Review paper

UV light in graphic technology: Usage, effects and safety measures

ABSTRACT

The introduction of ultraviolet (UV) light technologies to the graphic arts industry has revolutionised printing by offering better print quality, faster curing times and the ability to print on a variety of substrates. Despite these advances, UV light and UV-curable materials pose significant health risks to workers. This paper examines the potentially harmful effects of UV light on workers in the graphics technology sector and outlines key safety measures to mitigate these risks. The UV spectrum (100–400 nm) is categorised as UVA, UVB and UVC. While UVA and UVB are partially absorbed by the atmosphere, UVC is almost completely absorbed by the ozone layer. In graphics technology, however, artificial UV light sources can expose workers to harmful radiation. The increasing use of UV light in UV printing and UV curing requires a closer look at occupational hazards. Harmful effects include skin damage (erythema, skin ageing, pigmentation changes, skin cancer) and eye damage (photokeratitis, cataracts, retinal damage). UV-curable inks and coatings also contain photoinitiators and chemicals that pose health risks (irritation, allergic reactions and respiratory problems) and require comprehensive safety protocols. Key safety measures include personal protective equipment (PPE) such as protective clothing, goggles and respirators. Technical measures such as UV-blocking shields, covers and adequate ventilation reduce exposure. Comprehensive training, the use of PPE, safety protocols and regular inspections ensure the safety of employees. By addressing the risk of UV exposure, the industry can protect its employees while continuing to innovate.

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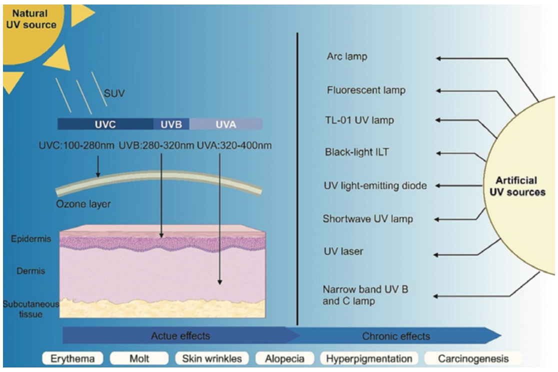
Introduction

Due to its high energy density, UV radiation has become an integral part of modern technological progress and is therefore ideal for processes that require efficient and fast curing or treatment. In practice, the use of high-energy radiation is often limited to UV light or electron beams, as both provide the necessary intensity to effectively initiate and maintain chemical reactions or material transformations. Decades of extensive research have expanded our understanding of this segment of the electromagnetic spectrum and provided deep insights into its mechanisms and applications. This growing knowledge has enabled ever more precise and innovative use of UV radiation in various industries, including the graphic arts industry.

UV radiation comes from both natural and artificial sources (Figure 1) and spans the electromagnetic spectrum between 100 and 400 nm.

It is usually divided into three ranges: UVA (315–400 nm), UVB (280–315 nm) and UVC (100–280 nm). More recently, the UVA and UVB spectra have been further subdivided into specific subcategories: Narrowband UVB (311–313 nm), UVA2 (320–340 nm) and UVA1 (340–400 nm), allowing a more detailed understanding of their different effects and applications (Ahmad, Christensen & Baron, 2017).

In the case of naturally occurring UV radiation, e.g. that of the sun, UVA and UVB are partially absorbed by the earth's atmosphere, while UVC is almost completely blocked by the ozone layer. While the effects of UV light, both beneficial and harmful, are well researched, the widespread and often unquestioned reliance on artificial UV sources in industrial processes harbours a number of potential risks.



» **Figure 1:** *Comparison of natural and artificial UV light sources and their biological effects (Tang et al., 2024)*

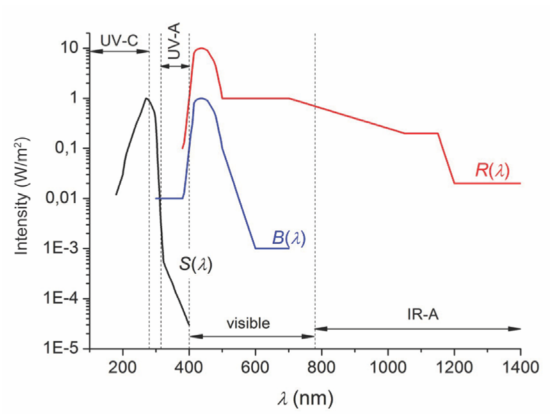
Prolonged exposure to UV light can have a number of harmful effects, particularly on the skin. These include erythema (similar to sunburn), accelerated skin ageing, pigmentation changes and, more importantly, an increased risk of skin cancer. The carcinogenic potential of UV radiation emphasises the need for strict protective measures. In addition to these skin problems, UV exposure also poses a significant risk to the eyes. Acute exposure can lead to photokeratitis, while chronic exposure increases the risk of cataracts and retinal damage, which can lead to visual impairment or, in severe cases, loss of vision. But these are not the only effects, as the WHO published a report in 2006 on the harmful effects of exposure to artificial UV radiation and skin cancer, which even mentions DNA and cell damage (IARC Working Group on Risk of Skin Cancer and Exposure to Artificial Ultraviolet Light, 2006).

In addition, UV curing inks and coatings commonly used in UV printing contain photoinitiators and various chemicals that pose additional health risks. Direct contact with these substances or inhalation of their vapours can lead to irritation, allergic reactions and respiratory problems. The complexity and toxicity of these chemicals requires the implementation of comprehensive safety protocols to adequately protect workers.

The harmful effects of incoherent optical radiation are quantified with three spectral weighting functions – *S(λ)*, *B(λ)* and *R(λ)* (Figure 2). These functions represent the risk of the radiation interacting with the tissue and potentially causing damage based on the spectral distribution and energy of the exposure. They are defined in the regulation as *„spectral weighting functions"* that help to assess the specific risks posed by different wavelengths of radiation and their potentially harmful effects on biological tissue.

The *S(λ)* function, also known as the *actinic UV hazard function*, represents the effectiveness of UV radiation in damaging the skin and eyes. It is defined in the range of 180–400 nm and peaks at 270 nm, with its effectiveness falling below 0.01 at 321 nm. Put simply, this function shows how dangerous UV light is for the skin and eyes – especially at short wavelengths where the energy is at its highest. The *B(λ)* function, or blue light hazard function, measures the photochemically induced retinal damage caused mainly by blue light between 400–500 nm. This means that it quantifies how prolonged exposure to blue light – such as from some LEDs – can damage our eyes, especially the retina.

Finally, the *R(λ)* function describes the thermal effects of visible and IR-A radiation, covers wavelengths from 380–1400 nm and considers risks such as IR-induced cataract and thermal retinal damage, including photoretinitis. In other words, this function indicates how much the heat from intense light sources can damage the eye tissue or skin, similar to a burn.



» **Figure 2:** *Risk functions for optical radiation sources: UV radiation – S(λ), visible light – B(λ) and visible and IR-A radiation – R(λ) (European Union, 2006; Commission Internationale de l'Eclairage, 1998)*

In industrial practice, e.g. in printing plants, the intensity and biological risk of UV radiation is measured using portable spectroradiometers or UV hazard metres. These devices record the spectral power distribution of the UV source directly at the nearest point of human exposure. In UV curing systems, for example, the probe is placed at the exit of the lamp housing or near areas accessible to the operator to determine the effective irradiance.

The device then applies the appropriate spectral weighting functions (e.g. *S(λ)* for skin and eye hazards) to calculate the Biologically Effective Dose (BED). If the measured values exceed the exposure limits mandatory in standards such as IEC 62471 or ICNIRP guidelines, technical and organisational measures — such as shielding, limiting the duration of exposure or prescribed PPE — must be taken to ensure the safety of the operator.

In 2002, the International Commission on Illumination (CIE) introduced standardised methods for assessing the radiation hazards of different lamps and lamp systems, with a focus on non-coherent radiation sources – ***CIE S 009/E:2002/IEC 62471:2006*** (Commission Internationale de l'Eclairage, 2002). These guidelines provide a framework for assessing the risks associated with the different types of radiation emitted by lamps, thus ensuring safety in the use of these lamps. In addition, ***Directive 2006/25/EC*** of the European Parliament and of the Council defines the spectral weighting functions and lays down minimum requirements for the protection of the health and safety of workers from artificial optical radiation (European Union, 2006).

Directive 2006/25/EC sets minimum standards for the prevention of skin and eye damage due to exposure to artificial optical radiation. It sets exposure limit values, defines the employer's obligations and establishes penalties for non-compliance. These limits aim to protect most people from harmful effects, even from repeated exposure. However, the Directive does not take into account people with increased photosensitivity or photosensitisers, nor does it address exposure to natural sunlight, which means that it does not impose any restrictions on outdoor activities. Manufacturers' data on radiation levels must be used for exposure assessment, although all devices require proper risk assessment and inclusion in comprehensive risk assessments. (European Union, 2006; Klanjšek Gunde, 2010; Commission Internationale de l'Eclairage, 1998).

In addition to the EU and CIE legislation mentioned above, there are several other important documents that regulate the harmful effects of ultraviolet (UV), infrared (IR) and non-ionising radiation (NIR). Directive 2006/25/EC, adopted as a part of the overarching ***framework Directive 89/391/EEC***, requires employers to assess the risks and take safety measures to protect workers from radiation, including UV and IR radiation. In addition, ***Directive 2013/35/EU*** addresses the health and safety requirements for exposure to electromagnetic fields (EMF), which include certain wavelengths of infrared and UV radiation.

The ***European Optical Radiation Directive*** is supported by EN standards that set safe limits for exposure to optical radiation, particularly in industries such as printing and manufacturing where UV radiation is often used for curing. In addition, ***ISO 15858:2016*** sets safety standards for UV-C devices used for air and surface disinfection to prevent human exposure.

CEN (European Committee for Standardisation) provides further safety guidelines for exposure to optical radiation in the workplace, such as ***EN 14255-1***, which outlines measurement and assessment protocols for artificial optical radiation.

Many CEN standards are in line with the ***recommendations*** of the ***ICNIRP*** (International Commission on Non-Ionising Radiation Protection) and set limits to reduce the harmful effects of optical radiation in industrial environments such as UV curing, welding and laser use. Standards such as ***EN 170*** ensure that PPE such as goggles, face shields and clothing fulfil the required safety criteria, especially for UV protection.

In addition, standards such as ***EN 12198*** provide methods for measuring radiation emissions and assessing their effects on workers to ensure compliance with safe exposure levels. CEN often develops harmonised standards that complement European regulations and help companies comply with Directive 2006/25/EC. Industries that rely on UV, IR or visible light sources must follow specific safety standards, such as ***EN 62471***, which assesses the photobiological safety of lamps and high-intensity light sources, including LEDs and lasers, which are often used in the printing and manufacturing industries.

In addition, national regulations should also be considered. Namely, EU member states also implement their own national regulations, which are often based on EU directives. In Germany, for example, there is the ***Ordinance on Artificial Optical Radiation (OStrV)***, which mandates detailed risk assessments and safety measures to protect workers from exposure to artificial UV and IR radiation. In combination, these directives and standards form a comprehensive regulatory framework that aims to minimise the health risks associated with exposure to optical radiation in the workplace.

The CIE has continuously updated and revised the ***CIE S 009/E:2002/IEC*** guidelines for the Photobiological Safety of lamps and Lamp Systems since the original standards. Whilst ***IEC 62471:2006*** remains the core standard for the assessment of photobiological safety, there have also been some developments. In particular, ***IEC TR 62471-2 (2009)*** provides guidance on the application of ***IEC 62471***, especially for LED sources, to improve compliance by manufacturers and authorities. The ***IEC 62778 (2014)*** standard focuses specifically on the hazards of blue light and targets the risks to the retina from LEDs and high-intensity light sources.

The ***CIE 231:2019*** standard emphasises the hazards of blue light and its potential impact on human health and addresses the concerns associated with the proliferation of LED and solid-state lighting.

These directives and standards underline the importance of accurate risk assessments, compliance with exposure limits and the implementation of protective measures to minimise health risks in industries heavily dependent on optical radiation. This comprehensive legal framework is essential to ensure the safety of workers in various industries.

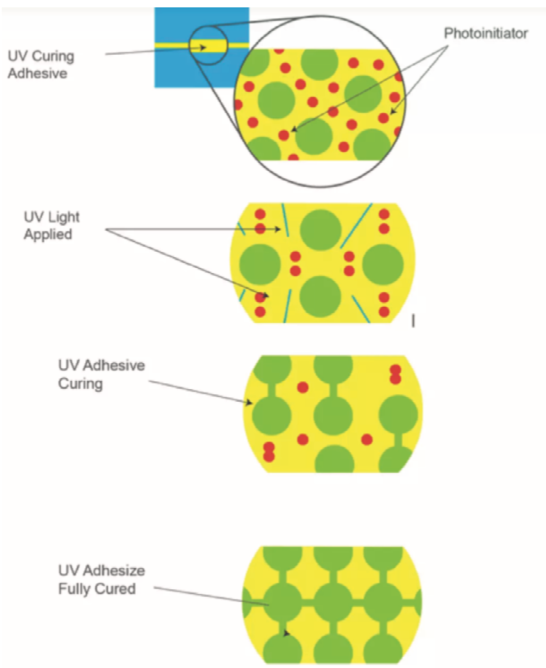
Applications of UV radiation in graphic technology

UV radiation is mainly used in processes such as drying, cross-linking, curing and (photo)polymerisation. In graphic arts technology, it plays a crucial role in UV printing, curing (Figure 3) and the production of printing plates for offset and flexographic printing through photopolymerisation or photoengraving.

Compared to conventional drying methods, UV radiation consumes significantly less energy, eliminates the need for organic solvents and ensures compliance with VOC guidelines. The efficiency of these processes is controlled by the spectral distribution of the UV light, the activation energy of the photoinitiator and the exposure time, which optimises both volume and speed (Klanjšek Gunde & Urbas, 2007; Excelitas, 2014).

An efficient UV-curable system must contain several key components: a photoinitiator that generates free radicals when exposed to UV light, a monomer that provides viscosity and flexibility, an oligomer that creates the essential coating properties, and additives to fine-tune performance. The photoinitiator decomposes into free radicals and initiates the curing process.

Monomers combine chemically with other molecules to form polymers, while oligomers are short-chain polymers or resins that affect the structure of the material. Finally, additives such as pigments, fillers and wetting agents are added to give the coating certain properties (Excelitas, 2014).



» **Figure 3:** *Curing process (Excelitas, 2014)*

During polymerisation, UV light sources are used to cure photopolymers. The areas containing photopolymer are cured and the unexposed areas are washed away. In addition, modern computer-to-plate (CTP) systems typically use UV laser or UV LED technologies so that the design can be transferred directly to the printing plate without the need for conventional film exposure.

UV applications in specific printing techniques

UV radiation in flexographic printing

In flexographic printing, UV curing is generally used with photopolymer printing plates and UV curing inks. The plates consist of light-sensitive polymers that are selectively cured by UV radiation. UV LED curing systems are increasingly being used instead of traditional mercury lamps due to their lower energy consumption, compactness and precise wavelength control. These systems allow immediate curing at lower temperatures, which is particularly beneficial for heat-sensitive substrates such as thin films or self-supporting labels (Gómez, Orme & Simmons, 2019).

UV radiation in screen printing

Screen printing relies on UV curing inks and varnishes, especially for printing on non-absorbent substrates such as plastics, metals, and glass. UV coatings are used for both protective and decorative purposes, including gloss, tactile or matt effects. As screen printing usually involves the application of thicker layers of ink, powerful UV lamps or controllable UV LED systems are used to ensure complete curing. These systems enable durable and resistant prints even on difficult surfaces. (Klanjšek Gunde et al., 2011)

UV radiation in offset printing

UV offset printing is often used to print on non-porous materials such as plastic cards, packaging foils or metal-coated papers. The UV inks used in this process contain photoinitiators that polymerise quickly when exposed to UV light. This eliminates the drying time, reduces emissions of volatile organic compounds (VOCs) and improves print sharpness and durability. Modern offset presses are increasingly utilising LED UV systems for greater energy efficiency, longer lamp life and improved print stability (Excelitas, 2014; Light Adviser, 2024b).

Each of these printing processes utilises the benefits of UV curing – fast drying, high durability and environmental friendliness – while adapting the type of light source, ink formulation and process parameters to the specific technological requirements.

UV light sources technologies and graphic applications

There are different types of UV sources/lights that can be used in graphics technology.

Mercury vapour lamps, which are frequently used in graphics technology, are available in both medium and high pressure versions. These lamps emit a broad spectrum of UV light (UVA, UVB and UVC) and are therefore ideal for curing UV-curing inks, varnishes and coatings as well as for the production of printing plates. High pressure mercury vapour lamps provide a more intense UV output and are suitable for applications that require fast curing, especially with thicker or more difficult substrates. Medium-pressure mercury vapour lamps, on the other hand, are mainly used in exposure systems, where their broad UV spectrum effectively cures photopolymer materials in printing plates.

Today, UV LED technology is mainly used because it is more energy-efficient, emits less heat and has a longer service life than conventional mercury lamps. UV LEDs emit mainly in the UVA range and offer precise wavelength control, making them ideal for curing inks and coatings in printing processes. Their precision and energy efficiency are also beneficial in the production of printing plates, where UVA light is used to cure photopolymer plates for digital printing. UV LED systems also offer an instant-on function that speeds up plate production. These environmentally friendly and mercury-free systems operate at cooler temperatures, maintaining the integrity of the photopolymer materials during exposure and improving sustainability without compromising quality.

Metal halide lamps are another viable option for UV curing applications, especially when substrates or inks require specific wavelengths for curing. These lamps emit a broad spectrum of light, similar to mercury vapour lamps, but can be adjusted for greater precision. In some cases, they are also used in UV exposure units for printing plate production, as they provide a balanced spectrum of UVA and UVB light.

This makes them ideal for curing photopolymer plates where accuracy is important. This combination of broad spectrum and finely tuned control ensures effective curing and exposure processes.

Xenon arc lamps emit a complete spectrum of UV radiation, with a particularly high intensity in the UVA range. They are often used for high-precision exposure and offer excellent resolution for imaging in printing plate production. In addition, xenon arc lamps are used in test environments where UV exposure and weathering tests are performed on printed materials to ensure their durability and performance.

Their ability to deliver consistent, high-intensity UV light makes them ideal for applications that require detailed imaging and rigorous testing.

Fluorescent UV lamps are typically used for low intensity applications such as quality control and inspection. Although they are not normally used for curing processes, they are very effective in the inspection of UV-reactive inks and coatings, enabling the accurate detection of defects or inconsistencies in printed materials. Their use in inspection processes ensures the quality and consistency of UV-sensitive materials without the need for high-intensity curing.

Laser-based UV systems are an essential part of CTP technologies, where laser diodes are used to selectively expose precise areas of photopolymer plates. This method enables highly detailed imaging and provides excellent control over the plate production process. Widely used in modern print workflows, laser-based UV imaging ensures the creation of offset printing plates with exceptional precision and consistency, making it a favoured technology for accurate and reliable results in professional printing environments.

Although less common in traditional printing, Excimer UV lamps are used in specialised printing processes or in areas where extreme precision in curing is required, such as microprinting or electronic printing. These lamps provide the high level of accuracy required for intricate applications, making them ideal for advanced production processes where detail and precision are essential. (Gálvez et al., 2022; Bahria & Erbil, 2016; Maloney, 2006; Klanjšek Gunde et al., 2011, Klanjšek Gunde & Urbas, 2007; SCENIHR, 2012; Light Adviser, 2024a; FDA, 2022; European Committee for Electrotechnical Standardization, 2008).

In summary, UV light sources play a crucial role in the production of printing plates, especially in photopolymerisation and laser-based imaging processes. Mercury vapour lamps and UV LEDs dominate in this area, but xenon arc and metal halide lamps also contribute in certain applications.

UV light sources are widely used in 3D printing, whether in subtractive or additive manufacturing technologies such as the polyjet process.

UV light is also critical in the printing of industrial coatings and in the graphics market for coatings on electronic and automotive components, overprint varnishes and various printing processes using inks such as flexographic, screen and lithographic inks. UV light also plays a role in laminating, pressure-sensitive adhesives, wooden furniture and flooring. It is also used for printing displays, touchscreens, solar cells, batteries, fuel cells and flexible electronics.

System design considerations: housing, ventilation and curing speed

Modern UV printing systems often use semi-enclosed or fully enclosed configurations to ensure safe operation of UV lamps and control emissions. High-pressure mercury lamps, for example, can reach temperatures in excess of 850°C, which poses a significant fire risk when printing on sensitive substrates. To minimise these risks, the systems are usually equipped with active cooling (either air or water-based), automatic shutters and paper jam detection sensors that immediately deactivate the UV lamp in the event of a malfunction (RiskStop, 2023).

Ventilation systems are also an important component of UV printing systems. These include local exhaust fans and ducts to remove ozone and vapours generated during the curing process and to supply the working environment with fresh air. Proper air management reduces the risk of photochemical smog formation and increases operator safety (Uvitron, 2023).

Curing speed is another important factor in the development of machines. Modern UV LED systems — especially for flexographic printing applications — can dynamically adjust the light intensity to the web speed (e.g. 150–200 m/min) and offer an instant on/off function. Water-cooled LED heads enable efficient curing with minimal thermal stress, enabling high-speed production with lower operating costs and better substrate compatibility (CureUV, 2023; Flint Group, 2024).

Guidelines addressing the use of UV light in graphic technology

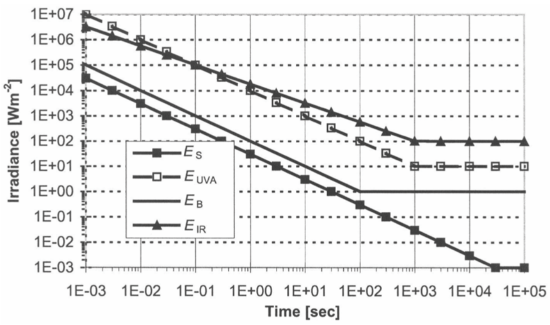
Several publications and guidelines deal with the use of UV light in the field of graphic arts technology, focussing on health risks and safety measures. Regulatory frameworks, industry standards and certifications aim to minimise the impact of UV light in the printing sector on health and the environment. This includes compliance with national and international regulations, an emphasis on worker protection, the handling of hazardous materials and the use of safe UV inks.

Health and environmental aspects point to exposure to harmful UV radiation and the release of volatile organic compounds (VOCs) from conventional UV inks. Safer alternatives such as UV LEDs and bio-based UV inks are becoming increasingly important due to their lower environmental and health risks.

Best practices for UV curing emphasise the use of proper light intensity to avoid under or overexposure, which can damage the material. Neglecting safety measures, such as wearing protective clothing or ensuring adequate ventilation, exacerbates these risks (SCENIHR, 2012; Commission Internationale de l'Eclairage, 2002; European Union, 2006).

IEC 62471:2008 specifies exposure limits for UV light based on intensity and duration. It specifies that at a light intensity of 1,000,000,000 W/sr/m² the safe exposure time is 1/1000 of a second. At a lower intensity of 100 W/sr/m², the permissible exposure time is 10,000 seconds, which corresponds to 2.78 hours (Figure 4). These limits contribute to safety by regulating the duration and intensity of exposure to prevent possible damage from UV light wavelengths.

The BED of UV radiation measures the amount of radiation an organism receives, taking into account the spectral distribution of the light source (e.g. a lamp) and the action spectrum of biological effects (e.g. skin damage). To calculate the BED, the spectral output of the lamp is measured at the nearest point of human exposure and then weighted with the corresponding spectrum of action. The resulting BED is compared to the maximum permissible exposure limits set by the ICNIRP, a scientific organisation that provides guidance on the risks of non-ionising radiation, including UV light and electromagnetic fields (EMF), which are adopted by regulatory authorities around the world (FDA, 2022; Klanjšek Gunde & Urbas, 2007).



» **Figure 4:** *Weighted radiation exposure limits as a function of time with constant exposure (E_s – for skin and eyes, E_{UVA} – for eyes in the UVA range, E_B – for blue light and EIR – for skin in the IR range) (FDA, 2022)*

The photobiological safety of UV lights can be measured with portable devices, using a three-step procedure:
1. Measure the spectral distribution of the selected lamp, taking into account factors such as the filter system and projection optics, at the nearest point to which a person could be exposed;
2. Weight the measured spectral distribution with the corresponding action spectrum to calculate the BED;
3. Compare the calculated BED with the maximum permissible exposure limits set by the ICNIRP to ensure safety.

The safety protocols for UV printing, curing and printing plates production emphasise the importance of using PPE such as UV-blocking goggles, protective clothing (gowns), protective gloves and ensuring adequate ventilation to prevent the build-up of harmful chemicals.

The protective properties of textile materials (clothing, including gloves, headgear (e.g. hats, caps)) against UV radiation are defined by the Ultraviolet Protection Factor (UPF), which indicates the ratio between the time when erythema appears on human skin when human skin is protected by textiles and the time when it does not.

It is defined by standards (such as the European standards EN 13758-1, EN 13758-3, 183 and UV STANDARD 801, the Australian/New Zealand standard AS/NZS 4399, the American standard AATCC TM). The protection values are listed in Table 1 (Urbas, 2005). Protection by textile material is simple and very effective.

In printing environments, protective clothing such as gloves, gowns, long-sleeved lab coats or visors with a high UPF rating is often worn by operators working near open UV curing equipment or during maintenance, where incidental exposure to UV radiation is more likely.

Table 1
UPF rating

UPF	UV protection	Blocking of UV radiation (%)
15 - 20	good	93.3 - 95.8
25, 30, 35	very good	95.9 - 97.4
40, 45, 50, 50+	excellent	>97.9

To protect the eyes from UV radiation, it is recommended to wear UV-blocking sunglasses that filter 99–100% of UVA and UVB rays, as well as a wide-brimmed hat for additional protection. Special safety goggles are also essential in industrial environments with UV exposure.

In a study investigating the effectiveness of laboratory protective clothing – laboratory gowns, gloves (such as latex PFE, nitrile latex free) and goggles – against UV radiation, Klanjšek Gunde et al. (2011) concluded that only goggles provide adequate protection, while gloves and gowns do not provide all-day protection. This emphasises the need for constant innovation in materials and products to improve UV resistance. As protective technologies are constantly evolving, it is crucial to carefully select laboratory equipment that fulfils the high requirements for adequate UV protection to ensure maximum safety during prolonged exposure (Klanjšek Gunde et al., 2011).

Conclusion

While the use of UV radiation in the graphic arts industry increases productivity and print quality, it also requires comprehensive safety protocols. All UV light sources pose a significant health risk, and without the proper use of PPE, these risks cannot be mitigated. It is imperative that the use of PPE is considered mandatory to protect workers from the harmful effects of UV exposure.

Employers have a major responsibility to ensure the safety of their employees from artificial optical radiation. They must evaluate the exposure of workers and assess the associated health risks. To this end, the radiation levels in the working environment must be measured and calculated. If exposure exceeds the safe limits, employers are obliged to take measures to reduce the risks, including adapting work processes, using alternative equipment, providing protective clothing or limiting the duration of exposure. Particular attention must be paid to sensitive groups of workers and the interaction between optical radiation and photosensitive chemicals. In addition, any work area where radiation exposure exceeds safe limits must be clearly labelled and access should be restricted. Workers must be trained and receive appropriate medical examinations to protect their health.

Despite numerous laws, regulations and directives dealing with UV protection, many critical questions remain unanswered. Questions such as whether UV-induced damage is fully regenerative, the potential effects of long-term exposure (which are still largely unexplored), the accumulation of non-regenerative damage and its possible consequences need further investigation. These complex questions can probably only be answered by a multidisciplinary approach involving photobiology, photochemistry, dermatology and ophthalmology.

Only by further improving our understanding of the biological effects of UV light, while adhering to strict safety standards, can we ensure that UV radiation remains a sustainable and safe tool in graphics technology.

Future developments and research perspectives

As UV technology continues to evolve, future developments in graphic arts printing are likely to focus on further improving energy efficiency, curing speed and substrate compatibility — particularly using modern UV LED systems. The move away from mercury-containing sources is likely to accelerate due to environmental regulations and safety concerns. However, challenges remain in ensuring uniform curing on complex substrates and scaling UV systems for high-speed industrial applications without compromising quality or safety.

Further research is needed to optimise ink formulations for low-energy curing, understand long-term material interactions with UV irradiation and develop intelligent control systems that dynamically adjust curing parameters in real time. In addition, interdisciplinary studies combining materials science, photochemistry and occupational health and safety are critical to the development of safe, efficient and sustainable UV printing processes tailored to flexo, screen and offset printing technologies.

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References

Ahmad, S. I., Christensen, L. & Baron, E. (2017) History of UV lamps, types, and their applications. In: *Ahmad, S. (ed.) Ultraviolet Light in Human Health, Diseases and Environment. Advances in Experimental Medicine and Biology, vol 996.* Cham, Springer. Available from: doi: 10.1007/978-3-319-56017-5_1

Bahria, H. & Erbil, Y. (2016) UV technology for use in textile dyeing and printing: Photocured applications. *Dyes and Pigments.* 134, 442–447. Available from: doi: 10.1016/j.dyepig.2016.07.042

Commission Internationale de l'Eclairage. (2002) S 009/E:2002 / IEC 62471:2006. *Photobiological safety of lamps and lamp systems.* Vienna, Commission Internationale de l'Eclairage.

Commission Internationale de l'Eclairage. (1998) CIE S 007/E-1998. *Erythema reference action spectrum and standard erythema dose. ISO 17166:1999(E).* Vienna, Commission Internationale de l'Eclairage.

CureUV. (2023) *350×25mm UV LED Curing System for Flexo Printing with Water Cooling*. Available from: https://www.cureuv.com/products/350x-25mm-uv-led-curing-system-forr-flexo-printing-with-water-cooling [Accessed 24th July 2025].

European Committee for Electrotechnical Standardization. (2008) EN 62471:2008. *Photobiological safety of lamps and lamp systems.* Brussels, European Committee for Electrotechnical Standardization.

European Union. (2006) Directive 2006/25/EC of the European Parliament and of the Council of 5 April 2006 on the minimum health and safety requirements regarding the exposure of workers to risks arising from physical agents (artificial optical radiation). *Official Journal of the European Union.* 114, 38-59. Available from: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:114:0038:0059:EN:PDF [Accessed 25th September 2024].

Excelitas. (2014) *Delivering superior optics and lighting for highest quality printing*. Available from: https://www.excelitas.com/application/industrial-manufacturing/printing [Accessed 25th September 2025].

FDA – Food and Drug Administration. (2022) *The Case for Regulation of Light Emitting Diode Products*. Available from: https://www.softlights.org/wp-content/uploads/2022/10/FDA-Update-to-Petition-to-Regulate-LEDs.pdf [Accessed 25th September 2025].

Flint Group. (2024) *EkoCure® F – UV LED Inks for Flexographic Printing*. Available from: https://www.flintgrp.com/media/tlxamfk1/ekocure-f_ver1_a4.pdf [Accessed 24th July 2025].

Gálvez, E. N., Aguilera, J., Solis, A., Gálvez, M. V., Andrés, J. R., Herrera-Ceballos, E. & Gago-Calderon, E. (2022) The potential role of UV and blue light from the sun, artificial lighting, and electronic devices in melanogenesis and oxidative stress. *Journal of Photochemistry and Photobiology B: Biology.* 228, 112405. Available from: doi: 10.1016/j.jphotobiol.2022.112405

Gómez, J., Orme, M. & Simmons, T. (2019) *LED UV Curing for Narrow Web Flexo Printing*. RadTech Europe.

IARC Working Group on Risk of Skin Cancer and Exposure to Artificial Ultraviolet Light. (2006) *Exposure to artificial UV radiation and skin cancer.* Available from: https://publications.iarc.fr/Book-And-Report-Series/Iarc-Working-Group-Reports/Exposure-To-Artificial-UV-Radiation-And-Skin-Cancer-2006 [Accessed 25th September 2024].

Klanjšek Gunde, M. (2010) Fotobiološka varnost nekoherentnih optičnih sevanj – določila nove uredbe. *Vakuumist.* 30 (3), 12–16. Available from: https://www2.arnes.si/~ljdvts/arhiv/2010/2010_3/2010_3_3_100dpi.pdf [Accessed 25th September 2024].

Klanjšek Gunde, M., Urbas, R., Sever Škapin, A. & Friškovec, M. (2011) Photobiological safety of radiation curing lamp sources applied for printing. In: *10th Seminar in Graphic Arts, 19–21 September 2011, Pardubice, Slovakia*. Pardubice, University of Pardubice, Department of Graphic Arts and Photophysics. pp. 37–42.

Klanjšek Gunde, M. & Urbas, R. (2007) Učinki UV svetlobe v organskih snoveh in njihovo izkoriščanje. In: A. Orgulan (ed.) *Svetloba in arhitektura – Zunanja razsvetljava.* Maribor, Slovensko društvo za razsvetljavo.

Light Adviser. (2024a) *5 Common Mistakes in Best Practices for Using UV Curing Lights Effectively*. Available from: https://lightadviser.com/5-Common-Mistakes-in-Best-Practices-for-Using-UV-Curing-Lights-Effectively/ [Accessed 24th September 2024].

Light Adviser. (2024b) *LED UV Curing System vs. Mercury UV System: Key Differences*. Available from: https://goodiuv.com/th/innovation-of-uv-technology/uv-curing-system-tips/led-uv-vs-mercury-uv-curing-system-key-differences/ [Accessed 24th July 2025].

Maloney, D. L. (2006) Choosing the right UV-curing lamp can brighten your future: Implementing UV technology can prove to be both productive and profitable. *Metal Finishing.* 104 (4), 57–59. Available from: doi: 10.1016/S0026-0576(06)80098-X

RiskStop. (2023) *UV Drying in the Printing Industry: Technical Bulletin*. Available from: https://www.riskstop.co.uk/technical-bulletins/uv-drying-in-the-printing-industry [Accessed 25th July 2025].

SCENIHR – Scientific Committee on Emerging and Newly Identified Health Risks. (2012) *Health Effects of Artificial Light*. Available from: https://ec.europa.eu/health/scientific_committees/emerging/docs/scenihr_o_035.pdf [Accessed 24th September 2024].

Tang, X., Yang, T., Yu, D., Xiong, H. & Zhang, S. (2024) Current insights and future perspectives of ultraviolet radiation (UV) exposure: Friends and foes to the skin and beyond the skin. *Environmental International.* 185, 108535. Available from: doi: 10.1016/j.envint.2024.108535

Urbas, R. (2005) *Analiza zaščitnega učinka tekstilij pred negativnimi vplivi ultravijoličnih žarkov na kožo.* PhD thesis. University of Ljubljana, Faculty of Natural Sciences and Engineering.

Uvitron. (2023) *UV Curing Safety 101: How to Protect Your Employees*. Available from: https://www.uvitron.com/blog/uv-curing-safety-101-how-to-protect-your-employees [Accessed 25th July 2025].