Energy Star Lighting Verification Program

(Program for the Evaluation and Analysis of Residential Lighting)

Final Report

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The data in this report is a spot check of a particular model number from a particular manufacturer. The results cannot be regarded as a representation that all products with this model number will conform to the results.

ABSTRACT

The Program for the Evaluation and Analysis of Residential Lighting (PEARL) is a watchdog program. It was created in response to complaints received by utility program managers about the performance of certain Energy Star lighting products being promoted within their service territories and the lack of a self-policing mechanism within the lighting industry that would ensure the reliability of these products and their compliance with ENERGY STAR specifications. To remedy these problems, PEARL purchases and tests products that are available to the consumers in the marketplace. The Lighting Research Center (LRC) tests the selected products against the corresponding Energy Star specifications.

This final report summarizes the experimental procedure and results of all cycles (Cycles 1 through 8) of PEARL program from the beginning of year 2000 to the end of 2007, along with the description of apparatus used, equipment calibration process, experimental methodology, and research findings from the testing.

In each cycle of PEARL program, PEARL Board selects a list of Compact Fluorescent Lamp (CFL) and Residential Lighting Fixture (RLF) models that are Energy Star qualified. In Cycle 5, Cycle 7, and Cycle 8, no fixture models were selected. After that PEARL sponsors procure product samples for each selected model from different stores and locations in the retail market and send them to LRC for testing. LRC then receive and select the samples, and test them against Energy Star specifications. After the testing LRC analyze and report the results to PEARL Board. Totally 185 models of CFL and 52 models of RLF were tested in PEARL program.

Along with the evolution of the Energy Star specifications from year 2000 to 2003, parameters that were required by Energy Star changed during the eight years of PEARL program. The testing parameters and number of samples tested in PEARL program also changed during this time. For example, in Cycle 1, three samples of each models were tested for their photometric and electrical parameters only; in Cycle 2, 1000-hour Lumen Maintenance and the Rapid Cycle Stress Test was added and an additional set of six samples of each models were tested for Rapid Cycle Stress Test. Also, Cycle 2 data analysis included the testing and verification results against both the “then existing” specification dated 2000 and the “then new” specification dated 8/9/2001. In Cycle 3, Lumen Maintenance at 40% life was added and the number of samples for photometric and electrical testing was increased to five. In Cycle 6, the number of samples for photometric and electrical testing increased again to ten so that five of them were tested in base-up position and five in base-down position. A total of 2375 CFL samples were tested in PEARL program, out of the more than 3000 CFL samples that were purchased for the testing purpose of this program.

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INTRODUCTION

In response to numerous complaints received by utility program managers about the performance of certain ENERGY STAR® lighting products promoted within their service territories, combined with the lack of industry-wide testing or self-policing mechanism, the Program for the Evaluation and Analysis of Residential Lighting (PEARL) was created. PEARL consists of utilities, energy efficiency advocates, and market transformation organizations. The Lighting Research Center (LRC) at Rensselaer Polytechnic Institute in Troy, NY administers the program and performs the testing.

The ENERGY STAR labeling program for residential lighting products merely requires data submission and certification by the product manufacturers. Product samples tested are "self-picked" by the manufacturer. No follow-up testing on actual products purchased from retail is required by ENERGY STAR. In addition, no centralized data review or challenge process exists within the lighting industry relative to the performance of residential ENERGY STAR lighting products.

This final report summarizes the experimental procedure and results of all cycles (Cycles 1 through 8) of PEARL program from the beginning of year 2000 to the end of 2007, along with the description of apparatus used, equipment calibration process, experimental methodology, and research findings from the testing. The experimental process includes procuring and receiving product samples, random selecting samples for different testing categories, testing the samples in the corresponding apparatus and collecting data using automated data acquiring system, compiling the data and analyzing the data against the Energy Star specifications, and reporting the results to PEARL board. The parameters tested mainly include Efficacy, 1000-hour Lumen Maintenance, Color Rendering Index (CRI), Correlated Color Temperature (CCT), Lumen Maintenance at 40% Rated Life, Power Factor, Run-up Time, Rapid Cycle Stress Test, and Interim Life Test. From Cycle 1 to Cycle 6, PEARL also verified parameters such as Transient Protection, Operating Frequency, Electromagnetic Interference (EMI), Input Voltage and Frequency, Lamp Base, Starting Temperature, Control Compatibility, Warranty, Energy Star Label, and Rated Life. Totally 185 models of CFL and 52 models of RLF were tested in PEARL program, which includes 2375 CFL samples tested and 52 RLF samples tested, from more than 3000 CFL samples and more than 100 RLF samples that were purchased for the testing purpose of this program.

EXECUTIVE SUMMARY

PEARL is a watchdog program created to monitor the performance of certain ENERGY STAR lighting products being promoted by utility companies. PEARL purchases and tests products that is available to the consumers in the marketplace.

From the beginning of year 2000 to the end of 2007, PEARL performed eight cycles (Cycles 1 through 8) of testing program. 185 models of CFL and 52 models of RLF from 35 different CFL manufacturers and 25 different RLF manufacturers were tested in PEARL program, which includes 2375 CFL samples tested and 52 RLF samples tested, from more than 3000 CFL samples and more than 100 RLF samples that were purchased for the testing purpose of this program. The types of CFL tested include Bare, Covered (including Globe), and Reflector lamps, and a few of them are dimmable or 3-way lamps. The types of RLF tested include Recessed, Ceiling-mounted, Wall-mounted, Suspended, Portable, Furniture/Cabinet Integrated, and Outdoor lighting fixtures. It is worth noted that even though there are currently about 2500 models CFL and 11200 models of RLF that are listed as Energy Star qualified, only a small portion of these models are available from the retail market. Almost all product samples tested in PEARL program were obtained from the retail market.

In each cycle of PEARL program, PEARL Board members select a list of Energy Star qualified CFL and RLF models that are popular on the retail market or that have quality concerns either due to reported quality problems or due to massive rebate programs rendered on these models. In Cycle 5, Cycle 7, and Cycle 8, no fixture models were selected. After that PEARL sponsors procure product samples for each selected model from different stores and locations in the retail market and send them to LRC for testing. LRC then receive and random select the samples for different testing categories, and test them in the corresponding apparatus against Energy Star specifications. Testing data were collected manually and/or by automated data acquiring system. The parameters tested for CFL models mainly include Efficacy, 1000-hour Lumen Maintenance, Color Rendering Index (CRI), Correlated Color Temperature (CCT), Lumen Maintenance at 40% Rated Life, Power Factor, Run-up Time, Rapid Cycle Stress Test, and Interim Life Test. From Cycle 1 to Cycle 6, PEARL also verified parameters such as Transient Protection, Operating Frequency, Electromagnetic Interference (EMI), Input Voltage and Frequency, Lamp Base, Starting Temperature, Control Compatibility, Warranty, Energy Star Label, and Rated Life. The parameters tested for indoor RLF models mainly include Lamp and Ballast Efficacy, Lamp Start Time, CRI, CCT, Dimming (for Torchieres), Maximum Ballast Case Temperature, Power Factor, and Lamp Current Crest Factor, and PEARL also verified parameters such as Lamp Life, Noise, Fixture Warranty, Durability, Safety, Ballast Performance, and Energy Star Label. After the testing LRC compile the data and analyze the data against the Energy Star specifications, and then report the results to PEARL board.

Along with the evolution of the Energy Star CFL specifications from year 2000 to 2003, parameters that were required by Energy Star changed during the eight

years of PEARL program. The testing parameters and number of samples tested in PEARL program also changed during this time. For example, in Cycle 1, three samples of each models were tested for their photometric and electrical parameters only; in Cycle 2, 1000-hour Lumen Maintenance and the Rapid Cycle Stress Test was added and an additional set of six samples of each models were tested for Rapid Cycle Stress Test. Also, Cycle 2 data analysis included the testing and verification results against both the "then existing" specification dated 2000 and the "then new" specification dated 8/9/2001. In Cycle 3, Lumen Maintenance at 40% life was added and the number of samples for photometric and electrical testing was increased to five. In Cycle 6, the number of samples for photometric and electrical testing increased again to ten so that five of them were tested in base-up position and five in base-down position.

Of all the parameters tested, four parameters for the CFL models were considered as more important from consumers' point of view: Efficacy, 1000-hour Lumen Maintenance, Lumen Maintenance at 40% Rated Life, and Rapid Cycle Stress Test. At the time of this report, some of the CFL models in Cycle 8 are still being seasoned toward their 40% rated life. For Cycle 8, the results of Lumen Maintenance at 40% Rated Life and Interim Life Test are not included in this report.

Out of all 185 CFL models tested, 171 models (92%) met the Efficacy requirement. For the 172 CFL models tested for 1000-hour Lumen Maintenance and Rapid Cycle Stress Test in Cycles 2 through 8, 119 models (69%) met the 1000-hour Lumen Maintenance requirement, and 125 models (73%) met the Rapid Cycle Stress Test requirement. Out of the 124 CFL models tested for Lumen Maintenance at 40% Rated Life in Cycles 3 through 7 (Cycle 8's 40% rated life seasoning is ongoing), 89 models (72%) met this requirement.

Out of 43 indoor RLF models tested, 39 models (91%) met the Lamp and Ballast Efficacy requirement, and 33 models (77%) met the Lamp Start Time requirement.

For results on other parameters please refer to the final reports included in Appendix 3.

EXPERIMENTAL

Apparatus

Please refer to Appendix I of this document for description of apparatus used for testing in PEARL program.

Apparatus Calibration

LRC integrating sphere system was calibrated when necessary. The following is a list of the calibration dates:

September 2000	June 2003	February 2006
February 2001	July 2003	April 2006
May 2001	September 2003	May 2006
August 2001	October 2003	September 2006
October 2001	November 2003	January 2007
January 2002	June 2004	March 2007
May 2002	February 2005	June 2007
September 2002	March 2005	July 2007
November 2002	May 2005	September 2007
February 2003	September 2005	December 2007

The power meter (before January 2006, XITRON 2503AH power analyzer, or after January 2006, YOKOGAWA WT210 digital power meter) and Agilent 34970A Data Acquisition Unit were also calibrated annually.

Product Selection

In each cycle of PEARL program, PEARL Board members select a list of Energy Star qualified CFL and RLF models that are popular on the retail market or that have quality concerns either due to reported quality problems or due to massive rebate programs rendered on these models. In Cycle 5, Cycle 7, and Cycle 8, no fixture models were selected. Occasionally, PEARL selects a few non-Energy-Star-qualified CFL models for comparison purposes. The list of selected CFL and RLF models goes through a few rounds of revisions based on the actual availability of the product samples and on the change of the list of qualified models on Energy Star website. Totally 185 models of CFL and 52 models of RLF were tested in PEARL program.

Product Purchasing and Sampling

After selecting the CFL models and RLF models to test, PEARL sponsors procure product samples for each selected model from different stores and locations in the retail market and send them to LRC for testing. Due to similarity of different product models and human errors in procuring process, a number of incorrect samples were purchased and sent to LRC in every cycle. LRC examined all samples at the time of receiving in order to obtain the correct ones. In some

cases, the LRC also purchased some product samples that the sponsors weren't able to procure.

After receiving and inventory of the CFL samples, the LRC randomized the samples, separated a certain number (three in Cycles 1 and 2, five in Cycles 3, 4, and 5, and ten in Cycles 6, 7, and 8) of samples as photometric and electrical testing samples, and six samples as Rapid Cycle Stress Test samples (except for Cycle 1 when Rapid Cycle Stress Test was not in Energy Star specification yet), and then installed the samples on life testing rack and rapid cycle stress testing rack respectively.

For the RLF models, only two samples were purchased for each model so randomized selection was not necessary.

Totally more than 3000 CFL samples and more than 100 RLF samples were purchased for the testing purpose of this program, from which 2375 CFL samples and 52 RLF samples were tested.

Product Testing

After receiving and sampling the product samples, LRC then test them in the corresponding apparatus against Energy Star specifications. Testing data were collected manually and/or by automated data acquiring system. The parameters tested for CFL models mainly include Efficacy, 1000-hour Lumen Maintenance, CRI, CCT, Lumen Maintenance at 40% Rated Life, Power Factor, Run-up Time, Rapid Cycle Stress Test, and Interim Life Test. From Cycle 1 to Cycle 6, PEARL also verified parameters such as Transient Protection, Operating Frequency, EMI, Input Voltage and Frequency, Lamp Base, Starting Temperature, Control Compatibility, Warranty, Energy Star Label, and Rated Life. The parameters tested for indoor RLF models mainly include Lamp and Ballast Efficacy, Lamp Start Time, CRI, CCT, Dimming (for Torchieres), Maximum Ballast Case Temperature, Power Factor, and Lamp Current Crest Factor, and PEARL also verified parameters such as Lamp Life, Noise, Fixture Warranty, Durability, Safety, Ballast Performance, and Energy Star Label.

Along with the evolution of the Energy Star CFL specifications from year 2000 to 2003, parameters that were required by Energy Star changed during the eight years of PEARL program. The testing parameters and number of samples tested in PEARL program also changed during this time. For example, in Cycle 1, three samples of each models were tested for their photometric and electrical parameters only; in Cycle 2, 1000-hour Lumen Maintenance and the Rapid Cycle Stress Test was added and an additional set of six samples of each models were tested for Rapid Cycle Stress Test. Also, Cycle 2 data analysis included the testing and verification results against both the "then existing" specification dated 2000 and the "then new" specification dated 8/9/2001. In Cycle 3, Lumen Maintenance at 40% life was added and the number of samples for photometric and electrical testing was increased to five. In Cycle 6, the number of samples for photometric and electrical testing increased again to ten so that five of them were tested in base-up position and five in base-down position.

In different PEARL cycles, the ENERGY STAR CFL specifications which the LRC tested the product samples against are:

PEARL Cycle 1: ENERGY STAR CFL specification dated Year 2000 and ENERGY STAR Residential Lighting Fixture specification Version 2.1
PAERL Cycles 2: ENERGY STAR CFL specifications dated Year 2000 and 8/9/2001, and ENERGY STAR Residential Lighting Fixture specification Version 2.1 and 3.0;
PAERL Cycles 3 through 5: ENERGY STAR CFL specifications dated Year 2000 and 8/9/2001 for Cycles 3 through 5, and ENERGY STAR Residential Lighting Fixture specifications Version 2.1 and 3.1 for Cycles 3 and 4;
PAERL Cycles 6 through 8: ENERGY STAR CFL specification dated 10/30/2003 for Cycles 6 through 8, and ENERGY STAR Residential Lighting Fixture specifications Version 3.2 for Cycle 6 only.

Details on testing parameters and test methods are given in the final reports of each PEARL cycle included in Appendix 3.

RESULTS AND DISCUSSION

Of all the parameters tested, four parameters for the CFL models were considered as more important from consumers' point of view: Efficacy, 1000-hour Lumen Maintenance, Lumen Maintenance at 40% Rated Life, and Rapid Cycle Stress Test. At the time of this report, some of the CFL models in Cycle 8 are still being seasoned toward their 40% rated life. For Cycle 8, the results of Lumen Maintenance at 40% Rated Life and Interim Life Test are not included in this report.

Out of all 185 CFL models tested, 171 models (92%) met the Efficacy requirement. For the 172 CFL models tested for 1000-hour Lumen Maintenance and Rapid Cycle Stress Test in Cycles 2 through 8, 119 models (69%) met the 1000-hour Lumen Maintenance requirement, and 125 models (73%) met the Rapid Cycle Stress Test requirement. Out of the 124 CFL models tested for Lumen Maintenance at 40% Rated Life in Cycles 3 through 7 (Cycle 8's 40% rated life seasoning is ongoing), 89 models (72%) met this requirement. Figure 1 shows the percentage of CFL models meeting these four requirements across different cycles of PEARL program. Figure 2 shows the percentage of CFL models meeting these four requirements across different bulb types: Bare, Covered, and Reflector.

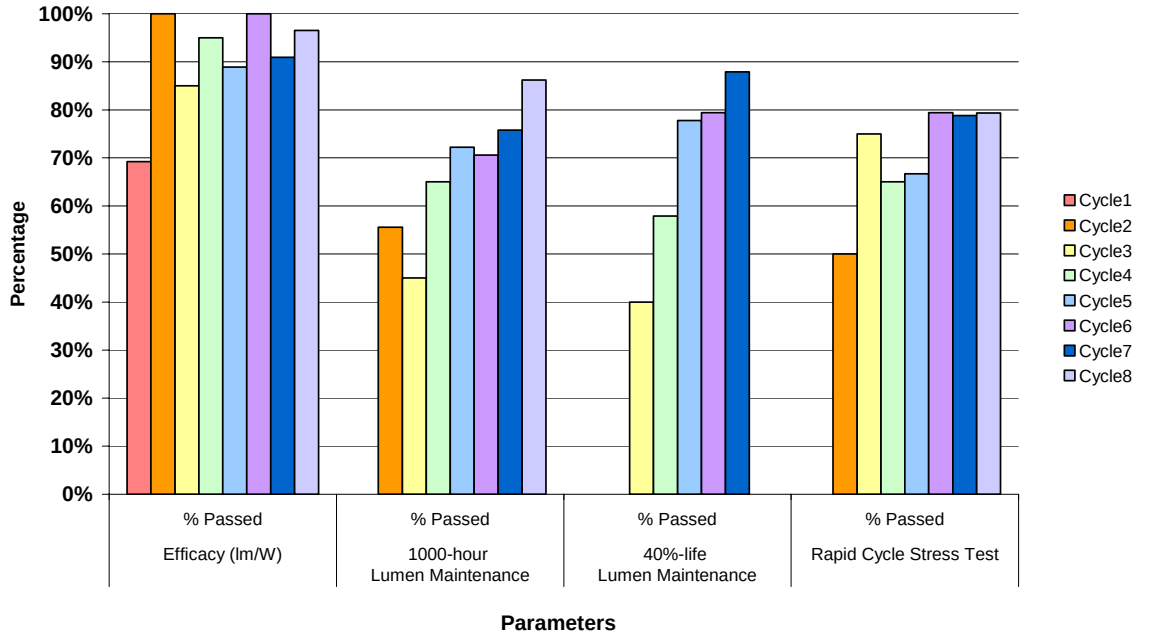

Figure 1: Percentage of Compliance with Energy Star Spec for All CFLs Tested in PEARL across Different Cycles

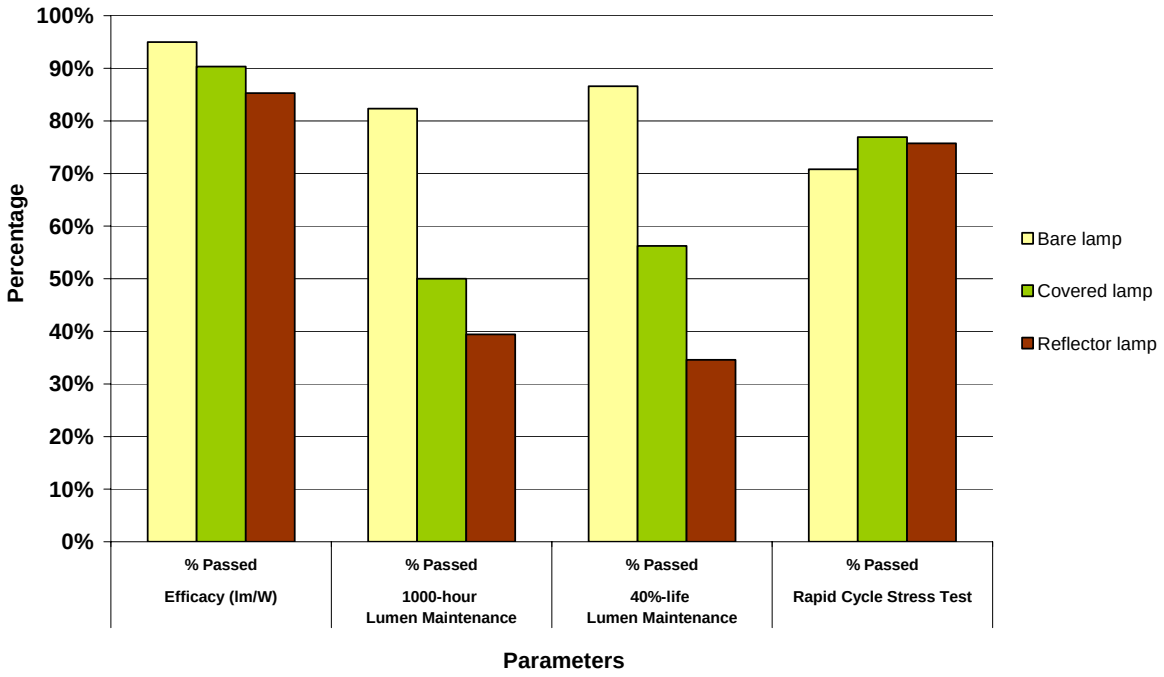

Figure 2: Percentage of Compliance with Energy Star Spec for All CFLs Tested in PEARL across Different Bulb Types

The overall quality of CFL models tested in PEARL program has improved over the eight cycles of testing, as we can see from Figure 1. The covered and reflector type CFL models are more difficult to meet the lumen maintenance requirements, and this is especially true for reflector type CFL models, as shown in Figure 2.

Out of 43 indoor RLF models tested, 39 models (91%) met the Lamp and Ballast Efficacy requirement, and 33 models (77%) met the Lamp Start Time requirement. Figure 3 shows the percentage of indoor RLF models meeting these two requirements across different cycles of PEARL program.

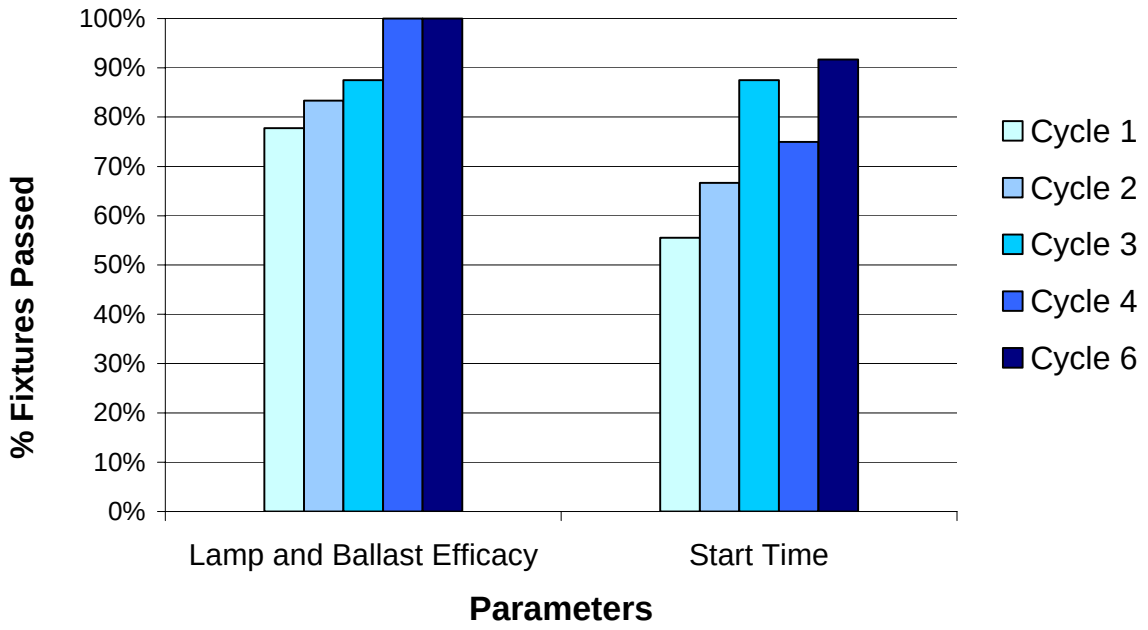

Figure 3: Percentage of Compliance with Energy Star Spec for All Indoor RLFs Tested in PEARL across Different Cycles

The overall quality of RLF models tested in PEARL program has also improved over the five cycles of fixture testing, as we can see from Figure 1.

Other than the parameters required in Energy Star specifications, PEARL also examined other quality problems of the product samples, such as cracked glass on the reflector lamp, bulb color change during operation, initial electrical failures of the ballast, and inconsistent components for samples of the same model number.

All testing results are presented in the final reports of different PEARL cycles, along with discussions of other quality problems that LRC found about the products during the testing and some recommendations on possible modifications to ENERGY STAR specifications. For more details please refer to the final reports of different PEARL cycles in Appendix 3.

CONCLUSION

In sum, the majority of CFL and RLF models tested in PEARL program met Energy Star specifications. Out of all 185 CFL models tested, 171 models (92%) met the Efficacy requirement. For the 172 CFL models tested for 1000-hour Lumen Maintenance and Rapid Cycle Stress Test in Cycles 2 through 8, 119 models (69%) met the 1000-hour Lumen Maintenance requirement, and 125 models (73%) met the Rapid Cycle Stress Test requirement. Out of the 124 CFL models tested for Lumen Maintenance at 40% Rated Life in Cycles 3 through 7 (Cycle 8's 40% rated life seasoning is ongoing), 89 models (72%) met this requirement. Out of 43 indoor RLF models tested, 39 models (91%) met the Lamp and Ballast Efficacy requirement, and 33 models (77%) met the Lamp Start Time requirement.

The overall quality of CFL and RLF models tested in PEARL program has improved over the eight years of testing. The covered and reflector type CFL models are more difficult to meet the lumen maintenance requirements, and this is especially true for reflector type CFL models.

REFERENCES

ENERGY STAR, "Energy Star Program Requirements for CFLs", Versions dated Year 2000, 8/9/2001, and 10/30/03.

ENERGY STAR, "Energy Star Program Requirements for Residential Lighting Fixtures", Versions 2.1, 3.0, 3.1, and 3.2.

RAND, "A Million Random Digits with 100,000 Normal Deviates", Published 2001 by RAND

ANSI C62.41:1991 IEEE Recommended Practice for Surge Voltages in Low-Voltage AC Power Circuits

ANSI C78.4:1998 American National Standard for Fluorescent Lamps - Self-Supporting, Single-Based, Compact Types - Dimensional and Electrical Characteristics

ANSI C78.5:1997 American National Standard for Electrical Lamps - Specifications for Performance of Self-Ballasted Compact Fluorescent Lamps

ANSI C82.3:1995 American National Standard Specifications for Fluorescent Lamp Reference Ballasts

IES LM-20:1994 Photometric Testing of Reflector-Type Lamps

IES LM-40: 2001 Life Performance Testing of Fluorescent Lamps

IES LM-45:2000 Electrical and Photometric Measurements of General Service Incandescent Filament Lamps

IES LM-49:2001 Life Testing of General Lighting Incandescent Filament Lamps

IES LM-54:1999 IES Guide to Lamp Seasoning

IES LM-58:1994 Spectroradiometric Measurements

IES LM-65:2001 Life Testing of Single Ended Compact Fluorescent Lamps

IES LM-66:2000 Electrical and Photometric Measurements of Single-Ended Compact Fluorescent Lamps

IES LM-9:1999 Electrical and Photometric Measurements of Fluorescent Lamps

NIST HB 150-1:1994 National Voluntary Laboratory Accreditation Program (NVLAP) Handbook for Energy Efficient Lighting Products. Lawrence S. Galowin, Wiley Hall, and Walter J. Rossiter, Jr.

NBST PB93 196 038 Experimental Statistics Handbook 1991

UL 1993 Standard for Safety for Self-Ballasted Lamps and Lamp Adapters

LIST OF ACRONYMS AND ABBREVIATIONS

AC	Alternative Current
ANSI	American National Standard Institute
CCF	Current Crest Factor
CCT	Correlated Color Temperature
CFL	Compact Fluorescent Lamp
CRI	Color Rendering Index
DC	Direct Current
IES	Illuminating Engineering Society
ISS	Integrating Sphere System
Lm	Lumen
IES-LM	Illuminating Engineering Society Lighting Measurement Guidance
LRC	Lighting Research Center
NEMA	National Electrical Manufacturers Association
NLPIP	National Lighting Product Information Program
PEARL	Program for the Evaluation and Analysis of Residential Lighting
PF	Power Factor
RPI	Rensselaer Polytechnic Institute
UL	Underwriter Laboratories
W	Watt

APPENDIX 1: Apparatus

LRC Laboratory Description

The Lighting Research Center (LRC), part of Rensselaer Polytechnic Institute, is a university-based research and education institution dedicated to lighting. Its laboratory performs testing of energy efficient products for the Program for the Evaluation and Analysis of Residential Lighting (PEARL), the National Lighting Product Information Program (NLPIP), and some research for the LRC's partners.

Located at 21 Union Street in Troy, New York, the LRC laboratory employs a staff of 12 (please see the organizational chart). The lab consists of three sub areas, of a total size of 2060 square feet: the 20x8 foot Ballast Testing Room, the 34x30 foot Lamp Testing Room, and the 44x20 foot Photometry Lab.

Integrating Sphere System (ISS)

The main apparatus in Lamp Testing Room is an Integrating Sphere System (ISS). The ISS consists of following items/instruments:

- Integrating sphere; interior access type, 65-inch diameter (Mfg: Labsphere, Model: IAS650) Figure 1
- Double monochromator at 5 nm band pass (Mfg: Optronic Laboratories, Model: 750-M-D)
  - Entrance slit width – 2.5 mm
  - Exit slit width – 2.5 mm
  - Center slit width – 5.0 mm
- Enhanced silicone detector module (Mfg: Optronic Laboratories, Model: DH-300)
- Detector support module (Mfg: Optronic Laboratories, Model: DSM-1D)
- System controller for the monochromator/detector system (Mfg: Optronic Laboratories, Model: 750-C)
- OL750 application software (supplied by Optronic Laboratories)
- Personal computer with Windows NT 4.0 (Mfg: Dell, Model: OptiPlex GX1p)
- GPIB Interface (Mfg: National Instruments, Model: GPIB-PCI)

National Standards Used

The national standards used in the testing for LRC testing lab are from ANSI/NEMA, UL, and Illuminating Engineering Society (IES). Below is a list of them:

- ANSI C62.41:1991 IEEE Recommended Practice for Surge Voltages in Low-Voltage AC Power Circuits
- ANSI C78.4:1998 American National Standard for Fluorescent Lamps - Self-Supporting, Single-Based, Compact Types - Dimensional and Electrical Characteristics
- ANSI C78.5:1997 American National Standard for Electrical Lamps - Specifications for Performance of Self-Ballasted Compact Fluorescent Lamps

- ANSI C82.3:1995 American National Standard Specifications for Fluorescent Lamp Reference Ballasts
- IES LM-20:1994 Photometric Testing of Reflector-Type Lamps
- IES LM-40: 2001 Life Performance Testing of Fluorescent Lamps
- IES LM-45:2000 Electrical and Photometric Measurements of General Service Incandescent Filament Lamps
- IES LM-49:2001 Life Testing of General Lighting Incandescent Filament Lamps
- IES LM-54:1999 IES Guide to Lamp Seasoning
- IES LM-58:1994 Spectroradiometric Measurements
- IES LM-65:2001 Life Testing of Single Ended Compact Fluorescent Lamps
- IES LM-66:2000 Electrical and Photometric Measurements of Single-Ended Compact Fluorescent Lamps
- IES LM-9:1999 Electrical and Photometric Measurements of Fluorescent Lamps
- NIST HB 150-1:1994 National Voluntary Laboratory Accreditation Program (NVLAP) Handbook for Energy Efficient Lighting Products. Lawrence S. Galowin, Wiley Hall, and Walter J. Rossiter, Jr.
- NBST PB93 196 038 Experimental Statistics Handbook 1991
- UL 1993 Standard for Safety for Self-Ballasted Lamps and Lamp Adapters

Spectral/flux Calibration of the ISS

The calibration procedure enables the integrating sphere system (ISS) to measure photometric output of test lamps. The process involves the determination of the relative spectral response of the ISS and normalization of the photometric output to a known flux standard(s). The relative spectral response is determined by comparing a spectral irradiance standard with the system response to the standard. This is done over the desired range of wavelengths. Once the relative spectral response is determined the flux standard(s) is used to normalize the system output to the known photometric output of the standard.

Standard lamps used for calibration

The following spectral/flux standards were used in the calibration process. All standards are traceable to NIST.

Relative spectral irradiance standard

FEL type incandescent lamp, traceable to NIST (Mfg: Hoffman Engineering, SN: 94406)

- Lamp current: 7.204 A (DC)
- Lamp voltage: 84.5 V (DC)
- Correlated color temperature: 2856 K
- CIE x: 0.448
- CIE y: 0.408
- Spectral range: 350 to 1100 nm

Flux standards

200W Wi40/Globe incandescent, inside frosted, calibrated at NIST (Mfg: Osram)

Lamp_RPI_1
- Lamp current: 5.725 A
- Lamp voltage: 29.36 V
- Luminous flux: 2225 lumens
- Correlated color temperature: 2750 K

Lamp_RPI_2
- Lamp current: 5.728 A
- Lamp voltage: 29.45 V
- Luminous flux: 2288 lumens
- Correlated color temperature: 2750 K

Lamp_RPI_3
- Lamp current: 5.623 A
- Lamp voltage: 29.31 V
- Luminous flux: 2234 lumens
- Correlated color temperature: 2750 K

Spectral lamp (Mfg: Osram)

- Lamp type: HgCd/10

Working standard lamp to be calibrated

The following lamp was calibrated for luminous flux using the calibrated ISS.

Lamp RPI_WS, 200W incandescent, clear (Mfg: Osram)
- Lamp type: Wi 40/G
- Rated voltage: 31.0 V
- Rated current: 6.0 A

Electrical equipment

- DC power supply (Mfg: Hewlett Packard, Model: 6675A)
- AC power supply (Mfg: Pacific Power Source, Model: 112-AMX)
- AC power supply (for the HgCd/10 spectral lamp; Mfg: Gates, Model: 12S-9)
- Data acquisition/switch unit (Mfg: Agilent Technologies, Model: 34970A)
- Digital power meter (Mfg: YOKOGAWA, Model: WT210)
- Bench type multimeter (Mfg: Hewlett Packard, Model: 34401A)
- Autoranging picoammeter (Mfg: KEITHLEY, Model: 485)
- Shunt resistance (Mfg: Isotek, Model: RUG-R050, 50 mΩ)
- Computer controlled data acquisition system (using GPIB)

Sphere Calibration Procedure

The whole calibration process involves three steps:

- Wavelength calibration
- Relative spectral response calibration
- Flux calibration

Wavelength calibration

The monochromator system is pre-calibrated for wavelength. The experimental procedure was to determine possible changes in the pre-calibration due to shipping/handling etc.

The spectral (HgCd/10) lamp was mounted at the center of the sphere. It was turned on and stabilized for about 20 minutes before the test. The stabilization was determined by monitoring the lamp current for a certain amount of time, and the lamp was considered as stabilized when the variation of lamp current was less than 1% within this period of time. A spectral scan from 360 to 650 nm at 0.2 nm intervals was taken using the monochromator system. Known spectral peaks for Hg and Cd were compared against the measured peaks. See Figure 2.

Relative Spectral Response Calibration

The relative spectral response of the ISS was determined using the spectral irradiance standard lamp 94406. The spectral data for the lamp were imported to the software program (software supplied by Optronic Laboratories).

The DC power supply was used to power up the lamp. The current limit was set at 7.204 A, and the power supply was operated at the constant current (CC) mode. The DC voltage across the shunt was monitored using the Data acquisition/switch unit to maintain the lamp current. The lamp voltage was measured using the multimeter. Lamp was stabilized for about 15 minutes before the scan. The room temperature was recorded at regular intervals.

A spectral scan from 350 to 800 nm was taken using the double monochromator system. The relative spectral response of the system is the ratio of the standard spectral data of the lamp to that of scanned data (the software program does the math automatically) for the wavelength range from 350 to 1100 nm. Figure 4 illustrates the system spectral response calibration curve.

Even though there was a slight discrepancy (figure 3) in the measured spectral power distribution of the spectral standard (94406) around 600 nm region, it produced close results of the reported CCT and chromaticity coordinates. Therefore the error introduced by placing the lamp inside the sphere is assumed negligible.

Flux calibration

The flux calibration was done using two flux standards RPI_2 and RPI_3 (calibrated at NIST). The lamp (RPI_2) was mounted at the center of the sphere. The DC power supply was used to power up the lamp. Current was set at 5.728 A, and the power supply was run at the CC mode. Lamp was stabilized for about 15 minutes before the test. The lamp current was monitored using the Data acquisition/switch unit to maintain the lamp current. The lamp voltage was

measured using the multimeter. The room temperature was recorded at regular intervals.

A spectral scan from 350 to 1100 nm was taken using the double monochromator system. The same procedure was repeated for the lamp RPI_3. Photometric calculations were performed using the software program. The photometric output for each lamp was used to obtain the normalization factor to find the absolute luminous flux.

The flux standard RPI_1 was tested using the calibrated ISS to check the calibration. The lamp was operated using the same DC power supply similar to the manner described above for RPI_2 and RPI_3 at the specified current of 5.725 A.

Calibration of the working standard
The working standard was calibrated using the calibrated ISS. The lamp (working standard) was mounted at the center of the sphere. The DC power supply was used to power up the lamp. Current was set at 5.728 A, and the power supply was run at the CC mode. Lamp was stabilized for about 15 minutes before the test. Stabilization was determined by monitoring the lamp current. When the lamp current changes less than 0.01% within 3 minutes, the lamp is considered as stable in its current and its light output. The lamp current was monitored using the Data acquisition/switch unit to maintain the lamp current. The lamp voltage (29.468 V, at the lamp leads about 6 inches away from the actual lamp terminals) was measured using the multimeter. The room temperature was recorded at regular intervals.

A spectral scan from 350 to 800 nm was taken using the double monochromator system. Photometric calculations were performed using the software program.

The auxiliary lamp (12 V, Quartz halogen) was used to determine the self-absorption factor for flux standards. The DC power supply was used to power up the lamp. Current was set at 2.869 A, and the power supply was run at the CC mode. Lamp was stabilized about 10 minutes before the test. Two spectral scans from 380 to 800 nm were taken with and without the unlit flux standard RPI_1 inside the sphere. The software program was used to determine the numerical sum of each scan, and the ratio was used as the self-absorption factor.

Other Equipment

- Lamp Racks
- Fixture Racks
- Double Monochromator and Controller
- Instrument Rack:
  - Power meter
  - Data acquisition unit
  - Multimeter
  - Picoammeter
  - AC Power Supply
  - DC Power Supply

- Examination Tables
- Computers

References for Appendix I

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Ohno Y. and Daubach O. 2000. Integrating Sphere Simulation on Spatial Nonuniformity Errors in Luminous Flux Measurement. IESNA Annual Conference, Washington DC, Jul. 31 – Aug. 2, 2000.

Short Course on Photometry, September 14-17, 1999. Section 11, Handouts and Reference Materials. National Institute of Standards and Technology, Optical Technology Division, Gaithersburg, MD.

APPENDIX 2: Figures for Apparatus and Calibration Equipment

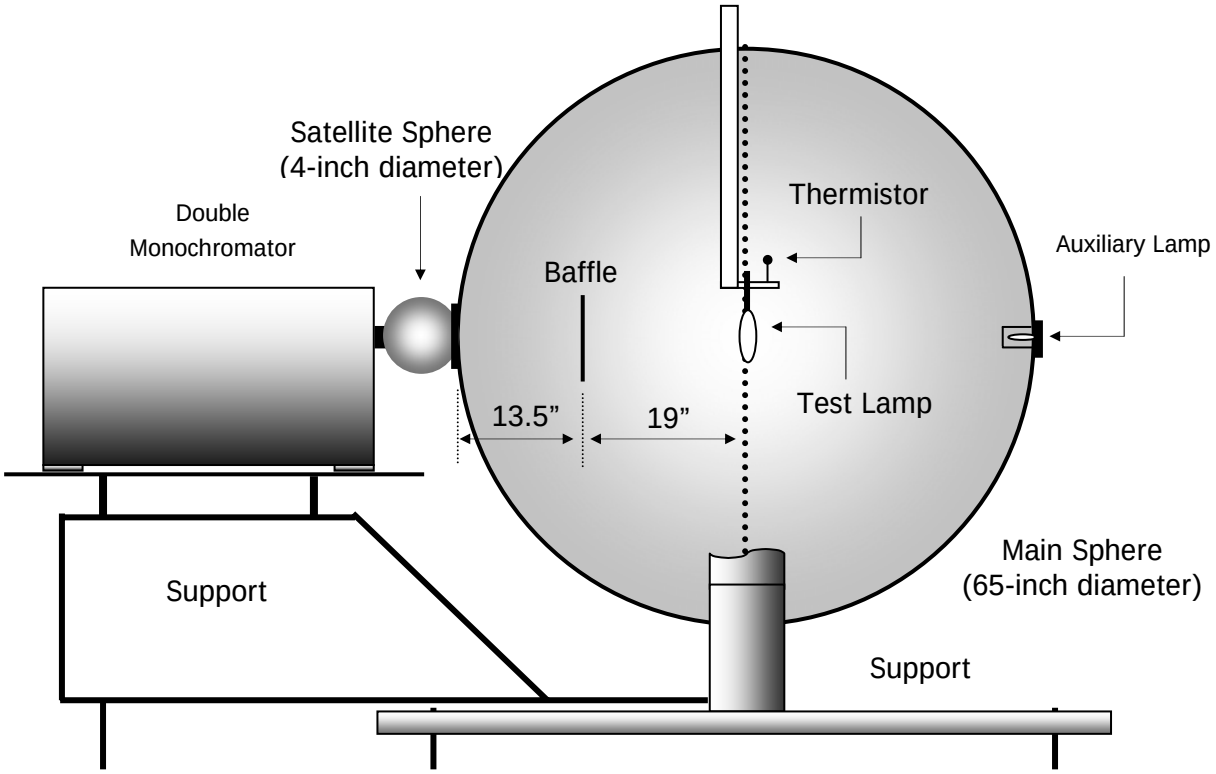

Figure 4. The integrating sphere system (ISS)

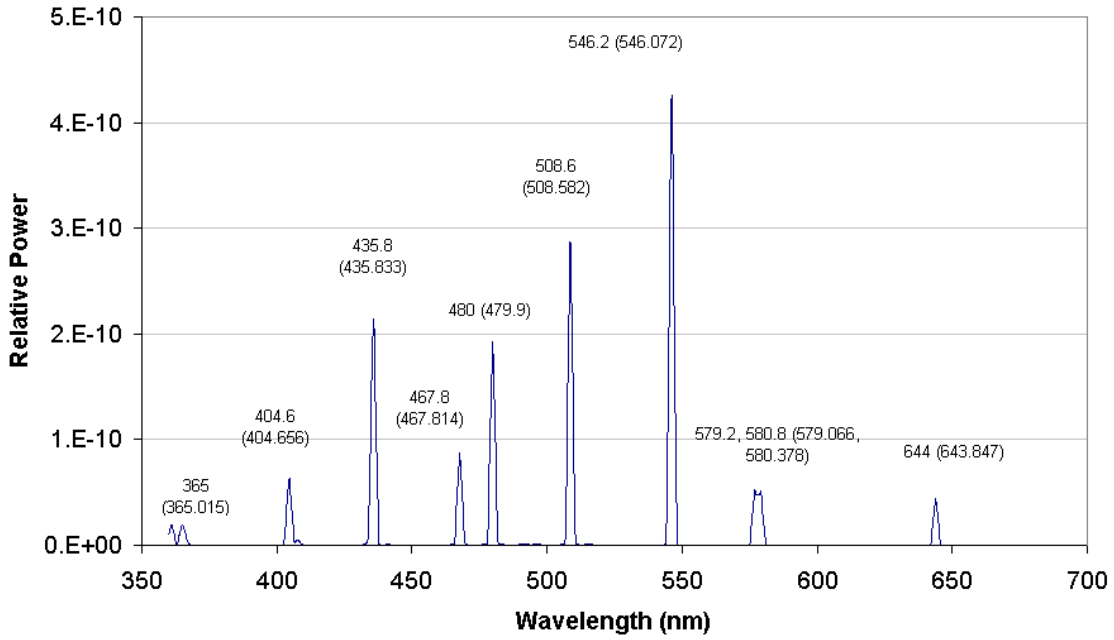

Figure 5. Measured line spectrum of the HgCd/10 spectral lamp. Values in parenthesis are the reference values for corresponding peaks.

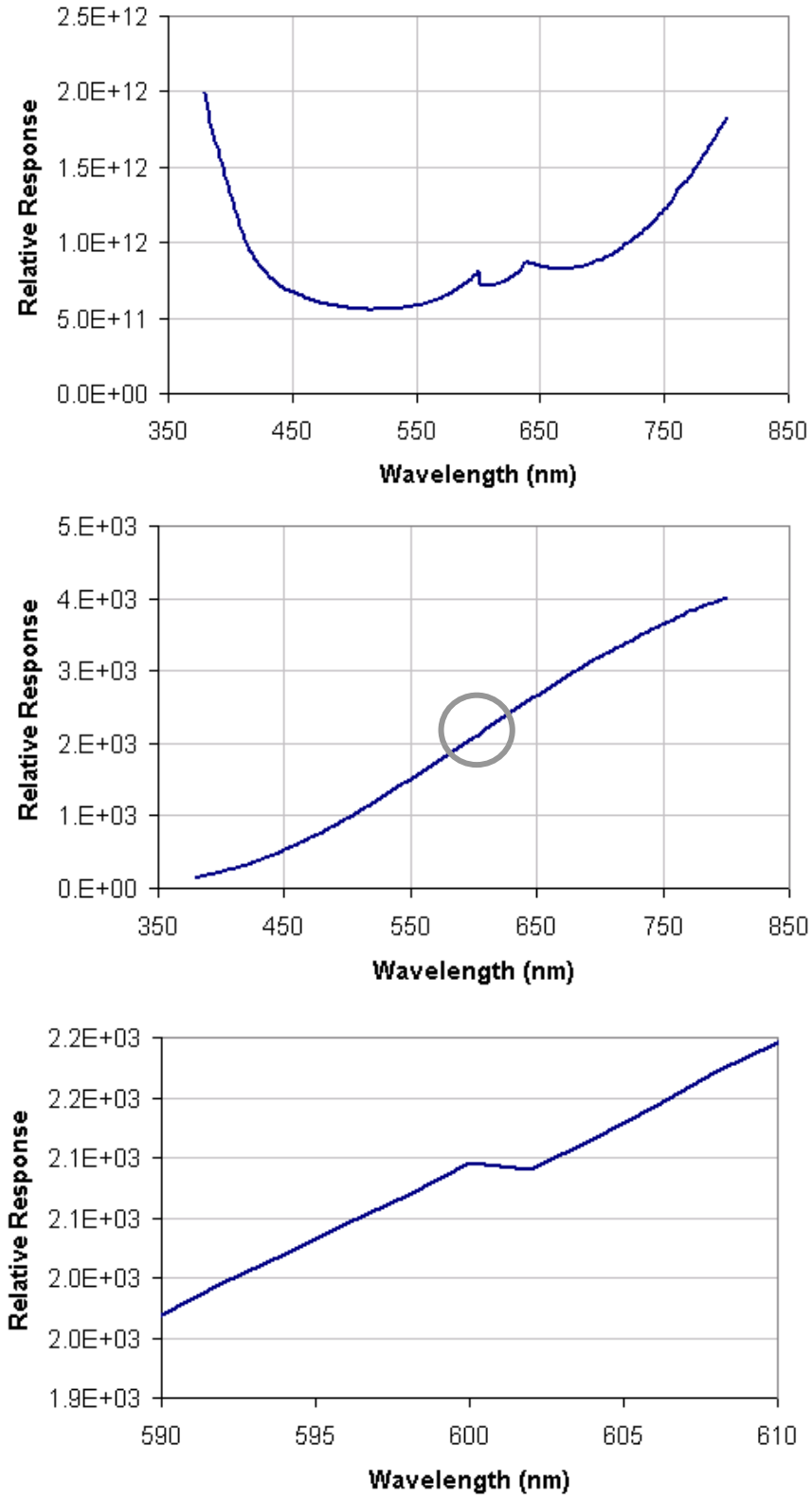

Figure 6. (a) Relative spectral response curve obtained by manual operation, (b) measured spectrum of the spectral standard (94406) inside the sphere using the calibration curve obtained by manual operation, and (c) enlarged portion showing the abnormal portion around 600 nm indicated by the circle in (b).

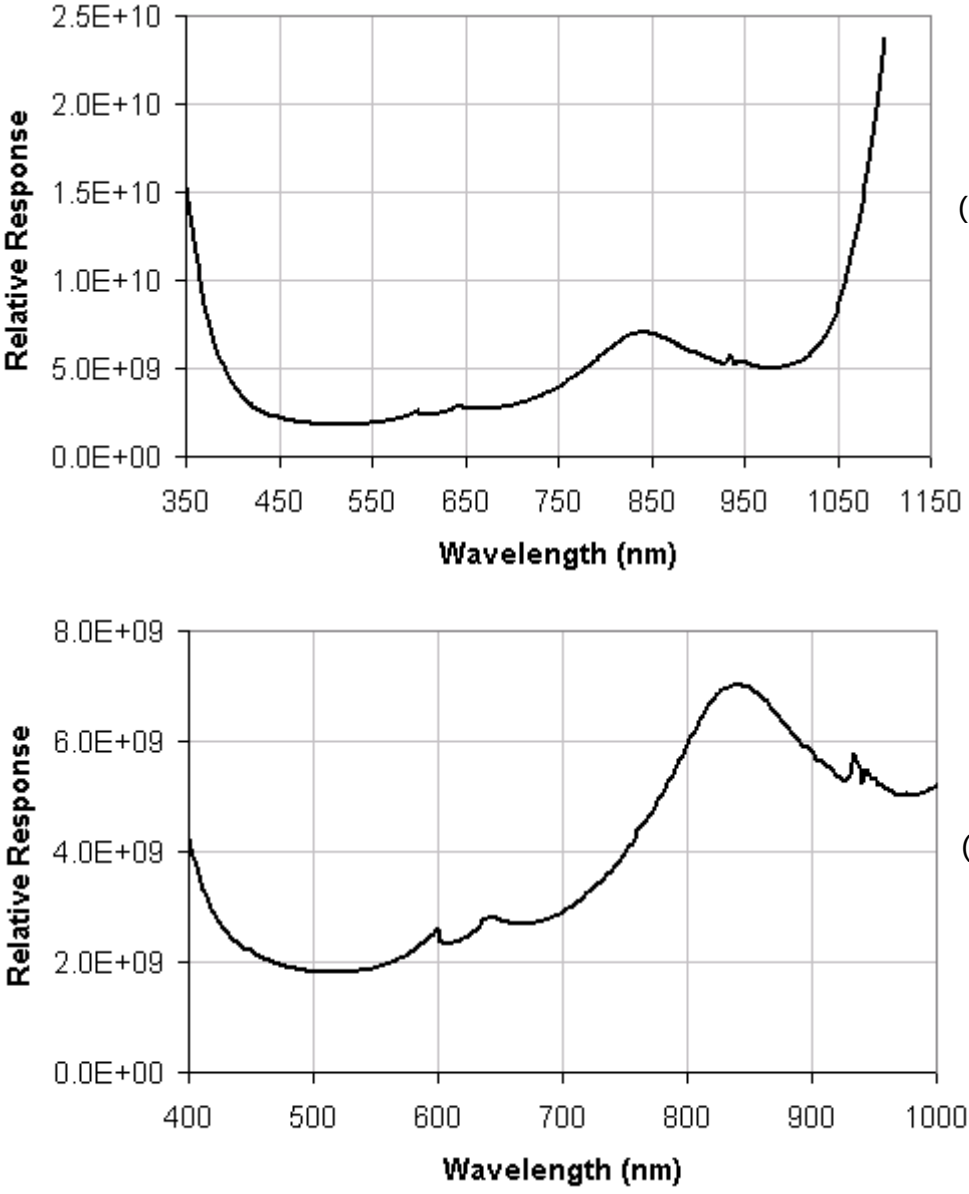

Figure 7. Relative spectral response of the ISS with the spectral standard located inside the sphere. (a) From 350 to 1100 nm measured at 2 nm intervals and (b) same data from 400 to 1000 nm at 2 nm intervals.

APPENDIX 3: Limited Rights Data --- PEARL Final Reports

PEARL Final Reports are considered as Limited Rights Data since they contain proprietary information and business sensitive information. Therefore these reports are submitted in a separate appendix in paper copies only. The following is a list of PEARL Final Reports included.

1. Program for the Evaluation and Analysis of Residential Lighting Final Report: Testing Cycle One, 42 pages, including data for 13 models of CFL and 9 models of RLF;
2. Program for the Evaluation and Analysis of Residential Lighting Final Report: Testing Cycle Two, 83 pages, including data for 18 models of CFL and 6 models of RLF;
3. Program for the Evaluation and Analysis of Residential Lighting Final Report: Testing Cycle Three, 59 pages, including data for 20 models of CFL and 8 models of RLF;
4. Program for the Evaluation and Analysis of Residential Lighting Final Report: Testing Cycle Four, 60 pages, including data for 20 models of CFL and 8 models of RLF;
5. Program for the Evaluation and Analysis of Residential Lighting Final Report: Testing Cycle Five, 44 pages, including data for 18 models of CFL;
6. Program for the Evaluation and Analysis of Residential Lighting Final Report: Testing Cycle Six, 126 pages, including data for 34 models of CFL and 12 models of RLF;
7. Program for the Evaluation and Analysis of Residential Lighting Final Report: Testing Cycle Seven, 70 pages, including data for 33 models of CFL;
8. Program for the Evaluation and Analysis of Residential Lighting Final Report: Testing Cycle Eight, 62 pages, including data for 29 models of CFL.