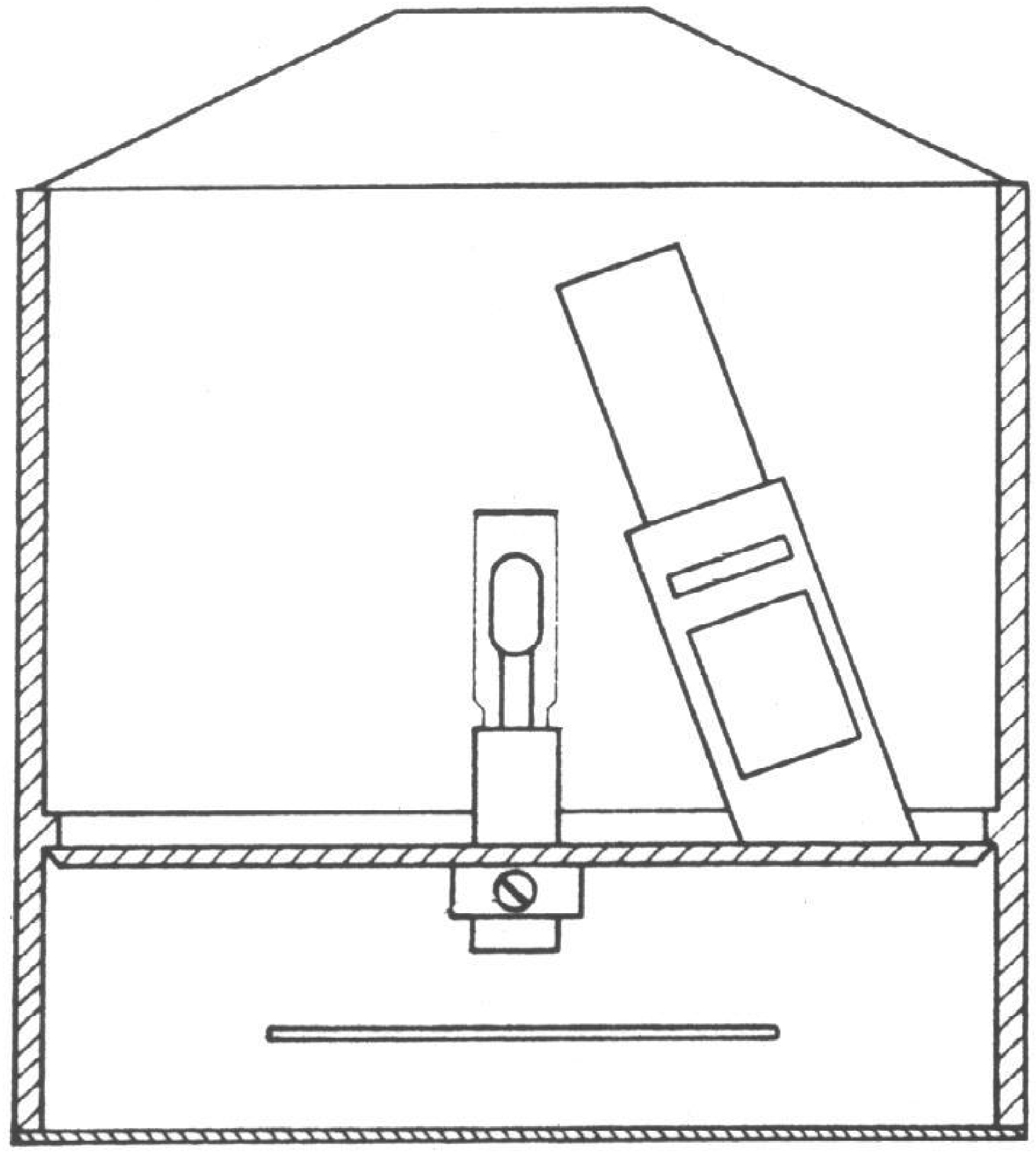


Figure 3. Design Modifications to Measurement Head

TEST MEASUREMENTS

To check the design modifications, two tests were devised. One, using both a diffuse and a specular NBS reflectance standard, consists of measuring the ratio of reflectance values for the two materials for each of the four detectors. The lamp adjustment was made so that the reflectance ratio was correct for the "red" detector. If the light coming from the specular direction is uniform over the required area, the ratios for the other detectors should be close to the calculated values. The second test consists of measuring the reflectance of a highly specular first surface reflector for each of the four detectors and then to approximate the effect of a thick second surface mirror, repeating the measurements with the mirror displaced from the port by "t/n" (t – thickness, n – index of refraction) as illustrated in Figure 4. Ideally, if the test material were perfectly specular, the readings should be unaffected since the light source should be perfectly uniform.

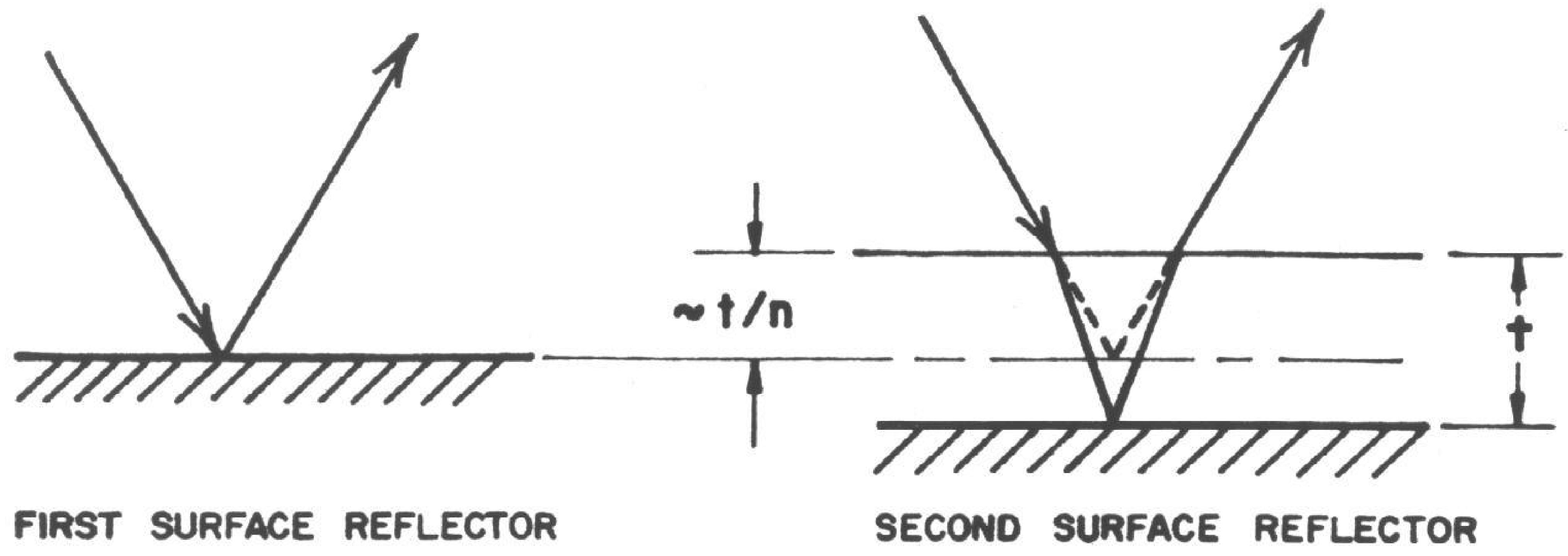


Figure 4.

Reflectance data for the NBS standards is given in Table 1. These values were calculated by integrating the reflectance as a function of wavelength over the spectral distribution for each detector. For the specular standard, the reflectance reported by the NBS is specular reflectance rather than hemispherical. For these measurements, the specular standard was assumed to be perfectly specular.

Table 1. Calculated Reflectance Values for NBS Standards

Standard	Description	IR	Red	Blue	UV	AM2*
2023	Specular, thin second surface	0.937	0.848	0.881	0.890	0.884
2019	Diffuse	0.864	0.845	0.788	0.636	0.833

* Air Mass 2 Measurement Spectrum

Table 2 lists the results of the measurements on the two materials. Notice that the measured and calculated reflectance ratios agree perfectly for the red detector because the red detector was used to set the lamp height.

Table 2. Reflectance Ratios for the NBS Standards

R2019/R2023	IR	Red	Blue	UV
Calculated	0.922	0.996	0.894	0.715
Measured	0.903	0.996	0.897	0.74
% Error	2%	-	0.3%	3.5%

The close agreement between measured and calculated reflectance ratios for the diffuse and specular standards verifies that each detector views essentially the same incident intensity in the specular direction.

For the second surface mirror test, a first surface aluminum mirror was used. Detector readings were taken with the sample against the port and with the sample at two distances X,

$$X = 0.125''/(1.5) = 0.084''$$
$$X = 0.25''/(1.5) = 0.167''$$

corresponding to 1/8" and 1/4" thick mirrors. The results are given in Table 3.

Table 3. Variation in Detector Readings with Displacement from the Port

	IR	Red	Blue	UV
X = 0	0.285	0.405	0.209	0.083
X = 0.084"	0.284	0.404	0.205	0.083
X = 0.167"	0.282	0.403	0.203	0.082
Error (X=0.167")	-1%	-.5%	-3%	-1%

A small decrease in output was observed for each detector, although the decrease is not perfectly uniform. Still the error is small enough so that a single correction for a second surface mirror can be estimated from this data. This ignores the reflection from the first surface of a second surface mirror and the loss of some of the multiple reflections inside the transparent material.

Averaged over the air mass 0, 1 or 2 measurement spectrum, the error is approximately −1% for a 0.25" thick glass. Corrections at other thicknesses, up to 0.25", can be estimated assuming a linear relationship between the thickness and the correction. The correction will probably vary from one reflectometer to another due to minor differences in the measurement heads.

SUBSTITUTION ERROR

A silicon cell, viewing the inside wall of the measurement head, controls the lamp current. The purpose of this control is to minimize the substitution error (see D&S Technical Note 79-16).

The error arises because the presence of a sample on the port affects the overall amount of light inside the head. By controlling the intensity of the lamp, this error is minimized. The correction is not exact, however, because changing the current in the lamp changes the filament temperature and thus shifts the weighting of the detectors.

By increasing the size of the measurement port, this error is increased. The shift in the weighting for the new configuration was determined by measuring the detector outputs at the two extremes of lamp intensity. The lamp current was measured with both the "black body" and a highly reflective barium sulfate material over the port, corresponding to the maximum and minimum current levels. The detector outputs were measured with the barium sulfate sample over the port at the normal current level. Then the current was adjusted to the higher level but with the reflective material over the port. The detector readings were taken again. Table 4 summarizes the results of this test.

Table 4. Detector Weightings at Maximum and Minimum Lamp Current

	IR	Red	Blue	UV
Minimum Current	0.294	0.444	0.209	0.027
Maximum Current	0.307	0.471	0.227	0.030

The maximum substition error occurs for a material that is perfectly reflective up to about 0.6 microns and absorbing beyond 0.6 microns. The silicon cell responds as if a black surface were over the port, increasing the lamp current. The actual reflectance (AM2) for the idealized surface described above is 29.6%. The measured reflectance will be approximately 27.2%. For most materials, the error is a small fraction of this amount.

CONCLUSIONS

1.) The proposed design modifications improve the accuracy of specular reflectance measurements and allow the instrument to be used with second surface reflectors up to 0.25" in thickness. A small correction is required for reflectance measurements of second surface reflectors.

2.) One specular and two diffuse secondary calibration standards are provided with the instrument. Calibration of these standards consists of direct comparison with the NBS standard material for each of the four detectors. The reflectance of the diffuse working standards will be determined against the diffuse NBS reflector (#2019) and the specular standard will be calibrated against the specular primary standard (#2023). Once the reflectance values are determined, the detector readings and total reflectance values for Air Mass 0, 1 and 2 are calculated and recorded.

Based on this data, which is provided on a reference card, set up of the instrument requires two steps.

1. Using one of the diffuse working standards (Figure 5), set the detector weightings for the desired measurement spectrum.

2. Set the switches to measure total reflectance (all detectors on) and then adjust the lamp height so that the ratio of total solar reflectance of the specular standard to that of the diffuse standard is correct.

CALIBRATION RECORD FOR WORKING STANDARDS
SSR serial no .... 19.....

	IR	Red	Blue	UV	Total
AIR MASS 2					
Ceramic #37	0.253	0.386	0.173	0.018	0.830
Ceramic #38	0.246	0.377	0.170	0.017	0.810
A1 #20	0.285	0.405	0.200	0.023	0.913
AIR MASS 1					
Ceramic #37	0.253	0.350	0.197	0.027	0.827
Ceramic #38	0.246	0.342	0.194	0.025	0.807
A1 #20	0.285	0.367	0.228	0.034	0.914
AIR MASS 0					
Ceramic #37	0.276	0.282	0.193	0.063	0.814
Ceramic #38	0.268	0.275	0.190	0.060	0.793
A1 #20	0.310	0.296	0.224	0.081	0.911
REFLECTANCE					
Ceramic #37	0.810	0.861	0.822	0.64	
Ceramic #38	0.787	0.841	0.808	0.61	
A1 #20	0.912	0.903	0.950	0.82	

Figure 5. Typical Reference Card Data

3.) Note that this adjustment achieves the best accuracy for total reflectance measurements of various materials. However, for a specular material, the detector weighting is slightly different than that reported on the reference card. If only specular materials were to be measured the weightings could be set with the specular standard, however there should be no significant differences in the measured reflectance values.

4.) If the SSR is to be used to measure reflectance of materials for any single detector, it is best to use the working standard most like the material to be measured (specular or diffuse) and use the reflectance data given on the reference card.

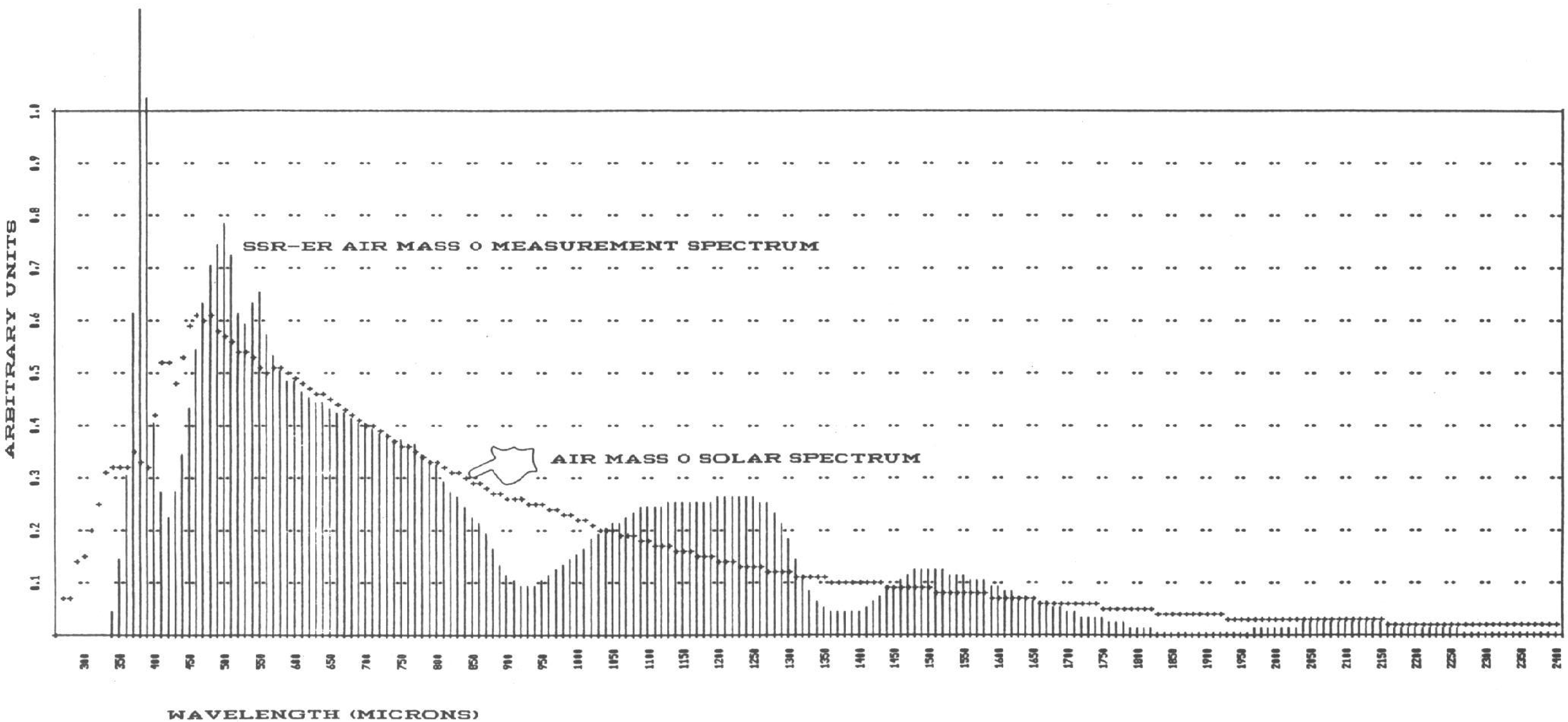
SSR UPDATE

The detector weighting to fit an Air Mass 0 distribution has been calculated. The weighting is given in Table 5 and plotted in Figure 6.

Table 5. Detector Weightings for Air Mass 0

IR	Red	Blue	UV	Total
0.341	0.328	0.236	0.095	1.000

FIGURE 6. COMPARISON OF AIR MASS ZERO SOLAR SPECTRUM AND SSR-ER MEASUREMENT SPECTRUM



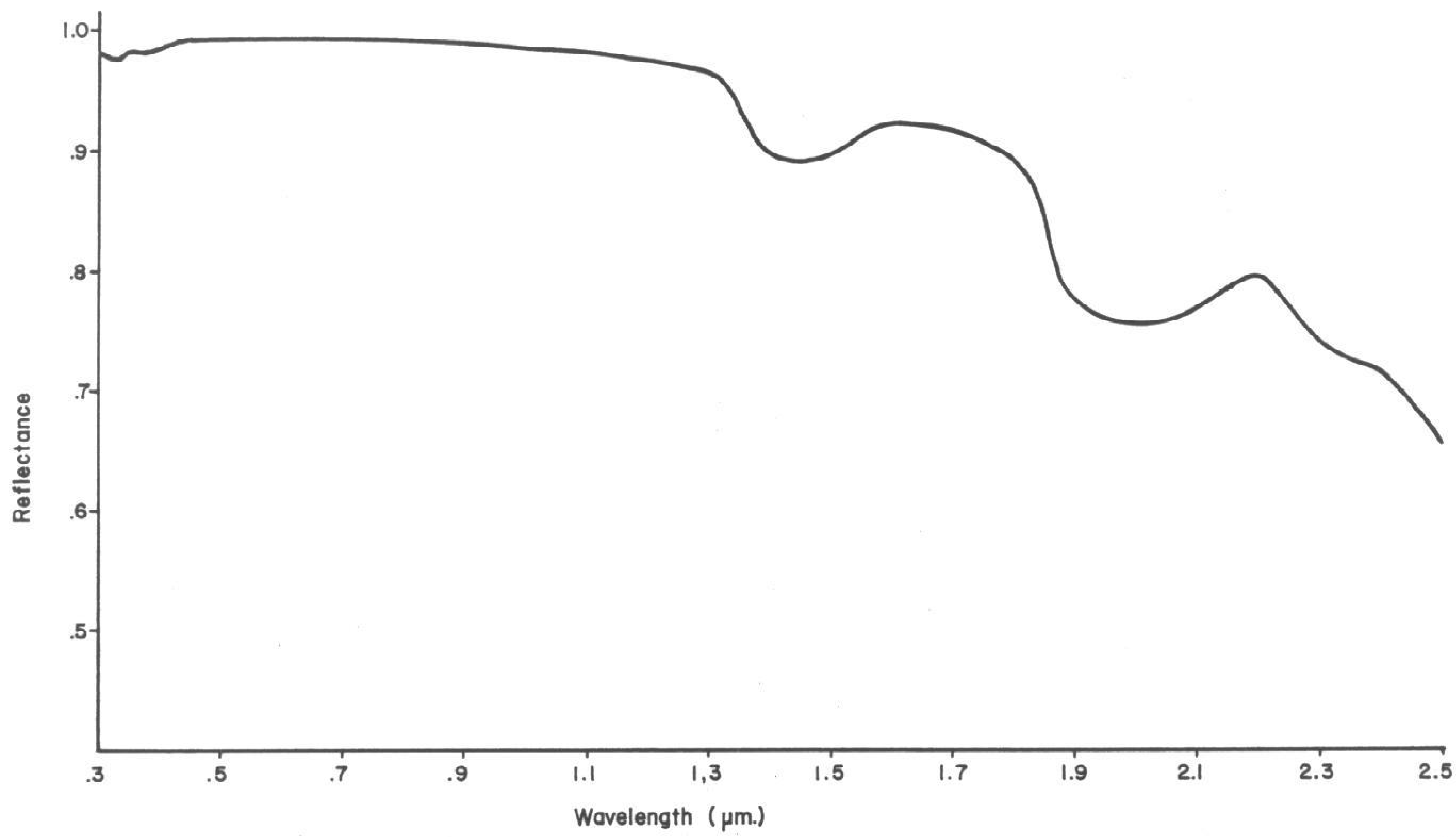


Figure 5. Spectral Reflectance of Barium Sulfate Standard

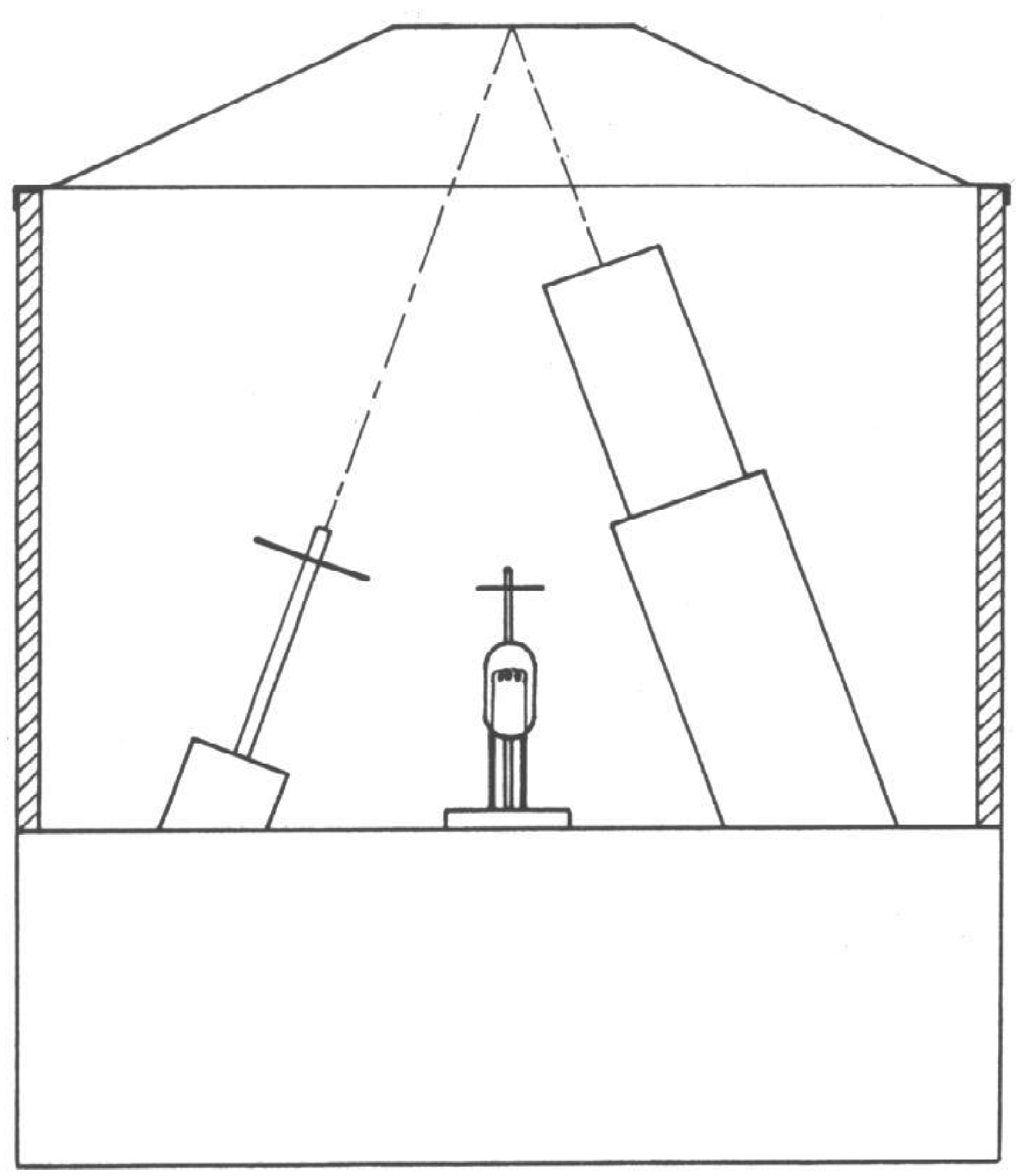


Figure 6. Cross Sectional View of Measurement Head