Accelerated Life Cycle Comparison of Millenniata Archival DVD

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SUMMARY

The NAWCWD Life Cycle and Environmental Engineering branch at China Lake performed an accelerated aging test of archival media from Millenniata Inc. August – October 2009. This test compared discs from Millenniata to current archival grade DVDs by evaluating their stability when exposed to combined light, heat and humidity. This was done in accordance with the Archival Optical Media Test Plan created by Millenniata.

The test that was performed met the intent of the specifications set forth in the original plan; however, the irradiance levels during light exposure could have been controlled better. It is believed that the results are valid.

None of the Millenniata media suffered any data degradation at all. Every other brand tested showed large increases in data errors after the stress period. Many of the discs were so damaged that they could not be recognized as DVDs by the disc analyzer.

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1 INTRODUCTION

In October 2009, the Life Cycle and Environmental Engineering Branch of the Naval Air Warfare Center Weapons Division at China Lake conducted an accelerated life cycle test of archival DVDs from Millenniata Incorporated. The test compared archival discs from Millenniata and competitors by observing the increase in read errors due to combined temperature, humidity, and light conditions. This test was carried out in accordance with the Archival Optical Media Test Plan supplied by Millenniata (1).

This report will cover the test in four sections. The first section, the introduction, will set forth some definitions used in the body of the report as well as give a brief overview of the Millenniata test plan. The test preparation and execution section which follows will describe the instrumentation, setup and execution of the test. Test results, including the test environment and its impact on the discs, will be presented in the results section. Lastly, the meaning of the results and recommendations springing from the test will be stated in the conclusion. Data not presented in the results section will be included in the appendices

1.1 DEFINITIONS

The following is a list of terms and phrases and abbreviations used in this report.

ECC - Error Correction Code, additional information written to a DVD to aid in recovering data

ECC block – 32KB block of data covered by one set of error correction data

PI – Parity Inner, a first level check of data in the Reed-Solomon correction algorithm used for DVDs

PO – Parity Outer, the second level of data checking in error correction algorithm

PIF – Parity Inner Failure, an error which could not be corrected at the first level

POF – Failure of the second level of error correction, irretrievable data

PI8 Sum – Number of PI errors over 8 consecutive ECC blocks

PI8 Max – The maximum PI8 sum encountered

PI8A – Average PI8 sum

1.2 MILLENNIATA TEST PARAMETERS

The current standard for optical media testing and lifetime estimation is ECMA-379 by Ecma International (2). This standard outlines a method for predicting the lifetime of an optical media based upon exposure to elevated humidity and temperature for extended periods of time. The Archival Optical Media Test Plan from Millenniata seeks to build upon and be used as an extension to the ECMA-379 standard.

The two key elements of the Millenniata test which differ from ECMA-379 are consideration of the initial write quality of the discs selected for testing, and the introduction of full spectrum light to the test environment.

1.2.1 DISC CREATION AND ANALYSIS

The Millenniata plan specifies a controlled environment during each session of media selection and analysis. It calls for a temperature between 17°C and 30°C as well as a relative humidity between 5% and 55% which does not deviate from a 30% window in that range (ex: 15% to 45%).

In the test plan, a write-drive selection process is called for. Drives from at least 3 different manufacturers must be tested with media of every dye-based brand used. The drive which provides the best write quality for each manufacturer is used to burn all discs for that manufacturer.

Discs used in the test are required to be less than 12 months old and obtained directly from the manufacturer or through known distribution channels. A minimum write speed of 4X must be used to write a 4.2 to 4.3 gigabyte image on each disc. Before testing, a visual inspection and read analysis must be performed on all discs. Those exhibiting visible imperfections or a PI8 Max Error rate above 175 were excluded from the test in order to ensure that only discs of acceptable write quality were used.

Under the specified test protocol, data analysis is not required to cover the entire disc; three test bands or regions are required. The protocol defines an inner band starting at a 25mm radius, a middle band at 40mm and an outer band at 55mm in order to reduce analysis time. A minimum of 2,400 ECC blocks are to be read from each band and re-read 5 times. The same 2,400 ECC blocks are to be read in each succeeding analysis.

1.2.2 TEST CONDITIONS

The stress test is a single combined temperature, humidity and light cycle. This cycle is composed of a ramp up, a 24 hour dwell, a ramp down and an equilibration period that is conducted with illumination throughout the cycle. Figure 1-1 depicts this cycle.

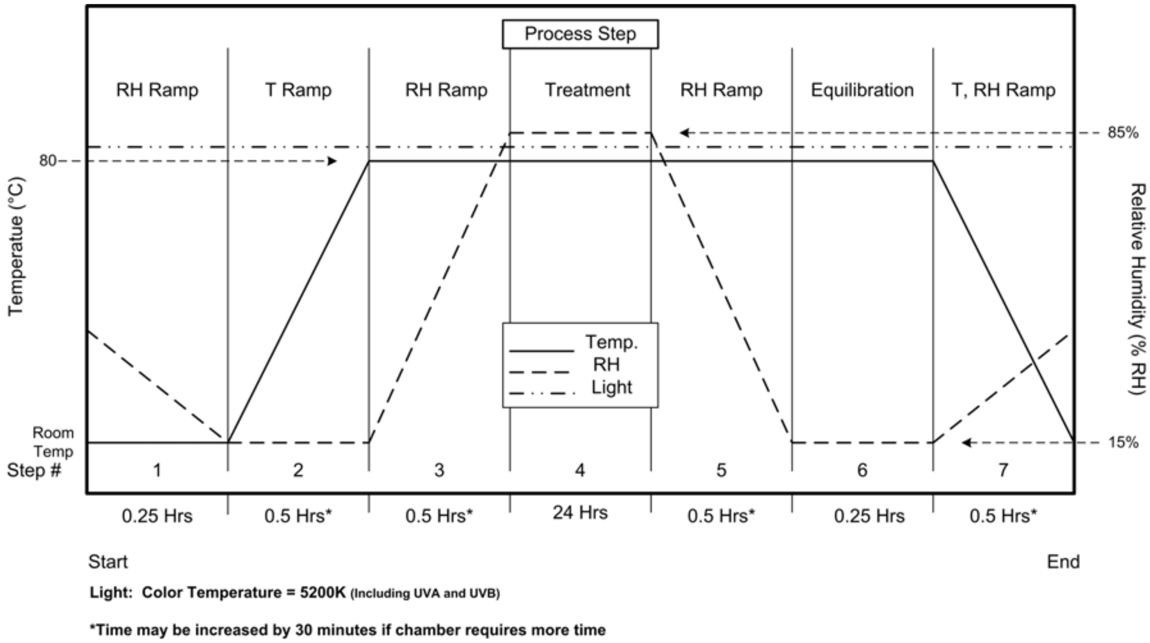

Figure 1-1. Millenniata Test Plan Stress Cycle

The conditions specified during the 24 hour dwell period are listed below in Table 1-1.

Variable	Target	Tolerance
Disc Temperature	85° Max	+2°C -5°C
Chamber Humidity	85%RH	±3%RH
Light Intensity	1120 W/m^2	±45 W/m^2

Table 1-1. Millenniata Dwell Specifications

The light used in the test is further defined by spectral power distribution guidelines. Military standard 810G and the spectral power distribution Table 505.5-I therein is referred to for irradiance levels. This table is shown below.

Spectral Region	Bandwidth (nm)	Natural Radiation (% of total)	Tolerance (% of total)		Irradiance (W/m2)	Spectral Region Irradiance (W/m2)
			Min	Max		
Ultraviolet - B	280-320	0.5	0.3	0.7	5.6	5.6
Ultraviolet - A	320-360	2.4	1.8	3	26.9	62.7
	360-400	3.2	2.4	4.4	35.8	
Visible	400-520	17.9	16.1	19.7	200.5	580.2
	520-640	16.6	14.9	18.3	185.9	
	640-800	17.3	12.8	19	193.8	
Infrared	800-3000	42.1	33.7	50.5	471.5	471.5
Totals					1120	1120

Table 1-2. MIL-STD-810G Table 505.5-I. Spectral power distribution.

2 TEST PREPARATION AND EXECUTION

2.1 TEST INSTRUMENTION

This test required two distinct sets of instrumentation, one for disc measurement and one for stress environment measurement.

2.1.1 DISC MEASUREMENT

To verify that the disc storage and analysis ambient conditions were maintained, an Extech Instruments Corp. 42280 Temperature and Humidity Data logger was procured. This instrument was located in the room containing all the discs and associated equipment. It was set to record temperature and humidity at intervals of 5 minutes. Its range and uncertainty are shown in Table 2-1.

Extech Instruments Corp. 42280 Temperature and Humidity Data logger		
Temperature	-20°C to 70°C	±.6°C
Humidity	0% to 100% RH	±3% RH

Table 2-1. Storage Condition Data logger Range and Uncertainty

For disc analysis two ShuttlePlex playability analyzers from Worthtech (3) were used. These units are not complete disc analysis systems but high-grade consumer technology-based analyzers. They are not meant for use as complete analysis systems to provide data in reference to a Standard. Instead, they are used to provide relative playability information. As a result, readings such as PI8 Max are not identical for different reads of the same ECC blocks. This was mitigated during the test by repeating all disc measurements 5 times and averaging the result.

2.1.2 CHAMBER MEASUREMENT

To aid in setting up the test and measure environmental conditions during the stress cycle, a number of instruments were used. For humidity in the chamber, a thin film polymer capacitor sensor from Omega Engineering Inc. was procured.

<table>
<tr><th colspan="3">Omega Engineering Inc. HX94V Humidity Probe</th></tr>
<tr><td>Humidity range</td><td colspan="2">3% to 95% RH</td></tr>
<tr><td rowspan="2">Response time</td><td rowspan="2">90% response in 1m/s airflow</td><td><20s, 10% to 90% RH</td></tr>
<tr><td><30s, 90% to 10% RH</td></tr>
<tr><td>Temperature compensation</td><td colspan="2">-20°C to 85°C</td></tr>
<tr><td>Sensitivity</td><td colspan="2">0 to 1V for 0 to 100% RH</td></tr>
<tr><td>Measurement uncertainty</td><td colspan="2">±2%</td></tr>
</table>

Table 2-2. Humidity Probe Range and Uncertainty

Self-adhesive type T thermocouples which meet the ANSI special limits specification were used to measure disc temperatures within the chamber. The insulation temperature range and ANSI special limit tolerances for these thermocouples are listed in Table 2-3.

Omega Engineering Inc. SA1 Series T-Type Thermocouple	
Temperature range	0°C to 175°C
Response time	<.3s
Sensitivity	43 μV/°C
Measurement uncertainty	±.5°C or .4%

Table 2-3. Thermocouple Range and Uncertainty

Irradiance information was collected with a CMP3 pyranometer manufactured by Kipp & Zonen B.V. This pyranometer was selected for cost and usability at elevated temperatures. The capabilities of the CMP3 are shown in Table 2-4.

Kipp & Zonen B.V. CMP3 Pyranometer		
Spectral range	310 to 2800 nm	
Response time	95%	<18s
Temperature dependence	-40°C to +40°C	<5%
	+40°C to +80°C	<10%
Calibrated sensitivity	12.05 μV/(W/m^2)	±3.5%
Combined uncertainty	25°C	±3.5%
Combined uncertainty	80°C	±13.5%

Table 2-4. Pyranometer Range and Uncertainty

The output voltage of the CMP3 was read and converted to W/m^2 by an Omega DP41-B universal input meter. This meter was then used to output a 1 Volt per 1000 W/m^2 signal to a National Instruments NI cDAQ-9172 chassis with a NI 9234 module. This NI 9234 module was also used to record the output from the humidity sensor. In addition to the NI 9234 module a NI 9213 module was used to measure the thermocouple outputs. The NI cDAQ-9172 chassis was linked to a computer running LabView Signal Express 3.0.

A program was made for Signal Express which recorded temperature, humidity and irradiance values every 10 seconds. For each reading 500 samples were taken at a rate of 1 kHz and then averaged to obtain the measurement for that 10-second interval.

2.2 DISC PREPARATION

The disc preparation for this experiment consisted of two parts, drive characterization and the actual disc creation / selection.

2.2.1 DRIVE CHARACTERIZATION

The Millenniata discs, while readable in normal DVD drives, are not writable in a standard drive due to the proprietary firmware required to write to the Millennial disc. As a result, there is only one drive that can be used to burn Millenniata media, the M-Writer. For the other discs used in this test, however, there are a vast number of drives available. The test plan sets forth a drive selection and characterization requirement for these drives. To meet this, three identical drives from five leading manufacturers were purchased. These drives and the abbreviations used in this test are listed in Table 2-5.

Abbreviation	Manufacturer / Brand	Drive
OP	Sony Optiarc	AD-7200A
PI	Pioneer	DVR-118LBK
iH	Lite-On	iHAP122
SH	Samsung	SH-S222
LG	Hitachi-LG	GH22NP20
MW	Millenniata	

Table 2-5. Write Drives and Abbreviations

The drives were connected to the ShuttlePlex units using USB to IDE adapters. This method of using the drives proved troublesome. In all configurations, the Hitachi-LG drives were not recognized and could not be used in the test. The other drives also exhibited issues with disc recognition throughout the characterization process. This was solved by the addition of a line conditioning uninterruptible power supply and did not create problems during any subsequent writing and analysis.

For characterization purposes, a single drive from each manufacturer was used to burn three discs from each media manufacturer. The written discs were then analyzed and the average PI8 Max value for each disc manufacturer was graphed for each drive. One or more drives were then selected for each media based on the lowest PI8 Max average. The Sony drive was determined to be best for Mitsubishi and Verbatim, Lite-On and Sony were chosen for MAM-A, and Pioneer was chosen for Delkin and Taiyo Yuden. After determining which drive performed best with each media brand, three discs of each media brand were burned using the remaining drives from the selected manufacturer in order to evaluate performance variation between same-brand drives.

This exercise demonstrated that all drives from the same manufacturer do not perform equally and cannot be used interchangeably. Thus, only the top performing drive, or drives, from each manufacturer were selected for use in this analysis. (In one instance, that of the Pioneer drives, two drives performed similarly, and therefore qualified for interchangeable use.) This exercise was conducted to ensure the best write quality for each dye-based disc brand. Again, this was done because not all drives from the same manufacturer performed equally and, therefore, could not be used interchangeably.

2.2.2 DISC CREATION AND ANALYSIS

With the drive characterization complete, the disc creation was free to be performed. It is important to note that during all aspects of the disc preparation and analysis the discs were handled carefully with nitrile gloves and inspected for dust or imperfections before all steps.

To provide a comparison to current media, every archival DVD currently on the market and a high quality non-archival DVD was tested alongside the Millenniata media. The six brands tested are listed below in Table 2-6.

Manufacturer	Abbreviation
Delkin	DE
MAM-A	MA
Millenniata	AR
Mitsubishi	MI
Taiyo Yuden	TY
Verbatim	VE

Table 2-6. Disc Manufacturers and Abbreviation

A sample size of 25 discs from each manufacturer was decided upon to balance statistical significance with test time. To account for defective discs, substantial quantities of each brand were bought. Discs from each manufacturer were burned on their matching drive and then analyzed. To save time, a full disc analysis was not performed on the discs. Instead, a 2,400 ECC block sample was repeated 5 times at an inner radius of 25mm, a middle radius of 40mm and an outer radius of 55mm. Discs which exhibited a PI8 max below 175 were admitted to the disc sample and those failing to meet this requirement were thrown away.

Four elements were instrumental in obtaining accurate results during this analysis. First, the ShuttlePlex units were warmed up before the start of each analysis session by running some non-test discs through an analysis. Second, the ShuttlePlex was programmed to perform the disc sampling and repetition without ejecting the sample disc. Thirdly, at intervals throughout the test, discs with known error levels were run through an analysis to check that the machines did not drift during the test. The data from these correlation runs was used to correlate the ShuttlePlex units back to a calibrated Pulstec ODU-1000. Lastly, the analyzers were powered by a line conditioning uninterruptible power supply to prevent reading differences cause by voltage fluctuations.

2.3 CHAMBER SETUP AND CHARACTERIZATION

Because neither the Millenniata test nor any other test with similar requirements had been performed at China Lake before, a considerable amount of effort was devoted to creating the environment that was called for. To prepare for this, test a fixture was fabricated, safety concerns were addressed, irradiance and temperature were characterized and the test cycle was modified for the chamber.

2.3.1 EXPOSURE FIXTURE

To carry out the Millenniata test plan, a fixture was required to hold the discs and lights. This rig required corrosion resistance, adaptability and efficient utilization of chamber volume.

The assembly fabricated to meet this need was designed for use in a Thermotron SE-1200L. The SE-1200L was found to have insufficient cooling and humidity generation capability for the test, so the fixture was modified for use in a Sexton Espec altitude chamber which had been retrofitted with a Thermotron 8800 controller. The assembly as it sits in the Sexton Espec chamber is shown in Figure 2-1.

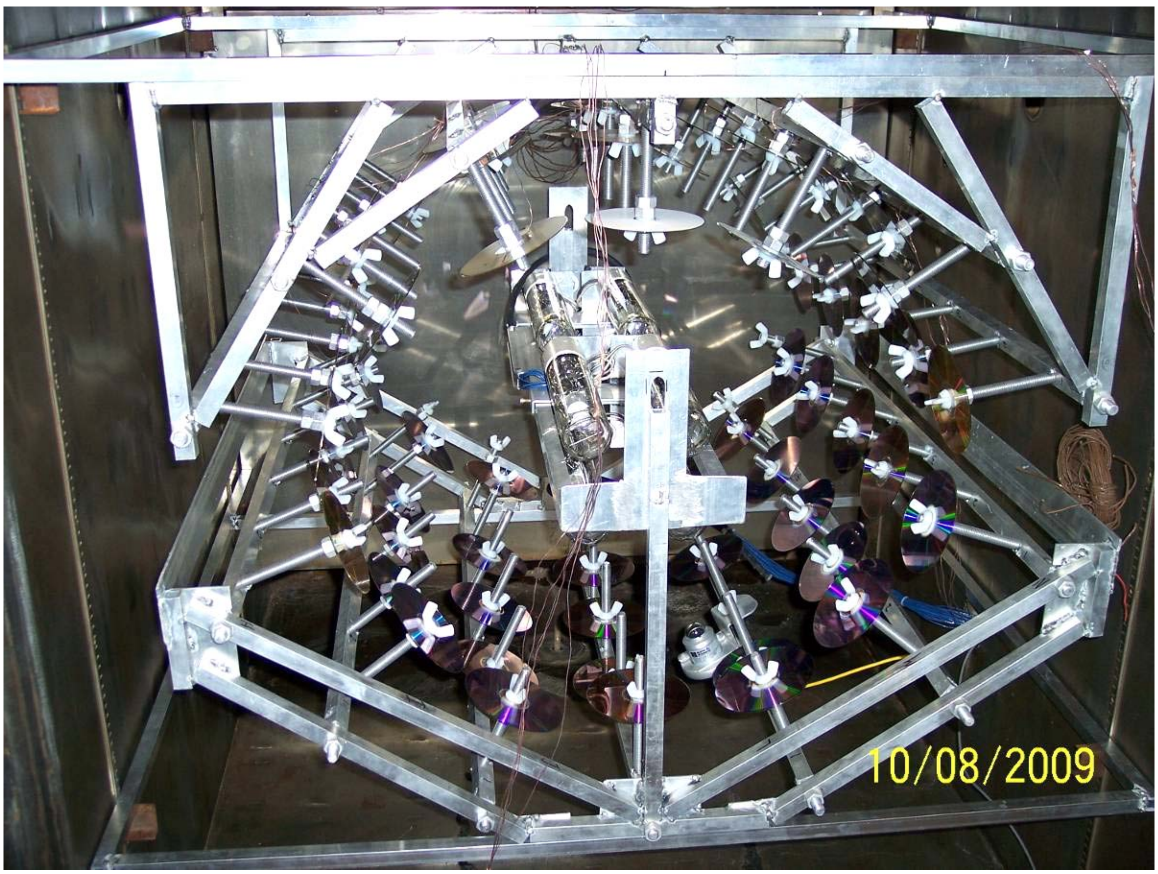

Figure 2-1. Disc Exposure Rack in Chamber

This rig uses eight lamps to produce 3.2kW of light and expose 50 DVDs to irradiance levels in the range of direct sunlight (1120 W/m^2). The setup is composed of four main sections: a ballast box, a light array, an upper rack and a lower rack.

The ballast box holds eight ballasts which conform to the ANSI H33 specification for 400W mercury lamp ballasts. The ballasts used in the box have taps for 120V, 208V, 240V and 277V. The box is wired for 208V and is limited to use on a minimum 20amp circuit. In addition to a 208V connection the box requires a 120V connection to power the fan. The fan is very important, as the transformers inside the box dissipate close to 700W of heat during operation. The interior of the box is shown in Figure 2-2.

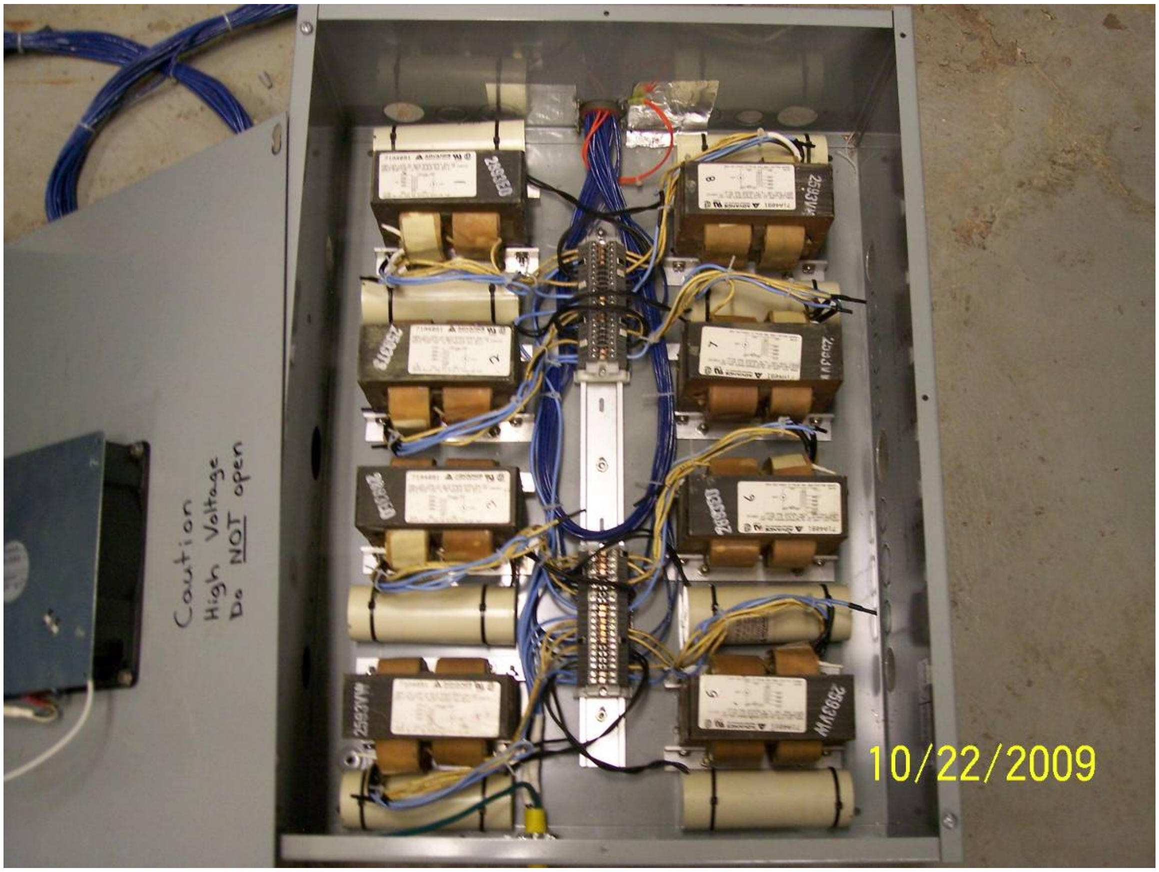

Figure 2-2. Ballast Box Interior

The ballast box is located outside of the chamber and is connected to the lamp array by a 10 foot long wiring harness with a multi-pin connector. This connector, shown in Figure 2-3, fits in the pass through holes on the chamber allowing easy placement and removal of the light array.

Figure 2-3. Wiring Harness Connector

The lamp array which the wiring harness connects to is 36" long and roughly 8" square. It holds eight Clean Ace™ MT400DL/BH metal halide lamps from Eye Lighting International of North America, Inc. These lamps provide light that is very similar to natural sunlight with a color rendering index of 90 and a corresponding color temperature of 6500K.

This array, as Figure 2-1 shows, is mounted horizontally between the two racks. It is supported by the lower rack and is adjustable in the vertical axis to allow positioning equidistant from the upper and lower racks. A more detailed view of the light bar is shown in Figure 2-4.

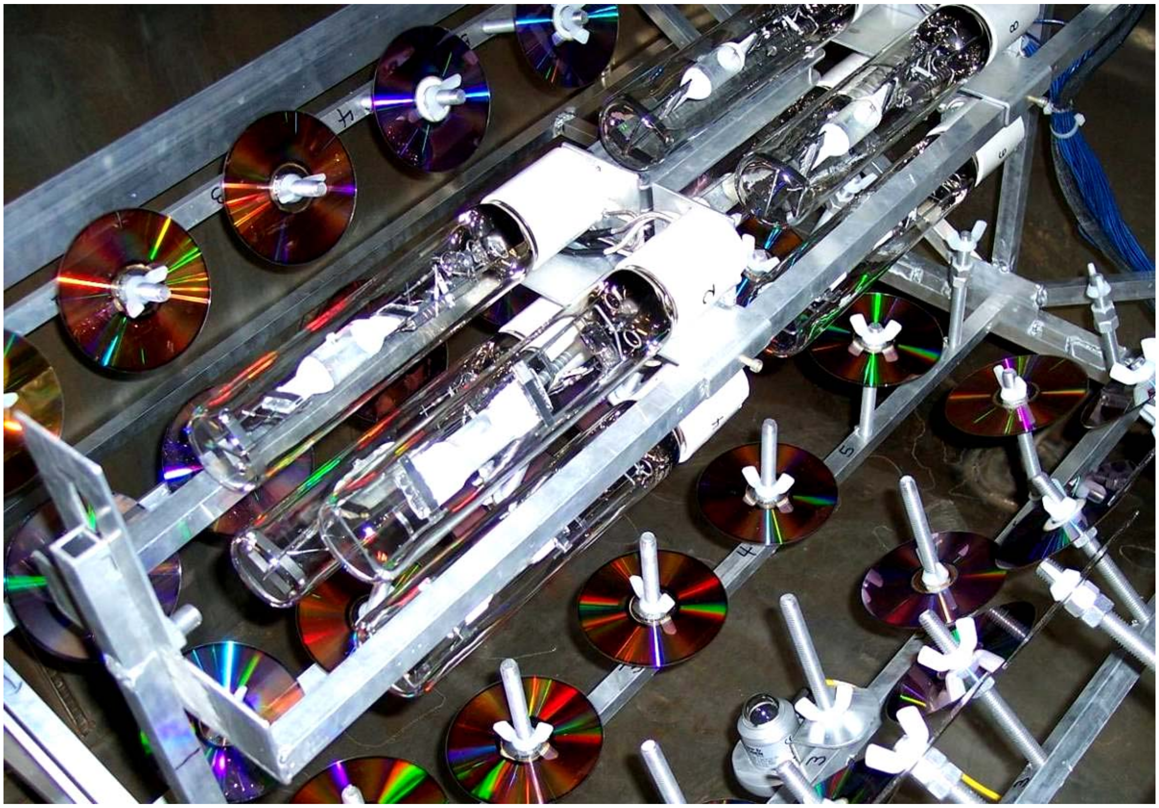

Figure 2-4. Lamp Array Detail

This photograph shows the front cluster of four bulbs. There is a front and rear set, both of which can be moved independently along the central axis of the setup. This allows the radiation pattern to be adjusted for uniformity along the depth of the racks.

Each rack is composed of a frame and 7 disc rows. The rows are arranged around the lamp array in an arc with a 20” radius. Each row is 36” long and has 6 rods spaced equally along the length. So that the discs can be pointed at the light source, each row is free to pivot around its long axis. To maintain the desired angle, the rows are secured by tightening a nut at each end. Figure 2-5 shows this pivot point and securing nut.

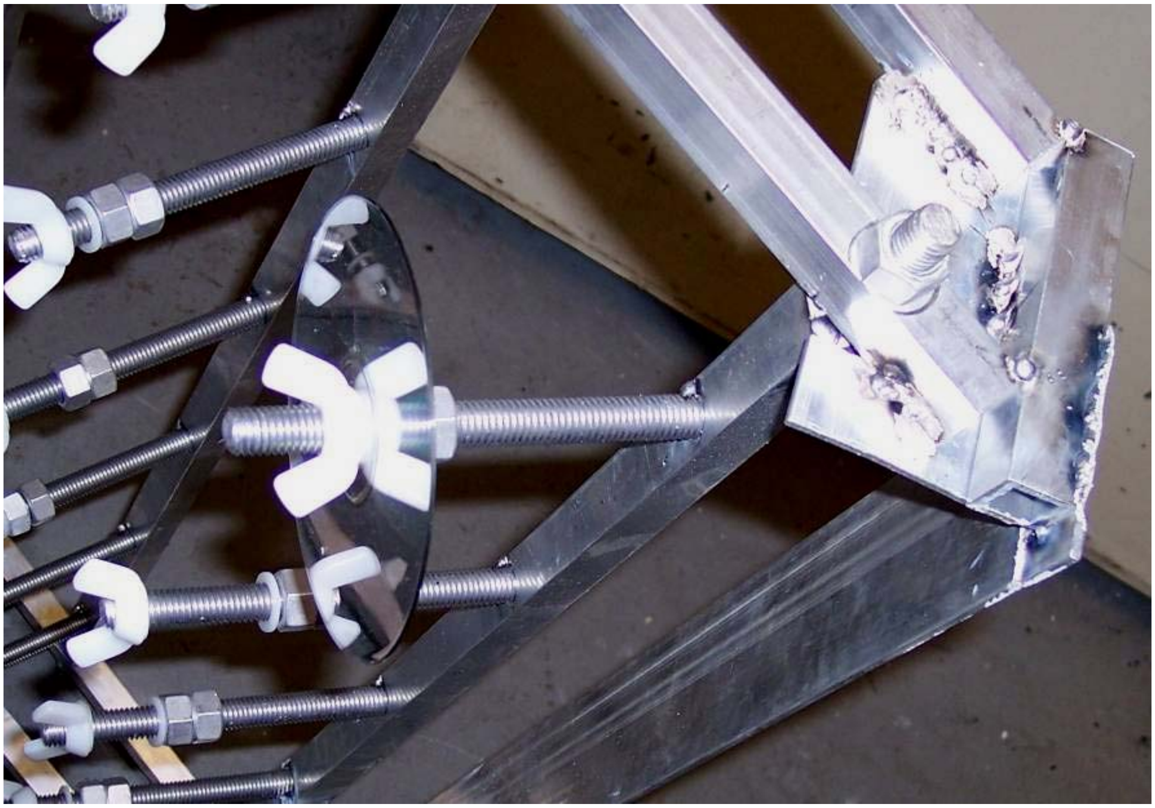

Figure 2-5. Disc Location Adjustment Detail

In addition to the pivoting point, Figure 2-5 also gives a good view of the rods used to hold discs. These rods are 6” long sections of threaded ½” aluminum. On each rod there are two aluminum nuts which are free to travel along the rod. This travel controls the irradiance at each location and is locked by tightening the nuts against each other. A nylon washer prevents the nuts from scratching test discs while a nylon wing nut clamps the discs down.

The final adjustment mechanism in the rig is the method of holding the rig in the chamber. As can be seen in Figure 2-1, both racks are suspended in the chamber by brackets on the side of the chamber. Because the racks are separate, they can be moved closer or farther apart to adjust light levels.

The racks include a numbering system. Figure 2-6 depicts the fixture as it would appear looking through the chamber door showing the alphabetic row designation used. The upper 7 rows are labeled A through G and the lower 7 rows are labeled H through N in counterclockwise order.

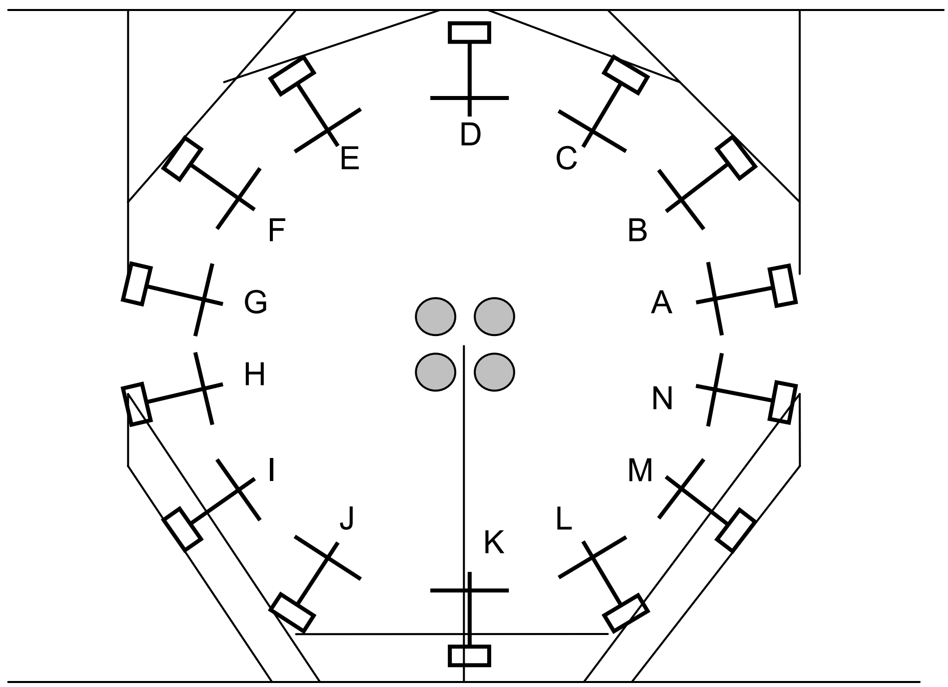

Figure 2-6. Chamber Layout Front View

The row designation is accompanied by a numeric depth starting with number 1 located in front next to the door and ending with the last usable location, number 5, at the rear of the chamber. This is illustrated in Figure 2-7 which shows a bird's eye view of the rack numbering.

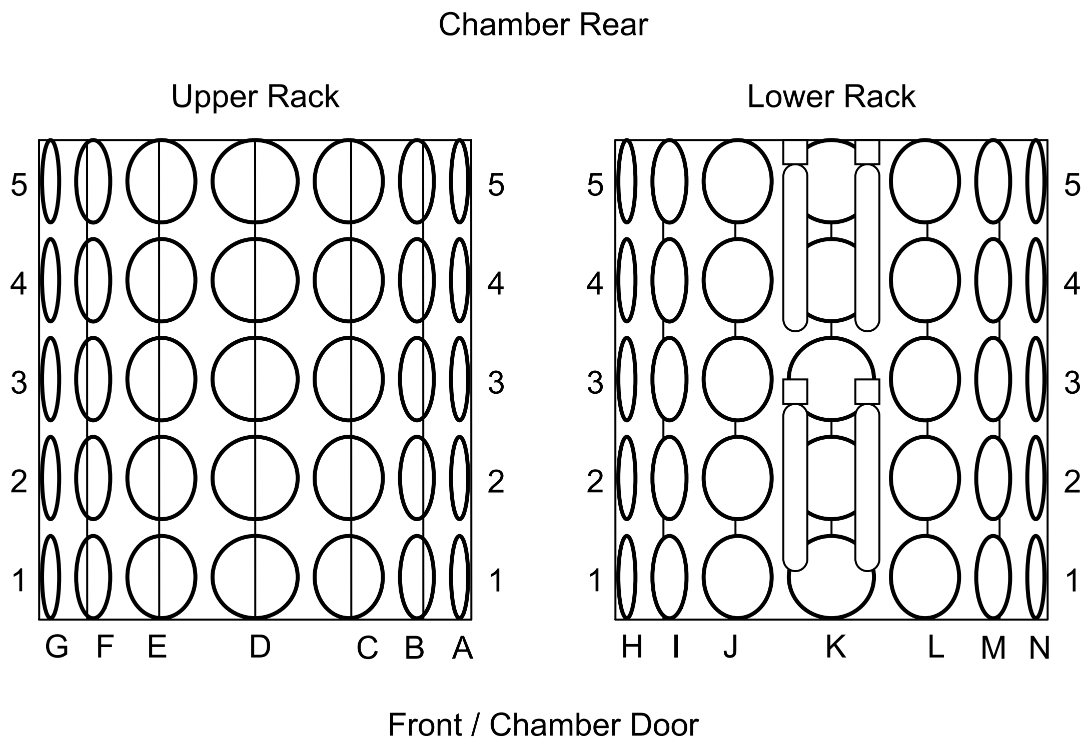

Figure 2-7. Chamber Layout Top View

This location numbering system was used throughout the test to record disc positions.

2.3.2 PROTECTIVE MEASURES

In addition to the common hazards of temperature chamber operation this test required extra safety precautions due to the 3.2kW light array.

While the fixture was designed for elevated temperatures and light levels it was important to inspect the wiring for melting or any other degradation that would indicate the system was being overstressed by the conditions. This was imperative since during the adjustment phase direct handling of the fixture while energized was necessary, increasing the consequences of system failure.

In addition to the electrocution hazard posed by the fixture, the light itself was a danger. Because the lamps used in this test were chosen for their representation of sunlight they are not filtered for ultraviolet radiation. Consequently, at the irradiance levels encountered while adjusting the fixture, sunburns and eye damage were a major concern. Due to the warm up and cool down periods inherent to metal halide lamps it was necessary to run the lights with the chamber open during all adjustments. This posed a danger for both those adjusting the fixture and bystanders.

To protect uninvolved people, spectra welding curtains which block the dangerous wavelengths below 500nm were set up around the chamber door and the viewing window of the chamber was covered.

For the operator head to toe covering was required. A welding helmet with a #10 shade was used to shield the eyes and face. Underneath the welding helmet a nomex hood was worn to protect the neck and uncovered portions of the head from light and heat. For protection of the arms and torso, in addition to a long sleeve shirt, a multilayer jacket was donned. The jacket had cuffs which could be tightened over the wrist to improve maneuverability as well as preventing entrance of light. These cuffs were tightened over sheepskin gloves with extra long gauntlets. The close fitting sheepskin was necessary for dexterity during the irradiance adjustment process. In addition to the gloves and other protective gear long pants were worn with leather shoes.

2.3.3 IRRADIANCE ADJUSTMENT

While the fixture was designed around the target irradiance, significant adjustment was needed to bring every disc location to the correct level. The first step in adjusting the assembly was hanging the racks an appropriate distance apart. This was done by trial and error. The lights were turned on and the irradiance was measured at various locations on both racks, the racks were then moved and process repeated. At the final position the lower rack holding bracket was located 14” above the floor chamber and the upper rack bracket was located 47” above the chamber floor.

Once this preliminary adjustment was completed the individual rows were all rotated to point at the center of the lamp array and tightened down enough to prevent movement during further adjustment and the test itself. The lights were then turned on and irradiance measurements taken to determine if the radiation pattern was reasonably consistent from the front to the back of the chamber. This was not the case and the lights were de-energized to move the two bulb clusters farther apart and closer to the front of the chamber. After adjustment proper irradiance levels were attainable from the door to depth 5.

With the major adjustments finished the chamber was ready for adjustment and recording of light levels at every disc location. To do this, the chamber was filled with a representative sample of discs and the lights were allowed to burn at room temperature for over an hour. The irradiance at each position was then adjusted by moving the aluminum nuts and taking a reading. When the reading appeared to be close to the desired irradiance, the chamber door was shut and the irradiance recorded. After every location was measured, the lights were extinguished and the nuts were tightened against each other to lock in the adjustments. This process was performed on all 70 usable locations and took two people a day to complete.

2.3.4 TEMPERATURE ADJUSTMENT

Due to energy addition from the lamps and airflow patterns in the chamber, disc temperatures were neither uniform nor the same as that of the chamber air. To achieve similar disc temperatures throughout the chamber and keep maximum temperatures below 85°C, both the chamber set temperature and airflow were modified.

Initially, disc temperatures within the chamber varied by more than 10°C. To remedy this various scoops and baffles were tested. Because full temperature tests with lights would have taken over 2 hours, they were not a viable option for trying new arrangements. Instead, as a first check, an anemometer was used to measure airspeeds in various areas. Once an arrangement was deemed to be worth testing further, the chamber was quickly ramped up to 60°C and back down as shown in Figure 2-8.

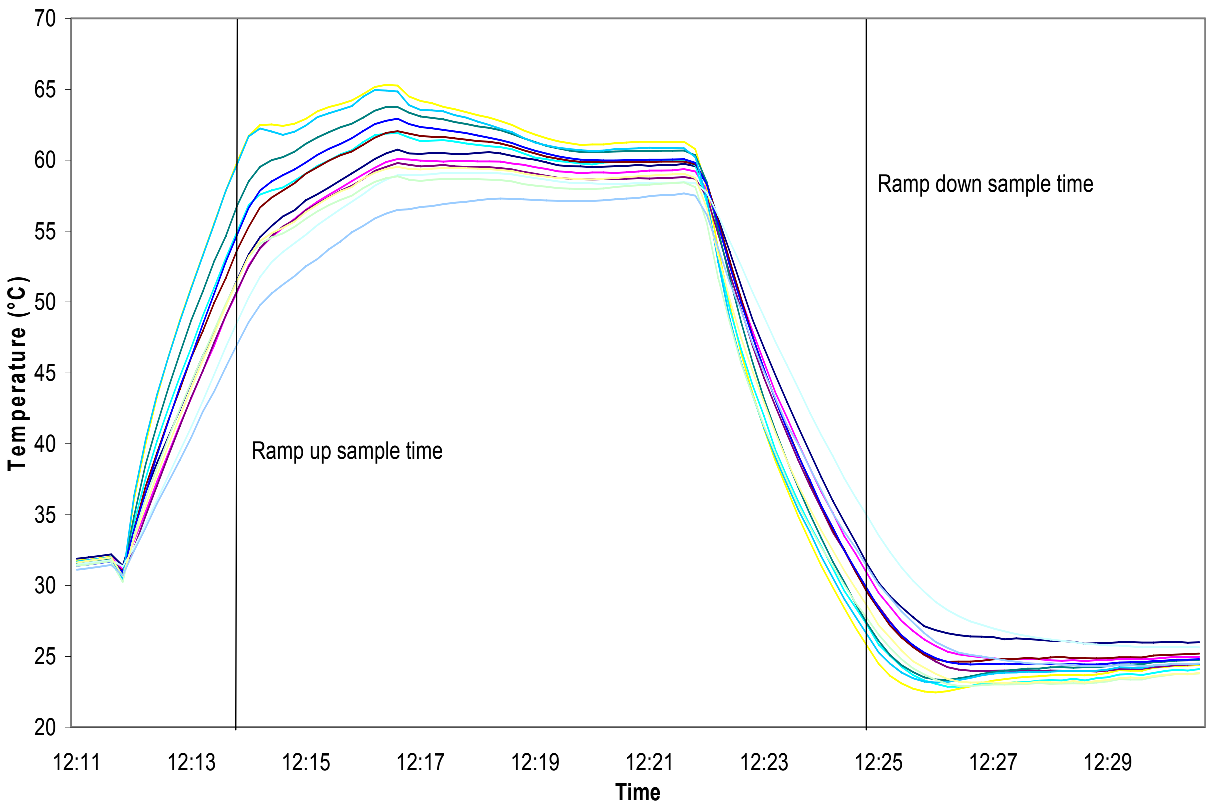

Figure 2-8. Representative Ramp Cycle for Airflow Measurement

This quick temperature ramp was useful because thermocouple equipped discs positioned in locations that had greater airflow responded to the chamber conditions quicker than other discs. To make use of this, two sets of thermocouple readings were taken, one at the end of ramp-up and one at the end of ramp-down. The average value for the ramp-up condition was then subtracted from every ramp-up reading and the average ramp-down temperature was subtracted from the ramp-down values. This ramp-down difference was then subtracted from the ramp up difference to give a total ramp difference. The total ramp difference was then graphed on bar charts such as Figure 2-9 to demonstrate which portions of the chamber had excessive or insufficient airflow.

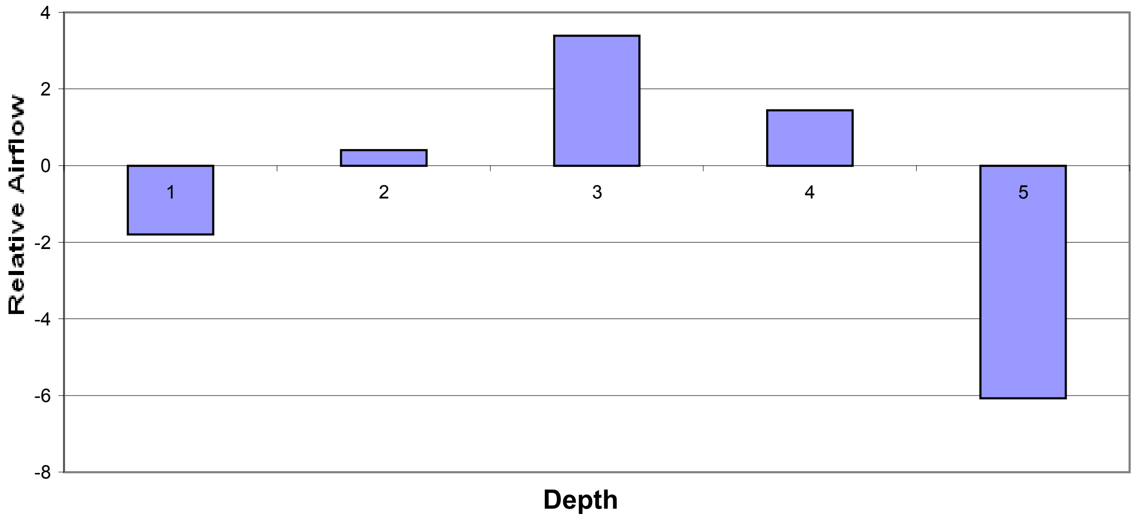

Figure 2-9. Representative Airflow Graph by Depth

When these graphs exhibited a significant improvement over previous attempts, the chamber was run up to temperature with lights and humidity to check the actual temperatures. The end result of this tweaking process was two scoops located on the chamber fan screen 3½" from the rear and a large amount of aluminum tape on the end nearest the door. Figure 2-10 below shows the fan screen as it was used in the test.

Figure 2-10. Airflow Redirection Solution

After 2 ½ days of airflow adjustment, this combination was judged to be the most effective solution with a temperature spread in the 5°C range. This range may have been improved marginally by further testing, but it was felt that the results were reasonable for this test and the effort would be better spent elsewhere.

During the initial testing to determine if the chamber could maintain temperature and humidity with the light rig, it was found that the disc temperatures were significantly higher than the chamber air. This was compensated for by adjusting the chamber set point during the airflow modification. The set point that was arrived at by the end of airflow testing was 77.5°C.

The final step in preparing the chamber with regards to temperature was mapping the disc locations for hot and cold spots. Ideally, this would have been performed by running the chamber one time with thermocouple discs in every location. Only ten discs with thermocouples were available however, so the chamber was characterized over multiple runs. Because the temperature runs were lengthy, readings were taken at every other location and the missing readings were interpolated from surrounding data.

The results of the temperature characterization revealed an issue with the chamber setup. The temperatures varied more than was indicated by the disc placement used to adjust the airflow in the chamber. As a result, many locations were over the limit or on the high side of the allowable range. It was observed that if the temperatures were universally lower the number of spots falling within tolerance would be improved. The chamber set temperature was therefore lowered 2°C to 75.5°C.

Instead of performing the temperature mapping again with the new set temperature, the chamber was run up twice to gather readings at the new set point. These readings were then compared to the previous readings to determine an adjustment value for the temperature map.

In addition to temperature differences within the chamber, there was a temperature difference between the Millenniata discs and the dye based media. This temperature difference was anticipated so, during the temperature mapping process, Millenniata discs with thermocouples were placed in locations that were recorded with a normal disc during other temperature mapping runs. The difference between the conventional disc temperatures and the Millenniata temperatures was then used in conjunction with the temperature map to place Millenniata discs in locations that would allow similar temperatures.

2.3.5 TEST CYCLE ADJUSTMENT

The original test profile decided upon with Millenniata consisted of a 30 minute temperature ramp up, a 30 minute humidity ramp up, a 24 hour dwell, a 30 minute humidity ramp down, a 30 minute temperature ramp down and a 15 minute equilibration period. However, during temperature adjustment, problems were encountered with condensation. This manifested itself in two ways. The first was the formation of water spots on the surface of the DVDs in the chamber. The second was a large variation in the disc temperature readings during ramp up and the start of dwell. Figure 2-11 demonstrates the observed temperature variations. The lower limit of the temperature swings corresponded to the wet bulb temperature for the current humidity and temperature conditions.

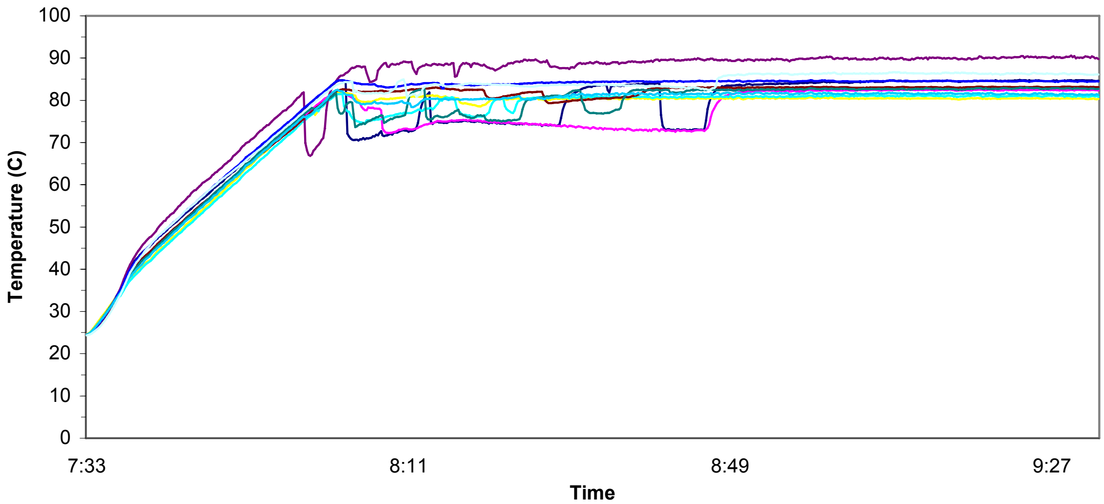

Figure 2-11. Temperature Ramp Showing Condensation

To alleviate this condensation issue, the ramp up profile was changed from the initial 30 minute temperature ramp and 30 minute humidity ramp to a 30 minute temperature ramp with a 45 minute humidity ramp.

In addition to modifying the ramp up program, the ramp down was changed as well. For the ramp down though, the humidity stage was left at 30 minutes and the temperature ramp was extended to 45 minutes. This was done to aid the de-humidification function of the chamber and avoid a large increase in relative humidity due to quickly cooling the air in the temperature ramp down.

These modifications to the ramp profile greatly decreased water spotting and completely eliminated reading fluctuations due to condensation. The final program that resulted from the modifications was 26 hours and 45 minutes long. This program is recorded in Table 2-7 and depicted graphically in Figure 2-12.

Step	Length	Light	Humidity	Temperature	
				Chamber	Disc
Temp Ramp Up	30 minutes	On	Room to 10%	25°C to 77.5°C	25°C to 86°C Max
Hum Ramp Up	45 minutes	On	10% to 85%	77.5°C	86°C Max
Dwell	24 hours	On	85%	77.5°C	86°C Max
Hum Ramp Down	30 minutes	On	85% to 10%	77.5°C	86°C Max
Temp Ramp Down	45 minutes	On	10%	77.5°C to 25°C	86°C Max to 30°C
Equalization	15 minutes	On	10%	25°C	30°C

Table 2-7. Chamber Stress Cycle Program

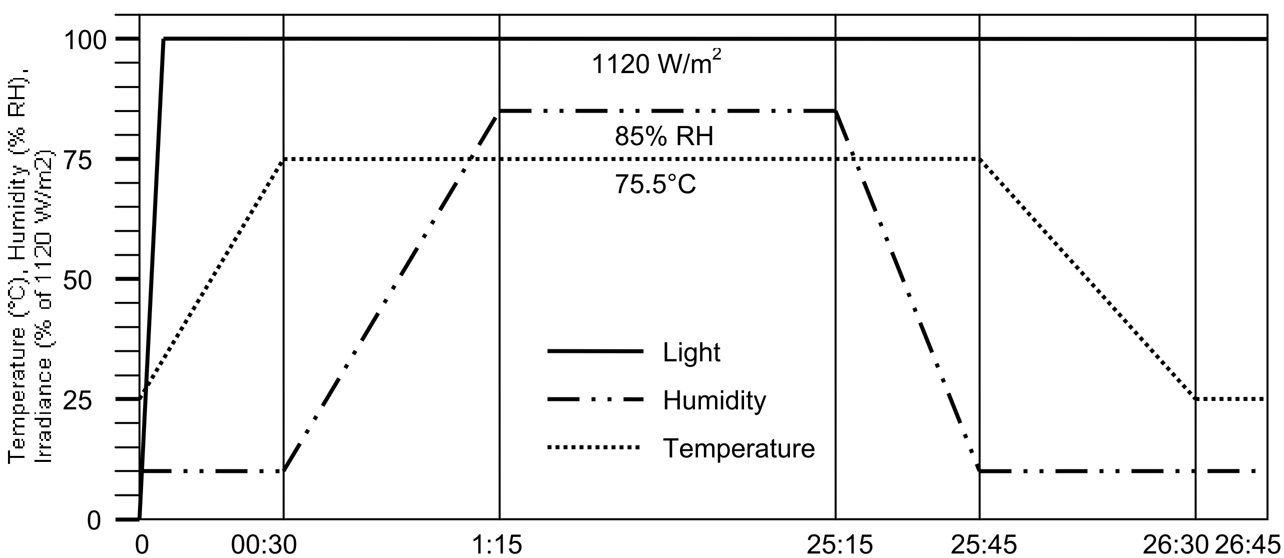

Figure 2-12. Chamber Stress Cycle Program

After checking with Millenniata this stress cycle was used for all three test runs.

2.3.6 DISC LOADING AND UNLOADING

Because of the sensitive nature of DVDs, the chamber loading and unloading process was of great importance. Nitrile gloves were worn and the data surface of the disc was not allowed to touch anything. To make this easier, the upper rack was removed from the chamber and placed on a table during loading.

For each run, an equal number of discs from each manufacturer were placed in a random order on the racks. The one exception to this was the Millenniata discs. They were placed in previously decided locations with lower temperatures that compensated for the higher running temperatures of the Millenniata media. A thermocouple equipped

Millenniata disc was also located in proximity to Millenniata test discs for actual temperature verification during the three runs. To make sure the location of each disc was recorded correctly, the disc location was recorded when putting the discs in as well as taking the discs out.

2.4 POST STRESS DISC MEASUREMENT

Despite measures taken to reduce condensation, the majority of discs came out of the stress cycle with a small amount of water spotting. This would have prevented correct reading of the discs and was removed by lightly misting each disc with an alcohol and de-ionized water solution, then wiping it clean with a soft microfiber cloth. The discs were then dusted with canned air to remove cloth fibers before insertion into the ShuttlePlex.

The same steps performed during the disc creation process were repeated for the final analysis. Each disc was analyzed on the machine it had originally been read on. The drives were warmed up before each analysis period was started and, periodically, a calibration disc was analyzed to check that there was no drift in the readings.

3 TEST RESULTS

3.1 DRIVE CHARACTERIZATION AND DISC CREATION

A data logger was set to record temperature and humidity in the disc test room at 5 minute intervals throughout the test. The data logger malfunctioned or was shut off however and the data was lost. Some data points were recorded by hand during the test. These are listed below in Table 3-1.

Date	Time	Temperature (°C)	Humidity (% RH)
9/16/09	9:10	22.8	33%
9/16/09	3:35	23.9	45%
9/17/09	11:00	23.3	48%
9/21/09	14:05	24.1	33%
9/21/09	17:00	23.7	32%
9/22/09	9:55	23.5	19%
9/22/09	12:06	23.4	17%
9/22/09	13:28	23.6	18%
9/23/09	10:48	23.6	20%
9/23/09	17:36	24.1	22%
9/24/09	10:37	23.9	19%
9/24/09	13:25	24.2	41%
9/24/09	13:33	24.3	34%
9/29/09	12:28	24.4	35%
9/29/09	15:45	24.6	29%
9/29/09	17:28	24.1	16%
9/30/09	14:22	24.1	16%
10/6/09	13:34	23.3	19%
10/13/09	14:43	23.3	46%
10/19/09	13:35	23.9	25%
10/19/09	15:08	23.3	23%
10/20/09	16:28	23.9	21%
10/22/09	8:23	23.8	35%

Table 3-1. Media Analysis Room Temperature and Humidity

As can be seen, the temperature stayed relatively constant between 22.8°C and 24.6°C during the test, well within the 17°C to 30°C limits defined in the Millenniata test plan. The humidity, however, varied greatly and was dependent upon the swamp cooling systems actions. The humidity swing observed during any single day of analysis did not exceed the 30% allowable range defined in the test plan; however, it was consistently above 20%.

The resulting plots from the drive characterization are shown below in Figure 3-1.

Figure 3-1. Drive Characterization Results

As the first two graphs show, the Pioneer DVR-118LBK was most suitable for burning Delkin discs, and the Lite-On iHAP122 and Sony Optiarc AD-7200D were the best for MAM-A discs. The Mitsubishi graph indicates the Sony Optiarc AD-7200D is the best match, the Taiyo Yuden graph shows the Pioneer drive again and the Verbatim graph does not show a significant difference between the Lite-On and Optiarc.

All three drives from each manufacturer used were characterized to determine if they could all be used for burning. The decision based upon this information in Figure 3-2 was that all drives were suitable for use except for the Lite-On B and C drives.

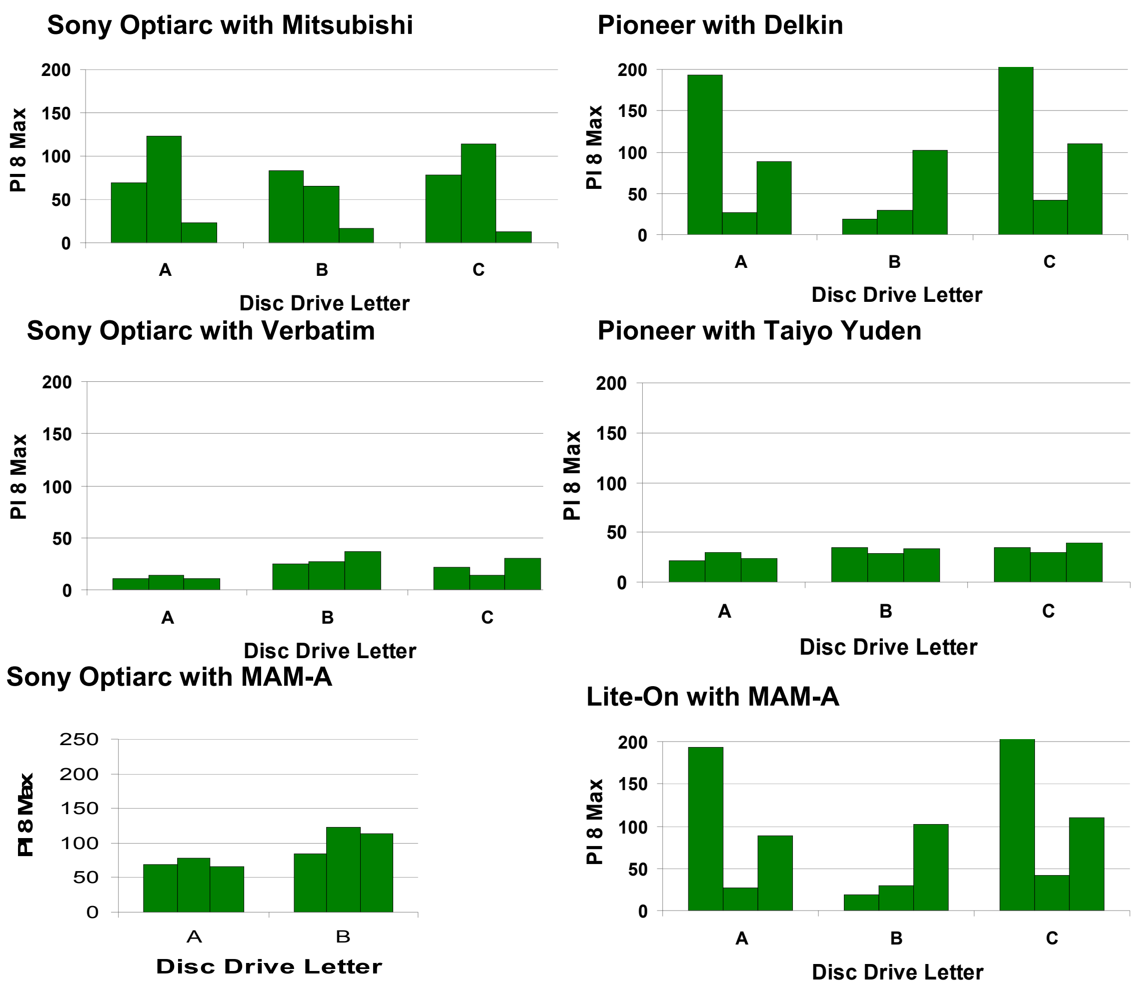

Figure 3-2. Within Manufacturer Drive Comparison

Even after qualifying the drives as described above, the number of discs required to obtain a test sample of 25 discs with PI8 max values below the maximum 175 threshold was not trivial. Certain brands had a successful sample rate of less than 50%. The number of discs that were burned and analyzed in order to provide a test sample of 25 usable discs is reported in Table 3-2. (It should be noted that in order to meet the test schedule, Millenniata agreed to provide preproduction discs. These discs were supplied without the benefit of a production quality assurance program and were recorded in preproduction drives; hence, 29 discs were required to achieve the requisite sample size of 25.)

Manufacturer	Number of Disks
Mitsubishi	25
Taiyo Yuden	25
Verbatim	25
Millenniata	29
Delkin	51
MAM-A	64

Table 3-2. Number of Discs Burned Before Achieving 25 Disc Sample

As can be seen the Delkin and MAM-A brands presented significant problems during the burning process and took more than twice as many attempts as other brands to create a usable sample.

3.2 ENVIRONMENT CONDITIONS

3.2.1 PRE TEST DATA

The result of the irradiance characterization of the chamber is presented below in Table 3-3.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	1106	1132	1117	1128	1122	1143	xxxxx	xxxxx	1147	1126	1132	1142	1129	xxxxx
2	1100	1106	1134	1135	1124	1126	1080	1121	1120	1127	1120	1118	1142	1111
3	1128	1111	1143	1105	1136	1138	1110	1109	1106	1128	1148	1115	1122	1103
4	xxxxx	1107	1136	1105	1100	1102	xxxxx	1115	1104	1119	1125	1130	1124	1153
5	xxxxx	1135	1108	1120	1128	xxxxx	xxxxx	xxxxx	xxxxx	xxxxx	xxxxx	1110	xxxxx	xxxxx

Table 3-3. Chamber Irradiance Map (W/m2)

This irradiance map was taken at room temperature where the pyranometer should have been most accurate. It shows the irradiance levels to be within the Millenniata specification of 1075 W/m^2 to 1165 W/m^2. The lowest irradiance in the setup was location G1 at 1080 W/m^2 and the highest was N4 at 1153 W/m^2.

The initial temperature map at a chamber set point of 77.5°C is shown below in Table 3-4.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	83.7	82.8	83.7	83.6	84.8	83.6	83.3	83.8	83.7	84.3	83.7	83.7	86.1	85.9
2	84.3	81.0	82.6	82.4	82.6	82.8	83.8	84.4	85.1	85.5	84.1	81.2	85.1	87.9
3	84.7	83.8	83.3	81.8	80.4	82.3	84.6	85.5	86.7	86.6	86.0	84.3	85.2	85.3
4	84.7	86.4	86.4	80.9	81.8	81.5	84.7	86.2	87.8	87.9	87.1	84.8	85.0	83.3
5	84.6	88.7	95.0	86.8	84.3	84.1	86.4	87.6	90.3	89.2	89.5	87.1	86.9	85.0
Unshaded cells are actual measurements								Shaded cells are an average of surrounding cells						

Table 3-4. Temperature Map at 77.5°C Set Point (°C)

Because temperature readings were not taken at every location to save time, the map is half actual data and half interpolation. The shaded cells are an average of the surrounding cells, while the cells without shading are actual measurements. What is important to notice about the temperature map is that many of the locations are on the hot side of the 80°C to 87°C range allowed in the test plan. This was remedied by adjusting the chamber set point 2°C down to 75.5°C. The data in Table 3-5 reflects the change this had on disc temperatures.

Location	Temperature (°C)		Difference (°C)
	77.5°C set point	75.5°C set point	
K4	87.1	84.7	2.4
F3	82.3	79.1	3.2
I3	86.7	84.8	1.9
M1	86.1	84.4	1.7
L2	81.2	81.6	-0.3
B2	81.0	79.0	2.0
B5	88.7	89.9	-1.3
D5	86.8	82.3	4.5
C4	86.4	82.5	3.9
C1	83.7	82.5	1.2
E4	81.8	79.7	2.1
E2	82.6	80.6	2.0
A5	84.6	85.6	-1.0
E2	82.6	80.7	1.9
F5	84.1	82.7	1.4
G1	83.3	80.4	2.9
G4	84.7	83.2	1.5
H1	83.8	80.0	3.7
H5	87.6	85.8	1.8
I4	87.8	86.2	1.5
K5	89.5	88.1	1.5
M5	86.9	83.2	3.7
N1	85.9	82.7	3.2
Average difference			**2.0**
Standard deviation			**1.5**

Table 3-5. Temperature Adjustment Data

The average difference in temperature readings as given by Table 3-5 was subtracted from the 77.5°C temperature map to create an adjusted 75.5°C temperature map. This map, Table 3-6, is the predicted temperature of every location during the test and was used to determine the placement of the test discs.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	81.7	80.8	82.5	81.7	82.8	81.6	80.4	80.0	81.7	82.3	81.8	81.7	84.4	82.7
2	82.3	79.0	80.6	80.4	80.7	80.8	81.8	82.4	83.1	83.6	82.2	81.6	83.1	85.9
3	82.7	81.8	81.3	79.8	78.4	79.1	82.6	83.5	84.8	84.6	84.1	82.3	83.2	83.3
4	82.8	84.4	82.5	79.0	79.7	79.6	83.2	84.2	86.2	85.9	84.7	82.8	83.1	81.3
5	85.6	89.9	84.9	82.3	82.4	82.7	84.4	85.8	88.3	87.3	88.1	85.1	83.2	83.0
Lower 25% of usable range				Middle 50% of usable range				Upper 25% of usable range				Outside of range		

Table 3-6. Temperature Map Adjusted for 75.5°C Set Point (°C)

It was anticipated that the Millenniata discs might react differently to the environmental conditions than the conventional dye based media. Table 3-7 shows that this was in fact the case.

	Run 23	Run 24	Run 25	Run 26
AR-1	84.2°C	86.7°C	88.6°C	89.3°C
Conventional	81.0°C	83.3°C	86.1°C	83.3°C
Difference	3.2°C	3.5°C	2.5°C	6.0°C
AR-2	86.4°C	88.7°C	91.2°C	90.3°C
Conventional	83.3°C	84.6°C	83.8°C	84.7°C
Difference	3.1°C	4.1°C	7.5°C	5.7°C
AR-3		91.2°C	89.9°C	88.6°C
Conventional		86.4°C	85.5°C	84.6°C
Difference		4.8°C	4.3°C	4.0°C
Average Difference		**4.4**°C		
Standard Deviation		1.5°C		

Table 3-7. Millenniata Temperature Adjustment

The Millenniata discs ran on average 4.4°C hotter than the other test discs. This is because the Millenniata discs are less reflective than their dye-based counterparts. They were, therefore, placed in locations predicted to be the coolest by the temperature map.

3.2.2 ACTUAL RUN CONDITIONS

The temperature and humidity data collected during the three test runs exhibited very similar cycles. Figure 3-3 and Figure 3-4 show the temperature and humidity ramp conditions for the start and end of the first test. These two graphs are representative of the data collected from the other two runs which is available in Appendix B.

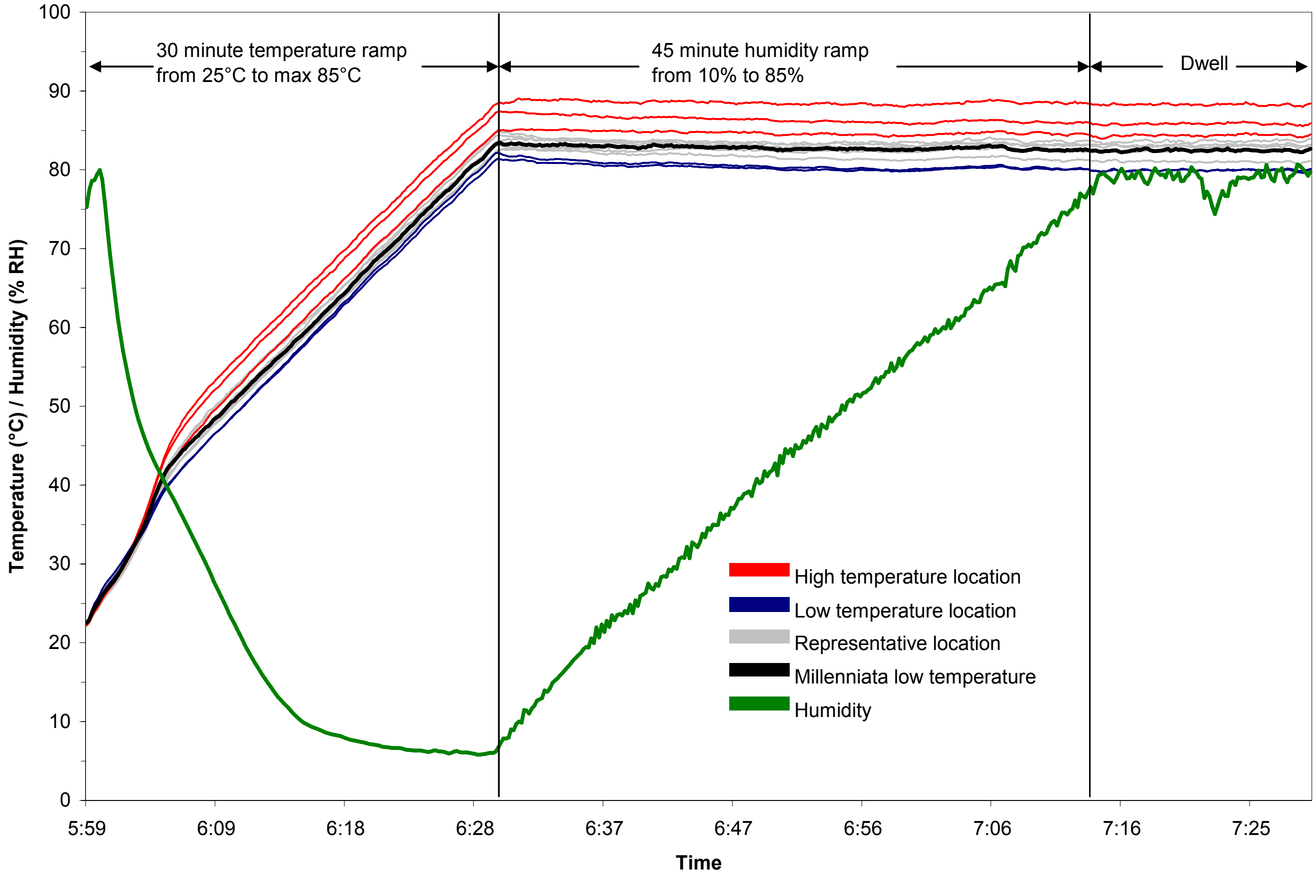

Figure 3-3. October 18-19 Temperature and Humidity Ramp Up

Figure 3-3 shows the individual disc temperatures quickly diverge as the lamps came up to temperature about 5 minutes into the test. It also shows the humidity reach 80% at the start of dwell.

Figure 3-4 below demonstrates the 85% humidity at the end of dwell and the increase in humidity during the temperature ramp for all three test runs. It also shows the 35°C disc temperatures during the settling period.

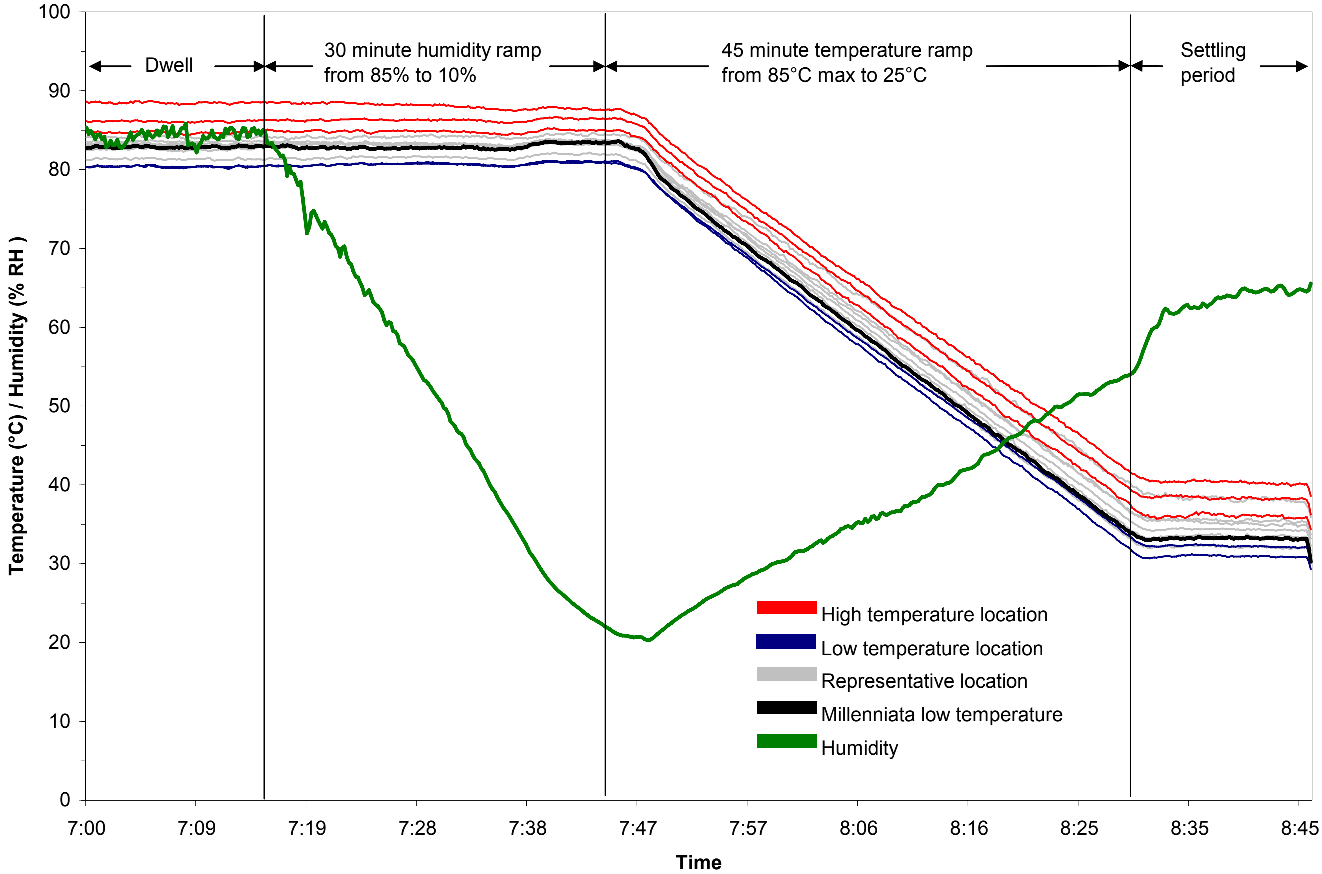

Figure 3-4. October 18-19 Temperature and Humidity Ramp Down

The disc temperatures during dwell were, like the ramp conditions, close for all three runs. Figure 3-5 demonstrates the constant dwell temperatures seen in the first run. The graphs of the other runs are included in Appendix B.

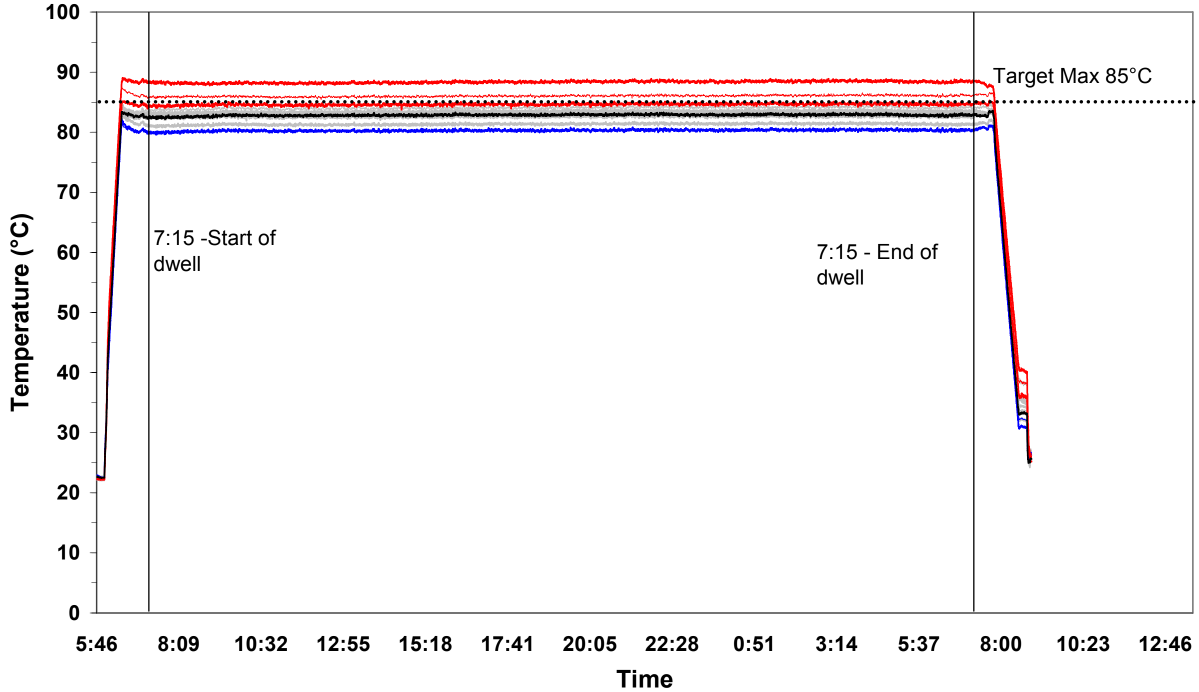

Figure 3-5. October 18-19 Disc Temperatures

The average dwell temperatures as well as the humidity and irradiance for all three runs are contained in Table 3-8.

	A5	E2	F5	G1	G4	H1	H5	I4	K5	M5	B2	N1	Humidity	Irradiance
10/18/2009	84.0	81.3	82.6	80.3	83.1	80.4	84.6	86.0	88.4	83.5	82.8	83.1	83	1095
10/19/2009	86.6	80.4	82.7	80.5	83.3	79.9	86.5	86.3	88.0	83.1	82.7	82.4	83	1094
10/20/2009	86.1	80.4	82.7	80.4	83.2	79.9	86.3	86.4	87.9	83.1	82.6	82.5	83	1056
Average	85.6	80.7	82.7	80.4	83.2	80.0	85.8	86.2	88.1	83.2	82.7	82.7	83	1082

Table 3-8. Dwell Temperature (°C), Humidity (% RH) and Irradiance (W/m2)

Figure 3-6 below is a graph of average dwell temperatures for several disc locations.

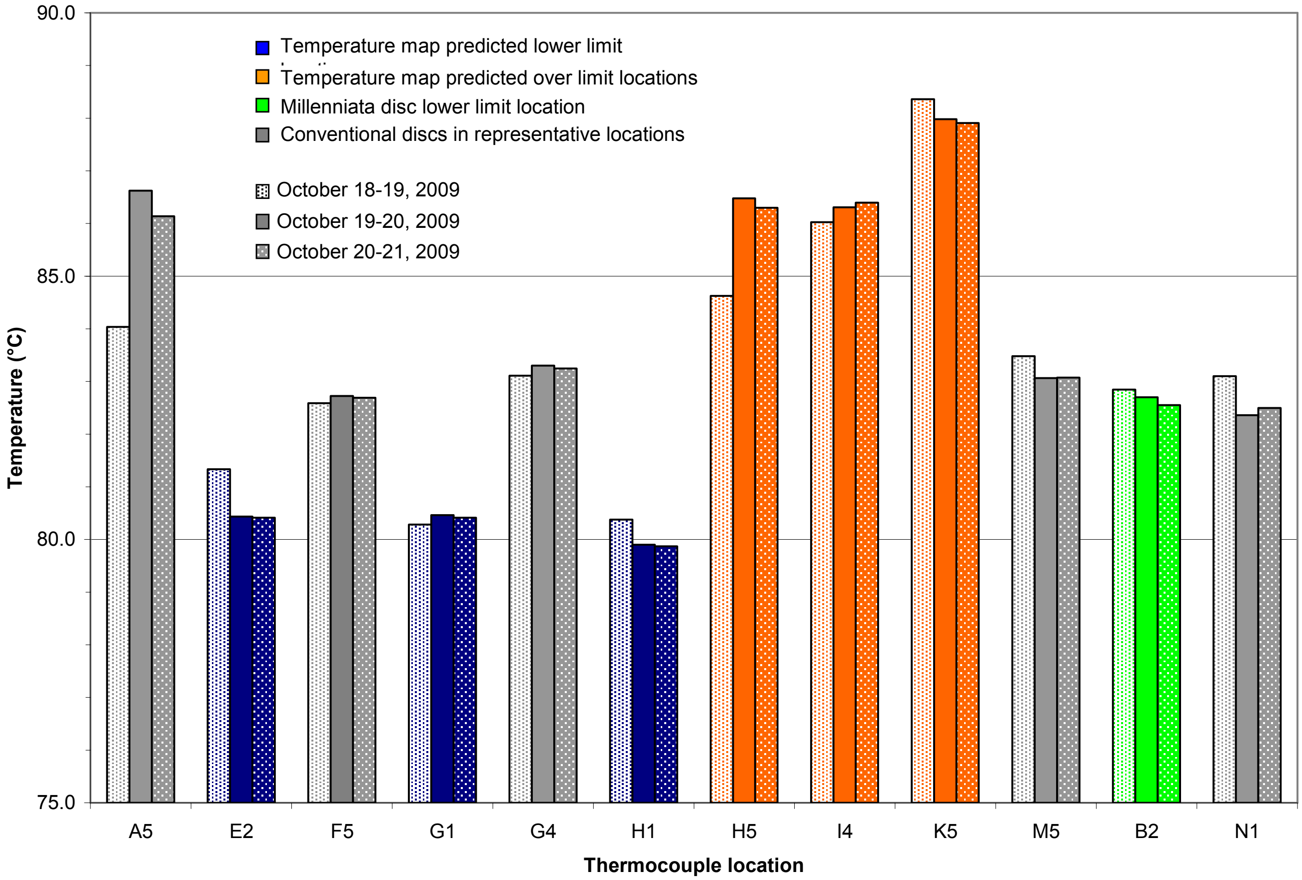

Figure 3-6. Average Dwell Temperature

The blue bars in the graph above represent locations predicted by the temperature map to be usable but on the lower limit of the allowable range. The orange data points are locations predicted to be over 85°C. The green temperatures come from a Millenniata disc that was placed in the lowest predicted temperature location and establishes a lower temperature boundary for the Millenniata discs. Finally, the grey bars are representative of temperatures seen by standard discs during the test. They are readings taken at locations which on the 75.5°C temperature map are within the target range.

An average humidity graph is not shown because, unlike the disc temperatures, the humidity did not reach equilibrium by the beginning of the dwell period. Figure 3-7 shows the humidity during the first run. It demonstrates the same trends as the graphs for the 2^{nd} and 3^{rd} runs included in Appendix B.

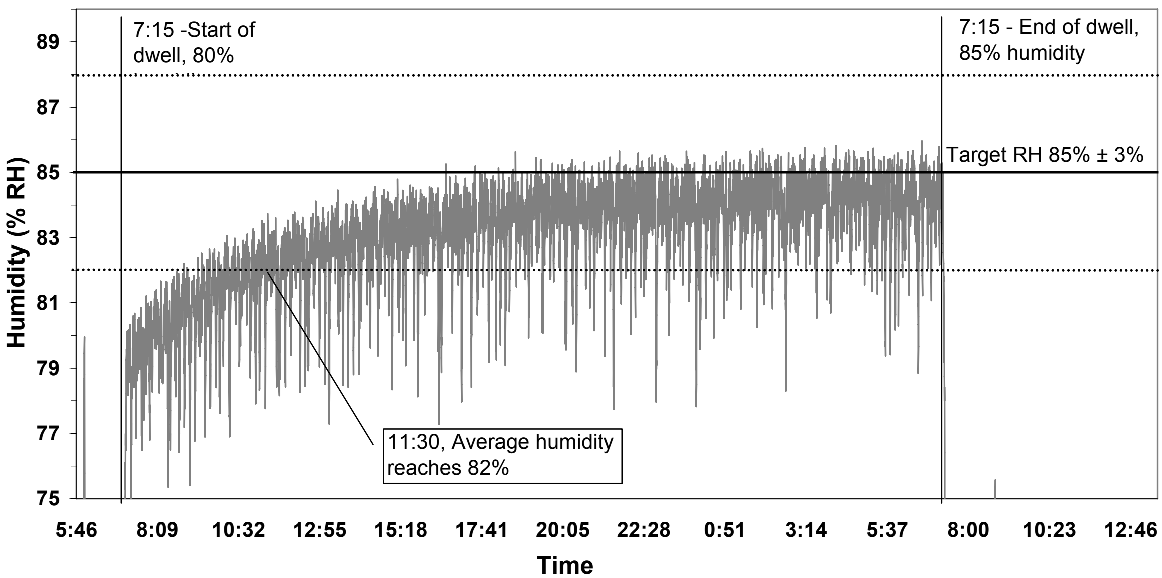

Figure 3-7. October 18-19 Humidity

As can be seen, the humidity started close to 80% and rose during the first 12 hours of the test until it reached a steady average of 84%. The many spikes and dips seen in the graph have time frames in the 2-4 minute range and were likely caused by the opening and closing of the steam addition solenoid. As a result of the ramp time and humidity dips, the average humidity during the dwell period for all three runs was 83%.

While the temperature and humidity data was very similar for each cycle, the irradiance data demonstrates differences. One element that was present in all three cases was the irradiance reading shooting up to a peak quickly during the temperature ramp up and then dropping down below the target irradiance before the start of the dwell period. Figure 3-8 shows this for the first test run.

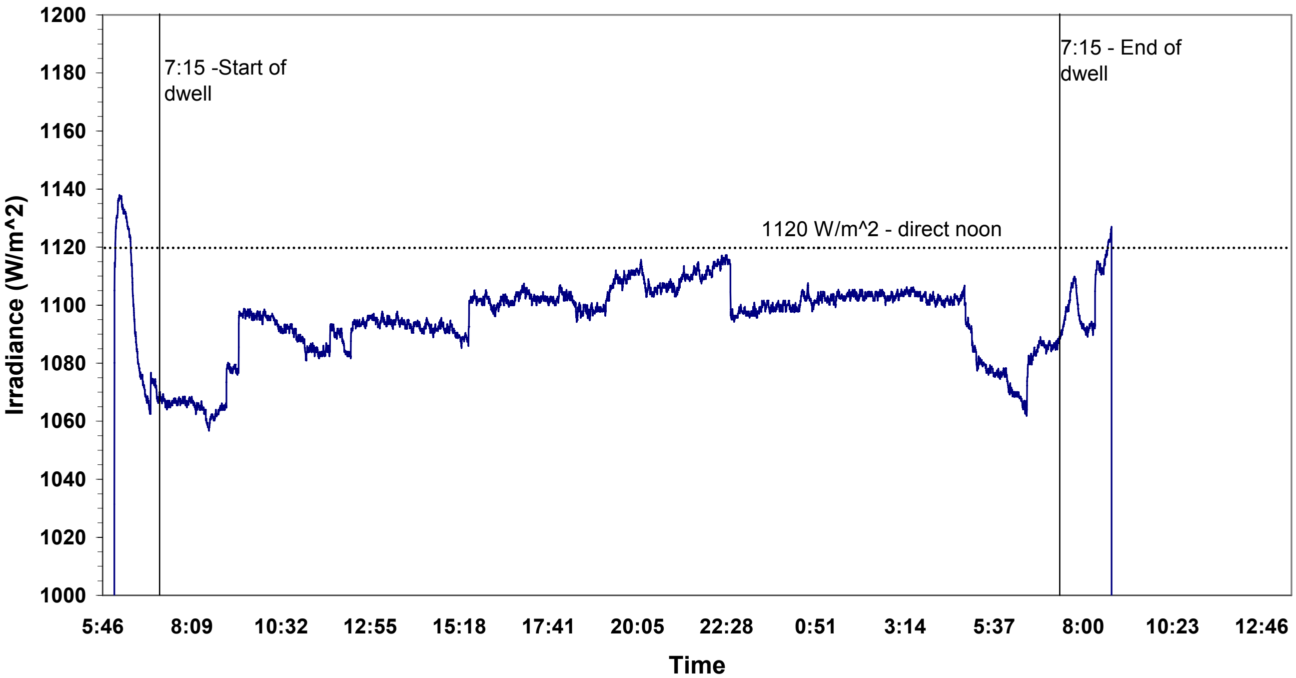

Figure 3-8. October 18-19 Irradiance

This peak and then drop is likely due to the effects of the temperature ramp upon the sensor. Likewise, the average irradiance at dwell is likely different from the irradiance measured at room temperature due to a temperature dependence of the CMP3. What is important to note, and can be seen in Figure 3-9 and Figure 3-10 as well, is that the irradiance levels appeared to vary during each test as much as ±30 W/m^2. While this data was taken at the edge of the pyranometer temperature range and may not be an accurate representation of the actual conditions, it indicates that the irradiance levels were not maintained within the Millenniata boundaries of 1075 W/m^2 and 1165 W/m^2.

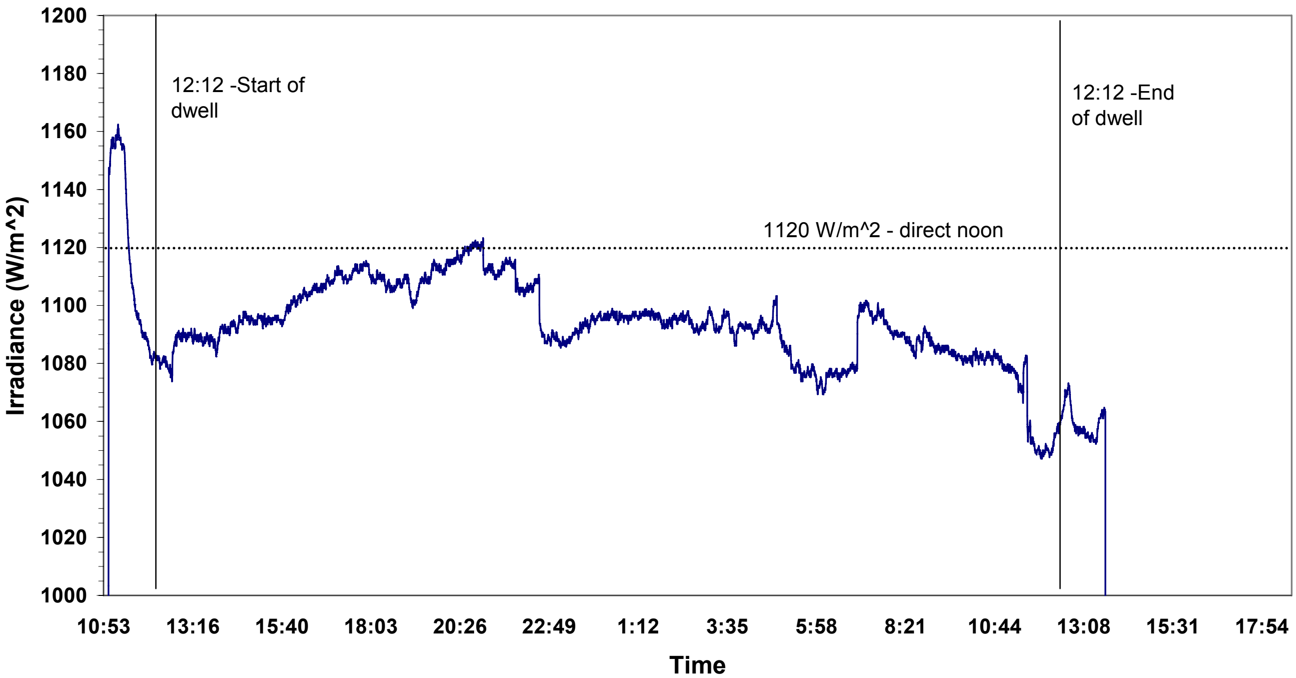

Figure 3-9. October 19-20 Irradiance

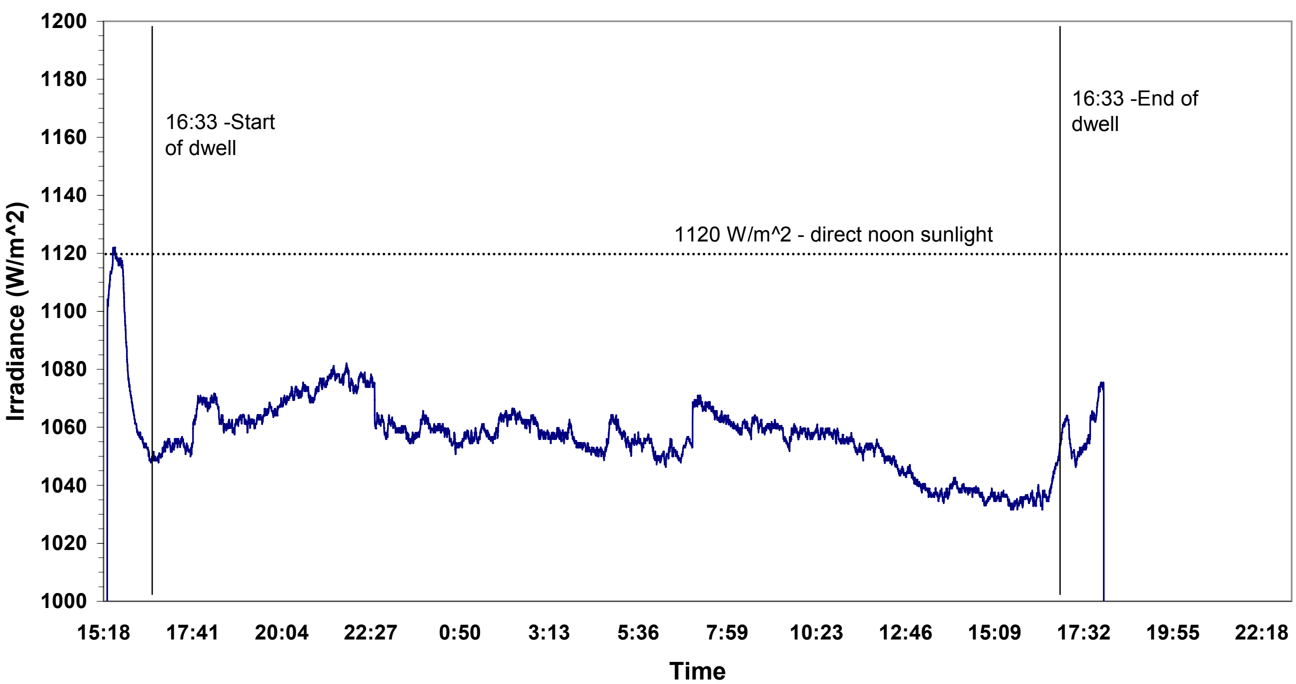

Figure 3-10. October 20-21 Irradiance

In addition to this within test irradiance fluctuation, it is also important to note that while the average irradiance during dwell for the first two runs were close at 1095 W/m^2 and

1094 W/m^2 the third run had a recorded average below the first two at 1056 W/m^2. It is not known whether this was a result of error from the pyranometer or an actual change in the output of the array but it did not appear to have an impact on the disc results.

The actual disc locations during each test run are included in Appendix B. These locations and the 75.5°C temperature were used to calculate the average disc temperature by manufacturer shown in Table 3-9.

Brand	Temperature (°C)
Combined	83.0
Mitsubishi	82.9
Delkin	82.6
Verbatim	82.6
MAM-A	82.6
Taiyo Yuden	83.1
Millenniata	84.1

Table 3-9. Average Brand Temperature

As the table demonstrates, random placement of discs resulted in uniform temperatures across the disc brands with the exception of the Millenniata media which ran more than 1°C higher.

The average irradiance was closer than the average temperature. Table 3-10 shows that the irradiance had a spread of only 6 W/m^2 between brand averages.

Brand	Irradiance (W/m^2)
Average	1122
Mitsubishi	1124
Delkin	1124
Verbatim	1122
MAM-A	1121
Taiyo Yuden	1125
Millenniata	1119

Table 3-10. Average Brand Irradiance

3.3 POST STRESS ANALYSIS

The first result of the test that was observed was the appearance of the discs. Some of the discs appeared to be unchanged but many of the discs exhibited obvious visible differences. The following 6 pictures show a representative pretest and post test disc for each manufacturer.

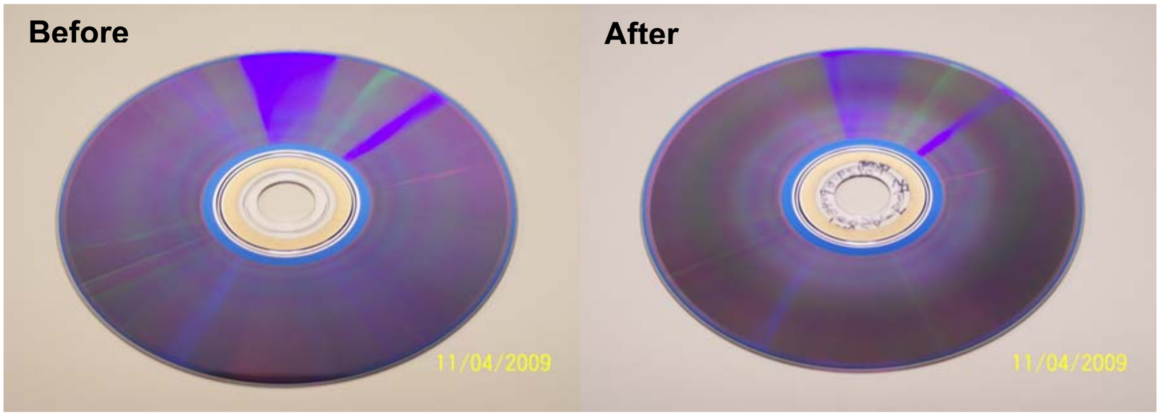

Figure 3-11. Delkin Disk Pictures

The Delkin discs showed very little change, only a little fading around the inner ring.

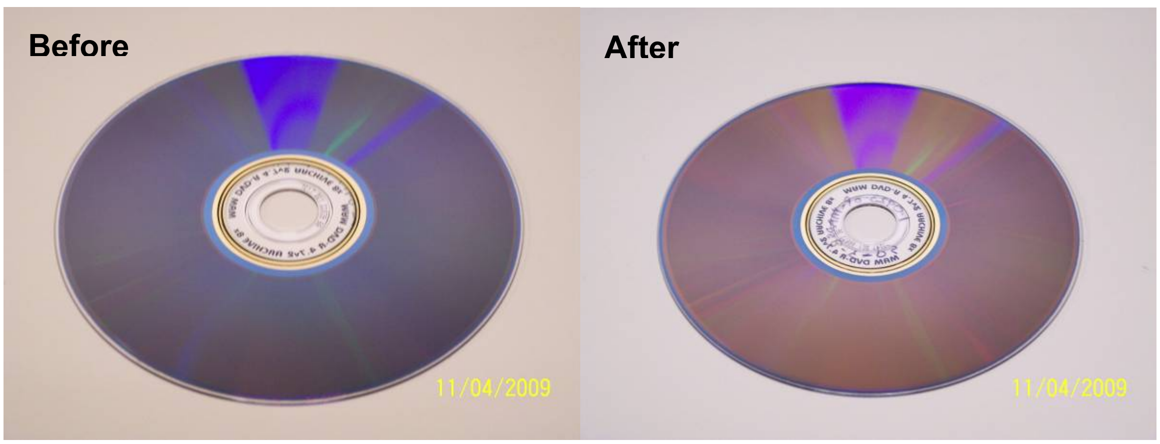

Figure 3-12. MAM-A Before and After Pictures

The MAM-A disks exhibited hardly any change. No patterns emerged. The only difference was a barely perceptible universal fade.

Figure 3-13. Millenniata Before and After Pictures

None of the Millenniata discs experienced any visible change during the test.

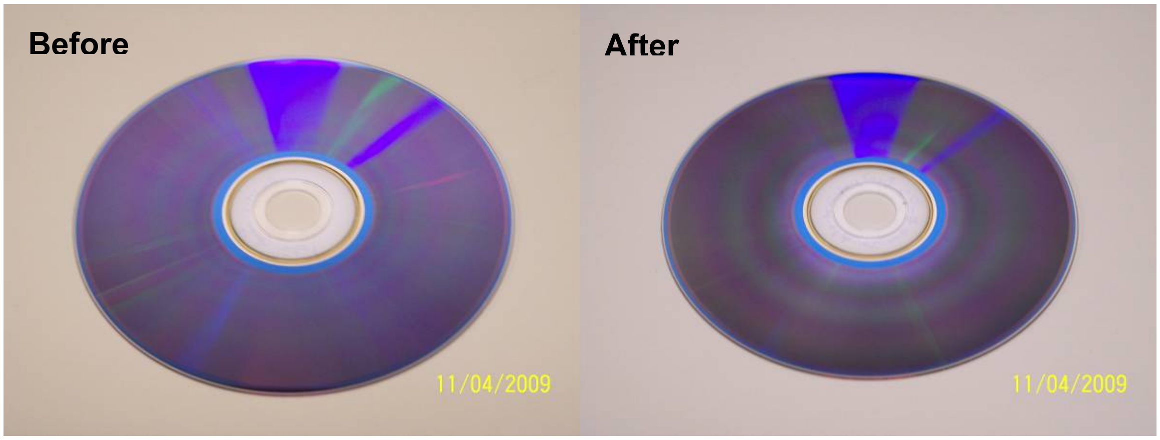

Figure 3-14. Mitsubishi Before and After Pictures

The greatest difference was visible on the Mitsubishi discs. Every disc exhibited obvious light and dark rings in an alternating pattern with the greatest fading on the inside radius.

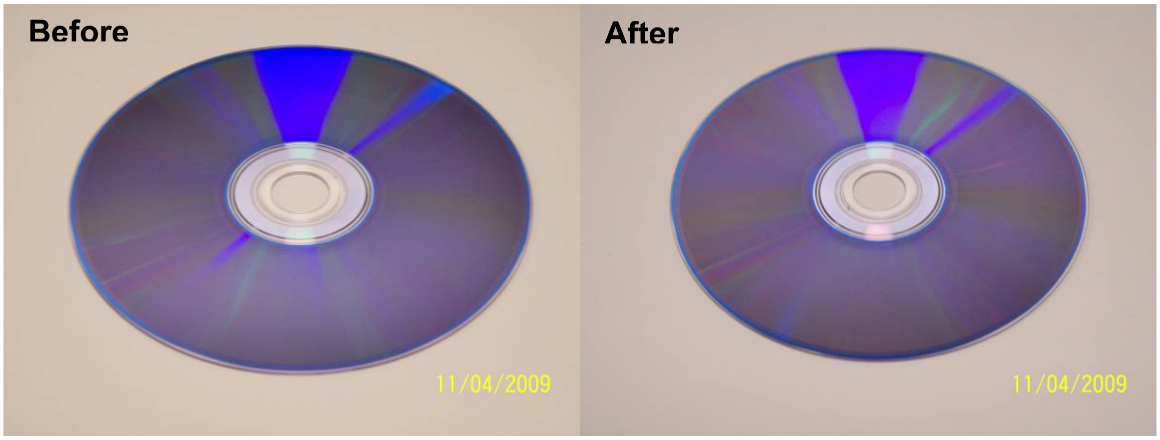

Figure 3-15. Taiyo Yuden Before and After Pictures

The Taiyo Yuden disks were visibly the least affected of the dye based media. Most discs failed to exhibit any perceptible difference.

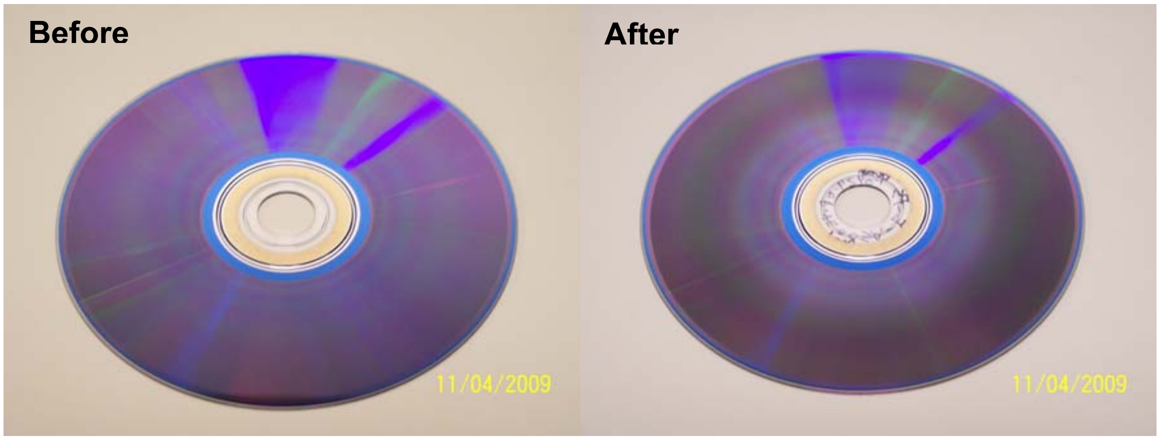

Figure 3-16. Verbatim Before and After Pictures

The Verbatim discs were second only to the Mitsubishi ones in visible damage. Every disc exhibited an obvious light ring on the inner radius.

The discs which sustained the heaviest visible damage, the Mitsubishi and Verbatim, all failed to be read by the analyzer. Many of the discs were not recognized at all by the drive. Those that were recognized and started to run quickly dropped down to read speeds approaching zero and eventually terminated unsuccessfully. Figure 3-17 and Figure 3-18 show combined baseline and post stress PI8 max graphs for the Mitsubishi and Verbatim discs.

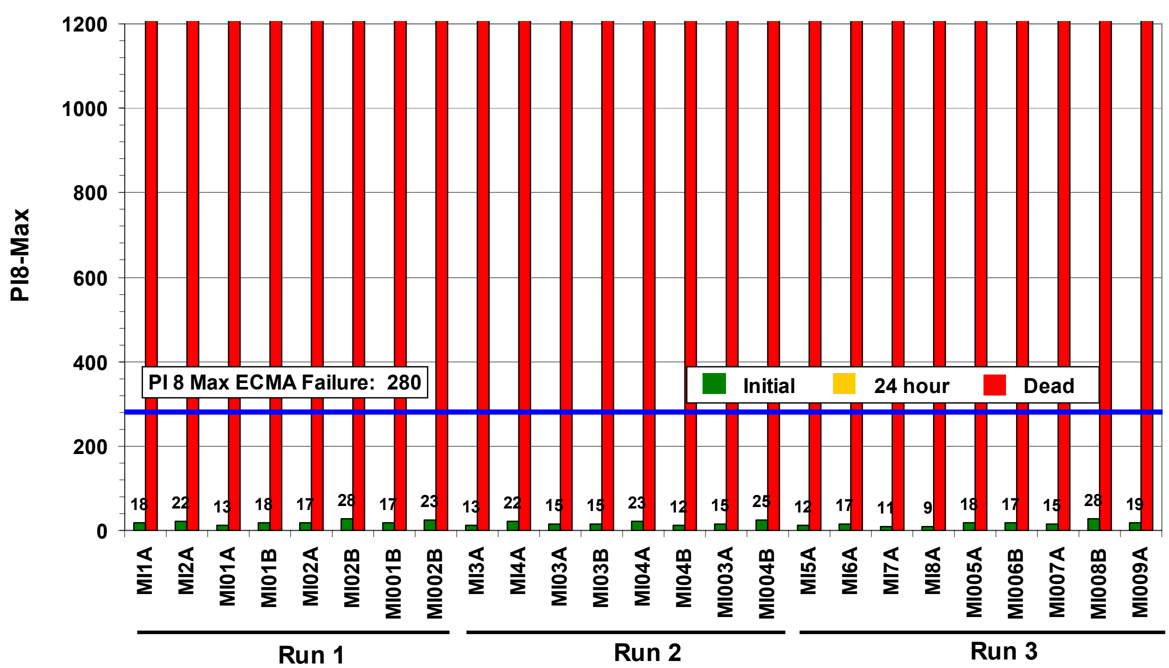

Figure 3-17. Mitsubishi PI8 Max

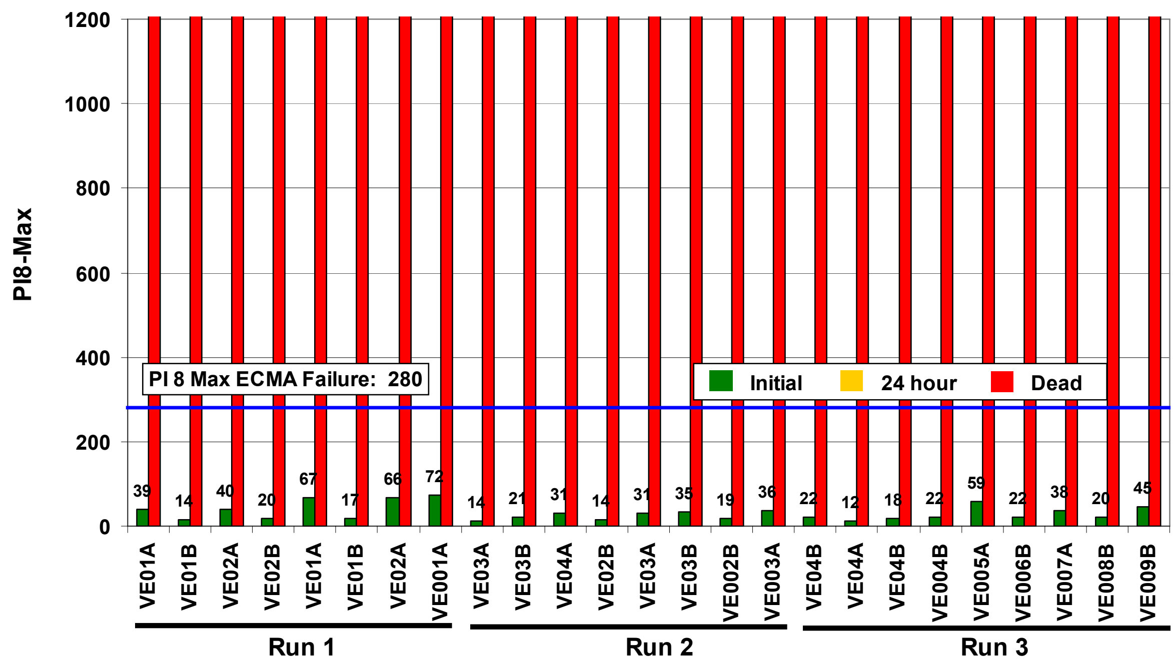

Figure 3-18. Verbatim PI8 Max

The Taiyo Yuden discs were the only non-archival grade media tested. Most of the discs were completely dead, but 5 of 25 were analyzable as Figure 3-19 shows.

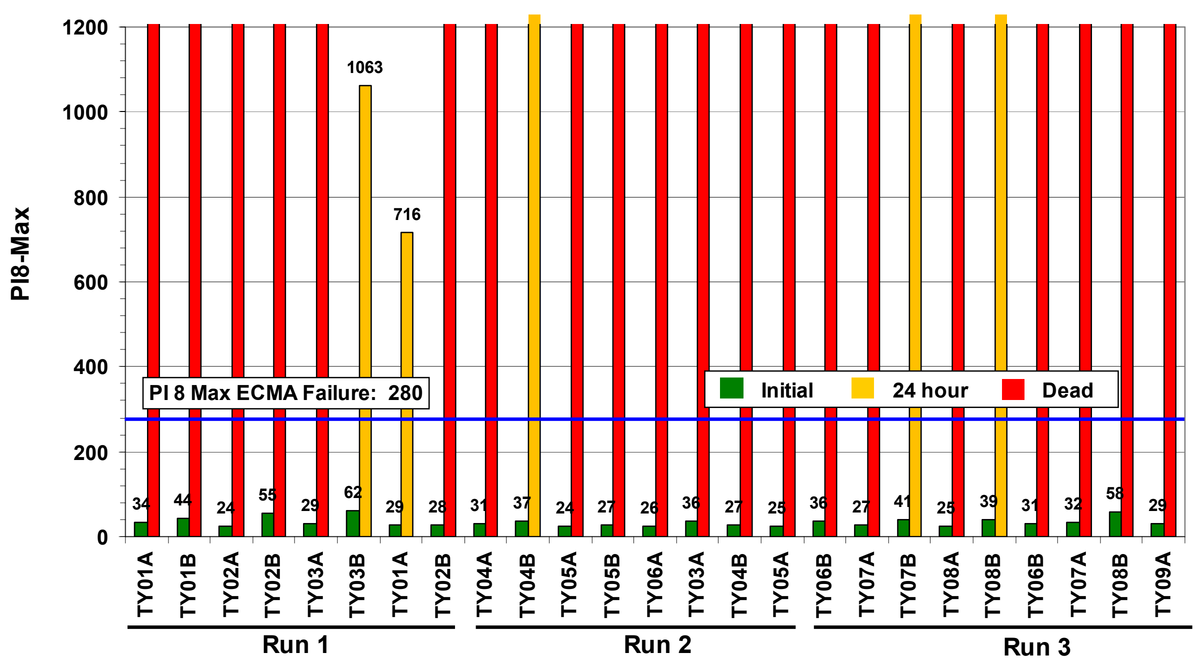

Figure 3-19. Taiyo Yuden PI8 Max

The Delkin discs faired better though one half of them still failed to read. None of these discs were able to meet the ECMA failure criteria as can be seen in Figure 3-20.

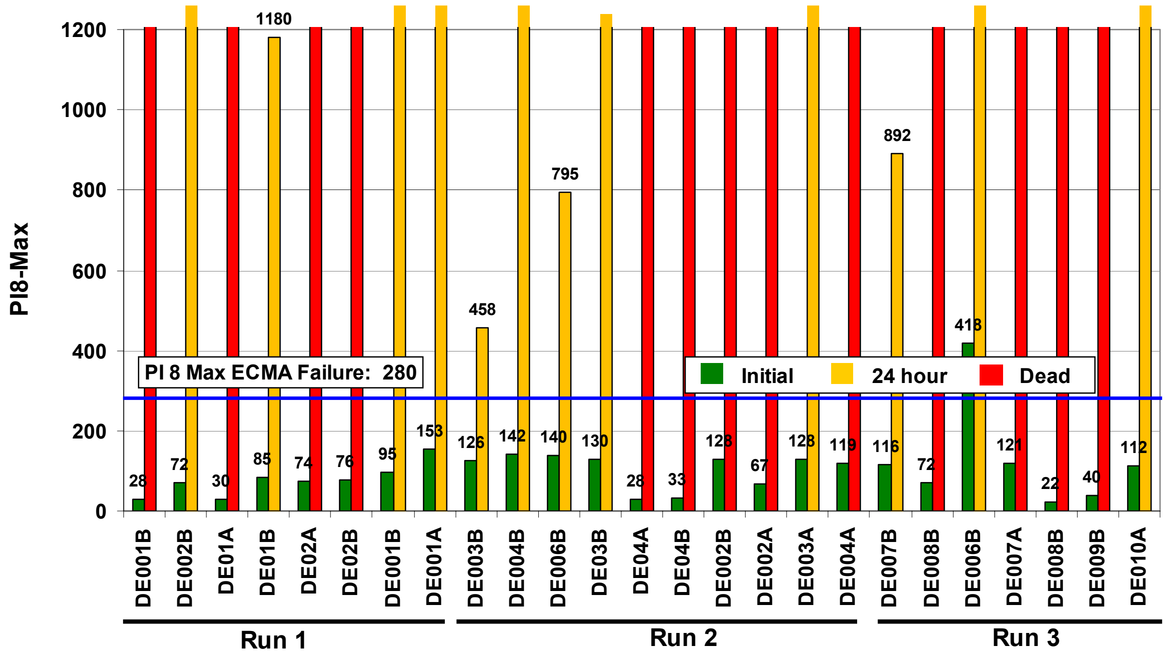

Figure 3-20. Delkin PI8 Max

Less than a third of the MAM-A discs failed to read, though none of the discs were able to meet the Ecma failure criteria.

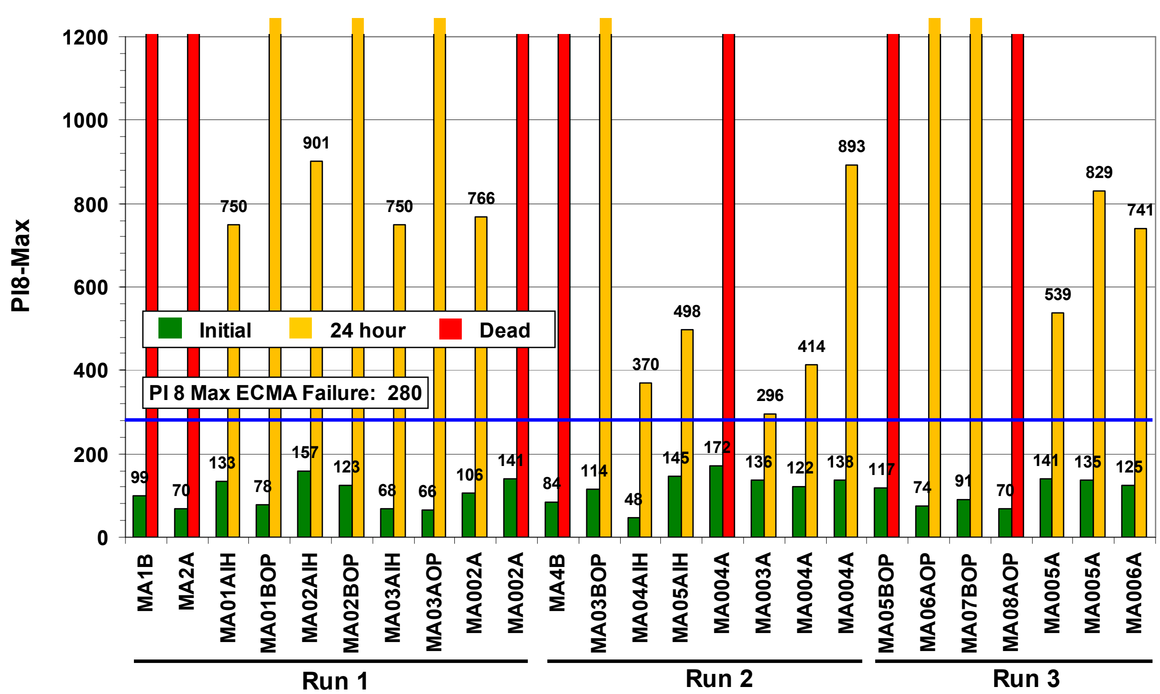

Figure 3-21. MAM-A PI8 Max

Finally, the Millenniata discs did not suffer any damage due to the exposure cycle. As shown in Figure 3-22, there was no data degradation. Every disc performed within the ECMA PI8 Max limit of 280.

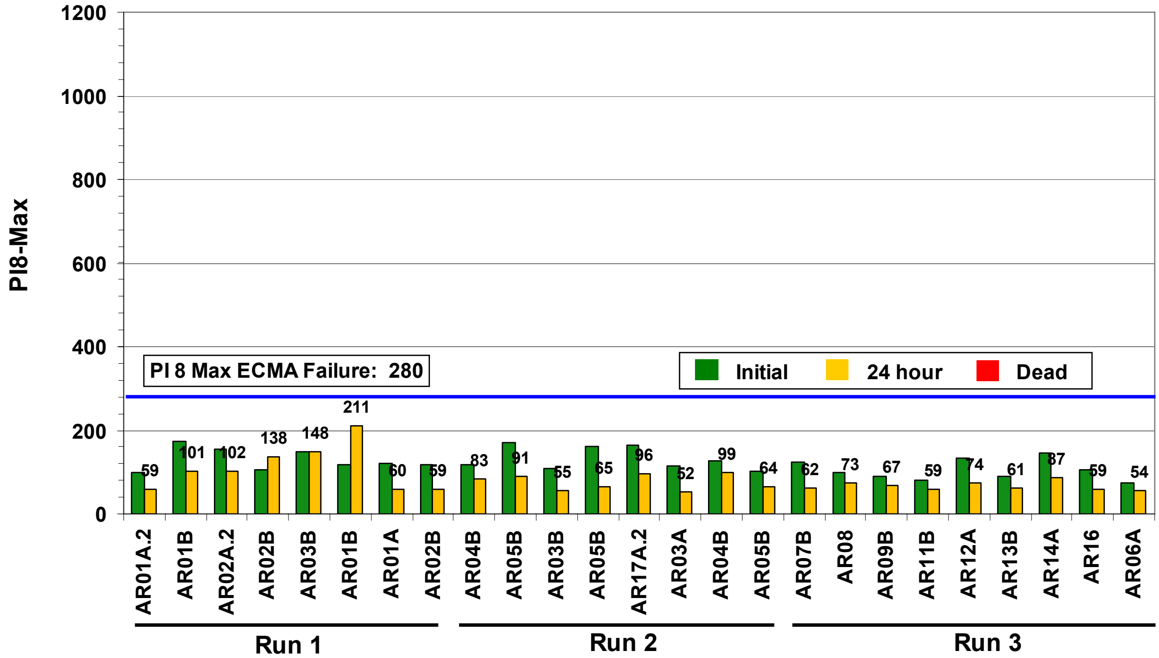

Figure 3-22 Millenniata PI8 Max

Figure 3-23 below compares the 6 disc brands by the average PI8 max error with dead discs included as a 5000 PI8 max reading (the maximum number the analyzer records).

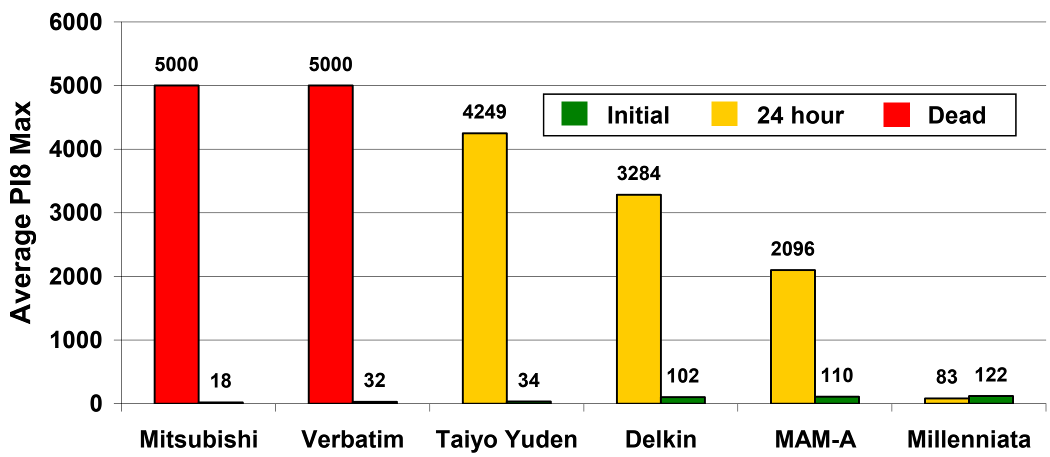

Figure 3-23 PI8 Max Average by Manufacturer Including Dead Discs

This result is mirrored by the number of dead discs after the test as shown in Figure 3-24.

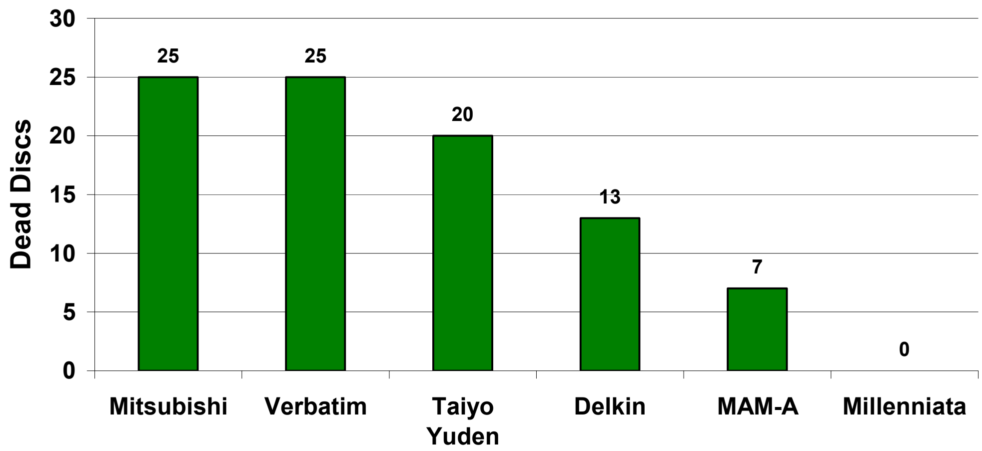

Figure 3-24. Number of Discs Dead After Stress Cycle

3.4 SUMMARY

- The variation in temperature and relative humidity during disc analysis met the requirements as set forth in the test protocol.

- The temperatures seen by test discs were maintained within the levels set forth in the test plan for all three test batches.

- While in all three test runs the humidity levels did not meet the specified range at the beginning of dwell, the average humidity over the entire dwell time met the target range in all three cases.

- The irradiance measured at each disc location at room temperature was within the test plan range of 1075 W/m^2 to 1165 W/m^2.

- The irradiance recorded during testing showed significant fluctuation during dwell with a low reading of 1031 W/m^2 during the third test and a high reading of 1122 W/m^2 during the second.

- The average temperature and irradiance levels were uniform across disc brands with the exception of the Millenniata media which was subjected to temperatures that were 1°C higher.

- All Mitsubishi and Verbatim discs failed to analyze after the test.

- All dye-based discs failed according to the ECMA PI8 max limit of 280.

- The post-test error statistics show all Millenniata disks pass the ECMA standard. The data recorded on these disks was recoverable. The Millenniata disks were the only ones tested that maintained information integrity.

4 CONCLUSIONS & RECOMMENDATIONS

- Voltage regulation should be added to the light system in future tests.

- A higher quality pyranometer that is more accurate at elevated temperatures, such as the Kipp & Zonen CM4, is recommended if more extensive tests are conducted.

- The device used to record an optical media can have a great impact upon the write quality and should be considered in all data storage situations.

- While initial write quality may, in many circumstances, be linked to data life, it is an independent variable when considering discs from different manufacturers and can not be used as an indication of longevity.

REFERENCES

1 Hanson Ph.D., Douglas A., Michael L. Bailey ME, Barry M. Lunt Ph.D., and David A. Bell Ph.D. *Archival Optical Test Plan*. Springville, UT: Millenniata Inc, 2009.

2 Ecma International, *ECMA-379 Test Method for the Estimation of the Archival Lifetime of Optical Media.* Geneva, CH: Ecma International, 2008.

3 Optical Disk Technologies, http://www.worthtech.com

APPENDIX A PRE TEST DATA

Date	DiscID	Drv	Run	Read Fail	PIE8-Max	PIE8-Avg	PIE8-Events	PIE-Max	PIE-Avg	POF-Count
9/22	DE001B	PI	1	Yes	28	9	0	9	1	0
9/22	DE002B	PI	1	No	72	36	0	20	5	0
9/23	DE01A	PI	1	Yes	30	9	0	10	1	0
9/23	DE01B	PI	1	No	85	40	0	22	5	0
9/23	DE02A	PI	1	Yes	74	37	0	19	5	0
9/23	DE02B	PI	1	Yes	76	36	0	19	4	0
9/29	DE001B	PI	1	No	95	41	0	23	5	0
9/30	DE001A	PI	1	No	153	88	8	32	11	0
9/22	DE003B	PI	2	No	126	71	0	29	9	0
9/22	DE004B	PI	2	No	142	79	0	35	10	0
9/22	DE006B	PI	2	No	140	76	2	32	9	0
9/23	DE03B	PI	2	No	130	67	1	28	8	0
9/23	DE04A	PI	2	Yes	28	9	0	9	1	0
9/23	DE04B	PI	2	Yes	33	13	0	10	2	0
9/29	DE002B	PI	2	Yes	128	70	1	27	9	0
9/30	DE002A	PI	2	Yes	67	30	0	18	4	0
9/30	DE003A	PI	2	No	128	62	1	32	8	0
9/30	DE004A	PI	2	Yes	119	54	1	29	7	0
9/22	DE007B	PI	3	No	116	66	0	26	8	0
9/22	DE008B	PI	3	Yes	72	33	0	19	4	0
9/29	DE006B	PI	3	No	418	280	1969	76	35	0
9/29	DE007A	PI	3	Yes	121	63	0	34	8	0
9/29	DE008B	PI	3	Yes	22	6	0	8	1	0
9/29	DE009B	PI	3	Yes	40	17	0	10	2	0
9/29	DE010A	PI	3	No	112	50	0	24	6	0

Table A-1. Delkin Pre Test Data

Date	DiscID	Drv	Run	Read Fail	PIE8-Max	PIE8-Avg	PIE8-Events	PIE-Max	PIE-Avg	POF-Count
9/22	MA1B	OP	1	Yes	99	53	0	26	7	0
9/22	MA2A	OP	1	Yes	70	35	0	20	4	0
9/23	MA01A	IH	1	No	133	73	11	32	9	0
9/23	MA01B	OP	1	No	78	40	0	20	5	0
9/23	MA02A	IH	1	No	157	88	236	38	11	0
9/23	MA02B	OP	1	No	123	58	1	30	7	0
9/23	MA03A	IH	1	No	68	33	0	20	4	0
9/23	MA03A	OP	1	No	66	30	0	19	4	0
9/30	MA002A	IH	1	No	106	60	1	27	8	0
10/06	MA002A	IH	1	Yes	141	75	172	34	9	0
9/22	MA4B	OP	2	Yes	84	46	0	25	6	0
9/23	MA03B	OP	2	No	114	62	0	32	8	0
9/23	MA04A	IH	2	No	48	21	0	15	3	0
9/23	MA05A	IH	2	No	145	85	131	33	11	0
9/29	MA004A	OP	2	Yes	172	101	321	41	13	0
9/30	MA003A	IH	2	No	136	80	126	31	10	0
9/30	MA004A	IH	2	No	122	74	11	32	9	0
10/06	MA004A	IH	2	No	138	71	5	35	9	0
9/23	MA05B	OP	3	Yes	117	63	0	30	8	0
9/23	MA06A	OP	3	No	74	36	0	21	4	0
9/23	MA07B	OP	3	No	91	49	0	26	6	0
9/23	MA08A	OP	3	Yes	70	32	0	20	4	0
9/30	MA005A	IH	3	No	141	85	3	40	11	0
10/06	MA005A	IH	3	No	135	73	38	34	9	0
10/06	MA006A	IH	3	No	125	67	22	34	8	0

Table A-2. MAM-A Pre Test Data

Date	DiscID	Drv	Run	Read Fail	PIE8-Max	PIE8-Avg	PIE8-Events	PIE-Max	PIE-Avg	POF-Count
9/22	AR01A.2	MW	1	No	98	59	0	24	7	0
9/22	AR01B	MW	1	No	173	109	26	39	14	0
9/22	AR02A.2	MW	1	No	156	91	81	39	11	0
9/22	AR02B	MW	1	No	105	59	0	25	7	0
9/22	AR03B	MW	1	No	149	93	5	31	12	0
9/23	AR01B	MW	1	No	116	57	0	28	7	0
9/25	AR01A	MW	1	No	120	69	173	25	9	0
9/25	AR02B	MW	1	No	118	68	1	33	9	0
9/22	AR04B	MW	2	No	118	71	0	28	9	0
9/22	AR05B	MW	2	No	172	98	39	37	12	0
9/23	AR03B	MW	2	No	108	50	0	27	6	0
9/23	AR05B	MW	2	No	161	92	56	40	11	0
9/24	AR17A.2	MW	2	No	163	108	428	36	14	0
9/25	AR03A	MW	2	No	115	59	52	25	7	0
9/25	AR04B	MW	2	No	128	76	1	28	10	0
9/25	AR05B	MW	2	No	102	58	21	24	7	0
9/23	AR07B	MW	3	No	125	64	0	33	8	0
9/23	AR08	MW	3	No	99	50	0	25	6	0
923	AR09B	MW	3	No	89	47	0	21	6	0
9/23	AR11B	MW	3	No	80	45	0	19	6	0
923	AR12A	MW	3	No	135	71	0	33	9	0
9/23	AR13B	MW	3	No	90	49	0	21	6	0
9/23	AR14A	MW	3	No	145	69	3	31	9	0
9/23	AR16	MW	3	No	105	59	0	24	7	0
9/25	AR06A	MW	3	No	75	41	0	19	5	0

Table A-3. Millenniata Pre Test Data

Date	DiscID	Drv	Run	Read Fail	PIE8-Max	PIE8-Avg	PIE8-Events	PIE-Max	PIE-Avg	POF-Count
9/22	MI1A	OP	1	Yes	18	4	0	6	1	0
9/22	MI2A	OP	1	Yes	22	6	0	9	1	0
9/23	MI01A	OP	1	Yes	13	2	0	6	0	0
9/23	MI01B	OP	1	Yes	18	5	0	9	1	0
9/23	MI02A	OP	1	Yes	17	5	0	7	1	0
9/23	MI02B	OP	1	Yes	28	10	0	10	1	0
9/29	MI001B	OP	1	Yes	17	3	0	6	0	0
9/29	MI002B	OP	1	Yes	23	7	0	8	1	0
9/22	MI3A	OP	2	Yes	13	1	0	4	0	0
9/22	MI4A	OP	2	Yes	22	6	0	8	1	0
9/23	MI03A	OP	2	Yes	15	1	0	5	0	0
9/23	MI03B	OP	2	Yes	15	3	0	6	0	0
9/23	MI04A	OP	2	Yes	23	6	0	8	1	0
9/23	MI04B	OP	2	Yes	12	2	0	5	0	0
9/29	MI003A	OP	2	Yes	15	2	0	6	0	0
9/29	MI004B	OP	2	Yes	25	8	0	8	1	0
9/22	MI5A	OP	3	Yes	12	1	0	4	0	0
9/22	MI6A	OP	3	Yes	17	4	0	7	1	0
9/22	MI7A	OP	3	Yes	11	1	0	4	0	0
9/22	MI8A	OP	3	Yes	9	1	0	4	0	0
9/29	MI005A	OP	3	Yes	18	3	0	6	0	0
9/29	MI006B	OP	3	Yes	17	3	0	6	0	0
9/29	MI007A	OP	3	Yes	15	2	0	6	0	0
9/29	MI008B	OP	3	Yes	28	9	0	9	1	0
9/29	MI009A	OP	3	Yes	19	5	0	7	1	0

Table A-4. Mitsubishi Pre Test Data

Date	DiscID	Drv	Run	Read Fail	PIE8-Max	PIE8-Avg	PIE8-Events	PIE-Max	PIE-Avg	POF-Count
9/23	TY01A	PI	1	Yes	34	12	0	11	1	0
9/23	TY01B	PI	1	Yes	44	19	0	13	2	0
9/23	TY02A	PI	1	Yes	24	8	0	9	1	0
9/23	TY02B	PI	1	Yes	55	26	0	17	3	0
9/23	TY03A	PI	1	Yes	29	9	0	9	1	0
9/23	TY03B	PI	1	No	62	25	0	23	3	0
9/29	TY01A	PI	1	No	29	9	0	10	1	0
9/29	TY02B	PI	1	Yes	28	11	0	9	1	0
9/23	TY04A	PI	2	Yes	31	12	0	9	1	0
9/23	TY04B	PI	2	No	37	16	0	11	2	0
9/23	TY05A	PI	2	Yes	24	8	0	8	1	0
9/23	TY05B	PI	2	Yes	27	9	0	10	1	0
9/23	TY06A	PI	2	Yes	26	10	0	9	1	0
9/29	TY03A	PI	2	Yes	36	14	0	13	2	0
9/29	TY04B	PI	2	Yes	27	10	0	10	1	0
9/29	TY05A	PI	2	Yes	25	9	0	9	1	0
9/23	TY06B	PI	3	Yes	36	14	0	11	2	0
9/23	TY07A	PI	3	Yes	27	8	0	9	1	0
9/23	TY07B	PI	3	No	41	19	0	12	2	0
9/23	TY08A	PI	3	Yes	25	8	0	9	1	0
9/23	TY08B	PI	3	No	39	17	0	12	2	0
9/29	TY06B	PI	3	Yes	31	12	0	9	2	0
9/29	TY07A	PI	3	Yes	32	12	0	11	1	0
9/29	TY08B	PI	3	Yes	58	28	0	16	3	0
9/29	TY09A	PI	3	Yes	29	10	0	11	1	0

Table A-5. Taiyo Yuden Pre Test Data

Date	DiscID	Drv	Run	Read Fail	PIE8-Max	PIE8-Avg	PIE8-Events	PIE-Max	PIE-Avg	POF-Count
9/22	VE01A	OP	1	Yes	39	7	0	13	1	0
9/22	VE01B	OP	1	Yes	14	3	0	6	0	0
9/22	VE02A	OP	1	Yes	40	7	0	15	1	0
9/22	VE02B	OP	1	Yes	20	5	0	8	1	0
9/23	VE01A	OP	1	Yes	67	15	0	26	2	0
9/23	VE01B	OP	1	Yes	17	1	0	6	0	0
9/23	VE02A	OP	1	Yes	66	12	0	22	2	0
9/29	VE001A	OP	1	Yes	72	14	1	31	2	0
9/22	VE03A	OP	2	Yes	14	1	0	5	0	0
9/22	VE03B	OP	2	Yes	21	5	0	9	1	0
9/22	VE04A	OP	2	Yes	31	5	0	14	1	0
9/23	VE02B	OP	2	Yes	14	2	0	7	0	0
9/23	VE03A	OP	2	Yes	31	6	0	11	1	0
9/23	VE03B	OP	2	Yes	35	9	0	13	1	0
9/29	VE002B	OP	2	Yes	19	4	0	6	1	0
9/29	VE003A	OP	2	Yes	36	7	0	11	1	0
9/22	VE04B	OP	3	Yes	22	6	0	9	1	0
9/23	VE04A	OP	3	Yes	12	1	0	5	0	0
9/23	VE04B	OP	3	Yes	18	4	0	7	0	0
9/29	VE004B	OP	3	Yes	22	4	0	8	1	0
9/29	VE005A	OP	3	Yes	59	12	0	22	1	0
9/29	VE006B	OP	3	Yes	22	5	0	8	1	0
9/29	VE007A	OP	3	Yes	38	7	0	15	1	0
9/29	VE008B	OP	3	Yes	20	5	0	8	1	0
9/29	VE009B	OP	3	Yes	45	8	0	18	1	0

Table A-6. Verbatim Pre Test Data

APPENDIX B STRESS CYCLE DATA

	A	B	C	D	E	F	G
1	1-09-22-09-op-a-ve-001-e	1-0923-op-mi02b-e	1-09-22-09-op-a-mi-002e	1-09-22-09-pi-b-de-001-f-c	1-0929-op-ve001a-e	01-09-22-09-op-a-ve-002-e	Theremocouple-4
2	1-0923-op-ma02b-f-c	Theremocouple-AR-1	1-09-22-09-op-a-mi-001-e	1-0922-mw-ar01ar-e	Theremocouple-2	1-0922-mw-ar02b-e	1-0923-pi-de01b-e
3	1-0923-pi-ty03a-e	01-09-22-09-op-b-ve-001-f	1-0930-ih-ma002a-c	1-0922-mw-ar01b-e	1-0925-mw-ar01a-c	1-0925-mw-ar02b-e	01-09-22-09-op-b-ve-002-f
4	Dummy Disc	1-0923-pi-ty03b-f	1-0923-op-ve01a-e	1-0923-mw-ar01b-e	1-0922-mw-ar02a.2-e	1-0922-mw-ar03b-e	Theremocouple-5
5	Theremocouple-1	Dummy Disc	1-0923-pi-de02b-e	1-0923-op-ve01b-f	01-0923-pi-de01a-f	Theremocouple-3	Dummy Disc
	H	**I**	**J**	**K**	**L**	**M**	**N**
1	Theremocouple-6	1-0923-pi-ty01a-f	1-0923-ih-ma02a-e	1-09-22-09-op-b-ma-001-f	1-0923-op-mi02a-e	1-0923-pi-ty02b-e	Theremocouple-O-1
2	1-0923-op-ma01b-f-c	1-0930-pi-de001a-e	1-0923-pi-ty01b-e	1-09-22-09-pi-b-de-002f-c	1-0923-ih-ma01a-e	1-1006-ih-ma002a-e	Dummy Disc
3	1-0929-pi-de-001b-e	01-09-22-09-op-a-ma-002-f	1-0923-op-mi01a-f	1-0929-pi-ty001a-c	1-0923-op-mi01b-f	1-0929-op-mi002b-e	1-0929-pi-ty002b-e
4	1-0923-op-ve02a-e	Theremocouple-8	Pyranometer	1-0923-de02a-f	1-0923-pi-ty02a-e	1-0929-op-mi001b-c	1-0923-op-ma03a-f
5	Theremocouple-7	Dummy Disc	Dummy Disc	Theremocouple-9	1-0923-ih-ma03a-f	Theremocouple-10	Dummy Disc

Table B-1. Disc Placement for October 18-19 Cycle

	A	B	C	D	E	F	G
1	1-09-22-09-op-a-mi-003-f	1-09-22-09-pi-b-de-003-e	1-09-22-09-op-b-ma-004-f	1-0923-pi-ty06a-e	01-09-22-09-op-a-ve-004-e	1-0923-op-mi03b-f	Theremocouple-4
2	1-0923-op-ma03b-f-c	Theremocouple-AR-1	1-0929-op-ve003a-e	1-0923-mw-ar05b-e	Theremocouple-2	1-0925-mw-ar04b-e	1-0923-op-ve02b-f
3	01-09-22-09-op-b-ve-003-f-c	1-0923-op-ve03b-e	1-0929-pi-ty005a-c	1-0925-mw-ar05b-c	1-0922-mw-ar05b-e	1-0925-mw-ar03a-c	1-0929-op-mi003a-c
4	Dummy Disc	1-0930-ih-ma003a-e	1-0930-pi-de003a-e	1-0923-ar03b-e	1-0922-mw-ar04b-f	1-0924-mw-ar17a.2-e	Theremocouple-5
5	Theremocouple-1	Dummy Disc	1-0923-op-mi03a-f	1-0929-pi-ty003a-e	1-0923-pi-de04a-f	Theremocouple-3	Dummy Disc
	H	**I**	**J**	**K**	**L**	**M**	**N**
1	Theremocouple-6	1-0923-ih-ma05a-e	1-0930-pi-de004a-e	1-0929-pi-de002b-e	1-0929-pi-ty004b-c	1-0923-pi-de03b-e	Theremocouple-O-1
2	1-0923-pi-de04b-f	1-09-22-09-pi-b-de-004-e	1-0929-op-ve002b-c	1-0923-ih-ma04a-f	1-0923-pi-ty05a-e	1-0923-op-mi04b-f	Dummy Disc
3	1-1006-ih-ma004a-e	1-09-22-09-op-a-mi-004-e	1-0923-pi-ty04a-f	1-0923-pi-ty04b-e	1-09-22-09-pi-b-de-006-e	1-0930-pi-de002a-c	1-0930-ih-ma004a-c
4	1-0923-op-ve03a-e	Theremocouple-8	Pyranometer	01-09-22-09-op-a-ve-003-f-c	1-0929-op-ma004a-c	1-0923-pi-ty05b-f	1-0929-op-mi004b-e
5	Theremocouple-7	Dummy Disc	Dummy Disc	Theremocouple-9	1-0923-op-mi04a-e	Theremocouple-10	Dummy Disc

Table B-2. Disc Placement for October 19-20 Cycle

	A	B	C	D	E	F	G
1	1-0929-pi-ty008b-c	1-09-22-09-op-a-mi-005-f	1-0929-op-ve007a-e	1-1006-ih-ma006a-e	1-0929-op-mi005a-c	1-0929-op-ve009b-e	Theremocouple-4
2	1-0929-pi-ty007a-e	Theremocouple-AR-1	1-0923-mw-ar14a-e	1-0923-mw-ar13b-e	Theremocouple-2	1-0923-mw-ar12a-e	1-0923-op-ma07b-f
3	1-0929-pi-de010a-e	1-0929-op-ve006b-c	1-0929-pi-ty009a-c	1-0923-mw-ar07b-e	1-0923-mw-ar16-e	1-0923-mw-ar08a-e	1-0929-op-mi008b-e
4	Dummy Disc	1-0923-pi-ty07b-e	1-0923-op-ma08a-f	1-0923-mw-ar11b-f-c	1-0923-mw-ar09b-e	1-0925-mw-ar06a-c	Theremocouple-5
5	Theremocouple-1	Dummy Disc	1-0923-pi-ty08a-f	01-09-22-09-op-b-ve-004-f-c	1-0929-op-ve008b-c	Theremocouple-3	Dummy Disc
	H	**I**	**J**	**K**	**L**	**M**	**N**
1	Dummy	1-0929-op-mi009a-e	1-09-22-09-pi-b-de-007-e	1-0930-ih-ma005a-c	1-0929-pi-de008b-c	1-0923-op-ma06a-f	Theremocouple-O-1
2	1-0929-pi-de006b-e	1-0923-op-ma05b-f	1-0923-pi-ty06b-f	1-0929-pi-de007a-c	1-0929-op-ve004b-c	1-0923-pi-ty07a-f	Dummy Disc
3	1-0923-pi-ty08b-e	1-09-22-09-op-a-mi-006-e	1-0923-op-ve04b-f	1-0929-op-mi006b-c	1-1006-ih-ma005a-e	1-0929-op-mi007a-c	1-09-22-09-op-a-mi-008-f
4	1-0923-op-ve04a-f	Theremocouple-8	Pyranometer	1-0929-pi-ty006b-e	1-09-22-09-pi-b-de-008-f-c	1-0929-op-ve005a-e	1-0929-pi-de009b-c
5	Theremocouple-7	Dummy Disc	Dummy Disc	Theremocouple-9	1-09-22-09-op-a-mi-007-f	Theremocouple-10	Dummy Disc

Table B-3. Disc Placement for October 20-21 Cycle

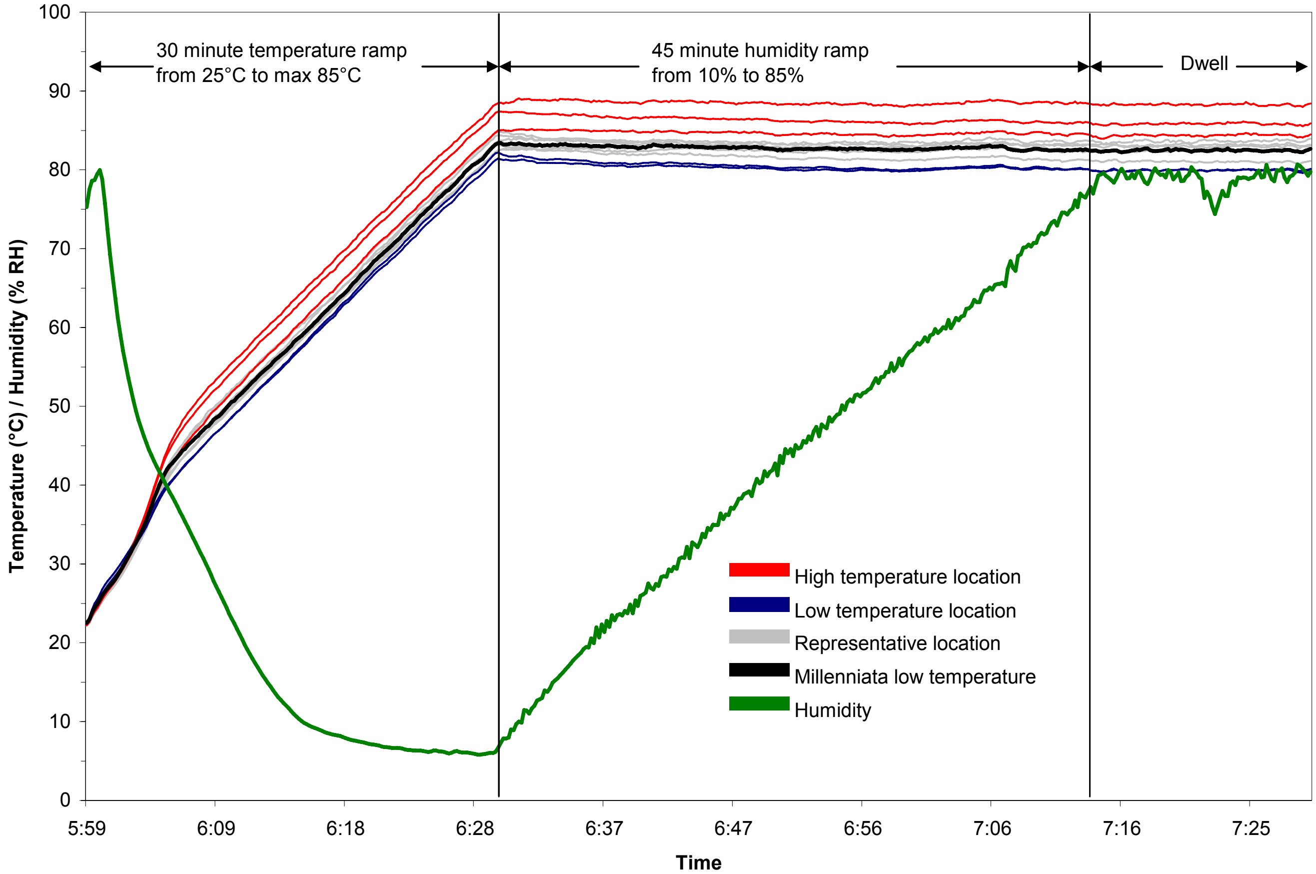

Figure B-1. October 18-19 Temperature and Humidity Ramp Up

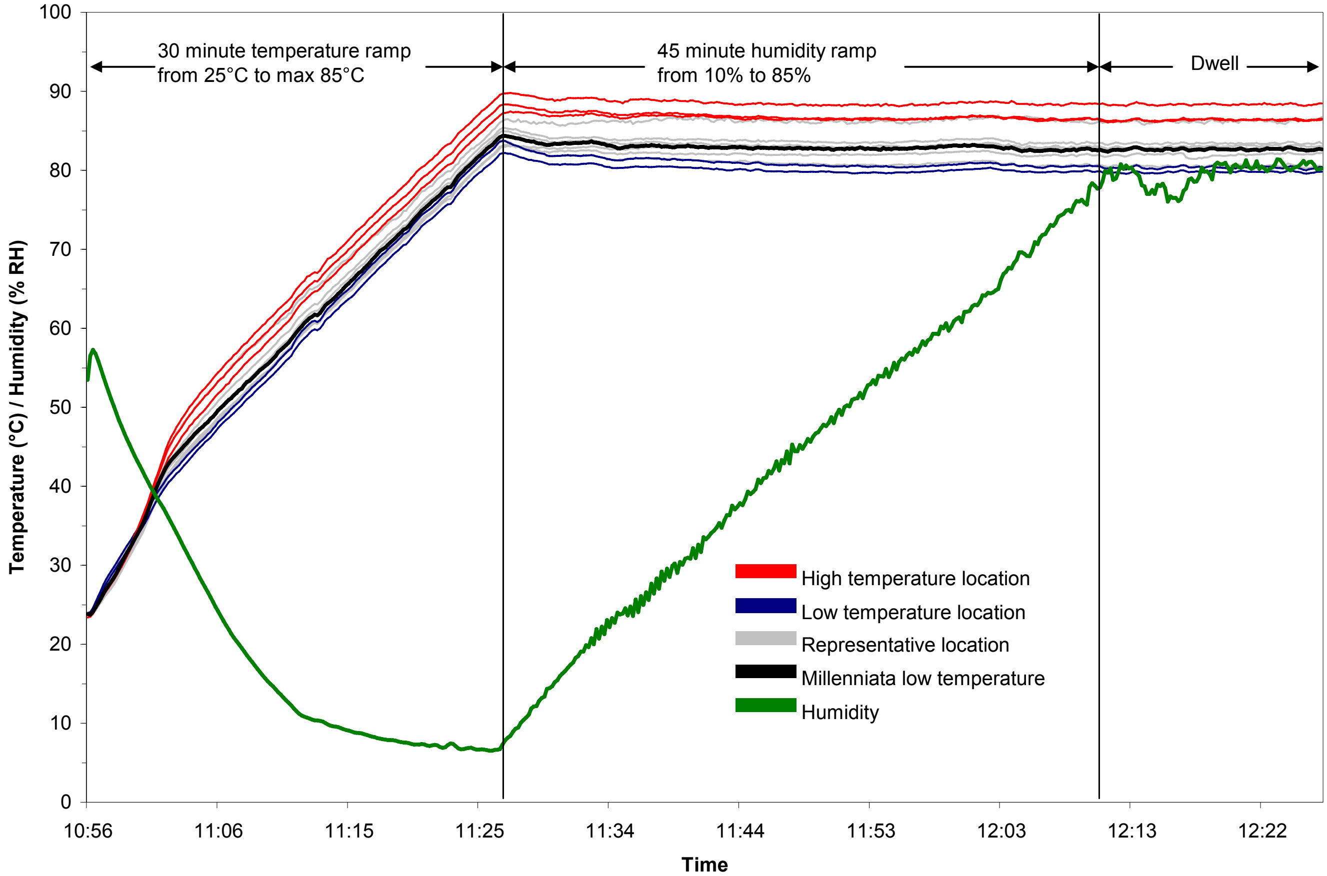

Figure B-2. October 19-20 Temperature and Humidity Ramp Up

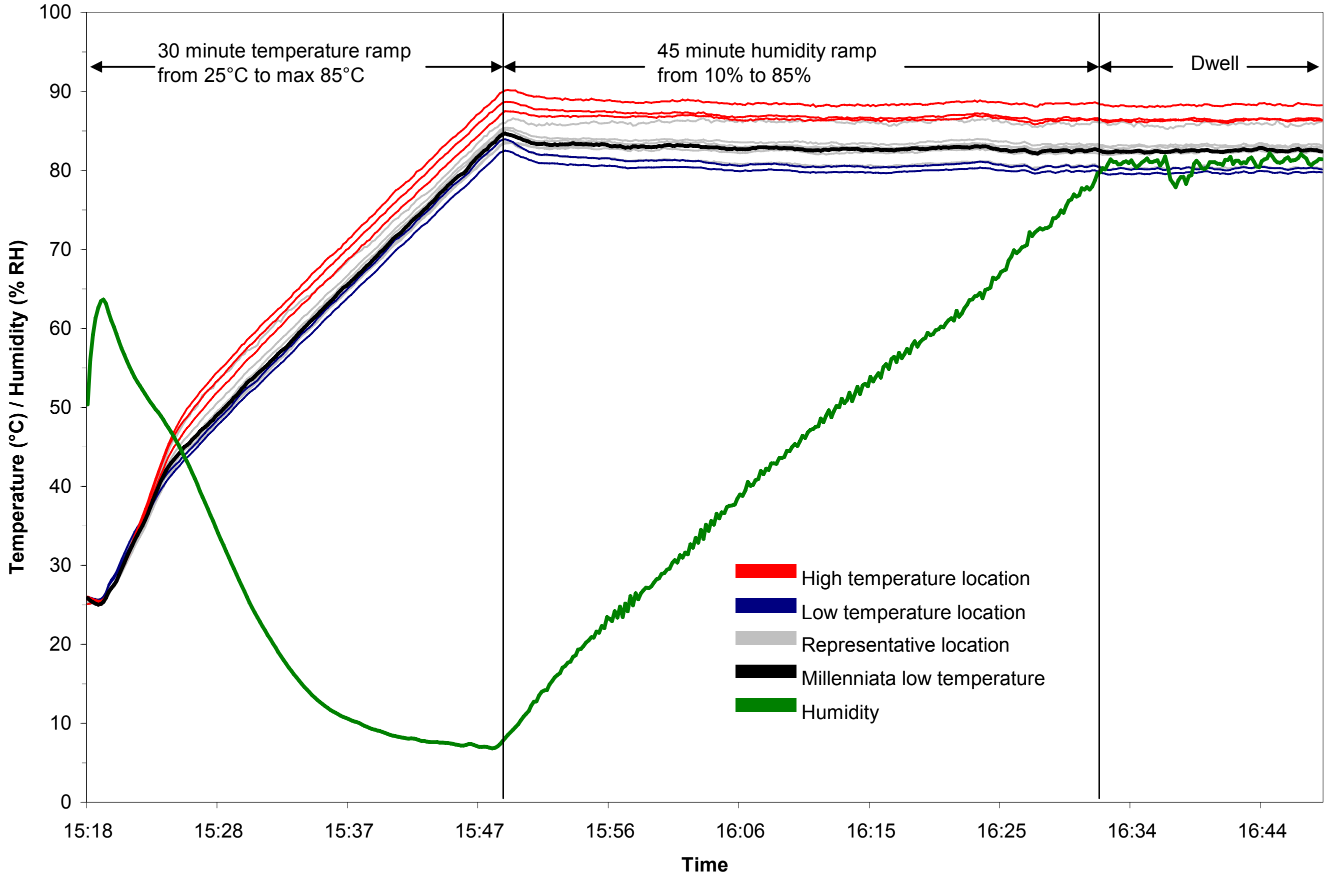

Figure B-3. October 20-21 Temperature and Humidity Ramp Up

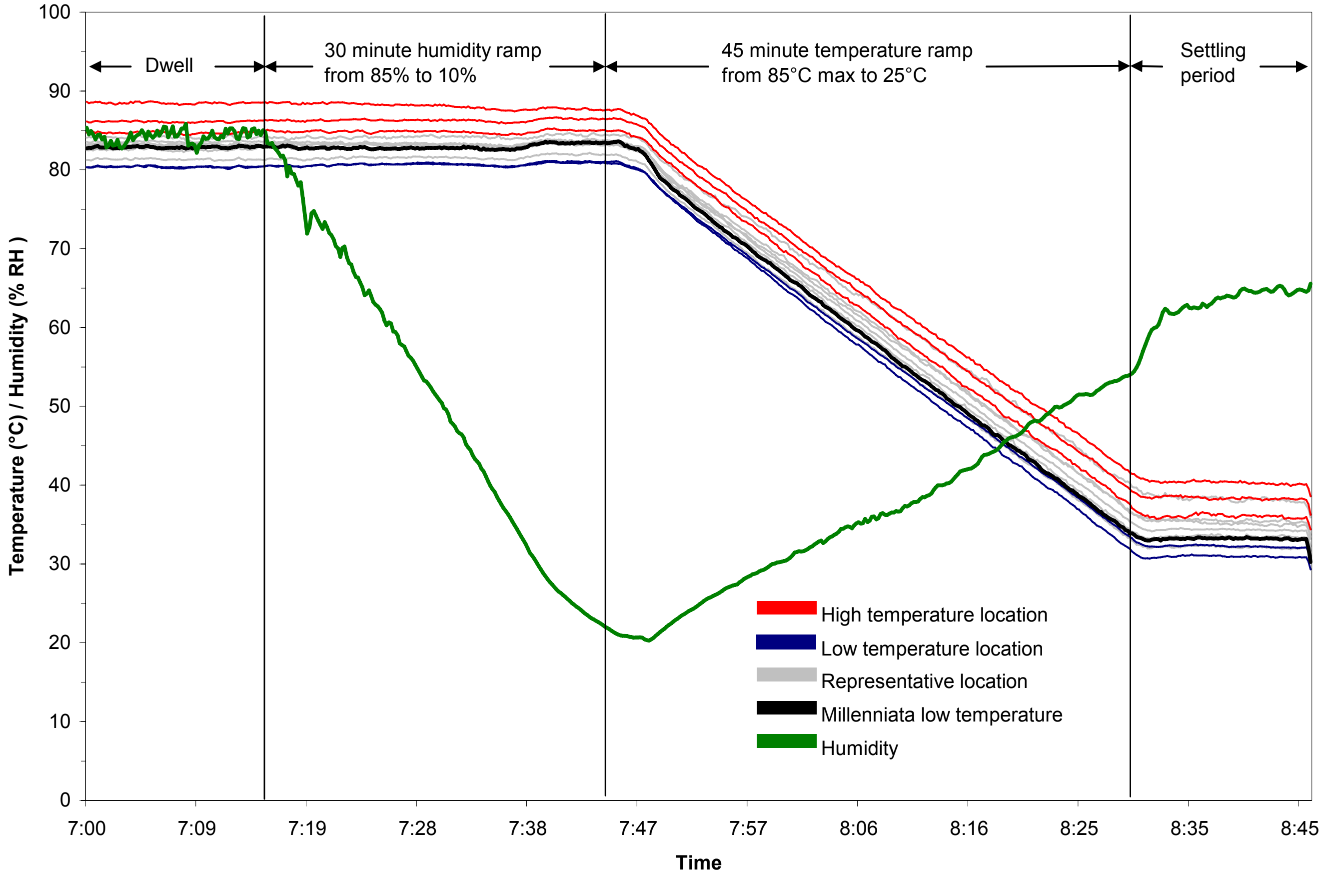

Figure B-4. October 18-19 Temperature and Humidity Ramp Down

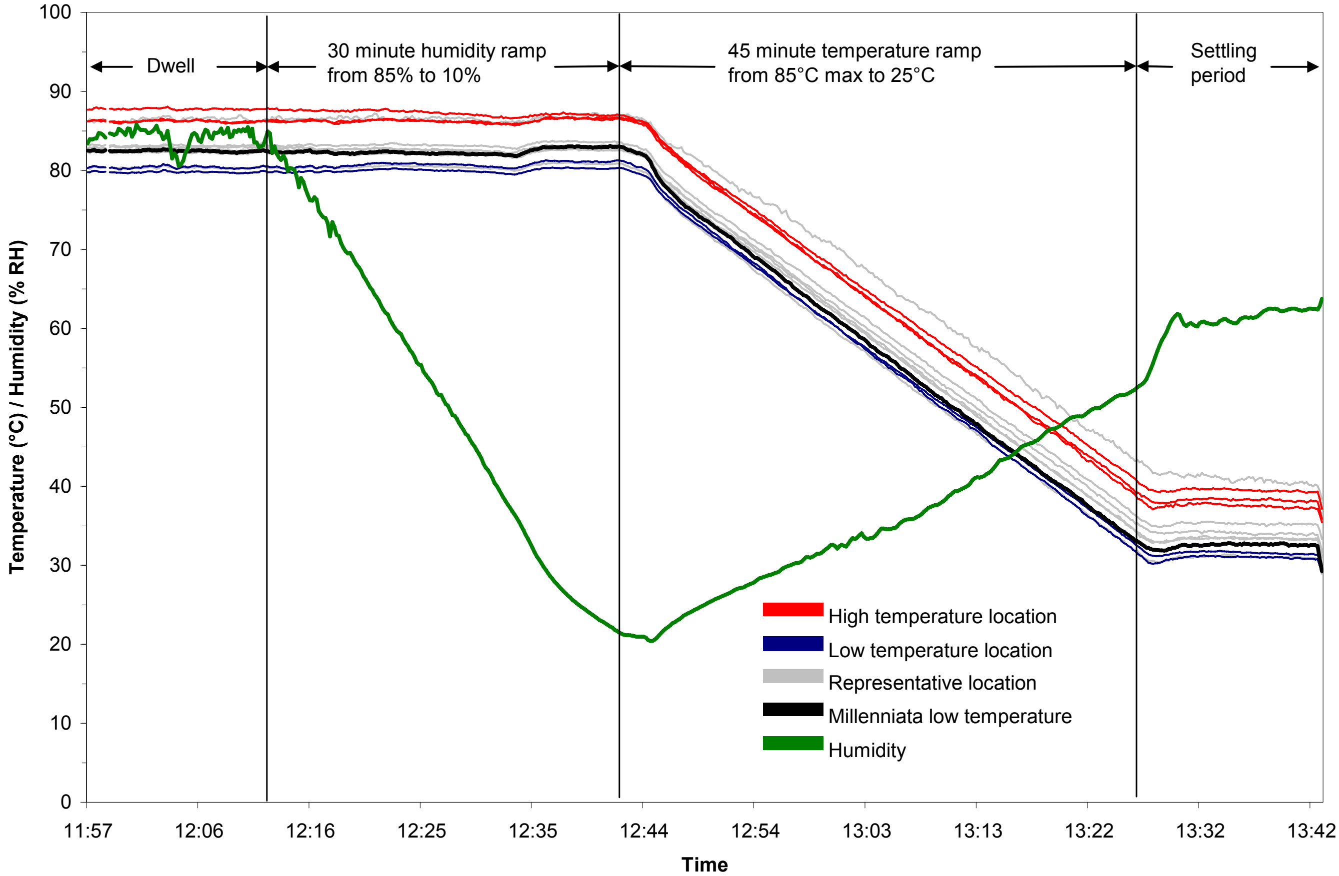

Figure B-5. October 19-20 Temperature and Humidity Ramp Down

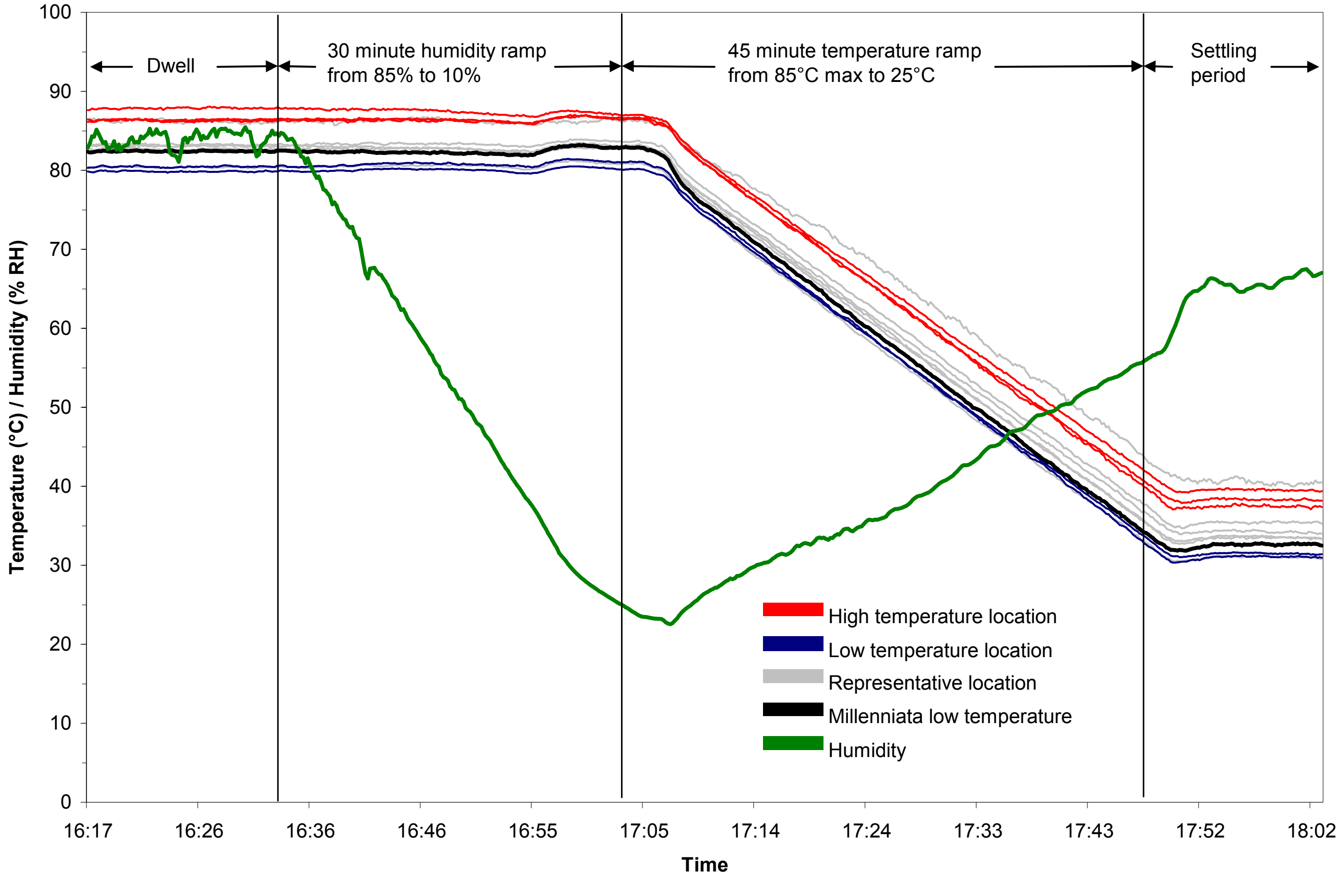

Figure B-6. October 20-21 Temperature and Humidity Ramp Down

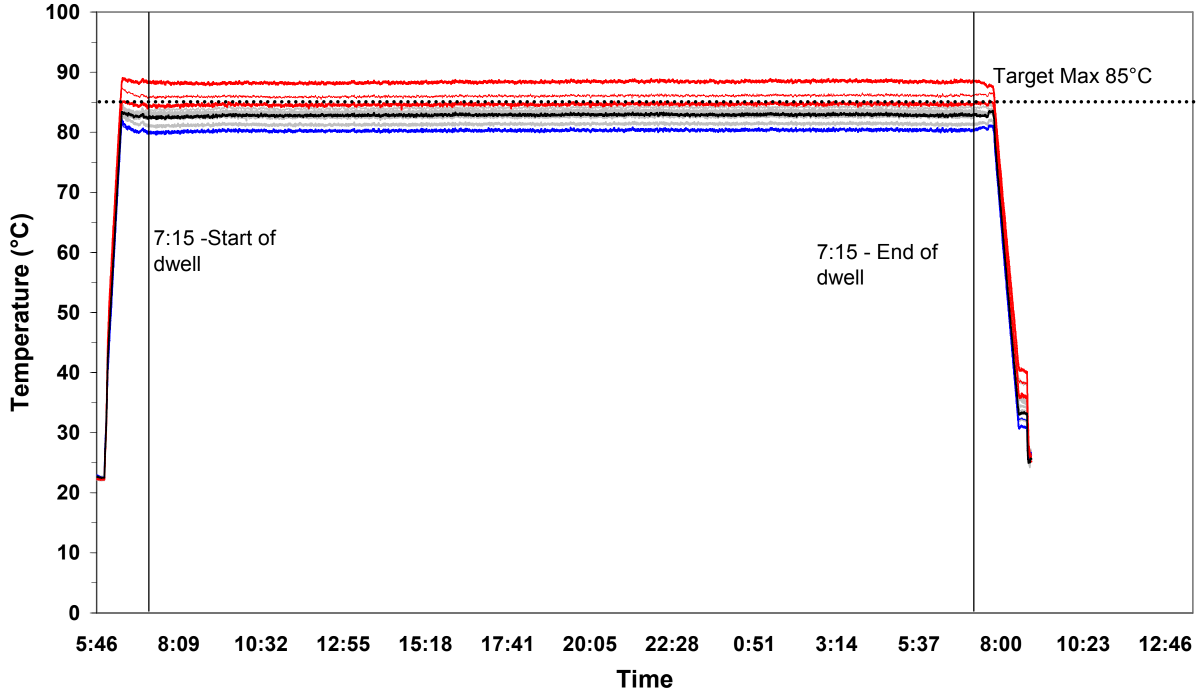

Figure B-7. October 18-19 Disc Temperatures

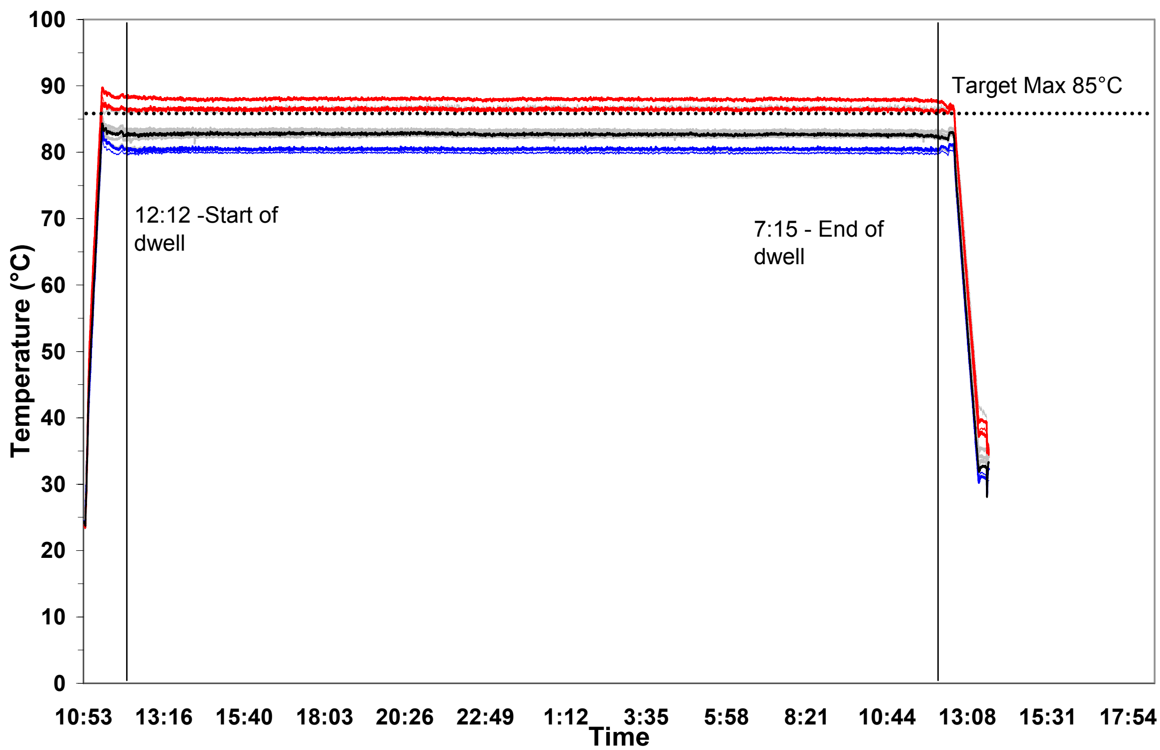

Figure B-8. October 19-20 Disc Temperatures

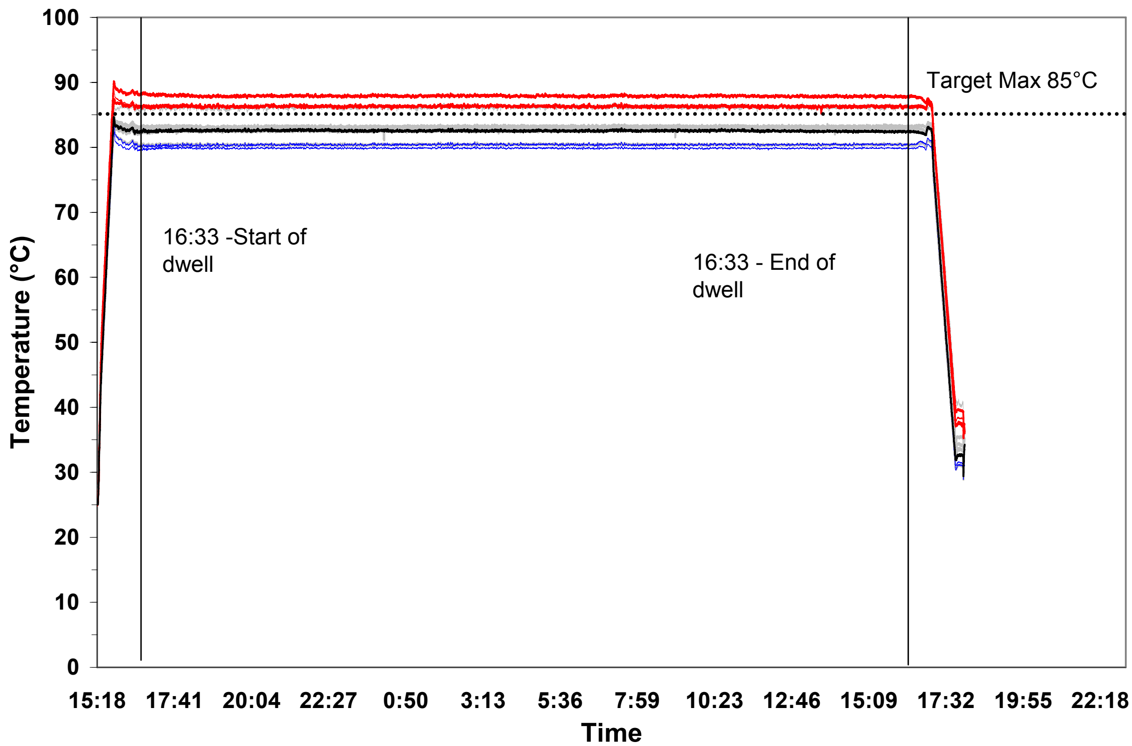

Figure B-9. October 20-21 Disc Temperatures

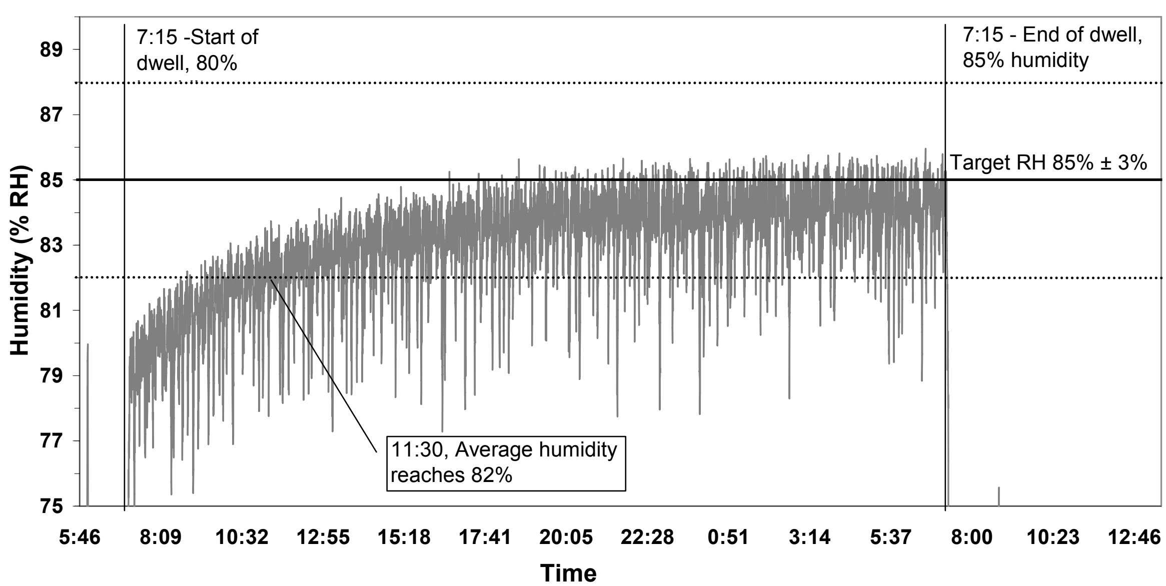

Figure B-10 October 18-19 Humidity

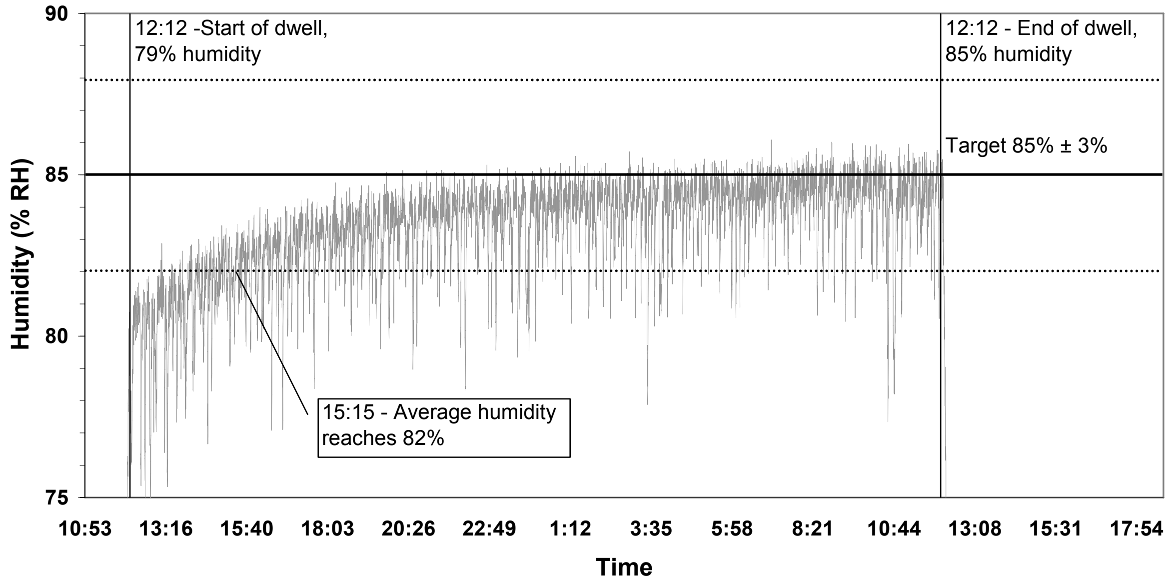

Figure B-11. October 19-20 Humidity

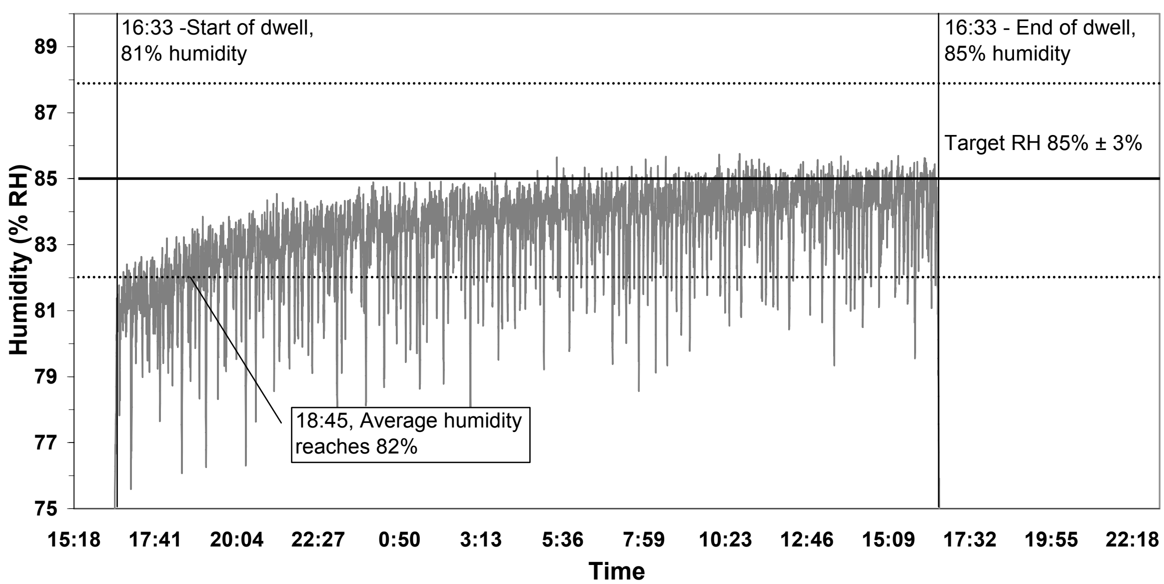

Figure B-12. October 20-21 Humidity

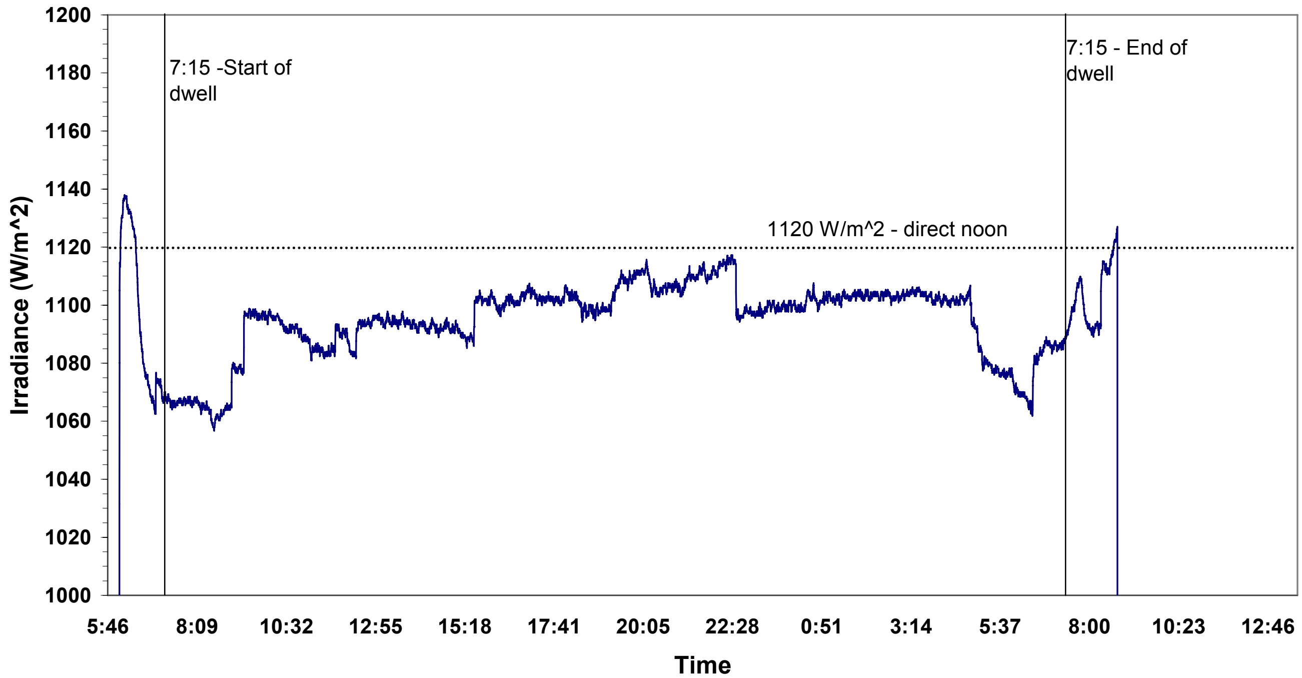

Figure B-13. October 18-19 Irradiance

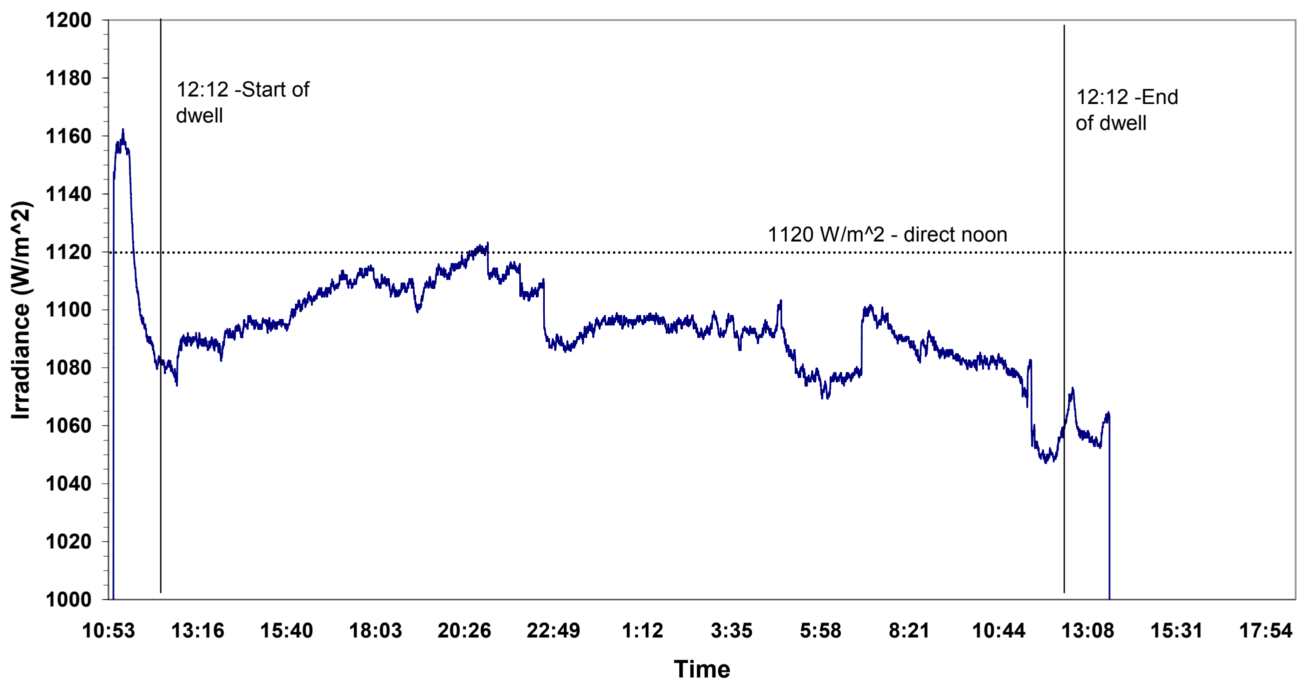

Figure B-14. October 19-20 Irradiance

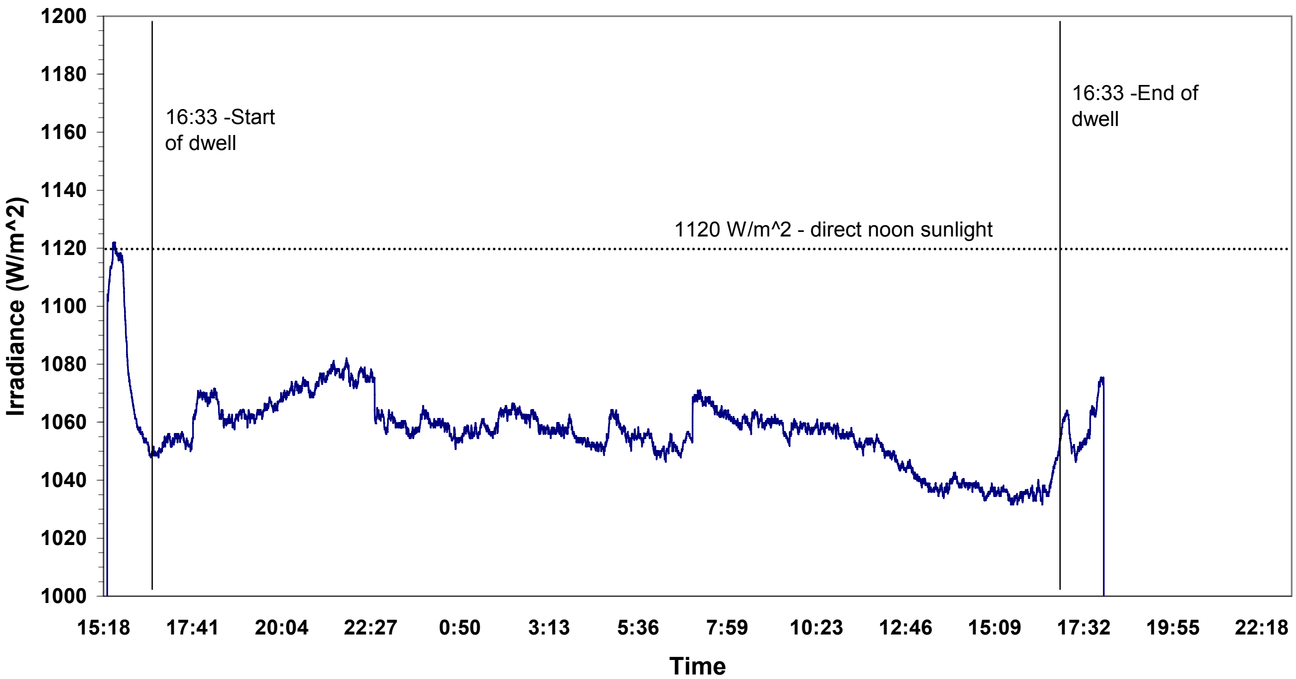

Figure B-15. October 20-21 Irradiance

APPENDIX C POST STRESS DATA

Date	DiscID	Drv	Run	Read Fail	PIE8-Max	PIE8-Avg	PIE8-Events	PIE-Max	PIE-Avg	POF-Count
9/22	DE01B	PI	1	Yes	2764	2274	3313	1870	1742	1667
9/22	DE02B	PI	1	No	1465	1068	2470	229	133	0
9/23	DE01A	PI	1	Yes	5000	5000	5000	5000	5000	5000
9/23	DE01B	PI	1	No	1180	898	2470	211	112	0
9/23	DE02A	PI	1	Yes	5000	5000	5000	5000	5000	5000
9/23	DE02B	PI	1	Yes	2892	2607	3313	1913	1784	1667
9/29	DE01B	PI	1	No	1522	1183	2470	249	148	0
9/30	DE001A	PI	1	No	1921	1516	2470	308	189	49
9/22	DE03B	PI	2	No	458	342	2386	86	43	0
9/22	DE04B	PI	2	No	1303	1838	2470	239	230	46
9/22	DE06B	PI	2	No	795	584	2470	140	73	0
9/23	DE03B	PI	2	No	1237	828	2470	234	104	0
9/23	DE04A	PI	2	Yes	5000	5000	5000	5000	5000	5000
9/23	DE04B	PI	2	Yes	5000	5000	5000	5000	5000	5000
9/29	DE02B	PI	2	Yes	2643	2379	3313	1854	1756	1667
9/30	DE002A	PI	2	Yes	5000	5000	5000	5000	5000	5000
9/30	DE003A	PI	2	No	1467	1027	2470	233	128	11
9/30	DE004A	PI	2	Yes	2255	2077	3313	1787	1718	1667
9/22	DE07B	PI	3	No	892	646	2470	189	81	0
9/22	DE08B	PI	3	Yes	2430	2185	3313	1813	1731	1667
9/29	DE06B	PI	3	No	1790	1548	2470	276	193	0
9/29	DE07A	PI	3	Yes	2433	2216	3313	1796	1735	1667
9/29	DE08B	PI	3	Yes	5000	5000	5000	5000	5000	5000
9/29	DE09B	PI	3	Yes	5000	5000	5000	5000	5000	5000
9/29	DE10A	PI	3	No	1417	1131	2470	236	141	0

Table C-1. Delkin Post Test Data

Date	DiscID	Drv	Run	Read Fail	PIE8-Max	PIE8-Avg	PIE8-Events	PIE-Max	PIE-Avg	POF-Count
9/22	MA01B	OP	1	Yes	2798	2572	3313	1887	1780	1668
9/22	MA02A	OP	1	Yes	3094	2857	3313	1889	1815	1667
9/23	MA01A	IH	1	No	750	493	2470	139	62	0
9/23	MA01B	OP	1	No	1359	1006	2470	257	126	0
9/23	MA02A	IH	1	No	901	574	2470	180	72	0
9/23	MA02B	OP	1	No	1318	950	2470	226	119	0
9/23	MA03A	IH	1	No	750	536	2451	191	67	0
9/23	MA03A	OP	1	No	1983	1667	2470	337	208	16
9/30	MA02A	IH	1	No	766	593	2470	134	74	0
10/06	MA02A	IH	1	Yes	4107	3904	4157	3447	3405	3333
9/22	MA04B	OP	2	Yes	4030	3921	4157	3459	3407	3333
9/23	MA03B	OP	2	No	1535	1360	2470	298	170	0
9/23	MA04A	IH	2	No	370	264	2006	82	33	0
9/23	MA05A	IH	2	No	498	361	2470	141	45	0
9/29	MA04A	OP	2	Yes	2785	2620	3313	1858	1786	1667
9/30	MA03A	IH	2	No	296	182	1419	69	23	0
9/30	MA04A	IH	2	No	414	300	2375	93	38	0
10/06	MA04A	IH	2	No	893	570	2470	167	71	0
9/23	MA05B	OP	3	Yes	3196	2964	3313	1923	1829	1667
9/23	MA06A	OP	3	No	1850	1490	2402	341	193	0
9/23	MA07B	OP	3	No	1607	1321	2470	313	165	0
9/23	MA08A	OP	3	Yes	3462	10939	3313	1930	2824	1685
9/30	MA05A	IH	3	No	539	393	2464	139	49	0
10/06	MA05A	IH	3	No	829	533	2470	148	67	0
10/06	MA06A	IH	3	No	741	530	2470	169	66	0

Table C-2. MAM-A Post Test Data

Date	DiscID	Drv	Run	Read Fail	PIE8-Max	PIE8-Avg	PIE8-Events	PIE-Max	PIE-Avg	POF-Count
9/22	AR01A.2	MW	1	No	59	28	0	15	3	0
9/22	AR01B	MW	1	No	101	53	0	27	7	0
9/22	AR02A.2	MW	1	No	102	48	0	23	6	0
9/22	AR02B	MW	1	No	138	86	13	32	11	0
9/22	AR03B	MW	1	No	148	95	2	34	12	0
9/23	AR01B	MW	1	No	211	147	837	47	18	0
9/25	AR01A	MW	1	No	60	31	0	16	4	0
9/25	AR02B	MW	1	No	59	29	0	17	4	0
9/22	AR04B	MW	2	No	83	43	0	20	5	0
9/22	AR05B	MW	2	No	91	49	0	22	6	0
9/23	AR03B	MW	2	No	55	24	0	15	3	0
9/23	AR05B	MW	2	No	65	34	0	16	4	0
9/24	AR17A	MW	2	No	96	51	0	27	6	0
9/25	AR03A	MW	2	No	52	25	0	15	3	0
9/25	AR04B	MW	2	No	99	58	0	24	7	0
9/25	AR05B	MW	2	No	64	32	0	17	4	0
9/23	AR07B	MW	3	No	62	31	0	16	4	0
9/23	AR08A	MW	3	No	73	30	0	25	4	0
9/23	AR09B	MW	3	No	67	30	0	16	4	0
9/23	AR11B	MW	3	No	59	27	0	16	3	0
9/23	AR12A	MW	3	No	74	40	0	19	5	0
9/23	AR13B	MW	3	No	61	26	0	15	3	0
9/23	AR14A	MW	3	No	87	39	0	22	5	0
9/23	AR16	MW	3	No	59	27	0	16	3	0
9/25	AR06A	MW	3	No	54	25	0	16	3	0

Table C-3. Millenniata Post Test Data

Date	DiscID	Drv	Run	Read Fail	PIE8-Max	PIE8-Avg	PIE8-Events	PIE-Max	PIE-Avg	POF-Count
9/22	MI1A	OP	1	Yes	5000	5000	5000	5000	5000	5000
9/22	MI2A	OP	1	Yes	5000	5000	5000	5000	5000	5000
9/23	MI01A	OP	1	Yes	5000	5000	5000	5000	5000	5000
9/23	MI01B	OP	1	Yes	5000	5000	5000	5000	5000	5000
9/23	MI02A	OP	1	Yes	5000	5000	5000	5000	5000	5000
9/23	MI02B	OP	1	Yes	5000	5000	5000	5000	5000	5000
9/29	MI001B	OP	1	Yes	5000	5000	5000	5000	5000	5000
9/29	MI002B	OP	1	Yes	5000	5000	5000	5000	5000	5000
9/22	MI3A	OP	2	Yes	5000	5000	5000	5000	5000	5000
9/22	MI4A	OP	2	Yes	5000	5000	5000	5000	5000	5000
9/23	MI03A	OP	2	Yes	5000	5000	5000	5000	5000	5000
9/23	MI03B	OP	2	Yes	5000	5000	5000	5000	5000	5000
9/23	MI04A	OP	2	Yes	5000	5000	5000	5000	5000	5000
9/23	MI04B	OP	2	Yes	5000	5000	5000	5000	5000	5000
9/29	MI003A	OP	2	Yes	5000	5000	5000	5000	5000	5000
9/29	MI004B	OP	2	Yes	5000	5000	5000	5000	5000	5000
9/22	MI5A	OP	3	Yes	5000	5000	5000	5000	5000	5000
9/22	MI6A	OP	3	Yes	5000	5000	5000	5000	5000	5000
9/22	MI7A	OP	3	Yes	5000	5000	5000	5000	5000	5000
9/22	MI8A	OP	3	Yes	5000	5000	5000	5000	5000	5000
9/29	MI005A	OP	3	Yes	5000	5000	5000	5000	5000	5000
9/29	MI006B	OP	3	Yes	5000	5000	5000	5000	5000	5000
9/29	MI007A	OP	3	Yes	5000	5000	5000	5000	5000	5000
9/29	MI008B	OP	3	Yes	5000	5000	5000	5000	5000	5000
9/29	MI009A	OP	3	Yes	5000	5000	5000	5000	5000	5000

Table C-4. Mitsubishi Post Test Data

Date	DiscID	Drv	Run	Read Fail	PIE8-Max	PIE8-Avg	PIE8-Events	PIE-Max	PIE-Avg	POF-Count
9/23	TY01A	PI	1	Yes	5000	5000	5000	5000	5000	5000
9/23	TY01B	PI	1	Yes	2431	2282	3313	1825	1744	1667
9/23	TY02A	PI	1	Yes	3594	3497	4157	3376	3354	3333
9/23	TY02B	PI	1	Yes	2844	2618	3482	2161	2077	2000
9/23	TY03A	PI	1	Yes	5000	5000	5000	5000	5000	5000
9/23	TY03B	PI	1	No	1063	679	2421	173	85	0
9/29	TY01A	PI	1	No	716	520	1648	163	65	0
9/29	TY02B	PI	1	Yes	2219	1974	3030	1752	1705	1667
9/23	TY04A	PI	2	Yes	5000	5000	5000	5000	5000	5000
9/23	TY04B	PI	2	No	1447	886	2465	268	111	0
9/23	TY05A	PI	2	Yes	5000	5000	5000	5000	5000	5000
9/23	TY05B	PI	2	Yes	2658	2416	3313	1833	1760	1667
9/23	TY06A	PI	2	Yes	2301	2064	3204	1773	1716	1667
9/29	TY03A	PI	2	Yes	5000	5000	5000	5000	5000	5000
9/29	TY04B	PI	2	Yes	1215	872	2470	223	109	0
9/29	TY05A	PI	2	Yes	5000	5000	5000	5000	5000	0
9/23	TY06B	PI	3	Yes	2832	2455	3313	1846	1765	1667
9/23	TY07A	PI	3	Yes	5000	5000	5000	5000	5000	5000
9/23	TY07B	PI	3	No	1469	982	2278	244	123	0
9/23	TY08A	PI	3	Yes	2027	1895	3027	1742	1695	1667
9/23	TY08B	PI	3	No	1532	946	2469	257	118	0
9/29	TY06B	PI	3	Yes	2249	1996	3313	1775	1708	1667
9/29	TY07A	PI	3	Yes	2231	1989	3200	1760	1707	1667
9/29	TY08B	PI	3	Yes	5000	5000	5000	5000	5000	5000
9/29	TY09A	PI	3	Yes	2294	2127	3312	1769	1724	1667

Table C-5. Taiyo Yuden Post Test Data

Date	DiscID	Drv	Run	Read Fail	PIE8-Max	PIE8-Avg	PIE8-Events	PIE-Max	PIE-Avg	POF-Count
9/22	VE01A	OP	1	Yes	3672	3619	4156	3409	3369	3333
9/22	VE01B	OP	1	Yes	5000	5000	5000	5000	5000	5000
9/22	VE02A	OP	1	Yes	5000	5000	5000	5000	5000	5000
9/22	VE02B	OP	1	Yes	5000	5000	5000	5000	5000	5000
9/23	VE01A	OP	1	Yes	5000	5000	5000	5000	5000	5000
9/23	VE01B	OP	1	Yes	5000	5000	5000	5000	5000	5000
9/23	VE02A	OP	1	Yes	5000	5000	5000	5000	5000	5000
9/29	VE001A	OP	1	Yes	5000	5000	5000	5000	5000	5000
9/22	VE03A	OP	2	Yes	5000	5000	5000	5000	5000	5000
9/22	VE03B	OP	2	Yes	5000	5000	5000	5000	5000	5000
9/22	VE04A	OP	2	Yes	5000	5000	5000	5000	5000	5000
9/23	VE02B	OP	2	Yes	5000	5000	5000	5000	5000	5000
9/23	VE03A	OP	2	Yes	5000	5000	5000	5000	5000	5000
9/23	VE03B	OP	2	Yes	5000	5000	5000	5000	5000	5000
9/29	VE002B	OP	2	Yes	5000	5000	5000	5000	5000	5000
9/29	VE003A	OP	2	Yes	5000	5000	5000	5000	5000	5000
9/22	VE04B	OP	3	Yes	5000	5000	5000	5000	5000	5000
9/23	VE04A	OP	3	Yes	5000	5000	5000	5000	5000	5000
9/23	VE04B	OP	3	Yes	5000	5000	5000	5000	5000	5000
9/29	VE004B	OP	3	Yes	5000	5000	5000	5000	5000	5000
9/29	VE005A	OP	3	Yes	5000	5000	5000	5000	5000	5000
9/29	VE006B	OP	3	Yes	5000	5000	5000	5000	5000	5000
9/29	VE007A	OP	3	Yes	5000	5000	5000	5000	5000	5000
9/29	VE008B	OP	3	Yes	5000	5000	5000	5000	5000	5000
9/29	VE009B	OP	3	Yes	5000	5000	5000	5000	5000	5000

Table C-6. Verbatim Post Test Data