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COST EFFECTIVE ALTERNATIVE TO LOW IRRADIANCE MEASUREMENTS

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ABSTRACT:

Martin Marietta's Space Simulation Laboratory (SSL) has a Thermal Environment Simulator (TES) with 56 individually controlled heater zones. The TES has a temperature range of approximately -129°C to +149°C (-200°F to +300°F). Because of the ability of the TES to provide complex irradiance distributions, it is necessary to be able to measure a wide range of irradiance levels. SSL currently uses ambient temperature controlled radiometers with the capability to measure sink irradiance levels of approximately 42.6 mw/cm^2 (135 Btu's/ft^{2}hr), sink temperature =21°C (70°F), and up. These radiometers could not be used to accurately measure the lower irradiance levels of the TES, therefore it was necessary to obtain a radiometer or develop techniques which could be used to measure lower irradiance levels.

INTRODUCTION:

There are a number of low irradiance measurement devices available, but they are complicated and very expensive. An alternative was to use the existing radiometers by cooling them to liquid nitrogen (LN_2) temperatures and establishing a new output (mv) vs. irradiance mw/cm^2 (Btu/ft^{2}hr) curve. This was done by developing a black body source which could be used in the calibration process and a method for modeling the characteristics of the radiometer at LN_2 temperatures. A method for obtaining an output (mv) vs. irradiance (Btu/ft^{2}hr) calibration curve was established as well as a model of the radiometer's response to temperature fluctuations. The following information was obtained for each radiometer:

1.) An output vs. irradiance curve was generated with a maximum error of ±1.26mw/cm^2 (±4 Btu/ft^{2}hr) at the upper end of the irradiance curve(69.4mw/cm^2 (220 Btu/ft^{2}hr)) .
2.) A model of how each radiometer responds to temperature fluctuations at three fixed sink temperatures; -129°C, -20°C, 60°C (-200°F, -4°F, and 140°F).

The results demonstrate the ability to measure low irradiance levels with an acceptable error, and at a fraction of the cost of other low irradiance measurement devices.

TEST PLAN:

A test was developed to ascertain the ability of the radiometers to measure low irradiance levels.

The test had four primary objectives:

1.) Obtain the irradiance vs. output data for fourteen P-8400 and two P-8410 radiometers, at liquid nitrogen temperatures. The black body cells were cycled between -129°C and 60°C (-200°F and 140°F). Temperatures of the black body source, the radiometer, and the radiometer's mv signal data was collected to establish the new calibration curve for the liquid nitrogen cooled radiometers.

2.) Obtain data on the response of each radiometer to temperature fluctuations. The radiometer temperature was varied between -193°C and -162°C (145°R and 200°R) at three fixed black body cell temperatures, -129°C, -20°C and 60°C (-200°F, -4°F and 140°F). Due to the difficulty of maintaining the radiometer at a constant temperature during an actual test, this information could be used to adjust the data if necessary.

3.) Compare the black body calibrated radiometer to the vendor calibrated ambient temperature radiometer data to evaluate the quality of the black body source. It was necessary to control the black body calibrated radiometer at ambient temperature while cycling the black body source. The radiometer was maintained at 26.7°C ± 3°C (80°F ± 5°F) with GN_2, while the sink temperature was cycled between 24°C (75°F) and 93.5°C (200°F). The data obtained from this test compared favorably to the vendor's calibration data.

4.) Three cycles were run to demonstrate repeatability and to establish confidence in the test methods used to obtain the irradiance data. The data from these cycles compared favorably.

BLACK BODY SOURCE FIXTURE DESCRIPTION:

An ideal black body has a very simple relationship between temperature and radiated energy, $I=e(Sig)T^4$. The value of the emissivity (e) is 1, Sig is Stefan-Boltzmann's constant $0.57 \times 10^{-8} W/m^2.K (1.714 \times 10^{-7} (btu/ft^2 hr)/{}^\circ R^4)$, and T is the temperature of the black body source.

The black body source was built using a cylindrical body with a large length to diameter ratio. This inherently gives a high value for the emissivity. Individual cells were constructed of 0.635 cm (1/4") wall aluminum tube, 4.76 cm (1 7/8") inner diameter by 30.48 cm (12") long, (see figure #1 for sketch of black body cell). This gave the black body source a length to diameter ratio of approximately 6.4. The thickness of the tube allowed the heat being applied to the external surface of the cell to be distributed evenly on the internal radiating surface. The inside of the cells were painted with Cat-A-Lack-Black which has a published emissivity of 0.92.

This geometry inherently contibutes to a good temperature uniformity on the internal radiating surface. The walls in the cavity radiate energy to each other and therfore have a tendency to wash out any local temperature gradients on the inside of the cell.

The black body cells were mounted on a temperature controlled base plate. The base plate was used to add or remove heat from the bottom portion of the cell to reduce the temperature gradient from top to bottom of the cell. The resulting black body fixture consisted of 16 individually controlled black body cells and a temperature controlled base plate. The external fixture was painted black for effective heat radiation. Cells were individually controlled, using a Variac power supply, manually controlled. This was done to eliminate the use of contact relays which could introduce noise in the radiometer output signal.

Heaters were spiraled up the external portion of the cell with the heater tape laid edge to edge in such a way as to prevent overlapping (hot spots) or gapping (cold spots) of the heating element.

To minimize the error in the reading due to the gradient, the temperature sensors were imbedded in the body of the cell as close as possible to the internal radiating surface.

RADIOMETER INSTALLATION AND INSTRUMENTATION CALIBRATION:

A number of actions were taken to ensure proper radiometer installation:

1.) The radiometers had a view of 180°. Therefore, care was taken to ensure the receiver surface was perpendicular to the cell so that it would view only the cell. Since the receiver surface was placed 0.635 cm (1/4") into the opening of the cell, care was taken to ensure that the radiometer did not come in contact with the sides. See figure #2.

2.) An indium sheet was used as an interface between the radiometer and the tubing to provide good conduction between the radiometer and the liquid nitrogen cooled line.

3.) Each radiometer and all liquid nitrogen lines were wrapped with multi-layer insulation (MLI) to limit losses.

4.) The thermocouples used to monitor the black body fixture and radiometer temperatures were calibrated end-to-end to reduce temperature measurement error. The calibration showed that the thermocouples were within ±0.2°C for the majority of the temperature ranges in which the black body cells were cycled.

5.) A thermocouple was imbedded approximately 0.635 cm (1/4") into the surface of the radiometer, and the wire wrapped twice around the body of the radiometer and down the LN_2 plumbing to reduce the thermal gradients which might exist along the wire.

RESULTS:

Results are best explained graphically:

PLOT #1: Calibration Curve: This curve plots the radiometer's output against a calculated irradiance level. The irradiance was calculated using the equation $I=e(Sig)T^4$. The data was compiled and a Least Squares Fit calculated to obtain the best fit line. One can see from the high correlation coefficient and the low value for three standard deviations, that the data is linear and has a small degree of error.

PLOT #2: Calibration Curve With Error Boundaries: This curve plots the calibration curve as well as three standard deviations of the data and the largest additional error due to the recorders. The curves indicate that the maximum error expected is approximately ± 1.26 mw/cm^2 (± 4 Btu/ft^2hr). This is a fairly small error for the higher irradiance ranges, but leads to a large percentage error for the lower irradiance ranges. The error in the lower ranges is exaggerated because the three standard deviation calculations take into account the entire temperature range tested.

PLOT #3, #4 and #5: Millivolt Signal Fluctuations at Fixed Sink Temperatures -129°C, -20°C and 60°C (262°R, 455°R and 600°R): These curves plot the radiomater's output against its temperature, in degrees Rankine, for a fixed sink. The sink temperature was held constant while the radiometers were cycled between -195°C and -162°C (140°R and 200°R). For a given sink temperature, the different runs compared favorably.

PLOT #6: Comparison Curves: This curve compares the black body calibrated radiometer against the vendor's calibration data. The lower curve represents the calibration curve, supplied by the vendor, for an ambient temperature controlled radiometer. The higher curve represents data obtained using the black body source and a radiometer maintained at ambient temperature. These curves compare favorably. If the black body source had a poor emissivity or poorly represented an ideal black body source, the line woukd have fallen below the vendor's calibration curve. Recently, a comparison test was run using a Kendall Cavity Radiometer (considered a standard), and two of the P-8400 radiometers. In this comparison test, the same type of curve shift was noted.

ERROR SOURCES:

There are a number of factors invloved in this test which impact the data.

When cycling the sink temperature, the radiometer temperature varied. At the lower sink temperatures the radiometers had a tendency to drift cold. This may have caused the data points in the lower irradiance ranges to be on the higher mv side of the curve. For this test, the temperature of the radiometer varied approximately 5.5°C (10°R).

The mv output for a given sink temperature while ramping cold is slightly different than the mv output at the same sink temperature while ramping hot. This is caused by the radiometer's slow response to sink temperature changes. This introduces a small error in the results. Also, the inability to sample mv and temperature data at precisely the same moment introduced a small error into the results.

The mv signal introduced an error of ± 0.03% of the reading + ±0.012% of the range. This is the published maximum error of the recorder.

CONCLUSION:

The test could be refined to reduce the error in the results, but the results of this test were adequate for the needs of most program requirements. The maximum error in the irradiance vs. output curves for the radiometers was ±1.26 mw/cm^2 (±4 $Btu's/ft^2hr$).

An NBS traceable calibration is not available at this time. Martin Marietta plans to obtain NBS approval using this calibration method.

LESSONS LEARNED:

For future radiometer calibration tests, three changes could be implemented to improve results:

1.) A temperature sensor could be used which is more accurate in the lower temperature ranges.

2.) A pressure controlled liquid nitrogen dewar could be used to precisely control the temperature of the radiometer, thus limiting temperature fluctuations during test.

3.) Increase data point collection by stabilizing the sink temperature every 5.6°C (10°F) during temperature transitions.

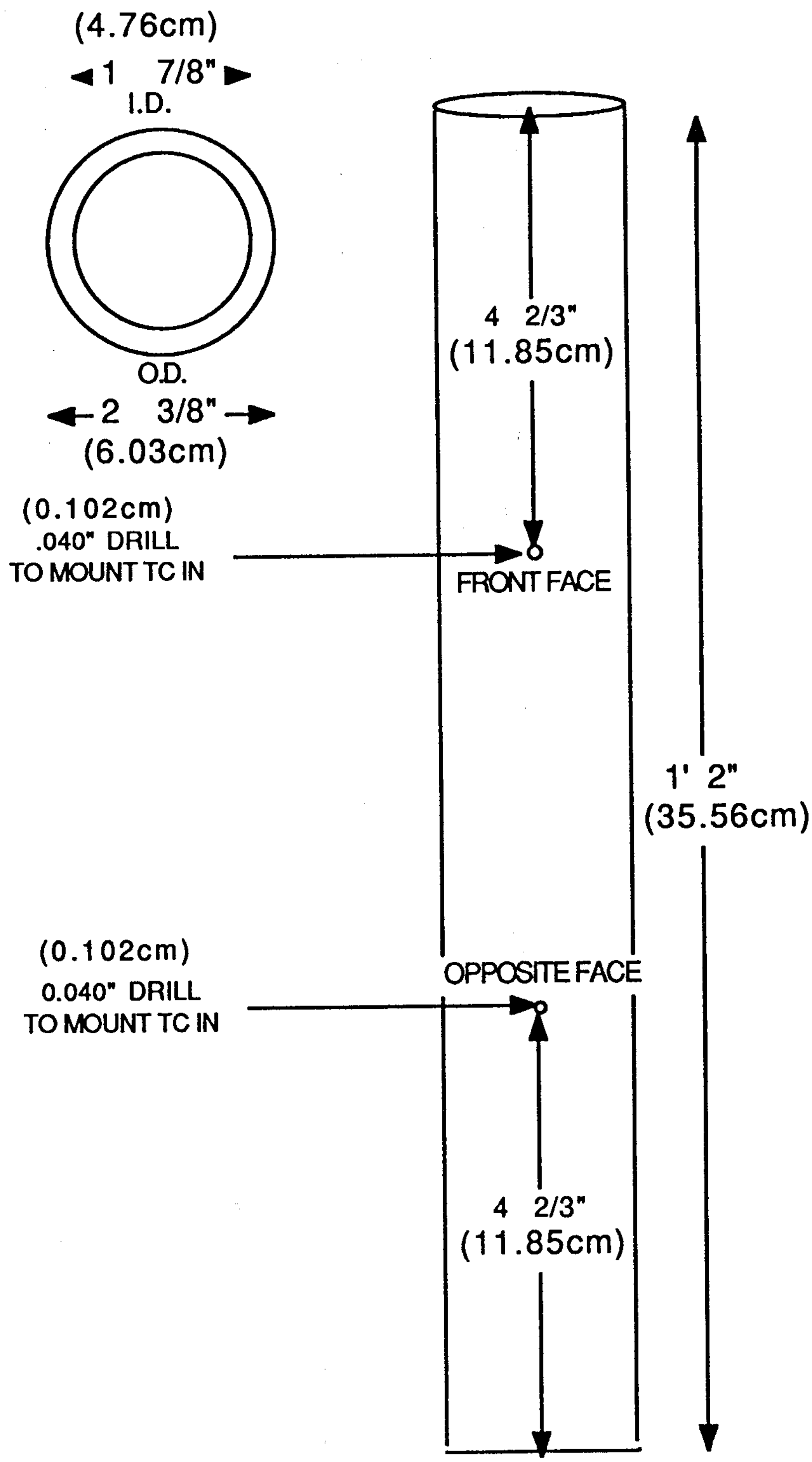
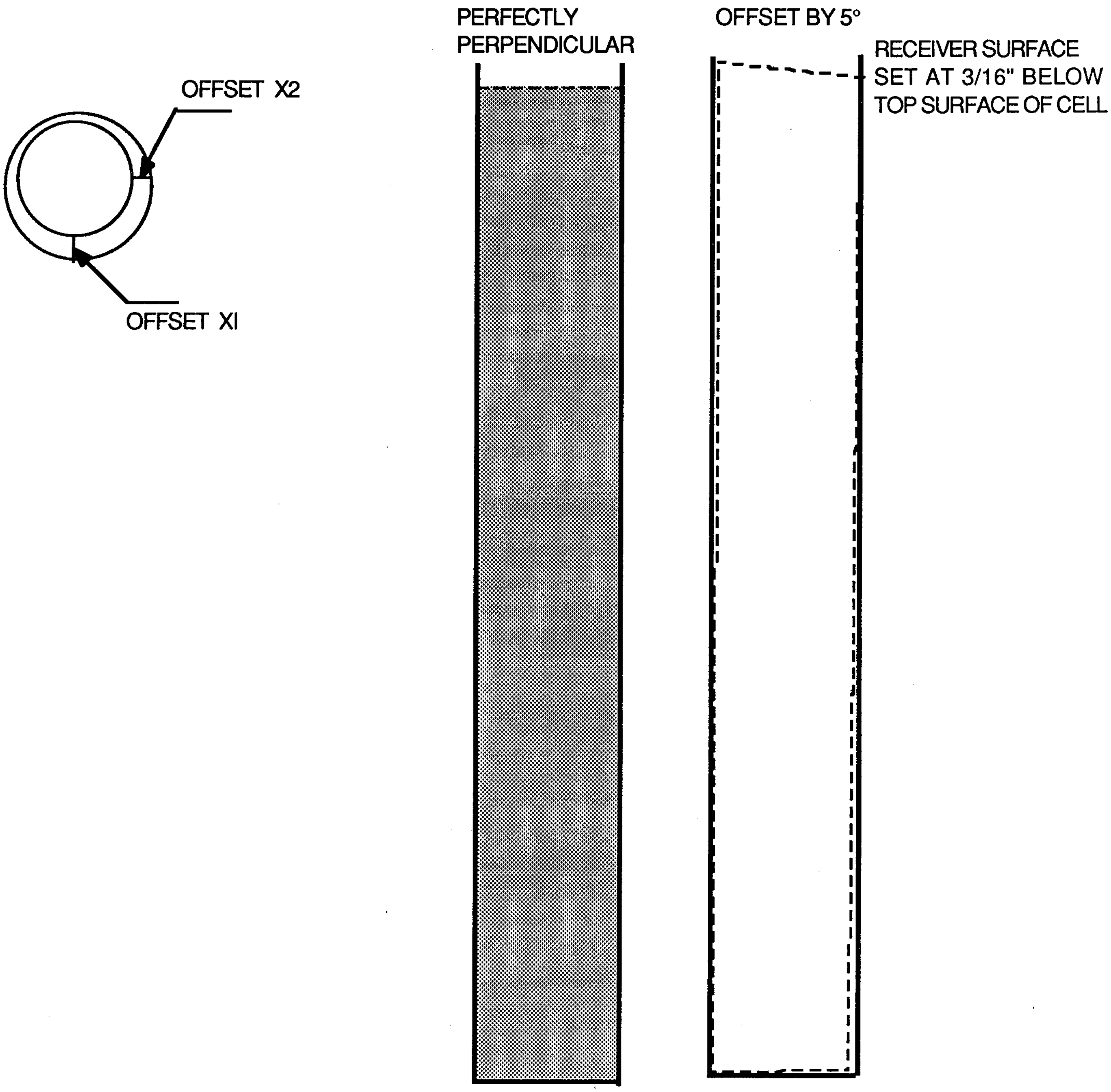


FIGURE 1. BLACK BODY CELL



FOR RADIOMETER WITH NO WINDOW
AND A 180° VIEW ANGLE

OFFSET ANGLES OF MORE THAN 5° COULD DISTORT THE DATA DUE TO THE RADIOMETER VIEWING THE COLD WALL.

FIGURE 2. RADIOMETER TILT AND ORIENTATION

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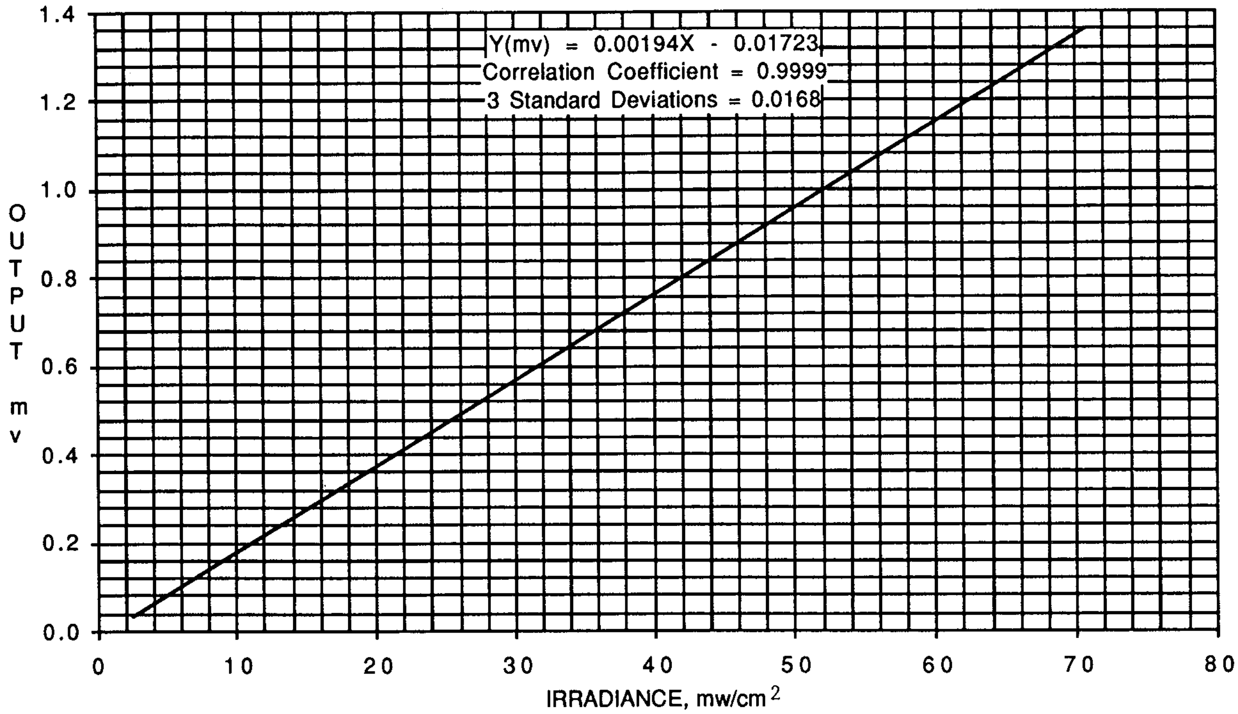
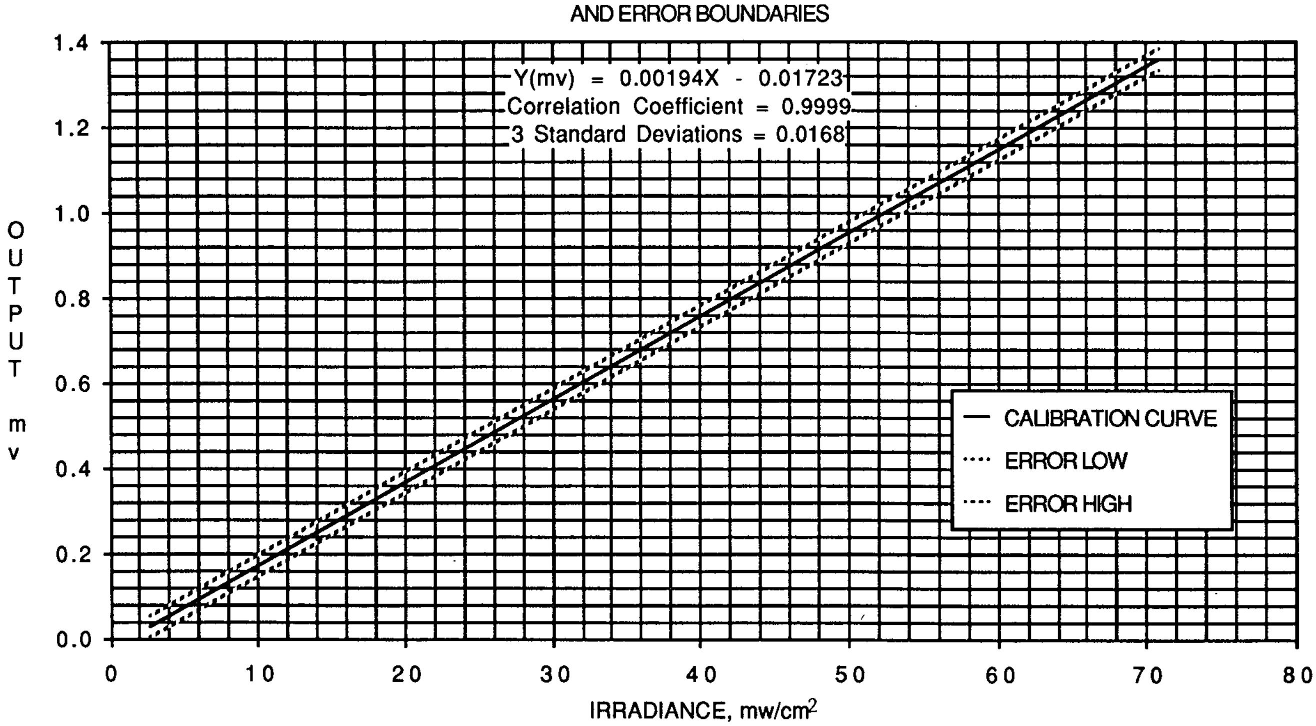
PLOT #1
CALIBRATION CURVE



PLOT #2
CALIBRATION CURVE
AND ERROR BOUNDARIES



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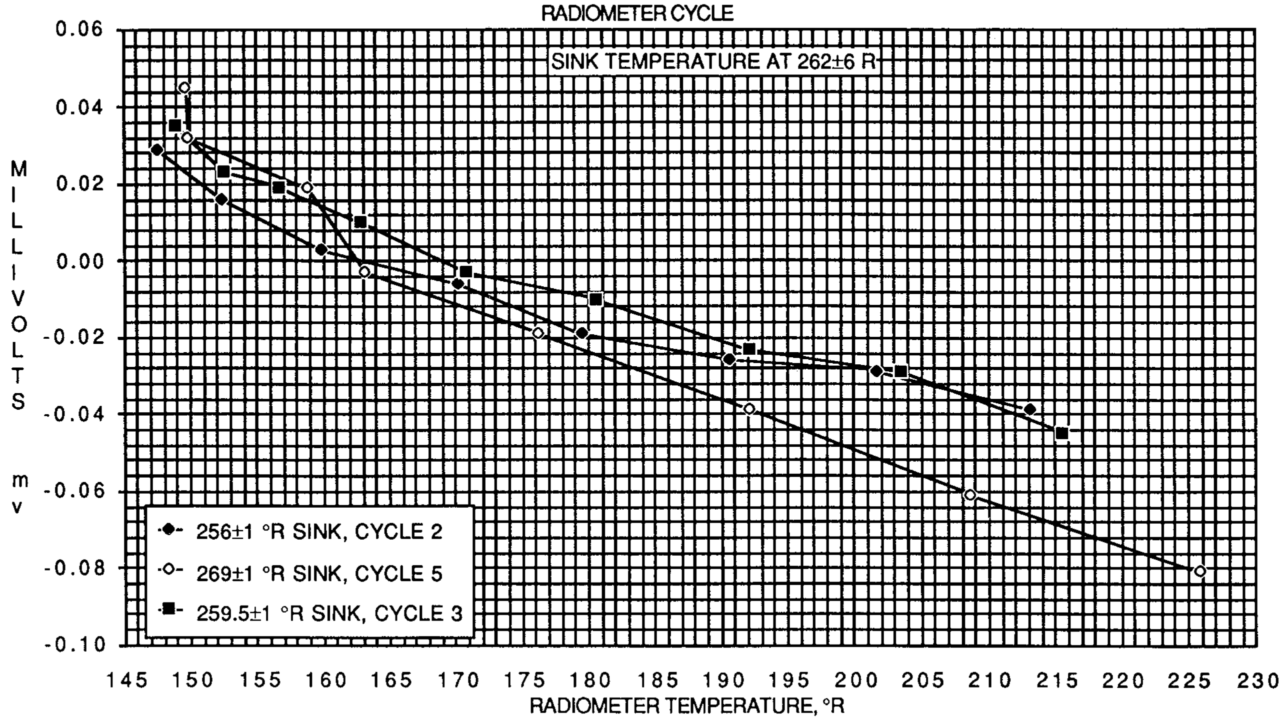
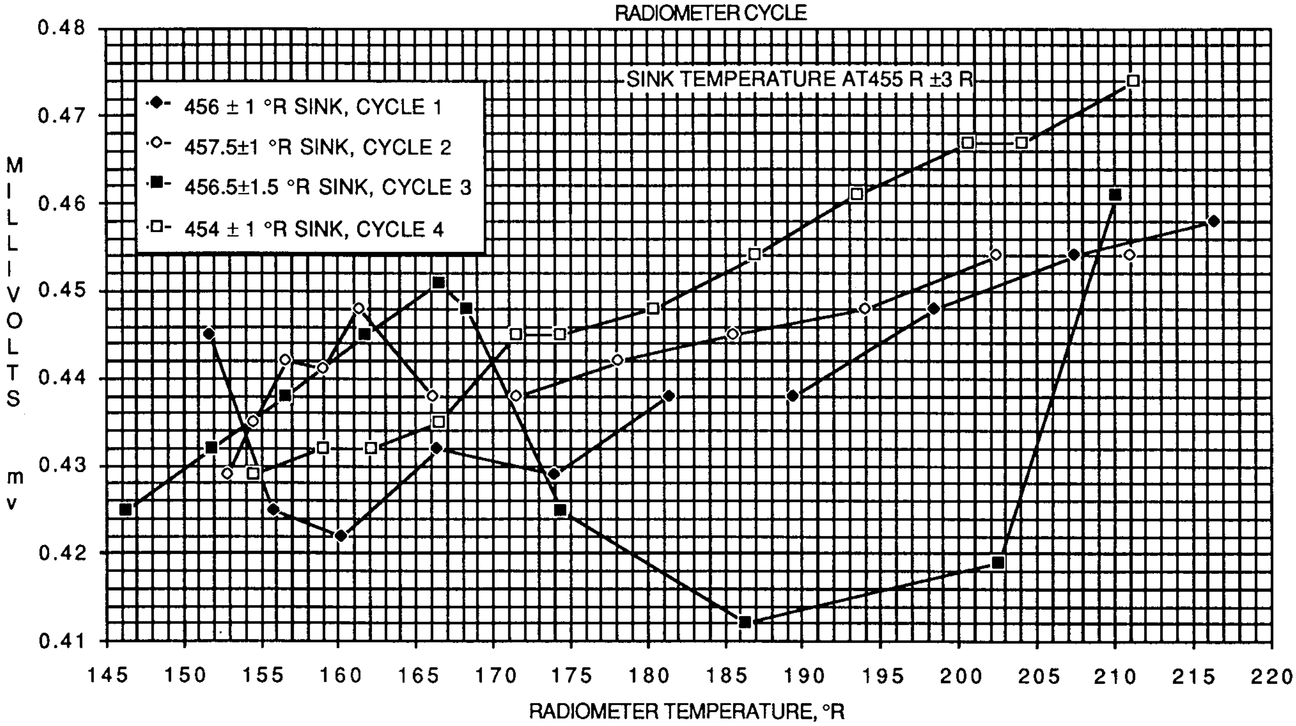
PLOT #3
COLD CASE
RADIOMETER CYCLE



PLOT #4
MID CASE
RADIOMETER CYCLE



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