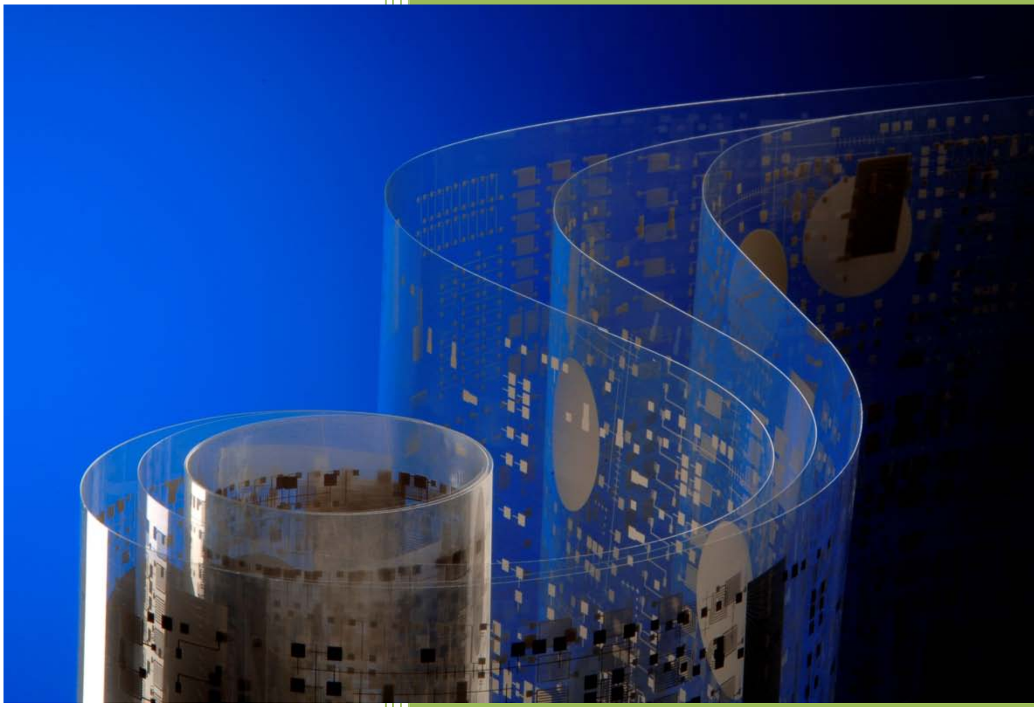
Xenon Corporation

Photonic Sintering for Printed Electronics using Pulsed Light



SB206A 10/10

Using SINTERON 500 and SINTERON 2000 Pulsed Light Sintering Systems

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Contents

1 – Introduction

This procedure is designed to assist in the use of Xenon Corporation's SINTERON 500 and SINTERON 2000 photonic curing systems and their application for R&D work with conductive nanomaterials on heat sensitive flexible substrates. These systems feature a high intensity pulsed xenon lamp that delivers a broadband spectrum. The user has the ability to select various operating conditions (see table below) to achieve sintering for a wide range of conductive ink materials on different substrates. Users of this procedure should first become familiar with the basic operation of the system. (See references below).

SINTERON 2000 and SINTERON 500 Systems Overview

- The SINTERON 500 consists of a table-top controller, separate lamp housing, sintering chamber and lamp housing blower. The controller provides all power and user control of the flash lamp mounted in an air cooled lamp housing. A blower is provided to cool the lamp. Two lamp housing options are available: model LH-910 with a 107mm diameter spiral flash lamp or model LH-840 with a 16" linear flash lamp.

- The SINTERON 2000 consists of a 19" electronics rack consisting of four bays that contain the power supply, controller and pulse forming networks. A blower is provided to cool the lamp. Two lamp housing options are available: model LH-910 with a 107mm diameter spiral lamp or model LH-840 with a 16" linear flash lamp.

The key performance features of the SINTERON systems are shown in the table 1.

Specification	LH-910 LAMP HOUSING		LH-840 LAMP HOUSING	
	SINTERON 500	SINTERON 2000	SINTERON 500	SINTERON 2000
Pulse Energy Range - Joules	465 - 830	450 - 2000	290 - 830	150 - 2000
Pulse Duration - µs	520	580, 1000, 1500, 2000	520	580, 1000, 1500, 2000
Sintering Area	3" x 3"	3" x 3"	0.75" x 12"	0.75" x 12"

Table 1 Specifications for SINTERON 500 and SINTERON 2000 Systems

Reference Documentation
- Sinteron 500 data sheet
- Sinteron 500 User Manual, part number 810-0115
- Sinteron 2000 data sheet
- Sinteron 2000 User Manual, part number 810-0116

Contact Xenon Corporation for copies documents listed above.

2 – Lamp Housings

Model LH-840 Housing

The LH-840 contains a 16" linear arc lamp that focuses the light 1" from the lamp housing window. Refer to Appendix A for outline drawing. The maximum optical energy is deposited on the target at this distance with an optical foot print of 0.75" x 12". This is shown in Appendix C.

Substrate Alignments

- Substrate alignment to lamp axis occurs 3.5" from either side of the housing.
- Substrate alignment to lamp midpoint occurs 15" from either end of the housing.
- Substrate alignment height for focus occurs 1" from the bottom of the housing.

Model LH-910 Housing

The LH-910 contains a 107mm diameter spiral lamp. The center of the lamp is 3.9" from the front and 3.9" from side. Refer to Appendix B for outline drawings. The LH-910 provides an area light source without a focus. The maximum energy occurs between 0.5" and 1" from the lamp housing window, at the center of the lamp. Refer to Appendix D for an intensity profile.

Optical Specifications

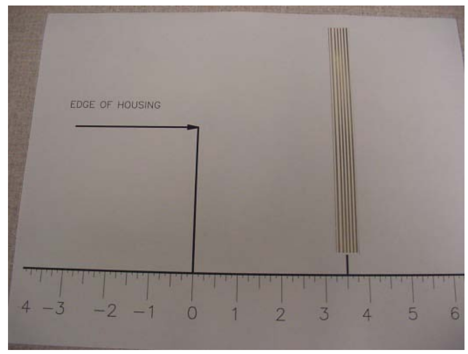
- Appendix C: Model LH-840 fall-off ray trace drawing.
- Appendix I and Appendix J: Model LH-840 and LH-910 intensity with distance from lamp window.
- Appendix D: Model LH-910 intensity uniformity at 1" distance from lamp housing window.

3 – Sintering Procedure

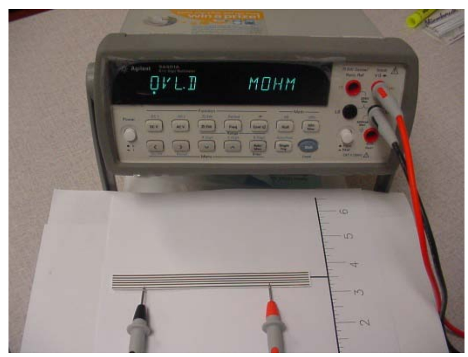
Initial testing of nanomaterial is performed by positioning the material under the lamp housing and exposing the material to a single pulse flash. This procedure is called static testing. After each exposure, the resistivity of exposed material is measured along with a visual examination. Based on these results, energy deposit changes are made by changing the voltage setting and PFN selection (Sinteron 2000 only). The optical intensity and uniformity can also be modified by changing the distance between the lamp housing and substrate. In general greater distance lowers the intensity while giving better uniformity and a wider footprint. An example is shown in the graphs located in Appendix C and I. A recommended data collection form is shown in Appendix H.

Step 1 - Place the substrate on an alignment fixture. This can be as simple as a white piece of paper with a reference line to position the substrate directly under the axis of the flash lamp.

- LH-840 Lamp Housing: 3.5" from the edge of the 7.0" wide housing.
- LH-910 Lamp Housing: 3.9" from the front edge and 3.9" from the right side of the housing



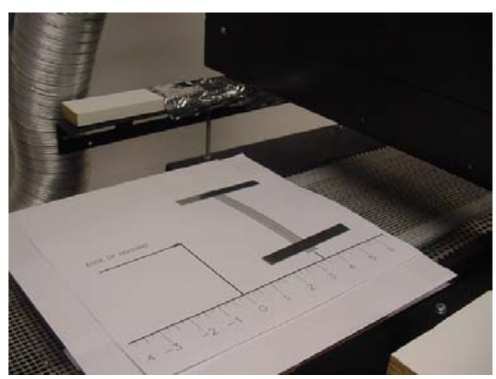
Step 2 -Measure the resistive properties of the material to be sintered with a digital meter and probes. Note the distance between the probes, the width of the potential conductive path, and the resistance (Resistance Before) in the data collection form.



Step 3 - Position the top of the substrate below the window of the lamp housing according to the housing.

- LH-840 Lamp Housing: 1.6"
  - This is 0.6" beyond the focal point.
- LH-910 Lamp Housing: 1"

This initial distance should be recorded in the data collection sheet.



Step 4 -Align the substrate at the midpoint of the lamp housing and on axis.

- LH-840 Lamp Housing: 15" from end and 3.5" in from side.
- LH-910 Lamp Housing: 3.9" from front and 3.9” in from side.

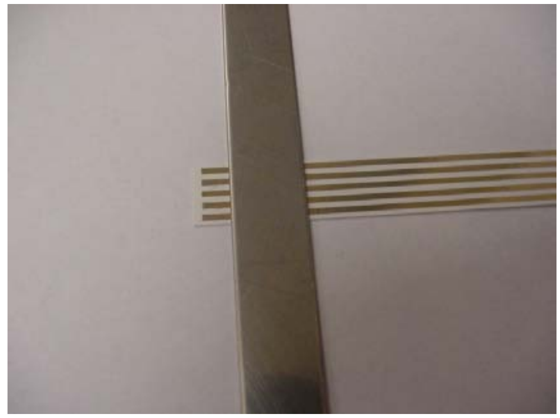
Step 5 - Turn ON the Xenon system and set the lamp voltage to the maximum allowed energy level for your PFN selection. Follow instructions in the specific user manual for the correct sequence for powering on the system. See Appendix E for maximum voltage setting levels for each PFN configuration. Record your system PFN selection. Sinteron 500 is recorded as PFN 1. Sinteron 2000 is recorded as PFN 1, PFN 1&2, PFN 1,2&3 or PFN 1,2,3&4. Also record the voltage, energy and pulse width settings in the data collection sheet.

Sinteron 2000 panel is shown in the photo. Note that the Sinteron 500 does not have a digital voltage display similar to the Sinteron 2000 and you must use a digital meter for reading voltage. (1 volt reading = 400 volts on lamp). For more information consult the Sinteron 500 User Manual.

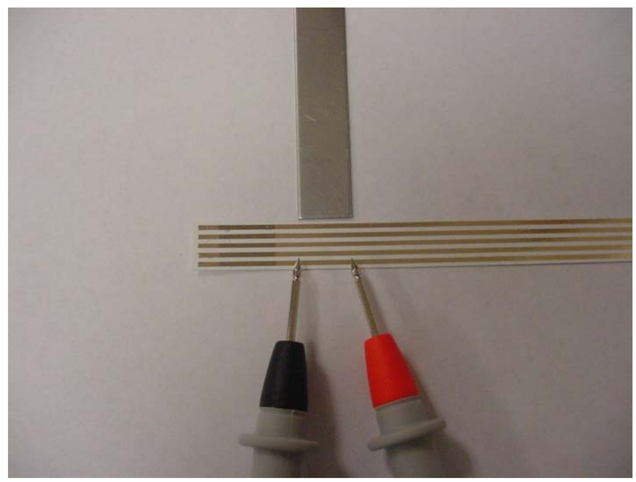
The photo illustrates a 2.00 KV lamp voltage using the Sinteron 2000 LED display. Also illustrated is a 5.032 VDC reading on a digital meter attached to the Sinteron 500 BNC connector. (5.032*400V = 2 KV)

Step 6 - Set the system timer for one pulse (0.2 sec setting – single shot mode) and expose the material to just one pulse by toggling upward and releasing the TIMER switch.

Step 7 - Remove the substrate and examine the material for visual signs of sintering or destruction.



Step 8 - Make a resistive measurement of the exposed area by placing your probes in the same location as used for the pre exposure reference measurement. Record the resistive measurement in the data collection form – *Resistance After.*

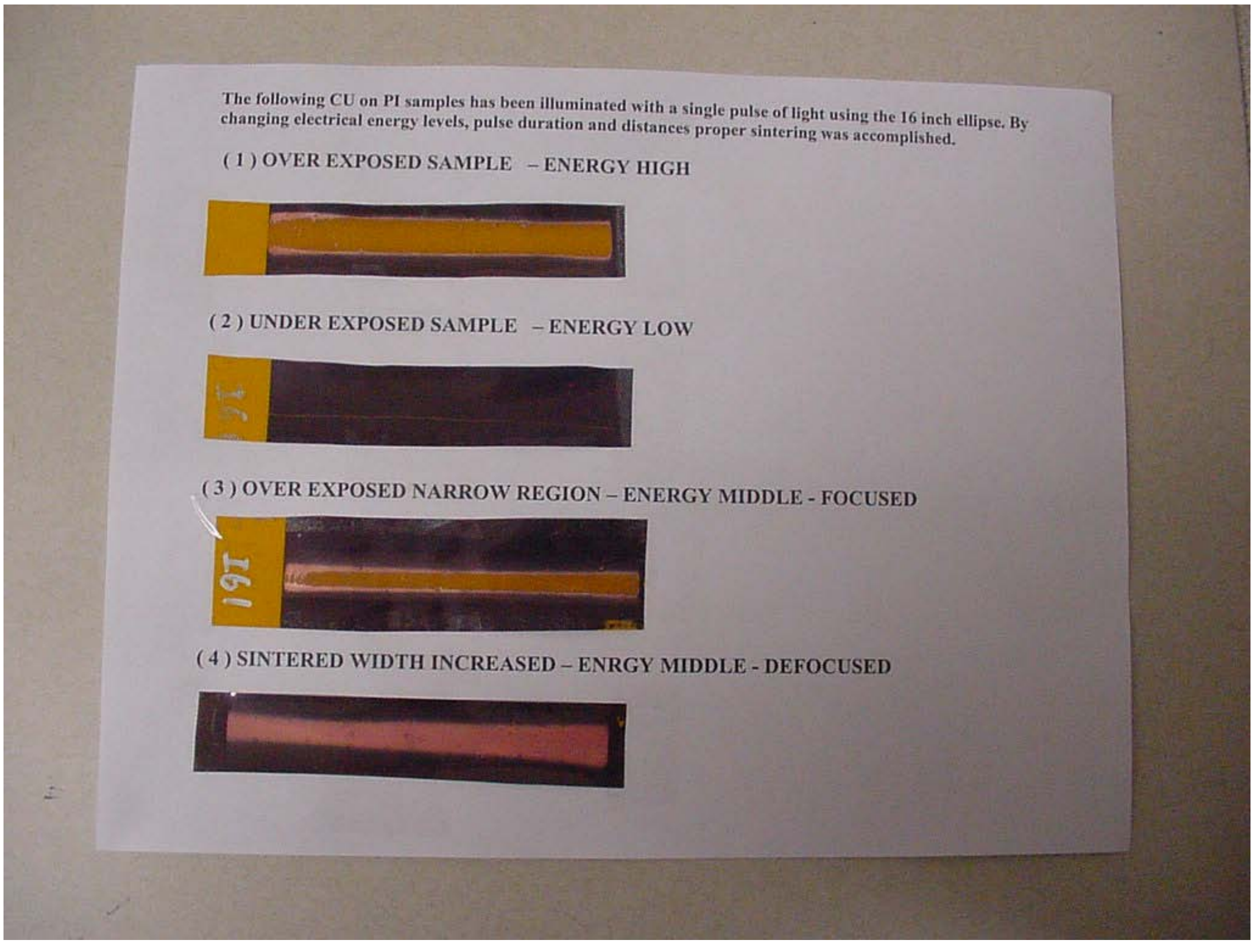


Step 9 - If excessive blow-off of material occurs in a localized area along the axis, move the substrate away from the window and repeat steps 1-8. Decrease of energy with distance is shown in Appendix I and Appendix J. If excessive blow-off of material occurs over the entire exposed substrate, lower the lamp voltage and repeat the test.

Step 10 - Continue to change the optical energy level and optical profile (distance from lamp window) by changing both the lamp voltage and the substrate distance, recording all data as you continue to change the settings.
Note that the material resistance will continue to decrease until excessive energy blows the material off the substrate, when a higher resistive reading will be observed.
Continue to develop the process window by testing with repeated pulses. After determining the best lamp voltage and material position under the lamp housing, based on achieving lowest resistivity, make note of the optimum distance, pulse energy, pulse width and length of sintered area.

Example of sintering copper

The picture below illustrates how sequentially changing electrical and optical parameters can influence sintering results. Samples were Cu on a Polyimide (PI) substrate using a single pulse 2 milliseconds duration with energy ranging from 920 - 1217 joules and distances varying from 1” to 1.7” Varying ink structure and thickness has an influence on success, requiring individually tests for different materials and substrates. Often the selected pulse duration can be reduced to accomplish similar results at lower energies. This would result in lower power consumption when converting to an inline application. See converting static test data in section 4.



4 – Converting static test data

The basic static testing performed in the earlier section can now be applied to moving targets typically found in conveyor or roll-to-roll applications. An example might be to expose a roll of printed metallic circuits that are web fed and moving at a specified speed; i.e. linear Ft/minute or meters/minute. The static data taken is used to determine the allowable web speed to insure the pulsed light foot print is applied to the moving target with all areas of the target being exposed. In performing this calculation, certain parameters must be included: web (conveyor) feed rate, optical foot print and flash (pulse) rate. These parameters will be discussed in the procedure below.

Step 1 - Examine static test data and select successful values for the following parameters:

- Distance from window to substrate.
- Electrical energy.
- Width of sintered (cured) area – perpendicular to lamp axis.
- Length of sintered (cured) area – along the lamp axis.

Step 2 - Select maximum pulse rate for the electrical energy and PFN configuration selected in step 1 (refer to Appendix G).

Step 3 - Multiply the width of sintered area by the max pulse rate determine in Step 2.

Example – if pulse energy of 505 Joules was determined from the static tests, and the sintered width was 1.5", the calculation would be: 5.5 (3 x 1.5 = 5.5). The maximum conveyor rate for one system would be 5.5" /sec = 27.5 Ft /minute.

Step 4 - To assure that no gaps occur between flashes you must recalculate using a more conservative evaluation based on a smaller width for the optical profile.

- Use 1.25 inches in place of the 1.5 inch width. (3 * 1.25 = 3.75)
- Maximum new feed rate, to assure no gaps, is now 3.75" /s = 18.75 FT/minute.
- If faster feed rate is required, additional systems are required.
- Length of cured area must also be coordinated with the width of the conveyor belt or target.

5 – Ink material and substrate properties

Structure and content of ink

The ink material, structure and thickness have a major influence on the amount of energy required to sinter and achieve low resistance. A guide to the degree of difficulty is shown below using a scale from 1 to 5. A rating of 1 indicates a relatively easy ink to sinter. A rating of 5 indicates the most difficult ink to sinter, i.e. requires highest pulse energy and longest pulse duration.

- Material
  - Silver (Ag) – 1 to 3
  - Gold (Au) – 1
  - Copper (Cu) – 1 to 5
- Structure
  - Flake (micro - flat) – 2
  - Spherical (nano - particle) – 1
- Particle size
  - Nano size; less than 30 nanometers diameter - 1
  - Micro flakes - 2
- State of ink
  - Dry – 1
  - Wet - 5
- Thickness
  - < 10 micron - 1
  - > 100 microns – 5

Substrate

The substrate has a major influence on the amount of energy required to sinter the conductive ink. The degree of difficulty is shown below using a scale from 1 to 5. A rating of 1 indicates a relatively easy ink to sinter. A rating of 5 indicates a more difficult ink to sinter, i.e. requires highest pulse energy.

Substrate examples with sintering difficulty

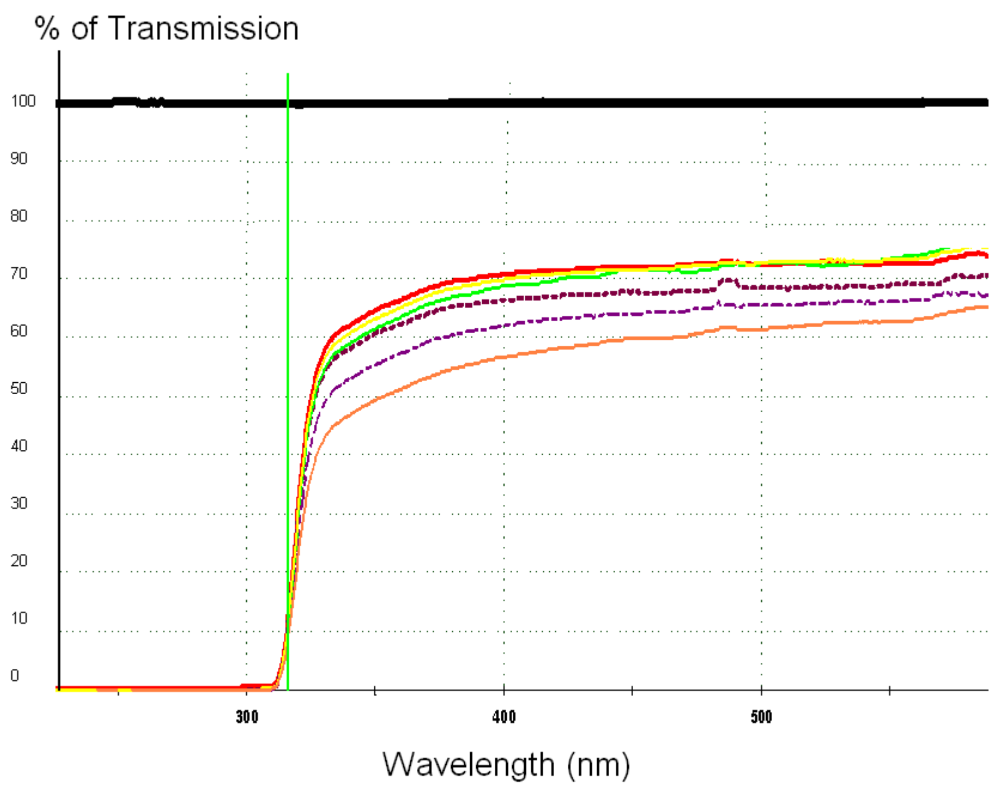
- Paper – 1
- PET – 2
- PI – 2
- Silicon – 5

6 - Special substrates

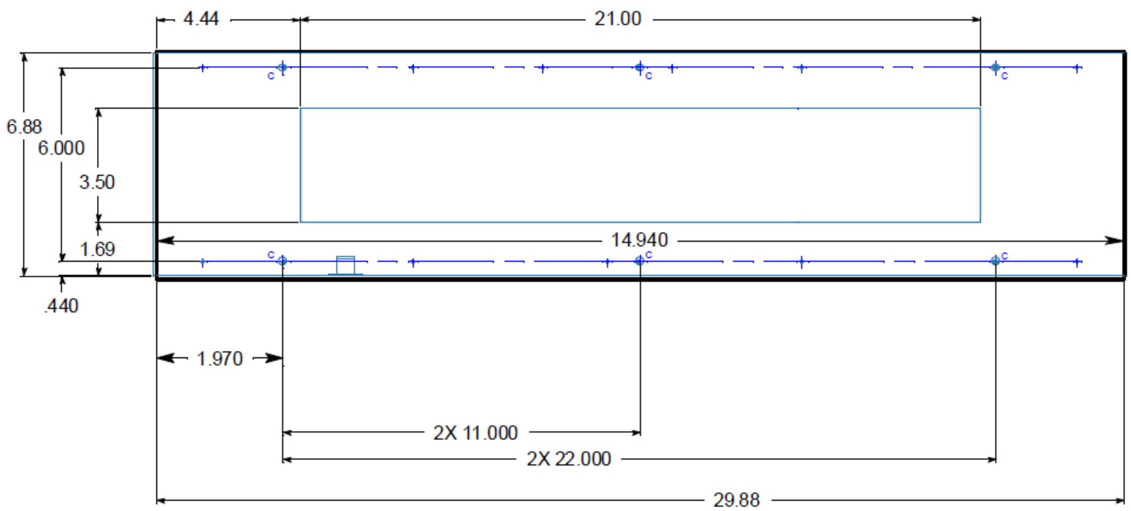
Conductive / transparent films

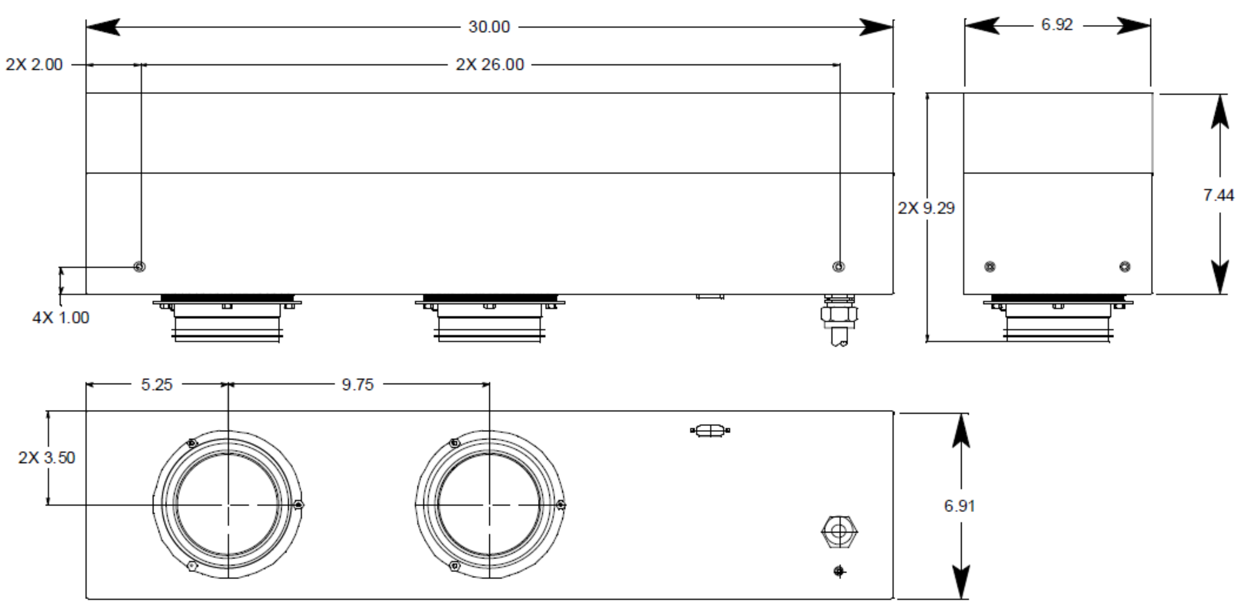
- Transmission test before
- Resistive read before
- Transmission test after
- Resistive read after

The graph below shows how the transmission of a transparent conductive substrate changes with energy. The orange line (bottom) represents the transmission of a substrate that received the highest energy exposure. The result was highest conductivity but lowest transmission. The red line (top) represents the transmission of a substrate that received the lowest energy exposure. The result was lowest conductivity with highest transmission. The lines going from orange to red show how transmission decreases and conductivity increases as the energy is increased. Fine tuning the best energy level for maximum transmission and conductivity is the challenge



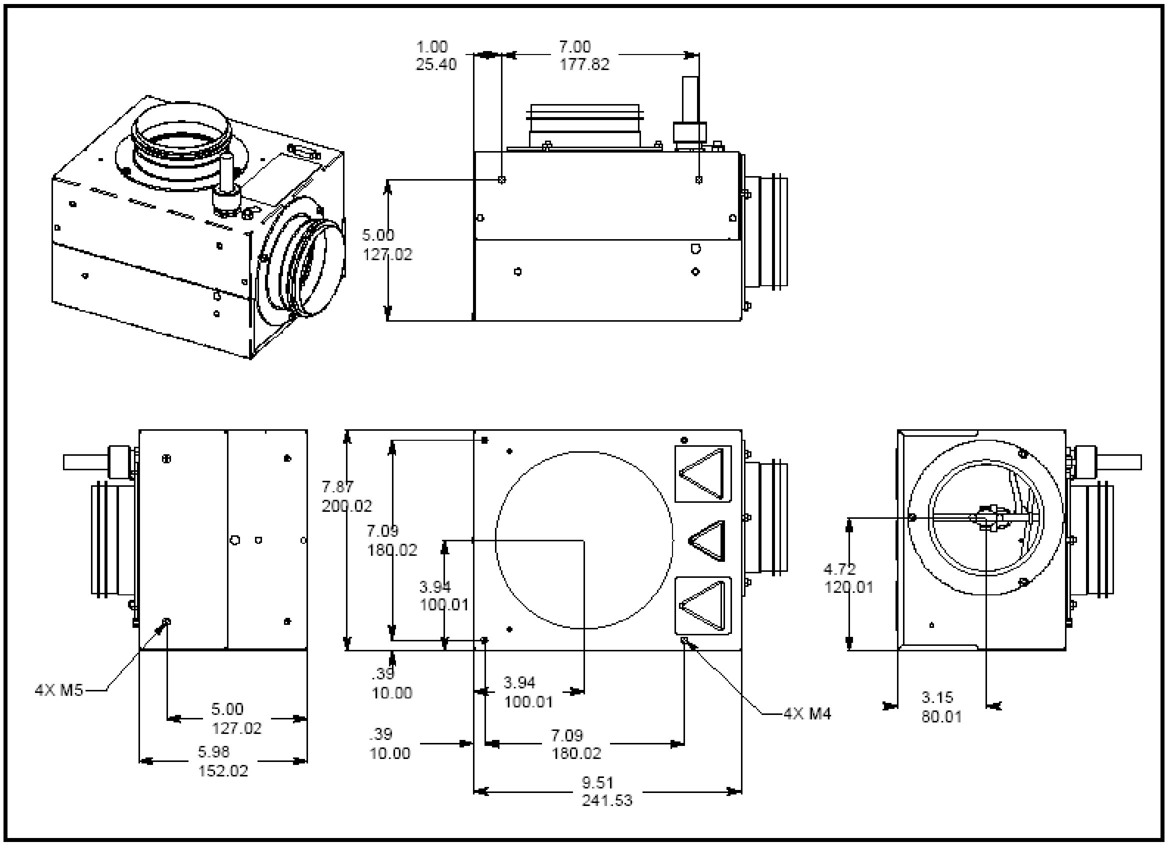
Appendix A – Model LH-840 Outline





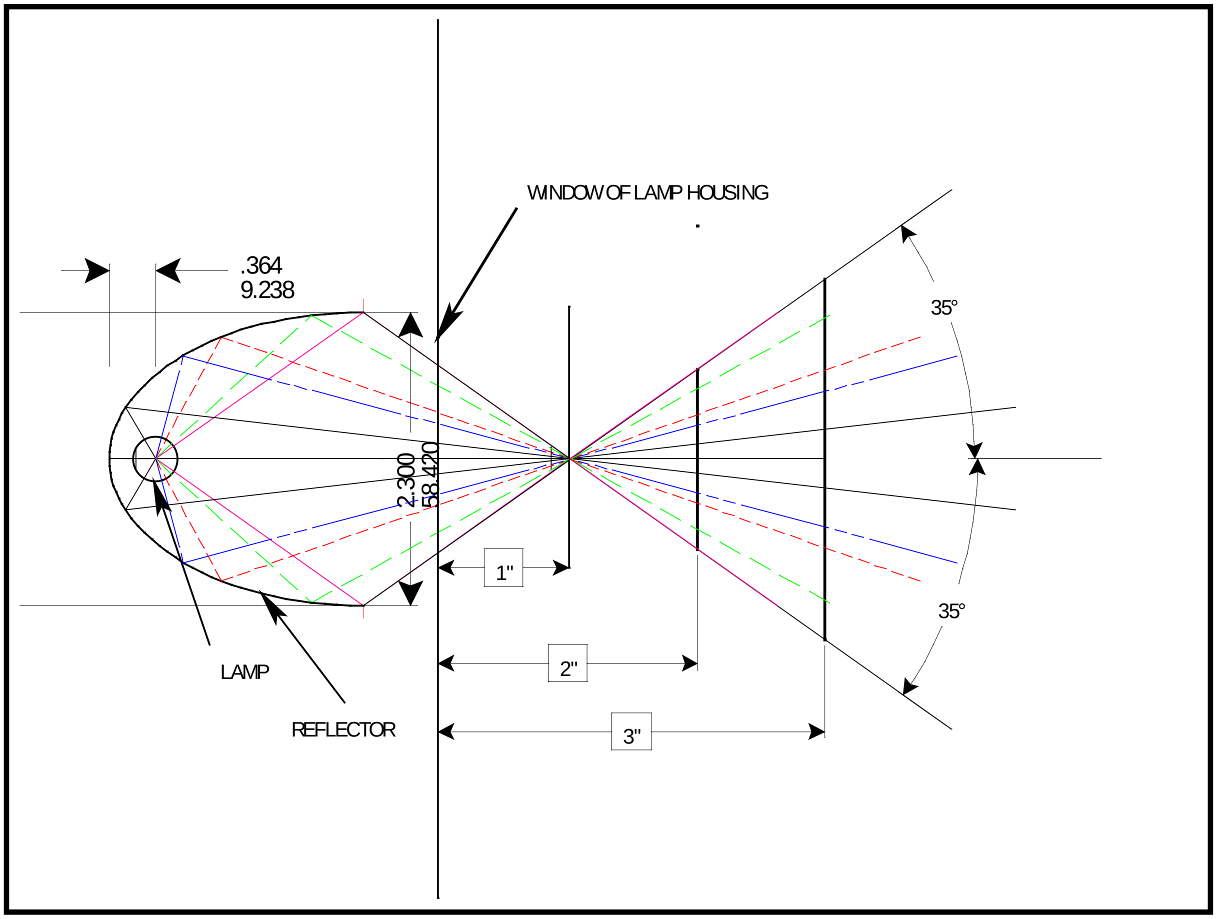
All dimensions are in inches.

Appendix B – Model LH-910 Outline



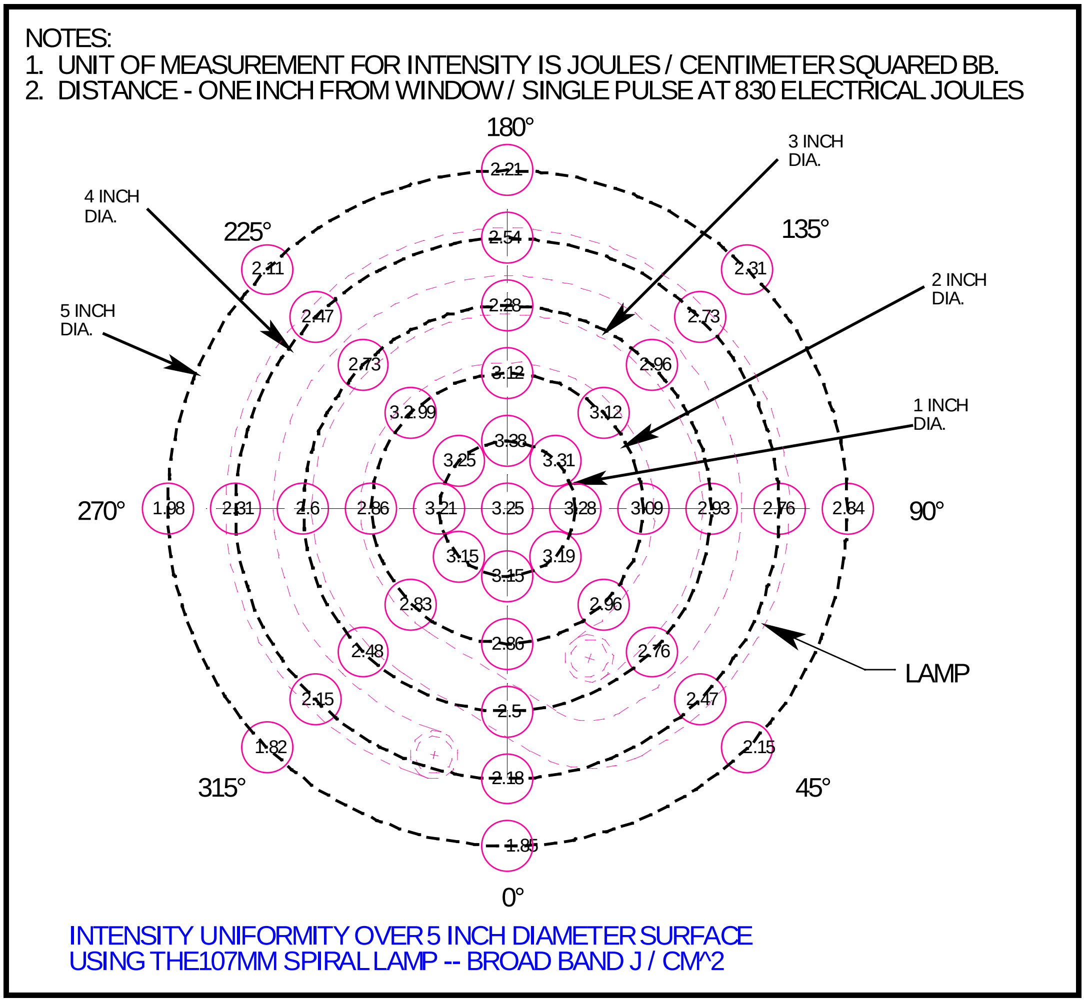
All dimensions in inches (mm)

Appendix C – Model LH-840 Focal Point



All dimensions in inches (mm)

Appendix D – Model LH-910 Intensity Distribution



Model LH-910 intensity uniformity over 5" diameter surface @ 1" distance from lamp housing window - single pulse @ 830Joules.

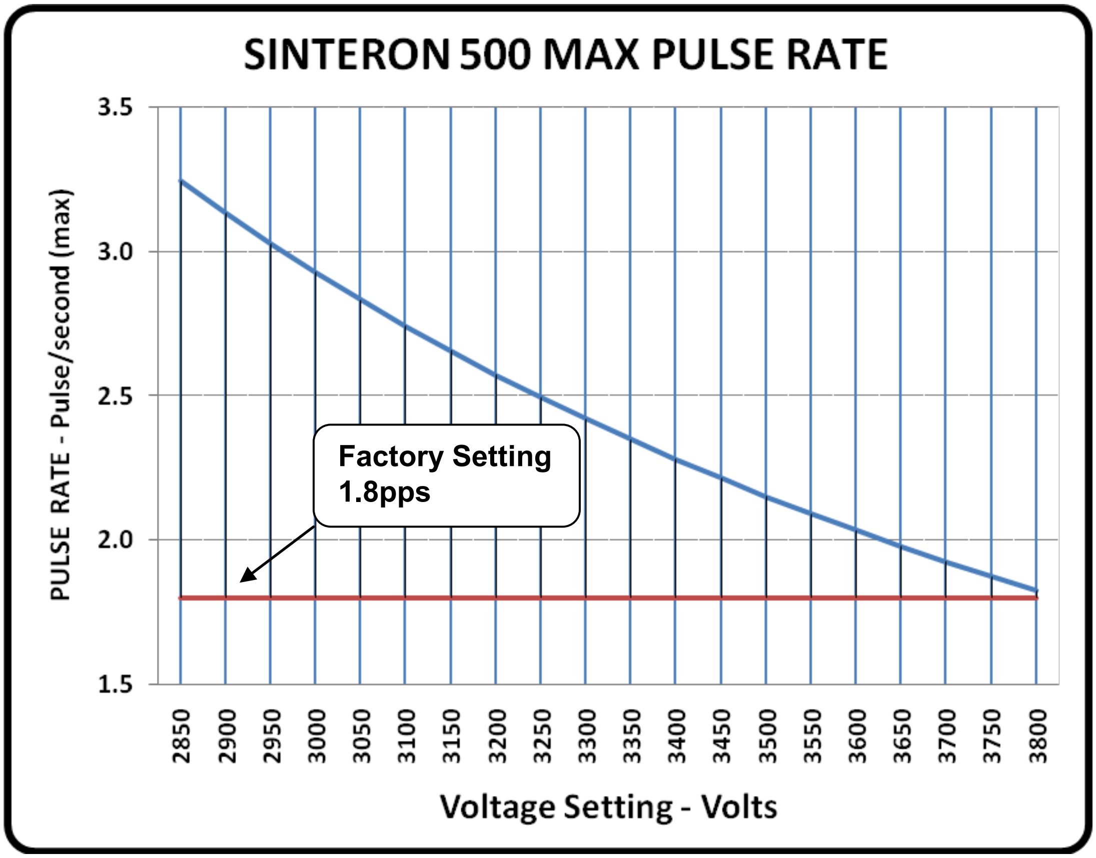
Appendix E- Sinteron 2000 with LH-840 – Pulse Energy

	PFN-1		PFN-1&2		PFN-1,2&3		PFN-1,2,3&4	
Voltage (Volts)	Pulse Energy (Joules)	Pulse Duration (µsec)	Pulse Energy (Joules)	Pulse Duration (usec)	Pulse Energy (Joules)	Pulse Duration (usec)	Pulse Energy (Joules)	Pulse Duration (usec)
1600	147	500	294	1000	442	1500	589	2000
1800	186	500	373	1000	559	1500	745	2000
1850	197	500	394	1000	590	1500	787	2000
1900	208	500	415	1000	623	1500	830	2000
1950	219	500	437	1000	656	1500	875	2000
2000	230	500	460	1000	690	1500	920	2000
2050	242	500	483	1000	725	1500	967	2000
2100	254	500	507	1000	761	1500	1014	2000
2150	266	500	532	1000	797	1500	1063	2000
2200	278	500	557	1000	835	1500	1113	2000
2250	291	500	582	1000	873	1500	1164	2000
2300	304	500	608	1000	913	1500	1217	2000
2350	318	500	635	1000	953	1500	1270	2000
2400	331	500	662	1000	994	1500	1325	2000
2450	345	500	690	1000	1035	1500	1381	2000
2500	359	500	719	1000	1078	1500	1438	2000
2550	374	500	748	1000	1122	1500	1496	2000
2600	389	500	777	1000	1166	1500	1555	2000
2650	404	500	808	1000	1211	1500	1615	2000
2700	419	500	838	1000	1258	1500	1677	2000
2750	435	500	870	1000	1305	1500	1739	2000
2800	451	500	902	1000	1352	1500	1803	2000
2850	467	500	934	1000	1401	1500	1868	2000
2900	484	500	967	1000	1451	1500	1934	2000
2950	500	500	1001	1000	1501	1500	2002	2000
3000	518	500	1035	1000	1553	1500	2070	2000
3050	535	500	1070	1000	1605	1500		
3100	553	500	1105	1000	1658	1500		
3150	571	500	1141	1000	1712	1500		
3200	589	500	1178	1000	1766	1500		
3250	607	500	1215	1000	1822	1500		
3300	626	500	1252	1000				
3350	645	500	1291	1000				
3400	665	500	1329	1000				
3450	684	500	1369	1000				
3500	704	500	1409	1000				
3550	725	500	1449	1000				
3600	745	500	1490	1000				
3650	766	500						
3700	787	500						
3750	809	500						
3800	830	500						

Appendix F - Sinteron 2000 with LH-910 – Pulse Energy

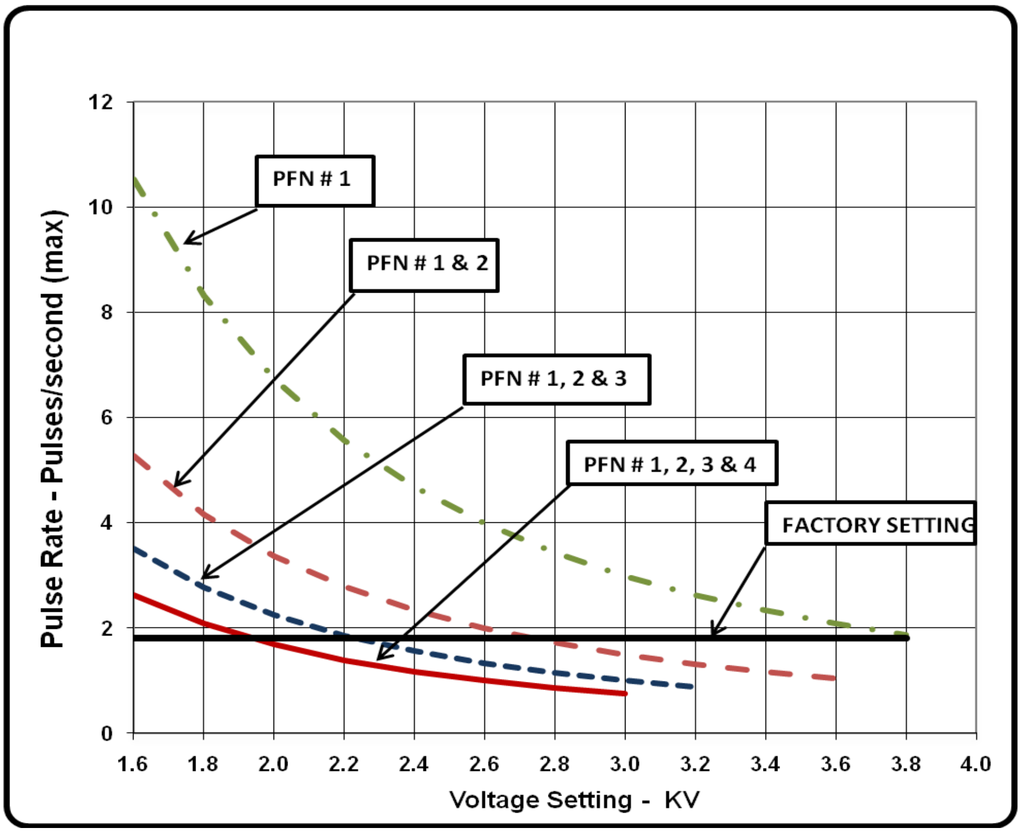
	PFN-1		PFN-1&2		PFN-1,2&3		PFN-1,2,3&4	
Voltage (Volts)	Pulse Energy (Joules)	Pulse Duration (µsec)	Pulse Energy (Joules)	Pulse Duration (µsec)	Pulse Energy (Joules)	Pulse Duration (µsec)	Pulse Energy (Joules)	Pulse Duration (usec)
2800	451	572	902	1055	1352	1571	1803	2044
3000	518	572	1035	1055	1553	1571	2070	2044
3200	589	572	1178	1055	1776	1571		
3400	665	572	1329	1055				
3600	745	572	1490	1055				
3800	830	572						

Appendix G-1 - Sinteron 500 max pulse rate



The SINTERON 500 has a factory set 1.8 pulse/second (pps) flash rate. Shown in the graph are allowable pulse rates depending on the lamp voltage setting. These settings are made with hardware changes to the SINTERON 500 controller. Consult factory for assistance when a change is needed to system pulse rate.

Appendix G-2 - Sinteron 2000 max pulse rate



The SINTERON 2000 has a factory set 1.8 pulse/second (pps) flash rate for all PFN selections. Shown in the graph are allowable pulse rates depending on the lamp voltage setting and PFN selection. Pulse rate changes are made with hardware changes to the SINTERON 2000 controller. Consult factory for assistance when a change is needed to system pulse rate.

Appendix H – Data Collection Form

SINTERING TEST DATA				
Test conducted by:			DATE	
Sample #	1	2	3	4
Material[1]				
Substrate[2]				
Voltage Setting				
PFN Configuration[3]				
Pulse Energy				
Housing				
Lamp				
Distance[4]				
Envelope Type[5]				
# of Pulses				
Light Read Ref. #[6]				
Resistance Before				
Resistance After				
Visual Exam				

Notes

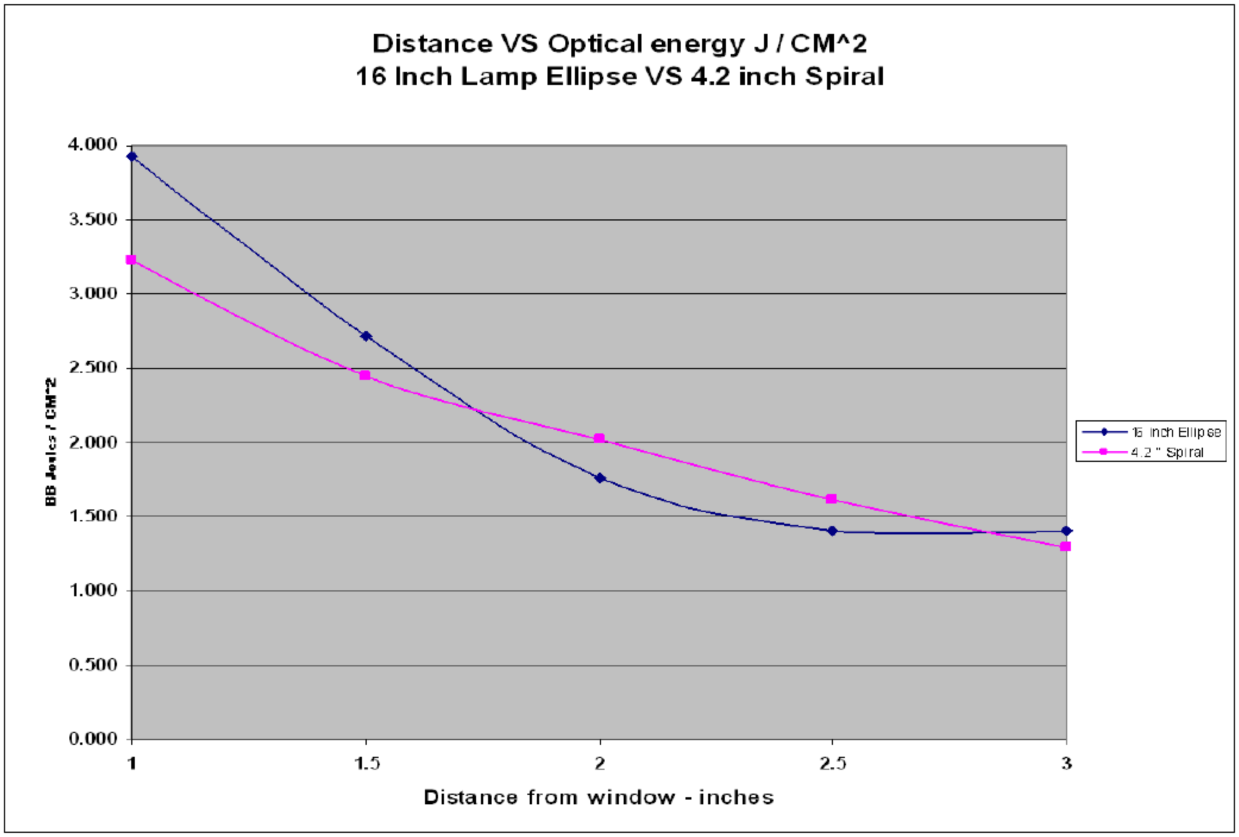
1 - Material = enter material type or ref. #	4- Distrance = from target to lamp housing window
2 - Substrate = enter substrate descriprion of ref. #	5 - Lamp Type A: Cerium; Lamp Type B: Germicil
3 - For Sinteron 500: PFN-1	6 - Refer to Light Measurements table below.

LIGHT MEASUREMENTS			
Light Dose	IL1700		Ophir
	mJ/cm² 033 "B"	mJ/cm² 240 ACT-5	BB J/cm² reading
Reading Reference #			
#1			
#2			
#3			
#4			
#5			
#6			
#7			

Photos of setup:

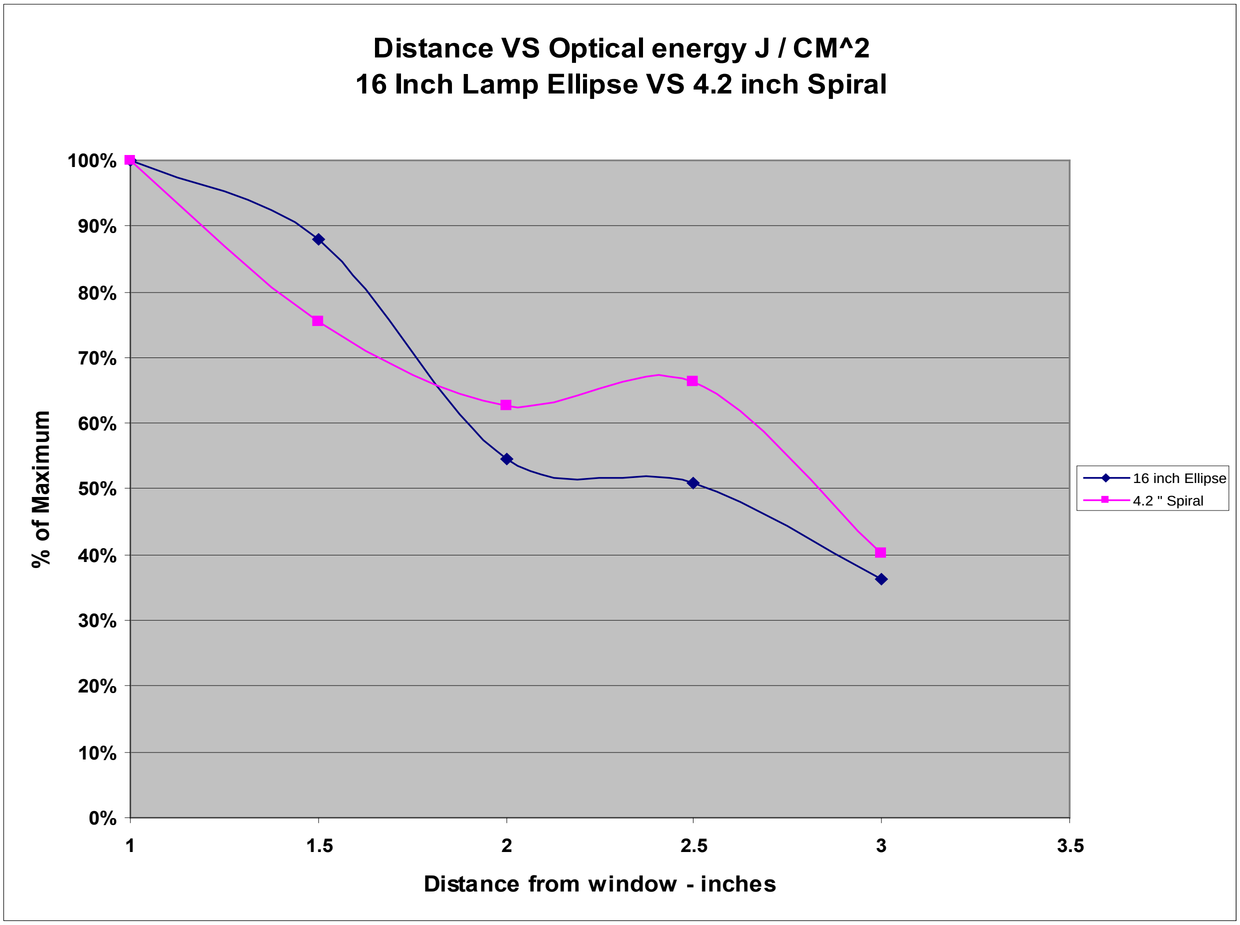
Test Conclusions:

Appendix I – Optical Energy – Model LH-840 & LH-910



Model LH-840: Blue curve
Model LH-910: Red Curve

Appendix J - Optical Energy – Model LH-840 & LH-910



Model LH-840: Blue curve
Model LH-910: Red Curve