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RESEARCH OF OPTICAL RADIATION IMPACT ON MATERIALS OF MUSEUM EXHIBITS AND REQUIREMENTS TO MEASUREMENT DEVICES

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ABSTRACT

LED lighting creates capability of the best representation of museum exhibits and creation of additional light perception effects. It also allows us to use the results of light and colour measurements for adjustment of quantity and quality of lighting. Photometric devices may become permanent assistants in decoration of exhibitions and museum premises. Even more important are photometers for monitoring of acceptable level of illuminance and UV irradiance. With correct evaluation of adverse impact of LED lighting, there is an opportunity to significantly increase the permitted level of exhibits lighting, which is a permanent requirement by designers. The recommendations for standardisation of lighting are based on results of special studies performed with consideration of material light-resistance groups and properties of light sources. Such studies were performed by STE TKA, LLC, and GOSNIIRESTAVRATSII by request of the Ministry of Culture. The article describes major results of this study, which mainly aimed at specification of safe acceptable level of UV irradiation of materials with application of energy-saving fluorescent lamps as well as major characteristics of produced photometers. Similar studies and elaboration of recommendation are required also for LED light sources.

Keywords: illuminance, UV irradiation, wavelength, spectral distribution, light-resistance, acceptable level

1. INTRODUCTION

In the course of development of optical radiation measurement devices for museums, it was found necessary to conduct additional studies for specification of acceptable levels of ultraviolet irradiation alongside with the known data of visible radiation.

It is well-known that continuous impact of radiation on objects causes visible changes of their appearance (colour, brightness, mechanical properties and structure of material). In the first significant scientific publication about impact of visible radiation on fading of watercolours, it was found that the fading effect depends on the level of irradiation and duration of exhibition [1]. The first qualitative dependencies for the processes of changing and destruction of objects were found [2].

Further research and practical works allowed us to specify simple recommendations for museum exhibitions: to limit maximum acceptable illuminance for the most of light-sensitive objects with a value of 50 lx and 200 lx for oil and tempera paintings. This approach was the basis for the museum lighting systems with lighting created by means of natural light or incandescent lamps.

The most of recommendations for museum premises lighting introduced in different countries were based on the value of illuminance in lx and the ratio of UV radiant power of the light source in μW to its luminous flux in lm. Such allowance was correct for thermal light sources (basically incandescent lamps) and became incorrect after appearance of new sources with significantly changed share of ultraviolet radiation, and direct measurements of ultraviolet radiation are required for its determination.

The work by professor Krochmann [3] describes typical museum materials subject to impact of radiation from different light sources. On the basis of these experiments, there was an attempt made to find qualitative standards of exhibit colour change after irradiation with consideration of relative destruction coefficient *D(λ)* (Fig.1).

It was found that impact of optical radiation on museum exhibits depends on:

- Spatial distribution of radiant flux;
- Chromaticity of radiation;
- Relative spectral responsivity of an exhibit, i.e. the degree of its resistance to impact of radiation;
- Duration of irradiation.

The valid CIE recommendations to museum lighting were issued in 2004 [4] and required significant update due to spread of LED light sources in museums.

2. METHODOLOGY OF THE STUDY

The idea of experimental determination of maximum acceptable values of UV radiation is based on determination of the process of changes of optical properties of surfaces of tested materials under UV radiation and its representation in the form of graphs up to previously specified values determined in accordance with selected criteria [5].

The methodology of determination of changes of properties of museum and library collections materials under UV radiation consist of separate methods:

- Method of creation of required level of irradiance with constant monitoring of the values of exposure at which physical and chemical and/or physical and mechanical properties (hereinafter referred to as changes of properties) occur;
- Method of measurement and control of the reached change of material properties;
- Method and procedure of irradiation of specific samples of museum and library materials selected for irradiation;
- Processing of the results of tests of reference and production samples.

Due to individual sensitivity to optical radiation of each material, as many as possible samples of various materials were prepared for the experiment. 83 samples were taken and grouped on 12 boards with proposed high and medium sensitivity to irradiation and were irradiated in different modes by sources with different power and chromaticity. Each sample was divided into 3 parts (Fig. 2) with roughly the same surface properties with the first one of them (the reference sample) was covered with a light-proof shield and the third one being irradiated only with visible light through protective film reflecting the UV region of the radiation spectrum.

The second part of each sample was directly irradiated by the source of UV radiation. The radiant intensity was monitored daily by means of

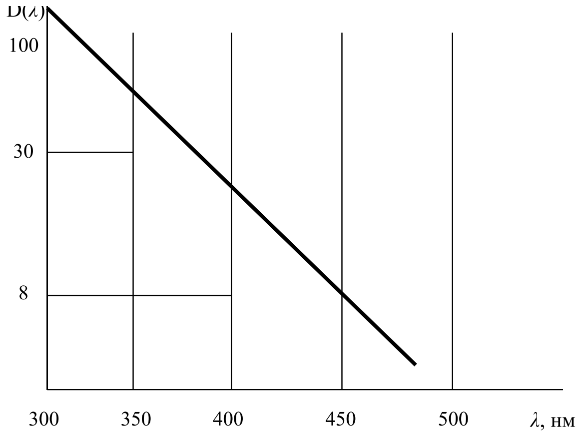

Fig. 1. The degree of harmful effect of radiation depending on wavelength (*D(λ)* = 100 % with *λ*=300 nm)

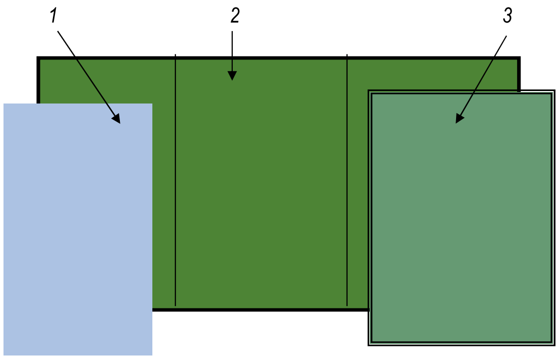

Fig. 2. Scheme of sample preparation for irradiation: 1 – the part covered with a light shield; 2 – an open part; 3 – a part closed with an UV filter

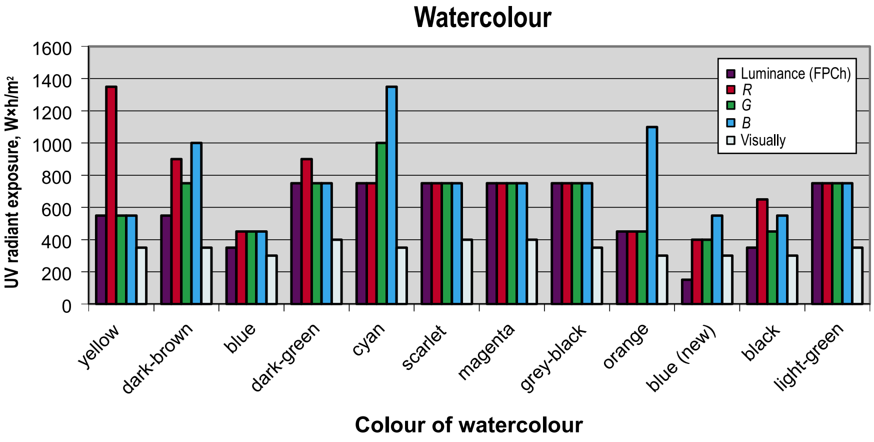

Fig. 3. The values of UV energy exposure causing threshold changes of luminance (more than 2 %) and chromaticity coordinates (more than (5–20)% for watercolours

a photometer in visible and UV regions, and exposure in W·h/m^2 was counted with cumulative sum each (8–9) hours of everyday irradiation. After each everyday irradiation, the optical properties of the samples surfaces were measured. In order to decrease measurement error caused by surface irregularities, these measurements were performed in 3–6 points of each part with averaging of results within each part while illuminating the samples with a special photometric lamp with high-stability radiation spectrum and colour temperature of T_c = 2856 K.

The luminance factor of each part of a sample and *R, G, B* colour coordinates, measured by means of FPCh luminance meter with colour filters made of KS13, ZS11, SS5 glass recommended for three-colour projection in a catalogue of coloured glass, were measured.

The absolute values of colour coordinates for different material types may vary by an order of magnitude and strongly depend on measurement conditions, therefore, they were not used for decreasing irregularities. More correct is comparison between characteristics of irradiated and non-irradiated areas, i.e. determination of change of luminance and chromaticity coordinates of areas irradiated with UV radiation as compared with those of the reference part. That is why, for further processing of measurement results, relative values of changes of luminance and chromaticity coordinates of areas irradiated with visible and UV radiation were calculated in percents of the reference area of each material after each daily irradiation.

The results of measurements for a quite long period of time (until the consequences of irradiation become visible) were tabled and the graphs of dependence of relative change of luminance[1] and colour on the increasing dose of UV radiation accepted by each sample were made in accordance with this table, i.e. the development of the process of change of surface optical properties under irradiation were graphically represented.

For graphical representation and analysis of the changes, the results were processed using special *Microsoft Excel*-based software developed for this purpose.

3. THE RESULTS OF THE STUDY

The selection of a criterion of acceptable value of luminance change was based on the Weber-Fechner law [6], according to which, relative threshold value of "visibility" of luminance change does not depend on its absolute value and is equal to about 2 %. The threshold value of "visibility" of colour change depends on individual aspects of colour perception by each individual (different spectral responsivity) and on illuminance, hue and colour saturation of an object. According to the results of the experiment, the threshold value of visibility of colour change was equal to (4–5) % for well-lighted saturated colours and up to (20–30) % for low-saturated and dark (brown, violet, dark-blue, dark-green) colours.

Using the specified criteria of maximum acceptable changes of luminance (±2 %) and colour (±5 %), maximum acceptable dose of UV radia-

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[1] Luminance was measured by means of a photoelectric portable photometer manufactured by ZOMZ, Sergiyev Posad (basic percentage error of the photometer does not exceed ±10 %).

Table 1. Acceptable Level of UV Exposure for Museum Materials

Light-resistance group of materials	Acceptable UV exposure, W·h/m^2
Newspapers	68
Paper	150
Watercolour	1250
Oil paint	1680
Textile	620

tion for each sample at which critical values of visibility of changes of sample luminance and colour had been reached (Fig. 3), watercolours as an example) was determined in accordance with the graphs of surface optical properties changes.

Maximum acceptable doses of UV radiation for material groups (e.g. for watercolours irrespective of colour) were determined by selecting the least value of maximum acceptable doses of all values for all samples included in this group of materials (Table 1). Thus, this value will be known safe for all other materials forming the group.

The maximum acceptable doses with consideration of recalculation factors taking integral transmission of protective film in areas irradiated with light and spectral responsivity of radiometer into account were taken as recommended values of maximum acceptable doses of UV radiation.

The recalculation factor for visible radiation was defined experimentally. Illuminance of one point with and without the film caused by one source was measured by means of an illuminance meter. Transmittance of the film was equal to 0.22, the light getting on the tested samples through the film was weakened by the same value. Hence, this is the factor to be introduced as correction of true value of illuminance of the samples.

The recalculation factor for UV radiation was determined by calculation in accordance with typical characteristic of chromaticity of high pressure mercury lamp DRSh-250 and spectral responsivity of the radiometer. It was equal to 1.14. The same factor should be introduced as correction of true value of irradiance of the samples.

For each type of materials, maximum acceptable doses and intensities for constant and temporary exhibitions and for long-term storage of especially valuable exhibits were specified (Table 2).

The following minimal acceptable values of illuminance/irradiance were taken:

– For UV radiation – as low as reasonably practical;

– For visible radiation – the standards [7] providing safe and emergency ways through museum premises as well as minimal illuminance levels for comfortable examination of exhibits.

The illustration of some results of the study is presented in Fig. 4.

4. PHOTOMETRIC DEVICES FOR MUSEUMS

The performed study was continued by development of a group of photometers for measurement of light environment characteristics in museums. The most required measurements in museum practice are:

– Measurement of illuminance;

– Measurement of UV irradiance;

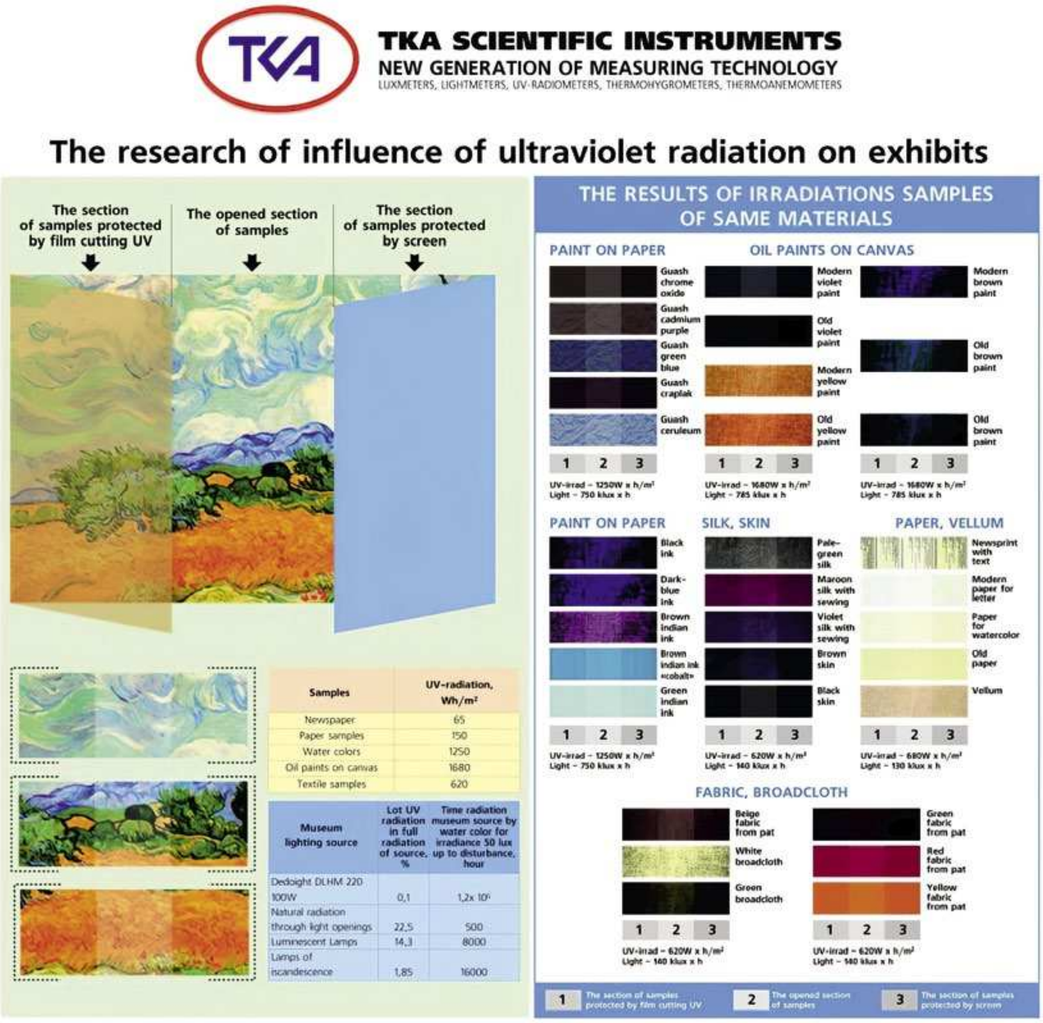
– Measurement of colour characteristic (colour temperature, colour rendering index, chromaticity coordinates);

– Measurement of radiance (i.e. luminance distribution in a spectator's field of view);

– Measurement of glare.

4.1. Illuminance Measurement

The most widely spread device for measurement of illuminance is reliable and simple illuminance meter. Significant changes in metrology of photometers occurred in the second half of the previous century. In [8], it was shown that application of widely spread illuminance meters based on selenium photoemissive cells and similar devices causes significant (more than 20 %) error when measuring fluorescent light sources. In accordance with CIE recommendations [9], the illuminance meters should be corrected in accordance with spectral luminous efficiency $V(\lambda)$ with high precision. VNIIOFI (All-Russian Research Institute for Optical and Physical Measurements Federal State Unitary Enterprise) has developed the relevant requirements to optical measurement devices and the



Samples	UV-radiation, Wh/m^2
Newspaper	65
Paper samples	150
Water colors	1250
Oil paints on canvas	1680
Textile samples	620

Museum lighting source	Lot UV radiation in full radiation of source, %	Time radiation museum source by water color for irradiance 50 lux up to disturbance, hour
Dedoight DLHM 220 100W	0,1	$1{,}2\times 10^{5}$
Natural radiation through light openings	22,5	500
Luminescent Lamps	14,3	8000
Lamps of incandescence	1,85	16000

Fig. 4. Visual changes of different materials

first photometer of the new generation which had passed state registration was the combined device TKA-01/3 (Fig. 5) developed especially for museums and libraries.

Depending on the exhibited materials, the level of museum lighting is usually within the range between 30 and 700 lx. However, it is rational to use one device for measurements (monitoring) of illuminance both in halls, corridors and stairs where it can be lowered down to 5 lx and outside the premises where illuminance may reach 100000 lx and more.

Therefore, the measurement range of the museum illuminance meter should be of (1–200,000) lx. Relative measurement error should not exceed 8 %. Most of the produced illuminance meters complies with these requirements: *Hagner* (Sweden), *Minolta* (Japan), TKA (Russia), *Testo* and *Krohmann* (Germany), *Kara Tekniikka Oy* (Finland) and others.

4.2. Measurement of UV Irradiance

Monitoring of the level of UV irradiance is even more important for preservation of museum exhibits. Development of UV radiometers was an especially complicated challenge in terms of metrology. The conventional method of reduction of photometric device characteristics to U-shape ones was not only complicated to be implemented but also, in our opinion, did not assist in obtainment of correct measurement results.

For the purpose of reduction of measurement error, different methods are applied: limitation of radiation source types, introduction of correction factors, etc. Thanks to the reached compromise, we’ve managed to find an opportunity to reduce the total UV radiation measurement error down to 10 % in serial UV radiometers TKA-AVS and Argus.

Table 2. Recommended Maximum Level of UV Irradiance for Materials According to Light-Resistance Groups

Irradiated object	Light-resistance group of materials	UV exposure causing visible change of material colour, W·h/m^2	Recommended maximum limit of UV irradiance, mW/m^2		
			For permanent exhibitions	For temporary exhibitions	For long-term storage (≥2 years) and for especially valuable exhibits
Newspapers, books	3	68	24	40	3
Photographs	3	60	21	35	2
Grades	3	80	28	45	3
Paper and parchment manuscripts	3	50	18	30	2
Iconography	3	100	35	50	3.5
Watercolour	3	80	28	45	3
Ink (including coloured)	3	60	21	35	2
Chinese ink	3	60	21	35	2
Tempera	3	80	28	45	2
Pastel paint	3	80	28	45	3
Carpets, gobelins, fabrics, clothes, goffering, fur, leather	3	80	28	45	3
Collections of insects, stuffed animals and birds	3	80	28	45	3
Oil paintings	2	150	52	90	6
Objects made of bones	2	400	139	180	14
Wooden accessories, furniture	2	500	174	220	20
Gouache	2	150	52	90	6
Some types of light-sensitive minerals and jewellery	2	1,000	350	350	30

Notes:
1. Limit values of UV irradiance are given for any light sources for everyday 8-hour exhibition.
2. The values given in Table 2 are maximum allowable ones with mandatory reduction if it does not influence the quality of visual perception of an exhibit.
3. If the level of UV irradiance created in premises by means of general lighting exceeds the limit given in Table 2, exhibition should be suspended and measures for exhibits preservation should be taken. Preservation measures may be both technical and organisational.
4. Minimal limit of UV irradiance is not specified but in any case it's required to aim at the lowest practicable values.

The TKA-type indicators which are quite simple in operation and user-friendly are overlooked.

In the future, according to the new studies and recommendations by CIE, it will be probably necessary to make measurements separately in A1 (315–340) nm and A2 (340–400) nm spectrum ranges. These spectral regions of LED luminaires are supposed to cause the most significant environmental impact.

Among the range of devices, it is worth noting the Khranitel device by TKA with its UV responsivity increased especially for museum purposes and which measures 5 major microclimate parameters.

Fig. 5. Combined device TKA-01/3

Fig. 6. Spectral colorimeter TKA-VD

4.3. Measurement of Colour Characteristics

Measurement of light chromaticity may be of sufficient importance for both storage and exhibition safety and better representation of exhibits [10]. A lot of produced models including portable ones are likely to provide measurement of major spectral characteristics of museum lighting. The spectral colorimeter developed for solving of this task (Fig. 6) has required metrology and operational characteristics.

TKA-VD spectral colorimeters are designed for measurement of chromaticity coordinates and correlated colour temperature of light sources in the CIE1931 and 1976 international colorimetric systems, illuminance and luminance. The device is included in the National Register of Measuring Equipments of the Russian Federation. Its new version has enhanced spectral resolution and is capable to send the measurement results to PC and gadgets via Wi-Fi.

4.4. Luminance Measurements

Remote measurement of luminance is provided by the new version of the TKA-Kino luminance meter (Fig. 7). It is a simple and reliable device which allows to measure luminance of a lighted surface just by pressing a button. It can also be applied for evaluation of contrast revealing coefficient[2] used in museum practice and luminance distribution.

Fig. 7. Remote luminance meter TKA-KINO

Temperature and humidity detectors are widely spread in museums and should be supplemented by illuminance or UV irradiance level detectors with wireless data transfer. There are a number of challenges to be solved in case of museum interest. It is necessary to restore cooperation between developers and manufacturers of measurement equipment and museum specialists.

5. CONCLUSION

The study performed and measurement devices created on its basis may be used for evaluation of museum lighting. But the low state of knowledge of impact of LED lighting on museum materials does not allow to draw conclusions about changing of applicable rules and to sufficiently increase acceptable levels of illuminance and UV irradiance without additional studies.

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