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COMMISSION INTERNATIONALE DE L'ECLAIRAGE
INTERNATIONAL COMMISSION ON ILLUMINATION
INTERNATIONALE BELEUCHTUNGSKOMMISSION

TECHNICAL REPORT

CONTROL OF DAMAGE TO MUSEUM OBJECTS BY OPTICAL RADIATION

CIE 157:2004

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Descriptor: Influence of radiation
Fastness to light

THE INTERNATIONAL COMMISSION ON ILLUMINATION

The International Commission on Illumination (CIE) is an organisation devoted to international co-operation and exchange of information among its member countries on all matters relating to the art and science of lighting. Its membership consists of the National Committees in 38 countries and one geographical area and of 4 associate members.

The objectives of the CIE are:

1. To provide an international forum for the discussion of all matters relating to the science, technology and art in the fields of light and lighting and for the interchange of information in these fields between countries.
2. To develop basic standards and procedures of metrology in the fields of light and lighting.
3. To provide guidance in the application of principles and procedures in the development of international and national standards in the fields of light and lighting.
4. To prepare and publish standards, reports and other publications concerned with all matters relating to the science, technology and art in the fields of light and lighting.
5. To maintain liaison and technical interaction with other international organisations concerned with matters related to the science, technology, standardisation and art in the fields of light and lighting.

The work of the CIE is carried on by seven Divisions each with about 20 Technical Committees. This work covers subjects ranging from fundamental matters to all types of lighting applications. The standards and technical reports developed by these international Divisions of the CIE are accepted throughout the world.

A plenary session is held every four years, at which the work of the Divisions and Technical Committees is reviewed, reported and plans are made for the future. The CIE is recognised as the authority on all aspects of light and lighting. As such it occupies an important position among international organisations.

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La Commission Internationale de l'Eclairage (CIE) est une organisation qui se donne pour but la coopération internationale et l'échange d'informations entre les Pays membres sur toutes les questions relatives à l'art et à la science de l'éclairage. Elle est composée de Comités Nationaux représentant 38 pays plus un territoire géographique, et de 4 membres associés.

Les objectifs de la CIE sont :

1. De constituer un centre d'étude international pour toute matière relevant de la science, de la technologie et de l'art de la lumière et de l'éclairage et pour l'échange entre pays d'informations dans ces domaines.
2. D'élaborer des normes et des méthodes de base pour la métrologie dans les domaines de la lumière et de l'éclairage.
3. De donner des directives pour l'application des principes et des méthodes d'élaboration de normes internationales et nationales dans les domaines de la lumière et de l'éclairage.
4. De préparer et publier des normes, rapports et autres textes, concernant toutes matières relatives à la science, la technologie et l'art dans les domaines de la lumière et de l'éclairage.
5. De maintenir une liaison et une collaboration technique avec les autres organisations internationales concernées par des sujets relatifs à la science, la technologie, la normalisation et l'art dans les domaines de la lumière et de l'éclairage.

Les travaux de la CIE sont effectués par 7 Divisions, ayant chacune environ 20 Comités Techniques. Les sujets d'études s'étendent des questions fondamentales, à tous les types d'applications de l'éclairage. Les normes et les rapports techniques élaborés par ces Divisions Internationales de la CIE sont reconnus dans le monde entier.

Tous les quatre ans, une Session plénière passe en revue le travail des Divisions et des Comités Techniques, en fait rapport et établit les projets de travaux pour l'avenir. La CIE est reconnue comme la plus haute autorité en ce qui concerne tous les aspects de la lumière et de l'éclairage. Elle occupe comme telle une position importante parmi les organisations internationales.

DIE INTERNATIONALE BELEUCHTUNGSKOMMISSION

Die Internationale Beleuchtungskommission (CIE) ist eine Organisation, die sich der internationalen Zusammenarbeit und dem Austausch von Informationen zwischen ihren Mitgliedsländern bezüglich der Kunst und Wissenschaft der Lichttechnik widmet. Die Mitgliedschaft besteht aus den Nationalen Komitees in 38 Ländern und einem geographischen Gebiet und aus 4 assoziierten Mitgliedern.

Die Ziele der CIE sind:

1. Ein internationaler Mittelpunkt für Diskussionen aller Fragen auf dem Gebiet der Wissenschaft, Technik und Kunst der Lichttechnik und für den Informationsaustausch auf diesen Gebieten zwischen den einzelnen Ländern zu sein.
2. Grundnormen und Verfahren der Meßtechnik auf dem Gebiet der Lichttechnik zu entwickeln.
3. Richtlinien für die Anwendung von Prinzipien und Vorgängen in der Entwicklung internationaler und nationaler Normen auf dem Gebiet der Lichttechnik zu erstellen.
4. Normen, Berichte und andere Publikationen zu erstellen und zu veröffentlichen, die alle Fragen auf dem Gebiet der Wissenschaft, Technik und Kunst der Lichttechnik betreffen.
5. Liaison und technische Zusammenarbeit mit anderen internationalen Organisationen zu unterhalten, die mit Fragen der Wissenschaft, Technik, Normung und Kunst auf dem Gebiet der Lichttechnik zu tun haben.

Die Arbeit der CIE wird in 7 Divisionen, jede mit etwa 20 Technischen Komitees, geleistet. Diese Arbeit betrifft Gebiete mit grundlegendem Inhalt bis zu allen Arten der Lichtanwendung. Die Normen und Technischen Berichte, die von diesen international zusammengesetzten Divisionen ausgearbeitet werden, sind von der ganzen Welt anerkannt.

Tagungen werden alle vier Jahre abgehalten, in der die Arbeiten der Divisionen überprüft und berichtet und neue Pläne für die Zukunft ausgearbeitet werden. Die CIE wird als höchste Autorität für alle Aspekte des Lichtes und der Beleuchtung angesehen. Auf diese Weise unterhält sie eine bedeutende Stellung unter den internationalen Organisationen.

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This Technical Report has been prepared by CIE Technical Committee 3-22 of Division 3 “Interior Environment and Lighting Design” and has been approved by the Board of Administration of the Commission Internationale de l’Éclairage for study and application. The document reports on current knowledge and experience within the specific field of light and lighting described, and is intended to be used by the CIE membership and other interested parties. It should be noted, however, that the status of this document is advisory and not mandatory. The latest CIE proceedings or CIE NEWS should be consulted regarding possible subsequent amendments.

Ce rapport technique a été élaboré par le Comité Technique CIE 3-22 de la Division 3 “Environnement intérieur et étude de l’éclairage” et a été approuvé par le Bureau de la Commission Internationale de l’Éclairage, pour étude et emploi. Le document expose les connaissances et l’expérience courantes dans le domaine particulier de la lumière et de l’éclairage décrit ici. Il est destiné à être utilisé par les membres de la CIE et par tout les intéressés. Il faut cependant noter que ce document est indicatif et non obligatoire. Il faut consulter les plus récents comptes rendus de la CIE, ou le CIE NEWS, en ce qui concerne des amendements nouveaux éventuels.

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FOREWORD

The following members of TC 3-22 "Museum lighting" took part in the preparation of this Technical Report. The TC comes under CIE Division 3 "Interior Environment and Lighting Design". This present report replaces CIE 89/3-1991 "On the deterioration of exhibited museum objects by optical radiation".

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Committee meetings have been conducted in various centres to suit the changing focus of the committee's work:

New York, USA	July 1994
Paris, France	September 1994
Berlin, Germany	February 1995
New Delhi, India	November 1995
London, United Kingdom	February 1996
Berlin, Germany	October 1996
Seattle, USA	August 1997
Ottawa, Canada	September 1997
London, United Kingdom	February 1998
Ottawa, Canada	May 1998
Warsaw, Poland	June 1999

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CONTROL OF DAMAGE TO MUSEUM OBJECTS BY OPTICAL RADIATION

SUMMARY

The report comprises three parts. The first part reviews the scientific principles that govern the processes of radiation-induced damage to museum objects with the aim of providing fundamental information for museum conservators and research workers. The second part reviews current knowledge and recent research to provide a commentary on the efforts of researchers to better understand how these processes may be retarded or eliminated in the museum environment. The final part gives the committee's recommendations for lighting in museums in the form of a practical procedure that covers setting up a new display and monitoring the lighting during the life of the display. This procedure takes account of the research findings that have been reviewed as well as recommendations published by other organisations, and is modelled on current practice in several of the world's leading museum institutions.

MAITRISE DES DEGRADATIONS OCCASIONEES PAR LES RADIATIONS OPTIQUES AUX COLLECTIONS MUSEALES

RESUME

Le présent rapport est constitué de trois parties. La première partie est un rappel des principes scientifiques qui régissent les dégradations induites par les radiations optiques aux objets de musée avec comme objectif de donner au personnel des musées une information de base. La seconde partie fait le point sur les connaissances actuelles et les derniers travaux des chercheurs réalisés dans le but de mieux envisager les moyens à mettre en œuvre pour retarder, voire éliminer les causes de ces dégradations. La dernière partie donne les recommandations du comité pour un éclairage muséographique, sous une forme pratique, par la mise en place de nouvelles présentations et d'un contrôle de la lumière durant celles-ci. Ces recommandations tiennent compte aussi bien des études citées dans le rapport que des recommandations éditées par d'autres organismes, le tout à la lumière de la pratique en place dans les principaux musées du monde.

BEGRENZUNG DES SCHADENS AN MUSEUMSOBJEKTEN DURCH OPTISCHE STRAHLUNG

ZUSAMMENFASSUNG

Der Bericht besteht aus drei Teilen. Der erste Teil gibt einen Überblick über die wissenschaftlichen Grundlagen der durch Strahlung verursachten Schädigungsprozesse an musealen Objekten. Das Ziel dabei ist, grundlegende Information für Museumskonservatoren und wissenschaftliche Mitarbeiter bereitzustellen. Der zweite Teil gibt einen Überblick über aktuelle Forschungsarbeiten und den Kenntnisstand zur Erläuterung der Bemühungen von Forschern, um besser zu verstehen, wie diese Prozesse im Bereich von Museen verzögert oder eliminiert werden können. Der letzte Teil enthält Empfehlungen des Komitees hinsichtlich der Beleuchtung in Museen in Form einer praktischen Vorgehensweise für die Darbietung eines neuen Ausstellungsgegenstandes und für die Überwachung der Beleuchtung während dessen Ausstellungszeit. Das Verfahren berücksichtigt die hier behandelten wissenschaftlichen Ergebnisse, aber auch Empfehlungen, die von anderen Organisationen veröffentlicht wurden, und folgt der gängigen Praxis von einigen der führenden Museumsinstitutionen der Welt.

INTRODUCTION

This report comprises three parts.

- Part 1 reviews the scientific principles of radiation exposure and conservation.
- Part 2 reviews current knowledge and recent research.
- Part 3 gives recommendations for lighting in museums.

Parts 1 and 2 comprise important information for professional conservators and research workers, but it is expected that some museum staff and exhibitions designers will choose to turn directly to Part 3.

The starting point for the committee's work was CIE 89/3-1991 (CIE, 1991), which had established a basis for relating the optical radiation exposure of an object to the photochemical response of the object. Initially the committee's intention was to develop this approach so that it could be applied to the practical task of controlling the degradation of museum exhibits.

The CIE 89/3-1991 (CIE, 1991) approach depends upon the action spectrum of the receiving object being defined, and in practical situations this incurs several problems. Materials vary in both absolute and relative spectral responsivity, and many museum objects comprise a combination of materials. However, recent research has made important contributions to knowledge of how museum materials react to exposure, and the work initiated by Prof. Jürgen Krochmann and continued by his colleagues in Berlin deserves particular mention. These researchers have selectively exposed a range of typical museum material samples, and from data of measured colour shifts have derived typical responsivity functions for several material groups. Each of these groups is defined by a logarithmic responsivity function, and this suggested a practical means of enabling museum staff to predict visible effects of exposure. For a given lamp and filter combination, the duration of exposure that would cause a given material to undergo a just noticeable change of colour is shown to be inversely proportional to the illuminance.

Attempts to apply this approach to practical situations revealed fundamental problems. The formulae defining the responsivity functions do not distinguish between radiant energy that is visually useful and that which is not. Large gains in permitted exposure are obtained by reducing short-wavelength radiation, so that long-wavelength rich light sources are always favoured regardless of the visual effect intended by the lighting designer. Furthermore, as only photochemical degradation is considered, the detrimental effects of infra-red exposure are ignored.

For these reasons, the committee has recommended a procedure that seeks to give lighting designers opportunities to achieve their display objectives while avoiding unnecessary exposure of the exhibits, and where necessary, achieving control by restricting the duration of exposure.

For Part 1, the committee's aim has been to outline the known facts that govern the processes of radiation-induced damage to museum objects. Part 2 provides a commentary on the efforts of researchers to better understand how these processes may be retarded or eliminated in the museum environment. The recommendations given in Part 3 are based upon these research findings, but clearly, this is a developing field and it must be expected that notions of good practice will change as research progresses and the technology of control develops. References are given throughout the document for more detailed information.

The committee's aim has been to give recommendations for good lighting practice wherever the conservation of museum objects is a cause for concern. These recommendations are modelled on the lighting policies in leading national institutions, and are considered to represent practical standards to which all museums should aspire. They include procedures for setting up lighting for a new display and for periodic monitoring during the life of a display, and in several respects these differ from conventional current practice. After much discussion, the committee has proposed a four-category material classification for limiting light exposure that includes a high responsivity category, for which permanent display is precluded. Also, the committee arrived at the decision that there is no rational basis for

recommending that museum objects may be subjected to any level of ultraviolet exposure, and elimination of UV is recommended.

It is recognised that some museums will decide that not all of its displays need to be fully compliant with the committee's recommendations. Some objects may be classified as inresponsive to radiation exposure, while others may be considered to have a limited lifespan, or to be of insufficient value to justify the expense of instituting the recommended procedure. In any such cases, the museum should consider all aspects of the committee's recommendations to ensure that its own policy is comprehensive. Also, staff should be alerted to the risks of putting light-responsive objects on long-term display in non-compliant conditions.

1. THE SCIENTIFIC PRINCIPLES

1.1 The processes of damage to museum objects

It is natural for many substances to change with time. Nature has provided processes to dismantle the substances produced by organic growth in order to provide for recycling of the molecules that are the building blocks of life on this planet. Even inorganic substances are not necessarily permanent, although change may occur much more slowly.

The principal aim of conservation policies in museums is to retard these processes, and these policies must address all causes of change that might affect objects in the museum's collection. It is only in the case of exposure to light that the needs for conservation and display are directly in conflict. For the conservation of many materials, the ideal environment would be completely dark.

There are two processes by which exposure to light may cause damage:

- Photochemical action;
- Radiant heating effect.

1.2 Photochemical action

1.2.1 The process of photochemical action

Photochemical action is the process by which a molecule undergoes a chemical change, with the activation energy for the change being derived from the absorption of a photon. While the initial event of the photon absorption is independent of the surrounding environment, subsequent chemical actions may be strongly affected by environmental factors such as temperature and humidity. The photon absorption may be the initial stage in a complex series of chemical changes, but whether or not the process is complex, the change is irreversible. All forms of chemical action affecting museum objects constitute damage, and where the aim is to minimise the effects of photochemical action on museum objects, the museum must have a comprehensive policy for environmental control.

Materials differ substantially in their responsivity to light exposure. The process by which a photographic film forms an image is also due to photochemical action, and obviously, even the most susceptible museum objects, including photographic prints, have low sensitivities in comparison with unexposed photographic emulsion materials. Even so, unless an object is totally irresponsive to light exposure, for every incident photon there is a finite probability of permanent damage. There is no safe level of exposure for a light-responsive object.

1.2.2 Effects of photochemical action

Colour change is usually the most obvious indication of light-induced damage to museum objects. The appearance of fading is well known, but the visible effects of photochemical action may be quite different. It can cause some colorants to darken, and some to undergo changes of hue that are quite unlike the yellowing and lightening associated with fading.

The other main effect of light-induced damage is loss of strength, which may be evident as fraying of fibres on fabrics, or embrittlement and surface cracking of artefacts. These effects may be difficult to distinguish from effects of radiant heating discussed in Section 1.3.

1.2.3 Causes of photochemical action

Four factors determine the level of photochemical action:

- Irradiance;
- Duration of exposure;
- Spectral power distribution of incident radiation;
- Action spectrum of receiving material.

1.2.4 Irradiance and duration of exposure

The principle that, for a given source of irradiation, exposure (H) is the integration of irradiance and time may be referred to as the Reciprocity Law, or the Bunsen-Roscoe Law, or, as in this document, the Reciprocity Principle. Whichever title is used, the principle may be expressed as:

$$H = \int_t E_e dt \quad \text{Wh/m}^2 \quad (1.1)$$

where

E_e is irradiance incident on the surface (W/m^2)

t is time in hours (h)

When E_e is constant, as with electric lighting, the equation takes the simple form:

$$H = E_e \cdot t$$

According to this principle, a total exposure of 10 W/m^2 for 10 hours is equivalent to 20 W/m^2 for 5 hours or 5 W/m^2 for 20 hours if the spectral power distribution is the same. It should be noted that the principle is defined in terms of irradiance, which is a measure of the density of incident radiant power, or as it is referred to hereafter, incident radiant flux. It needs to be recognised that illuminance is not a reliable alternative measure, as it represents the density of luminous flux, being radiant flux evaluated according to a typical human visual response, defined by the photopic spectral luminous efficiency function $V(\lambda)$. Not only does illuminance take no account of irradiance outside the visible spectrum, but also radiant flux within the visible spectrum is weighted according to its relative visual effect, which is not related to its damage effect. Illuminance meters are reasonably affordable and easy to operate, whereas meters that measure radiant flux irrespective of wavelength are more specialised scientific instruments. It is common practice for museum staff to use an illuminance meter to monitor light exposure, but they should be aware that an illuminance reading can not alert them to the presence of non-visible radiation, either UV or IR, nor is it an entirely reliable indicator of the damage effect due to visible radiant flux. Some hand-held UV meters are available, but it is important to check that the spectral range covered is appropriate for conservation assessments. These instruments are useful only for checking the presence of UV. They can not indicate the extent of possible damage, because for this both the UV spectrum and the action spectrum of the receiving object must be known. See Section 3.2 for more discussion of this topic.

The aim of preventive conservation is to retard the photochemical process and extend it over many years, and this makes it more likely that extraneous factors will complicate the process. For example, the radiant heating effect of lighting may raise the surface temperature of the object to the extent that chemical reactions which may follow photochemical action are accelerated. Also, as discussed in the following subsection, the spectral power distribution of the incident radiant flux affects the rate of photochemical action.

1.2.5 Spectral power distribution of incident irradiation

Radiant flux, which includes ultraviolet (UV), visible and infrared (IR) wavebands may be envisaged as a stream of photons in which each photon is a discrete energy package. Photons differ widely in energy level, although they all travel at the same velocity in vacuum. Photon energy level E (Joules) is directly proportional to frequency, and is given by the expression:

$$E = h \nu \quad \text{J} \quad (1.2)$$

where h is Planck's constant, a number that relates the units of frequency to energy

($h = 6,626 \times 10^{-34} \text{ J s}$)

ν is frequency (Hz)

The photons are the "bullets" that trigger photochemical reactions, and if absorbed, their energy levels indicate their potential to cause damage (Feller, 1964). Different molecules have different photon energy thresholds. A molecule that is highly responsive to light exposure will have a low photon energy threshold, so that a low level of photon energy is sufficient to trigger a chemical change.