Phase 3 – HID Persistence Testing

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A Report of BPA Energy Efficiency's Emerging Technologies Initiative

Prepared for
Levin Nock, Project Manager for Aerotek Staffing Agency,
on assignment to Bonneville Power Administration
John Wilson, Program Manager
Bonneville Power Administration

And

Washington State University Energy Program

The Lighting Research Center, Rensselaer Polytechnic Institute
21 Union Street
Troy, NY 12180

Leora C. Radetsky
Nick Skinner
BPA Contract Number: 115761 G003306

Abstract

Mogul base LED replacement lamps are being marketed as equivalent replacements for incumbent HID lamps. Utilities have expressed concern that HID lamp sockets that have the ballast bypassed for LED replacement lamp retrofits could be eventually relamped with a conventional HID lamp. 18 probe-start metal halide (MH) lamps of different brands, wattages and enclosure-ratings were operated with 277V applied directly to the socket. LRC found that 17 of the 18 probe-start MH lamps tested, ignited without a ballast when 277V was applied. Fourteen of these lamps experienced some type of failure. None of the 9 protected MH lamps, which are rated to be used in open fixtures, had an outer envelope rupture. LRC also found that in-line fast-acting fuses could prevent non-passive MH lamp failure when the lamp was operated at 277V.

An Emerging Technologies for Energy Efficiency Report

The following report was funded by the Bonneville Power Administration (BPA) as an assessment of the state of technology development and the potential for emerging technologies to increase the efficiency of electricity use. BPA is undertaking a multi-year effort to identify, assess and develop emerging technologies with significant potential for contributing to efficient use of electric power resources in the Northwest.

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The Lighting Research Center (LRC) at Rensselaer Polytechnic Institute is the world's leading center for lighting research and education. Established in 1988 by the New York State Energy Research and Development Authority (NYSERDA), the LRC has been pioneering research in energy and the environment, light and health, transportation lighting and safety, and solid-state lighting for more than 25 years. Internationally recognized as the preeminent source for objective information on all aspects of lighting technology and application, LRC researchers conduct independent, third-party testing of lighting products in the LRC's state of the art photometric laboratories, the only university lighting laboratories accredited by the National Voluntary Laboratory Accreditation Program (NVLAP Lab Code: 200480-0). LRC researchers are continuously working to develop new and better ways to measure the value of light and lighting systems, such as the effect of light on human health. The LRC believes that by accurately matching the lighting technology and application to the needs of the end user, it is possible to design lighting that benefits both society and the environment.

Acknowledgments

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Project Background

In December 2013, Washington State University Energy Program (WSU) / Bonneville Power Administration (BPA) requested that the LRC create a work plan for market characterization and performance testing of mogul base LED replacement lamps to support cost-effective LED retrofits for multiple types of lighting applications, particularly high bay and decorative post top, also including wall pack, yard light and cobra head.

The LRC proposed that the project be broken into three phases. The first phase[1] consisted of market characterization and pilot photometric testing of representative mogul base LED lamps alone and in luminaires, in order to develop a testing plan to ensure application equivalency. The second phase consisted of additional performance testing of mogul base LED replacement lamps in representative luminaire types and analyses[2]. The third phase consists of HID persistence testing in converted sockets and a field demonstration of mogul base LED replacement lamps to determine real-world performance and acceptability.

This report describes the results of the HID persistence testing task in Phase 3.

[1] http://www.bpa.gov/EE/Technology/EE-emerging-technologies/Projects-Reports-Archives/Documents/Mogul_LED_Lamps_LRC_BPA_Phase1_finalNov24.pdf
[2] http://www.bpa.gov/EE/Technology/EE-emerging-technologies/Projects-Reports-Archives/Documents/Mogul_LED_Lamps_LRC_BPA_Phase2_2015Jan.pdf

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Background

Utilities have expressed concern that HID lamp sockets that have the ballast bypassed for LED replacement lamp retrofits could be eventually relamped with a conventional HID lamp. To address this snap-back concern, LRC tested several metal halide (MH) lamps, using line voltage applied directly to the socket to determine if the HID lamps would start when connected directly to ac line voltage. Prior pilot testing in Phase 2 showed that several wattages of MH lamps would start every time when tested with an input voltage of 305V (110% of 277 V line voltage), as shown in Table 1. The 70W, 175W, and 250Wlamps started and sustained an arc at this input voltage and higher. Based on the pilot testing results, LRC created a testing apparatus using a commercial electrical distribution panel to determine if non-passive failures would occur when commercial HID-rated breakers were used.

Table 1: Lamp starting results from Phase 2. N = lamp did not start during 2 minute sustained input voltage. Y = lamp started during 2 minute sustained input voltage.

ANSI Code	Model Number	Ballast Type	Ambient Temp (^{0}C)	132V (120V + 10%)			305V (277V + 10%)			528V (480V + 10%)			132V w/ spark	305V w/ spark	528V w/ spark
				Trial			Trial			Trial			Trial		
				1	2	3	1	2	3	1	2	3	1	1	1
50-watt, M110	MH50/U/MED	Probe	25.8	N	N	N	N	N	N	N	N	N	N	Y	Y
70-watt, M98	MCP70/U/MED/830	Probe	25.8	N	N	N	Y	Y	Y	Y	Y	Y	N	N/A	N/A
100-watt, M90	MHC100/U/M/3K ELITE	Probe	26	N	N	N	N	N	N	N	N	Y	N	Y	N/A
150-watt, M102	MVR/U/MED	Probe	25.9	N	N	N	N	N	N	N	N	N	N	Y	Y
175-watt, M57	M175/U	Probe	25.7	N	N	N	Y	Y	Y	Y	Y	Y	N	N/A	N/A
250-watt, M58	MH250/U	Probe	25.8	N	N	N	Y	Y	Y	Y	Y	Y	N	N/A	N/A
400-watt, M59	MH400W/U/ED28	Probe	26	N	N	N	Y	Y	Y	Y	Y	Y	N	N/A	N/A
N/A - lamp started with line voltage, did not require high voltage "spark" to start.															

Method

36 MH lamps, as shown in Table 2, were procured from a local distributor and tested by the LRC. LRC purchased two of each lamp type in case of breakage. Non-protected lamps must be used in enclosed luminaires; protected lamps have an additional envelope around the arc tube

making them suitable for use in open luminaires. The lamps are from the 3 largest lamp manufacturers, however, the manufacturer's names are anonymized in this report.

Table 2: Tested MH Lamps

Single-ended lamps ANSI Code	Lamp ID Non-protected lamp	Manufacturer	Lamp ID Protected lamp	Manufacturer
175-watt, M57	1	A	4	A
	2	B	5	B
	3	C	6	C
250-watt, M58	7	A	10	A
	8	B	11	B
	9	C	12	C
400-watt, M59	13	A	16	A
	14	B	17	B
	15	C	18	C

The equipment for testing HID lamps consisted of:

- a 70 KVA 3 phase diesel generator producing 480 VAC (277 VAC line to neutral)
- a lighting panel board (480/277 VAC, 3PH) in a NEMA enclosure
- 20 A and 50A HID-rated bolt-on circuit breakers
- a junction block that allowed the experimenters to switch testing luminaires without disturbing the wiring attached to the circuit breakers
- a timing circuit with a manual override for setup
- an emergency stop button that terminated power to the panel in the event of non-passive failure
- enclosed area lighting luminaire located inside a locked plywood box with a Lexan viewing window
- oscilloscope with a current probe (current transformer) to capture voltage and current waveforms for each lamp test
- digital video camera with a 120 FPS frame rate to capture lamp breakage

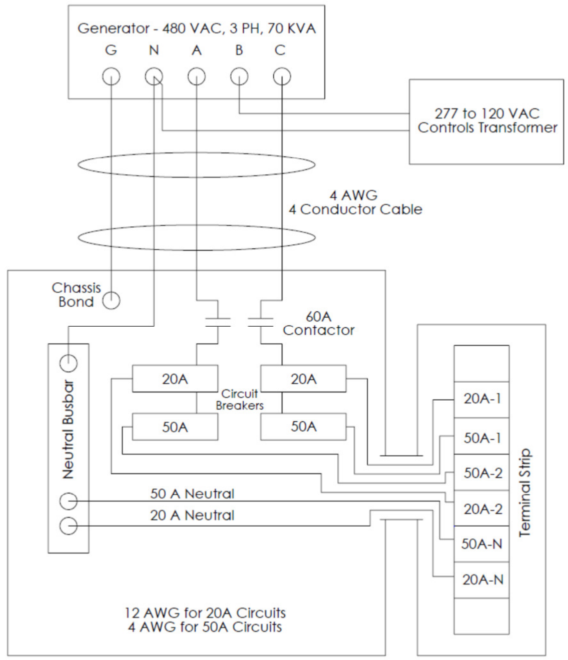


Figure 1: HID lamp testing circuit

The lamps were each tested up to 3 times and the input voltage was applied for 2 minutes or until the lamp failed. All the lamps were tested once, in ascending order of rated power (from low – to high) before the lamps were retested so that each test on a particular lamp was separated in time for independence. Using Table 2 as a reference, the 175 W lamps were tested, and retested, in this order: 1, 2, 3, 4, 5, and 6. Two 20A circuit breakers were alternately used in testing to allow each breaker to cool between uses. If the 20A circuit breaker were to trip during testing, a new lamp sample would be tested on the 50A breaker.

The input voltage used for the test was 277 V.

Results

Fourteen of the lamps tested sustained physical damage after one or more applications of power. The 20 A circuit breakers never tripped to protect the lamps in any of the testing, so there was no need to test the lamps on the 50 A breakers since they would offer less protection.

Two of the 18 lamps tested exhibited a ruptured outer envelope (bulb) when the testing voltage was applied. Ten of the 18 lamps demonstrated a ruptured arc tube, but the outer envelope remained intact. In 2 of the tested lamps, elements other than the arc tube broke, causing failure. Three of the lamps demonstrated a flash when voltage was applied, but there was no observed physical failure. None of these lamps would start after the flash event. One of the lamps never started during any of the three trials.

Table 3 documents the failure mode for each of the tested lamp samples. The key at the bottom of the table describes each event. Table 4 and Table 5 list the maximum current and pulse energy (explosion energy) measured for each lamp. There is no current or energy data for lamp 12, as the oscilloscope did not measure the arc tube rupturing event.

Table 3: Lamp starting results. See key below table for abbreviation explanations.

Single-ended lamps ANSI Code	Lamp ID Non-protected lamp	Manufac.	Input Voltage: 277V			Lamp ID Protected lamp	Manufac.	Input Voltage: 277V		
			Trial					Trial		
			1	2	3			1	2	3
175-watt, M57	1	A	F	NS	NS	4	A	B		
	2	B	E_O			5	B	E_A		
	3	C	E_A			6	C	E_A		
250-watt, M58	7	A	F	NS	NS	10	A	E_A		
	8	B	E_A			11	B	E_A		
	9	C	NS	E_O		12	C	NS	E_A	
400-watt, M59	13	A	E_A			16	A	B		
	14	B	E_A			17	B	F	NS	NS
	15	C	E_A			18	C	NS	NS	NS

Key

F = lamp flashed but did not rupture

NS = lamp did not start, no flash or rupture

B = lamp element broke causing lamp to fail (not arc tube)

E_A = arc tube ruptured

E_O = outer envelope ruptured

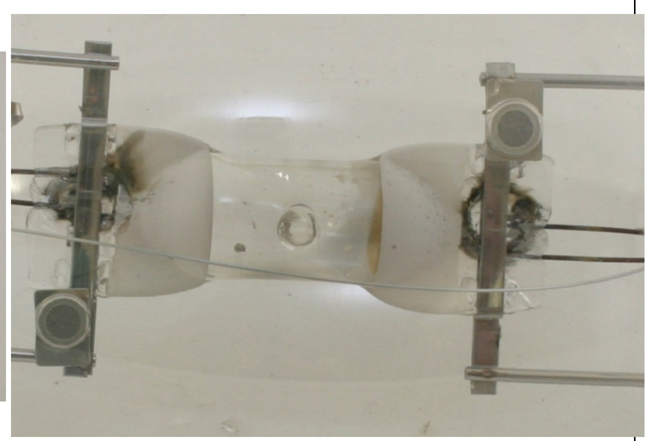
Table 4: Maximum measured current (A) for each HPS lamp operated at 277V.

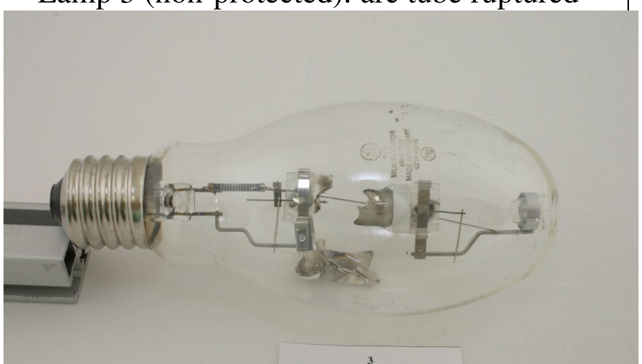
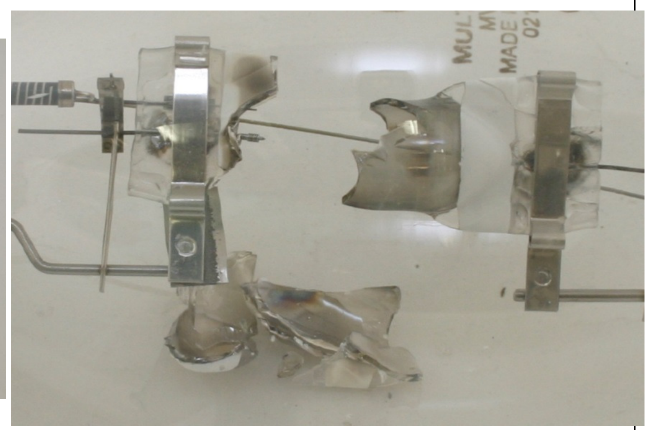
Single-ended lamps ANSI Code	Lamp ID Non-protected lamp	Manufac.	Maximum current (A)			Lamp ID Protected lamp	Manufac.	Maximum current (A)		
			Trial					Trial		
			1	2	3			1	2	3
175-watt, M57	1	A	7.9			4	A	50.0		
	2	B	78.7			5	B	79.4		
	3	C	41.2			6	C	43.7		
250-watt, M58	7	A	39.1			10	A	78.1		
	8	B	57.8			11	B	59.4		
	9	C		71.9		12	C		Missing data	
400-watt, M59	13	A	45.3			16	A	48.4		
	14	B	57.8			17	B	48.4		
	15	C	53.1			18	C			

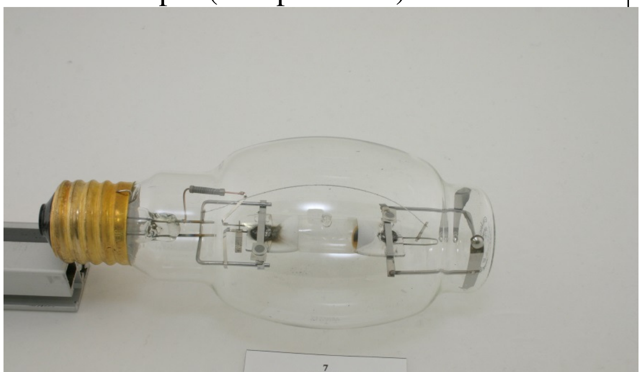
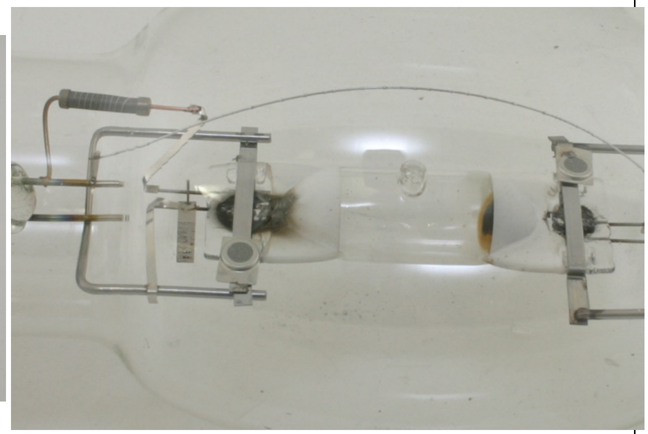
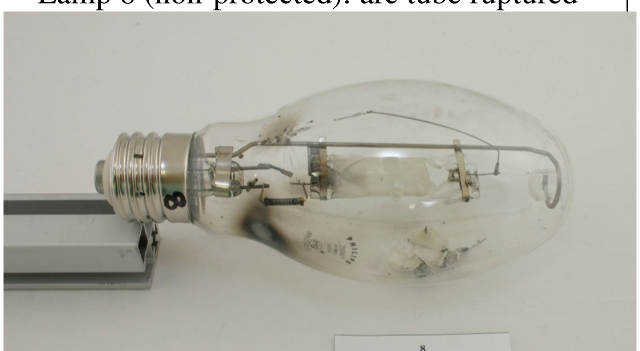
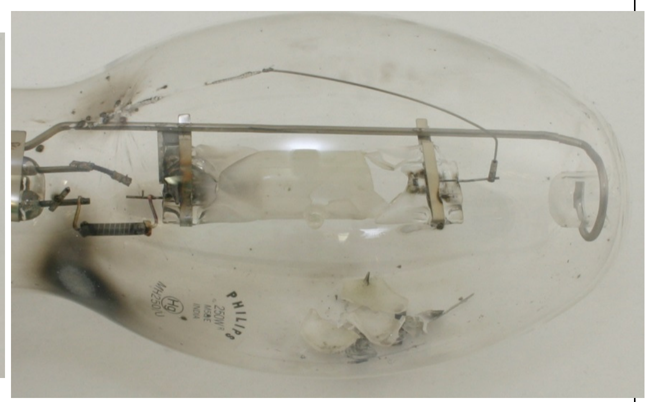
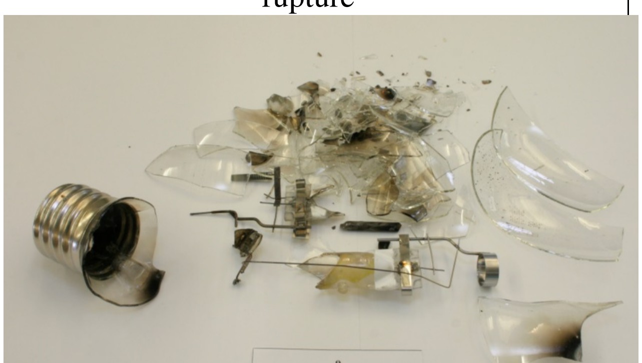
Table 5: Maximum measured explosion energy (J) for each HPS lamp operated at 277V.

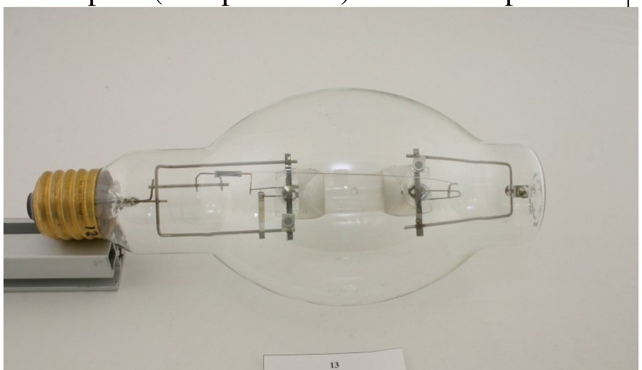
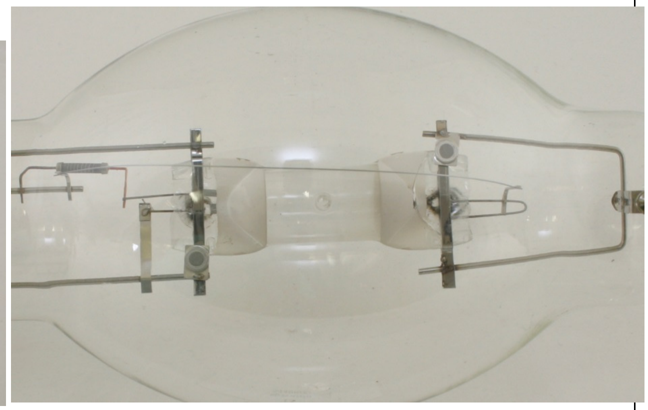
Single-ended lamps ANSI Code	Lamp ID Non-protected lamp	Manufac.	Pulse energy (J)			Lamp ID Protected lamp	Manufac.	Pulse energy (J)		
			Trial					Trial		
			1	2	3			1	2	3
175-watt, M57	1	A	9.5			4	A	35.1		
	2	B	213.1			5	B	165.1		
	3	C	13.7			6	C	19.8		
250-watt, M58	7	A	36.0			10	A	303.5		
	8	B	183.0			11	B	27.5		
	9	C		304.6		12	C		Missing data	
400-watt, M59	13	A	17.0			16	A	24.7		
	14	B	81.0			17	B	14.1		
	15	C	20.7			18	C			

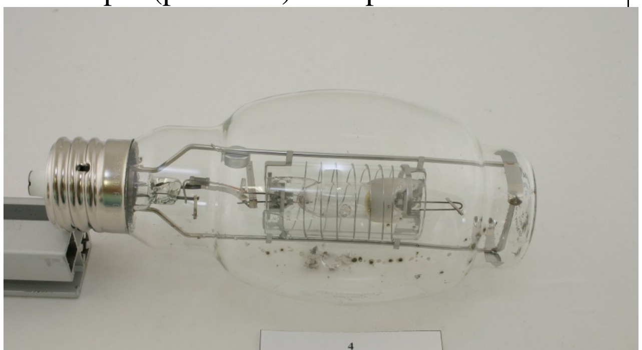
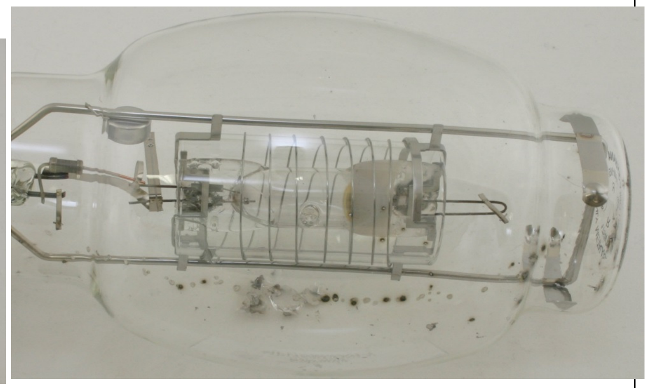
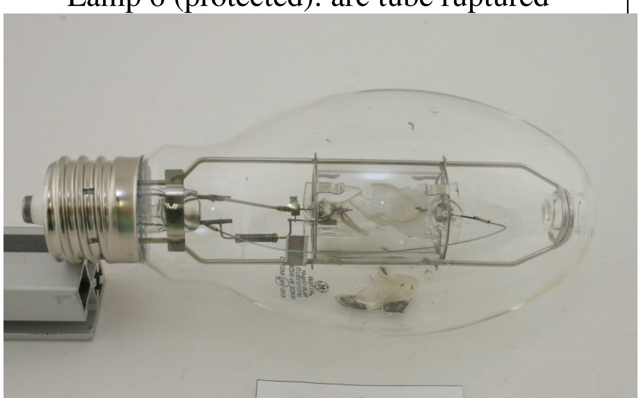
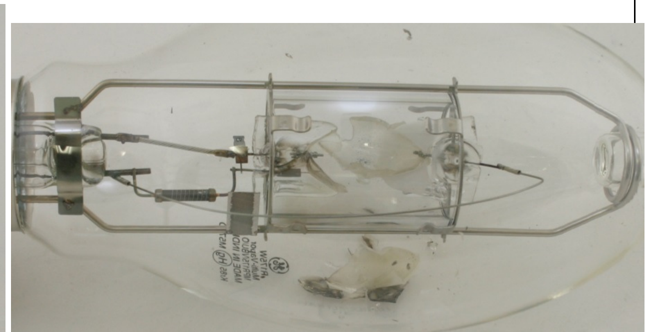
Lamp photos

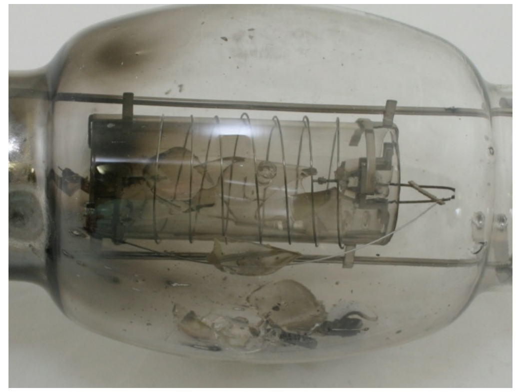
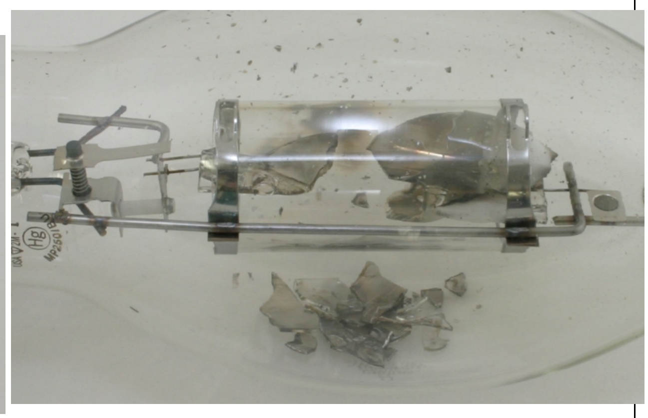
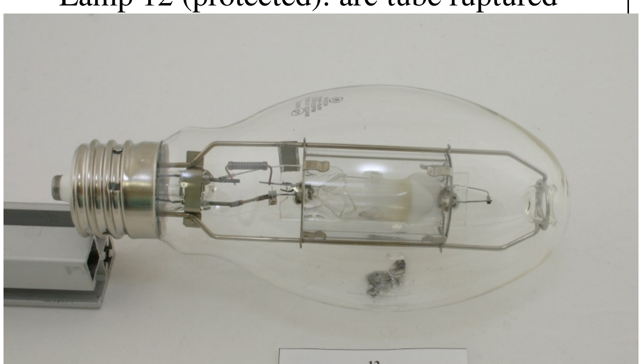
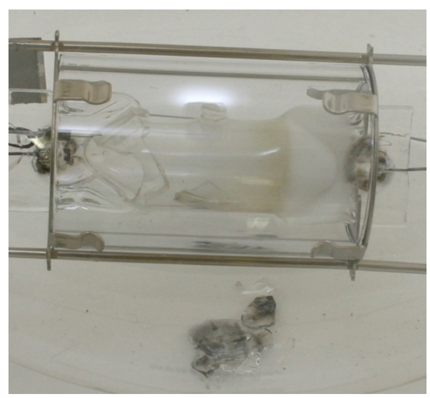
Lamp photo and failure mechanism	Lamp close-up
Lamp 1 (non-protected): flashed 	

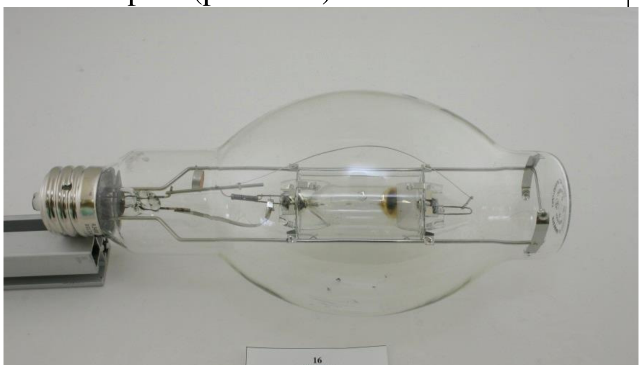
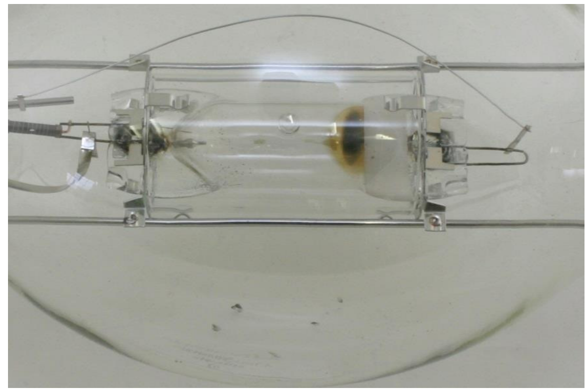
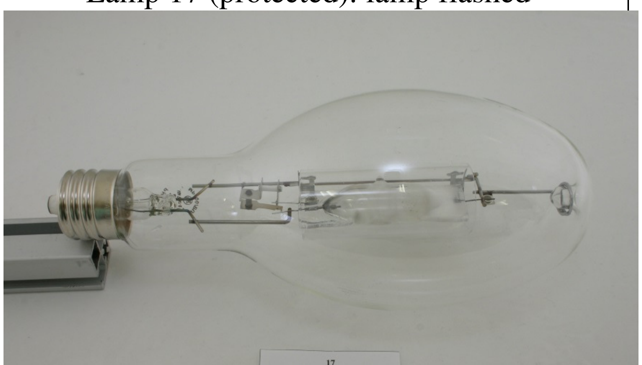
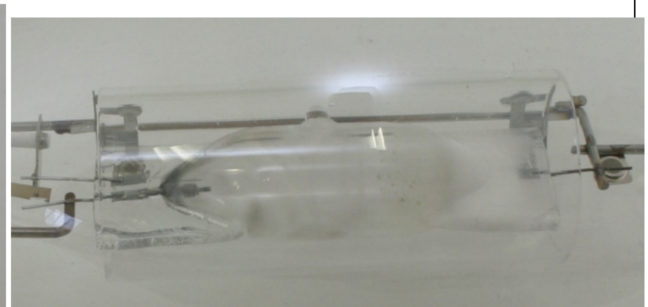
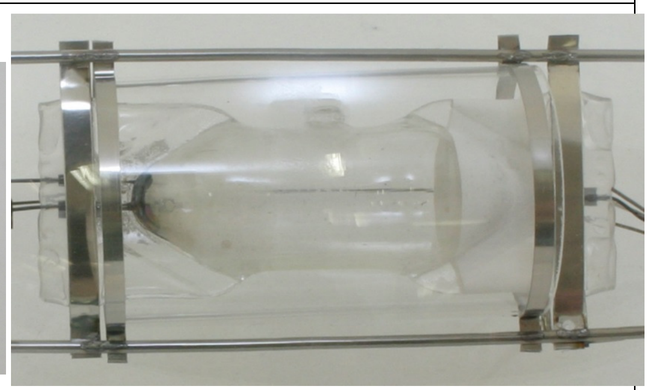
Lamp photo and failure mechanism	Lamp close-up
Lamp 2 (non-protected): outer envelope rupture 	
Lamp 3 (non-protected): arc tube ruptured 	

Lamp photo and failure mechanism	Lamp close-up
Lamp 7 (non-protected): flashed 	
Lamp 8 (non-protected): arc tube ruptured 	
Lamp 9 (non-protected): outer envelope rupture 	

Lamp photo and failure mechanism	Lamp close-up
Lamp 13 (non-protected): arc tube ruptured 	
Lamp 14 (non-protected): arc tube ruptured 	
Lamp 15 (non-protected): arc tube ruptured 	

Lamp photo and failure mechanism	Lamp close-up
Lamp 4 (protected): lamp element broke 	
Lamp 5 (protected): arc tube ruptured 	
Lamp 6 (protected): arc tube ruptured 	

Lamp photo and failure mechanism	Lamp close-up
Lamp 10 (protected): arc tube ruptured 	
Lamp 11 (protected): arc tube ruptured 	
Lamp 12 (protected): arc tube ruptured 	

Lamp photo and failure mechanism	Lamp close-up
Lamp 16 (protected): broken element 	
Lamp 17 (protected): lamp flashed 	
Lamp 18 (protected): lamp never started 	

A follow-up pilot experiment was conducted using the same testing apparatus, after it was observed that the circuit breakers never tripped during the HID lamp testing. The oscilloscope results showed that the maximum measured current was only 2-4 times higher than the circuit breaker rating and that the maximum current was only present for a brief period of time (not long enough to trip the circuit breakers). This experiment applied fast-acting fuses in series with the lamp socket used in the testing circuit and sought preliminary answers for the following questions:

- Could fast-acting in-line fuses prevent non-passive failures?
- Could LED mogul base replacement lamps still operate with the in-line fuses in place?

For this pilot testing, three MH lamps were tested with a fast-acting 2A fuse, a 4A fuse, and a bypassed fuse holder. The lamps chosen were from the same manufacturer and another sample that had failed in the first round of testing. As shown in Table 6, the fast-acting fuses prevented the non-passive failures; the arc ignited and flashed. Once the in-line fuse was bypassed in the testing circuit, the arc tubes in these lamps ruptured. Tables 7 and 8 show the measured maximum current and pulse energy, respectively, for each test.

One mogul base LED lamp for outdoor lighting was selected from prior Phase 2 testing (Lamp 109531) to include in this pilot test. Several days were allowed to pass between testing the 2A and 4A fuses to permit the capacitors in the lamp's driver circuit to discharge completely. The lamp functioned correctly with both the 2A and 4A fuses in series with it, indicating that the fuses could sustain the inrush current during a typical start.

Table 6: MH lamp results with and without fast-acting fuses in the testing circuit. See key below Table 2 for abbreviation explanations.

Lamp ID	Trial 1: 2A fuse	Trial 2: 4A fuse	Trial 1: No fuse
Lamp 2 (175W)	F	F	E_A
Lamp 8 (250W)	F	F	E_A
Lamp 14 (400W)	F	F	E_A

Table 7: Measured maximum current (A) for MH lamps with and without fast-acting fuses in the testing circuit.

Lamp ID	Trial 1: 2A fuse (A)	Trial 2: 4A fuse (A)	Trial 1: No fuse (A)
Lamp 2 (175W)	12.5	26.6	51.6
Lamp 8 (250W)	9.4	23.4	48.4
Lamp 14 (400W)	9.4	25.0	48.4

Table 8: Measured pulse energy (J) for MH lamps with and without fast-acting fuses in the testing circuit.

Lamp ID	Trial 1: 2A fuse (J)	Trial 2: 4A fuse (J)	Trial 1: No fuse (J)
Lamp 2 (175W)	0.8	0.6	19.4
Lamp 8 (250W)	0.3	0.6	68.5
Lamp 14 (400W)	0.3	0.4	17.1

Discussion

The original purpose of this research was to address the concerns of energy efficiency programs about the persistence of energy-saving LED lamps. If a new LED lamp could be easily replaced by a MH lamp that used more energy, then the energy savings from a new LED lamp might only persist for the lifetime of that lamp. This research addressed that concern. After the ballast has been removed from a mogul socket on a standard 20A circuit, in order for a MH lamp to function in that socket for more than a few seconds, it is very likely that the socket must be rewired with a new ballast.

In the process of answering the original question, a new concern was raised about safety, because when MH lamps were installed in a socket converted for LED lamps, most of the MH lamps failed, and 2 of the failures shattered the lamp's outer envelope. While both of these envelope failures occurred in lamps rated for enclosed luminaires, this research did not eliminate the possibility that a lamp rated for open luminaires might fail in a similar manner, when operated off of line voltage.

UL Code 1598C requires that mogul base LED lamps be packaged with properly approved stickers, to be placed inside the luminaire fixture housing in clear view and on the base socket. These yellow labels should have sufficient size and type size to provide caution to a lamp installer or electrician as follows: "This luminaire has been modified and can no longer operate the originally intended lamp."

Despite the cautionary labels, a maintenance worker might install a new MH lamp in a converted mogul socket while the circuit is energized. If that ever occurred, then an inline, fast-acting fuse of appropriate amperage at each socket could provide a redundant level of safety to complement the cautionary labels.

Summary

Probe-start MH lamps can ignite without a ballast on input voltages of 277V or higher[3]; 17 of the 18 probe-start lamps tested in this phase started when 277V was applied. Fourteen lamps experienced some type of failure: 10 of the lamps had a ruptured arc tube, 2 of the lamps had a ruptured outer envelope and 2 of the lamps had other lamp elements that failed. None of the 9 protected lamps, which are rated to be used in open fixtures, had an outer envelope rupture. The additional envelope around the arc tube appears to have a protective effect.

The fuse testing conducted in this phase suggests that adding an inline fast-acting fuse could be a potential solution for preventing non-passive HID lamp failures in bypassed HID fixtures. More testing is suggested to determine optimum fuse rating and fuse type capable of supporting peak inrush current for LED lamps while still affording adequate protection against non-passive HID failures. Recent conversations with UL staff on safety implications of such a fuse have yielded the following conclusions. A fuse that is properly marked and installed (per the requirements in UL1598 Clause 6.6) should not present a safety concern as long as it does not contradict the conversion kit's[4] instructions. The best practice approach would be for a manufacturer to include a fuse and fuseholder in their LED conversion kits when they are submitted to UL so that

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[3] http://www.bpa.gov/EE/Technology/EE-emerging-technologies/Projects-Reports-Archives/Documents/Mogul_LED_Lamps_LRC_BPA_Phase2_2015Jan.pdf

[4] The phrase "conversion kit" refers to an LED lamp with its associated instructions, stickers, etc. that are delivered as a packaged unit to a consumer. This is different from the DesignLights Consortium phrase "retrofit kit" that refers to an LED replacement for a MH lamp that is powered by a wire that bypasses the original screwbase socket.

compliance with the fuse requirements in UL 1598 is verified. UL encourages a revision to 1598C such that a fuse is required in a HID to LED conversion kit using a mogul base socket. Currently there is no requirement for fusing when the ballast is removed, and UL believes LRC research supports such rationale.[5]

[5] Phone and email conversations between LRC and UL staff