



**Illuminating**  
ENGINEERING SOCIETY

**TECHNICAL MEMORANDUM:**  
**PROJECTING LONG-TERM LUMINOUS,  
PHOTON, AND RADIANT FLUX  
MAINTENANCE OF LED LIGHT SOURCES**  
AN AMERICAN NATIONAL STANDARD



**Documents**  
[www.ies.org](http://www.ies.org)  
Download Center Hub



**TECHNICAL MEMORANDUM:  
PROJECTING LONG-TERM LUMINOUS, PHOTON, AND  
RADIANT FLUX MAINTENANCE OF LED LIGHT SOURCES  
AN AMERICAN NATIONAL STANDARD**

Publication of this Technical Memorandum  
has been approved by IES.  
Suggestions for revisions  
should be directed to IES.

**Prepared for IES  
IES Testing Procedures Committee**



*Copyright 2021 by the Illuminating Engineering Society.*

*Approved by the IES Standards Committee May 26, 2021, as a Transaction of the Illuminating Engineering Society.*

*Approved August 6, 2021, as an American National Standard.*

*All rights reserved.* No part of this publication may be reproduced in any form, in any electronic retrieval system or otherwise, without prior written permission of the IES.

Published by the Illuminating Engineering Society, 120 Wall Street, New York, New York 10005.

IES Standards are developed through committee consensus and produced by the IES Office in New York. Careful attention is given to style and accuracy. If any errors are noted in this document, please forward them to Brian Liebel, Director of Standards, at [standards@ies.org](mailto:standards@ies.org) or the above address for verification and correction. The IES welcomes and urges feedback and comments.

Printed in the United States of America.

ISBN# 978-0-87995-408-6

---

## DISCLAIMER

IES publications are developed through the consensus standards development process approved by the American National Standards Institute. This process brings together volunteers representing varied viewpoints and interests to achieve consensus on lighting recommendations. While the IES administers the process and establishes policies and procedures to promote fairness in the development of consensus, it makes no guaranty or warranty as to the accuracy or completeness of any information published herein.

The IES disclaims liability for any injury to persons or property or other damages of any nature whatsoever, whether special, indirect, consequential or compensatory, directly or indirectly resulting from the publication, use of, or reliance on this document.

In issuing and making this document available, the IES is not undertaking to render professional or other services for or on behalf of any person or entity. Nor is the IES undertaking to perform any duty owed by any person or entity to someone else. Anyone using this document should rely on his or her own independent judgment or, as appropriate, seek the advice of a competent professional in determining the exercise of reasonable care in any given circumstances.

The IES has no power, nor does it undertake, to police or enforce compliance with the contents of this document. Nor does the IES list, certify, test or inspect products, designs, or installations for compliance with this document. Any certification or statement of compliance with the requirements of this document shall not be attributable to the IES and is solely the responsibility of the certifier or maker of the statement.

## AMERICAN NATIONAL STANDARD

Approval of an American National Standard requires verification by ANSI that the requirements for due process, consensus, and other criteria have been met by the standards developer.

Consensus is established when, in the judgment of the ANSI Board of Standards Review, substantial agreement has been reached by directly and materially affected interests. Substantial agreement means much more than a simple majority, but not necessarily unanimity. Consensus requires that all views and objections be considered, and that a concerted effort be made toward their resolution.

The use of American National Standards is completely voluntary; their existence does not in any respect preclude anyone, whether that person has approved the standards or not, from manufacturing, marketing, purchasing, or using products, processes, or procedures not conforming to the standards.

The American National Standards Institute does not develop standards and will in no circumstances give an interpretation to any American National Standard. Moreover, no person shall have the right or authority to issue an interpretation of an American National Standard in the name of the American National Standards Institute. Requests for interpretations should be addressed to the secretariat or sponsor whose name appears on the title page of this standard.

CAUTION NOTICE: This American National Standard may be revised at any time. The procedures of the American National Standards Institute require that action be taken to reaffirm, revise, or withdraw this standard no later than five years from the date of approval. Purchasers of American National Standards may receive current information on all standards by calling or writing the American National Standards Institute.

**Prepared by the IES Testing Procedures Committee:**

**KC Fletcher, *Chair***

**Andrew Jackson, *Vice Chair***

**David N. Randolph, *Secretary***

**Members**

|                  |                |                |               |
|------------------|----------------|----------------|---------------|
| C. K. Andersen   | J. Hospodarsky | K. M. Liepmann | E. Radkov     |
| R. P. Bergin     | J. N. Hulett   | S. Longo       | D. Rogers     |
| R. S. Bergman    | P.-C. Hung     | J. P. Marella  | M. B. Sapcoe  |
| E. Bretschneider | J. Jiao        | P. McCarthy    | J. C. Vollers |
| D. J. Ellis      | M. Kotrebai    | G. McKee       |               |
| M. L. Grather    | B. Kuebler     | C. C. Miller   |               |
| Y. H. Hiebert    | J. E. Leland   | S. Mitsuhashi  |               |

**Advisory Members**

|                  |                 |                |                 |
|------------------|-----------------|----------------|-----------------|
| L. M. Ayers      | P. Elizondo     | J. D. Kramer   | T. Schneider    |
| C. A. Bloomfield | A. A. Feldman   | K. C. Lerbs    | A. Serres       |
| B. Boudreaux     | J. Frazer       | J. Lockner     | G. A. Steinberg |
| P.-T. Chou       | K. J. Hemmi     | Y. Ohno        | L. Swainston    |
| P. Cruz          | S. Hua          | E. Page        | J. S. Swiernik  |
| M. Damle         | G. John         | D. Park        | S.-H. Teoh      |
| L. Davis         | J. Juhasz       | E. S. Perkins  | A. Thorseth     |
| J. J. Demirjian  | H. Kashaninejad | M. Piscitelli  | R. C. Tuttle    |
| M. E. Duffy      | T. Kawabata     | T. W. Rasinski | J. E. Walker    |
| V. Eberhard      | R. Kelley       | M. P. Royer    | Y. Zong         |

---

Please refer to the IES Bookstore for possible Errata: [www.ies.org](http://www.ies.org).  
An accompanying online calculator for ANSI/IES TM-21-21 is available: [www.ies.org/tools](http://www.ies.org/tools)

# CONTENTS

|            |                                                                                |          |
|------------|--------------------------------------------------------------------------------|----------|
| <b>1.0</b> | <b>Introduction and Scope</b>                                                  | <b>1</b> |
| 1.1        | Introduction                                                                   | 1        |
| 1.2        | Scope                                                                          | 1        |
| <b>2.0</b> | <b>Normative Reference</b>                                                     | <b>1</b> |
| <b>3.0</b> | <b>Definitions</b>                                                             | <b>1</b> |
| 3.1        | DUT                                                                            | 1        |
| 3.2        | LED light source                                                               | 2        |
| 3.3        | rated flux maintenance life, $T_p$                                             | 2        |
| <b>4.0</b> | <b>Data and Sample Size</b>                                                    | <b>2</b> |
| 4.1        | Data to Be Used                                                                | 2        |
| 4.2        | Sample Size Recommendation                                                     | 2        |
| 4.3        | Flux Data Collection                                                           | 2        |
| 4.4        | Sample Selection and Data Usage                                                | 2        |
| <b>5.0</b> | <b>Flux Maintenance Life Projection</b>                                        | <b>2</b> |
| 5.1        | Method                                                                         | 2        |
| 5.2        | Procedures                                                                     | 3        |
| 5.2.1      | Normalization                                                                  | 3        |
| 5.2.2      | Average                                                                        | 3        |
| 5.2.3      | Data Used for Curve-Fit                                                        | 3        |
| 5.2.4      | Curve-Fit                                                                      | 3        |
| 5.2.5      | Adjustment of Results                                                          | 4        |
| 5.2.6      | Notation for Projected Flux Maintenance Life                                   | 4        |
| 5.2.7      | Limit for Projecting Flux Maintenance                                          | 4        |
| <b>6.0</b> | <b>Temperature Data Interpolation</b>                                          | <b>4</b> |
| 6.1        | Select Tested Case Temperatures                                                | 5        |
| 6.2        | Convert All Temperatures to Kelvins                                            | 5        |
| 6.3        | Use the Arrhenius Equation to Calculate the Interpolated Flux Maintenance Life | 5        |
| <b>7.0</b> | <b>Current Data Interpolation</b>                                              | <b>5</b> |
| 7.1        | Select Tested Drive Currents                                                   | 5        |
| 7.2        | Interpolate Between Drive Currents                                             | 6        |

|                               |                                                                                                             |           |
|-------------------------------|-------------------------------------------------------------------------------------------------------------|-----------|
| <b>8.0</b>                    | <b>Simultaneous Temperature and Current Interpolation .....</b>                                             | <b>6</b>  |
| <b>8.1</b>                    | <b>Current Data Interpolation for the Lower In-Situ DUT Case Temperature Conditions.....</b>                | <b>6</b>  |
| <b>8.2</b>                    | <b>Current Data Interpolation for the Higher In-Situ DUT Case Temperature Conditions .....</b>              | <b>7</b>  |
| <b>8.3</b>                    | <b>Temperature Interpolation Between Lower and Higher Current Interpolated In-Situ Case Temperatures ..</b> | <b>7</b>  |
| <b>9.0</b>                    | <b>Limits for Extrapolation .....</b>                                                                       | <b>7</b>  |
| <b>10.0</b>                   | <b>Report .....</b>                                                                                         | <b>8</b>  |
| <b>Annex A</b>                | <b>– Rationale for the Recommended Data Extrapolation Method.....</b>                                       | <b>10</b> |
| <b>Annex B</b>                | <b>– Sample Size Selection for Data Extrapolation.....</b>                                                  | <b>12</b> |
| <b>Annex C</b>                | <b>– Least-Squares Formula .....</b>                                                                        | <b>12</b> |
| <b>Annex D</b>                | <b>– Limit for Duration of Prediction .....</b>                                                             | <b>13</b> |
| <b>Annex E</b>                | <b>– Data Test Set for Validation of Calculation – Examples.....</b>                                        | <b>14</b> |
| <b>Annex F</b>                | <b>– Consideration of Manufacturer’s Prediction Model.....</b>                                              | <b>29</b> |
| <b>Annex G</b>                | <b>– Analysis of Mathematical Modeling as a Method of Projecting Luminous Flux Maintenance Life .</b>       | <b>30</b> |
| <b>Annex H</b>                | <b>– Rationale for Method of Drive Current Interpolation .....</b>                                          | <b>36</b> |
| <b>Annex I</b>                | <b>– Analysis of Uncertainty of Calculated Values of Alpha.....</b>                                         | <b>37</b> |
| <b>Annex J</b>                | <b>– Interpolation of Value for <math>B</math> .....</b>                                                    | <b>39</b> |
| <b>Informative References</b> | <b>.....</b>                                                                                                | <b>41</b> |





## 1.0 Introduction and Scope

### 1.1 Introduction

One of the benefits that LED light sources can provide is very long usable life. Unlike other lighting technologies, LEDs typically do not fail catastrophically\* during use. However, over time the light output will gradually depreciate. At some point in time the light emitted from an LED depreciates to a level where it is no longer considered adequate for a specific application. It is important in lighting design to understand when this “useful lifetime” of an LED source is reached.

ANSI/IES LM-80 defines the setup, conditions, and procedures for performing luminous flux maintenance testing of LED light sources and is the IES standard that is used widely to measure the lumen depreciation behavior of LEDs. LED device manufacturers routinely provide ANSI/IES LM-80 reports for their products, with data collected during testing for 6,000 hours or more. However, how the data collected from ANSI/IES LM-80 testing is used to best determine the useful lifetime of the tested product is not well defined.

The rated flux maintenance life of an LED is the elapsed operating time over which an LED light source maintains a given percentage of its initial light output. It is defined as  $\tau_p$ , where  $\tau$  is the lumen, photon or radiant flux, and  $p$  is the percentage value. For example,  $L_{70}$  is the time (in hours) when the luminous flux output from the LED has dropped to 70% of initial;  $Q_{90}$  is the time (in hours) when the photon flux output from the LED has dropped to 90% of initial;  $R_{80}$  is the time (in hours) when the radiant flux output from the LED has dropped to 80% of initial. The flux maintenance of an LED light source is dependent upon many variables, including the operating temperature, drive current, and technology and materials used to construct the product. As such, the flux maintenance of LEDs can vary not only from manufacturer to manufacturer, but also between different LED package types produced by a single manufacturer.

\* Used in this sense, a “catastrophic failure” is a sudden failure that results in a complete inability to perform all required functions of an item. (Laplante, Philip A. Dictionary of Computer Science, Engineering and Technology. CRC Press, 2017)

This Technical Memorandum recommends a method of projecting the flux maintenance of LED light sources from the data obtained by ANSI/IES LM-80 testing.

This document was developed by a dedicated TM-21 Working Group of LED industry professionals. The analyses of the ANSI/IES LM-80-15 (the 2015 publication of ANSI/IES LM-80) test data provided by major LED manufacturers are used to rationalize and support this document. Much of the ANSI/IES LM-80-15 data came from testing that extended to 9,000 hours, and in some cases beyond.

Two additional notes are relevant here:

- In 2018, IES issued *PS-10-18, IES Position on LED Product Lifetime Prediction*.<sup>1</sup>
- An accompanying online calculator for ANSI/IES TM-21-21 is available: [www.ies.org/tools](http://www.ies.org/tools).

### 1.2 Scope

This document provides recommendations for projecting flux maintenance of LED light sources using data obtained when testing them per ANSI/IES LM-80.

This method shall not be used to project lumen, photon or radiant flux maintenance below 70%.

## 2.0 Normative Reference

Illuminating Engineering Society. *ANSI/IES LM-80-21, Approved Method: Measuring Luminous Flux and Color Maintenance of LED Packages, Arrays and Modules*. New York: IES; 2021.

## 3.0 Definitions

In addition to the terms defined in this section, illuminating engineering terms are defined in ANSI/IES LS-1-20.<sup>2</sup>

### 3.1 DUT

The *device under testing* is the LED light source as defined in **Section 3.2**.



### 3.2 LED light source

An LED package, array, or module that is operated via an auxiliary driver.\*

### 3.3 rated flux maintenance life, $\tau_p$

The elapsed operating time (hours) over which the LED light source will maintain the percentage,  $p$ , of its initial flux output\*; e.g.:

- $\tau_{70}$  = time to 70% flux maintenance
- $\tau_{90}$  = time to 90% flux maintenance
- $\tau$  =  $L$  (luminous flux),  $Q$  (photon flux), or  $R$  (radiant flux)

## 4.0 Data and Sample Size

### 4.1 Data to Be Used

The data to be used in this projection method shall be collected according to the methods described in ANSI/IES LM-80, provided the measurement intervals comply with the uniformity requirements of **Section 4.3**.

### 4.2 Sample Size Recommendation

All data from the sample set at a given case temperature and drive current from the ANSI/IES LM-80 test report for a specific product model should be used for flux maintenance life projection. The recommended number for the sample set is a minimum of 20 units in order to be able to use a multiplication factor of 6 times the test duration, as specified in **Section 5.2.5**, for flux maintenance life projection.

A sample size of fewer than 20 units may be used when specified by the requestor of the application of this estimation method. When a sample size smaller than 20 units is specified and used, the sample size shall be noted in any reporting of the use of this method. Any change in sample size will lead to a change in uncertainty and the time interval for the projection of the luminous flux maintenance life. For a sample size of 10 units, a multiplication factor of 5.5 times the test duration, as specified in **Section 5.2.5**, shall be used for flux maintenance life projection.

\* Per ANSI/IES LM-80; see **Section 2.0 Normative References**.

### 4.3 Flux Data Collection

Additional measurements after the initial 1,000 hours at intervals less than 1,000 hours are encouraged. Additional measurements beyond 6,000 hours are encouraged and will provide the basis for more accurate flux maintenance predictions.

Data collected within 48 hours (a 96-hour window) of each “1,000 hour measurement point”—e.g., for a 1,000-hour interval, data collected from 952 hours to 1,048 hours, or from 1,952 hours to 2,048 hours—are acceptable for use in product flux maintenance projections. This 48-hour leeway is also applicable to intervals smaller than 1,000 hours. The exact time designation shall be used in the projection calculation.

The same time interval requirements shall apply to luminous flux maintenance, photon flux maintenance and radiant flux maintenance projections.

### 4.4 Sample Selection and Data Usage

The DUT samples tested per ANSI/IES LM-80 shall be selected to be sufficiently representative of the overall population of the product. All data collected for the DUT samples tested per ANSI/IES LM-80 shall be used for projection, with the exception of failed DUT samples as defined in ANSI/IES LM-80. Specially built samples to be used as DUTs shall not be allowed. Selectively excluding data based on performance shall not be allowed.

## 5.0 Flux Maintenance Life Projection

### 5.1 Method

The recommended method of flux maintenance projection is the application of a curve-fit of the collected data to extrapolate the flux maintenance value to the time point where the flux output decreases to a predetermined level (for example, 70% of initial flux). This time point is the flux maintenance life. The same curve-fit of the collected data can also be used to determine the flux output level at specific time points (e.g., 25,000 hours, 35,000 hours).



This method is applied separately for each set of DUT test data collected at each operational (e.g., drive current) and environmental (e.g., case temperature) condition, as specified in ANSI/IES LM-80.

The procedures below outline the process for luminous flux maintenance projection. The same mathematical steps shall be followed for photon flux maintenance projection or radiant flux maintenance projection, with the substitution of photon flux data and use of  $Q_p$  or radiant flux data and use of  $R_p$ , respectively.

## 5.2 Procedures

**5.2.1 Normalization.** All collected data shall be normalized to a value of 1 (100%) at 0 hours for each DUT tested.

**5.2.2 Average.** The normalized measured data of all samples within the same data set defined in **Section 5.1** for each test condition at each measurement point shall be averaged.

**5.2.3 Data Used for Curve-Fit.** Data shall be collected according to the method described in **Section 4.3**.

For data sets of test duration  $D$  from 6,000 hours up to 10,000 hours, the data used for the curve-fits shall be applied to the last 5,000 hours of data. Data before the 1,000-hour reading shall not be used for the curve-fit.

The data collection points used in the projection calculation shall be at regular intervals (to within 48 hours). No two consecutive data collection intervals after the initial 1,000 hours shall differ by more than 96 hours in length. For example, data may be used in the projection calculation which are collected every 1,000 hours ( $\pm 48$  hours), or every 500 hours ( $\pm 48$  hours), but not every 1,000 hours and occasionally at 500 hours, since this would give excessive statistical weight to certain data points.

For data sets of test duration greater than 10,000 hours, the data for the last 50% of the total test duration shall be used for the curve-fit. In other words, all data points between  $D/2$  and  $D$  shall be used. For example, if the test duration is 13,000 hours, all data points between

6,500 hours and 13,000 hours are used. If there is no data point at  $D/2$ , then data from the next lower time point shall be included in the curve fit. For example, if the test duration is 13,000 hours, with data taken every 1,000 hours, all data points between 6,000 and 13,000 hours are used.

**5.2.4 Curve-Fit.** An exponential least-squares curve-fit is applied to the averaged values, as specified in **Section 5.2.3**, for the following equation (see **Annex E** for calculation examples):

$$\Phi(t) = B e^{-\alpha t},$$

where:

- $t$  = operating time in hours
- $\Phi(t)$  = averaged normalized flux output at time  $t$
- $B$  = projected initial constant derived by the least-squares curve-fit
- $\alpha$  = decay rate constant derived by the least-squares curve-fit

Use the following equations to project the luminous flux maintenance life:

$$\tau_{70} = \ln(B/0.7)/\alpha$$

or:

$$\tau_{90} = \ln(B/0.9)/\alpha$$

For any level of luminous flux maintenance, use the following generic form of the equation:

$$\tau_p = \ln(100B/p)/\alpha,$$

where:

- $\tau_p$  = flux maintenance life expressed in hours, where  $\tau = L$  for luminous flux,  $Q$  for photon flux, or  $R$  for radiant flux, and  $p$  is the percentage of initial flux output that is maintained.

When  $\alpha < 2.0 \times 10^{-6}$ , then the value of  $\alpha$  shall be set to  $2.0 \times 10^{-6}$ . To avoid step changes between collected data and projected flux maintenance, when the minimum value of  $\alpha$  is used the value of  $B$  shall be recalculated based on the last LM-80 data interval.

$$B_{\min\alpha} = \Phi_f e^{\alpha t},$$

where:

$B_{\min\alpha}$  =  $B$  value when minimum  $\alpha$  value is used

$\Phi_f$  = flux value at last LM-80 measurement interval

$t$  = last LM-80 measurement interval

Whenever a  $\Phi$  (normalized flux) value is reached experimentally in the course of ANSI/IES LM-80 testing, the reported value shall be obtained by linear interpolation between the two nearest test points and takes precedence over any value projected by the formulas above.

**5.2.5 Adjustment of Results.** For a sample size of 20 units or more, flux maintenance values shall not be projected beyond 6 times the total test duration (in hours) of measured data. For a sample size of 10 to 19 units, flux maintenance values shall not be projected beyond 5.5 times the total test duration of measured data.

When the calculated flux maintenance life (e.g.,  $\tau_{70}$ ) is less than or equal to 6 times (5.5 times for a sample size of 10 to 19 units) the total test duration, the calculated flux maintenance life is the reported flux maintenance life.

When the calculated flux maintenance life (e.g.,  $\tau_{70}$ ) is greater than 6 times (5.5 times for a sample size of 10 to 19 units) the total test duration, the reported flux maintenance life value is limited to 6 times (5.5 times for a sample size of 10 to 19 units) the total test duration.

#### 5.2.6 Notation for Projected Flux Maintenance Life.

The flux maintenance life projected in this method shall be expressed using the following notation:

$\tau_p (D \text{ k}) [y, z]$ ,

where:

$\tau$  =  $L$  for luminous flux,  $Q$  for photon flux, or  $R$  for radiant flux and  $p$  is the percentage of initial flux output that is maintained

$D$  = the total duration of the test in hours divided by 1,000 and rounded to a nearest integer.

$y$  = the minimum wavelength evaluated in nm (for photon flux or radiant flux)

$z$  = the maximum wavelength evaluated in nm (for photon flux or radiant flux)

For example:

$L_{70}(6k)$  indicates 6,000 hours of test data for luminous flux maintenance

$Q_{90}(10k) [400, 700]$  indicates data from 400 to 700 nm and 10,000 hours of test data for photon flux maintenance

$R_{70}(8k) [350, 850]$  indicates data from 350 to 850 nm and 8,000 hours of test data for radiant flux maintenance

If the calculated  $\tau_p$  value is limited to the test duration (see **Section 5.2.5**), the flux maintenance life value shall be expressed with a "greater-than" (>) symbol. For example:

- $\tau_{70}(6k) > 36,000$  hours (at  $\tau_s = 55^\circ\text{C}$ ,  $I_F = 350$  mA) for a sample size of 20 or more units
- $\tau_{70}(6k) > 33,000$  hours (at  $\tau_s = 55^\circ\text{C}$ ,  $I_F = 350$  mA) for a sample size of 10 to 19 units

If the  $\tau_p$  value is reached experimentally in the course of ANSI/IES LM-80 testing, then the flux maintenance life shall be expressed with the  $D$  value equal to the  $\tau_p$  value in hours divided by 1,000 and rounded to a nearest integer. For example:

$\tau_{70}(4k) = 4,400$  hours (at  $\tau_s = 55^\circ\text{C}$ ,  $I_F = 350$  mA)

#### 5.2.7 Limit for Projecting Flux Maintenance.

As explained in **Annex A** it is possible for the flux maintenance behavior of a DUT to change over time and at different flux maintenance levels. For this reason, this method shall not be used to project lumen, photon, or radiant flux maintenance below 70%.

## 6.0 Temperature Data Interpolation

When in-situ DUT case temperature,  $T_{s,ir}$  is different from the temperatures used for ANSI/IES LM-80 tests (e.g.,  $55^\circ\text{C}$ ,  $85^\circ\text{C}$ , and a third temperature provided by the DUT manufacturer), the following procedures shall be used to predict flux maintenance life of the DUT

corresponding to the in-situ case temperature with the same operational condition (e.g., drive current).

### 6.1 Select Tested Case Temperatures

The tested case temperatures used for in-situ case temperature flux maintenance life interpolation shall include the closest lower temperature,  $T_{s,1}$ , and the closest higher temperature,  $T_{s,2}$ , to the in-situ case temperature to be interpolated.

### 6.2 Convert All Temperatures to Kelvins

The following formula shall be used to convert the temperatures to the unit of kelvins:

$$T_s[\text{K}] = T_s[^\circ\text{C}] + 273.15$$

Only values expressed in kelvins shall be used in the calculations shown in the following sections.

### 6.3 Use the Arrhenius Equation to Calculate the Interpolated Flux Maintenance Life

The Arrhenius equation shown below shall be used to calculate in-situ decay rate constant  $\alpha_i$ :

$$\alpha_i = A \exp\left(\frac{-E_a}{k_B T_{s,1}}\right),$$

where:

$A$  = pre-exponential factor

$E_a$  = activation energy (eV)

$T_{s,i}$  = in-situ absolute temperature (K)

$k_B$  = Boltzmann's constant ( $8.617385 \times 10^{-5}$  eV/K)

The following intermediate calculation steps need to be carried out in order to find the decay rate constant  $\alpha_i$  at an in-situ temperature  $T_{s,i}$  between  $T_{s,1}$  and  $T_{s,2}$ .

**Step 1:** Obtain  $\alpha_1$  and  $\alpha_2$  for the two temperatures  $T_{s,1}$  and  $T_{s,2}$ , which were calculated in the curve-fits performed per **Section 5.2.4**. Calculate the ratio of  $E_a/k_B$ :

$$E_a/k_B = (\ln \alpha_1 - \ln \alpha_2) / \left( \frac{1}{T_{s,2}} - \frac{1}{T_{s,1}} \right)$$

**Step 2:** Using the above ratio, plug in  $T_{s,1}$  to calculate pre-exponential factor  $A$ :

$$A = \alpha_1 \exp\left(\frac{E_a}{k_B T_{s,1}}\right)$$

The above equation can also be used for substituting  $\alpha_1$  and  $T_{s,1}$  with  $\alpha_2$  and  $T_{s,2}$ .

**Step 3:** Calculate  $B_0$ :

$$B_0 = m_B T_{s,i} + b_B,$$

where:

$T_{s,i}$  = interpolation temperature

$m_B = (B_2 - B_1) / (T_{s,2} - T_{s,1})$

$b_B = B_1 - m_B T_{s,1}$

$B_1$  = projected initial constant for lower temperature ( $T_{s,1}$ ) case

$B_2$  = projected initial constant for higher temperature ( $T_{s,2}$ ) case

**Step 4:** Using the above result for  $B_0$ , calculate flux maintenance life,  $\tau_p$ , for in-situ case temperature  $T_{s,i}$ :

$$\tau_p = \ln(100 B_0 / p) / \alpha_i$$

Results from the above calculation steps, as well as the parameters used in the calculations, are reported in **Table 10-2** (see **Section 10.0 Report**).

**Step 5:** Calculate the in-situ flux output at time  $t$ ,  $\Phi_i(t)$ , for  $T_{s,i}$  as:

$$\Phi_i(t) = B_0 \exp(-\alpha_i t)$$

The reader is referred to **Annex E** for calculation examples.

## 7.0 Current Data Interpolation

When in-situ DUT drive current,  $I_{s,i}$ , is different from the drive current used for ANSI/IES LM-80 tests (e.g., ANSI/IES LM-80 DUT drive current = 350 mA and 700 mA, in-situ current = 520 mA), the following procedures shall be used to predict flux maintenance life of the DUT corresponding to the drive current with the same case temperature.

### 7.1 Select Tested Drive Currents

The tested drive currents used for drive current luminous flux maintenance life interpolation shall contain the



closest lower drive current,  $I_{s,1}$ , and the closest higher drive current,  $I_{s,2}$ , to the drive current to be interpolated. For DUTs with a maximum input power of 0.6 W or lower, the difference in drive current between any two data points being used for current interpolation shall not exceed a factor of 1.5. For DUTs with a maximum input power greater than 0.6 W, the difference in drive current between any two data points being used for current interpolation shall not exceed a factor of 2.

## 7.2 Interpolate Between Drive Currents

Use a linear function of temperature to interpolate  $\alpha$ , used to calculate the interpolated flux maintenance life.

*Step 1:* The linear equation below shall be used to calculate in-situ decay rate constant  $\alpha_i$ :

$$\alpha_i = m_\alpha I_{s,i} + b_\alpha,$$

where:

$$m_\alpha = (\alpha_2 - \alpha_1)/(I_{s,2} - I_{s,1})$$

$$b_\alpha = \alpha_1 - m_\alpha I_{s,1}$$

*Step 2:* Calculate  $B_0$ :

$$B_0 = m_B I_{s,i} + b_B,$$

where:

$$m_B = (B_2 - B_1)/(I_{s,2} - I_{s,1})$$

$$b_B = B_1 - m_B I_{s,1}$$

$B_1$  = projected initial constant for lower temperature ( $T_{s,1}$ ) case

$B_2$  = projected initial constant for higher temperature ( $T_{s,1}$ ) case

*Step 3:* Using the above result of  $B_0$ , calculate the flux maintenance life, or  $\tau_p$ , for drive current  $I_{s,i}$  as:

$$\tau_p = \ln(100 B_0 / p) / \alpha_i$$

Results from the above calculation steps, as well as the parameters used in the calculations, are reported in the **Table 10-2** (see **Section 10.0 Report**).

*Step 4:* Calculate the in-situ flux output at time  $t$ ,  $\Phi_i(t)$ , for  $I_{s,i}$  as:

$$\Phi_i(t) = B_0 \exp(-\alpha_i t)$$

The reader is referred to **Annex E** for calculation examples.

## 8.0 Simultaneous Temperature and Current Interpolation

When in-situ DUT drive current,  $I_{s,i}$ , and in-situ DUT case temperature,  $T_{s,i}$ , are different from the ANSI/IES LM-80 values, the following procedures shall be used to predict luminous flux maintenance life of the DUT corresponding to the drive current and in-situ DUT case temperature.

In general, this procedure requires a total of four data points. For clarity, the low temperature, low current point is referred to using the subscript (1, 1). The low temperature, high current data point is referred to using the subscript (1, 2). Similarly, the high temperature, low current data point is referred to using the subscript (2, 1). The high temperature, high current data point is referred to using the subscript (2, 2).

As with current interpolation, the difference in drive current between any two data points being used for current interpolation for DUTs with a maximum rated input power of 0.6 W or less shall not exceed a factor of 1.5. The difference in drive current between any two data points used for current interpolation for DUTs with a maximum rated input power greater than 0.6 W shall not exceed factor of 2.0.

### 8.1 Current Data Interpolation for the Lower In-Situ DUT Case Temperature Conditions

This is the in-situ DUT case temperature at the closest temperature below the interpolation temperature,  $T_1$ , that includes at least two drive currents such that at least one drive current is above the interpolation drive current and one drive current is below the drive current. Current interpolation at the highest temperature that meets these requirements shall be used to create a first-temperature interpolation point using the current interpolation procedure as per **Section 7.1**. The closest drive currents to the interpolation current shall be used (i.e., the closest drive current below the interpolation drive current,  $I_{1,1}$ , and the closest drive current above the interpolation current,  $I_{1,2}$ . If a data point exists at the same drive current as the interpolation current and is at the closest lower temperature to the interpolation temperature, that data point shall be used for interpolating with the higher temperature condition.

When this type of interpolation is necessary, the following formulas shall be used:

$$\begin{aligned} m_{\alpha,1} &= (\alpha_{1,2} - \alpha_{1,1}) / (I_{1,2} - I_{1,1}) \\ b_{\alpha,1} &= \alpha_{1,2} - m_{\alpha,1} I_{1,2} \\ \alpha_{i,1} &= m_{\alpha,1} I_i + b_{\alpha,1} \\ m_{B,1} &= (B_{1,2} - B_{1,1}) / (I_{1,2} - I_{1,1}) \\ b_{B,1} &= B_{1,2} - m_{B,1} I_{1,2} \\ B_{i,1} &= m_{B,1} I_i + b_{B,1} \end{aligned}$$

## 8.2 Current Data Interpolation for the Higher In-Situ DUT Case Temperature Conditions

This is the in-situ DUT case temperature at the closest temperature above the interpolation temperature,  $T_2$ , that includes at least two drive currents such that at least one drive current is above the interpolation drive current and one drive current is below the drive current. Current interpolation at the lowest temperature that meets these requirements shall be used to create a second temperature interpolation point using the current interpolation procedure as per **Section 7.1**. The closest drive currents to the interpolation shall be used (i.e., the closest drive current below the interpolation drive current,  $I_{2,1}$ , and the closest drive current above the interpolation current,  $I_{2,2}$ . If a data point exists at the same drive current as the interpolation current and is at the closest higher temperature to the interpolation temperature, that data point shall be used for interpolating with the lower temperature condition.

When this type of interpolation is necessary, the following formulas shall be used:

$$\begin{aligned} m_{\alpha,2} &= (\alpha_{2,2} - \alpha_{2,1}) / (I_{2,2} - I_{2,1}) \\ b_{\alpha,2} &= \alpha_{2,2} - m_{\alpha,2} I_{2,2} \\ \alpha_{i,2} &= m_{\alpha,2} I_i + b_{\alpha,2} \\ m_{B,2} &= (B_{2,2} - B_{2,1}) / (I_{2,2} - I_{2,1}) \\ b_{B,2} &= B_{2,2} - m_{B,2} I_{2,2} \\ B_{i,2} &= m_{B,2} I_i + b_{B,2} \end{aligned}$$

## 8.3 Temperature Interpolation Between Lower and Higher Current Interpolated In-Situ Case Temperatures

Temperature interpolation is performed as per **Section 6.3** using the interpolated current values at the lower in-situ DUT case temperature,  $T_1$ , and the higher in-situ DUT case temperature,  $T_2$ .

**Step 1:** Convert in-situ DUT case temperatures to kelvins:

$$\begin{aligned} T_{A,1}[\text{K}] &= T_1[^\circ\text{C}] + 273.15 \\ T_{A,2}[\text{K}] &= T_2[^\circ\text{C}] + 273.15 \\ T_{A,i}[\text{K}] &= T_i[^\circ\text{C}] + 273.15 \end{aligned}$$

**Step 2:** Calculate the ratio of  $E_a/k_B$ :

$$\frac{E_a}{k_B} = \frac{\ln(\alpha_{i,1}) - \ln(\alpha_{i,2})}{\frac{1}{T_{A,2}} - \frac{1}{T_{A,1}}}$$

**Step 3:** Calculate the pre-exponential factor  $A$ :

$$A = \alpha_{i,1} \exp\left(\frac{E_a}{k_B T_{A,1}}\right)$$

**Step 4:** Calculate the in-situ DUT case temperature interpolated value of  $\alpha$ :

$$\alpha_i = A \exp\left(\frac{-E_a}{k_B T_{A,i}}\right)$$

**Step 5:** Calculate  $B_0$ :

$$m_B = (B_{i,2} - B_{i,1}) / (T_{A,2} - T_{A,1}),$$

where:

$$\begin{aligned} b_B &= B_{i,1} - m_B T_{A,1} \\ B_0 &= m_B T_{A,i} + b_B \end{aligned}$$

**Step 6:** Calculate flux maintenance life, or  $\tau_p$ , for the interpolated drive current and interpolated in-situ DUT case temperature:

$$\tau_p = \frac{\ln\left(\frac{100 B_0}{p}\right)}{\alpha_i}$$

Results from the above calculation steps, as well as the parameters used in the calculations, are reported in **Table 10-2** (see **Section 10.0 Report**).

The reader is referred to **Annex E** for calculation examples.

## 9.0 Limits for Extrapolation

Extrapolation of any  $\tau_p$ , (luminous flux maintenance life, photon flux maintenance life, or radiant flux



Documents

Document Sharing Hub