Investigation of a light fixture fire

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FEATURE

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Metal-halide lamps produce light by discharging an electric arc through a gaseous mixture of vaporized mercury and metal halides. Metal-halide lamps for use in spaces with lower mounting heights can produce excessive visual glare in the normal, higher field-of-view unless they are equipped with prismatic lenses. Should the bulb fail, high internal operating pressure of the arc tube can launch fragments of arc tube at high velocity in all directions, striking the outer bulb of the lamp with enough force to cause the outer bulb to break. This article reports an investigation of a light fixture fire and reviews a case study of a metal-halide lamp fire. Causal analysis of the metal-halide lamp fire uncovered contributing factors that created the environment in which the incident occurred. Latent organizational conditions that created error-likely situations or weakened defenses were identified and controlled. Effective improvements that reduce the probability or consequence of similar metal-halide lamp fire incidents were implemented.

By James D. Jurney, Michael E. Cournoyer, Stanley Trujillo, Stephen B. Schreiber

INTRODUCTION

Metal-halide lamps produce light by discharging an electric arc through a gaseous mixture of vaporized mercury and metal halides.[1,2] They are a type of high-intensity gas discharge lamp. Once the arc tube reaches its running temperature, the metal dissociates from the halide. As a result, metal-halide lamps have high luminous efficacy of about 75–100 lumens per watt, which is about twice that of mercury vapor lights and three to five times that of incandescent lights. Metal-halide lamps, which produce an intense white light, are used for wide area overhead lighting of commercial and industrial buildings, including buildings where chemicals are stored.

Metal-halide lamps for use in spaces with lower mounting heights can produce excessive visual glare in the normal field of view. For these lower mounting heights, metal-halide lamps come equipped with prismatic lenses, which reduces the brightness of the light produced. Using the wrong type of lens increases the risk that the metal-halide; lamps will not adequately contain a lamp rupture if a lamp rupture should occur.

Chemical attack, thermal stress, and mechanical vibration cause metal-halide lamps to deteriorate in strength over their lifetime.[3] Chemical reaction of the arc tube wall material with the metal halides may, over time, weaken areas of the arc tube to the extent that it may fail because of a crack or excessive thinning. As the lamp ages, the arc tube becomes discolored, absorbing light and getting hotter. The tube will continue to become weaker until it eventually fails, causing the breakup of the tube. Most metal halide lamps reach end of life in a benign manner. Since metal-halide lamps contain gases at significantly high pressures (up to 50 psi), a non-passive failure of the arc tube is a violent event. Fragments of arc tube are launched at high velocity in all directions, striking the outer bulb of the lamp with enough force to cause the outer bulb to break.

Special care must be taken when storing flammable, combustible, or oxidizing materials under metal-halide lamps. If the fixture has no secondary containment, e.g., a lens, then the extremely hot pieces of debris will fall down onto people and property below the light, likely resulting in serious injury, damage, and possibly causing a building fire. See Figure 1.

As previously reported in this Journal,[4] a causal analysis of drum handling incidents uncovered contributing factors that created the environment in which the incident reported herein existed. Latent organizational conditions that create error-likely situations or weaken defenses were identified and controlled. Effective improvements that reduce the probability or consequence of similar drum handling incidents were implemented. The following Case Study of a Metal-Halide Lamp Fire is reviewed in a similar manner. Similar conclusions have been reached.

CASE STUDY OF A METAL-HALIDE LAMP FIRE

The methodology described in a previous case study on a drum handling incident was again followed. First, the incident was described.[4] A "Fact

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Figure 1. Serious property damage after a metal-halide bulb non-passive failure.

Finding” meeting was conducted to establish a timeline. Causal factors were determined. Conclusions were drawn. Corrective actions were developed. Finally, the Lessons Learned were communicated.

The Incident

On the morning of October 16, 2015 at 11:22 a.m., the Los Alamos Fire Department (LAFD) went to the north side of Technical Area 46, Building 25 in response to a fire alarm.[5] The LAFD found a broken mercury halide 400 W lamp bulb. See Figure 2.

The Critique

A Fact Finding was held to discuss activities leading up to this incident. The incident timeline shown in Figure 3 was developed.

- The metal-halide lamp is designed around a sealed tube with an electrode in each end. This assembly of a quartz or ceramic tube and electrodes is commonly called the arc tube. The arc tube is mounted to a metal frame, sealed within a glass outer bulb, and fitted with a base to form a lamp. See Figure 4.
- The arc tube temperature range is between 1000 °C and 1300 °C during normal operations.
- This type of metal-halide lamp (ANSI M59/S)[6] is position dedicated, i.e., they are specifically designed to be run in particular operating positions. This type of metal-halide lamp is suitable only if operated vertically ±15°, and provided the installation is not near people or flammable or combustible material.
- The lamp rated life is 20,000 hr.
- The lamp position was horizontal as shown in Figure 5.
- The fixture had a horizontal lamp holder, compatible magnetic ballast, i.e., 400 W, and an acrylic lens. The acrylic material has a flash point >250 °C and an auto-ignition temperature >400 °C.

Causal Factors. A cause-and-effect diagram was used to systematically review the causal factors that contributed to the incident. See Figure 6. LTA is an acronym for less than adequate. MOV is an acronym for management observations and verification. MOVs were previously discussed as management walk-arounds in this Journal.[7]

Managers performed MOVs to implement a systematic and formal process for observing work and interacting with workers in the field. For this case study, ten causal codes were identified. See Table 1.

Recommended corrective actions from the DOE causal analysis tree are highlighted in Table 1.[8] Engineering, equipment, human performance, and management errors have been compiled. The following factors contributed to the incident:

- The wrong bulb was installed.
- The lens material was acrylic.
- Inspection of the task (installing the bulb) was LTA.
- Preventive maintenance of the metal-halide lamp was LTA.

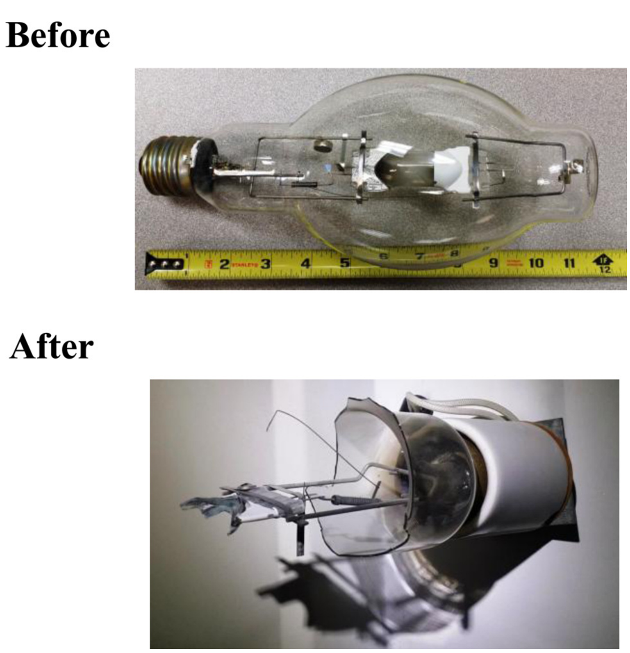

Figure 2. Metal-halide bulb non-passive failure.

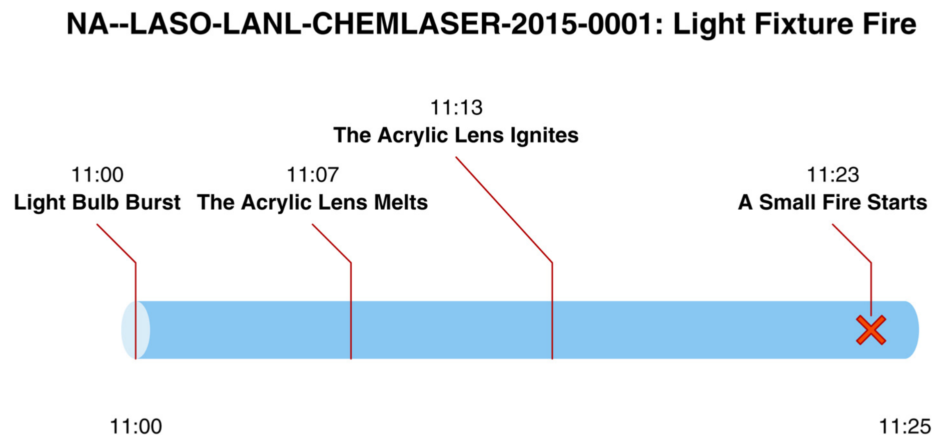

Figure 3. Metal-halide lamp fire timeline.

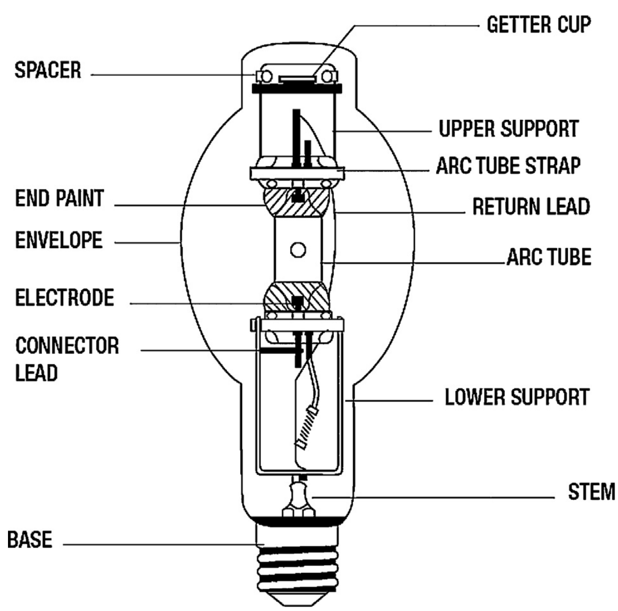

Figure 4. Metal halide lamp.

- Monitoring of the metal-halide lamp installation was LTA.
- Implementation of Lessons Learned was LTA.

The programmatic group researched metal-halide lamp options. One of the options was to replace all metal-halide lamps with light-emitting diode (LED) lamps.[9] LED lamps have a lifespan and electrical efficiency that is comparable to metal-halide lamps. LED lamps contain no mercury. No ballast bypass or rewiring is required. LED lamps operate at <93 °C, are thermally regulated and may be positioned at any angle. In addition, the operating life is two and half times longer than that of metal-halide lamps: 50,000 hr life vs 20,000 hr life.[10]

Conclusions

An apparent cause has been concluded from this causal analysis: a wrong metal-halide lamp bulb caused a small fire. The acrylic lens material exacerbated the incident. The engineer should have required lenses that are compatible with metal-halide lamps instead of acrylic lens. The worker should have known that he or she was installing the wrong bulb. The worker's supervisors should have checked the worker's task and discovered that the wrong bulb was installed. The worker's manager should have monitored the worker's task and discovered that the wrong bulb was installed and known that acrylic lens material could not contain hot lamp fragments up to 1100 °C for quartz. Implementing Lessons Learned from two previous incidences could have prevented the small fire.[11,12]

Corrective Actions

Based on the conclusions presented above, the following corrective actions are recommended:

- Position all metal-halide lamps in one direction.
- Store only one type of metal-halide lamp bulbs that are designed for the assigned position.
- Replace acrylic lens with lenses that are compatible with metal-halide lamps.
- Iterate the importance of management monitoring programs.
- Iterate the importance of the Lessons Learned Program.

Lessons Learned

Because the results of the incident were significant and relevant to other processes, activities, and organizations, improvements were shared through the Lessons Learned Program. The salient lessons learned were the following:

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Figure 5. Metal-halide lamp position.

- Administrative preventive actions needed include training workers what equipment is to be installed, having supervisors check workers' tasks, having managers monitor workers' tasks.
- Engineered preventive actions needed include selecting appropriate equipment types that could be substituted or materials for presently-used equipment with attention paid to how the equipment is to be positioned and used, stocking only type of the equipment to be used, providing for uniform positioning of equipment each place it is installed, or selecting equipment less likely to cause the problem.

DISCUSSION

As shown in the case study, causal analysis provides additional insights in determining the causes of metal-halide lamp fire incidents. The use of cause and effect diagrams in the analysis of glove breaches and failures and air-purifying respirator and drum handling incidents, have been previously reported in this Journal.[4] Installation of the wrong bulb was the active error that triggered the immediate, undesired consequences: a small fire, as shown in Figure 1. In this case study, engineering, equipment, human performance, and management issues were uncovered.

Position dedicated metal-halide lamps exhibit improved performance over standard, universal operating metal-halide lamps of similar wattage. The metal-halide lamp that failed was in the horizontal position, as shown in Figure 4. Enclosed metal-halide bulbs rely on the fixture lens or diffuser as another layer of protection. Because people and combustible material are near, metal-halide lamps require suitable lenses, i.e., those made from material able to contain hot lamp fragments up to 1300 °C for quartz. The acrylic lens was unsuitable.

The cause-and-effect diagram identified two apparent root causes: the lens material was acrylic and the wrong type of bulb was installed, as shown in Figure 5. The ten causal codes identified organizational weaknesses in skill-based tasks and management methods, as shown in Table 1. Peer checking would reduce the skill-based errors.[13] Peer checking is a series of actions by two individuals working together at the same time and place, before and during a specific action. Peer checking augments self-checking by the performer–it does not replace it. The purpose of peer checking is to prevent an error by the performer. Peer checking focuses on performing the correct act. Peer checking is the least rigorous of the checking and verification tools.

Providing only one type of bulb would also reduce the skill-based errors. Inspecting metal-halide lamps as part of a management monitoring program and strengthening the Lessons Learned Program would improve management methods.

The previous paper in this series published in this Journal discussed the value of a Lessons Learned Program.[4] As the causal node, A4B1C06, in Table 1 demonstrates, the Lessons Learned Program used was not effective. Two incidents of metal-halide lamp fires were documented in the last four years.[11,12] Any of several corrective actions would have prevented this metal-halide lamp fire. The following steps to ensure implementation of Lessons Learned are recommended:

1. Assign a metal-halide lamp subject matter expert (SME).
2. Have the metal-halide lamp SME make an inventory of metal-halide lamps.
3. Have managers perform an inspection of metal-halide lamps in their areas of responsibility.
4. Have the metal-halide lamp SME revise the metal-halide lamp procedure such that the following corrective actions are incorporated:
   - Position all metal-halide lamps in one direction.
   - Store only one type of metal-halide lamp bulbs.
   - Replace acrylic lenses with lenses that are compatible with metal-halide lamps.
5. Have the metal-halide lamp SME supervisor review the metal-halide lamp procedure to ensure that the corrective actions have been incorporated in the procedure.

In summary, a wrong type of metal-halide lamp bulb exploded causing a small fire. Latent organizational conditions created error-likely situations and weakened defenses. Corrective actions included standardizing the type of metal-halide lamp bulbs, replacing acrylic lenses with lenses that are compatible with metal-halide lamps, and adding the inspection of metal-halide lamps to management monitoring programs. A significant improvement to the task consists of replacement of metal-halide lamps with LED lamps. This improvement was shared through a Lessons Learned Program.

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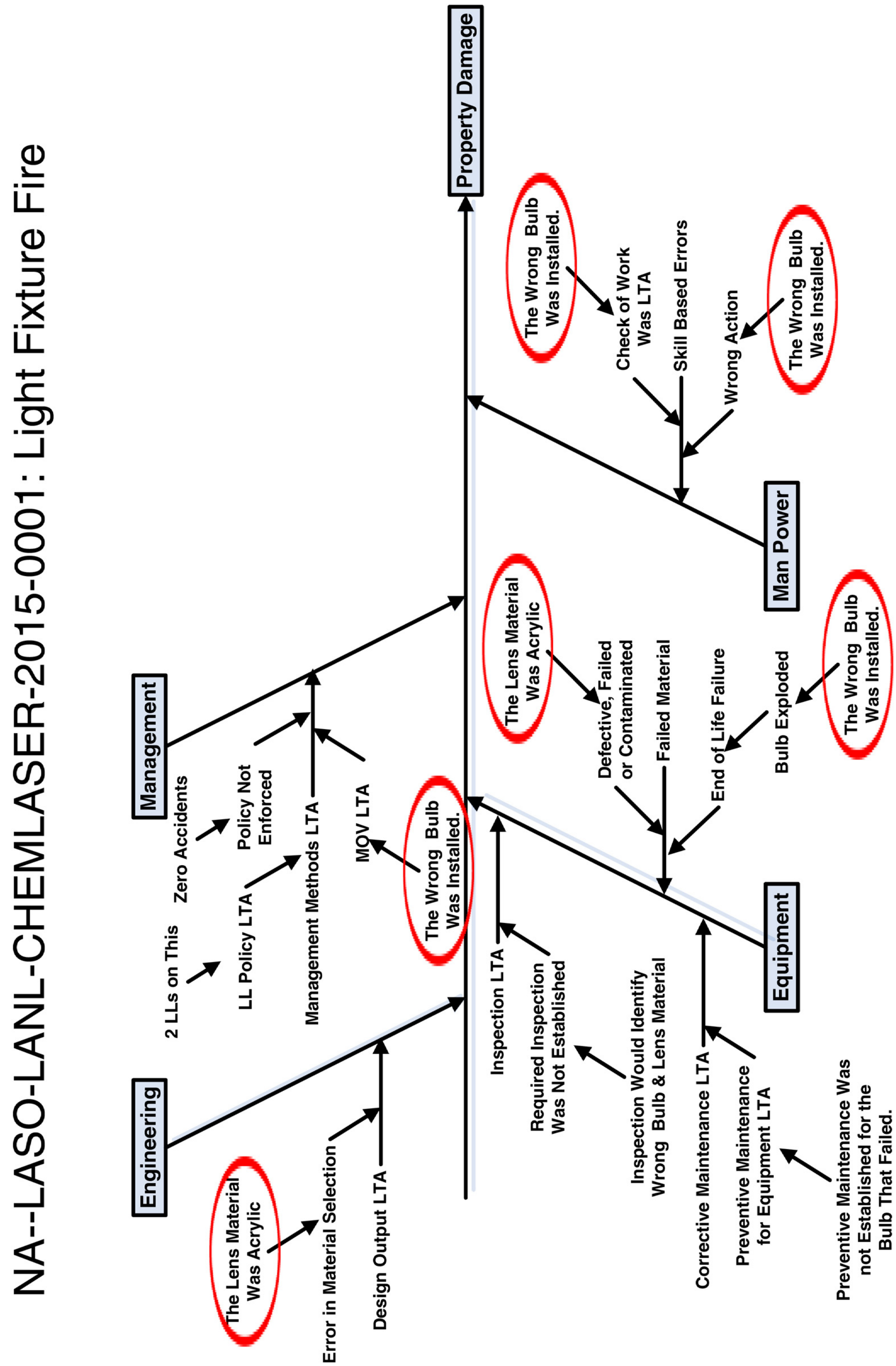

Figure 6. Light fixture fire cause and effect diagram.

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Table 1. Casual Analysis Tree Causal Codes.

Casual Factor	Casual Factor Definition	Explanation	Context	Potential Corrective Action
A1B2C07	Error in equipment or material selection	The wrong metal-halide bulb was installed. The lens was made of the wrong material: acrylic.	A bulb labeled ANSI M59/S was installed instead of one labeled ANSI M59/E. The enclosed lens material must be able to contain hot lamp fragments up to 1100 °C for quartz.	Replace part with a bulb or lens per applicable specifications.
A2B2C01	Preventive maintenance for equipment less than adequate (LTA)	Preventive maintenance was not established for the equipment or component that failed.	A good preventive maintenance program would have replaced the metal-halide lamp bulb before it failed.	Adjust preventive maintenance frequencies to correspond to manufacturer's recommendations.
A2B3C02	Inspection and testing LTA	Required inspection was not established or performed for the metal-halide bulb involved in the incident.	A good inspection program would have determined that the wrong metal-halide bulb was installed and that the acrylic lens material could not contain hot lamp fragments up to 1100 °C for quartz.	Establish an inspection program for metal-halide bulbs.
A2B6C02	Defective or failed material	The acrylic lens was used as the enclosed luminaire material.	The acrylic lens material could not contain hot lamp fragments up to 1100 °C for quartz.	Replace acrylic lens with material that can contain hot lamp fragments up to 1100 °C for quartz.
A2B6C04	End of life failure	Metal-halide bulb experienced a non-passive end of life failure.	The failure was a result of the normal aging process for this metal-halide bulb.	Replace metal-halide bulb.
A3B1C01	Check of work was LTA	An individual made an error that would have been detectable and correctable if a check of the completed work had been performed.	The wrong metal-halide bulb was installed.	Simplify and standardize manual checks (skill of the craft). Increase supervision or include additional personnel to peer check critical steps of a task.
A3B1C01	Check of work was LTA	An individual made an error that would have been detectable and correctable if a check of the completed work had been performed.	The wrong metal-halide bulb was installed.	Simplify and standardize manual checks (skill of the craft). Increase supervision or include additional personnel to peer check critical steps of a task.
A3B1C06	Wrong action selected based on similarity with other actions	Metal-halide bulb designed to be installed vertically was installed horizontally.	A bulb labeled ANSI M59/S was installed instead of one labeled ANSI M59/E.	Allow worker to have access to only to the ANSI M59/E bulbs.
A4B1C01	Management policy guidance and expectations not well-defined, understood, or enforced	Policy was not enforced.	Zero accidents policy requires that metal-halide bulbs be installed correctly, maintained, and inspected.	Modify safety and security policies to balance concerns and still meet operational mission.
A4B1C04	Management follow-up or monitoring of activities did not identify problems	Management routinely checks electrical safety issues.	The translucent acrylic lens made checking for the proper bulb difficult.	Incorporate inspection of metal-halide bulb for proper type in next electrical safety issue monitoring.
A4B1C06	Previous industry or in-house experience was not effectively used to prevent recurrence	Similar incidents occurred at Savannah River Site and Fermi National Accelerator Laboratory.	Previous Lessons Learned on metal-halide lamp fires have not been adequately implemented.	Re-review the information provided particularly actions taken at other sites, determine if actions taken were effective, and implement appropriate corrective actions.

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CONCLUSIONS

Causal analyses of metal-halide lamp fire incidents uncovered contributing factors that created the environment in which the incident occurred. Latent organizational conditions that create error-likely situations and weaken defenses have been identified and controlled. Incorporating corrective actions selected from the DOE causal analysis tree provide corrective based on decades of incidences. Effective improvements that reduce the probability or consequence of similar metal-halide lamp fire incidents have been implemented.

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