Marine Signal Lights Service Conditions Factor

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Executive Summary

The General Lighthouse Authorities (GLA) utilise a wide range of light sources, lenses and self-contained lanterns in their lighthouses to provide appropriate visual aids to navigation (AtoN). The performance of this equipment is determined or validated in a number of ways including measurement in the R&RNAV light ranges, measurement in situ and calculation. These methods capture the performance of a light at a specific point in time and, with some exceptions, are often in ideal conditions. A method to account for non-ideal conditions and varying performance over time is therefore required.

Some of the IALA (International Association of Marine Aids to Navigation and Lighthouse Authorities) E-200 series of recommendations discuss methods for measurement, calculation and notation of the performance of marine signal lights. Discussed in a number of these documents is the "service conditions factor", a factor applied to the measured/calculated intensity of a light in order to account for degradation of luminous intensity due to service conditions not typically tested in a lab environment. These include dirt/salt deposits on equipment, equipment degradation over time (primarily lumen output of light source) and meteorological conditions. The resulting intensity (after any other necessary factors have been applied) is then used to determine the nominal range for publishing. IALA E-200 recommends that the value of a service conditions factor be 0.75. It is likely this value was chosen as a compromise between providing a reasonable margin to account for degradation while not being so large as to significantly affect the nominal range. This value has been in use for some time.

The Commissioners of Irish Lights has asked for confirmation as to whether this factor should be used within the GLA and whether the factor of 0.75 remains valid when utilising LED light sources.

It was concluded that:

- The lumen output of all light sources and lanterns used by the GLA (including those utilising LED technology) depreciates over the service life.
- The optical equipment and lantern glazing degrades from a clean condition between maintenance visits, which reduces the luminous intensity of the light. This is exacerbated as visit intervals are pushed further apart and high priority is not given to cleaning the equipment; if the latest, most reliable and efficient equipment is enclosed in a lantern room with dirty glazing much of the performance is lost.
- As responsible lighthouse authorities, the GLA should be applying a service conditions factor to measured/calculated luminous intensity results before determining the nominal range. Without this, lights belonging to the GLA will have a lower than expected luminous intensity and in many cases a lower than published nominal range
- There is no single service factor to accurately account for the service conditions of a given station. The appropriate value of the service conditions factor is determined by a combination of the external conditions (rate of dirt/salt deposition), lumen depreciation of the light source and the maintenance regime of a given lighthouse.
- Certain types of measurement will capture some components accounted for within the service conditions factor. For example, the lens/glazing condition is captured during a field measurement and the lumen depreciation of a light source is captured if measured at the end at the end of its service life. The components captured in the measurement would not need to be accounted for again; however, any further degradation would need to be accounted for. For example where the lens and glazing may deteriorate further from the condition they were measured in.
- The service conditions factor is applied to the intensity of a light to ensure the published nominal range is met under service conditions. The nominal range of a light is not

affected by the prevailing visibility. Any modifications to the required intensity to meet navigational requirements in lower than nominal visibility are a distinct and additional assessment from the service conditions factor.

It was recommended that:

- The GLA apply a service conditions factor to measured/calculated luminous intensity results before determining the nominal range. Without applying a service conditions factor it is likely the performance of many GLA lights will be less than published.
- The service conditions factor for a light utilising LED technology is to be determined in the same manner as a light utilising any other light source technology.
- The value of the service conditions factor should be selected based on the maintenance regime (lens/glazing cleaning and light source replacement) of a given lighthouse. Alternatively the maintenance regime can be designed around a given value for the service conditions factor.
- Where it can be shown that components of the service conditions factor have been adequately captured during a measurement/calculation, these components are not then subsequently applied. For example the prevailing lens/glazing condition is captured during a field measurement. However, potential further degradation from any captured condition should be considered and accounted for.
- Care should be taken if the calculated value for the service conditions factor is greater than 0.75 as this is less cautious than the value recommended by IALA. In this case clear evidence for using a higher value should be documented.
- In absence of specific station information, the value used for the service conditions factor should be 0.75, as recommended in the IALA E200 series of recommendations.
- Light sources should be changed well before their lumen output depreciates to the service conditions factor since it covers more than just lumen depreciation of the light source. Examples of the relationship between the service conditions factor and light source replacement interval are given in Table 3-Table 6.
- High importance is given to cleaning of lenses, lanterns and lantern glazing.
    - From Table 1 it can be seen that dirt and condensation accumulating on a lens can be a major contribution to the intensity degradation of an AtoN light. On stations where this is a known problem, strategies, such as heating, venting and dust reduction, should be considered in order to reduce the rate of degradation and thereby increase the maintenance period.
- Special attention should be given to the service conditions factor of lights known/suspected to suffer heavy salt/guano deposits.
- If there is a navigational requirement for a light to meet a given range in lower than nominal visibility, then the required intensity for these conditions should be calculated before using the service conditions factor. The service conditions factor should then be applied as a separate and additional process.
- The R&RNAV department provides more information on the service conditions factor in its reports and test sheets, specifically:
    - The maximum permissible service conditions factor of a light before its nominal range, when rounded to the nearest nautical mile, reduces.
    - Upon request: measured results after applying a service conditions factor that has been determined by the customer from their specific maintenance intervals.
    - Where a specific service conditions factor is not provided by the customer: measured results after applying the IALA recommended service conditions factor of 0.75 (light range results only).

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Applicable Documents

AD1	IES Approved Method: Measuring Luminous Flux and Color Maintenance of LED Packages, Arrays and Modules. Illuminating Engineering Society. 2015
AD2	Projecting Long Term Lumen Maintenance of LED Light Sources. Illuminating Engineering Society. 2011

Reference Documents

RD1 IALA NAVGUIDE: Aids to Navigation Manual, International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA), Seventh Edition, 2014.

RD2 IALA Recommendation E-200-2 On Marine Signal Lights Part 2 – Calculation, Definition and Notation of Luminous Range, International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA), Edition 1, December 2008.

RD3 IALA Recommendation E-200-3 On Marine Signal Lights Part 3 – Measurement, International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA), Edition 1, December 2008.

RD4 IALA Recommendation E-200-5 On Marine Signal Lights Part 5 – Estimation of the Performance of Optical Apparatus, International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA), Edition 1, December 2008.

RD5 IALA Recommendations on the Determination of the Luminous Intensity of a Marine Aid-to-Navigation Light, International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA), December 1977. [Superseded by IALA E-200]

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RD7 RPT-06-LP-15 Light Measurement of Ardnakinna Lighthouse. R&RNAV. 16/01/2015.

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1 Introduction

The General Lighthouse Authorities (GLA) utilise a wide range of light sources, lenses and self-contained lanterns in their lighthouses to provide appropriate visual aids to navigation (AtoN). The performance of this equipment is determined or validated in a number of ways including measurement in the R&RNAV light ranges, measurement in situ and calculation. These methods capture the performance of a light at a specific point in time and, with some exceptions, are often in ideal conditions. A method to account for non-ideal conditions and varying performance over time is therefore required.

Some of the IALA (International Association of Marine Aids to Navigation and Lighthouse Authorities) E-200 series of recommendations discuss methods for measurement, calculation and notation of the performance of marine signal lights. Discussed in a number of these documents is the "service conditions factor", a factor applied to the measured/calculated intensity of a light in order to account for degradation of luminous intensity due to service conditions not typically tested in a lab environment. These include dirt/salt deposits on equipment, equipment degradation over time (primarily lumen output of light source) and meteorological conditions. The resulting intensity (after any other necessary factors have been applied) is then used to determine the nominal range for publishing.

IALA E-200 also discusses a factor to account for glazing and astragal losses; a factor to compensate for the losses incurred when a light is installed in a lantern room in clean condition. The service conditions factor is a distinct and additional factor to the factor used to account for glazing and astragal losses although the two are somewhat related; part of the service conditions factor accounts for additional glazing losses due to dirt, salt and guano deposits causing degradation from the clean condition.

The wording over whether the factor *should* or *may* be applied varies between IALA E-200 documents. R&RNAV do not presently apply a service conditions factor to field measurements, light range measurements or performance indication calculations. In the interest of quality, Irish Lights has asked for confirmation as to whether this factor should be used within the GLA.

IALA E-200 recommends that the value of a service conditions factor be 0.75. In recent years, the GLA have used an increasing number of LED light sources and lanterns to provide their visual AtoN. LEDs are a relatively new technology, introduced into service long after IALA initially recommended a value of 0.75 for the service conditions factor. LEDs typically have a longer service life and slower lumen depreciation than other technologies. Because of this, Irish Lights has also asked whether the factor of 0.75 remains valid when utilising LED light sources.

2 Objectives

- Determine whether the GLA should apply a service conditions factor to the intensity of a light.
- If a service conditions factor is to be used, determine whether 0.75 remains an appropriate value when using LED technology

3 Background

The wording over whether a service conditions factor *should* or *may* be applied varies between the IALA NAVGUIDE [RD1] and individual documents of the IALA E-200 series of recommendations [RD2-RD4].

The IALA NAVGUIDE states:

"Under normal operating conditions the luminous intensity of a light is likely to degrade between service (maintenance) intervals. There are several components to this degradation:

- Meteorological conditions (which may only be temporary)
- Dirt and salt deposition (which can be minimised by an efficient regular programme of cleaning of the optical system and housing);
- Progressive deterioration of the light source over the service interval.

It is clearly impossible to represent such a complex array of factors in any simple way, and a proper assessment of the various effects could only be made by measurements on site at regular intervals. However, in order to give a more realistic figure for the performance of the light under normal operating conditions than when the luminous intensity is measured in a laboratory or a photometric range, it may be appropriate to apply a service conditions factor to the measured intensity".

E200-2 on the calculation, definition and notation of luminous range states: "It is recommended that the intensity used to calculate the nominal range for publication should include a service factor. It is recommended that this service factor be taken as 0.75 (corresponding to a reduction in intensity of 25%)".

E200-3 on measurement states: "Where applicable, a service conditions allowance may be applied to the measured intensity. This allowance accounts for the reduction in intensity through equipment degradation over the lifetime and service period of the equipment when it enters service. The details of such an allowance, and how it was applied, should be clearly reported".

E200-5 on the estimation of the performance of optical apparatus states: "The factor to cover practical service conditions may also be applied. It is recommended that this factor be taken as 0.75 (25%); this should be stated clearly in any calculation".

The wording in the IALA NAVGUIDE and recommendations E200-3 and E200-5 state that a service conditions factor *may* be applied. The IALA NAVGUIDE, being a guidance document, uses the typical guidance vocabulary of "may". E200-3 and E200-5 relate to reporting results of luminous intensity, at this stage the service conditions factor may be applied but it is not essential that it is done so. E200-2 on calculation, definition and notation of luminous range recommends the factor *should* be applied. At this final stage, when determining the nominal range of a light for publishing, if the service conditions factor has not already been applied it should be now. Therefore, to comply with this recommendation, the intensity of a light whether derived from measurement or calculation should have a service conditions factor applied before calculating (or looking up) the nominal range. However, while complying with IALA recommendations is important, in order to properly answer the question proposed by Irish Lights specific reasons for using the factor will be scrutinised in later sections.

The recommended value of 0.75 for the service conditions factor has been used for some decades, at least since 1977 [RD5]. However, the application of LEDs in AtoN is a relatively new endeavour and, furthermore, has made significant advancements since first being used in AtoN. The lumen output of LED light sources tends to depreciate at a slower rate than other types of light source previously used in AtoN. Since part of the service conditions factor covers progressive deterioration of the light source, or "lumen depreciation", the presently recommended value of 0.75, may not be the most appropriate value for the specific lumen depreciation characteristics of LEDs. However, lumen depreciation is only one component of the factor and the individual contributions to the value of 0.75 are not specified in the recommendations. This makes it difficult to modify the factor should an individual component need to change.

Since IALA is an international association, the recommended value for the service conditions factor is an estimate used in an attempt to compensate for service conditions of lighthouses around the world. Clearly, it cannot be an accurate factor for each individual lighthouse of each individual lighthouse authority. The recommended value is only adequate if a certain standard of maintenance (e.g. cleaning and/or replacing components) is upheld. If the actual standard of maintenance falls below this inherent standard, then there is a risk that the nominal range of the light will fall below the published figure. If the recommended value of 0.75 is used to adjust the measured/calculated intensity of a given lighthouse, the maintenance procedures of that lighthouse should be suited to this value. If a service conditions factor of 0.75 does not match the degradation of luminous intensity during the maintenance period, a more appropriate factor should be used. However, the value of any alternative factor used should be verified through measurements taken over the whole maintenance period, and include degradation of the light source output during its service life.

4 Should the GLA use a service conditions factor?

Here the individual components of the service conditions factor are discussed and how they might affect or have been seen to affect stations under the jurisdiction of GLA.

4.1 Meteorological Conditions

Meteorological conditions may be thought of as having two different effects on the luminous range of a light. One effect is on visibility; as the transmissivity of the atmosphere reduces, visibility worsens and the luminous range of a given light reduces. Another effect is on the transmissivity of the lantern glazing caused by rain drops or build-up of snow/ice.

The published range of a light is a *nominal range* based on a visibility of 10 M. Nominal range is not to be confused with luminous range; the luminous range of a light is the range of that light under the prevailing conditions. The luminous range is therefore dependent upon the prevailing meteorological conditions. The nominal range is not dependent on the prevailing meteorological conditions; a light with an 18 M nominal range, still has an 18 M nominal range in poor visibility. Since the service conditions factor is applied to the intensity of a light to ensure the correct nominal range is published, then the prevailing visibility does not need to be accounted for within the factor. The effect of visibility is distinct from the maintenance requirements of equipment and is something that should be considered when determining the navigational requirements of a specific station. For example a station may have a navigational requirement of 18 M but there is frequent poor visibility in this area. It should be considered whether there is a navigational requirement for the light to provide the 18 M range (or some other range) during conditions where visibility is less than 10 M. If so, the required intensity for the prevailing visibility and required range will need to be determined separately from the service conditions factor.

The effect caused by rain/snow/ice deposits on the glazing does affect the nominal range of a light and it is therefore appropriate to consider it in the service conditions factor. Deposits of snow/ice on the glazing could severely reduce the intensity of the light and the reduction could be much greater than accounted for by the entire present service conditions factor. IALA is an international association and the recommendations are intended to be applicable to lighthouse authorities around the world. Some countries are likely to experience ice and snow regularly; however the rare occurrence of these in the UK and Ireland makes it impractical to account for a potentially very large factor as standard course.

4.2 Dirt and Salt Deposition

RD4 recommends that where a light is enclosed in a lantern room, a factor of 0.85 should be applied to the intensity to account for the losses through the glazing and astragals of a system in clean condition. Part of the service conditions factor is intended to cover degradation of the lens and glazing from a clean condition, caused by deposits such as dirt, dust, salt and guano. As noted, the degradation may be minimised by a suitable cleaning regime. When lighthouses were manned by keepers, a regular cleaning regime could be effectively implemented. Since automating lighthouses, keepers are no longer used and attendants are employed in their place by some GLAs. The attendants visit the station several times a year, but will not be on station every day as the keepers were. Other GLA do not employ attendants and are striving for a single maintenance visit per year. With personnel on station less frequently, the potential effectiveness of a cleaning regime is reduced.

The regular duties of Trinity House (TH) attendants include “Lantern, lattice framework and glazing inspection. Identify any leaking glazing. Clean as necessary” and “Main lens assembly Inspection. Check lamp changer cable within optic. Clean lens” [RD6]. It is specified in the master list that these checks are to be carried out at a frequency of once a month although some lighthouses are less accessible and undergo checks every three months with some only being checked every six months.

The wording of the tasks states that the lens is to be cleaned, but that the glazing is to be cleaned as necessary; this leaves the cleaning of the glazing up to a subjective assessment by the attendant. The glazing may not appear dirty and therefore not in need cleaning, but there may well be an impact on its transmittance.

Field measurements at Ardnakinna Point lighthouse (Irish Lights) showed that the dirt on the lens alone reduced the intensity of a clean system by 45 % [RD7]. A year later a repeat of the measurement showed that dirt on the lens reduced the intensity of a clean system by 20 % [RD8]. It is probable that no cleaning of the lens had taken place in the year between the two field measurements. It is also unknown when the lens had last been cleaned before the first field measurement: possibly a few years prior to the measurement. It is thought that condensation on the Ardnakinna lens was a contributing factor in accumulating the deposits.

Previous experiments at St Ann’s Head, a station known to suffer from salt deposits on the glazing, show that the transmissivity of glazing coated with Clear Shield was reduced to 84 % [RD9]. The report states that clear glass has an initial transmittance of ~93 % and that the Clear Shield coating did not affect the transmittance of the glass. The factor to account for this level of salt deposits is therefore: $\frac{0.84}{0.93} = 0.90$. The exact time frame of the experiment is unknown but it is thought to be four to six months. It is stated that 84 % was the worst transmittance. It may well be that this was an isolated patch on the glazing and does not represent the transmissivity across the entire glazing panel, although a photo of a glazing panel in the report does indicate the salting is fairly evenly spread across the entire panel. The report also states the worst transmittance due to guano deposits as 40 %. The factor to account for this level of guano deposits is therefore: $\frac{0.40}{0.93} = 0.43$.

Table 1 combines the results from the experiments above to give estimated values for the component of the service conditions factor that accounts for degradation from clean condition. The glazing losses are based on salting. Stations known/suspected to suffer from above guano deposits (such as those close to bird colonies) should be given specific attention. Without regular measurement, the progressive effect of accumulating dirt, salt and guano on the luminous output with time cannot be known. To provide an indication, it has been assumed that degradation is proportional with time. The figures show that there is potential for severe degradation within one year.

Lens losses due to 1 year of deposits			20%	
Additional glazing losses due to 6 months of deposits			10%	
Cleaning period (months)	Losses through lens due to deposits	Additional losses through glazing due to deposits	Combined lens and glazing losses due to deposits	Factor to compensate for degradation from clean condition
1	2%	2%	3%	0.97
3	5%	5%	10%	0.90
6	10%	10%	19%	0.81
9	15%	15%	28%	0.72
12	20%	20%	36%	0.64
18	30%	30%	51%	0.49
24	40%	40%	64%	0.36

Table 1 – Lens and glazing losses due to degradation form clean condition
The values presented in the table have been rounded. Calculations were performed on the raw figures.

The figures in Table 1 were taken from data obtained at two stations that were selected for having noticeable degradation from clean condition. It is possible that these stations have above typical rates of degradation. However analysis of other stations would be required to show this.

It may be the case that the progressive increase of deposits on the glazing is not proportional with time. There may be a cyclic property where salt, dirt and guano are deposited on the glazing and later washed away by rain. Therefore, the level of deposits found on the glazing after six months may not be proportionally different to that after a shorter/longer amount of time. A more detailed study would be required to determine the progressive deterioration. A lens installed in a lantern room will not have its deposits washed away by rain. The results of Ardnakinna show that the losses, caused by deposits on the lens, after one year (20 %) were less than half the maximum losses measured at that station (45 %).

The effect of glazing is not captured during a light range or lab measurement. In the case that equipment measured in this way is to be installed in a lantern room then both the factor to account for losses through clean glazing and astragals and the factor for service conditions of the glazing and light source should be applied to give an accurate indication of the performance of the equipment in situ (e.g.0.85 x 0.75). Without both of these factors applied the real performance of the equipment will be less than measured/calculated.

Where equipment is measured in a lab or light range but is to be installed externally then the factor for glazing and astragal losses does not need to be applied but there is still an argument for applying a service conditions factor to account for degradation of the optical components from a clean condition.

During a field measurement, the light is measured in situ and therefore the effect of lantern glazing, including degradation from a clean condition is captured (but not necessarily the effect of astragals since it is typically measured from one direction only). Of course it is only the condition at that moment in time that is captured which may not be representative of the typical condition or the condition towards the end of a maintenance interval (ie shortly before the next maintenance visit). In a field measurement where the lens and glazing have very recently been cleaned, the full component of the service conditions factor that accounts for degradation from a clean condition would need to be applied. In the case that the station is measured at the end of a maintenance interval, it would be unduly pessimistic to apply the entire factor; perhaps no factor to account for lens/glazing degradation would be needed. However it should be heeded that the conditions at the end of that maintenance interval may well be better than the conditions after a similar interval at a different time of year. Any further degradation from the measured condition should be considered and accounted for in the service conditions factor if necessary.

Where the performance of a light is estimated by calculations based on a field measurement of another light (referred to as “ratio calculations”), the results will include the prevailing service conditions from that field measurement.

4.3 Light Source Lumen Depreciation

A light source will operate for an amount of time before eventually failing in some way and thus reaching the end of its life. During this time the lumen output of the light source, whether tungsten, tungsten halogen, metal halide or LED, will decrease. Part of the service conditions factor accounts for the reduction in luminous output of a light source throughout its service life, before it is replaced by a new light source.

The luminous output of a light source after a given number of running hours, expressed relative to the initial luminous output, is known as the lumen maintenance. Figure 1 to Figure 3 show example lumen maintenance curves for some light source technologies used by the GLA. They show that all lamps used by the GLA suffer lumen degradation and therefore that this needs to be accounted for in a service conditions factor.

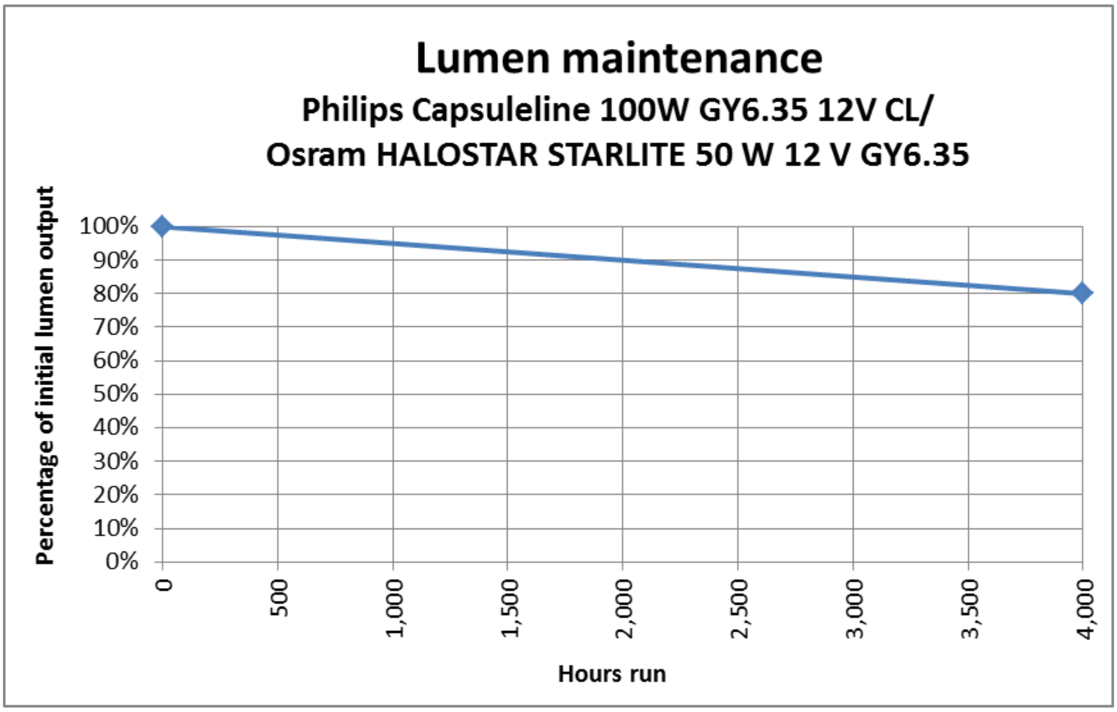

Figure 1 - Example lumen maintenance curve of a tungsten halogen filament lamp. [RD10][RD11]

The datasheets for the tungsten halogen lamps only contained the lumen maintenance value at the end of life. A straight line was plotted from 100 % lumen maintenance at zero hours to the lumen maintenance figure at end of life, assuming a linear degradation. However, the actual rate of depreciation may not be constant throughout the life of the lamp.

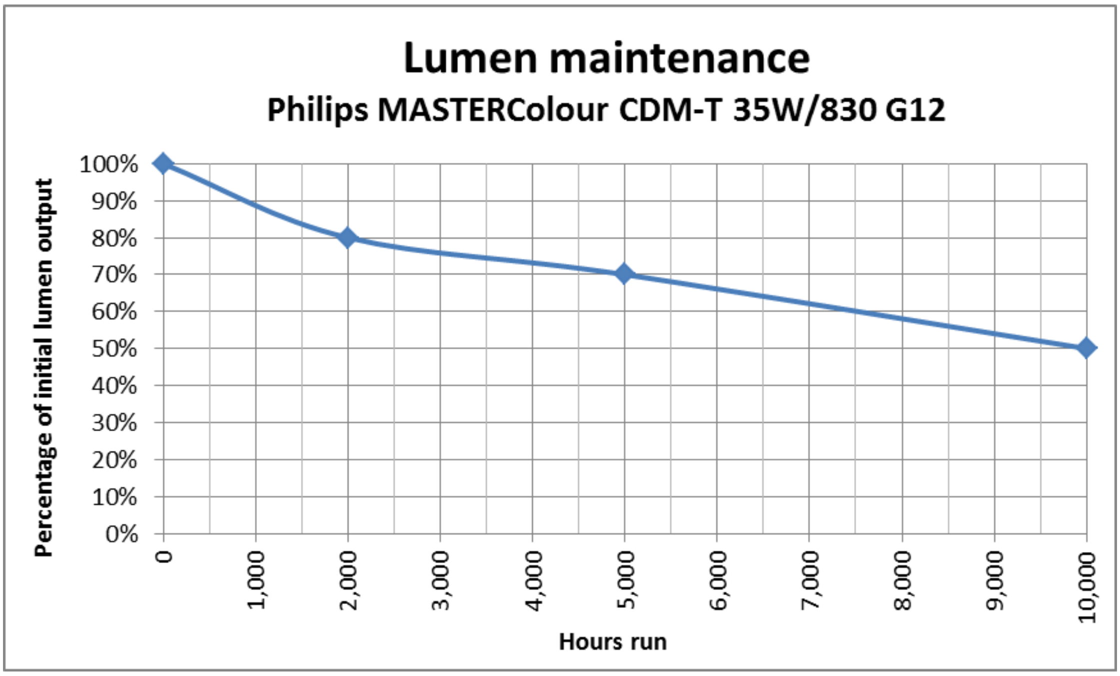

Figure 2 – Example lumen maintenance curve of a metal halide lamp [RD12]

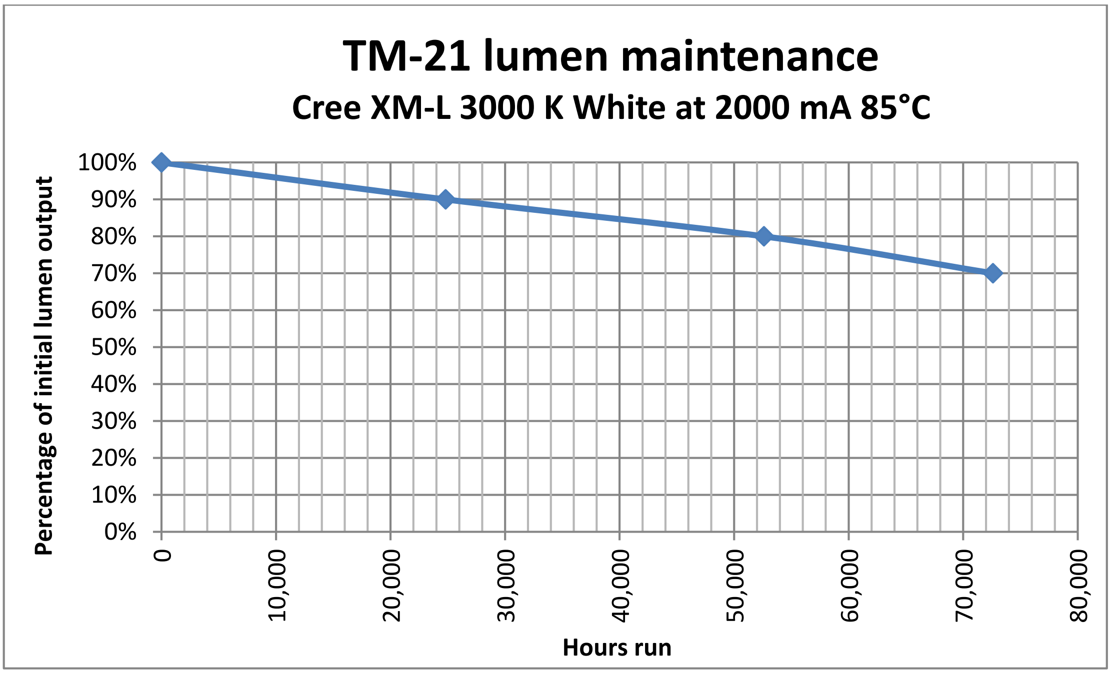

Figure 3 Example lumen maintenance curve of a LED [RD13]. It should be noted that the test data does not conform to LM-80 since fewer than 25 samples were used (21). However the test was an extension of the initial 25 sample set allowing extrapolation of the results over a longer time frame.

During the lifetime of a tungsten halogen lamp, the lumen maintenance may only reduce to around 80 %, for example the Philips Capsuleline 100 W, 12 V lamp. Failure of the lamp gives a convenient indication that the luminous output has reduced to a certain level. Most styles of lampchanger presently offered by suppliers are designed with the intention of running each halogen lamp to complete failure before changing to the next lamp.

The luminous output of both metal halide lamps and LEDs can degrade significantly before total failure and the lumen output reduces to an unacceptable level long before the device fails. For example, the luminous maintenance of the metal halide lamp shown in Figure 2 is 50 % at the end of the lamp's life compared to 80 % for the tungsten halogen shown in Figure 1. Clearly failure is a less useful indication for metal halide lamps as the lumen depreciation is over twice that of a tungsten halogen lamp. It is typical to change a light source after a given number of hours running time. The replacement interval is determined by using the allowable useable maintenance figure and the luminous maintenance table/graph in the technical datasheet for the lamp. Using Figure 2 as an example, if it is determined that the lamp will be changed when the luminous output falls to 85 %of the initial output, the number of hours before changing the light source would be 1,250 h.

Figure 3 shows an example lumen maintenance curve for an LED. Due to the long life of LEDs it is not feasible to provide measured lumen maintenance curves over the entire life because it would take years of constant running to obtain the complete curve, by which time the particular model would likely have been superseded. The curve shown in Figure 3 is based partly on several thousand hours of measured data and partly on extrapolated data using the projection method defined in IES TM-21 [AD2]. Measurements of an R&RNAV light source from Baily Lighthouse (Irish Lights) show that after 12,200 to 14,300 hours of operation (installed 16/10/2012, removed 31/07/2015, running 12-14 hours per night) the average azimuth intensity increased by 2 % [RD14][RD15]. It is not unusual for the output of an LED to increase before eventually decreasing.

The general concept of lumen maintenance is the same for all light source technologies discussed in this report, although exact lumen maintenance curves vary between the individual technologies and between individual models of a given technology. The general procedures around lumen maintenance for an LED light source are no different from the other technologies; the allowable reduction in lumen output before changing is determined and the light source changed at the corresponding interval. If the light source is changed frequently then only a small factor is required to account for the lumen degradation. To use a small factor the lamp replacement intervals would be prohibitively short for most lamps. However, the lifetime of the LED is typically much greater than the other technologies discussed here and the lumen depreciation slower. It is possible to replace an LED light source less frequently than other light sources yet still incur a lower amount of lumen depreciation, meaning a smaller factor is required to account for the lumen degradation. However, if maintenance visits are less frequent because of this, degradation of the lens and glazing from a clean condition will become a larger factor.

It will not always be cost effective to change an LED light before the lumen output degrades beyond a minimal amount. A self-contained lantern costing tens of thousands of pounds may be prohibitively expensive to change every few years. A light source in a traditional lens would be considerably more cost effective to change at intervals that allow minimal lumen depreciation.

While future lumen depreciation of LEDs can be accounted for by setting the LED output higher than initially required, some authorities may wish to use an alternative approach: Many LED control systems allow the LED drive current to easily be increased in the field, thus giving the capability to compensate for lumen degradation. However, once the maximum allowable LED/driver current is reached, the light output will degrade. Furthermore, a station will need the initial capability to supply the increased power demands or have its capability increased throughout the LEDs service life to meet the increasing power demands. This method is not practical for the other light source technologies discussed in this document. This method has an additional risk since the lumen depreciation curve throughout the LEDs life must be known; when initially compensating for the entire future lumen depreciation there is only one point on the lumen deprecation curve that must be known, reducing the chances of error. Future generations of lanterns may well include a feedback loop to measure and compensate for lumen deprecation.

Clearly, measurement of a light will not capture any subsequent lumen depreciation of the light source. Therefore, where a light is not measured at the end of the light source service interval, a factor to account for subsequent depreciation should be applied before determining the nominal range.

5 Is the present value of the service conditions factor the most appropriate?

IALA recommends a value of 0.75 for the service conditions factor. It is likely this value was chosen as a compromise between providing a reasonable margin to account for degradation while not being so large as to significantly affect the nominal range. Table 2 shows the effect on nominal range by applying a 0.75 factor to the intensity over a range of intensity values. It can be seen that, for the values shown, the range does not drop by more than 1 M and does not reduce by more than 10 %.

	Intensity (cd)	Range (M)	Intensity (cd)	Range (M)	Intensity (cd)	Range (M)	Intensity (cd)	Range (M)
Clean	76.7	5.0	1,372	10.0	13,805	15.0	109,760	20.0
Degraded	57.5	4.5	1,029	9.4	10,354	14.3	82,320	19.2
Factor	0.75	0.90	0.75	0.94	0.75	0.95	0.75	0.96

Table 2 – The effect on nominal range by applying a 0.75 factor to the intensity

Should the GLA wish to use a lower value for the factor (e.g. 0.70 or 0.65) then this would be on the side of caution from the recommended value and hence the GLA would be going above and beyond the recommendation. Using a higher value for the factor (e.g. 0.80 or 0.85) is less cautious than using the value recommended by IALA. Therefore should a value greater than 0.75 be used, evidence as to why this value is appropriate for a particular station should be clearly documented.

While it would be important to properly assess the appropriate value for the service conditions factor were it to be increased, it is also important to assess whether the present value is low enough to account for the service conditions encountered on GLA stations. For example, should the GLA wish to maximise intervals between light source replacement by using a light source until its lumen output depreciates to 75% then the entire service conditions factor is used up accounting for the lumen depreciation of the light source alone. In this case, degradation of the lens and glazing from a clean condition has not been accounted for and the performance of the light will be less than measured/calculated at times between the cleaning and lamp replacement intervals.

The following tables show the required service conditions factor for varying lens/glazing cleaning intervals and lamp replacement intervals. It is assumed that there will not be ice/snow deposits on the glazing and therefore the component of the service conditions factor for meteorological conditions has been omitted. The “burning hours” figures are for a lamp that is continuously burning. A flashed lamp will accrue hours at a slower rate depending on the rhythmic character. It is thought that the lamp replacement intervals of the LEDs may be scaled to suit the rhythmic character. Results in RD16 show that the life of tungsten/tungsten halogen light sources does not necessarily extend when flashed at a given character. Metal halide lamps are only used in rotating optics where they remain continuously on throughout the character.

Example Lamp: BSL L24 1500 W 100 V. Life 800 h				
Lamp replacement period (months)		0.5	1	1.9
Burning hours in period (if 14 h per night)		213	426	810
Factor for lumen depreciation of lamp		0.91	0.81	0.65
Cleaning period (Months)	Factor for degradation from clean condition	Required service conditions factor		
1	0.97	**0.88**	**0.79**	**0.62**
3	0.90	**0.82**	**0.73**	**0.58**
6	0.81	**0.73**	**0.66**	**0.52**
9	0.72	**0.66**	**0.59**	**0.47**
12	0.64	**0.58**	**0.52**	**0.41**

Table 3 - Example service conditions factor for a tungsten lamp e.g. the 0.58 service conditions factor is the result of multiplying the 0.91 factor for lumen depreciation by the 0.64 factor for degradation from clean condition.

Measurements at Roches Point Lighthouse showed that the intensity of a used lamp in the lens was 65 % that of a new lamp [RD17]. This would reduce even further with more use (although how much life remains before complete failure is unknown).

Example Lamps: OSRAM HALOSTAR STARLITE 50 W 12 V GY6.35. Life 4,000 h, Philips Capsuleline 100W GY6.35 12V CL. Life 4,000 h				
Lamp replacement period (months)		3	6	9
Burning hours in period (if 14 h per night)		1,278	2,557	3,835
Factor for lumen depreciation of lamp		0.94	0.87	0.81
Cleaning period (Months)	Factor for degradation from clean condition	Required service conditions factor		
1	0.97	**0.91**	**0.84**	**0.78**
3	0.90	**0.84**	**0.79**	**0.73**
6	0.81	**0.76**	**0.71**	**0.65**
9	0.72	**0.68**	**0.63**	**0.58**
12	0.64	**0.60**	**0.56**	**0.52**

Table 4 – Example service conditions factor for a tungsten halogen lamp

Example Lamp: Philips MASTERColour CDM-T 35 W/830 G12. Life to 10% failures 10,000 h							
Lamp replacement period (months)		3	6	7	12	18	24
Burning hours in period (if 14 h per night)		1,278	2,557	2,983	5,114	7,670	10,227
Factor for lumen depreciation of lamp		0.86	0.78	0.75	0.70	0.60	0.50
Cleaning period (Months)	Factor for degradation from clean condition	Required service conditions factor					
1	0.97	**0.83**	**0.75**	**0.73**	**0.68**	**0.58**	**0.48**
3	0.90	**0.78**	**0.70**	**0.68**	**0.63**	**0.54**	**0.45**
6	0.81	**0.70**	**0.63**	**0.61**	**0.57**	**0.49**	**0.41**
9	0.72	**0.62**	**0.56**	**0.54**	**0.51**	**0.43**	**0.36**
12	0.64	**0.55**	**0.50**	**0.48**	**0.45**	**0.38**	**0.32**

Table 5- Example service conditions factor for a metal halide lamp

Example Lamp: Cree XM-L 3000 K White at 2000 mA drive current							
Lamp replacement period (months)		12	24	36	48	60	120
Burning hours in period (if 14 h per night)		5,114	10,227	15,341	20,454	25,568	51,135
Factor for lumen depreciation of lamp		0.98	0.96	0.94	0.92	0.90	0.80
Cleaning period (Months)	Factor for degradation from clean condition	Required service conditions factor					
1	0.97	**0.95**	**0.93**	**0.91**	**0.89**	**0.87**	**0.77**
3	0.90	**0.88**	**0.87**	**0.85**	**0.83**	**0.81**	**0.72**
6	0.81	**0.79**	**0.78**	**0.76**	**0.75**	**0.73**	**0.65**
9	0.72	**0.71**	**0.69**	**0.68**	**0.66**	**0.65**	**0.58**
12	0.64	**0.63**	**0.61**	**0.60**	**0.59**	**0.58**	**0.51**

Table 6- Example service conditions factor for LED light source

From the above tables it can be seen that the existing value of 0.75 for the service conditions factor is sufficient to account for some possible maintenance periods but that in many cases it will not be enough. This demonstrates the importance of using appropriate maintenance intervals to keep the system in the condition assumed in the service conditions factor. In some cases the service conditions factor will need to be increased or the maintenance intervals revised.

6 A further consideration: Rounding nominal range to the nearest nautical mile

The published nominal luminous range of a light is typically rounded to the nearest nautical mile and RD2 contains a table allowing range, rounded to the nearest nautical mile, to be looked up for a given luminous intensity. For example, a light that has a nominal range of 18.4 M would be published as an 18 M light. This light has a fair margin for a reduction in luminous intensity before the range, when rounded to the nearest nautical mile, drops to 17 M. Another light having a measured/calculated nominal range of 17.5 M would still be published as an 18M light but has only a small margin for reduction.

In some cases applying the service conditions factor may not affect the published range; clearly a desirable scenario for the GLA. However, in other cases applying the service conditions factor will reduce the rounded range and although this means higher specification equipment will be needed to meet the navigational requirements, the alternative is not using the service conditions factor and having lighthouses performing at a nominal range less than published. Clearly the alternative is undesirable for any responsible lighthouse authority.

7 Conclusions

- The lumen output of all light sources and lanterns used by the GLA (including those utilising LED technology) depreciates over the service life.
- The optical equipment and lantern glazing degrades from a clean condition between maintenance visits, which reduces the luminous intensity of the light. This is exacerbated as visit intervals are pushed further apart and high priority is not given to cleaning the equipment; if the latest, most reliable and efficient equipment is enclosed in a lantern room with dirty glazing much of the performance is lost.
- As responsible lighthouse authorities, the GLA should be applying a service conditions factor to measured/calculated luminous intensity results before determining the nominal range. Without this, lights belonging to the GLA will have a lower than expected luminous intensity and in many cases a lower than published nominal range
- There is no single service factor to accurately account for the service conditions of a given station. The appropriate value of the service conditions factor is determined by a combination of the external conditions (rate of dirt/salt deposition), lumen depreciation of the light source and the maintenance regime of a given lighthouse.
- Certain types of measurement will capture some components accounted for within the service conditions factor. For example, the lens/glazing condition is captured during a field measurement and the lumen depreciation of a light source is captured if measured at the end at the end of its service life. The components captured in the measurement would not need to be accounted for again, however; any further degradation would need to be accounted for. For example where the lens and glazing may deteriorate further from the condition they were measured in.
- The service conditions factor is applied to the intensity of a light to ensure the published nominal range is met under service conditions. The nominal range of a light is not affected by the prevailing visibility. Any modifications to the required intensity to meet navigational requirements in lower than nominal visibility are a distinct and additional assessment from the service conditions factor.

8 Recommendations

It is recommended that:

- The GLA apply a service conditions factor to measured/calculated luminous intensity results before determining the nominal range. Without applying a service conditions factor it is likely the performance of many GLA lights will be less than published.
- The service conditions factor for a light utilising LED technology is to be determined in the same manner as a light utilising any other light source technology.
- The value of the service conditions factor should be selected based on the maintenance regime (lens/glazing cleaning and light source replacement) of a given lighthouse. Alternatively the maintenance regime can be designed around a given value for the service conditions factor.
- Where it can be shown that components of the service conditions factor have been adequately captured during a measurement/calculation, these components are not then subsequently applied. For example the prevailing lens/glazing condition is captured during a field measurement. However, potential further degradation from any captured condition should be considered and accounted for.
- Care should be taken if the calculated value for the service conditions factor is greater than 0.75 as this is less cautious than the value recommended by IALA. In this case clear evidence for using a higher value should be documented.
- In absence of specific station information, the value used for the service conditions factor should be 0.75, as recommended in the IALA E200 series of recommendations.
- Light sources should be changed well before their lumen output depreciates to the service conditions factor since it covers more than just lumen depreciation of the light source. Examples of the relationship between the service conditions factor and light source replacement interval are given in Table 3-Table 6.
- High importance is given to cleaning of lenses, lanterns and lantern glazing.
    - From Table 1 it can be seen that dirt and condensation accumulating on a lens can be a major contribution to the intensity degradation of an AtoN light. On stations where this is a known problem, strategies, such as heating, venting and dust reduction, should be considered in order to reduce the rate of degradation and thereby increase the maintenance period.
- Special attention should be given to the service conditions factor of lights known/suspected to suffer heavy salt/guano deposits.
- If there is a navigational requirement for a light to meet a given range in lower than nominal visibility, then the required intensity for these conditions should be calculated before using the service conditions factor. The service conditions factor should then be applied as a separate and additional process.
- The R&RNAV department provides more information on the service conditions factor in its reports and test sheets, specifically:
    - The maximum permissible service conditions factor of a light before its nominal range, when rounded to the nearest nautical mile, reduces.
    - Upon request: measured results after applying a service conditions factor that has been determined by the customer from their specific maintenance intervals.
    - Where a specific service conditions factor is not provided by the customer: measured results after applying the IALA recommended service conditions factor of 0.75 (light range results only).

9 Further work

The data used for the lumen maintenance of tungsten halogen light sources only contained the lumen maintenance value at the end of life of the lamp. A straight line was plotted from 100 % lumen maintenance at zero hours to the lumen maintenance figure at end of life. To confirm or correct the shape of the lumen degradation curve, the lamps could be tested in a light range over their life time. This could be easily performed on lamps with a 300 h life at nominal voltage. The lamps with a lifetime reaching thousands of hours could be supplied at higher than nominal voltage to accelerate the aging.

The data on degradation from a clean condition, as shown in Table 1, only contained one point and as an estimation of the progressive deterioration a straight light was again used. It would be beneficial to obtain several, more detailed, samples over shorter time intervals from various stations.