International Association of Marine Aids to Navigation and Lighthouse Authorities

AISM Association of Internationale de Signalisation Maritime IALA

IALA Guideline No. 1043

On

Light Sources used in Visual Aids to Navigation

Edition 1.1

May 2008

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Document Revisions

Revisions to the IALA Document are to be noted in the table prior to the issue of a revised document.

Date	Page / Section Revised	Requirement for Revision
December 2004		Initial issue
May 2008	Entire document	Reviewed and updated at IALA Floating Aids 2008 workshop (April 08) and EEP11.

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1. Introduction

Through the work of the IALA Committees and various workshops, IALA has been providing timely and accurate information to members on developing light sources. These documents have been integrated into a single Guideline on existing and developing light sources that should be more beneficial to members.

2. Scope

This Guideline is intended to provide information to members on existing and developing light sources used in maritime aids to navigation (AtoN) systems. It provides information on associated operational considerations, such as lamp life, reliability, operating costs and power consumption.

It also gives examples of typical applications. It covers the light sources themselves and not the associated optical parts of an AtoN system.

3. Light Sources

3.1 Brief History

Until the first application of electricity to lighting in the early twentieth century, all artificial light was produced by fire. Illuminants progressed from pyres of wood (used up until the 1700's), to oil wick lamps, vaporised oil and gas burners, electric arc and tungsten filament lamps. Optical devices matched these developments, first with reflector systems and later with lenses.

It is interesting to note that the efforts to understand human perception of light and to improve the efficiency and effectiveness of AtoN illuminants and optical apparatus were for many years at the forefront of scientific endeavours.

The lens design pioneered by Fresnel, around 1820 remains, a principal element of the modern AtoN light. However, modern lenses are often made of plastic rather than glass.

While a number of countries still have gas lights, that burn acetylene or propane, the majority of AtoN lights use electric lamps of various types. Increasingly, these lamps are powered from renewable energy sources such as solar, wind and wave (see IALA Guideline on Power Sources for Aids to Navigation - December 2004 (1042)).

Optical equipment for lighthouses and beacons are generally proprietary products although, from time to time, lighthouse authorities have developed their own equipment.

Some electric lamps have been specifically designed for AtoN applications, particularly for smaller beacons that are used in large numbers. However, lamps selected from the enormous range of commercial products have also been used or adapted for AtoN equipment.

Light emitting diode (LED) technology is developing rapidly as an alternative light source, either singly or in arrays.

Some common types of incandescent light sources are shown in Fig 2.

3.2 Categories of Light Sources

Figure 1 shows the categories of the various light sources that are commonly used in AtoN. The light sources that are described in this Guideline are identified by a reference to the sub-sections in which the information is contained.

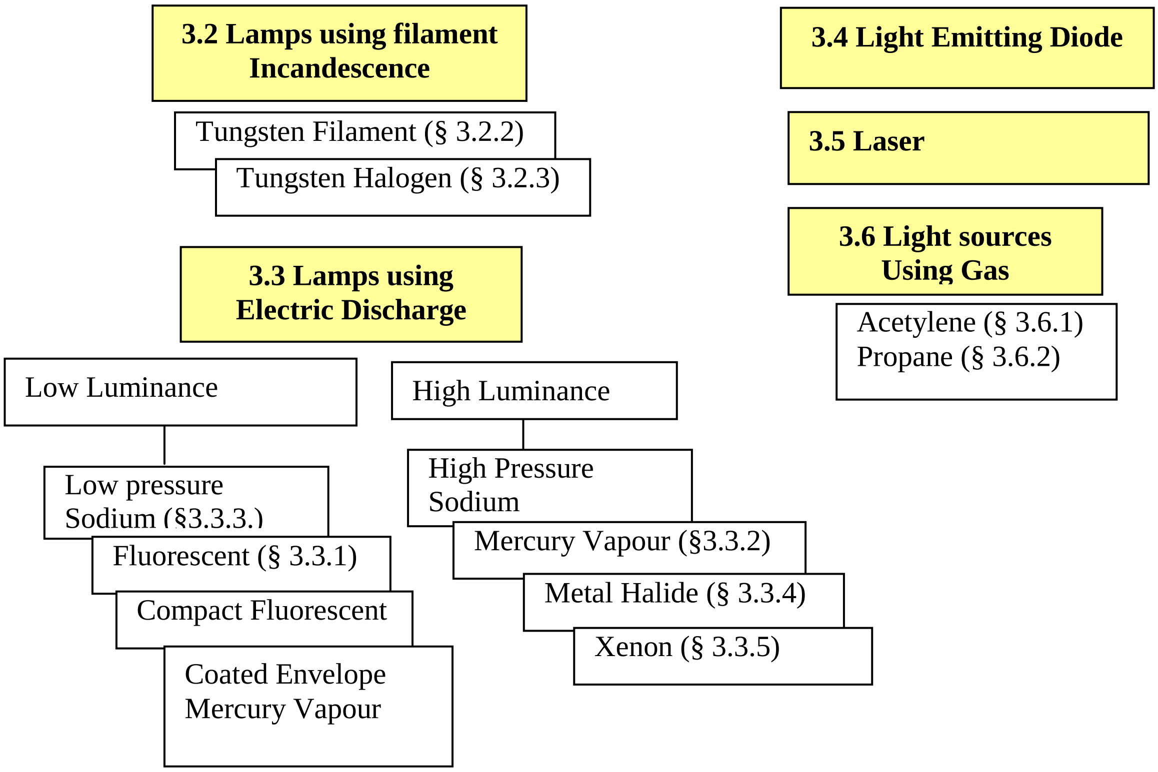

Figure 1 Categories of light sources

3.2.1 Incandescent Lamps

Incandescent lamps are thermal radiators and generate light by heating a solid body to a high temperature - the higher the temperature, the "brighter" the light. In electric incandescent lamps, this solid body (usually a filament) must also be an electrical conductor.

The incandescent material must fulfil two requirements in order to be useful as a light source:

- High melting point.
- Low rate of vaporization.

Early electric lamps used carbon for the incandescent filament. At temperatures above 2,500°C the carbon vaporizes relatively quickly and results in a short lamp life.

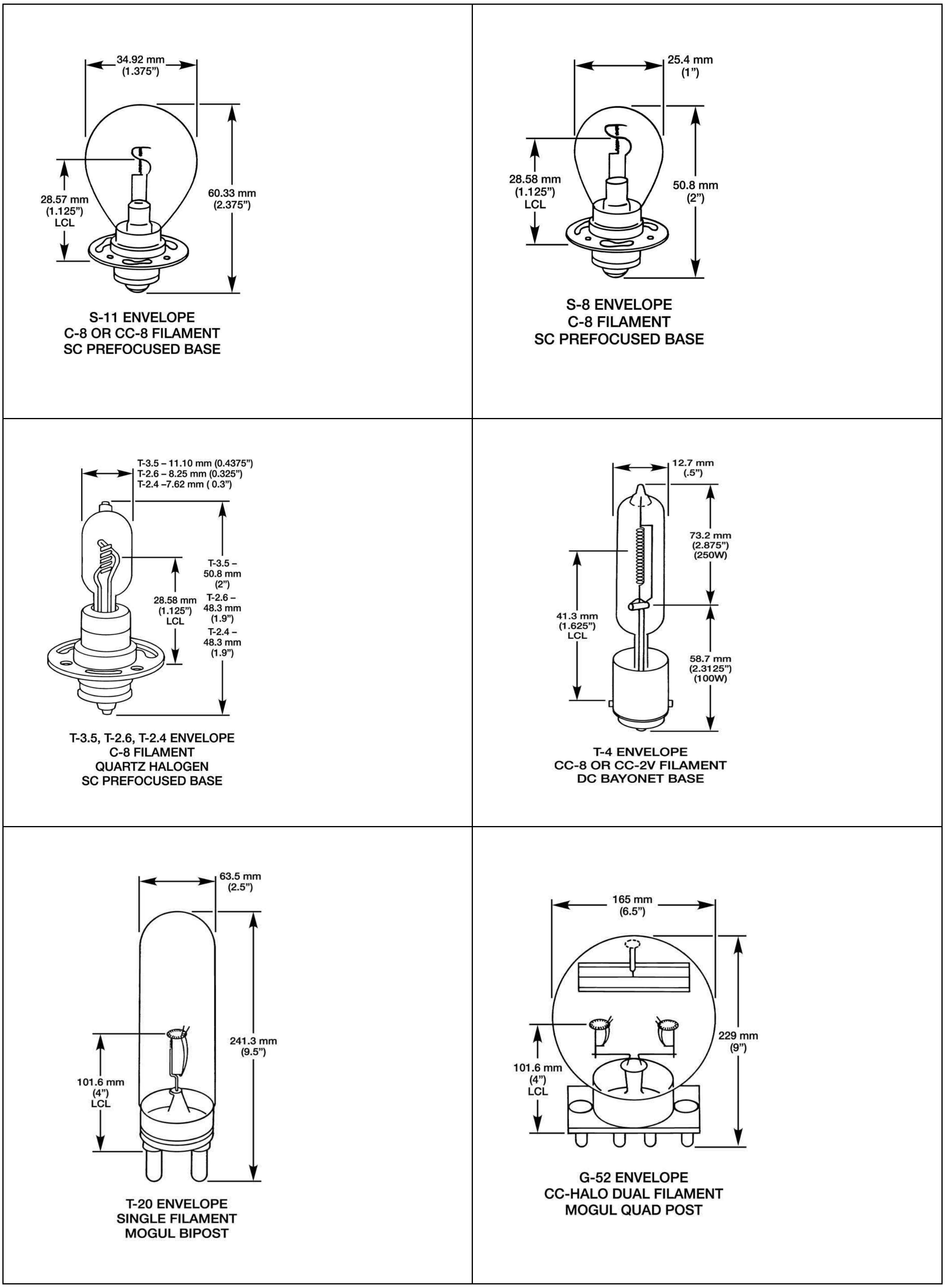

Figure 2 A selection of lamps manufactured for AtoN applications

(Courtesy of Tideland Signal Corporation, USA)

3.2.2 Tungsten Filament Lamps

Although tungsten is not quite as good a thermal radiator as carbon, it is a more suitable incandescent filament material due to its low rate of vaporization at elevated temperatures approaching its melting point[1].

Historically, the manufacture of tungsten filaments presented a number of problems due to the brittleness of pure tungsten and the difficulty of forming fine wires. In modern lamps, tungsten alloys are used that enable the properties to be controlled within wide limits.

The emissivity or radiation from a hot tungsten source has a spectral distribution over the ultraviolet, visible and infrared (heat). At the highest practicable temperatures, the radiation distribution peaks at about 850 nanometres. In this case the energy balance is typically:

- Visible light 5%.
- Heat losses 12%.
- Radiated infrared 83%.

Over the operating life of the lamp, vaporized filament material is deposited on the inner wall of the glass bulb and blackens it in the process. The blackening reduces the amount of light emitted from the lamp. Increasing the envelope size is a means of distributing the tungsten deposits more widely. An example of this can be seen with the 3.0 amp, CC8 filament, P30s lamp that is available in an S8 or S11 envelope. The S8 has a higher initial lumens output than the S11, but degrades more quickly through blackening[2].

Lamps that have been specifically developed for AtoN beacons generally consist of:

- A coiled or coiled-coiled tungsten filament.
- A precision glass envelope that is either
  - filled with an inert gas such as nitrogen or argon,
  - evacuated (less common).

With a prefocus cap base, such as the:

- P30s (as used in four or six position lamp changers)
- BA22d-3 (twin filament lamps)
- 3 pin Bayonet (twin filament lamps).

Advantages

- Low investment cost.
- Reliable.
- Availability on small size lamps.
- Proven technology.
- Small size dual filament available.
- Can be switched on and off to provide character with appropriate power supply design and character ratio.
- Can be used with coloured filters
- Universal lamp operating position
- Choice of filament geometry to suit optic
- Relatively simple to operate (compared with metal halide and LED lights).

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[1] Tungsten has a melting point of 3656°Kelvin (≡ 3383°C).

[2] The location of the filament high up in the envelope compounds the rate of deterioration in light output because it is closer to the area that blackens first.

Disadvantages

- High operational costs.
- Relatively short lifetime.
- Relatively low colour temperature (with some possibly not in the IALA white preferred region).
- Aging during storage.
- Sensitive to shocks and vibration.
- Intensity drops due to blackening during the lifetime.
- Availability of special high power lamps is limited.
- Care must be taken when selecting commercial lamps to ensure filament geometry, lamp life, etc., are appropriate for the required application.

Operational, Environmental and Financial Issues

- Voltage: From 6 to 240 volts.
- Current: From 0.125 to 15 amps.
- Colour temperature range from 2,200 to 3,000 °K.
- Efficiency up to 16 Lumens/Watt.
- Lamp life ranges from 50 to 1,500 hours.
- Envelope material is fragile.
- Envelope temperature - risk of burning.
- Problems with flashing for larger lamps above 100W (longer time to full incandescence).
- For larger lamps, maintain a "simmering" current of about 10-20% of the rated current on the lamp during the eclipse times.
- Filament position tolerances should be considered when re-lamping.
- Supply voltage control, must be sufficiently precise to ensure long life.
- Filament geometry may affect the beam profile.
- Protection required against direct contact with water.
- Envelope and filament design and tolerance may affect distribution of light output.
- General precautions in handling glass apply.
- Requires mechanical lamp changer for redundancy and extended service interval.
- Transmittance when used with acrylic coloured filters:
  - red Plexiglas 501 24%
  - green Plexiglas 1677 34%
  - green Plexiglas 701 20%
  - yellow Oroglas 2246 69%
  - yellow Plexiglas 1989 65%

Application Area

Applicable to all AtoN (from buoys to large optics) but use is diminishing due to high operation cost.

3.2.3 Tungsten Halogen Lamps

Tungsten halogen lamps feature a tungsten coil filament mounted in a quartz glass envelope that has been filled with an inert gas (usually krypton or xenon) mixed with traces of a halogen element (usually bromine or iodine).

When the lamp is operating under normal conditions, convection currents are set up between the hot filament and the cooler walls of the lamp. The circulating gas mixture drives the "**halogen cycle**" in which tungsten molecules, vaporized from the incandescent filament, combine with oxygen and halogen atoms in the cooler region near the envelope wall (around

700°C) to form tungsten oxyhalide molecules. These molecules remain in a vapour phase at the lower temperatures around the envelope wall, which prevents the tungsten condensing onto the envelope. The tungsten oxyhalide vapour is then carried on convection currents back towards the filament. In the hotter region around the filament (3000°C), the tungsten oxyhalide separates, by dissociation, allowing the tungsten to be deposited back onto the filament or to continue as tungsten vapour on the convection currents towards the envelope. The result of this cycle is that the glass envelope stays relatively clean.

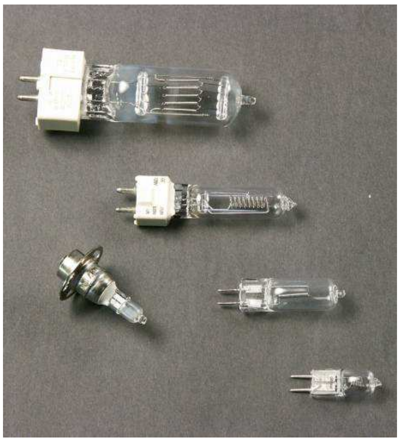

Figure 3 Selection of tungsten halogen lamps

In order for the halogen cycle to function correctly, the temperatures at the envelope wall need to be controlled within certain limits. This is done by making the envelope the correct size and shape relative to the filament and the resultant envelope is usually much smaller than those of non-halogen tungsten filament lamps. With a small envelope, a more expensive glass can be used such as quartz glass, and the combination of quartz glass and a smaller envelope allows a higher gas pressures and the efficient use of more expensive gas mixtures (such as krypton or xenon). The higher gas pressure (up to 20 bar) helps suppress the rate of vaporization of the incandescent filament. The reduced rate of vaporization of the incandescent filament can be used to either increase the lamp life, or increase the filament temperature.

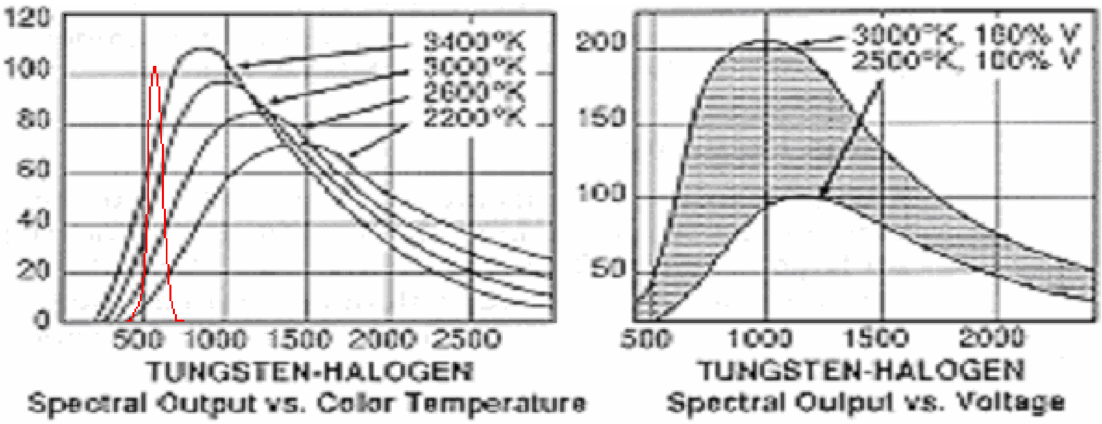

Figure 4: The visible spectrum (red) lies between 380 and 780 nanometres. The figures show how the luminous efficacy decreases as the lamp voltage / colour temperature is lowered.

During operation, the surface temperature of a tungsten halogen lamp envelope can be 600°C or more, however, lampholder temperatures are generally limited to around 250°C to prevent oxidation of the conductors and premature lamp failure.

Operating tungsten halogen lamps significantly below their rated voltage can lower temperatures to an extent that may inhibit the halogen cycle and lead to blackening of the envelope and a shorter life. Interruption of the halogen cycle can also occur when the lamp is flashed for short durations at low duty cycles.

Users should be informed on occupational safety issues relating to tungsten halogen lamps.

The issues include:

- The high operating temperatures and the need to wait a sufficient time for lamps to cool down once extinguished.
- The risk of eye damage due to glare and UV emissions:
  - The high average luminance values of (up to 3,000 cd/cm^2 at the filament) can cause glare problems and the lamp housing should not be viewed with the naked eye.
  - Depending on the applied voltage and colour temperature, a tungsten halogen lamps with quartz glass envelopes will emit about 0.2 % to 0.3% of the electrical power in the form of UV radiation (i.e. below 380 nanometres). The UV radiation is higher than for standard filament lamps, but still very low compared to other lamps. UV-free lamps are now widely available, whereby special absorbing elements are introduced into the glass envelope; these are recommended for use where possible.
  - If possible, a tungsten halogen lamp should only be held by the base. Any fingerprint residues left on the quartz glass will burn when the lamp is operated and cause the glass to devitrify. This can make it opaque, reduce the strength of the glass and increase the risk of the envelope rupturing.

Advantages

- High luminance allows the design of lights with a very narrow angular distribution, as often required for direction lights.
- Relatively low investment cost.
- Reliable.
- Availability on small size lamps.
- The lamp envelope can be made smaller.
- There is less degradation of the light output over the life of the lamp.
- Higher colour temperature than tungsten filament lamp ("whiter" light ~3,000°K)
- Universal lamp operating position for most low-power lamps (some lamps with high power consumption have limited operating positions)
- Longer operational life than a tungsten filament lamp.
- Longer shelf life than a tungsten filament lamp.
- Higher efficiency than a tungsten filament lamp.
- Robust compared with a tungsten filament lamp.
- Can be switched on and off to provide character with appropriate power supply design and character ratio.
- Physically and electrically compatible with existing tungsten filament lamp equipment.
- Relatively simple to operate (compared with metal halide and LED lights).

Disadvantages

- Lamp must operate above the temperature necessary to sustain the halogen cycle.
- High in-rush current.
- On higher wattage lamps, avoid having the lamp experience continuous cold starts. This situation can be overcome by using a current limiting “soft start” or by maintaining a “simmer” current of about 10-20% of the rated current on the lamp during the eclipse times.
- Limited choice of filament geometry.

- Filaments are usually compact which may be too small for some applications, especially with respect to wide vertical divergence.
- More sensitive to power supply variations than tungsten filament lamp (filament burnout).
- Flash length may be restricted due to halogen cycle.
- High temperatures may cause problems with lampholder contacts.
- Envelope and filament design and tolerance may affect distribution of light output.
- Poor manufacturing tolerances may cause selection or adaptation to be required for marine AtoN applications otherwise consistency in performance will be poor.
- Special lamps, e.g. for marine applications, are less easily manufactured.
- Care must be taken when selecting commercial lamps to ensure filament geometry, lamp life, etc., are appropriate for the required application.
- More handling precautions are required than with tungsten filament lamps.
- Training in handling may be required.

Operational, Environmental and Financial Issues

- Voltage: From 6 to 240 volts.
- Current: From 0.5 to 15 amps.
- Colour temperature range from 2,900 to 3,400 °K (IALA preferred region).
- Luminous efficacy of up to 25 lumens per Watt.
- Lamp life of up to 4,000 hours.
- Batteries usually have very low internal resistance and a cold lamp experiences a high in-rush current that places a very heavy load on filament and lead-in wires, welds and connecting foils.
- When a battery is fully charged or is being recharged, the terminal voltage may exceed the rated lamp voltage to an extent that brings the filament of high output lamps close to its melting point and causes premature lamp failures. To ensure the correct lamp operating conditions, the use of voltage regulators is highly recommended.
- Avoid operating the lamp below the temperature necessary to sustain the halogen cycle[3].
- Avoid having the lamp experience continuous cold starts. This situation can be overcome by using a current limiting "soft start" or by maintaining a "simmer" current of about 10-20% of the rated current on the lamp during the eclipse times.
- Halogen cycle operation failure of cycle results in rapid lamp blackening.
- Envelope material.
- Envelope temperature.
- Small, compact filament.
- Problems with flashing for larger lamps above 100W (halogen cycle).
- When used with coloured filters, red transmittance is slightly lower than with a tungsten filament lamp.
- Supply voltage control, must be sufficiently precise to ensure long life.
- Safety in handling, as contamination from fingerprints on the envelope can reduce life.

[3] An Osram publication "Tungsten Halogen Low Voltage Lamps – Photo Optics" indicates that generally there are no problems with 5 to 10% reductions in rated voltage and that some modern tungsten halogen lamps can be dimmed without detriment.

- Compatibility with existing equipment may be a problem because the envelope shape or size and/or the filament shape and size may not match optic (esp. in larger or high VA optics).
- Bi-pin capsule lamps with high current may suffer pin/base contact problems.
- A tungsten halogen lamp is usually more durable than the equivalent tungsten filament lamp due to its rugged filament and compact envelope.
- Safety procedures should be defined to include gloves, goggles and advice on glare. The gloves can also protect the envelope by minimising finger print contamination.
- Some protection around the lamp may be advisable.
- Training in handling is required but this applies to all high performance lamps.
- Care should be taken in disposal due to the high pressure in the envelope.
- General precautions in handling glass apply.
- When UV-free lamps are not used, UV radiation should be considered, especially for high power lamps. The use of UV safety goggles is recommended in this case.
- Usually requires less energy than conventional filament lamps, which is a positive effect on the environment.
- Longer life produces less waste.
- Smaller lamps produce less waste.
- Longer life than conventional filament lamp reduces maintenance visits.
- Higher efficiency reduces power (design) requirements.
- Lamps are usually more expensive than tungsten filament equivalent but this is offset by increased life.
- Cost of training may be slightly higher.
- Requires mechanical lampchanger for redundancy and extended service interval.
- Reduced stock holdings due to longer life.
- Transmittance when used with acrylic coloured filters:
  - red Plexiglas 501 19%
  - green Plexiglas 1677 36%
  - green Plexiglas 701 18%
  - yellow Oroglas 2246 65%
  - yellow Plexiglas 1989 65%

Typical Application

It is applicable in all AtoNs (buoy to large optics). It is still a common solution in long range flashing application.

3.3 Lamps Using Electric Discharge

Discharge lamps differ from filament lamps in that their operation depends not on the incandescence of a hot piece of wire but on electrical discharge through an ionised gas or vapour causing an arc of hot gaseous particles. All discharge lamps require some form of igniter to start the ionisation. Once started, electrical current can be enormous and cause damage to the lamp. To prevent this, a ‘ballast’ is placed in series with the arc tube in order to limit or regulate current.

Low-pressure discharge lamps typically have long arc tubes and low igniter voltages. At low pressures, the spectral content of ionised gas or vapour tends to consist of a few narrow spectral lines (for instance, a mercury vapour lamp has four spectral lines in the visible spectrum). These lamps do not provide good colour rendering, in other words details and colours of surfaces viewed under such light are poorly defined. The spectral output of low-pressure lamps can be used to excite a phosphor coating, deposited on the inside of the lamp envelope, so that an improved spectral distribution of light is emitted. This is the case with fluorescent tubes that can give coloured or white light depending on the type of phosphor coating.

When the pressure inside the arc tube is increased, the spectral content of the ionised gas or vapour becomes more spread. Some high-pressure discharge lamps, with arc tube pressures of up to 50 bar, give a very broadband, white light. Such lamps have very short arcs and very high strike voltages. The handling and operation of such lamps can be risky, with the potential for arc tube explosion. Because of the very high luminance of such lamps, they are often called 'high intensity discharge' (HID) lamps.

When metal halides were introduced into the arc tubes of mercury and sodium vapour lamps, it was found that only moderate pressure was needed in the arc tube to yield a white light. By-products of lower arc tube pressure were improved safety and lower ignition voltage. Metal halide and high-pressure sodium lamps are commonplace in street and floodlighting applications.

With the exception of coated envelope multi-vapour and fluorescent lamps, low-pressure discharge lamps are generally unsuitable for AtoN. One exception is low-pressure sodium lamps that are sometimes used as fixed yellow AtoN lights.

3.3.1 Fluorescent Tube

Fluorescent tube lights are sometimes used to mark breakwaters' jetty heads and to provide leading lines. This is a low cost approach that may be suitable for meeting the needs of recreational and fishing vessels. Typical colours used are red, green, white and blue, although they may not comply with IALA Recommendations for the colours of light signals on AtoN.

Other application areas are sign illumination and direction arrows.

3.3.2 Mercury Vapour, High-pressure Sodium

The spectral distribution from uncoated mercury and high-pressure sodium lamps is not well suited to white AtoN signal light applications. These lamps are not normally used as AtoN light sources.

3.3.3 Low-pressure Sodium

Figure 5: Some low-pressure sodium lamps

A low-pressure sodium lamp has two lines very close together (so that they may be considered as one) in the yellow preferred region. This makes them useful for applications such as markings for inland waterway channels or small waterways (e.g. Kiel Canal). Since service life is about 5 years in practice and their efficacy is about 5-times higher than a yellow LED, they remain a popular choice of light source.

Low-pressure sodium lamps are sometimes used for marking structures (e.g. bridge supports and pier heads) where they are particularly useful during foggy conditions.

3.3.4 Metal Halide

Figure 6 Examples of Metal Halide Lamps

Metal halide lamps consist of an arc tube that contains mercury vapour, various metal halides, and argon. Some have an outer envelope containing the arc tube and other controlling devices. These lamps generally require a ballast circuit to regulate the lamp current, an igniter or ‘striker’ to initiate ionisation during start up and possibly some regulator or autotransformer to accommodate supply voltage fluctuations.

When the lamp is operating, the metal halides are vaporised and disassociated in the inner core of the arc into the halide and the metal, with the latter radiating their appropriate spectrum, thereby adding to the spectral content.

When a lamp is turned on, it takes several minutes to reach normal operating conditions (including vapour pressures). If the supply voltage is interrupted sufficiently for the arc to be extinguished, the lamp will not relight until it cools and arc-tube vapour pressure decreases to a level that allows the arc to re-strike. This may take as long as fifteen minutes. The metal halide lamp cannot be flashed for AtoN applications and is only used in rotating lens and rotating shutter optics. Hot re-strike circuits, that apply a very high voltage to the hot arc tube electrodes, are available but these can cause arcing in single ended lamps and can drastically shorten lamp life.

Advantages

- High efficiency (up to 120 lm/Watt).
- Long operational life (6,000 to 20,000 hours).
- Rugged construction.
- Lower relative operating temperature.
- Choice of white available (3,000 - 6,000°K).
- Choice of colours available (floodlighting effects).

Disadvantages

- Cannot be switched on and off to provide a rhythmic character.
- Some lamps have restricted burning positions.

- Lamp warm up period required.
- Restarting time in the event of power interruption.
- Light output reduces significantly over operating life.
- Colour changes significantly over operating life.
- Complex power supply required.
- Inherent Radio Frequency Interference (RFI) is a potential problem.
- Significant UV output.
- Lamp bases are often not precision/pre-focus (re-focus on replacement).
- Limited choice of arc tube geometry (usually tall and thin).
- Poor transmittance and colour variance with red filters.

Operational, Environmental and Financial Issues

- Wide range of wattages available.
- Attention must be give to the proximity between the ballast, the igniter and the lamp due to the capacitance of the cable.
- Low ambient temperatures may affect ballast operation.
- Monitoring systems are more complex.
- Select a lamp colour temperature to match AtoN requirements, typically white.
- Select a lamp with low UV output due to environmental concerns.
- Due to colour variation and light output reduction over age, scheduled lamp replacement is important.
- Shape of the arc may resemble a teardrop and care must be given to focus to ensure light centre placement gives correct beam direction.
- Wider variety of bases exists.
- High strike voltage hazard.
- Mercury content may create disposal problems.
- Protective clothing such as goggles, gloves, etc., required due to potential arc tube explosion and high operating temperature.
- High efficiency saves energy.
- Lower disposal rate due to longer life.
- Low maintenance cost due to longer life.
- Lamp cost is higher than equivalent tungsten halogen or tungsten filament lamp.
- Initial installation costs higher.
- Training of personnel required.
- When using with coloured filters, care should be taken to ensure spectral content of lamp yields correct colour.
- Transmittance when used with acrylic coloured filters (1kW MBI):
  - red Perspex 4401 — 6%
  - green Plexiglas 1677 — 36%
  - green Plexiglas 701 — 18%

Typical Application

Long range beacons, lighthouses and upgrading of the light source using existing rotating optics (modernization and/or longer range). Also sometimes used for floodlighting.

3.3.5 Xenon Lamp

The xenon arc lamp has a short-arc length, high arc tube pressure and provides a compact light source. They typically reach 80% of their final output immediately after start.

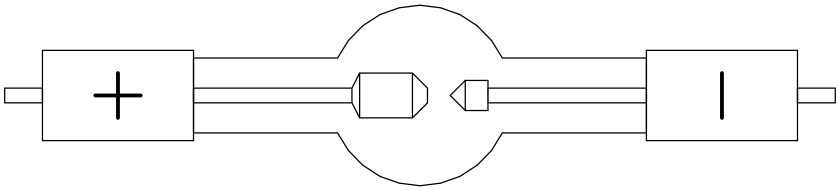

Figure 7 Drawing of a Xenon lamp

The xenon lamp has the highest luminance of all artificial light sources. Therefore, lights with very narrow angular distributions can be realized with them. A typical application is the use of a 2000W xenon lamp in a rotating optic or a precision sector light.

A 150W xenon lamp developed for automotive headlights has been considered for the light source for a rotating reflector array[4] for lighthouse applications. The lamp operates on a voltage between 16 and 20 volts dc, supplied from a 12 volt dc input. It is claimed to have a relatively flat spectral output over the visible wavelength band allowing for excellent colour projection in both red and green as well as providing a 6000 °K "daylight" coloured white light.

A combination of xenon and metal halide technologies has resulted in compact low-wattage lamps (typically 10 - 60W) for use in bicycle and automotive headlights.

Traditional short-arc xenon lamps:

Advantages

- Highest luminance available.
- High energy efficiency.
- Approximately 3000 hours life.

Disadvantages:

- The lamp is hazardous: extremely high UV output, it may explode, it is very hot and ignition needs 40 kV.
- An inability to flash the lamp at a rate suitable for AtoN applications.
- A complex power supply monitor/control circuit.
  - also makes it impractical to use a lamp changing mechanism.
- A service life that is heavily dependent on the number of ignitions experienced.
- Limited availability.
- Expensive.

New developments in automotive headlamps:

Advantages

- High energy efficiency.
- Compact light source.
- Low wattages available (10-60W).
- Low voltage DC control available.
- Relatively long life.
- Automotive spec (rugged).

Disadvantages:

[4] IALA Conference 1994: "New Visual Signals" USCG – reference to Vega Industries XAB 17.

- High initial cost.
- Not suited to flashed rhythmic characters.
- Not efficient when used with red filters.
- A complex power supply monitor/control circuit.

3.4 Light Emitting Diodes

A LED is not an incandescent lamp but a solid-state light source (photo-luminescent semiconductor junction). It emits radiation in a narrow spectral band in the infrared, ultra-violet or visible spectrum when a current is passed through the junction. Spectral distribution is narrow, in the order of 50 nm. To obtain white light, rather than a single colour, two techniques are employed: phosphor- conversion (pcLEDs) that use a blue LED surrounded by a yellow phosphor; multi-chip, typically three LEDs of red, green and blue (RGB). The mixture of blue and yellow or RGB produces a near-white light. The RGB mixture can be varied to produce different colours. This is useful in colour displays but can present problems with colour consistency for a signal light.

There are two main types of LED junction, InGaN and AlInGaP. The InGaN or nitride types operate in the shorter wavelengths from green to ultraviolet. The AlInGaP or phosphide types are confined to the longer wavelengths from yellow to infrared.

When compared with incandescent technology, coloured LEDs are much more efficient than incandescent lights with filters, and white is presently at least twice as efficient as incandescent. However, white LEDs are fast being developed for use in general illumination and recent developments have delivered efficacies of 50lumens per Watt.

Power ratings for LEDs vary from a few milliwatts up to 5W per junction. LEDs can be arranged into groups or arrays depending to improve intensity and light source geometry. When used in groups or arrays wiring arrangements can vary considerably, but are typically series/parallel, with consequences on the number of LEDs that may be lost if a single LED fails.

LEDs require careful thermal management and complex drive circuitry that can vary in efficiency. Within an LED, up to 15% of the energy is emitted as light and the remainder as heat. Unlike conventional light sources, which dissipate heat by radiation, convection and conduction, all heat from the LEDs must be conducted away by the mounting or luminaire.

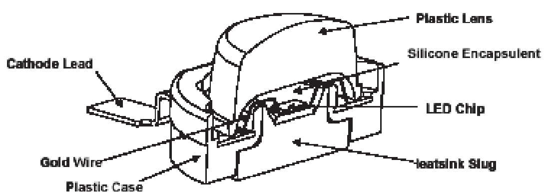

Figure 8 High power LED

Some individual LEDs have an integrated lens that produces a beam. Secondary lenses may be used to modify the beam to the required shape. However, when comparing LED's with tungsten halogen lamps, such as used in searchlights, it can be shown that the low luminance of the LED leads to poor performance, even when the latest developments are considered. The luminance (in candela/sq m) of a tungsten halogen lamp is five to ten times more than a white LED. Consequently, multiple LEDs / large output areas are required in order to provide the same intensity as a tungsten halogen lamp.

LEDs encapsulated in clear epoxy have both lower reliability and shorter life than newer LEDs encapsulated in optical silicone. Epoxy LEDs can lose as much as 50% of their original brightness in as little as 3000 hours, whereas those encapsulated in silicone can maintain 70% of their original brightness at 50000 hours.

Advantages

- Reliability
- Energy efficient coloured light generation.
- Rugged, robust, shock-resistant.
- Long life.
- Instantaneous on-off.
- Possible advantage of improved conspicuity due to the colour (narrow spectral distribution) and square-wave flash profile.
- Does not have a high inrush current.
- No filament supports creating support shadows.
- No complex maintenance requirements.
- LED groups or arrays can substantially reduce the probability of total lamp failure.
- No mechanical moving parts such as lampchangers.

Disadvantages

- Low luminance.
- Not recommended for very high intensity lights with a very narrow angular distribution.
- Light output and colour vary up with junction temperature.
- Heat management of LED devices is essential to limit degradation of performance and maintain life.
- Multi-chip (RGB) LEDs are not recommended for white light sources because their colour consistency varies with operating conditions and age.
- Individual LEDs within an array can vary greatly in their light output and beam distribution, affecting overall beam pattern.
- LED technology is changing and developing rapidly. Long term experience with these devices is therefore limited.
- Degradation of light output over operating time.
- Complex electronic control needed to achieve long life and high performance.
- Difficulty in using LEDs as a replacement for lamps in traditional lenses, especially with coloured sectors.
- Monitoring systems are more complex.

Operational, Environmental and Financial Issues

Operational

- The very long operating life and low power requirement may reduce requirements for maintenance resources and infrastructure.
- Minimal guidelines needed for LED lanterns since they are largely maintenance free.
- Reduces complexity of maintenance and, hence, the technical competence required.
- Photometric test results may contain large errors.
- Luminous efficacy of LEDs is improving steadily, so LED lanterns will continue to improve in efficiency for the foreseeable future.
- LED lights are now widely used.
- Region-specific safety labelling requirements.

Environmental

- LED lanterns present no more environmental issues than other lanterns.
- Self-contained LED lanterns that contain a battery can present disposal problems. It is recommended that they be returned to the manufacturer for recycling.
- Less power consumption leads to less batteries, solar panels, fuel requirements, etc., possibly resulting in smaller buoys and smaller moorings. These factors reduce the environmental impact of the AtoN to which LEDs are fitted.
- Less frequent servicing reduces impact on environment from ships, aircraft, etc.

- LED itself is better than a lamp in terms of toxic materials. The very tiny amount of solid-state electronics involved is encased in epoxy, and there are no discarded lamps during life of lantern.
- LEDs allow the production of small, robust, self-contained lanterns.
- Purchase cost depends on range and features. Low cost lights available for low intensity, up to high intensity where the initial purchase cost can be higher than incandescent lamp lanterns.

Issues that should be considered when purchasing a LED light

- It may be difficult to select optimum LED lanterns for applications as there are fairly complex differences in drive circuitry, LED array arrangements, etc.
- Intensity and colour should be specified over operational temperature range.
- Horizontal consistency of intensity should be specified.
- Required angle of vertical divergence.
- Lifetime expectation depends on correct LED current and junction temperature.
- To optimise the lifetime of a LED AtoN, the electronic equipment and enclosure must be as robust as possible.
- Required working hours of the light.
- Power source requirements, including power consumption when light is on and off.
- The operational effect of the reduction in intensity with time.
- Temperature effect on intensity and colour.
- The effect of variation in voltage on LED intensity.
- Effect of loss of a single LED or group of LEDs.
- LEDs must be current controlled (incandescent lamps are voltage controlled), the intensity can be controlled via PWM if required.
- Detecting LED failure is difficult. There might still a high electric current without any LED producing light. Therefore, the use an integrated photometric sensor to sense the light (optical feedback) is recommended since LED may fail to open circuit, short circuit or partial short, failures are difficult to sense.
- Compliance of LED with the IALA Colours for Signal Lights (1977).
- CE standard for Electromagnetic Interference/Immunity and Electromagnetic Compatibility, or other national standards.
- Additional lightning protection may be required if not included.
- Requirements for mechanical vibration/ shock.

Typical Application

LEDs are being increasingly used in AtoN equipment. These include LED lanterns for buoys, small beacons, range lights and illuminated ‘dayboards’, which may be encapsulated, sealed units. The nominal range for LED omnidirectional beacons can be up to 18 nautical miles, with greater ranges beginning to appear for directional lanterns.

3.5 Laser

A laser is a device that produces a coherent highly collimated beam of monochromatic light. Several types of laser are available on the market but for marine applications green solid-state (e.g. Nd:YAG) laser and red semiconductor (GaAs) lasers must be considered first because of their high power efficiency and their robust nature. A laser should only be considered for applications that require high intensity narrow beams. Electric discharge lasers are also available but tend to be used for high power applications and are therefore not recommended for AtoNs because of eye hazard.

3.5.1.1 Guiding Approach

- A laser aimed directly at mariners requires low power and works in mostly all weather conditions.
- A laser using scattering in the atmosphere, requires high power and works only during night and when there are enough scattering particles in the atmosphere.
- A concentrated, high power narrow light beam with a highly directional light source is possible.
- Approximately 0.1 degree beam angle with a 25mm diameter optic.
- Behaves as a point source (source of the order of micrometers).
- Monochromatic (very narrow wavelength bandwidth).
- Laser power 20-300 mW (Black Board pointer laser uses 1-5 mW).

3.5.1.2 Types

- Lasers are available in different colours.
- Red semi-conductor devices are recommended and have a life of approximately 10,000 hours.
- Green solid state lasers are recommended and have a life of approximately 30,000 hours.
- Gas lasers offer a large variety of colours but are not as efficient or robust. They have a life of at least 2,000 hours.

Advantages

- Good source for high intensity, narrow and accurate beams.
- Long day time ranges are easily achievable.
- Short range systems are easy to install.
- High power efficiency, even long day time ranges only require low power, possibly solar.
- Does not require large optics, 25mm is enough for an angle larger than 0.1 degree.
- Low maintenance system as laser need only be changed approximately every 3 years.
- No colours change with atmospheric propagation.
- Can be pulsed to further increase power efficiency.
- Highest electrical efficiency for high intensity narrow beams.
- Good source for compact system.
- Very accurate sector cut off allows exact marking of hazards.

Disadvantages

- Not fully developed yet for all applications.
- Systems having more than 3 coded sectors are difficult to construct.
- Due to the large coherence length and the small diameter of the beam the light tends to show flicker or speckle that may conflict with flash characters.
- Replacement of laser more expensive than replacement of standard light source.
- Not cost effective for low range wide-angle applications.
- Maximum width of narrow beam restricts the use of laser lights to narrow channels.
- Difficult to have other colours than green and red in circumstances where efficiency and robustness have to be taken into account. All colours are available where these circumstances do not apply.
- At high ambient temperature, of 40^{o} C and above, the system efficiency decreases due to cooling device consumption.
- Tower needs to be very stable.
- Training is required for safety reasons.
- Special provision must be made for **eye safety** at close range.

Operational, Environmental and Financial Issues

Operational

- Require one tower only for laser range light projector.
- Easy to install.
- A gun scope is necessary for alignment.
- A short-range system can be installed by one person.
- Low power consumption.
- A system designed for a range in the order of 3 km and a divergence of 4.3 degrees when operated around 15ºC has a power consumption of 5W. At low temperature (approximately - 20ºC) the power consumption is 18W.
- A system designed for longer ranges (30 km) would have power consumption in the order of 100W.

Environmental

- No need for special disposal, arrangements for disposing of electronic components are suitable.
- Components can be replaced on site.
- The system can easily be designed to be safe for observation with the naked eye and with binoculars at the operational range.
- The system is environmentally friendly due to very low power requirements.

Financial

- Quantity production and anticipated new, cheaper lasers should decrease the price.
- Installation costs are very low.
- The system can use small, cost efficient sources of power supply, solar in many cases.

Example of LASER Light Application

Hay River Artic two colour laser.

A two-colour laser range light (20mW Red and Green lasers) with a 3 km range was designed and installed for the Hay River entrance channel. The laser lights are powered by solar equipment and the output power varies during night and day, with reduced power at night.

The equipment is easy to install and maintain, was aligned during installation with a gun scope and the lasers have a planned service life of 10,000 hours.

The front tower of the existing leading lights has been used to install the laser range and, for safety purposes, the laser system is used in parallel with the existing system until its reliability is proven. The laser system is eye-safe for mariners and the objective of the trial is to evaluate the possibility of replacing the existing system of ranges.

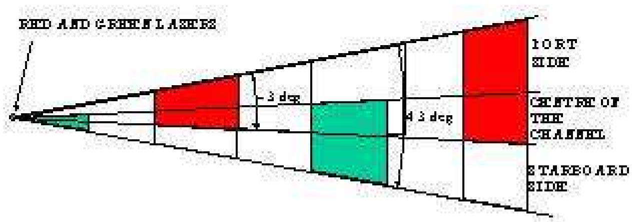

Figure 9: The laser code used in the Hay River project

The laser range was installed in June 2000 and has performed up to expectations. Development of the system cost 60,000 US$ and the cost of replicating the system is estimated as 30,000 US$.

3.6 Gas lamps

3.6.1 Acetylene

The acetylene light has a special place in the history of AtoN, primarily for being the first reliable means of automating lighthouses, buoys and beacons during the earlier part of the 20th century. The predominant acetylene lighting systems carry the AGA[5] brand and these originate from the inventions of Gustaf Dalen[6]. The key inventions included:

- Production methods for generating, purifying and drying large quantities of acetylene.
- The design of a transportable cylinder for storing acetylene gas under pressure[7].
- The development of a reliable open flame burner system (and low gas consumption pilot burner) that could generate a regular flash rate.
- The development of a sun valve[8] to economise on gas consumption[9] by limiting the operating light to night time conditions.

Acetylene lighting technology was further enhanced by the development of the Dalen "mixer" that allowed gas and air to be drawn into a chamber and then consumed in an incandescent mantle to produce a brighter light source than the open flame type. The incandescent mantle could be operated as a flashing source inside a fixed lens or as a continuous source inside a rotating lens. Related developments included a gas-operated mechanism for rotating a lens and a clockwork powered automatic mantle changing device.

3.6.2 Propane and Butane

Propane and butane gas have been used as an alternative fuel to acetylene. The lighting equipment typically uses a mantle burner similar to the Dalen design.

Propane is recommended for regions where temperatures lower than 0°C occur. Butane liquefies at temperatures lower than -0.5°C in the normal atmosphere and the flame is extinguished.

Advantages

- Proven technology.
- Gas equipment is less likely to be vandalized or stolen than other types of light sources.
- Mechanical components have a long life.

Disadvantages

- High Service and maintenance costs.
- Limited suppliers / expensive.
- Low light intensity.
- Safety (explosion hazard)

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5 The Swedish AB Gas accumulator company

6 Gustaf Dalen was awarded the Nobel Prize for Physics in 1912 in recognition of these inventions.

7 Typically, a steel cylinder filled with a porous mass containing a quantity of acetone that absorbs many times its own volume of acetylene in suspension under a modest pressure of around 20 Bar.

8 The principle of the sunvalve uses the differential expansion between two metal bodies, one polished and the other blackened, to close a gas valve when exposed to daylight.

9 The combination of replacing a continuous flame with a flashing character and the sunvalve achieved a gas savings typical around 80%.

Filter Information

- yellow Plexiglas 1989 70% (for gas)

Typical Application

- Buoy light.

4. Summary and Comparison of Light Sources

A summary of the light sources described in the section of the Guidelines and a comparison of their attributes is given in Table 1.

TABLE 1 - LIGHT SOURCE SUMMARY AND COMPARISON

	Usual AtoN use	Cost of light Source (USD)	Lifetime (hours)	Robustness	Maximum Input Power (Watt)	Lumen pr. Watt	Emission Geometry	Colour Spectrum	Flashable	Safety and Other issues
Filament Lamp	All Round	5-20	300-2,000	Low	3,000	up to 16	Spherical	Broadband	YES	Hot envelope Glass may break.
Tungsten Halogen Lamp	All Round	10-20	Up to 3,000	Medium	3,000	Up to 25	Spherical	Broadband	YES	.Very hot envelope Glass may break Fingerprints on envelope may cause failure.
Metal Halide Lamp	Rotating Optics and medium range Range Lights ?	30-100	6000-20,000	Low (vibration)	10,000	Up to 120	Spherical	Strong spectral lines and UV	NO	Hot envelope. Glass may break Arc tube can explode. UV Hazard
Lasers	Range Lights	1,000	10,000	Medium	20	??	Narrow Beam	Monochromatic	YES	May cause damage to the eyes.
Low Power LED	All Round except long range	0,25-1 (Need many 4-600)	>100,000 White <10,000	High	150mW	25 - 50	Medium to wide Beam	Narrow Bandwidth (50nm) but pcLED broadband	YES	May cause damage to the eyes.
High Power LED	All Round except long range	8 – 15	>100,000 White >50000	High	5	25 - 50	Medium to wide Beam	Narrow Bandwidth (50nm) but pcLED broadband	YES	May cause damage to the eyes.
Low Pressure Sodium	Inland waterways & marking structures	10-20	>10,000	Medium	135	150	Spherical	Monochromatic (yellow)	No	Glass may break
Xenon	Sector lights & high range lights	300	Up to 3,000	Medium	35 – 15K	40	Spherical	Broadband	No	Hazardous: UV, explosion risk, very hot envelope, glass hazard.

5. Spectral Distribution of Light Sources

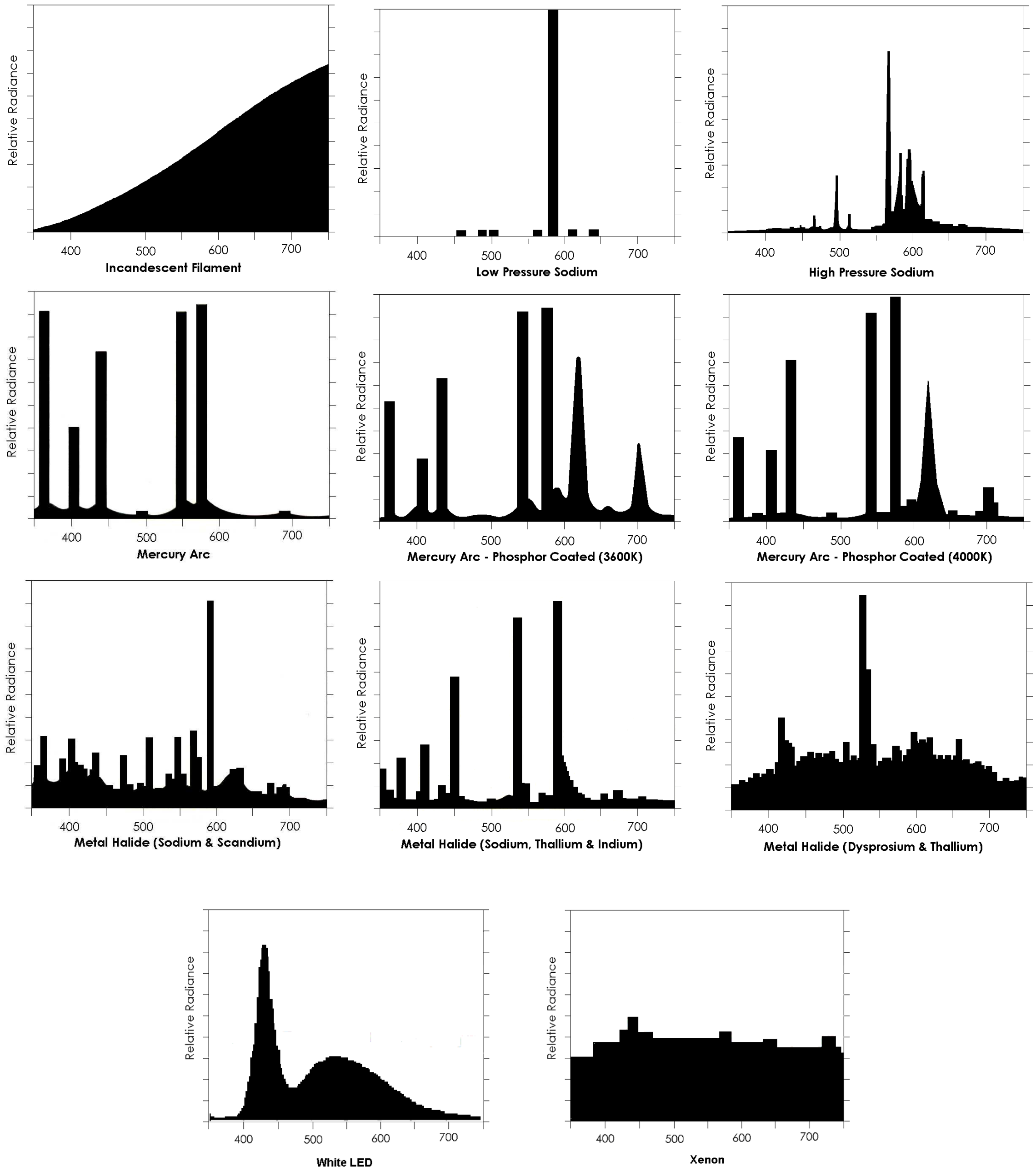

Figure 10 Spectra of Various Light Sources

6. Special Applications of Light Sources

6.1 Light Poles and Light Pipes

Light poles and pipes may be used to give a conspicuous shape or to enhance the outline of a building or structure. Different shapes and colours can improve the conspicuity of an AtoN in areas where background lighting is a problem. Such devices can be realised with LED technology, with fluorescent lamps or with prismatic diffusion.

Conspicuity is increased with the size of the light signal viewed and decreased with density of background lighting. High-density backgrounds cause less reduction in conspicuity of 'extended' signals than 'point source' signals. Whereas, flashing enhances conspicuity of 'point source' signals more than extended ones.

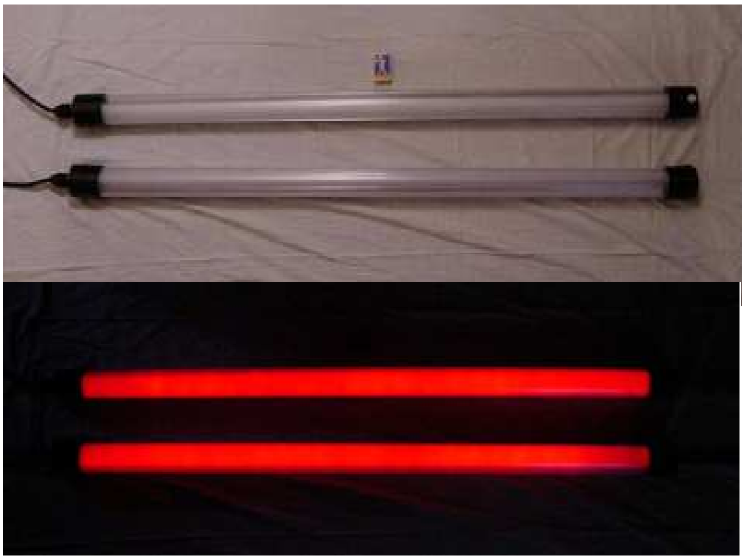

Figure 11 Light Pipes for Swedish Maritime Administration (0.4W per lamp)

Figure 12 Example of Application of Light Pipes

Figure 13 Light Pole Detail

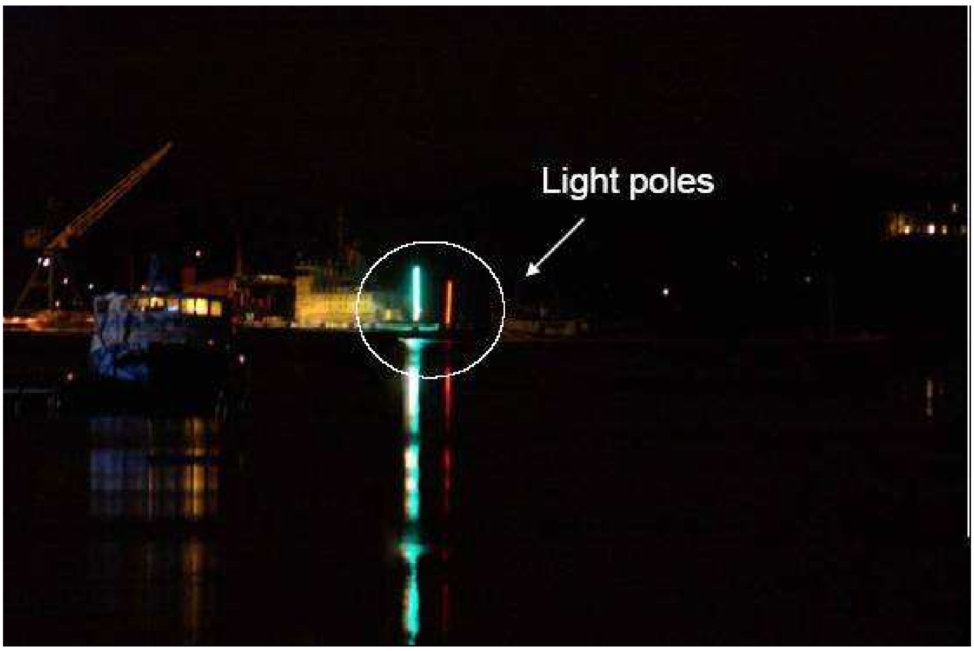

Figure 14 Light Pole in Operation

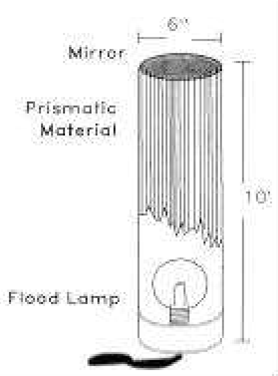

Figure 15: Prismatic Diffusion Technique

6.2 Signage

Light sources may be used to illuminate signs that give information to the mariner or navigator. The requirement is usually that the light source illuminates a recognisable area rather than a point source. Several point sources could be used together to form shapes or extended light sources could be used to provide illuminated areas. A typical use of such signage is shown below, where the sides of the triangles illuminated indicate the movement of vessels further along an inland waterway.

Figure 16 Mandatory warning sign showing vessel traffic

7. References

IALA References

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