Metrology
for Solid State Lighting

EURAMET
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Report on methods for accelerated ageing tests of SSL

EMRP-ENG05-2.4.6

Version 1.2

D. Renoux
Laboratoire National de Métrologie et d'Essais, France

A report of the EMRP Joint Research Project

Metrology for Solid State Lightning

www.m4ssl.npl.co.uk

Title	:	Report on methods for accelerated ageing tests of SSL
Reference	:	EMRP-ENG05-246
Version	:	1.2
Date	:	02-04-2013
Dissemination level	:	PUBLIC
Author(s)	:	D. Renoux Laboratoire National de Métrologie et d'Essais, France
Keywords	:	Accelerated ageing, thermal stress, life time projection, SSL, LED
Abstract	:	This report presents the facilities and the methods used to conduct accelerated ageing tests on LED lamps using thermal stress at two elevated operation temperatures. A brief state-of-the-art is first given, and then the methodology and measurements performed are fully described. The main characteristics of the facilities and the main instruments performance are presented, including a comparison of optical measurements with MIKES which performed the natural ageing on lamps of the same types. The main results of the two accelerated tests are given to conclude on the investigated methods.
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The European Metrology Research Programme (EMRP) is a metrology-focused European programme of coordinated R&D that facilitates closer integration of national research programmes. The EMRP is jointly supported by the European Commission and the participating countries within the European Association of National Metrology Institutes (EURAMET e.V.). The EMRP will ensure collaboration between National Measurement Institutes, reducing duplication and increasing impact. The overall goal of the EMRP is to accelerate innovation and competitiveness in Europe whilst continuing to provide essential support to underpin the quality of our lives. See http://www.emrponline.eu for more information.

About the EMRP JRP "Metrology for Solid State Lighting"
In the EMRP Joint Research Project (JRP) "Metrology for Solid State Lighting", the following partners cooperate to create a European infrastructure for the traceable measurement of solid state lighting: VSL (Coordinator), Aalto, CMI, CSIC, EJPD, INRIM, IPQ, LNE, MKEH, NPL, PTB, SMU, SP, Trescal, CCR, TU Ilmenau and Université Paul Sabatier. See http://www.m4ssl.npl.co.uk/ for more information.

The research leading to these results has received funding from the European Union on the basis of Decision No 912/2009/EC.

SUMMARY

This report presents the facilities and the methods used to conduct accelerated ageing tests on LED lamps using thermal stress at two elevated operation temperatures. The detailed results on the selected set of lamps are presented in the deliverable D242. A brief state-of-the-art of 'lifetime determination' is given with the measurement standards dealing with lifetime determination and endurance tests applying to LED system or lamps. The rational for the method choice, within the framework of the task, is explained . The present framework of the related task is dedicated to junction temperature measurement by optical methods to derive a lifetime expectancy. The methodology implementation and the measurements performed are fully described. The main characteristics of the facilities and the main instruments performances are presented. A comparison of measurement results of optical and electrical characteristics has been performed on a set of lamps measured at MIKES and delivered to LNE to perform accelerated ageing on it. The goal was to compare the measurement chains at LNE and MIKES to correctly exploit the measurements results performed at LNE and MIKES. The main results of the two accelerated tests compared to those of natural ageing are given to conclude on the investigated methods.

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LIST OF SYMBOLS

X	<Definition>

LIST OF ABBREVIATIONS

EMRP	European Metrology Research Programme
NMI	National Measurement Institute
JRP	Joint Research Project
SSL	Solid State Lighting

1. Introduction

Due to their long lifetime, inherited from the robustness of the LED, SSLs are claimed to have superior lifetime, in term of 70% lumen maintenance, up to 50000 hours or 5,7 years. The European commission started to publish regulations for LED lamps with functionality parameters assessed over long-term period up to 6000 h. Such so long durations can not be easily measured in laboratories, slows down the introduction on the market and limits consumer's organisation assessment and then have aroused the interest of accelerated lifetime tests or projection methods of lifetime.

The present report describes the methods investigated and apparatus used for accelerated ageing tests of SSLs in the framework of task 4 of WP2 devoted to Lifetime expectancy determination of SSLs.

We will start, section 2, with a brief state-of-the-art of general lifetime tests for lighting products. Then section 3 will explain the choice of the thermal stress as the best method for this study with respect to the objective of the task. The method and procedure are described in the next section 4.

The described accelerated test has been applied on two sets of 15 lamps, each one aged at two operating conditions at LNE while MIKES was conducting natural ageing test on another set of 20 lamps. Detailed results are given in the deliverable D242, we will just expose in section 5 global comparative results to draw conclusion and perspective about the investigated method.

2. Brief state-of-the-art of lifetime test and regulation

The SSL as a novel technology motivated the revision of all the measurement standards including the lifetime test. Some standards are finalized for LEDs and LED modules [1][2] and other are preliminary drafts for GLS (General Lighting Service) [3]. Recently the European Commission published a regulation with regard to the eco-design requirements [4] applicable on 1st March 2014 for directional lamps. This regulation includes lamp survival factor at 6000 h and lumen maintenance at 2000h and 600 h.

1. The IESNA LM-80 –2008 provides the methods of the measurement of the lumen maintenance of LEDs and LED modules.

2. The IESNA LM-21 is a guideline to derive a Lumen maintenance Life projection from the data collected with the LM-80-2008.

3. The IEC/PAS 62612 is a pre-standard for self-ballasted LED-lamps for general lighting services (GLS).

The LM-80 approved standard defines conditions to conduct an ageing test : number of samples, case temperature, airflow, ambient temperature and so on.

The TM-21 is a guideline for data extrapolation with uncertainty estimation. Some rules are given like for a sample size of 20 lamps : the projected lamp life shall not be projected longer than 6 times the test.

The IEC/PAS specifies the performance requirements for self-ballasted LED lamps with the tests methods. A section is related to the endurance test for built-in electronic ballast including :

- Thermal choc test,

- Thermal cycling,
- Supply voltage switching test,
- Accelerated operation test : ambient temperature test at 45°C and the test period is equal to 25% of the rated lamp life.

From the literature we can learn that the main factor affecting the LED are the junction temperature and the current density [5] and that the power supply units and electronic drivers will probably last shorter than the LED with some common weakness like the electrolytic capacitors.

To summarize ageing, accelerated or not, of LEDs or lamps are either using electrical stress or thermal stress : switching, cycling, shocking. There is no approved standard for accelerated LED-based lamps and model for lifetime projection.

3. Method description

3.1. Method selection

The main approach of the task 2 relies upon the fact that the junction temperature of the LEDs in the SSL is the major influent parameter of the lifetime and also that the characteristics of the emitted spectra are linked to the junction temperature. The first challenge of this task is to determine a lifetime expectancy based on a junction temperature obtained only from the spectra and thus to provide a very useful and efficient optical method to estimate the lifetime of these new lighting devices. Several stages toward this goal have been achieved but barriers are left to determine the junction temperature from any lamp spectrum, some results are available and presented in the dedicated deliverable.

It was proposed for task 2 to work on the lifetime expectancy of SSLs not on LEDs to avoid results not reflecting the real lamps behaviour along the time of operation, as the consumer experiences at home.

Natural ageing and accelerated ageing tests are the second part of this task : primarily to provide data for the ageing model based on junction temperature and to assess stand-alone accelerated ageing tests.

So a the link between the two parts of this task could be to age the LEDs inside the lamps and to compare with the model derived from junction temperature. We assume that electrical stress could affect more the electronics rather than the LEDs and is rather and endurance test. Therefore we deliberately avoid any electrical stress to age the lamp. There is no way to increase the current trough the electronics, many drivers have a current regulator, so an over voltage does not yield to an elevated current. More over the natural ageing conducted at MIKES on a set of 20 lamps did not apply any electrical or thermal stress : the lamps were just turned on at room temperature and measured each 2 months.

LNE therefore proposed an accelerated ageing method based on high ambient temperatures operation to be consistent with the natural ageing test and to provide data for further deprecation model targeted in the first part of the task.

To measure the effect o the electronic and to observe the variation of the current accounting for the flux variation we extended, on a set of separate lamps, the wire connected to the LED PCB out of the lamp cap. Two small holes of the wire diameter were drilled in the cap. The wires out of the lamp were inserted a current clamp. These lamps with minor modification were aged in the same conditions than the lamps. The flux emitted by the modified lamps were not measured because of the lack of optical stability and rigidity of the wire that could have an effect on the optical output. A coloured sheath can fade out and a white sheath can turn yellow.

Figure 1: LED PCB current wire extension

The temperature selection is a critical choice, prior to fix any temperature we observed the relative deprecation of the flux in a climatic chamber featured with a window. The lamps were measured through a white diffuser and trough the window in the same way for each temperature of the climatic chamber. The results are illustrated on the figure 2 below.

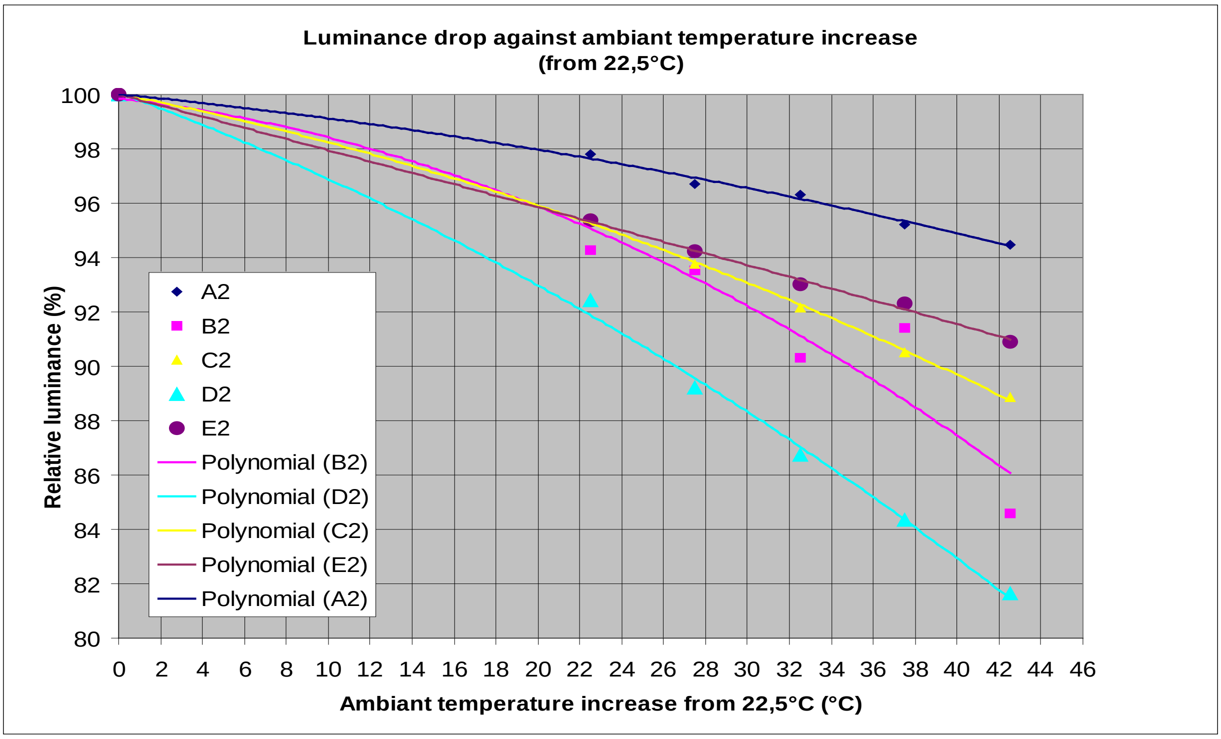

Figure 2: Effect of ambient temperature on luminous flux

We also visually observed that all the lamps till 65°C are normally functioning with a flux gradually decreasing to less than 20% at 65°C. We conclude than we can chose temperatures in the range of 20-60°C with a limited risk of over-burning.

We started the first experiment at a not too elevated temperature, i.e. 45°C , and given the very slow acceleration factor obtained, but well matching the behaviour of the natural ageing data, we pushed the second temperature to 60°C.

3.2. Method description

Mikes provided 3 samples of 5 different reference of lamps and on extra set of 1 sample of each reference for electrical current monitoring.

For the two temperatures the following steps have applied :

1. initial burning : 100 h – first optical/electrical measurement at MIKES,
2. initial optical/electrical measurement at LNE on the 5x3 lamps,
3. 2 months of ageing in a climatic chamber : ambient temperature 45°C or 60°C ,
4. periodic measurement – stabilisation time 2 hours,
5. back to 3 until the lamps are aged by 6 months.

No specific care was taken to handle the lamps and switch on/off the lamps. The lamp are turned on at room temperature in the climatic chamber, turn off in the climatic chamber at the elevated temperature and handled with clean wool gloves to avoid optical contamination and thermal effect.

4. Method implementation

The method implementation uses basic instrumentation and tools available in a metrology institute and testing laboratory.

4.1. Description of equipments

- Aluminium rack for lamps and porcelain socket (lamp-holder), parallel electrical connection
- 230 VAC stabilized power supply and an auto-transformer for voltage adjustment,
- Climatic chamber (cooling / heating) (~1.5 m x 1.5 m x 2 m),
- Integrating sphere with a photometer and a cooled spectro-photometer,
- Specific electrical measurements unit : current clamp

We used our standard equipment except for the integrating sphere. Our flux measurement system, integrating sphere based, does not enable to introduce warm lamp, then long stabilization time is need after the lamp is placed inside the sphere. To enable efficient and fast measurement during ageing we built a measurement system enabling to introduce the lamps initially warmed and stable (see figure3 bellow). The lamp with its socket and base is clamped to the moving rod terminated by a disk to close the sphere. The f1' of the system (combined sphere efficiency and photometer response) is equal to 1,6%.

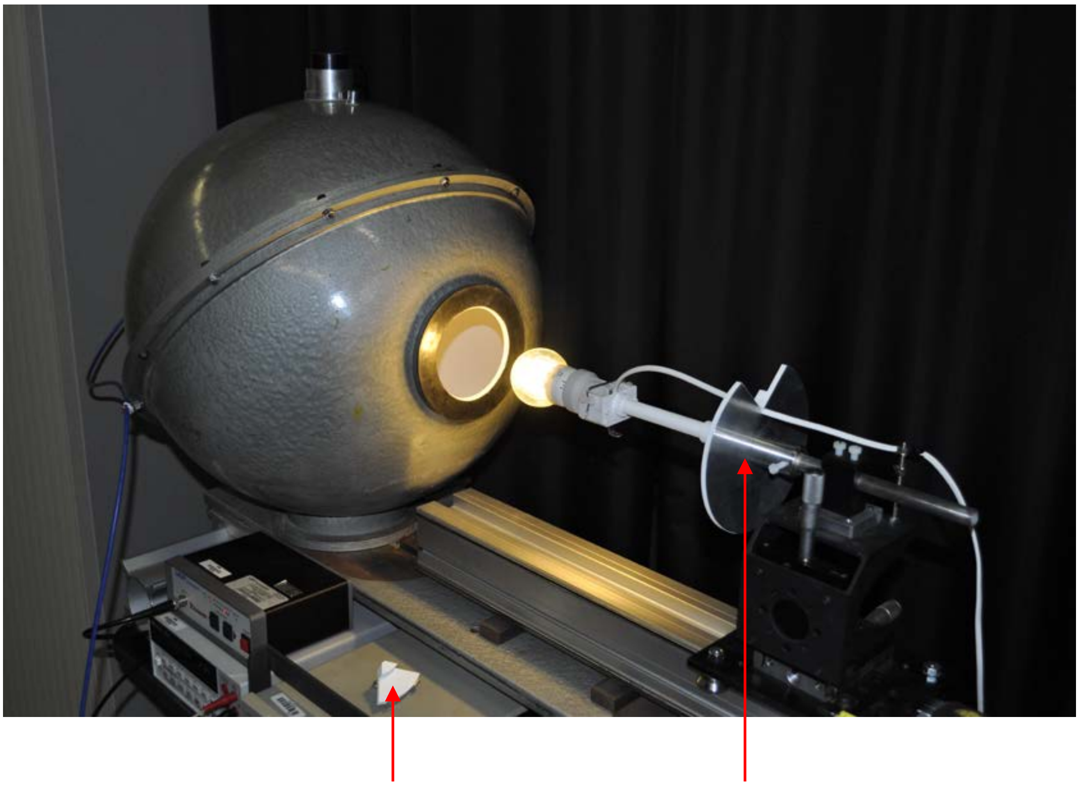

Figure 3 : 50 cm integrating sphere and moving lamp support

4.2. Equipments performances

4.2.1. Climatic chamber stability

A large heating/cooling climatic chamber has been chosen, small chamber with no cooling will not dissipate the 200W. The temperature has been measured with 4 thermocouples located inside the chamber and the graphs are presented below showing the uniformity and stability of the chamber : roughly +/- 1°C at 45°C and +/- 2°C at 60°C.

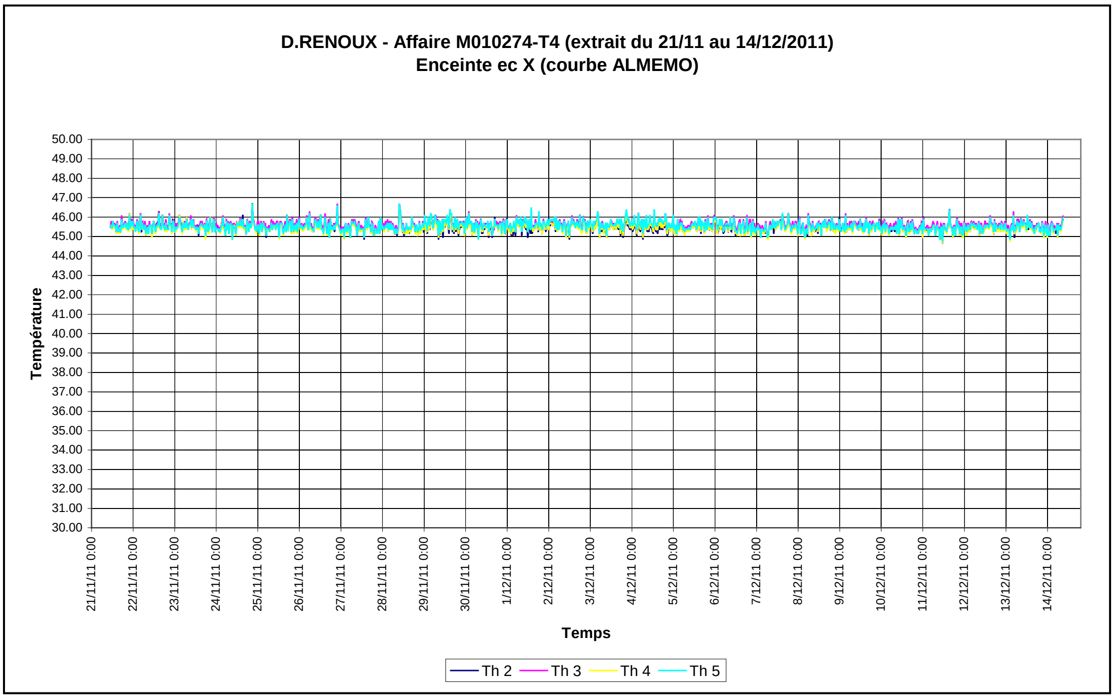

Figure 4: Long-term temperature stability at 45°C

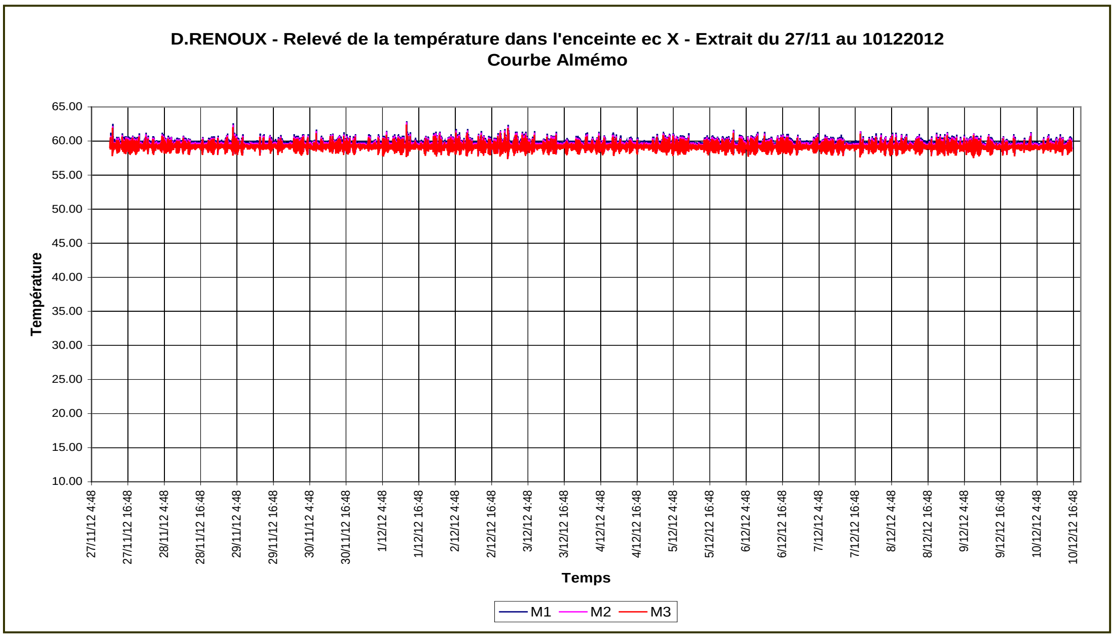

Figure 5: Long-term temperature stability at 60°C

4.2.2. Power supply stability

The voltage has been adjusted during the 2-month period, the maximum deviation was +/- 0,5 VAC.

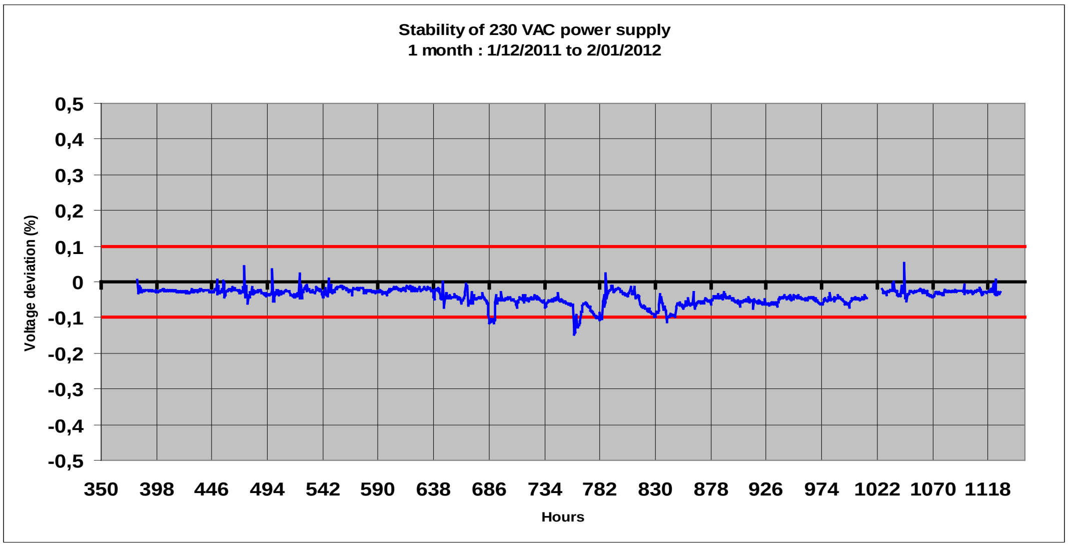

Figure 6: Long-term stability of the electrical power supply

4.2.3. Flux measurement system performance

Calibration

The calibration of the flux measurement system, before and after the first 6-month ageing period, exhibited a drift of 0,06%. The calibration of the flux measurement system, before and after the second 6-month ageing period, exhibited a drift of 1,60 %.

Comparison MIKES-LNE

MIKES uses a metrological optical flux system: a 2-metre integrating sphere equipped with a photometer and with a double monochromator/PMT. We checked at once that the two systems give the same flux measurement for the first batch of lamps. The agreement was quite good for the luminous flux, with absolute relative difference smaller than 2%, and for the spectral density of flux (see figures 6,7 and 8 hereafter).

Reproducibility

The reproducibility of the measurement was better than 0,6% except for one type of lamps (lamp D) : these lamps use blue LED and yellow phosphor and extra red LEDs which are very instable with respect to photometric data, radiometric data and ageing curves.

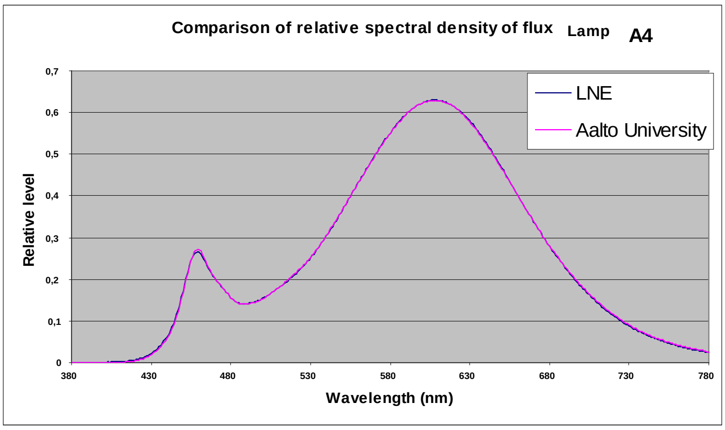

Figure 7: Graphs of SPD – lamp A4 – measured at LNE and MIKES

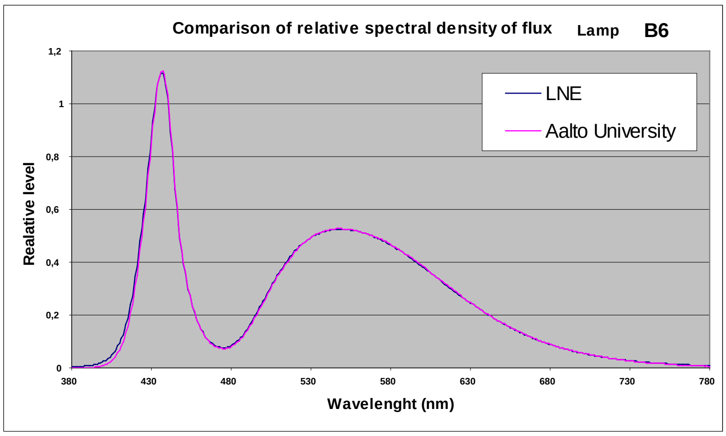

Figure 8: Graphs of SPD – lamp B6 – measured at LNE and MIKES

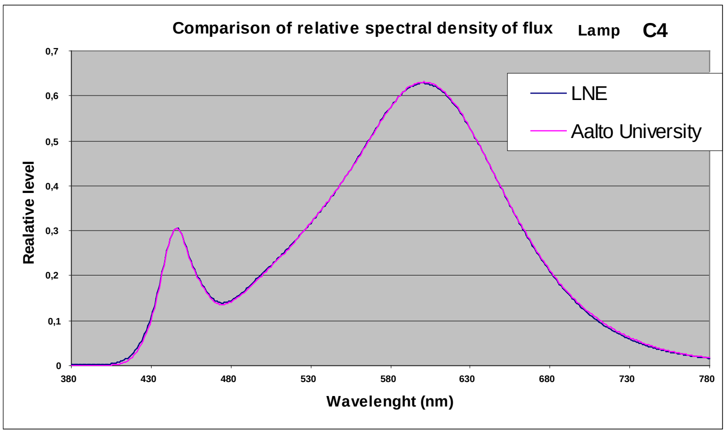

Figure 9: Graphs of SPD – lamp C4 – measured at LNE and MIKES

5. Main results

The following two graphs (figures 10 and 11 below) show the comparison on average of natural ageing and accelerated ageing, with no calibration correction of the measurement system, with respectively an acceleration factor, as a gain on time scale, of 1.34 and 2.96. The detailed results are presented in the deliverable D242.

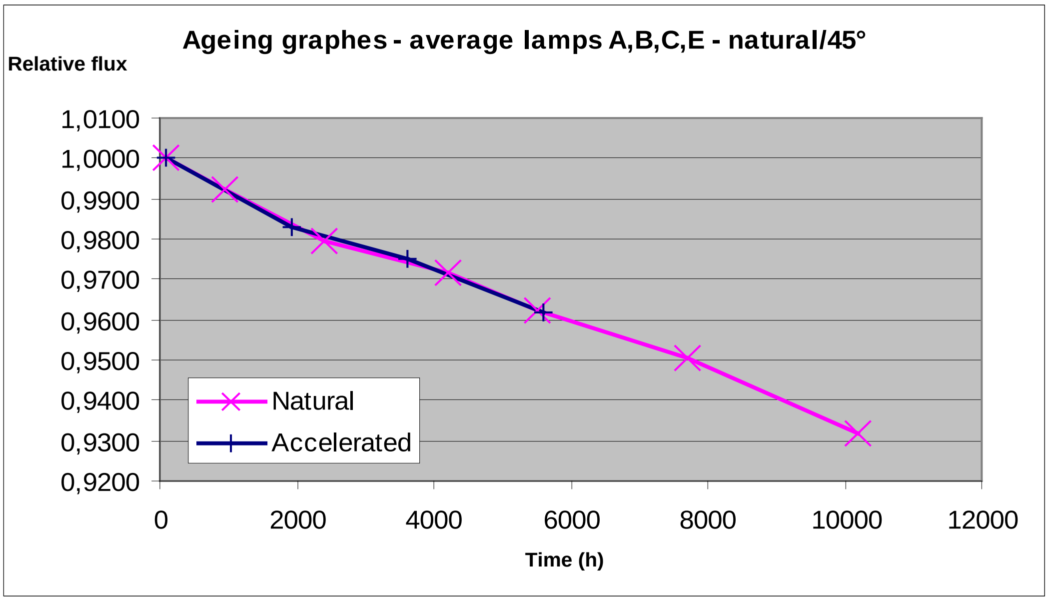

Figure 10 : Flux deprecation with natural and accelerated ageing at 45°C

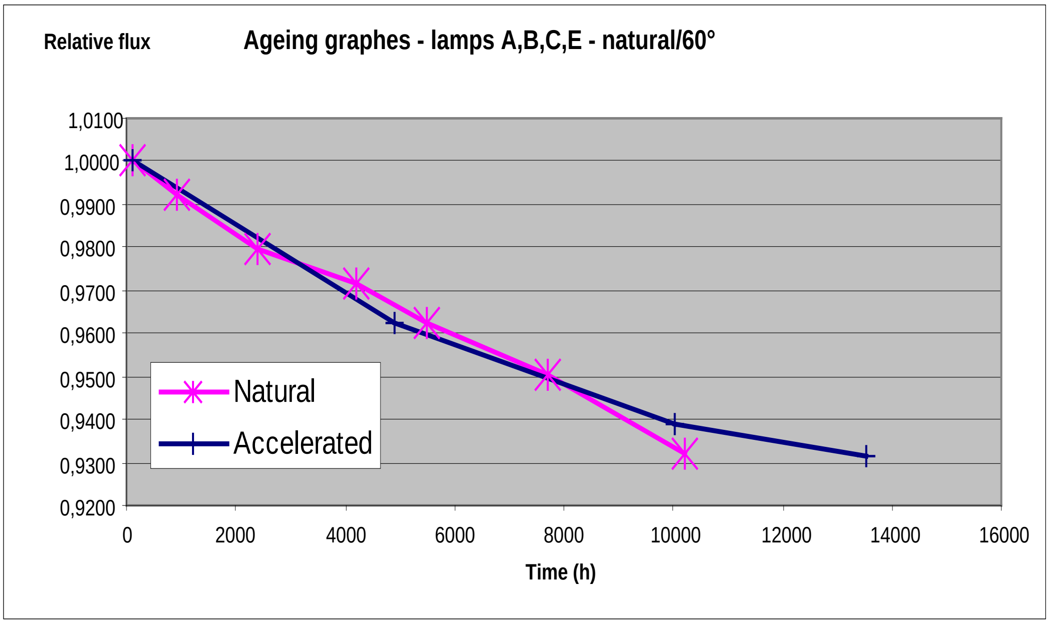

Figure 11: Flux deprecation with natural and accelerated ageing at 60°C

6. Conclusion and perspectives

An adapted measurement chain is proposed and validated for the purpose of the fast periodic measurement of luminous flux and spectral density of flux of lamps under ageing process. The integrating sphere was designed to measure in few days a large number of samples during the ageing period. The recommended samples size is generally 20 samples par lamp type [1][3] and was limited by the labour and consumables cost of the project.

A basic accelerated ageing experiment is also proposed with minimal requirements on the climatic chamber (+/- 2°C) and the power supply stability (+/- 0.5 VAC) for end lighting product (lamp, luminaire).

Despite the low sample size this preliminary work on ageing method demonstrates the potential of accelerated ageing by operation under elevated ambient temperature. The results on average (12 lamps) shows (1) a very good matching for the accelerated operation at 45°C but with a low acceleration factor of 1.34 and (2) a approximate matching at the accelerated operation at 60°C with a greater acceleration factor of 2.96 (see report D242). The matching is observed by comparison of the flux evolution curve for natural and the flux evolution curve for accelerated with a gain in time equal to the acceleration factor.

The low samples sizes, 4 for natural and 3 for accelerated ageing, on 5 lamp types do not enable accurate computation of life time projection : inter-variability between lamps of the same type is too high to project the life time with a good accuracy.

It is recommended that the lifetime projection shall not exceed 6 times the lumen maintenance test time [3], thus to project a 50000 h of lifetime a natural ageing of 8300 h (0.95 x year) is needed. The IEC standard in preparation [3] for self ballasted lamps requires to conduct an endurance test at 45°C for the 25% of the rated lifetime with a maximum of 6000h, the related compliance requirements are under consideration. This study shows that the average acceleration factor at this temperature is not so high (1.34). Then using the acceleration factor deduced from results of this test at the elevated temperature of 45°C and for the lamps we have tested we can project the flux evolution only on a 8000h (~1.34 x 6000h) period of time.

References

[1] IES-LM80-2008 - Measuring Lumen Maintenance of LED light source

[2] IES TM-21 –11 - Projecting Long Term Lumen Maintenance of LED Light Sources

[3] IEC/PAS 62612 - Self-ballasted LED-lamps for General Lighting Services

[4] Regulation n° 1194/2012 of 12 December 2012

[5] Philips Lumileds : Evaluating the lifetime behaviour of LED system

[6] Accelerated life test for high-power white LED based on spectro-radiometric measurement. Shen H. Pan J., Feng H. Zhejiang University, EVERFINE PHOTO-E-INFO CO, China.

[7] Long-term performance of white LEDs and systems Nararajah N, Jayasinghe L, Freysssinier JP, Zhu Y, Lighting Research Center , NY - Usa