NLPIP :: Lighting Answers

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Mid-wattage Metal Halide Lamps

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Abstract

Lighting Answers: Mid-wattage Metal Halide Lamps helps lighting professionals to understand mid-wattage metal halide lamps and their most important performance characteristics. It explains the how the lamps work, the differences between quartz and ceramic **arc tubes**, and the differences between probe-start and pulse-start technologies. It provides information about issues such as burning position, **warm-up**, and **restrike** times. Finally, this publication provides pointers to lighting professionals on how to choose mid-wattage metal halide lamps.

This publication was first issued in 2003 and revised in 2005. It answers commonly asked questions about mid-wattage metal halide (MH) lamps. This revision includes new data gathered from testing conducted over a 15-month period (October 2002 to January 2004). It does not include information about any additional products. Readers familiar with the original publication will notice new information about **lumen maintenance**, **color shift**, and **color variation**, located in the question: "What are some important characteristics of MH lamps?" This question is complex and has been separated into several sections.

Introduction

Metal halide (MH) lamps are available in low, mid-range, and high wattages from 35 to 2000 watts (W). Mid-wattage MH lamps range from 175 to 400 W. All major lamp manufacturers offer MH lamps in this range, commonly in wattages of 175, 200, 225, 250, 300, 320, 350, 360, and 400.

MH lamps are a type of **high-intensity discharge (HID)** lamp that offers long **lamp life**, high **efficacy**, and good color rendering properties. In general, they are energy efficient and allow for good optical control. These qualities make them attractive for applications such as retail establishments, where both low operating cost and good light quality are important. Because of their long life, MH lamps are also appropriate for buildings with high ceilings and other facilities in which lighting is constantly in use for many hours at a time. They are popular choices for high-bay and low-bay industrial operations, warehouses, street lighting, and stadium and sports lighting. Like other **gas-discharge lamps**, all MH lamps require a **ballast** to operate. (See "Why do metal halide lamps require a ballast?")

MH lamps provide white light in a variety of **correlated color temperatures (CCTs)** ranging from 3200 to 5200 **Kelvin**, and are commonly available with a **color rendering index (CRI)** of 65 to 70, but can also have a CRI of 90 or above. They are superior in color characteristic to most **high-pressure sodium (HPS)** and **mercury vapor (MV) lamps** that have lower CRI values.

MH lamps compete with HPS lamps for outdoor applications such as streetlights, roadway lights, security lights, and pedestrian walkways. HPS lamps provide more photopic **lumens** per watt, but the whiter light of MH lamps provides better peripheral visibility at low illumination levels.

How do metal halide lamps work?

Metal halide (MH) lamps consist of an **arc tube** (also called a discharge tube or "burner") within an outer envelope, or bulb. The arc tube may be made of either quartz or ceramic and contains a starting gas (usually argon), mercury, and MH salts. Traditional quartz MH arc tubes are similar in shape to **mercury vapor (MV)** arc tubes, but they operate at higher temperatures and pressures.

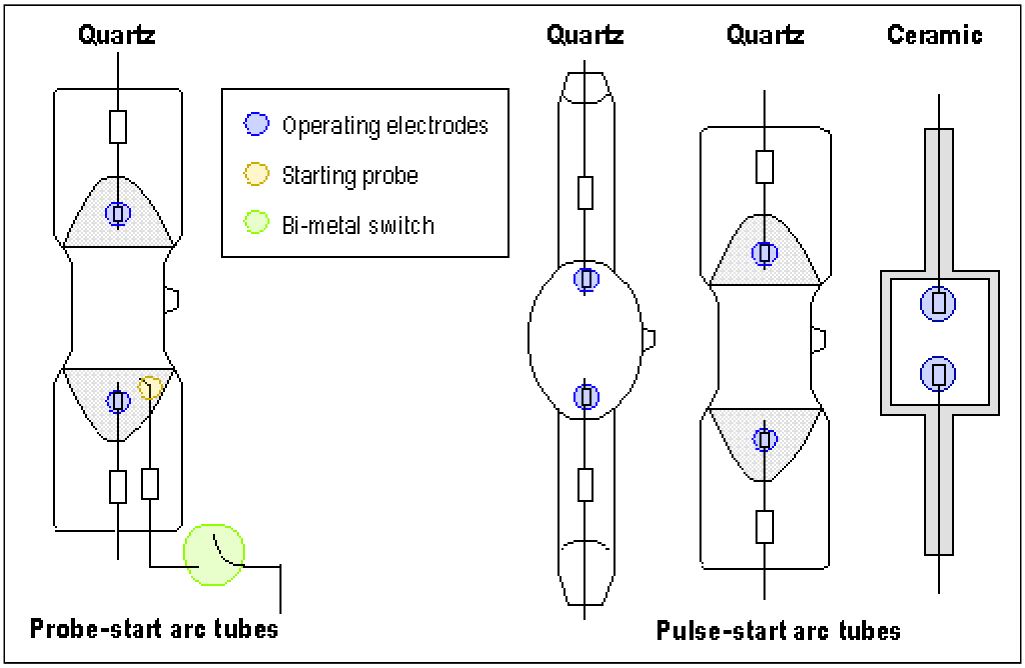
MH lamps start when their **ballast** supplies a high **starting voltage** higher than those normally supplied to the lamp **electrodes** through a gas mixture in the arc tube. The gas in the MH arc tube must be ionized before current can flow and start the lamp. In addition to supplying the correct starting voltage, the ballast also regulates the **lamp starting current** and **lamp operating current**. (See "What types of ballasts are available to use with metal halide lamps?")

As pressure and temperature increase, the materials within the arc tube vaporize and emit light and **ultraviolet (UV)** radiation. A bulb (also called "outer jacket" or "outer envelope"), usually made of borosilicate glass, provides a stable thermal environment for the arc tube, contains an inert atmosphere that keeps the components of the arc tube from oxidizing at high temperatures, and reduces the amount of UV radiation that the lamp emits. Some MH lamps have a coated finish on the inside of the bulb that diffuses the light. Often a **phosphor** coat is used to both diffuse the light and change the lamp's color properties.

What is the difference between quartz and ceramic arc tubes?

Metal halide (MH) lamp **arc tubes** are made of either quartz or ceramic (see Figure 1). Ceramic arc tubes allow higher arc tube temperatures, which manufacturers claim results in better **efficacy**, color rendering, and color stability. In 2003, when this report was originally written, lamps with ceramic arc tubes were available mainly in wattages below 150 watts (W). Mid-wattage ceramic MH lamps were only beginning to make their way onto the market. Only one manufacturer offered a mid-wattage ceramic MH product, which was also a pulse-start technology. (See "What is the difference between probe-start and pulse-start?")

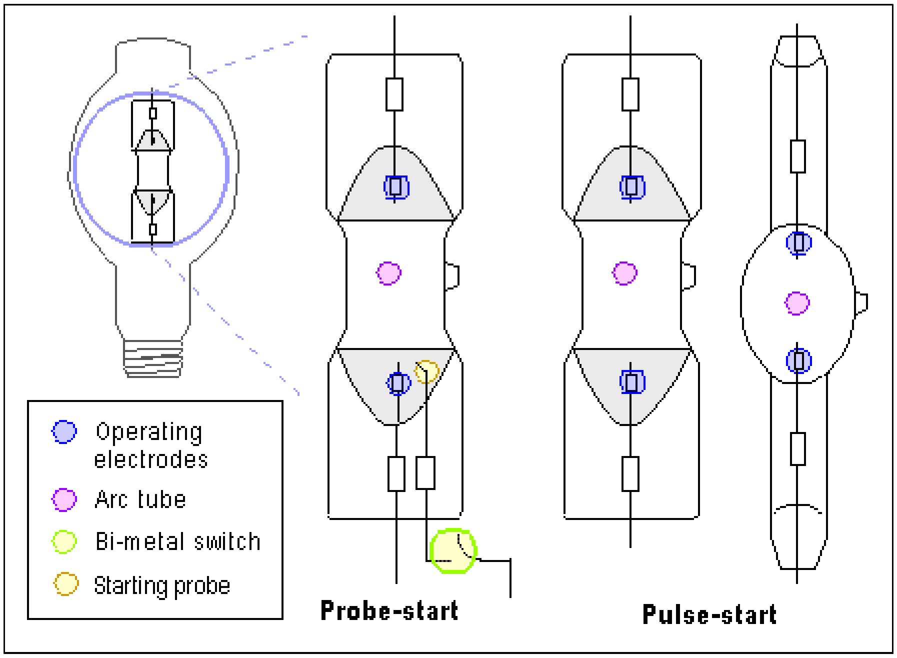
Figure 1. Arc tube construction



What is the difference between probe-start and pulse-start lamps?

Traditional metal halide (MH) lamps use probe-start technology. Three **electrodes** are present in the **arc tube** of a probe-start MH lamp: a starting probe electrode and two operating electrodes (see Figure 2). To start the lamp, a discharge is created across a small gap between the starting probe electrode (also called the starter electrode) and the operating electrode. Electrons then jump across the arc tube to the other operating electrode to help start the lamp. Once the lamp is started, a bi-metal switch removes the starting probe electrode from the circuit.

Figure 2. Probe-start and pulse-start technologies



Each time a MH lamp is turned on, tungsten sputters from the electrodes. Over the **lamp life**, this tungsten can cause the arc tube wall to blacken, thus reducing performance of the lamp.

Pulse-start MH lamps do not have the starting probe electrode (Figure 2). Instead they have a high-voltage **ignitor** that works with the **ballast** to start the lamp using a series of high-voltage pulses (typically 3 to 5 kilovolts). Without the probe electrode, the amount of pinch (or seal) area at the end of the arc tube is reduced, which results in a reduced heat loss. Furthermore, using an ignitor with a lamp reduces the tungsten sputtering by heating up the electrodes faster during starting. **Warm-up time** is also reduced. Pulse-start technology was developed to increase lamp life and to have both the energy efficacies of **high-pressure sodium (HPS)** lamps and the desirable color characteristics of MH lamps.

Pulse-start technology is not new; it has been available in low-wattage MH systems for years. Manufacturers claim that pulse-start systems achieve the following:

- Provide longer lamp life of up to 50% over traditional MH lamps.
- Increase **lumen maintenance** by up to 33% (see the lumen maintenance section of "What are some important characteristics of MH lamps?").
- Provide better cold starting capability-these lamp-ballast systems will start at temperatures as low as -40°C (-40°F)
- Allow faster starting when cold, shorter warm-up times, and a faster **restrike** (re-start).

Table 1 compares the probe-start and pulse-start lamps and presents some of their important characteristics such as lamp life, **initial light output**, **mean light output**, ballast type, and color. Each lamp described in the table represents a category of products by that manufacturer, not single products. For the revision of this publication, NLPIP tested eight groups of six lamps each, representing four types of MH lamps. Comparisons were made between 320 W pulse-start and 400 W probe-start MH lamps, as well as between 250 W pulse-start and 250 W probe-start MH lamps.

(NOTE: Table 1 is available online as a separate PDF file by clicking the link below. If you obtained a printable PDF file of this report, Table 1 is at the end.)

Click here to view Table 1 "Characteristics of mid-wattage metal halide lamps."

Why do metal halide lamps require a ballast?

Metal halide (MH) **ballasts** are required to start the lamp, regulate the lamp starting and **lamp operating currents**, and provide appropriate sustaining **supply voltage**. (See "What are warm-up and restrike times for metal halide lamps?")

Starting the lamp: In MH lamps, ballasts provide the **starting voltage** and ignition pulses (pulse-start lamps) necessary to ignite the lamp. Probe-start MH ballasts, however, can take as long as 10 to 20 minutes to restrike (re-start) a lamp. Pulse-start MH ballasts can restrike the lamp within 2 to 8 minutes of an interruption in current, because they provide high-voltage pulses to start these lamps.

Regulating lamp current and **power**: The ballast regulates the lamp operating current flowing through the lamp after the lamp has been started. The ballast is set to deliver relatively stable power to the lamp while regulating the lamp current despite typical **line voltage** fluctuations. This maximizes **lamp life** and ensures other performance characteristics such as color and light output.

Providing appropriate sustaining voltage: MH ballasts must maintain suitable voltage and current wave shape to the lamp. MH lamp voltage typically increases over time, and the ballast must continue to provide sufficient voltage to the lamp as it ages. In addition, the American National Standards Institute (**ANSI**) and/or the lamp manufacturers specify a suitable current wave shape to the lamp to achieve good **lumen maintenance**. Lamp **current crest factor (CCF)** is defined by ANSI as the ratio of the peak value of lamp current to the **root-mean-square** value of the current. A low CCF (between 1.4 and 1.6) contributes to good lamp lumen maintenance and longer life.

What types of ballasts are available to use with metal halide lamps?

Commonly used probe-start metal halide (MH) **ballast** systems for mid-wattage MH lamps include high-reactance autotransformer (HX-HPF), constant-wattage autotransformer (CWA), constant-wattage isolated transformer (CWI), and regulated lag (magnetically regulated) ballasts.

Pulse-start MH lamps require a different type of ballast than probe-start MH lamps. Pulse-start MH ballast systems include super constant-wattage autotransformer (SCWA), linear reactor, and regulated-lag ballasts. Descriptions of each of these ballast types were obtained from manufacturers' literature and are summarized below.

Several manufacturers offer solid-state electronic ballasts for MH lamps. Manufacturers claim that these ballasts provide better performance in a smaller package, have a high **power factor**, save more energy, generate less heat, have less than 3% change in output **power**, and have lower maintenance costs. Manufacturers also claim that high frequency ignition reduces blackening on the **arc tube** wall, which gives better **lumen maintenance**, better color stability, and longer **lamp life**. In addition, electronic ballasts can dim the lamp down to 33% of full light output. Two concerns with electronic ballasts that operate at high frequency are acoustic resonance and electromagnetic interference. Some manufacturers are using a low frequency square wave to avoid the problem. These ballasts are more commonly available for lamps below 150 watts (W), but higher wattages are becoming more available. Magnetic ballasts are still the most common ballasts used with mid-wattage MH lamps.

High-reactance autotransformer (HX-HPF): These ballasts are similar in performance to reactor ballasts (discussed below), but their additional coils allow them to start the lamp from **supply voltages** that are lower than those necessary to start the lamps. As a result, these ballasts are bigger, heavier, and less efficient than reactor ballasts, but they can be used in a wide variety of applications, because they come with **multitap** capability. A typical **current crest factor (CCF)** range for these ballasts is 1.4 to 1.6. Most HX-HPF ballasts are rated to handle supply voltage variations of 5%, which results in a 9 to 12% lamp power variation.

Constant-wattage autotransformer (CWA): Also known as lead style ballasts, CWA ballasts are the most common ballasts used on 175 W or higher MH lamps. This type of ballast has a different design than the reactor and high-reactance autotransformer (HX-HPF) ballasts. CWA ballasts offer better lamp power regulation, but they are heavier, larger, less efficient, and more expensive than reactor or HX-HPF styles. CWA ballasts tend to be higher in CCF, typically in the range of 1.6 to 1.8 and high power factor (0.9) due to a **capacitor**. They are rated to handle supply voltage variations of 10% or higher.

Constant-wattage isolated transformer (CWI): This ballast is similar to CWA design, but has an electrical isolation between the primary and secondary windings. They are very common in the Canadian market, but are larger and less efficient than CWA styles.

Super constant-wattage autotransformer (SCWA): This two-coil ballast system is used to operate pulse-start MH lamps. High power factor is achieved by using a capacitor in series with the lamp. These ballasts have good lamp regulation and can handle voltage variations of up to 45%.

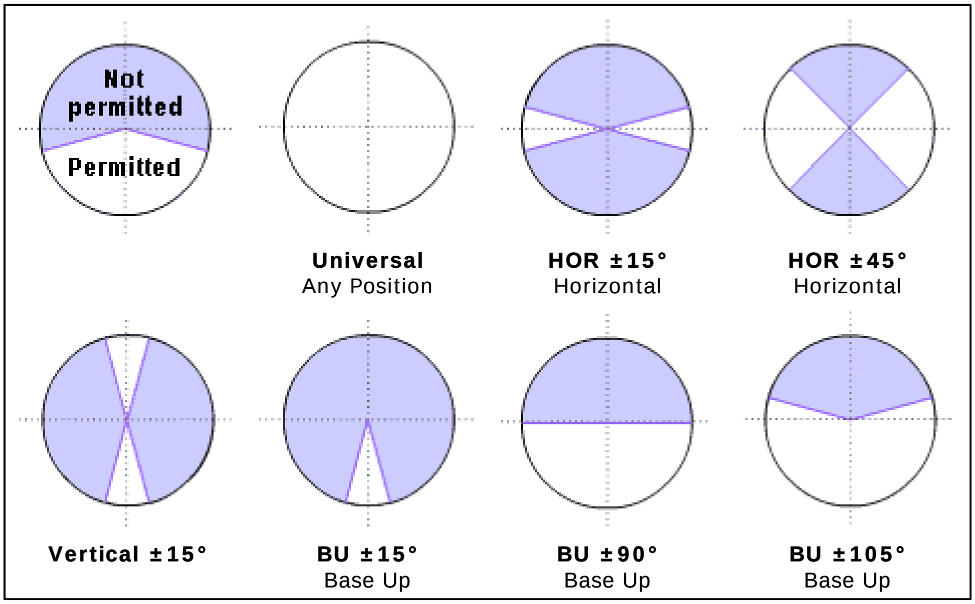
Linear reactor pulse start: This single-coil reactor ballast, **ignitor**, and capacitor are used to operate a pulse-start MH lamp. It is available only in 277 volts, and it is a very efficient system because the single-coil design reduces both input lamp W by 8% and power loss by up to 50% when compared to the SCWA ballast.

Regulated lag (magnetically regulated): This ballast design is the most sophisticated and provides the highest power regulation to the lamp. It provides a **voltage regulation** and circuit wave shape that is the most beneficial for lamp life and lumen maintenance. These ballasts are larger and less efficient than other types, but they should be used when large input voltage variation is expected. A typical CCF range for magnetically regulated ballasts is 1.4 to 1.6. They are rated to handle supply voltage variations of 10% or higher, which results in approximately 5% lamp power variation. In regions where **line voltage** variations greater than 10% are expected, however, they will not operate efficiently.

What effect does burning position have on metal halide lamps?

The position in which metal halide (MH) lamps are installed makes a difference in the **color variation** and **color shift** of the lamps. Position can also affect **lamp life**. Installing MH lamps in a base-up position generally gives the best results in terms of minimizing color variation and maximizing lamp life, but some lamps perform equally well when installed base down. Some lamps should only be installed horizontally (see Figure 3). The manufacturer's literature should be consulted to determine the best installation position for a MH lamp. Most manufacturers' catalogs give the **lumen** output for lamps installed in specific burning positions.

Figure 3. Lamp operating positions

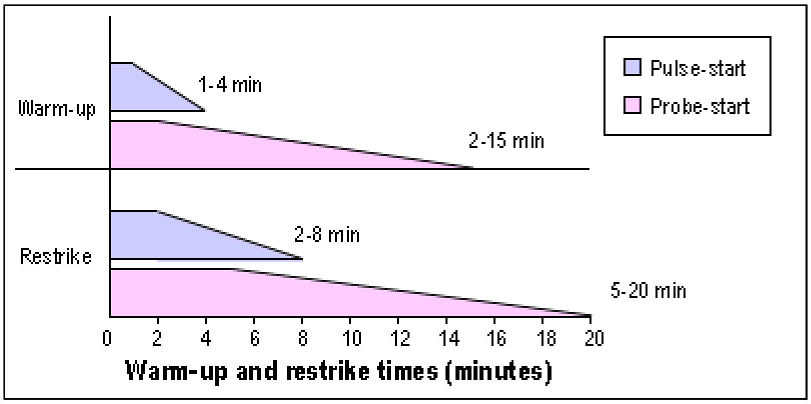


Source: Adapted from Venture Lighting International

What are warm-up and restrike times for metal halide lamps?

Metal halide (MH) lamps do not achieve their full light output immediately after starting. Rather, they require a period of time-1 to 15 minutes-to reach 90% of their full light output. This period is called the **warm-up** (or run-up) time. After a lamp has been on for a period of time and then extinguished, it cannot be immediately turned back on. Before the lamp can be turned back on, the **arc tube** must have a chance to cool down or the lamp will not restart. This period of time is called the **restrike time**. Restrike times for traditional probe-start MH lamps can take 15 minutes or longer, but restrike times for pulse-start MH lamps are generally much shorter (see Figure 4). According to manufacturers' literature, restrike times for pulse-start MH lamps can be more than twice as fast as for probe-start MH lamps.

Figure 4. Warm-up/restrike times for probe-start and pulse-start technologies



What are some important characteristics of metal halide lamps?

Note: This is a complex question and has been separated into the following sections:

Energy efficiency
Lumen Maintenance
Lamp life
Color variation and color shift

Mid-wattage metal halide (MH) lamps have many characteristics that make them good choices for a variety of applications, including white light, energy efficiency, and long life.

Table 1 summarizes some characteristics of the technology available as of 2003. The information in the table has been compiled from manufacturers' literature.

(NOTE: Table 1 is available online as a separate PDF file by clicking the link below. If you obtained a printable PDF file of this report, Table 1 is at the end.)

Click here to view Table 1 "Characteristics of mid-wattage metal halide lamps."

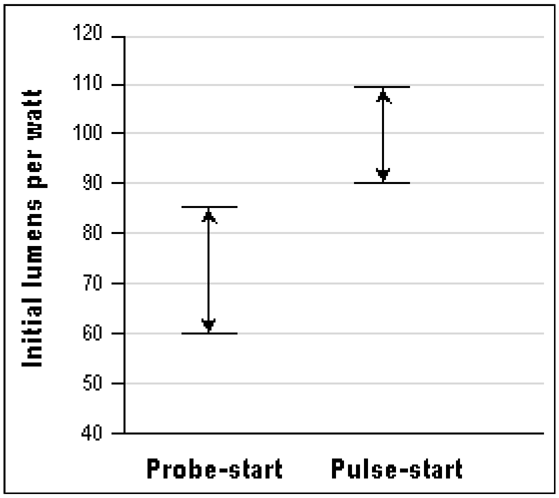
Energy efficiency

Relative energy savings using mid-wattage MH lamps will depend on the application. Manufacturers' claims for the energy efficiency of their products rest on two assumptions:

- Although both probe-start and pulse-start MH lamps have high efficacies or **lumens** per watt (Figure 5), pulse-start MH lamps have higher rated efficacies.

- If pulse-start MH lamps indeed have higher efficacies and greater lumen maintenance than probe-start MH lamps, then for the same target illuminance, specifiers could use either lower wattage lamps or fewer **luminaires** than would be required for probe-start MH lamps. For example, manufacturers claim that a 320 watt (W) pulse-start MH lamp has similar **initial light output** as a 400 W probe-start MH lamp, so the same amount of light is achieved by using lower wattage lamps. Another option is to use fewer luminaires of the higher lamp wattage (400 W, for example) to achieve the target illuminance. In this case, it is important to follow the recommended luminaire spacing criteria to maintain a uniform light distribution. (See lumen maintenance section of this question).

Figure 5. Initial lumens per watt for probe-start and pulse-start technologies



Lumen maintenance

All lamps undergo some **lumen depreciation**, or decrease in light output, as a lamp is operated. The lower the light loss over time, the higher a lamp's **lumen maintenance** will be. High lumen maintenance is good because lamps can operate longer before needing to be replaced due to insufficient illumination for the application.

NLPIP undertook limited lumen maintenance testing of medium wattage (250 watt [W], 400 W, and 320 W) metal halide (MH) lamps. **Color variations** and **color shifts** among these lamps were also measured (see color variation and color shift section). Details of the testing protocols and the results are given in the Appendix. Figure 6 illustrates the rated and measured lumen output values for the high wattage MH lamps listed in Table App-1 (located in Appendix); relative lumen maintenance values are presented in Table 2. The manufacturers' initial rated lumens agreed fairly well with NLPIP's measured values (+/-6%). Manufacturer A's rated lumens at 40% of rated life agree quite closely with the measured lumens, both for the 400 W probe-start and the 320 W pulse-start MH lamps. However, the measured lumens emitted at 40% of rated life for the two types of MH lamps produced by Manufacturer B were substantially lower than the rated lumens for these two lamp types. In terms of lumen maintenance, based on the measurements, the relative loss in lumens was greater for the 400 W probe-start MH lamps than for the 320 W pulse-start MH lamps. At 40% of rated life both types of MH lamps produced essentially the same lumens, although there were marked differences between the two manufacturers in terms of absolute lumen maintenance, as previously noted.

Note: Illuminating Engineering Society of North America (IESNA) specification LM-51-00 requires lumen output measurements to be obtained at the rated power of the lamp (i.e., 400 W or 320 W). Therefore, the "efficacy maintenance percentages" will be identical to the lumen maintenance percentages presented in Table 2.

Figure 6: Comparison of lamp lumen output at 100 hours (h) of operation and at 40% of lamp life for 320 W pulse-start and 400 W probe-start MH lamps from Manufacturers A and B

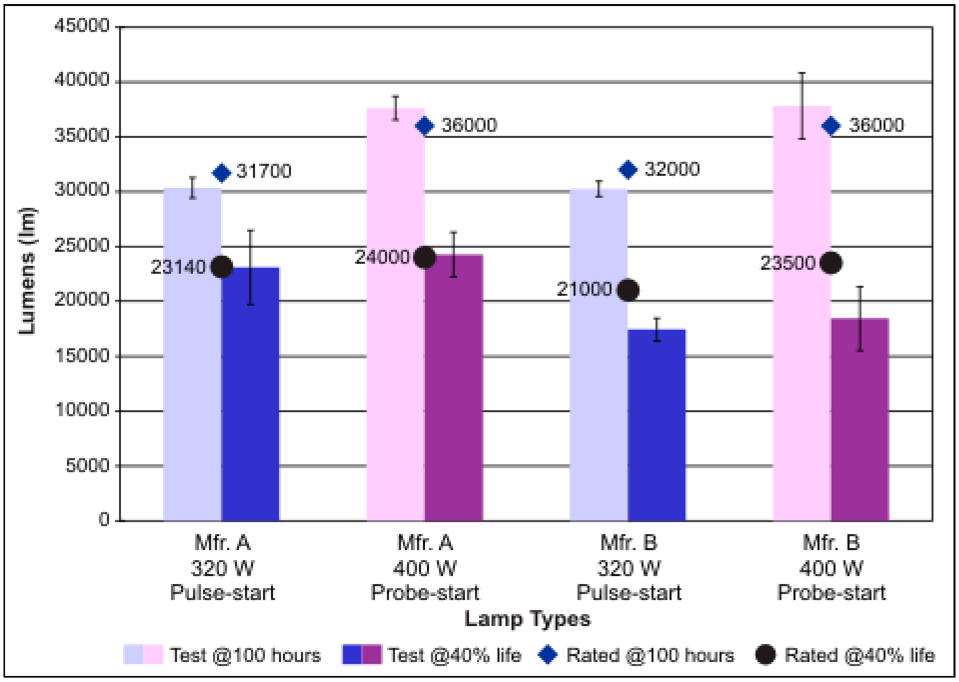


Table 2: Lumen maintenance at 40% of lamp life for 320 W and 400 W MH lamps from Manufacturers A and B

Manufacturer		**A**		**B**	
Lamp Type		Pulse Start	Probe Start	Pulse Start	Probe Start
Rated Lamp Wattage (W)		320	400	320	400
Ballast Model Number		71A5892	78E6091	71A5892	78E6091
Lumen Maintenance @40% Lamp Life	Rated	73%	67%	66%	65%
	Measured	75%	65%	58%	49%

Lumen maintenance

Figure 7 illustrates the rated and measured **lumen** output values for the medium wattage MH lamps from Table App-2 (located in Appendix); **lumen maintenance** values are presented in Table 3. The testing showed that the manufacturers' initial rated lumens agreed quite well with the measured values (+/- 5%). However, in the case of the pulse-start MH lamps from Manufacturer D there were marked discrepancies between the manufacturers' rated lumens at 40% of rated life and the measured lumens at 40% of rated **lamp life**. Based on these measurements, it is impossible to conclude that 250 W pulse-start is better than 250 W probe-start in terms of lumen maintenance. It should be remembered, however, that lumen maintenance values at 40% of lamp life differ in terms of the absolute hours of operation for the pulse-start and probe-start MH lamps; pulse-start lamps at 40% of rated lamp life are expected to provide 2000 more hours of light operation than probe-start lamps at 40% of rated lamp life.

Note: Specification LM-51-00 of the Illuminating Engineering Society of North America (IESNA) requires lumen output measurements to be obtained at the rated **power** of the lamp (i.e., 250 W). Therefore, the "**efficacy** maintenance percentages" will be identical to the lumen maintenance percentages presented in Table 3.

Figure 7: Comparison of lamp lumen output at 100 hours (h) of operation and at 40% of lamp life for 250 W pulse-start and 250 W probe-start MH lamps from Manufacturers C and D"

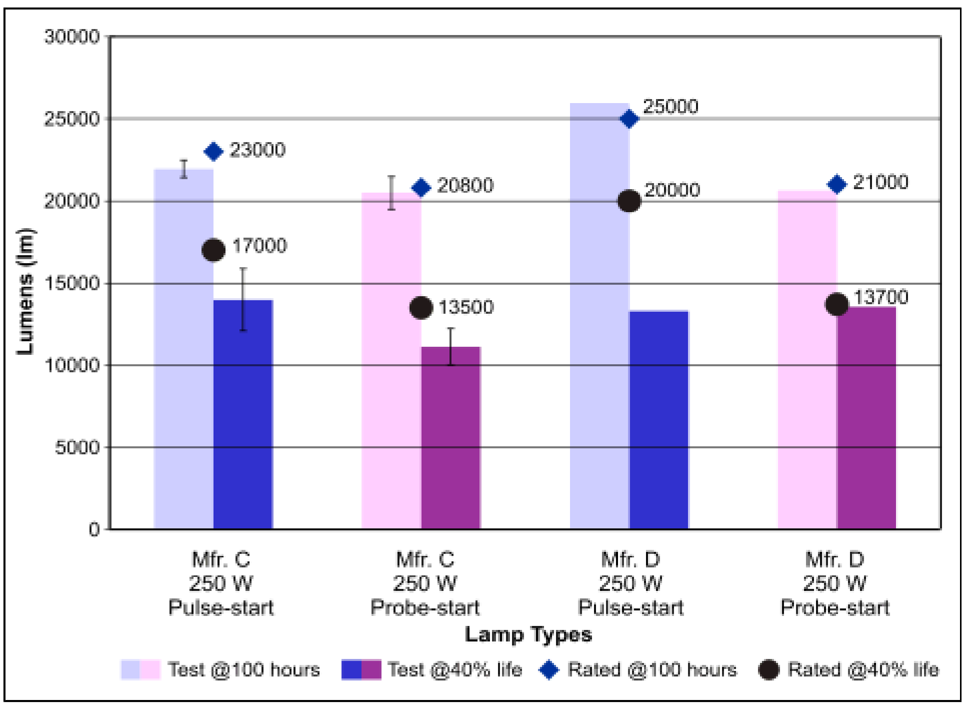


Table 3: Lumen maintenance at 40% of lamp life for 250 W MH lamps from Manufacturers C and D

Manufacturer		C		D	
Lamp Type		Pulse Start	Probe Start	Pulse Start	Probe Start
Lamp Wattage (W)		250	250	250	250
Ballast Model Number		71A5793	78E5790	71A5793	78E5790
Lumen Maintenance @40% Life	Rated	74%	65%	80%	65%
	Measured	64%	54%	51%	66%

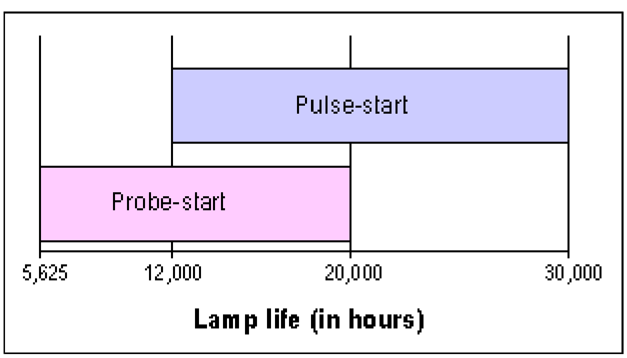
Based upon the results of the limited testing presented here, initial rated lumens are fairly accurately represented by manufacturers. At 40% of rated lamp life, however, rated lumens can be overestimated by some manufacturers. Finally, specifiers should remember that because rated lamp life is different for 250 watt probe-start and pulse-start MH lamps, the absolute number of useful hours of operation will differ even if lumen maintenance values are the same for the two technologies.

Manufacturers claim that pulse-start MH lamps have from 10 to 33% better lumen maintenance than probe-start MH lamps. This cannot be taken as a general statement, because, as shown by NLPIP testing, lumen maintenance depends to a great extent upon manufacturer and wattage.

Lamp life

Mid-wattage MH lamps vary between 5,625 and 20,000+ hours (h) of rated lamp life, based on an operating cycle of 11 h on and 1 h off. A few are rated for more than 20,000 h. One manufacturer claims a lamp life of 30,000 h for its products provided the lamps run continuously. Generally, the probe-start MH lamps are on the lower end of this range (5,625 to 10,000 hours), while the pulse-start MH lamps are on the upper end of the range (12,000 to more than 20,000+ h), although a few probe-start MH lamps are rated for as much as 20,000 h (Figure 8).

Figure 8. Rated lamp life for probe-start and pulse-start technologies (using CWA ballasts)



MH lamps should be relamped at or before the end of their rated lives. Operating them until they fail increases the likelihood of the **arc tube** rupturing, which would cause the bulb to explode. Also, if the bulb ruptures, it could potentially expose users to **ultraviolet (UV)** radiation.

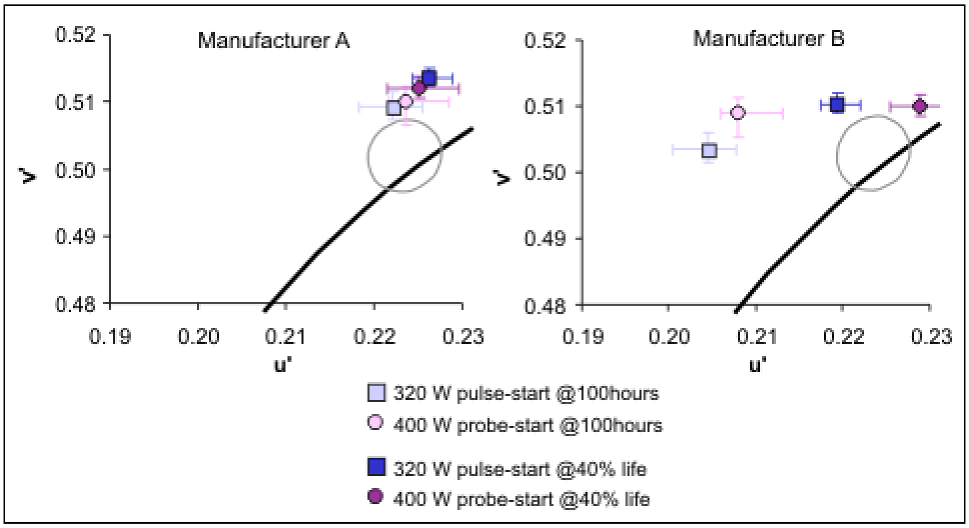
Color variation and color shift

Color variations among MH lamps of the same type can be much greater than color variations among incandescent lamps of the same wattage or among linear fluorescent lamps of the same rated **correlated color temperature (CCT)**. Color variations among MH lamps are particularly noticeable during the first 100 hours (h) of operation. Color variations can be minimized by selecting MH lamps of the same wattage, from the same manufacturer and orienting them with the same operating position (e.g., all base-up). MH lamps also exhibit **color shifts** as they age, more than with either incandescent or linear fluorescent lamps. Group relamping will help to minimize color shifts as lamps age.

NLPIP performed limited testing of color variations and color shifts on medium wattage (250 watts [W], 400 W, and 320 W) MH lamps. These were the same lamps examined for their **lumen maintenance**. Details of the testing protocols and the results are given in the Appendix.

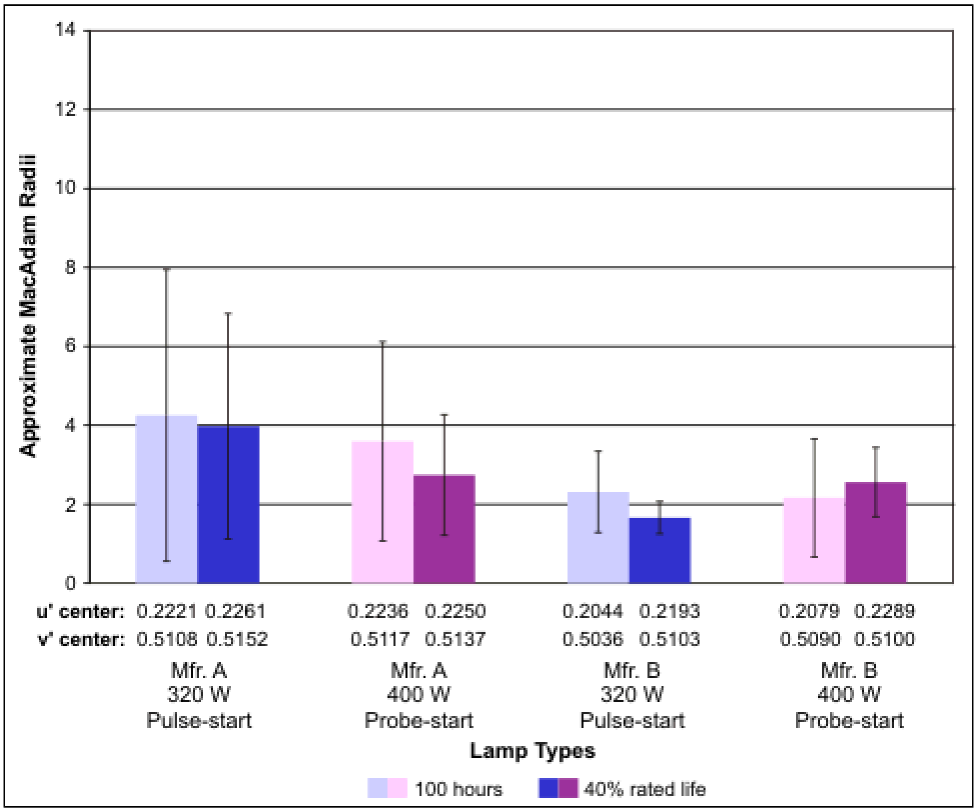
Figure 9 shows the average chromaticities (u', v'), and their associated standard deviations, in the **CIE** 1976 uniform color space for the 320 W pulse-start and 400 W probe-start MH lamps produced by Manufacturers A and B, respectively. Equal distances throughout the CIE 1976 uniform color space correspond to approximately equal perceptual color differences to a normal observer. Also shown in both figures is the blackbody locus, which forms the reference line for CCT calculations and the American National Standards Institute (**ANSI**) designated four-step **MacAdam ellipse** for linear fluorescent lamps having a (cool) CCT of 4000/4100 K (ANSI C78.376-2001). The chromaticities of all linear fluorescent lamps produced by manufacturers with the cool designation should lie within this particular four-step MacAdam ellipse. Although not directly relevant to MH lamps, ellipses of this type provide an indication of acceptable manufacturing tolerances for the color of light emitted by fluorescent lamps designated as having the same CCT.

Figure 9: Comparison of color variations at 100 hours (h) of operation and at 40% of rated lamp life for 320 W and 400 W MH lamps from Manufacturers A and B



Manufacturer A rates its 320 W pulse-start MH lamp at 3900 K and its 400 W probe-start MH lamp at 4000 K. Manufacturer B rates its 320 W pulse-start MH lamp at 4300 K and its 400 W probe-start MH lamp at 4000 K. Figure 9 shows that nearly all of the lamp **chromaticities** produced by both manufacturers lie outside the four-step MacAdam ellipse designated as cool by ANSI for linear fluorescent lamps. Although this four-step **MacAdam ellipse** is not strictly applicable to MH lamps, specifiers should be aware that fluorescent lamps and MH lamps of the same rated **CCT** may not necessarily have the same apparent color. There is also much greater color variation among the MH lamps produced by Manufacturer A than those produced by Manufacturer B, both at 100 h and at 40% of rated life. These variations are more clearly shown in Figure 10.

Figure 10: Average color variations at 100 h of operation and at 40% of rated lamp life for 320 W and 400 W MH lamps from Manufacturers A and B



The paired histogram bars in Figure 10 represent the color variations in each of the four groups (320 W pulse-start and 400 W probe-start MH lamps from two manufacturers) of six, MH lamps. The average chromaticity coordinates of the six lamps in each sample for both testing periods (at 100 h and at 40% of rated life) are indicated below each histogram bar. The height of each histogram bar represents the average deviation of the six lamps in that group at both testing times (at 100 h and at 40% of rated lamp life) from their average chromaticity coordinates, measured in terms of "approximate MacAdam radii"; a four-step MacAdam ellipse has an approximate MacAdam radius of 4. Assuming that the four-step MacAdam ellipse represents a useful tolerance criterion in lamp color, it appears that nearly all of the lamps would have "acceptable" color variation at both 100 h and at 40% of rated lamp life.

The shift in color over time is another important criterion to consider with MH lamps. Figure 11 shows how far the colors shift from 100 h to 40% of lamp life for the four groups of high wattage MH lamps. The height of each histogram bar in Figure 11 represents the average distance in color space the chromaticities changed over the two test times for the six lamps in each group. Again assuming the four-step MacAdam ellipse represents a useful tolerance criterion for **color shifts**, all of the lamps from Manufacturer B shift by more than this criterion from 100 h to 40% of rated lamp life. Interestingly, despite the greater variability among the lamps produced by Manufacturer A at a given time (Figure 10), they tend to shift much less over time. Of note, the 400 W probe-start MH lamps produced by Manufacturer A are almost always within the four-step MacAdam ellipse criterion, between testing periods, as shown in Figure 11.

Figure 11: Average color shifts for 320 W and 400 W MH lamps from Manufacturers A and B

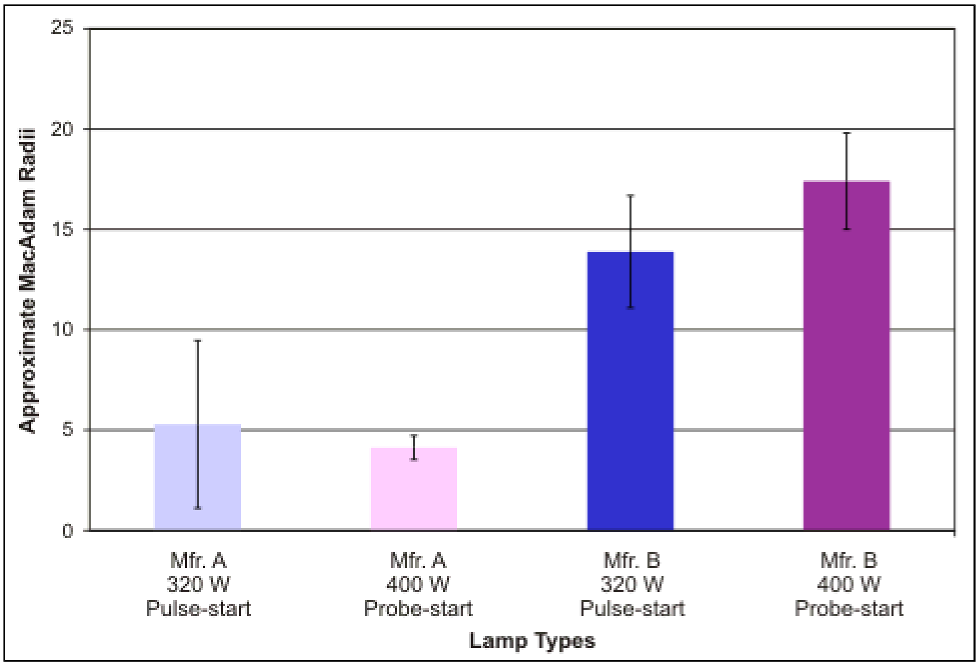
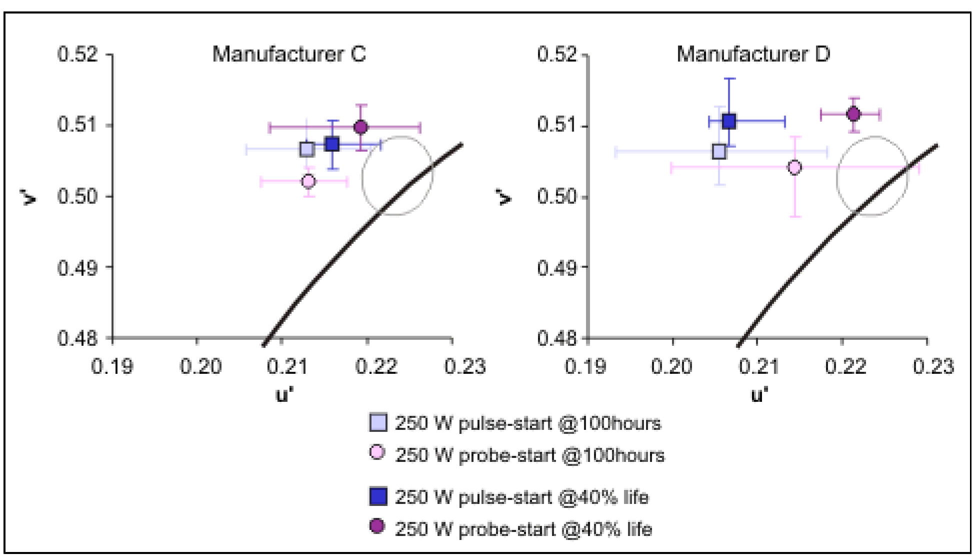


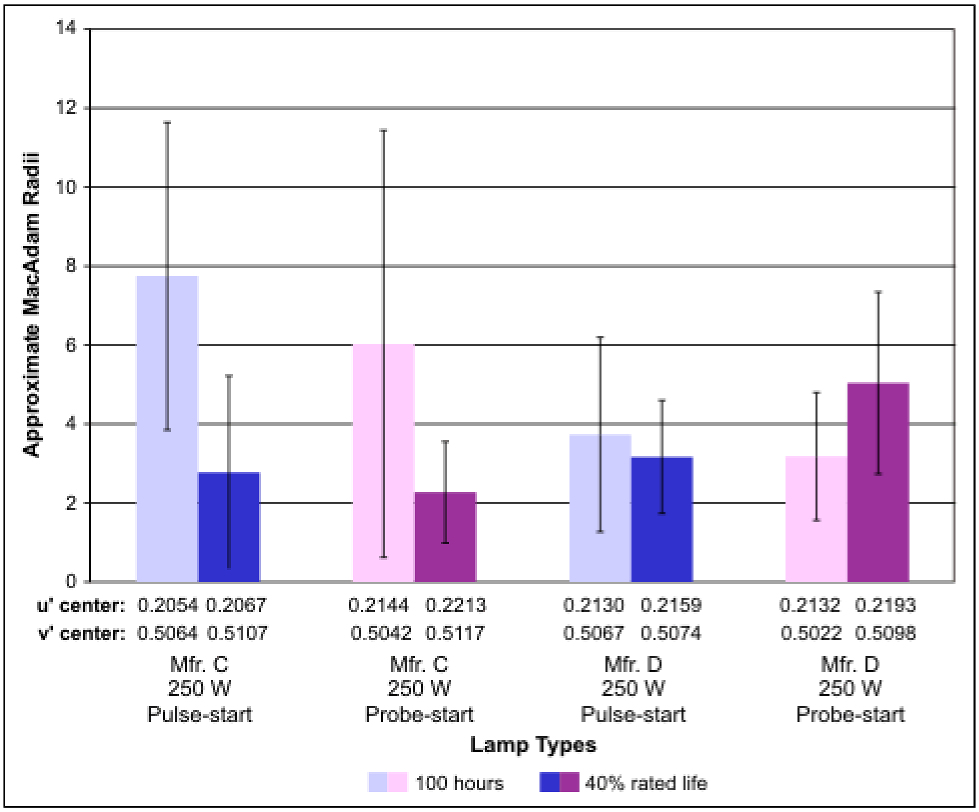
Figure 12 shows the average chromaticities (u', v'), and their associated standard deviations, in the CIE 1976 uniform color space for the 250 W MH lamps produced by Manufacturers C and D, respectively.

Figure 12: Comparison of color variations at 100 h of operation and at 40% of rated lamp life for 250 W MH lamps from Manufacturers C and D



Manufacturer C rates its 250 W MH lamps, both pulse-start and probe-start, at 4200 K. Manufacturer D rates its lamps at 4000 K. Figure 12 shows that nearly all of the chromaticities of the lamps produced by both manufacturers lie outside the four-step **MacAdam ellipse** designated as cool by **ANSI** for linear fluorescent lamps. There is greater variation among the lamps produced by Manufacturer C than those produced by Manufacturer D, both at the 100 h mark and at 40% of rated lamp life. These variations are more clearly shown in Figure 13.

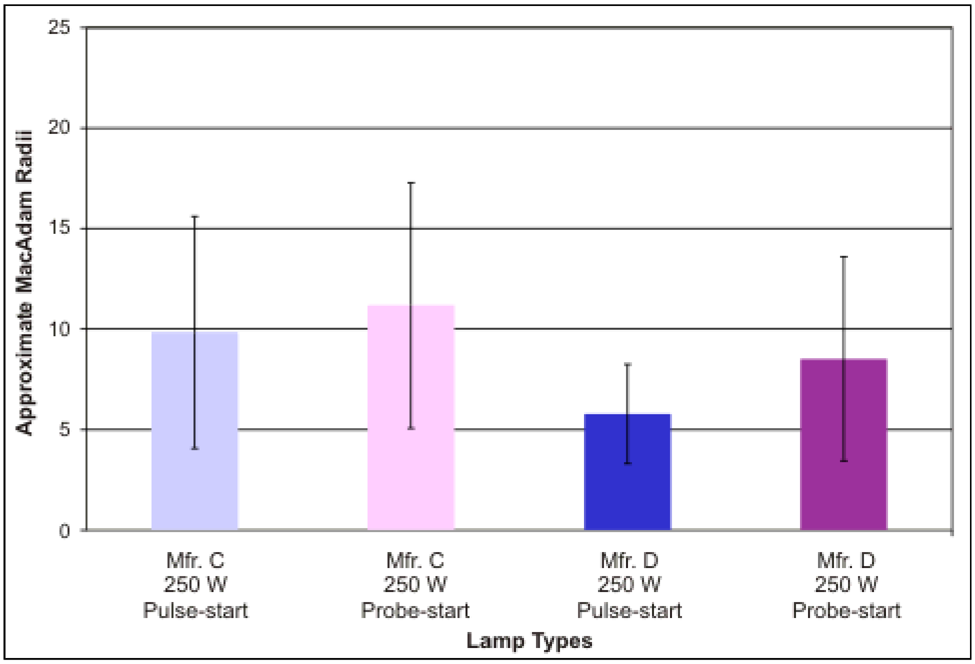
Figure 13: Average color variations at 100 h of operation and at 40% of rated lamp life for 250 W MH lamps from Manufacturers C and D



The paired histogram bars in Figure 13 represent the color variations in each of the four groups (pulse-start and probe-start from two manufacturers) of six, 250 W MH lamps. The average **chromaticity** coordinates of the six lamps in each sample for both testing periods (at 100 h and at 40% of rated life) are indicated below each histogram bar. As in Figure 10, the height of each histogram bar represents the average deviation of the six lamps in that group from their average chromaticity coordinates measured in "approximate MacAdam radii"; a four-step MacAdam ellipse has an approximate MacAdam radius of 4. Assuming that the four-step MacAdam ellipse represents a useful tolerance criterion in lamp color, it appears that only the pulse-start lamp from Manufacturer D would have "acceptable" color variation at both 100 h and at 40% of rated life. Interestingly, Manufacturer C has greater variability in lamp color at 100 h than does Manufacturer D, whereas the reverse is true at 40% of rated lamp life. However, it does not appear that probe-start MH lamps, as a group, have greater, or worse, color variations than pulse-start MH lamps.

Figure 14 shows how far the colors shift from 100 h to 40% of rated **lamp life** for the four groups of 250 W MH lamps. The height of each histogram bar in Figure 14 represents the average distance in color space that the chromaticities changed over the two test times for the six lamps in each group. Again assuming the four-step **MacAdam ellipse** represent a useful tolerance criterion for **color shifts**, all of the 250 W MH lamps shift by more than this criterion from 100 h to 40% of rated lamp life. Among the four groups, however, the pulse-start MH lamps from Manufacturer D show the smallest color shift.

Figure 14: Average color shifts for 250 W MH lamps from Manufacturers C and D



SOURCE: Adapted from Advance Transformer Co.

There appears to be no simple generalization about color shift over time when comparing the 250 W MH lamps (Figure 14) with the higher wattage MH lamps (See Figure 11).

Based upon the results of the limited testing presented here, **color variations** and color shifts of MH lamps are certainly issues for specifiers to consider. Unfortunately, it is difficult to make major generalizations about these attributes because color performance varies considerably among the different MH lamp wattages and manufacturers.

Are mid-wattage metal halide lamps a cost-effective option?

According to manufacturers, the new pulse-start metal halide (MH) lamps cost less to own than probe-start MH lamps, because the total cost includes both initial and operating costs. Compared to probe-start MH systems, fewer pulse-start lamps are required, which means fewer **luminaires** and, thus, require less installation labor. Better energy efficiency and fewer lamps reduce energy costs during operation. Longer **lamp life** and better **lumen maintenance** mean less frequent relamping, which reduces labor costs.

In retrofits, where the use of fewer luminaires may not be an option, manufacturers suggest replacing probe-start MH lamps with lower wattage pulse-start MH lamps. For example, manufacturers recommend that a 320 W pulse-start MH lamp replace an existing 400 watt probe-start MH lamp.

NLPIP testing showed that, for a given manufacturer, there was no obvious difference between 320 W pulse-start and 400 W probe-start MH lamps in terms of absolute **lumens** at 40% rated life, even though there were differences in terms of lumen maintenance (see Figure 6).

How well do mid-wattage metal halide lamps work in retrofitting?

Metal halide (MH) lamps can be used to retrofit systems that use incandescent lamps of at least 150 watts (W), although the **luminaires** will have to be replaced. Some mid-wattage probe-start MH lamps can be operated on **high-pressure sodium (HPS) ballasts**.

Ballasts for pulse-start and probe-start lamps use completely different methods to start the lamps, and they are not interchangeable. Because pulse-start ballasts have an **ignitor** added to the basic design, they may be slightly more expensive to buy. However their higher initial cost may be offset by energy savings over the life of the ballast and lamp.

At the time this report was written, many mid-wattage pulse-start MH lamps were designed to fit in the same luminaires as probe-start MH lamps. Probe-start ballasts, however, would have to be replaced. New mid-wattage ceramic MH lamps were available only with pulse-start ballasts.

What safety issues should specifiers consider?

Metal halide (MH) lamps can explode (typically referred to as sudden nonpassive failure) because they operate at high pressures, but some products are manufactured with safety features to prevent injury. For example, many **luminaires** include a tempered-glass or acrylic enclosure to contain any debris in the event of explosion. This debris, consisting of hot pieces from the lamp, could injure people nearby or pose a fire hazard if it escapes from the luminaire. Some **arc tubes** come encased in protective glass shrouds or have Teflon® coatings on their outer bulbs to minimize shattering and to allow them to be used safely in open luminaires.

Some MH lamps do not contain such protection and, although they can be used in open luminaires, appropriate precautions must be taken. Such lamps should be mounted in a vertical position ±15°, they should be turned off at least 15 minutes per week, and they should be relamped as a group after no more than 70% of their rated lives.

Some of these MH lamps can cause serious skin burns and eye inflammation if the outer envelope of the lamp is broken or punctured and the arc tube continues to burn, because the arc tube emits **UV** radiation. Some MH lamps are self-extinguishing-they will automatically extinguish if the outer envelope is broken.

Group relamping will remove the MH lamps from service before they become susceptible to arc tube rupture. Turning the MH lamps off periodically (called "cycling") helps to ensure that MH lamp failures occur without exploding. This method avoids explosion because the arc tube cools while the MH lamp is turned off, and any cracks that may occur in the tube wall are more likely to propagate while the MH lamp's internal arc tube pressure is low (rather than when the pressure is high, as it is while operating).

MH lamps carry ratings such as "E" (Enclosed), "S" (Suitable), and "O" (Open/closed) that identify under what conditions they should be used. According to American National Standards Institute (ANSI), the "E" rating refers to lamps that must be used in enclosed luminaires that meet the safety requirements of UL1598. The "S" rating refers to lamps that are considered suitable for open luminaire operation only if operated in the vertical position ±15° and turned off at least 15 minutes per week. Group relamping is required before reaching rated life (Figure 3). The "O" rating refers to lamps that can be operated in both open and enclosed luminaires. The manufacturer's product information indicates the ratings and specifies how each type of MH lamp can be safely used.

Like fluorescent lamps, MH lamps contain small amounts of mercury. One should always wear gloves when handling broken lamp fragments, and always dispose of spent lamps according to waste disposal guidelines established by the U.S. Environmental Protection Agency (EPA) or other appropriate state or local authorities.

Table 1. Characteristics of mid-wattage metal halide lamps (data gathered from manufacturers' literature)

Rated lamp power (watts)	Manufacturer	Start type	Bulb designation	Initial light output (lumens)	Mean light output (lumens)	Lamp life (hours)	ANSI code	CCT (kelvin)	CRI	Warm-up time (minutes)	Restrike time (minutes)
175	GE	Probe	BD17 PAR38 ED28	U: 14100—15000 V: 12900—13600 H: 11700	V: 8800 H: 7400	V: 10000 H: 6000	M57 (CWA)	3900–4000	65–70	2–4	10 – 15
	GE	Pulse	BD17 ED23.5	16000–17500	12000–13000	15000	M137	3200–4000	65–75	<2	<6
	OSRAM SYLVANIA	Probe	ED17 BT28	U: 12500–14400 V: 11800–14400 H: 11080–15000	U: 10000–12000 V: 7600–12000 H: 7500–10300	U: 7500–10000 V: 10000 H: 7500	M57 (CWA)	4200	65–70	2–4	9–15
	Philips	Probe	ED17 ED28	12000–15000	7560–12000	10000	M57	3200–4300	65–70	3–5	10–20
	Philips	Pulse	ED28	16000	11200	15000	M137	3900	65	2–4	2–4
	Venture	Probe	ED17 ED28 T15	V: 12000–15000 H: 10800–12600	7800–9800	7500–10000	M57 (CWA)	3200–5200	65–75	3–5	5–10
	Venture	Pulse	ED17 ED28	16600–17500	13300–14000	15000	M137 M152	3700–4000	65–70	1–2	2–4
200	Venture	Pulse	ED17 ED28	19000–21000	15200–16800	12000–15000	M136	3200–4000	65–70	1–2	2–4
225	Venture	Probe	ED28	18000–20000	11700–13000	10000	M58 (CWA)	3700–4000	65–70		

Table 1 continued

Rated lamp power (watts)	Manufacturer	Start type	Bulb designation	Initial light output (lumens)	Mean light output (lumens)	Lamp life (hours)	ANSI code	CCT (kelvin)	CRI	Warm-up time (minutes)	Restrike time (minutes)
250	GE	Probe	ED28 T15	U: 19000–21000 V: 19800–20800 H: 18200–19100	U: 9400–13300 V: 13000–13500 H: 11600–12400	U: 10000–15000 V: 10000 H: 6000	M58 (CWA)	3900–4200	65–70	2–4	10–15
	GE	Pulse	ED28	21500–23000	15500–17000	15000, 20000	M138	3900–4200	65	<2	<6
	OSRAM SYLVANIA	Probe	BT28 ET18	U: 17500 V: 17500–23000 H: 17200–23000	U: 13000 V: 13000–17500 H: 15000–17500	U: 10000 V: 10000 H: 10000	M58	3200–4200	65–70	2–4	7–12
	OSRAM SYLVANIA	Pulse	BT28	23500	19200	15000	M138	4200	65	2–3	4–7
	Philips	Probe	ED18 ED28 T15 BT28	18000–23000	11300–19125	10000	M58 S50	3200–4300	65–70	3–5	10–20
	Philips	Pulse	ED28	23800	16600	15000	M138	4300	65	2	4
	Venture	Probe	ED28 T15	V: 19000–33000 H: 17100–18900	12400–15000	V: 7500–10000 H: 5625–7500	M58 (CWA) S50	3200–5200	65–75	3–5	5–10
	Venture	Probe	T8	20000	13000	10000	M80 (CWA)	3000–4200	70		
	Venture	Pulse	ED28	22600–25000	18100–20000	15000	M138 M153	3700–4000	65–70	2–3	3–5
300	Venture	Pulse	ED28 ED37	27500–30500	22000–24400	20000+	M151	3700–4000	65–70		

Table 1 continued

Rated lamp power (watts)	Manufacturer	Start type	Bulb designation	Initial light output (lumens)	Mean light output (lumens)	Lamp life (hours)	ANSI code	CCT (kelvin)	CRI	Warm-up time (minutes)	Restrike time (minutes)
320	GE	Pulse	ED28 ED37	30000–34000	16500–25000	20000	M132	3700–4000	65–70	<2	<6
	OSRAM SYLVANIA	Pulse	BT28	30000–32000	19700–21000	20000	M132	3900–4300	65–70		4–7
	Philips	Pulse	ED28	V: 30080–31700 H: 27200–28800	V: 21960–23140 H: 19860–21000	V: 20000 H: 15000	M132	V: 3600–3900 H: 3900–4300	65–70	2	5–7
	Venture	Pulse	ED28 ED37	29700–34000	23800–27200	15000–20000+	M132 M154	3700–4000	65–70	2–3	4–8
320/350	OSRAM SYLVANIA	Pulse	BT28	V: 30000–32000 H: 28000–30000	V: 19700–21000 H: 18400–19700	V: 20000 H: 15000	M132 M131	4300	65–70	2–4	4–7
325	GE	Probe	ED37	V: 26300–28000 H: 24200–25800	V: 12900–13300 H: 11800–12200	V: 20000 H: 10000		3700–4000	65–70	10–15	10–15
	Venture	Probe	ED37	26600–28000	17300–18200	20000	H33	3700–4000	65–70		
350	GE	Pulse	ED37	33400–37000	23500–27500	20000, 30000	M131	3700–4000	65–70	<2	<6
	Philips	Pulse	ED37	35000–37000	26250–28000	20000	M131	3700–4000	65	2	4
	Venture	Pulse	ED28 ED37	33300–37000	26600–29600	15000–20000+	M131	3200–4000	65–70	2–3	4–8

Table 1 continued

Rated lamp power (watts)	Manufacturer	Start type	Bulb designation	Initial light output (lumens)	Mean light output (lumens)	Lamp life (hours)	ANSI code	CCT (kelvin)	CRI	Warm-up time (minutes)	Restrike time (minutes)
350/400	OSRAM SYLVANIA	Pulse	BT37	32000–39000	23000–28000	20000	M131 M135	3300–3500	65–70	2–4	5–7
360	GE	Probe	ED37	35000–39000	23000–27000	20000	M59 (CWA)	4000–4300	65–70	10–15	10–15
	OSRAM SYLVANIA	Probe	BT37	V: 34500–36000 H: 30000	V: 22500–24200 H: 19000	V: 20000 H: 15000	M59 (CWA)			2–4	7–12
	Venture	Probe	ED28 ED37	33500–36000	21800–23400	20000	M59 (CWA)	3700–4000	65–70		
400	GE	Probe	BT28 BT37 ED18 ED28	U: 25000–44000 V: 31000–36000 H: 28500–33100	U: 17500–32000 V: 18600–24000 H: 17100–22100	U: 10000–20000 V: 15000–20000 H: 10000–15000	M59	3700–4000	65–70	2–4	10–15
	GE	Pulse	ED37	40000–44000	27500–33000	20000, 30000	M135	3700–4000	65–70	<2	<6
	OSRAM SYLVANIA	Probe	BT28 BT37	U: 35000–41000 V: 35000–42000 H: 32000–40000	U: 20600–28000 V: 22000–26000 H: 20500–26000	U: 20000 V: 20000 H: 15000–20000	M59	3200–4500	60–70	2–4	7–12
	OSRAM SYLVANIA	Pulse	BT37	42000	31000	20000	M135	4000	65–70	2–4	5–7
	Philips	Probe	ED18 ED28 ED37 T15	32500–40000	20800–30600	20000	M59 S51	3200–4100	65–70	4	15
	Philips	Pulse	ED37 BT37	42000–44000	29400–31000	20000	M135 M128	3700–4000	66–92	3	4

Table 1 continued

Rated lamp power (watts)	Manufacturer	Start type	Bulb designation	Initial light output (lumens)	Mean light output (lumens)	Lamp life (hours)	ANSI code	CCT (kelvin)	CRI	Warm-up time (minutes)	Restrike time (minutes)
(400 (cont'd)	Venture	Probe	BT37 ED28 ED37 T15	29300–40000	21100–26000	7500–20000	M59 (CWA) S51	3200–5200	65–75	3–5	8–15
	Venture	Pulse	ED28 ED37	40000–44000	32000–35200	15000–20000+	M135 M155	3700–4000	65–70	2–3	4–8

Notes: At present all the mid-wattage MH lamps have a quartz arc tube. Ceramic arc tube lamps will be available soon.

Definitions of terms used in Table 1:

ANSI code—Indicates the electrical operating designation of the lamp, which must match that of the ballast. The letter M represents the high-intensity discharge lamp classification, which in this case is metal halide. The number following the letter represents the set of all key electrical characteristics of the lamp, so as to ensure electrical interchangeability. For more information, see ANSI C78.380-1997.

Bulb designation—An abbreviation of the shape and size of the lamp's outer envelope; the letter or letters indicate the shape and the numbers indicate the bulb's maximum diameter in eighths of an inch. For example, an ED17 is an elliptical, dimpled lamp that is 17/8 in. (2 1/8 in.) in diameter.

CCT—Correlated color temperature, which describes the color appearance of the light that is produced as compared to a reference source.

CRI—Color rendering index, a scale for describing the effect of a light source on the color appearance of objects being illuminated, with 100 representing the reference condition and being the maximum CRI possible.

CWA—Constant wattage autotransformer.

Initial light output—The lamp's light output in lumens, after 100 hours of seasoning.

Lamp life (also known as average rated life)—The number of hours at which half of a large group of lamps has failed under standard test conditions.

Mean light output—The lamp's light output at 40% of rated lamp life. **U** = universal burning position; **V** = vertical burning position; **H** = Horizontal burning position.

Rated lamp power—Manufacturer-supplied lamp power in watts.

Restrike time—The time it takes for the lamp to produce 90% of its initial light output after it has been extinguished and immediately restarted, unless otherwise indicated.

Start type—Technology used to start the lamp, which can be either probe or pulse start.

Warm-up time—The time it takes for a lamp to produce 90% of its initial light output when it is started, unless otherwise indicated.

Appendix

The National Lighting Product Information Program (NLPIP) tested eight groups of six lamps each, representing four types of metal halide (MH) lamps. Comparisons were made between 320 watt (W) pulse-start and 400 W probe-start MH lamps, as well as between 250 W pulse-start and 250 W probe-start MH lamps.

NLPIP purchased all lamps for these tests from distributors in the Troy, New York area in October 2002. All testing was conducted during a 15-month period (October 2002 to January 2004). Testing performed in our laboratory met the requirements of Illuminating Engineering Society of North America (IESNA) specification LM-51-00; ambient temperatures ranged from 28°C to 42°C during the testing period. Light output in **lumens (lm)**, **efficacy** (lm/W), and color characteristics (**correlated color temperature [CCT]** and **color rendering index [CRI]**) were measured after 100 hours (h) of seasoning. Lamps were then operated on an 11-h on/1-h off cycle until they reached 40% of rated life. At that point the same attributes were measured again.

The 320 W pulse-start and the 400 W probe-start MH lamps were from two manufacturers producing both types of MH lamps. Advance Transformer Company's constant wattage autotransformer (CWA) **ballasts** (**ANSI** code number M59) operated the 400 W probe-start MH lamps and its Super CWA ballasts (ANSI code number M132) operated the 320 W pulse-start MH lamps. The 320 W pulse-start MH lamps as well as the 400 W probe-start MH lamps had rated lives of 20,000 h, so all lamps were tested after 8000 h (40% of rated life) of operation. Measured values at 100 h and at 40% of rated life were then compared.

The 250 W lamps were from two manufacturers producing both pulse-start and probe-start MH lamps. These two manufacturers differed from those that produced the 400 W and 320 W MH lamps. Advance Transformer Company's CWA ballasts (ANSI code number M58) operated the probe-start lamps, and its Super CWA ballasts (ANSI code number M138) operated the pulse-start lamps. The 250 W pulse-start lamps had a rated life of 15,000 h, so these lamps were tested after 6000 h (40% of rated life) of operation; however, the 250 W probe-start lamps had a rated life of 10,000 h, so they were tested after 4000 h. Measured values at 100 h and at 40% of rated **lamp life** were then compared.

Table App-1 shows rated and measured values for the 320 W and 400 W MH lamps; table APP-2 shows rated and measured values for 250 W MH lamps. Lamp and ballast information, including the rated values, come from the manufacturers' catalogs current at the time the products were acquired. All measured values represent the arithmetic mean of six samples; values in parentheses are standard deviations.

Table App-1: Comparison of lumen output, lamp efficacy, CCT, and CRI for 320 W and 400 W pulse-start and probe-start MH lamps from Manufacturers A and B

Manufacturer			A		B	
Lamp Type			Pulse Start	Probe Start	Pulse Start	Probe Start
Rated Lamp Wattage (W)			320	400	320	400
Ballast Model Number			71A5892	78E6091	71A5892	78E6091
Lumen Output (lm)	100 hour	Rated	31700	36000	32000	36000
		Measured	30348 (923)	37625 (1083)	30251 (689)	37822 (3005)
	40% life	Rated	23140	24000	21000	23500
		Measured	23089 (3385)	24262 (2047)	17424 (1036)	18438 (2897)
Lamp Efficacy (lm/W)	100 hour	Rated	99	90	100	90
		Measured	94.9 (3.0)	94.1 (2.7)	94.5 (2.1)	94.5 (7.5)
	40% life	Rated	72	60	66	59
		Measured	72.1 (10.6)	60.6 (5.1)	54.4 (3.2)	46.1 (7.2)
CCT (K)	100 hour	Rated	3900	4000	4300	4000
		Measured	3969 (257)	3897 (201)	4779 (158)	4509 (79)
	40% life	Measured	3762 (213)	3816 (146)	4067 (85)	3737 (122)
		CCT Shift	-207	-81	-712	-772
CRI	100 hour	Rated	65	65	65	65
		Measured	67.3	59.4	64.8	64.3
	40% life	Measured	66.0	65.0	69.7	68.6

Note: All measured values represent the arithmetic mean of six samples.
Values in parentheses are standard deviations.

Table App-2: Comparison of lumen output, lamp efficacy, CCT, and CRI for 250 W pulse-start and probe-start MH lamps from Manufacturers C and D

Manufacturer			C		D	
Lamp Type			Pulse Start	Probe Start	Pulse Start	Probe Start
Rated Lamp Wattage (W)			250	250	250	250
Ballast model number			71A5793	78E5790	71A5793	78E5790
Lumen Output (lm)	100 hour	Rated	23000	20800	25000	21000
		Measured	21952 (529)	20486 (460)	25946 (525)	20650 (978)
	40% life	Rated	17000	13500	20000	13700
		Measured	13979 (1179)	11110 (919)	13286 (1900)	13563 (1101)
Lamp Efficacy (lm/W)	100 hour	Rated	92	83	100	84
		Measured	87.8 (2.0)	81.9 (1.8)	104 (2.2)	82.6 (3.9)
	40% life	Rated	68	54	80	55
		Measured	55.9 (4.7)	44.4 (3.7)	53.1 (7.7)	54.2 (4.4)
CCT (K)	100 hour	Rated	4200	4200	4000	4000
		Measured	4697 (505)	4382 (462)	4371 (237)	4459 (213)
	40% life	Measured	4246 (177)	4082 (282)	4528 (185)	3973 (119)
		CCT Shift	-451	-300	157	-486
CRI	100 hour	Rated	65	65	65	65
		Measured	61.7	63.4	69.6	61.6
	40% life	Measured	64.3	64.7	71.3	63.7

Note: All measured values represent the arithmetic mean of six samples.
Values in parentheses are standard deviations.

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Credits

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Glossary

Sources of term definitions: National Lighting Product Information Program (NLPIP), Lighting Research Center's Lighting Education Online, the IEEE Standard Dictionary of Electrical and Electronics Terms (IEEE Std 100-1996).

ANSI code	American National Standards Institute (ANSI) code that indicates the electrical operating designation of the lamp, which must match that of the ballast.
Arc tube	An envelope, usually quartz or ceramic that contains the arc of a discharge light source.
Ballast	A device required by electric-discharge light sources such as fluorescent or HID lamps to regulate voltage and current supplied to the lamp during start and throughout operation.
Capacitor	A device used in electric circuitry to temporarily store electrical charge in the form of an electrostatic field. In lighting, a capacitor is used to smooth out alternating current from the power supply.
Chromaticity	The dominant or complementary wavelength and purity aspects of the color taken together, or of the aspects specified by the chromaticity coordinates of the color taken together. It describes the properties of light related to hue and saturation, but not luminance (brightness).
CIE	Abbreviated as CIE from its French title Commission Internationale de l'Eclairage, the International Commission on Illumination is a technical, scientific, and cultural organization devoted to international cooperation and exchange of information among its member countries on matters relating to the science and art of lighting.
Color rendering index (CRI)	A measure of the degree of color shift that objects undergo when illuminated by a lamp, compared with those same objects when illuminated by a reference source of comparable correlated color temperature (CCT). A CRI of 100 represents the maximum value. A lower CRI value indicates that some colors may appear unnatural when illuminated by the lamp. Incandescent lamps have a CRI above 95. The cool white fluorescent lamp has a CRI of 62; fluorescent lamps containing rare-earth phosphors are available with CRI values of 80 and above.
Color shift	The change in a lamp's correlated color temperature (CCT) at 40% of the lamp's rated life, in kelvin (K).
Color variation	Lamps of the same type made by the same manufacturer may exhibit a certain degree of variation in color, even when operated under the same conditions and seasoned for the same about of time.
Correlated color temperature (CCT)	A specification of the apparent color of a light source relative to the color appearance of an ideal incandescent source held at a particular temperature and measured on the Kelvin (K) scale. The CCT rating for a lamp is a general indication of the warmth or coolness of its appearance. As CCT increases, the appearance of the source shifts from reddish white toward bluish white; therefore, the higher the color temperature, the cooler the color appearance. Lamps with a CCT rating below 3200 K are usually considered warm sources, whereas those with a CCT above 4000 K usually considered cool in appearance.
Current crest factor (CCF)	Defined as the peak current divided by the root-mean-square (rms) current of a lamp. Current crest factor ranges from 1 to infinity. ANSI requires current crest factor to be less than 1.7. Lamp manufacturers usually will not warranty

	their lamps when operated on a ballast having a current crest factor greater than 1.7.
Efficacy	The ratio of the light output of a lamp (lumens) to its active power (watts), expressed as lumens per watt.
Electrodes	The structure that serves as the electric terminals at each end of electric discharge lamps.
Gas-discharge lamps	An electric lamp that produces light from gas atoms excited by an electric current.
High-intensity discharge (HID)	An electric lamp that produces light directly from an arc discharge under high pressure. Metal halide, high-pressure sodium, and mercury vapor are types of HID lamps.
High-pressure sodium (HPS)	A high-intensity discharge lamp type that uses sodium under high pressure as the primary light-producing element. HPS lamps produce light with a correlated color temperature (CCT) of approximately 2000 kelvins, although CCTs for lamps having higher CRI values range from 2200 to 2700 kelvins. Standard lamps have a CRI value of 22; others have CRI values from 60 to 80. HPS lamps are among the most efficacious light sources, with efficacies as high as 150 lumens per watt, although those with higher CRI values have efficacies as low as 25 lumens per watt.
Ignitor	A device, either by itself or in association with other components, that generates voltage pulses to start discharge lamps.
Initial light output	A lamp's light output, in lumens, after 100 hours of seasoning.
Kelvin	Color temperature is measured in degrees Kelvin, which indicathe hue of a specific type of light source. Higher temperatures indicate whiter, "cooler" colors, while lower temperatures indicate yellower, "warmer" colors.
Lamp life	The median life span of a very large number of lamps (also known as the average rated life). Half of the lamps in a sample are likely to fail before the rated lamp life, and half are likely to survive beyond the rated lamp life. For discharge light sources, such as fluorescent and HID lamps, lamp life depends on the number of starts and the duration of the operating cycle each time the lamp is started.
Lamp operating current	Current flowing through a lamp during normal operation.
Lamp starting current	Current flowing through a lamp during starting operation.
Line voltage	The 110-120-volt household current, generally standard in North America.
Lumen (lm)	A unit measurement of the rate at which a lamp produces light. A lamp's light output rating expresses the total amount of light emitted in all directions per unit time. Ratings of initial light output provided by manufacturers express the total light output after 100 hours of operation.
Lumen depreciation	The decrease in lumen output that occurs as a lamp is operated, until failure. Also referred to as lamp lumen depreciation (LLD).
Lumen maintenance	The ability of a lamp to retain its lumen output over time. Greater lumen maintenance means a lamp will remain brighter longer. The opposite of lumen

maintenance is lumen depreciation, which represents the reduction of lumen output over time. Lamp lumen depreciation factor (LLD) is commonly used as a multiplier to the initial lumen rating in illuminance calculations to compensate for the lumen depreciation. The LLD factor is a dimensionless value between 0 and 1.

Luminaire	A complete lighting unit consisting of a lamp or lamps and the parts designed to distribute the light, to position and protect the lamp(s), and to connect the lamp(s) to the power supply. (Also referred to as fixture.)
MacAdam ellipse	Researcher David L. MacAdam showed that a just noticeable difference (JD) in the colors of two lights placed side-by-side was about three times the standard deviation associated with making color matches between a reference light and a test light)MacAdam 1942, Wyszecki and Stiles 1982). These JNDs form an elliptical pattern of "constant discriminability" in a chromaticity space, centered on the chromaticity of a reference light, known as MacAdam ellipse.
Mean light output	Light output typically evaluated at 40% of rated lamp life. In combination with initial light output, mean light output may be used to estimate lamp lumen depreciation.
Mercury vapor (MV) lamp	A high-intensity discharge lamp type that uses mercury as the primary light-producing element. Mercury vapor lamps produce light with a CCT from 3000 to 7000 K. Mercury vapor lamps with clear outer bulbs have CRI values from 15 to 25, whereas phosphor-coated lamps have CRI values from 40 to 55. Mercury vapor lamps are less efficacious than other HID lamp types, typically producing only 30 to 65 LPW, but they have longer lamp lives and lower initial costs than other HID lamp types.
Multitap	A passive distribution component composed of a directional coupler and a splitter with two or more output connections.
Operating cycle	The frequency with which lamps are cycled on and off.
Phosphors	The white, powdered material coating the inside of the glass tube of a lamp. The phosphors fluoresce (emit visible light) when excited by the ultraviolet radiation produced by the mercury vapor that is energized by the electric arc sustained inside the lamp.
Position factor	The light output of the lamp in a certain position divided by the light output of the lamp in the base-up position.
Power	The power (in watts) used by a device to produce useful work (also called input power or active power). In lighting, it is the system input power (in watts) for a lamp and ballast combination. When referred to as benchtop active power, the measurement procedure follows ANSI standards, which include horizontally mounted bare lamp(s) at an ambient temperature of 25° C, ±1°C, and air movement less than 5 feet per minute. The lamps are seasoned 100 hours before testing, and the measurements are conducted after lamp light output stabilizes.
Power factor (PF)	The ratio of active power (in watts) to apparent power (in rms volt-amperes), power factor is a measure of how effectively an electric load converts power into useful work. Power factor (PF) is calculated using the equation PF = (active power) / [(rms voltage) x (rms current)]. Phase displacement and current distortion both reduce power factor. A power factor of 0.9 or greater indicates a high power factor ballast.
Restrike time	The time required for a lamp to restrike, or start, and to return to 90% of its initial light output after the lamp is extinguished. Normally, HID lamps need to cool before they can be restarted.

Root-mean-square (rms)	The effective average value of a periodic quantity such as an alternating current or voltage wave, calculated by averaging the squared values of the amplitude over one period and taking the square root of that average.
Starting voltage	The voltage applied across the lamp during starting.
Supply voltage	The voltage, usually direct, applied by an external source to the circuit of an electrode.
Ultraviolet	Any radiant energy within the wavelength range 100 to 400 nanometers is considered ultraviolet radiation (1 nanometer = 1 billionth of a meter, or 1 X 10^{-9} m).
Voltage drop	The difference between the voltages at the transmitting and receiving ends of a feeder, main, or service.
Voltage regulation	The change in output voltage that occurs when the load (at a specified power factor) is reduced from rated value to zero, with the primary impressed terminal voltage maintained constant.
Warm-up time	The time it takes for a lamp to produce 90% of its initial light output when it is started, unless otherwise indicated.

Legal

Lighting Answers is a serial publication that complements the National Lighting Product Information Program's (NLPIP's) other serial, *Specifier Reports*. Each issue of *Lighting Answers* presents information in one of three formats: educational information about a specific topic of concern to lighting professionals, a summary of available information about a particular technology in an educational format with no testing, and information about a new or special technology on which NLPIP has performed some limited testing.