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COMPARISON TESTING OF SELECTED NATURALLY VENTILATED SOLAR RADIATION SHIELDS

by

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COMPARISON TESTING OF SELECTED NATURALLY VENTILATED SOLAR RADIATION SHIELDS

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Summary

Five types of naturally ventilated Solar Radiation Shields were wind tunnel tested for relative heating errors and for response times under peak global simulated solar radiation intensities above a simulated snow surface. Tests were conducted at very low air flow rates over range 0.2 to 3.0 m/sec; and at sun elevation angles of 10, 20, 40, 70, and 90 degrees. The ratings of the shields both for small heating errors and speed of response best to worst were: Gill Type III; CCIW; and the following three shields all about the same--NDBC's General Service Buoy Payload, NDBC's C-MAN, and Kahlsico's Model #37AM500.

1.0 INTRODUCTION

1.1 McTaggart-Cowan and McKay's testing of both naturally ventilated and artificially ventilated radiation shields (1976, 1977)[1,2] showed that the Thaller multiplate shield was the best of the naturally ventilated shields, and that the CCIW (Canada Center for Inland Waters) was a close second (it being a simplified version of the Thaller Shield). They also found that in winter tests in full sun over a snow covered surface, those shields whose temperature sensors could "see" part or a lot of the snow surface had a corresponding increase in heating error. The Thaller temperature sensor which could "see" very little of the reflecting snow surface has practically no heating from this source.

1.2 The report, "Development of a small rugged radiation shield for air temperature measurements on drifting buoys," (Gill, 1979)[3] describes the development and testing of a smaller Thaller-type shield developed for the NOAA Data Buoy Center (NDBC). This shield differed from the regular Thaller shield in three main respects:

1. No solar radiation direct, or reflected from the underlying surface (sea or land), could reach the temperature sensor directly. (The temperature sensor could not "see" out.)

2. The shield was much smaller--about 12 cm diam. x 16 cm high compared to about 60 cm wide x 22 cm high.

3. The shield was of more rugged construction--to withstand very strong winds and ocean waves breaking over the shield.

This shield was tested for relative heating errors when subjected to solar radiation from low sun angles (10°) to high sun angles (90°) but not for sun reflected off a snow-covered land surface.

1.3 The writer wished to test this new shield (now referred to as Gill Type III Radiation Shield) for general use--over grass and snow covered surfaces as well as over water for use on buoys. Since the NOAA Data Buoy Center was very interested in this too, they agreed to support the writer in these tests; and to test three other shields, one currently in use on buoys, and two others that they might deploy both over land and water surfaces. Accordingly, a contract for these tests was signed in September, 1982.

1.4 Pertinent paragraphs from this contract read as follows:

"1.0 BACKGROUND

. . . .

"The excellent performance of the prototype shield (Gill Type III) encouraged NDBC to request that the air temperature sensor for its newest measurement system, the Coastal-Marine Automated Network (C-MAN), be designed similar to the prototype. The C-MAN solar radiation shield, however, has not yet undergone laboratory or field tests to demonstrate its effectiveness. Also, because the C-MAN sites will be on land where snow will accumulate on the ground, special tests must be performed to determine the immunity of the shield to reflected radiation from a snow surface. Snow reflection tests have never been performed on any of the temperature sensor shields used by NDBC.

. . . .

"3.0 TASKS

"3.1 Task A--Test C-MAN Type Radiation Shields

"The contractor shall determine the effectiveness of two C-MAN type solar radiation shields supplied by NDBC for the test. The test shall be performed in a low speed wind tunnel at air speeds in the range of 0.3 to 3.0 meters per second and at expected peak solar radiation intensities. A simulated snow surface and a calibrated sun simulator shall be used. The design, fabrication, and calibration of the sun simulator and the artificial snow surface is also part of this task.

"Air temperature differences between the unheated free air in the wind tunnel and that of the temperature sensor in the radiation shield shall be accurately measured. Resultant sensor heating curves shall be prepared.

"The two C-MAN shields supplied for this task have identical dimensions but are constructed from different plastic materials.

"3.2 Task B--Test GSBP Type Radiation Shield

"The contractor shall test a GSBP type radiation shield supplied by NDBC under conditions and methods identical to those used in Task A.

"3.3 Task C--Test Gill Type III Radiation Shield

"The contractor shall test a Gill type III radiation shield under conditions and methods identical to those used in Task A."

1.5 In addition to the tests on the above-mentioned four shields, the writer considered it almost essential to test two of the shields McTaggart-Cowan and McKay used--so that the shields tested in the current program could be tied to the results of the former comparison. The writer tried to obtain the loan of the Thaller shield from D. J. McKay but that shield could not be located; so he has used the CCIW and Kahl shields employed in the 1979 study.

The current report is on the work performed in connection with Tasks A, B, and C.

2.0 DEVELOPMENT OF SUN SIMULATOR

2.1 In reference 3 (Gill, 1979), section 2, are listed some of the lamps used by others to simulate the sun's radiation. After testing a bank of 12 incandescent reflector spot lamps, see Fig. 1, (as used by Eppley), the writer opted for a G.E., type DXW, 1000-watt quartz-tungsten halogen lamp as used by the National Bureau of Standards. This lamp (in its reflector mount, see Fig. 16 a) and c) of Gill 1979 report) worked well for that study, but had too narrow a beam to adequately illuminate the radiation shield and the simulated snow surface at the desired radiation intensities. [Four such lamps (in their reflector mounts) would probably have done the job.]

2.2 Just at this time (with the closing of the Bendix Systems Division in Ann Arbor), Bendix made available to the writer two "sun simulators," each with twelve 1000-watt, G.E. quartz-tungsten halogen lamps (cat. # QH1000T3/2CL/HT). It seemed the answer to a maiden's prayer. Each lamp, measuring about 14 inches in length and 3/8 inches diameter, was mounted in a semicylindrical gold-plated reflector (for high reflectance of solar wave lengths). Four of these lamps should suffice for our needs, thus leaving plenty of spare lamps in case of individual lamp failures. Figure 2 shows these four lamps, with reflectors, in their frame, the lamps radiating a shield and the simulated snow surface.

This four-lamp 4000-watt sun simulator was calibrated in the same manner as was the 1000-watt, G.E., type DXW lamp (see Fig. 14 of 1979 report). This calibration employed the same Eppley Radiometer, Model PSP, as before. The proximity of the lamp assembly to the Eppley Radiometer for indicated radiation intensities of 1.0 to 1.6 langleys per minute was less than expected. Subsequently, when the lamp assembly was used at various sun angles to illuminate the radiation shield under test, the heating of the shield was 2 to 4 times that expected. The writer phoned Mr. Walter Scholes of the Eppley Laboratory to describe the set-up and get his advice. He said that the QH1000T3/2CL/HT lamps produced a large amount of long-wave heat radiation that would not be registered by the Eppley PSP radiometer, as the latter cut off most of the long-wave heat radiation. He suggested operating these lamps at a higher voltage (to raise their color temperature well above 2500° K), or to choose other incandescent lamps with a much higher color temperature. We tried operating the lamps at a steady 480 volts instead of 240 volts (company graphs gave data for doubling the voltage), but the lamps had too short an operational life; the gold plating on the reflectors soon evaporated; and Eppley readings were not as high as expected.

2.3 The writer discussed his problem with Mr. Perry Thrasher in the appropriate section of the Lamp Division of G.E. in Cleveland. Mr. Thrasher recommended the use of their Quartzline tungsten halogen dichro 1000-watt lamps (type Q1000PAR64/7D) having a color temperature of 5200° K. He thought these lamps would suit my needs better than any other he was aware of. Four of these medium flood lamps were purchased and mounted as shown in Fig. 3. Each lamp was mounted in gymbals that permitted individual beam orientation for relatively uniform radiation over a circular area 50 cm in diameter, at radiation intensities in the range 1.0 to 1.6 langley/min. For most of our work it was found that 2 lamps were adequate for the radiation intensities needed.

Both the 4-lamp and 2-lamp combinations were calibrated in the same way as the G.E., type DXW, 1000-watt lamp was calibrated. Figure 4 shows the 4-lamp assembly above the 100 cm x 120 cm grid table. (The Eppley PSP is sketched in place on the table as it was scarcely visible due to its white frame and clear glass envelope.)

The lamp assembly was raised to four selected levels above the sensitive surface of the PSP radiometer--levels of 60, 70, 90, and 115 inches. At each of these levels the radiometer was moved along parallel lines 10 cm apart and a reading was taken at each 10 cm spacing. The lamp voltage was maintained steady at 120 ± 1 volt throughout a test. The output of the PSP radiometer was read on a Fluke Digital Voltmeter, set on the 0-200 mv range. A plot of the calibration carried out for a lamp to sensor distance of 90 inches is shown in Figure 5. The figures on the grid are radiation intensities in langley/min. A circle representing a circular area 50 cm in diameter is drawn on the chart to determine the average radiation intensity over this area. It is to be noted that the average intensity was 0.94 langley/min. The range in intensities over the whole area was 0.85 to 1.03 langley/min., that is, 0.94 ± 10%.

Also on Figure 5 is drawn an isometric line of radiation intensity 0.80 ± .01 langley/min. It is noted that this curve is somewhat of an ellipse with the major axis about 70 cm in width and minor axis about 50 cm in width. In the wind tunnel the lamp assembly was oriented so that this major axis was in a vertical plane as this permitted the most uniform radiation on the front face of the shield and on the snow simulator area below the shield.

The average values of radiation intensity for the four lamp-to-radiometer distances are plotted in Figure 6. (These distances are measured in inches rather than centimeters because the retractable steel measuring tape fastened to the lamp assembly read in inches--see Figure 3.)

2.4 There arose the question of what radiation intensities one should use for the various sun angles (angles of the sun above the horizon) from 0° to 90°. For the 1979 report, the writer used the peak solar radiation intensities we observed in Ann Arbor on clear days at various sun angles--see 1979 report, pages 17 and 18. For the fuller current study, the writer desired to know the peak radiation intensities one might obtain almost anywhere in the world from equator to the poles; for sun angles 5° to 90°; and at elevations from 0 ⟶ 2000 m MSL. These values would then be used in the sun simulator tests.

At low sun angles where the sun's rays pass through greater lengths of the earth's boundary layer, one would expect higher radiation intensities in the cold, clear, dry air of the arctic and antarctic rather than in the warmer, clear, moister air of mid latitudes and equatorial regions. References 4 and 5 confirm this. These references provide reliable data on peak radiation intensities one might expect in both near pole and near equator locations.

Reference 4, page 21, speaking of the Maudheim station (Antarctic, lat. 71.03° S., 10.56° W., 37 m MSL), "Maximum intensity [of direct solar radiation] is reached in the late spring and early summer, i.e., November and December, when values around 1.55

ly min^{-1} occur." Table 5, page 22 of the same publication gives the peak direct solar radiation received at Zugspitze (Switzerland) (47.25° N., 10.53° E., 2962 m MSL) at noon in June as 1.55 ly min^{-1} at a sun angle of 50°.

Reference 5, page 78, Figure 46, shows the "1977 average monthly clear-sky normal incidence irradiance at Mauna Loa versus air mass." This figure shows the peak May-June irradiance for Mauna Loa (Hawaii, 10.29° N., 155.36° W., 4170 m MSL) to be 1.57 ly min^{-1} (1095 W m^{-2}). This would be when the sun angle was 90°--directly overhead on a clear day, and would be higher than the value at 2000 m MSL. The peak irradiance value in the region 0⟶2000 m MSL was then taken to be 1.55 ly min^{-1}.

2.5 The data from these various sources are plotted in Figure 7, and a peak intensity curve drawn. From this curve the peak radiation intensities at 5, 10, 20, 30, 40, and 50 degree sun angles were determined and are given in Table I. Using this tabular data and the curve of Figure 6 the new curve Figure 8 was drawn, with the various radiation intensities marked on it. From this, Table II was determined.

3.0 DEVELOPMENT OF SNOW SURFACE SIMULATOR

3.1 It is a frequent comment that a snow surface is highly reflective of solar radiation. But what is a "highly reflective snow surface"?--a reflectivity of 80%? of 90%? of 95%, or of 99%? I discussed this matter with a colleague of mine, Dr. Paul Hays, of our Space Research Laboratories working in the arctic on Aurora ("Northern Lights") and Airglow experiments. He advised that the high reflectivity of fresh snow was very short lived--within 24 hr. it would probably be down to 90% or less.

Then for my tests attempting to get 98% or higher reflectivity (as needed on the inside of the 2-meter diameter integrating spheres used in the calibrating of pyranometers) would not be necessary, and really would not represent the average snow surface. Hays suggested the use of a good quality outside house paint, with a high content of titanium oxide.

Hays' comments were strongly confirmed by Lillequist[4] where on page 82 the text reads, "Measurements of the albedo of snow have been made by quite a number of authors, both with photoelectric and caloric methods, generally giving results varying between 60⟶90%, the low values obtained over an old or wet snow surface, and the high ones over new-fallen or fresh snow." In Figure 46, page 89, "Albedo of the snow-surface (clear sky) as a function of the solar altitude; November, 1951 and December-January, 1951-52," with 36 observations plotted, the reflectance at any sun angle never exceeded 84%.

3.2 With this authoritative information where reflectance from any snow surface did not exceed 84%, the writer accepted Hays' suggestion and looked into good quality outside white paints. After examining the labels on three manufacturers of quality paints, the writer selected Sherwin Williams Latex Flat Paint, House and Trim, Super White 107-8013 (Pigment by weight; titanium oxide 21%, zinc oxide 2%, silicate 20%, total 43%; vehicle by weight; acrylic resin 16%, soya alhyd 2%, water 38%, total 57%).

Before using the Sherwin Williams paint, the writer obtained and coated flat surfaces with the following white reflectance paints:

1. Eastman Kodak White Reflectance Paint, cat. #6080--composed primarily of barium sulphate + binder and solvent--an exceptionally high reflectance paint,[6] and very expensive (list price $102/pint), and I would need at least two pints.

   I obtained and used one pint, but had great difficulty applying the paint uniformly even when using the recommended type of spray gun applicator.

2. 3M's "Nextel" Brand, Velvet Coating, #101-A10 white.

   Although this is a highly reflective white paint (98+% reflectance of most of the solar spectrum), I was able to get only two 8-oz. spray cans of it from 3M headquarters and that was not enough to adequately cover the 3 x 4 ft. rectangular plywood sheet needed for the sun simulator. Since the product "has been dropped from our product line," the writer looked elsewhere for a suitable matt white paint.

3. Plasticool Standard Solar Heat Reflective Coating (Coating Laboratories Inc., 3133 East Admiral Place, Tulsa, Okla. 74110).

   This material was not nearly as expensive as the other scientific white paints ($14.00 per gallon in small quantities), and produced a fairly uniform white matt finish that might have worked well. However, the writer was not supplied with the type of white pigment used, or with a scientific report that would give him confidence in the use of this paint. He opted to use the Sherwin Williams titanium oxide paint as suggested by his colleague, Dr. Hays.

The photograph of Figure 8 shows a representative shield; snow simulator; and sun simulator in their respective positions during testing operations. Other radiation shields are shown in Figure 9.

4.0 WIND TUNNEL TESTING OF RADIATION SHIELDS

4.1 In the development and testing of the Gill Type III Radiation Shield[3] the testing was done in the 5' x 7' working section of the Aeronautical Department "Low Speed Wind Tunnel." Since this tunnel was designed for aeronautical testing in the normal air speed range 10⟶90 m/sec (20⟶180 mph), the motor speed control (heavy duty wire wound rheostats) is scarcely adequate at very low speeds (0.5⟶5 m/sec). Also the accuracy in measuring the air flow rate at speeds of 0.5 to 5 m/sec (using the customary pressure differential method) was less than desirable. So consideration was given as to how one might adjust the tunnel to these very low flow rates and to measure these flow rates with greater accuracy than routinely available. Mr. James Amick suggested I put our equipment to be tested in the large "settling chamber" of the tunnel where the air speed is roughly 1/15 that of the speed in the normal working section. This was a wonderful suggestion as it would solve both problems simultaneously, without modifying the wind tunnel.

Figure 10 shows the exterior of the large wind tunnel showing the settling chamber in the background of the photograph. Figure 11 shows the opposite side of the wind tunnel--mostly the settling chamber. Some details of the arrangement are noted in the figure description. Our equipment was mounted on the inside floor of the tunnel just to the right of #5 screen (Fig. 11). As indicated in the figure, the settling chamber at this location is. 20 ft. high by 26 ft. across so there is no crowding of space for the sun simulator, the snow surface simulator, the radiation shield under test, or any of the auxiliary equipment needed. Figures 12 and 13 show typical installations of the equipment in the tunnel.

With five successive fine mesh screens smoothing out the air flow in the tunnel, the flow over the radiation shield and other equipment was very steady and uniform at any speed control setting we used. In Table III are listed the air speeds desired in the settling chamber, and the corresponding wind speeds to which the air passing through the "working section" was adjusted.

4.2 The temperature rise in a radiation shield under test was measured by a copper-constantan thermocouple. Duplex copper-constantan cables of either B. & S. Gage #28 or #24 were used in all tests. Output voltages from the thermocouple were recorded on a Honeywell volt/millivolt recorder, Electronic #195 Type DAZAS. The input range was digitally adjusted several times during each wind tunnel run to compensate for wind tunnel temperature changes. Normally full scale sensitivity of the temperature measuring system was 100.0 scale divisions on the recorder corresponded to 20.0 C° temperature difference. The reference thermojunction was located at the entrance to a motor-aspirated radiation shield (Fig. 8, d) located a few centimeters from screen #5, and out of range of the sun simulator. The thermojunction in the radiation shield under test was located where one would expect the temperature sensor would be found when the shield was in regular service. The accuracy of the system was tested by placing the reference junction in a large beaker of well-stirred water, and the other junction in a second large beaker of well-stirred water, each beaker having a quality thermometer. Scale readings of temperature difference agreed with mercury thermometer indications of temperature difference within ± 1%--well within the desired accuracy.

4.3 During daytime runs during the fall of 1982, random temperature difference fluctuations of the order of 0.2 to 0.5 C° would sometimes occur at the two lowest tunnel speeds. These fluctuations were traced to temperature fluctuations in the tunnel caused by gusty winds on partly cloudy days. To overcome these problems subsequent runs were conducted, either in the early morning hours (before sunrise), or starting two to three hours after sunset and continuing into the night. This eliminated most of the problem. However, when testing the C-MAN shields, which have very long time constants, it was further necessary to speed-up the tunnel to 150 ft/sec for several minutes (to wipe out these small temperature fluctuations) prior to each low speed run.

4.4 In practice, each radiation shield was tested at sun angles of 10, 20, 40, 70, and 90 degrees. Air speed rates across the shield were 3.0, 2.0, 1.2, 0.8, 0.4, and 0.2 m/sec. The voltage applied to the lamps was maintained steady at 120 ± 1 volt. Two men were on duty at all times; one usually had responsibility for wind tunnel operation, the other had responsibility for recording all of the data, and maintenance of the 120 ± 1 volt to the sun simulator. Overall operation procedures and almost all analysis were the responsibilities of the writer.

5.0 CHECKING AND RECHECKING OF OBSERVATIONS

Heating recorded for all the shields was higher than expected--2 to 4 times as great. Was there some major error made in any of the procedures? In searching for such an error, the following checks were made:

5.1 Accuracy of temperature difference measuring system

In the description of the temperature difference measuring system, it was mentioned that the system was checked (early in the operations) by placing the two thermojunctions in two well-stirred baths of water at 18 to 20 C° apart in temperature using mercury-in-glass thermometers. The thermocouple system agreed with the thermometer system within ± 1% (0.1 to 0.2 C°). Near the end of the wind tunnel study the thermocouple-recorder system was again checked using the same procedure but larger plastic water containers, and higher quality mercury-in-glass thermometers. The findings were unchanged--the copper-constantan temperature difference measuring system was accurate within ± 1% of the true value.

5.2 Measurement of radiation intensity from the sun simulator

In the chapter on the sun simulator, the method used to calibrate this instrument was gone into in detail--using a particular Eppley PSP Radiometer and a certain Fluke Digital voltmeter. To check on the reliability of these two latter instruments, the writer with an assistant transported the two instruments to the roof of our Space Research Bldg., and mounted the Eppley PSP Radiometer adjacent to a similar one which has been recording solar radiation routinely for the past several months. The day was almost cloudless. Over a period of an hour the two independent systems agreed within ±5% of one another as to average intensity of the total radiation intensity. Thus the reliability of our radiation measuring system was also confirmed.

5.3 Measurement of air speed over radiation shield

Errors in this measurement could possibly occur from the following sources:

i) The measurement of the air speed in the "working section" of the tunnel.

ii) Human memory error as to the ratio of cross-sectional area of the "settling chamber" to that of the "working section."

iii) Dust on fine screen(s) near where our equipment was to be used.

In connection with (i), two procedures were done: (a) the static pressure holes on the walls of the "settling chamber" and the "working section" were inspected and dusted off, but nothing out of the ordinary was detected; (b) a Gill 4-bladed helicoid anemometer with indicating meter was installed in the "working section" to assist in the low speed operation of the tunnel. There was no apparent difference in wind speeds indicated by the two independent systems.

In connection with (ii), the writer carefully measured the cross-sectional areas of both sections of the wind tunnel. He found the "settling chamber" to have 15.08 times the area of the "working section." This compares favorably with the value of 15 times given him by Mssrs. Amick and Glass of the Aero. Dept.

In connection with (iii) above, the writer examined #5 screen for dust in the area near our installation. There was surprisingly little dust on the screen, and it appeared to be pretty uniform across it. No cleaning or modification of the screen was attempted, as this would probably create larger errors than were currently present.

The writer was led to the conclusion there were no significant errors in the wind speed determinations.

* * * * * *

5.4 In checking the overall system of measurements, no significant error in technique or mode of operation was detected. So we should have confidence in the relative heating obtained for the various radiation shields, even though the heating was several times that expected. (One student, with a sense of humor, suggested the heating temperatures be in °G instead of °C--where 1°G = 5°C, but fail to define the term °G. In this way, the indicated peak heating would range from about 1.4 G° (for the Gill Type III) to about 3.7 G° (for the Kahlisco shield). In this way the heating errors found would seem to be closer to the values McTaggart-Cowan and McKay reported.)

6.0 OBSERVATIONS AND CONCLUSIONS

6.1 The following seven radiation shields were tested for potential solar radiation heating errors:

1) NDBO's C-MAN shield, of Rovel
2) NDBO's C-MAN shield, of PVC
3) NDBO's General Service Buoy Payload
4) Gill, Type III, of Rovel
5) Gill, Type III, of PVC
6) CCIW (Canada Center for Inland Waters)
7) Kahlsico, Model #37AM500, painted white

The first four shields were specified for testing by the contract. Shield 5) was tested to ascertain if a second type of white moldable plastic, UV stabilized, might be as good or better than the white Rovel, UV stabilized. Shields 6) and 7) were tested, as indicated earlier, so that these relatively new shields (#1 through #5) could be compared to two of the best shields McTaggart-Cowan and McKay[1,2] had reported on.

The heating curves for these seven shields are shown in Figures 14 and 15.

For each radiation shield there are two curves which essentially provide an envelope for nearly all the individual heating measurements for that shield. The most significant measurement in each series was the maximum heating error of that shield.

6.2 The following observations and conclusions may be drawn from an examination of these graphs:

1. The heating errors, as discussed in Section V, were about 2 to 4 times that which the writer expected. But since we were primarily interested in the relative error of the various shields, this was still very discernible from the series of graphs.

2. Maximum heating in every case was at the minimum ventilation rate of 0.2 m/sec. (This was expected.)

3. Maximum heating occurred in all shields with a sun angle of 40° or 70°. (This was not expected, but seems to be of no great significance.)

4. The peak heating of the two Gill Type III shields was practically the same; as was the heating of the two C-MAN shields. We are thus led to the conclusion that new white PVC plastic, UV stabilized, is equally as good as new white Rovel plastic, UV stabilized, for the reflection of solar radiation.

5. The Gill Type III shield is superior to the other four types of shields. Its superiority over the CCIW shield is gratifying as the CCIW shield was the second best naturally ventilated shield McTaggart-Cowan and McKay[1,2] had found in their tests.

6. The two C-MAN shields had heating errors over twice that of the Gill Type III shields at nearly all ventilation rates. The style of the C-MAN shields was based on the Gill Type III, but with less than half the number of parallel plates, and with the plates of a much simplified design. These changes have greatly reduced the effectiveness of the shield. It is the writer's strong recommendation that NDBC accept the Gill Type III design (for whose development they have paid), and use it unchanged in design for their C-MAN instrument packages.

The radiation intensities given in the tables in Figures 14 and 15 are slightly higher for sun angles of 10° and 20° than the values given in Table I. The reason that the values in Table I are slightly lower than the others is that in preparing this report all the reference data was replotted and the earlier abstracted tabular data needed some correction. The radiation intensities used in the tests for these two angles were slightly higher than needed, yet the heating was less than that at 40° and 70°. Thus there was no need to repeat the tests at 10° and 20° as the conclusion of the study would be unchanged.

6.3 Although not requested in the contract, the writer determined the approximate time constants of the seven shields. These are given in Table IV for two air flow rates, 3.0 m/sec and 0.4 m/sec--corresponding to a light breeze, and to essentially calm conditions. (This figure of 0.4 m/sec for calm conditions may surprise some observers, but the writer and his two assistants found that they could scarcely detect any air movement on the face at that air speed, and would describe such conditions as "calm.")

For buoy use where air speeds of 0.4 m/sec, or lower, are rarely if ever experienced, it would seem to the writer that all of the seven shields have fast enough response wherever temperatures are taken but once per hour. But for land use where almost "calm" conditions occur frequently at night at many locations, the three NDBO shields, as presently supplied, have pretty slow response. Encapsulating the temperature sensors in a protective white cylinder certainly protects the sensors from breakage and corrosion, but markedly increases the time constants. (The time constants shown for the C-MAN shield of PVC are not representative of the shield as supplied, as in our tests the copper-constantan thermojunction was located below and not touching the protective white cylinder--in the free air space in the cavity of the shield.)

6.4 To summarize the main findings of the study:

1. The Gill Type III shield has lower heating at all ventilation rates than either of the two shields (CCIW and Kahlsico) McTaggart-Cowan and McKay[1,2] found to be second and third best naturally ventilated shields in their tests.

2. This same shield had markedly less heating errors than any of the three NDBO shields tested.

3. The Gill Type III shield had relatively short time constants, equal to or less than the other four types tested. It should be suitable for use above most land, snow, or water locations.

The writer believes the Gill Type III Radiation Shield will give smaller air temperature errors over land or water, winter or summer, than any of the other four types of radiation shield.

7.0 ACKNOWLEDGEMENTS

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James Amick (aeronautical engineer)--for suggesting that the tests be made in the settling chamber of the Low Speed Tunnel--to permit getting flow rates in the speed range 0.2 to 3.0 m/sec accurately and consistently.

Roger Glass (research scientist)--for approving the use of the settling chamber for the study; help in conducting the tests there; locating a very stable source of 100 ampere, 440 volt A.C. power for whatever solar lamps I might select; and routine assistance throughout the several months of the study.

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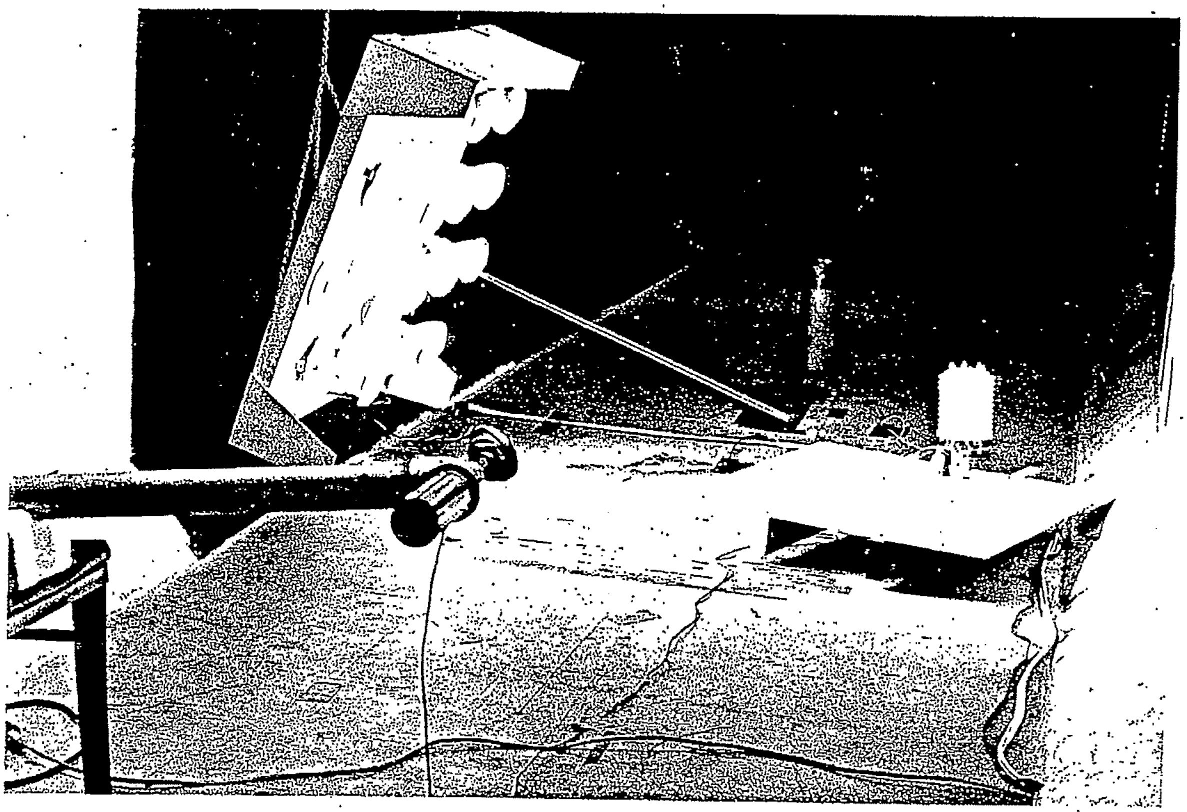

Figure 1 - Bank of twelve 150-watt reflector spot lamps radiating the prototype Gill Type III Radiation Shield supported above a simulated snow surface. (Picture was taken in the working section of the "Low Speed Wind Tunnel," Dept. of Aerospace Engineering, Univ. of Mich.)

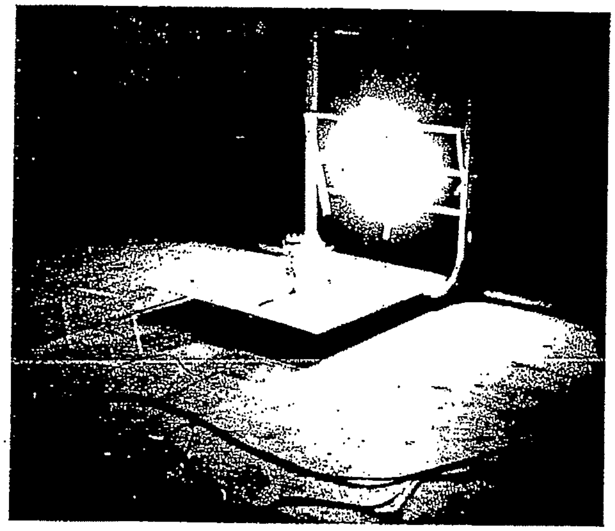

Figure 2 - "Sun simulator" given by Bendix Systems Division to writer--bank of four, 1000-watt G.E. quartz-tungsten halogen lamps radiating a representative radiation shield and simulated snow surface. (Picture taken in the large settling chamber of the "Low Speed Wind Tunnel.")

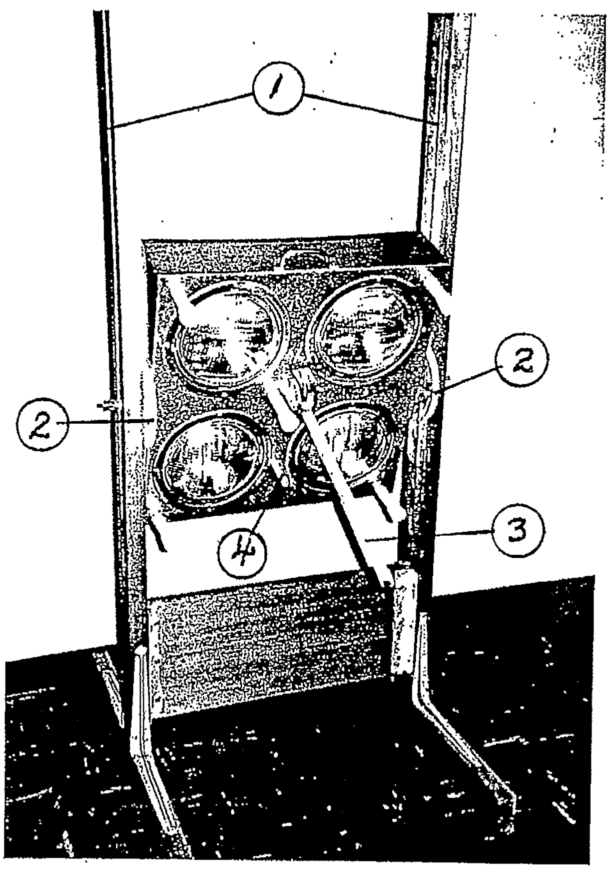

Figure 3 - "Sun simulator," composed of four, 1000-watt G.E. Quartzline tungsten halogen dichro lamps (type Q1000OPAR64/7D) in a special mount. Following features are noted: 1) slots in frame permit raising or lowering center of bank of lamps from 0.6 to 2.0 above the tunnel floor; 2) protractors permit easy adjustment of "sun angle" from 0° to 90° in 10° steps; 3) 25-ft. retractable measuring tape permits quick and accurate distance adjustments of lamp face to radiation shield; 4) siting tube to insure proper height of radiation beam (when lower two lamps are used) for various sun angles and lamp-to-shield distances.

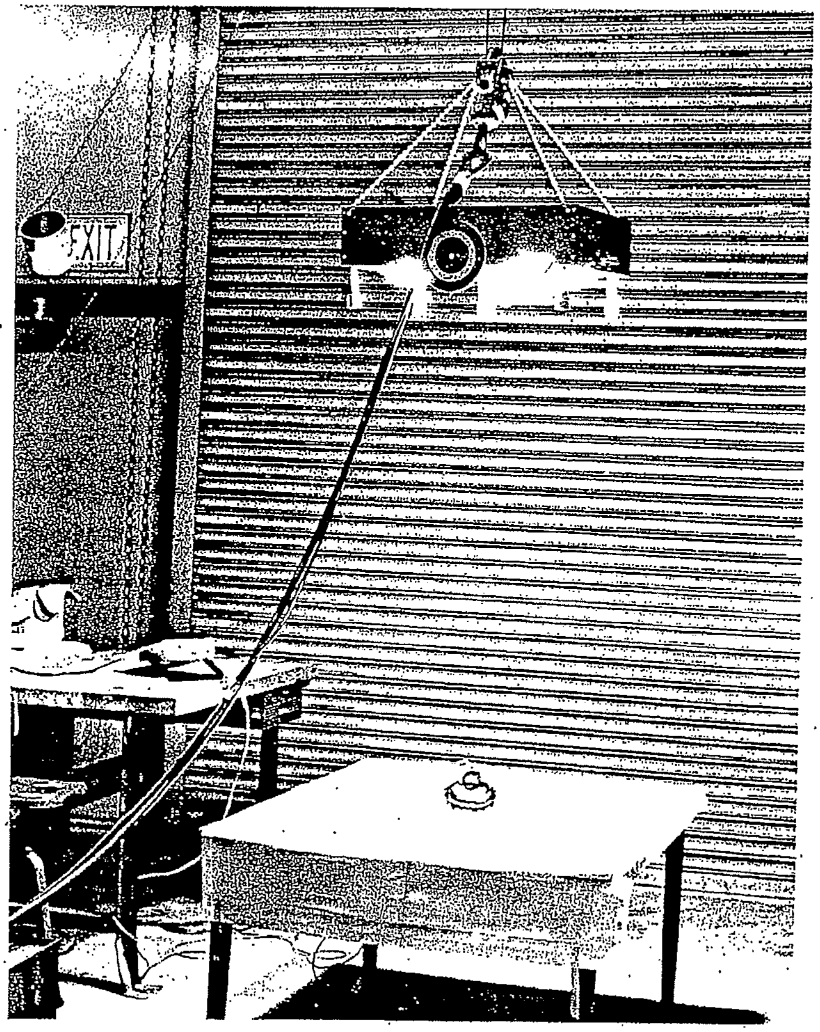

Figure 4 - Calibrating Sun Simulator [to determine the variations in radiation intensity (ly/min) over flat surfaces at various distances from simulated solar source].

a) simulated solar source (4 lamps in place).

b) horizontal table with sheet of graph paper 120 x 100 cm in size with grid lines 5 cm apart.

c) Eppley Radiometer, Model PSP.

d) Fluke Digital Voltmeter to register output of Eppley, Model PSP in millivolts.

e) support cable to hydraulically raise or lower sun simulator.

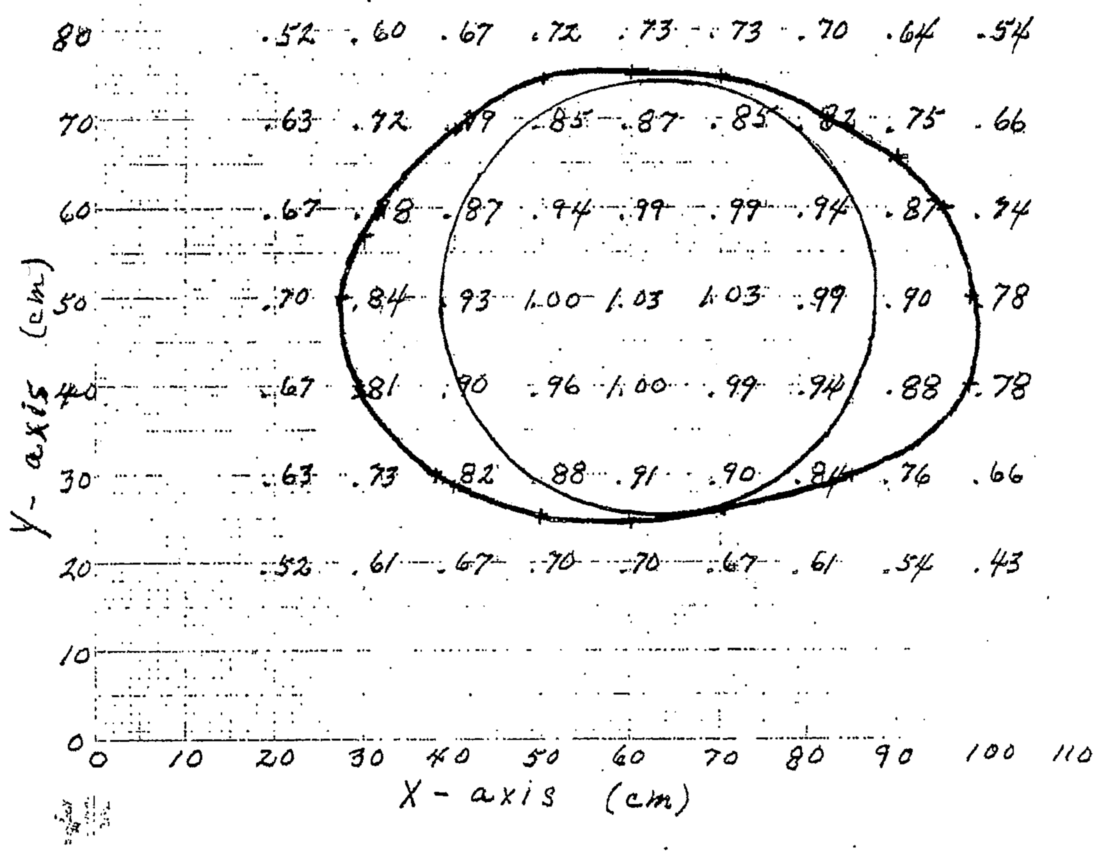

Figure 5 - Representative plotting of radiation intensities on a flat surface at a fixed distance from the sun simulator shown in Figures 3 and 4. In this case the lamps to plane of sensor distance is 90 inches; the sun simulator is two 1000-watt G.E. dichro lamps (type Q10000PAR64/7D of color temperature 5200° K); and the radiation intensities are measured in langley/min.

Curve a) is the isoline of intensity 0.80 langley/min. Note that this is not quite a circle in form but more elliptical having a major axis to minor axis ratio of about 7/5.

Curve b), a circle of 50 cm diameter, has an arithmetical average radiation intensity of 0.94 langley/min. This determination is one of four cardinal points plotted in Figure 6.

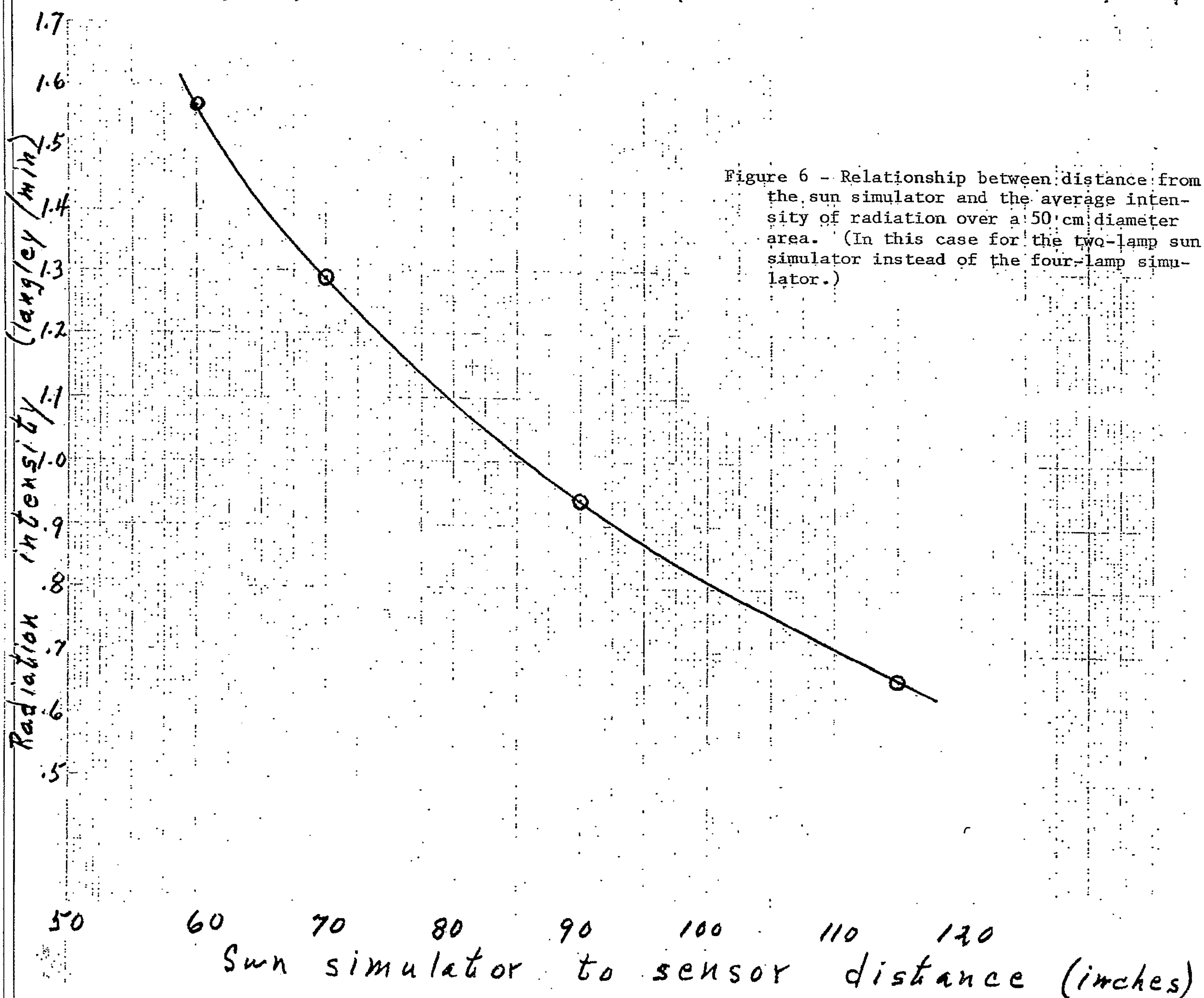

Figure 6 - Relationship between distance from the sun simulator and the average intensity of radiation over a 50 cm diameter area. (In this case for the two-lamp sun simulator instead of the four-lamp simulator.)

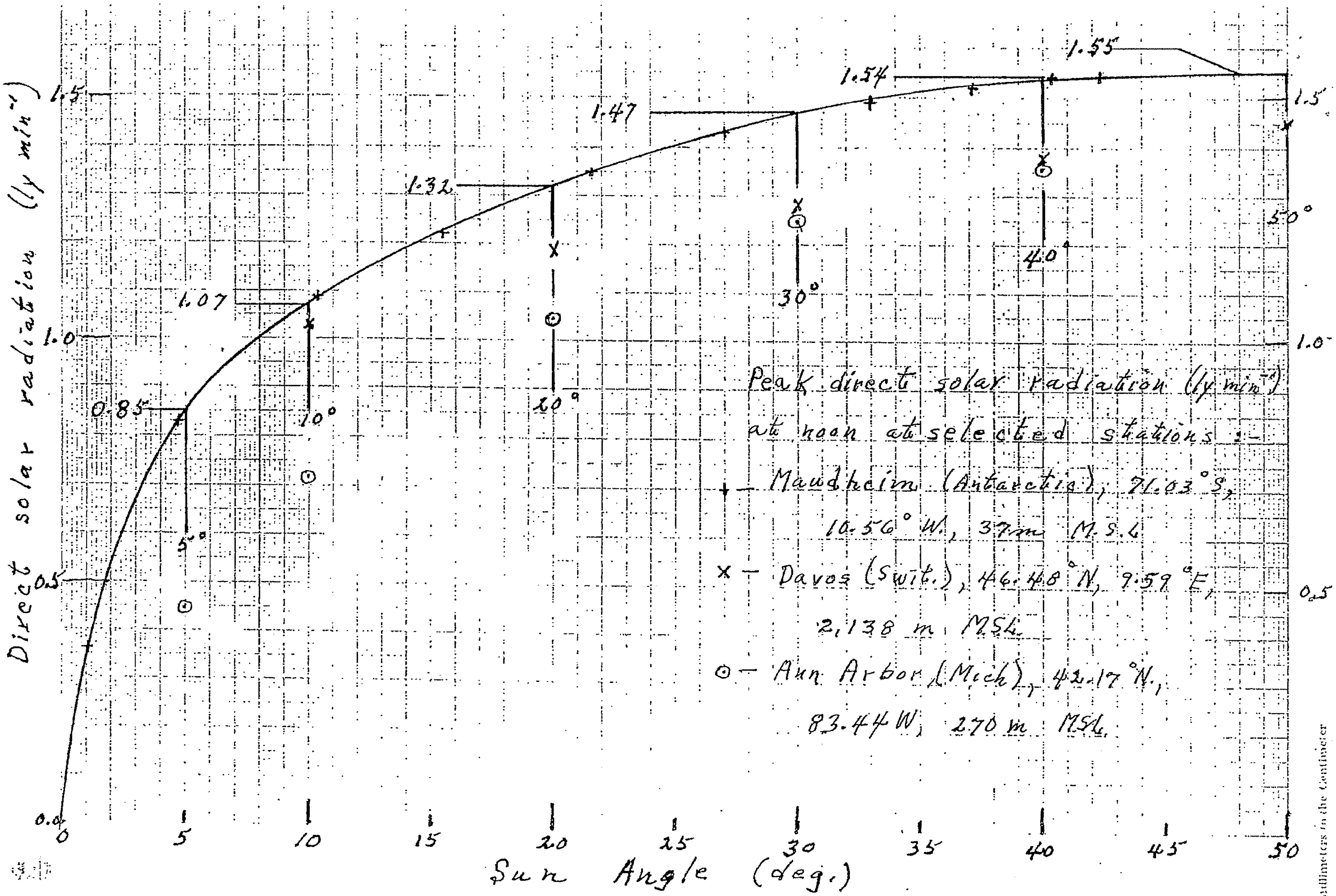

Figure 7 - Curve showing peak solar radiation intensities measured world wide for various elevation angles of the sun. The data is for heights of 0 to 2000 m above sea level. From this curve the maximum solar radiation intensities likely to occur at sun angles of 5°, 10°, 20°, . . . 90° were obtained--see Table I, columns (1) and (2).

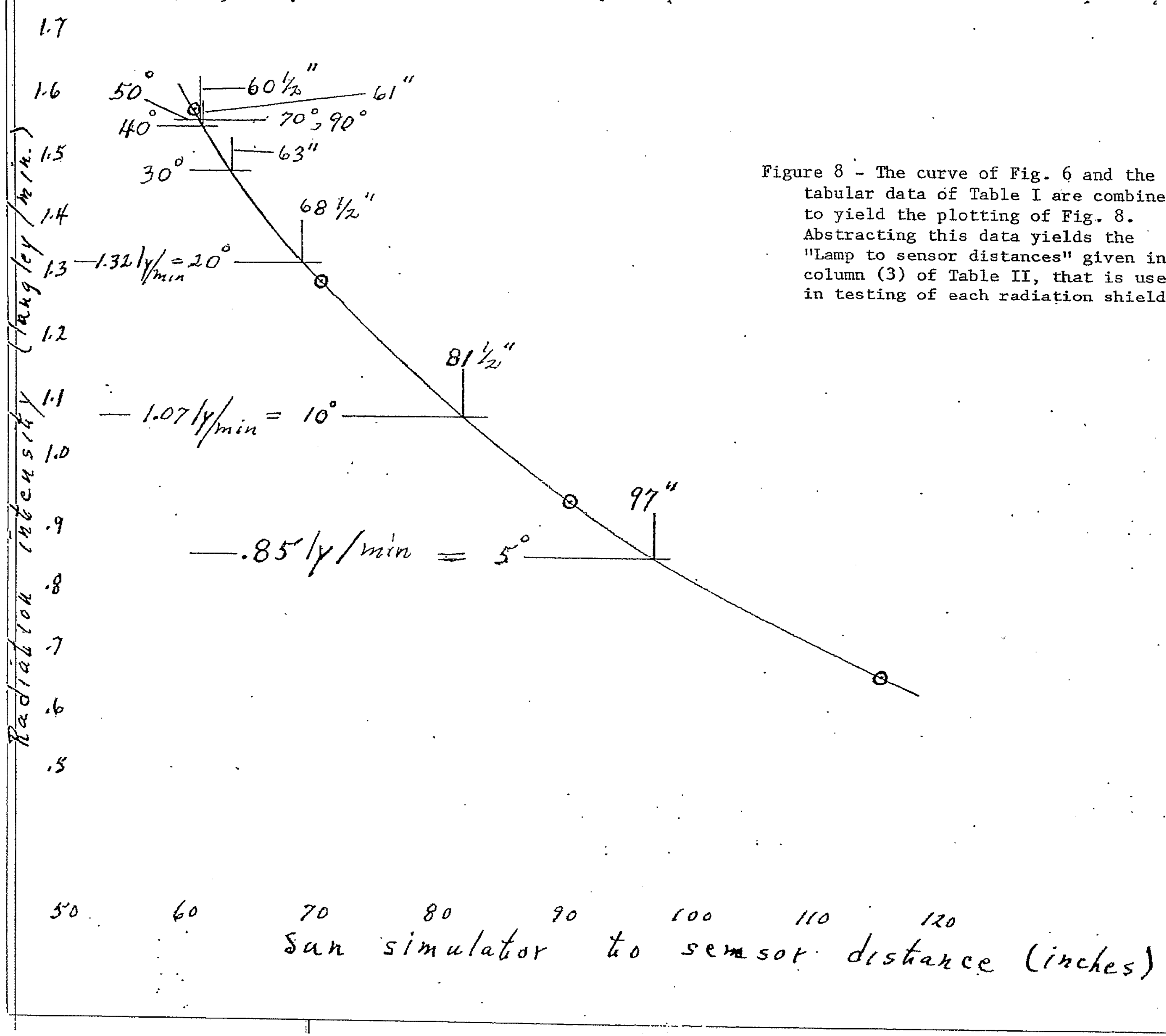

Figure 8 - The curve of Fig. 6 and the tabular data of Table I are combined to yield the plotting of Fig. 8. Abstracting this data yields the "Lamp to sensor distances" given in column (3) of Table II, that is used in testing of each radiation shield.

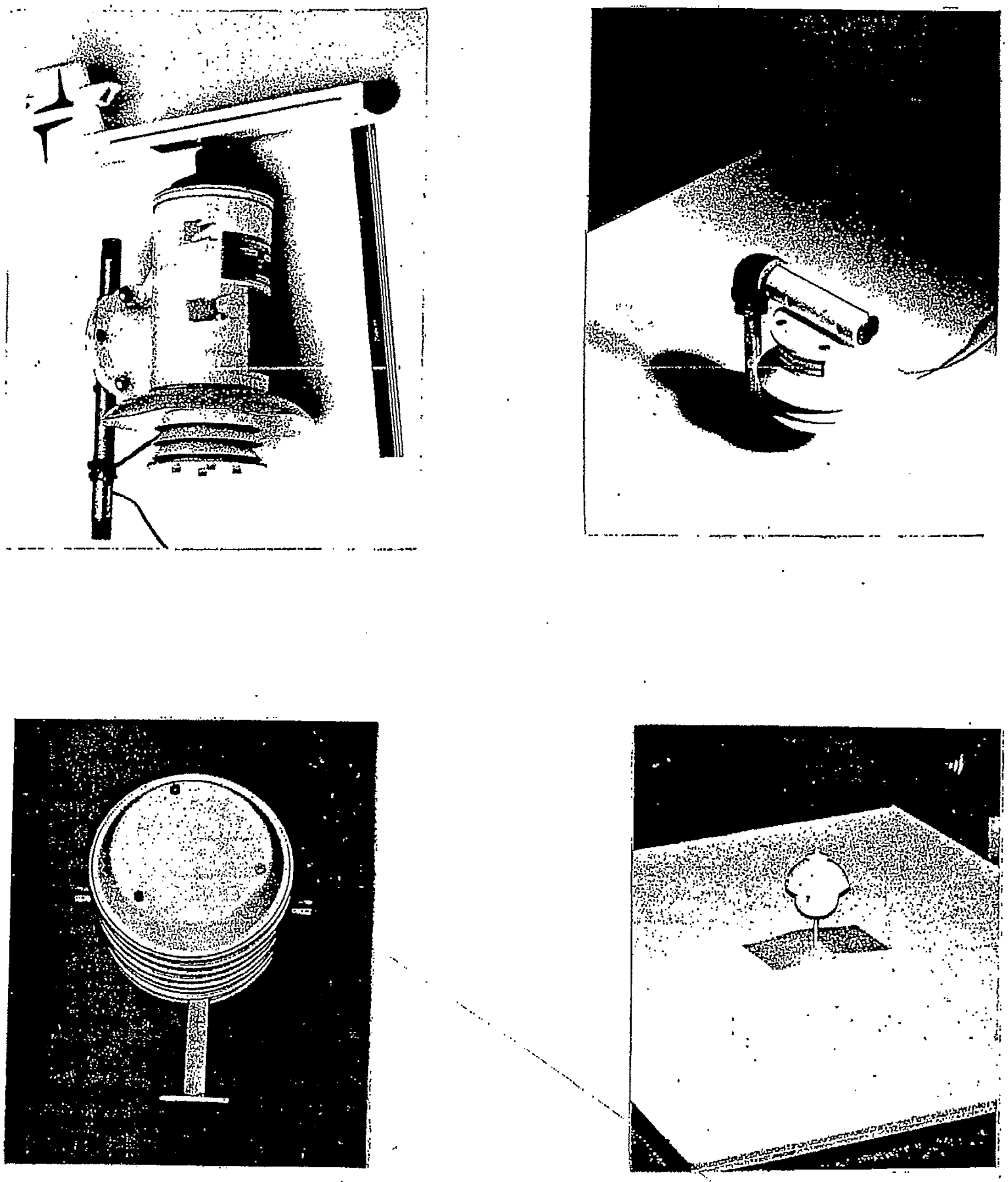

Figure 9 - Photographs of other radiation shields tested:

a) NDBC's General Service Buoy Payload.

b) NDBC's C-MAN.

c) CCIW.

d) Kahlsico Model #37AM500.

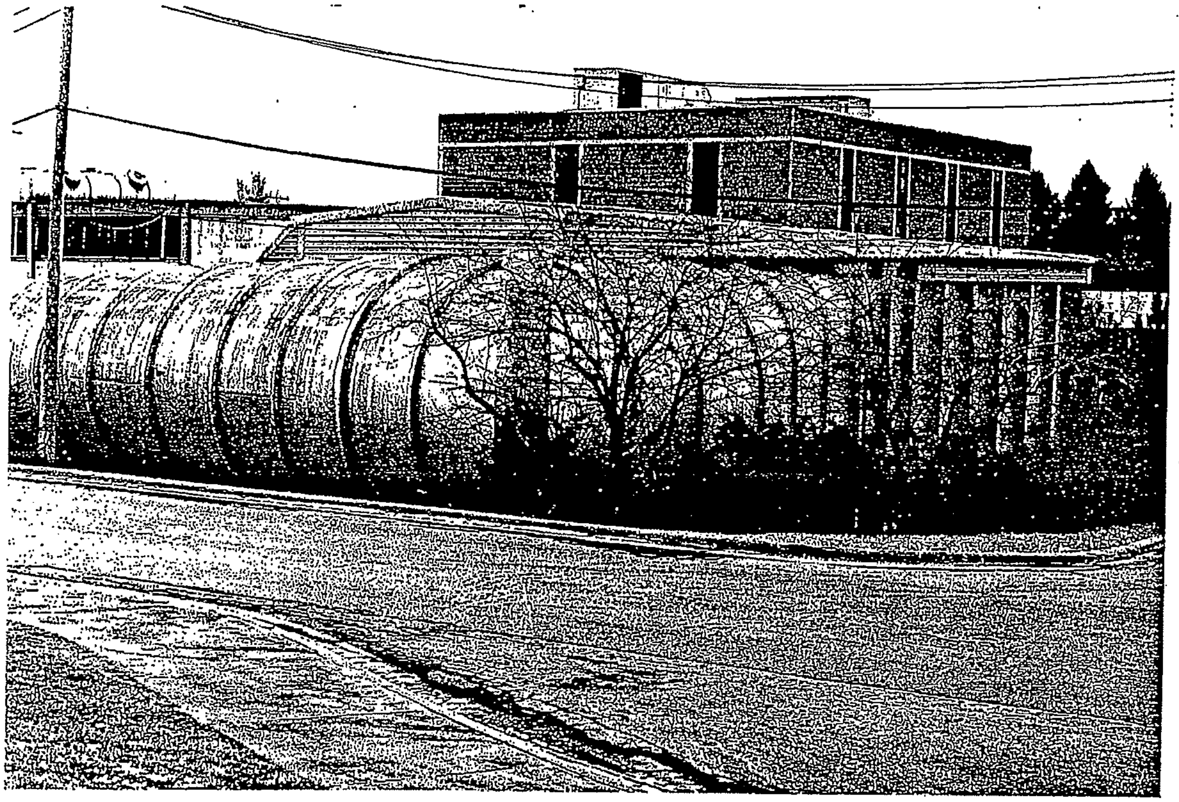

Figure 10 - Exterior of large wind tunnel where tests were conducted. Settling chamber is corrugated metal section on far side of tunnel.

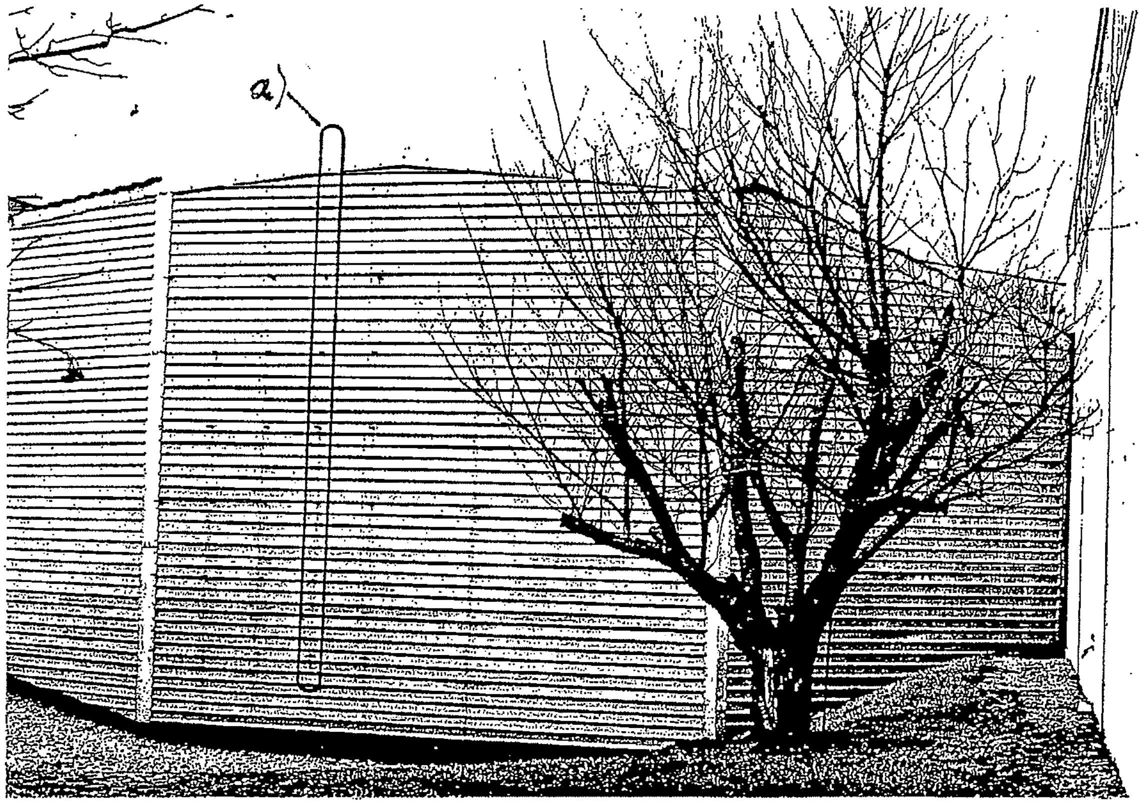

Figure 11 - Exterior view of settling chamber. Inside cross-section of tunnel is 20 ft. high by 26 ft. wide. Air moves from left to right inside the tunnel through five successive fine mesh screens covering complete cross-section of tunnel. Test equipment set up (inside) just to right of #5 screen.

a) Note 6 bolts for tightening one end of #4 screen.

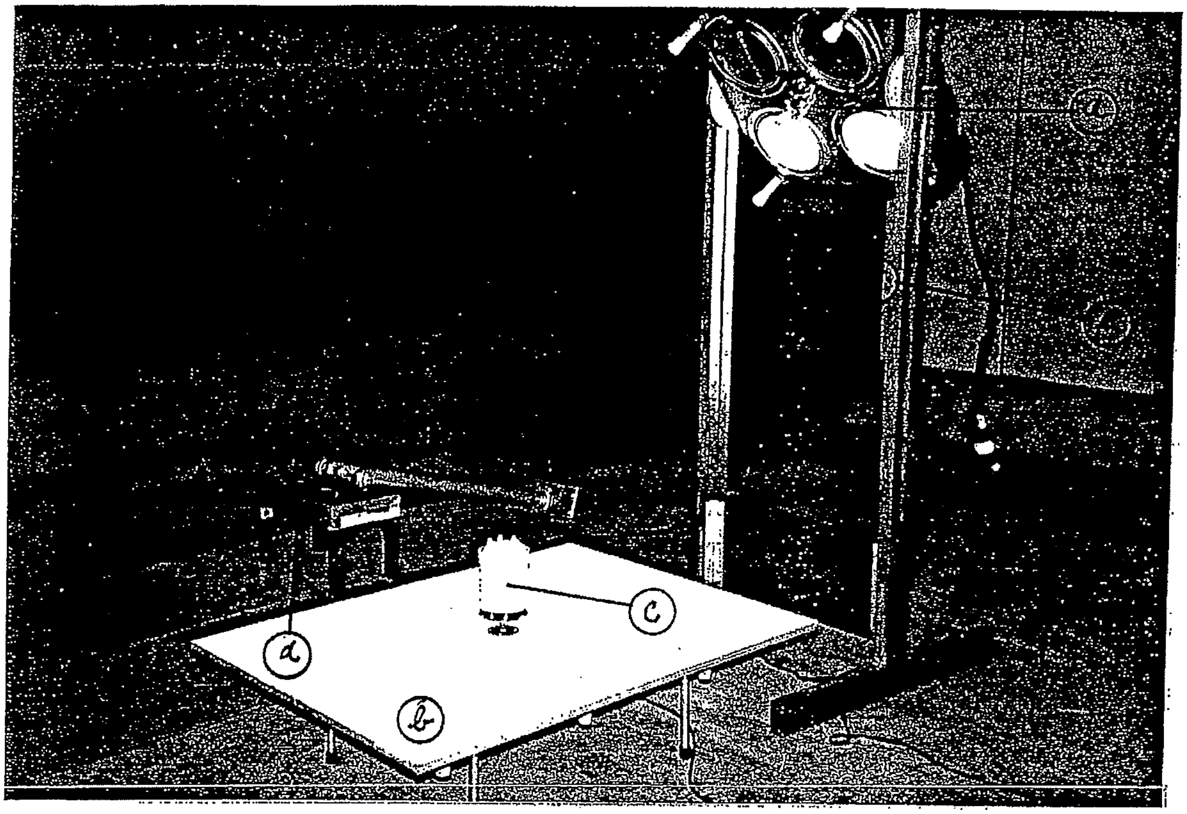

Figure 12 - Test equipment set-up in settling chamber of wind tunnel--so that steady air flow rates as low as 0.1 m/sec may be conveniently and accurately maintained.

a) sun simulator, with two 1000-watt quartz halogen dichro lamps with a color temperature of 5200° K.

b) snow surface simulator--3 ft. x 4 ft. sheet of plywood coated with several layers of high reflectance white paint, dull finish.

c) representative radiation shield under test (Gill Type III, of Rovel).

d) intake of artificially ventilated shield containing reference junction of copper-constantan thermocouple, used to measure heating of shield under test.

e) vertical edge of #5 wind tunnel screen.

Equipment is set-up to simulate the sun at an elevation angle of 40°. Air flow is from point d) toward point c).

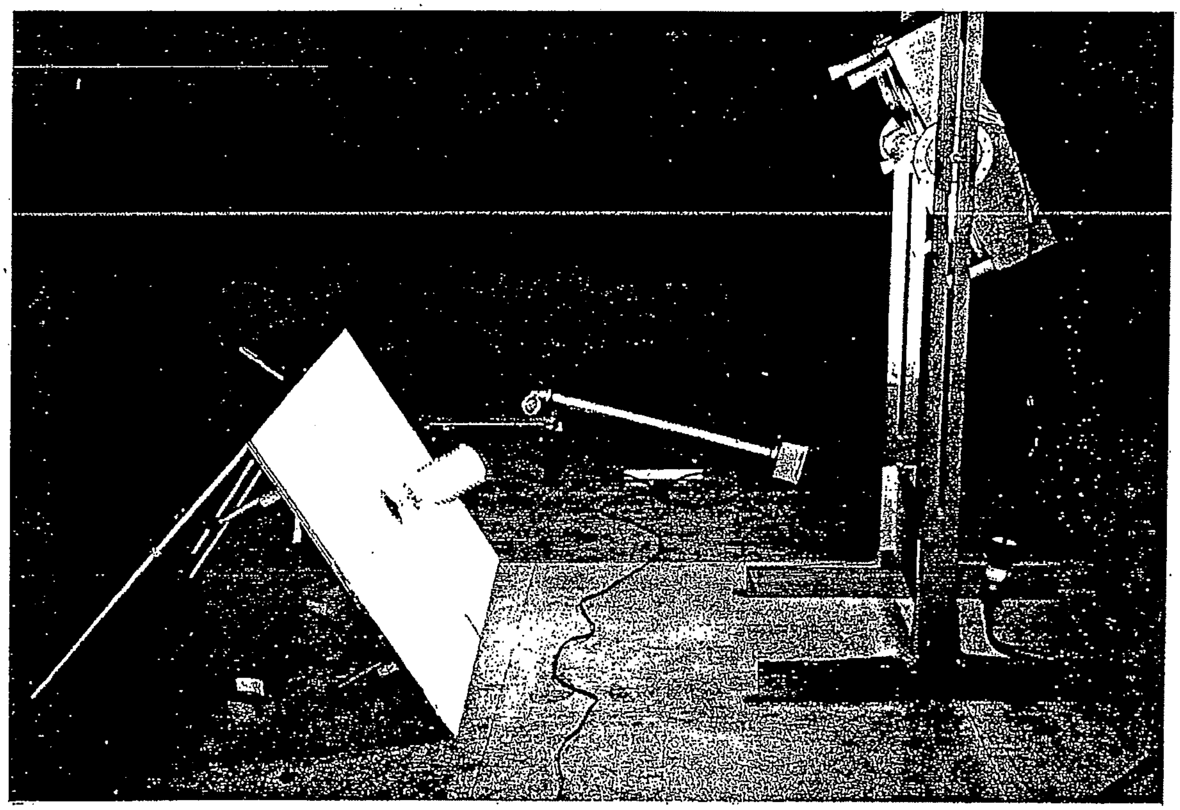

Figure 13 - Radiation shield in place ready for run--similar to Figure 12, except that set-up simulates a 90° sun angle. (Air flow is from dark center interior toward the camera, parallel to plane of snow simulator.)

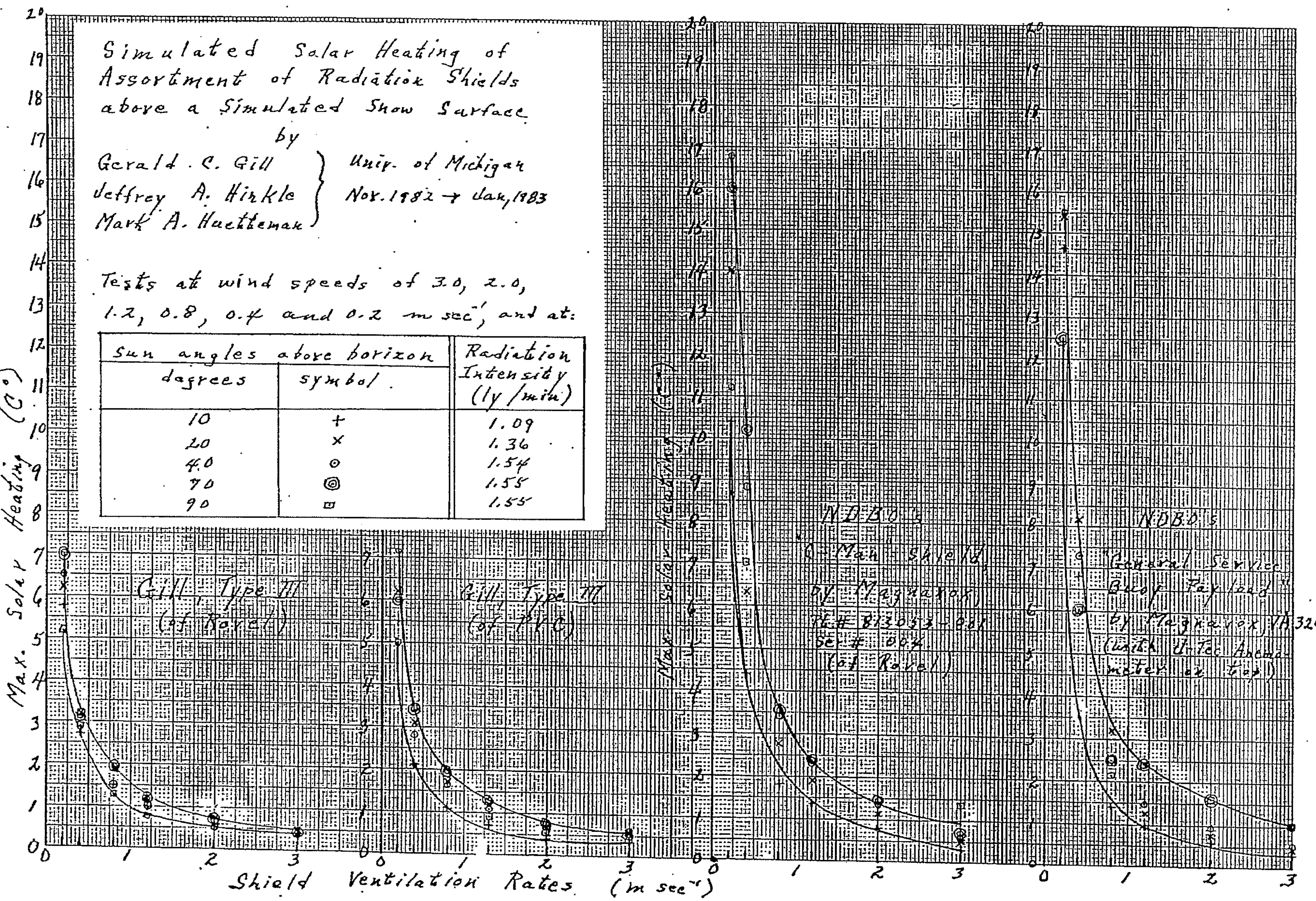

Figure 14 - Heating of four radiation shields, each sequentially located above the simulated snow surface, and irradiated by the sun simulator.

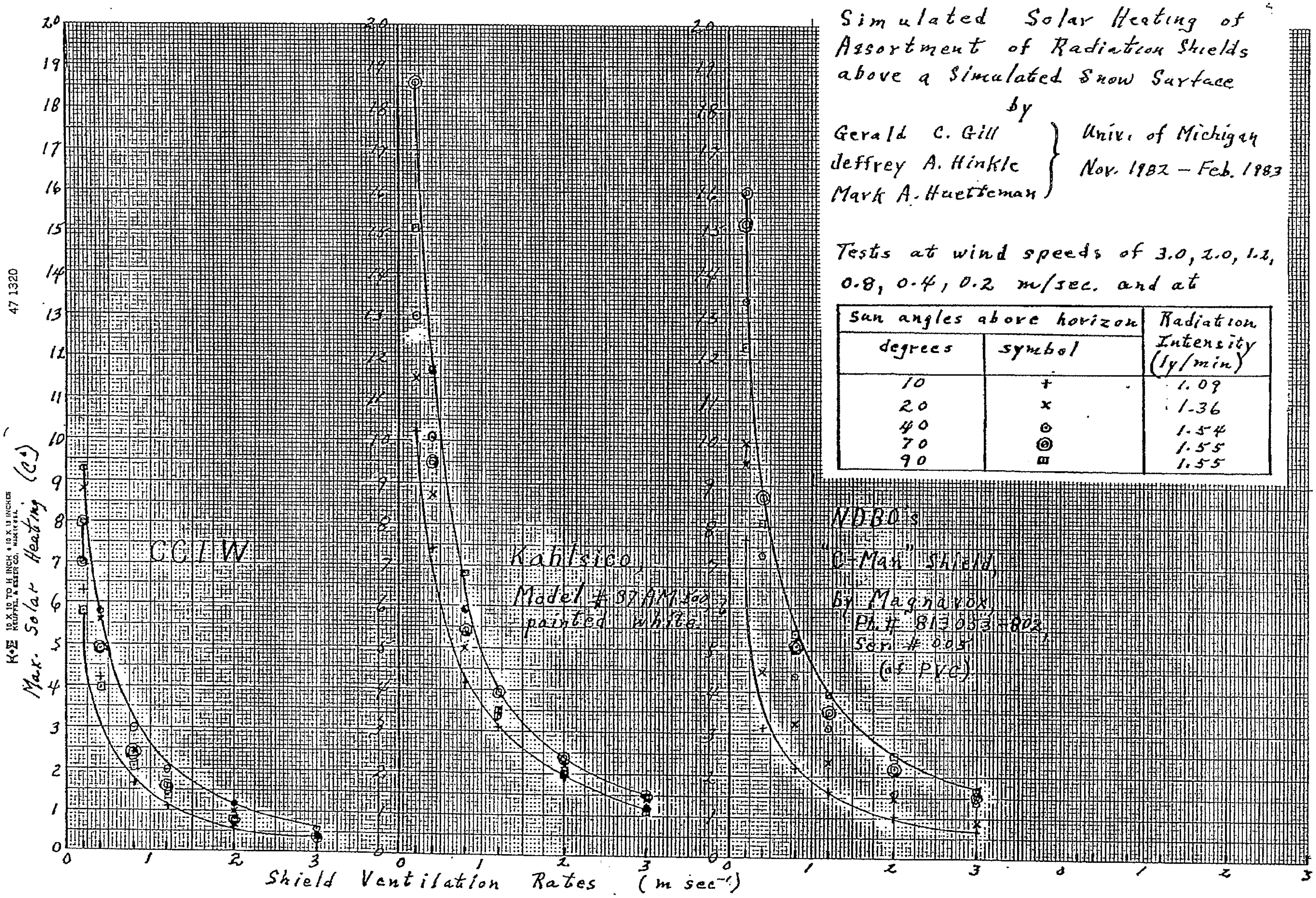

Figure 15 - Heating of other three radiation shields, each sequentially located above the simulated snow surface, and irradiated by the sun simulator.

Sun Angle (degrees above horizon)	Peak Direct Solar Radiation Intensity (langley/min.)
5	0.85
10	1.07
20	1.32
30	1.47
40	1.54
50	1.55
70	1.55
90	1.55

Table I - Peak global solar radiation intensities versus the elevation angle of the sun

Sun Angle (degrees above horizon)	Peak Direct Solar Radiation Intensity (langley/min.)	Lamp to Sensor Distance (inches)
5	0.85	97
10	1.07	81½
20	1.32	68½
30	1.47	63
40	1.54	61
70	1.55	60½
90	1.55	60½

Table II - Lamp to sensor distance for various elevation angles of the sun

Settling chamber of tunnel	"Working Section" of wind tunnel	Dynamic Pressure (inches water on manometer)
0.2 m/sec	10 ft/sec	.027
0.4 "	20 "	.108
0.8 "	40 "	.433
1.2 "	60 "	.975
2.0 "	100 "	2.708
3.0 "	150 "	6.093

Table III - Air speeds used in radiation shield calibrations

Shield Tested[1]	Ventilation Rates 3.0 m/sec: Time Constant T_3 (min)	3.0 m/sec: Time for 90% response to sudden temp. change $2.3T_3$ (min.)	0.4 m/sec: Time Constant T_4 (min)	0.4 m/sec: Time for 90% response to sudden temp. change $2.3T_4$ (min.)
CCIW - (Canada Center for Inland Waters	1.2 (min)	2.8 (min)	5 (min)	12 (min)
Gill Type III (of PVC)	0.7	1.6	4	9
Gill Type III (of Rovel)	0.6	1.4	3.6	8.3
Kahlsico (Model #37AM500, painted white)	2.6	6.0	6.1	14
NDBO, "General Service Buoy Payload," Type VA320[2]	0.7	1.6	10	23
NDBO, "C-Man," of PVC by Magnavox, Pt. # 813053-802	0.6	1.4	3.7	8.5
NDBO, "C-Man," of Rovel, by Magnavox, Pt. # 813053-801[3]	0.5	1.2	19	44

Table IV - Summary of time constants of selected radiation shields

Notes:

(1) Unless specified otherwise, temperature thermojunction located near center of shield cavity.

(2) White plastic cylinder containing thermistor removed before tests and temperature thermojunction installed in center of former space, about 1 cm from any plastic.

(3) Temperature thermojunction taped to underside of white cylindrical thermistor capsule--so time constants more nearly represent complete instrument as supplied.