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Laboratory UV Exposure: Risk Assessment and Protective Measures¶

Orietta Cazzuli[1] and Elio Giroletti*[2]

[1]Agenzia Regionale Protezione Ambiente della Lombardia—Milano, Milan, Italy
[2]Dip. Fisica nucleare e teorica, Università degli Studi di Pavia—INFN sezione di Pavia, Pavia, Italy

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ABSTRACT

In research laboratories ultraviolet radiation is widely used, particularly in photochemistry and photobiology, as a sterilizing agent and for the characterization of samples. The results of a survey conducted near several university laboratories are presented with the aim of quantifying exposure levels to UV-incoherent radiation and to assess individual risk for researchers and students. It has been shown that exposure is not negligible, especially if safety procedures are neglected and personal protective equipments, described in this study, are not used.

INTRODUCTION

A great variety of ultraviolet radiation (UVR) sources are used in industry, research and medicine. They can give a relevant contribution to ultraviolet population exposure. Whereas solar UVR exposure of outdoor workers is extensively studied, information is scarce for students or other groups of populations exposed to artificial sources of UV in indoor activities (1,2). In universities, UVR is widely used in several activities. In biological and chemical laboratories, it is in use, particularly, in photochemistry studies (*e.g.* polymerization of molecules and synthesis of chemical products, diagnostic methodologies and analytics) and in photobiology as a sterilizing agent (*e.g.* disinfection of closed-air environments and of liquids and in surface material sterilization) and for the characterization of samples (*e.g.* spectrophotometry, observation of fluorescent substances).

A great variety of UV sources are used, often with significant risk if adequate protective devices and procedures are not used. In this study we present the results of the survey conducted near several laboratories, with the objective of assessing worker and student risk. We have evaluated the UVR exposure levels by measuring the effective exposure with a spectrophotometric system and calculating the effective irradiance. There are two main target organs to consider for UVR exposure in laboratories: (1) eyes—the UVR can damage the cornea and crystalline lens with short-term effects (*e.g.* photokeratitis, photoconjunctivitis) and with long-term effects (*e.g.* cataract, cancer cell formation of conjunctiva, pterygium), and (2) skin on hands, face and neck—UV exposure can induce short-term effects, such as erythema and pigmentation, and long-term effects, such as premature aging, malignant melanoma and skin carcinoma.

MATERIALS AND METHODS

UV sources and their use

Risk has been assessed through the characterization of about 20 UVR sources of different typology (Table 1), representative of those generally used in chemistry, biochemistry, genetics, biology and microbiology laboratories. Considering the variety of source typologies and the consequent risk of each source, it is necessary to consider the main characteristics and the modalities of their uses. Sources are described separately on the basis of their application: chemistry, genetics and microbiology, and biology (3). The code—reported in square brackets—is detailed in the text and in the tables to identify each UV source.

Chemical area. (1) Source with eight fluorescent vertical lamps, each of 15 W [L3102] and (2) source with four fluorescent vertical lamps, each of 15 W [L3652]. Both sources are assembled on a homemade structure with cylindrical geometry. The lamps are positioned on lateral surface, whereas sample is logged on central axis of cylinder by the operator himself or herself. Possible areas of exposure: hands, eyes and face. Both the sources are used to induce analytical photochemical reactions and are used during teaching activities too. The operator limits himself or herself to positioning the sample and turning the lamps on. Each measure requires few minutes, during which operator presence is not necessary, whereas the same worker might repeat such operations several times in a working day. The apparatus is shielded with black, removable cardboard panels mounted on all sides of the device. The sources are used both by students and by researchers.

(3) High-pressure mercury lamp (P = 500 W) [LHG] (Fig. 1). Possible areas of exposure: hands, eyes and face. It is used to induce preparative photochemical reactions on samples that are positioned manually by the operator. The lamp is lodged on a workbench, inside a cabin that is open on the front side; the window is closed with a black cloth. Also, in this case, the operator, student or researcher limits himself or herself to set the sample in a short time, but such activities may be performed many times in a day. Generally, the lamp is kept switched on during the day, when measures are programmed, assuring the stability of UVR emission.

(4) Two positions plate viewer [L2542] and [L3653]. Possible areas of exposure: hands. This source is widely used to identify compounds with chromatography on thin layer in chemical and biochemical laboratories. The source is a mercury lamp at low pressure, emitting between 254 and 365 nm. The viewer does not have an additional screen except the same lamp's lodging and the radiation emission is toward the bottom. The operator (student or researcher) can therefore expose his hands during the activation of the compound to be identified. This activity is extremely short (at the end of each exposure the lamp is switched off), but it is repeated many times.

(5) Spark medium-pressure mercury lamp (P = 50 W) [LB254] and (6) high-pressure mercury lamp for optical bench—quartz filtered (P = 250 W) [LBAN]. Possible areas of exposure: eyes and face. Both sources are lodged in a laboratory with controlled access and are used by expert operators to induce analytical photochemical reactions. There are no screens to protect

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*To whom correspondence should be addressed: Dip. Fisica nucleare e teorica, Università degli Studi di Pavia—INFN sezione di Pavia, Via Bassi 6, 27100 Pavia, Italy. Fax: 39-0382-507752; e-mail: elio.giroletti@unipv.it

Abbreviations: EL, exposure limit; ICNIRP, International Commission on Non-Ionizing Radiation Protection; PPE, personal protective equipment; SOP, specific operating procedures; SPD, spectral power distribution; UVR, ultraviolet radiation.

Table 1. Monitored sources and related work areas

Area	Source	Source code
Chemical	Rump with eight vertical fluorescent lamps	L3102
	Rump with four vertical fluorescent lamps	L3652
	High-pressure lamp	LHG
	Plate viewer 254 nm (low-pressure lamp)	L2542
	Plate viewer 365 nm (low-pressure lamp)	L3653
	Spark bifil medium-pressure lamp	LB254
	High-pressure quartz filtered lamp	LBAN
	TLC plate viewer 254 nm (Hg low-pressure lamp)	TLC
	Plate viewer 365 nm (fluorescent lamp)	CHINO
	Plate viewer 365 nm (fluorescent lamp)	MER
	High-pressure lamp	HG
Genetics and microbiology	Transilluminator (fluorescent lamp)	T320
	Transilluminator (fluorescent lamp) with camera	TGEN1
	Transilluminator (fluorescent lamp)	TGEN2
	Transilluminator (fluorescent lamp)	SANTA01
	Germicide hood	RAN
	Sterile hood	DEL
	Germicide hood	CAP
Biology	Animal pound lamp (spark low-pressure lamp)	PATL

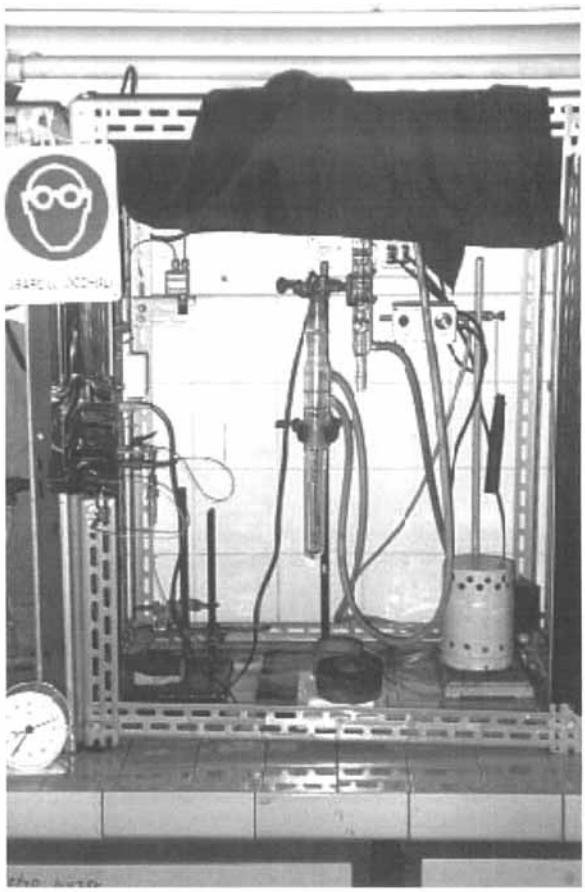

Figure 1. Arc lamps for polymerization activity and synthesis of chemical products, studies of photobiology, in chemical area.

the operator from the primary UV beam. The operator prepares his experiment and does not stay in the laboratory with sources switched on.

(7) Spark low-pressure mercury lamp, chromatographic plate viewer [TLC] and (8) fluorescence lamps, chromatographic plate viewer [CHINO] and [MER]. Possible areas of exposure: hands, eyes and face. These UV sources are similar, in typology and use, to the one described in point (4), with the lamp displaced horizontally. Whereas the first viewer (source [TLC]) does not have an additional screen, the third viewer (source [MER]) has a cardboard positioned by the operator in case he decides to leave the lamp switched on for a long period. Viewer [CHINO] is lodged in an appropriate closet, open at the top. The front screen is made of one sheet of black plastic with two openings for the eyes. Unlike the viewer described in point 4, eye exposure, in these configurations, also has been evaluated. Sources are normally used both by researchers and by students. Their use demands operator presence for a short time, a few minutes, but the operation is generally repeated several times in a working day.

(9) High-pressure mercury vapor lamp (P = 1 kW), with filter UG5 (glass–uranium) for visible radiation + water for infrared radiation [HG]. Possible areas of exposure: hands, eyes, face and head–neck. This lamp is used to produce radical species and to study kinetic reaction. It is sited in a closed laboratory, completely shielded and has a water-cooling system. The laboratory is accessible only to authorized researchers, who prepare their experiments, position samples and follow reactions with a computer. Irradiance levels have been measured at eye and hand positions [HG1-O, HG6-M], to assess exposure when sample is positioned. Eye [HG3-E] and head–neck [HG2-S] exposures were measured at the workplace also.

Genetics and microbiological area. (1) Fluorescent lamp in a trans-illuminator with camera for DNA observation [TGEN1] (Fig. 2), [T320], [TGEN2] and [SANTA01]. Possible areas of exposure: hands, eyes and face, with the exception of [SANTA01] source, where hands are not exposed. This typology of source is widely used in genetics and microbiology laboratories. UVR is used to observe subcellular structures, such as DNA, in samples prepared on a thin gel layer. The operator manipulates the gel with the lamp switched on because UV light allows the setting of relevant parts being manipulated. The operator wears mask, coat with long sleeves and gloves. Each observation and the gel manipulation lasts a few minutes but can be repeated several times in a day. The first source is coupled with a photographic apparatus. The lamp is therefore located in a darkroom.

(2) Germicide lamp inside a germicide hood [CAP] and [RAN] and (3) germicide lamp inside a sterile hood [DEL]. Possible areas of exposure: hands, eyes and face. Germicide lamps are widely used in genetics, biology and medicine laboratories, installed on laminar flow hoods or biological hoods (biohazard). Using sterile and germicide hoods the operator can work in the presence of an ignited lamp. UVR is generally activated at night and the lamp is switched off before worker activity begins. We monitored both old hoods (*e.g.* same typology as the mentioned [CAP] source) that have manual light extinction and latest hoods that have automatic switching off of source when opening the screen of [RAN] and sterile [DEL] hoods. UV lamps, both sterile and germicide hoods, are switched on for several hours, and unlike the [RAN] hood, they are located in laboratories in contact with other workplaces.

Biological area. In this area there are lamps similar to those that were studied in the chemical area (in particular plate viewer) and in the genetics and microbiological area (germicide hood). A different source, not in typology but in use, is the spark low-pressure mercury lamp [PATL] for animal experiments in animal pounds. The operator positions the animal (guinea pig) to be exposed in an appropriate box for a short time. The lamp is equipped with a protecting screen avoiding spread of radiation upward. However, table height does not prevent eyes, face and hands exposure.

Exposure limits

To evaluate biological effects, the exposure concept is used, rather than dose. Indeed, the dose implies a detailed knowledge of microscopic energy transfer in biological matter, which, for incoherent UVR, is not always

available. However, UV exposure risk assessment requires the determination of physical parameters correlated with the biological effects induced in the exposed organs or tissue (2,4). UVR exposure is quantified in terms of irradiance (W m^{-2}) in case of continuous exposure and in terms of radiant exposure (J m^{-2}) for time-integrated (or pulsed) exposures of the eye and skin. The occupational exposure limit (EL) is 30 J m^{-2} of radiant exposure within any 8 h period, with UVR incident perpendicular to the skin or eye. EL assumes that the exposure is delivered during any period of eight successive hours, even where such a period overlaps work shifts or calendar days (2). When irradiance and radiant exposure are weighted with the spectral biological effectiveness of UVR, they are named effective irradiance and effective radiant exposure, respectively.

The International Commission on Non-Ionizing Radiation (ICNIRP) states, for skin (280–400 nm) and eye (180–315 nm) exposures, that each value of measured UVR spectral irradiance, E_λ (W m^{-2} nm^{-1}), must be weighted using the tissue spectral effectiveness factor, S_λ, according to the following equation (5–8):

$$E_{\text{eff}} = \sum_{\lambda} E_\lambda S_\lambda \Delta\lambda$$

where E_{eff} is effective irradiance (W m^{-2}), $\Delta\lambda$ is bandwidth of broadband measurement (nm) and λ is wavelength (nm). Effective radiant exposure (J m^{-2}) can be obtained from effective irradiance as follows:

$$\text{ED} = \int_{t_0}^{t_1} E_{\text{eff}}(t)\,\mathrm{d}t$$

where ED is effective radiant exposure, t_0 and t_1 are the start and end times of UVR exposure, respectively. If E_{eff} is constant in time, the effective radiant exposure is the product of exposure time (s) and effective irradiance.

As far as the quantitative evaluation of exposure levels is concerned, in the absence of a specific national law, the guidelines of the ICNIRP were taken as the reference (5–8). These guidelines are also adopted by the Italian National Institute of Health (9). It must be noted that EL is concerned with occupational exposures that may induce biological short-term effects (erythema and photokeratitis), without considering carcinogenic effects. Moreover, they define an action spectrum that takes into account the biological effectiveness of several constituent wavelengths of the spectral power distribution (SPD) of UV sources.

Measurement methods

Risk assessment, in operational terms, is carried out by measuring the source SPD at the point of worker maximum exposure and calculating total irradiance. To estimate the effects of the different wavelengths on biological targets, the biological effectiveness curve is applied to the measured spectrum. In this manner, the effective irradiance is obtained, and maximum exposure times can be evaluated to ensure that the limits are observed (5–8).

The incident SPD was acquired for all monitored sources in the 240–400 nm range, with steps of 1 nm. The total irradiance, E_{tot}, was calculated over the whole spectra and over the UV-A band, whereas the effective irradiance, E_{eff}, was evaluated over the whole spectra and, separately, over UV-A and UV-B + UV-C (actinic band) portions.

The technical characteristics of the spectroradiometer are: spectral range, 200–800 nm (240–800 nm with diffuser); measurement range, $10^{-9}/10^{2}$ W m^{-2} nm^{-1}; monochromator, double monochromator with computer-controlled holographic concave reticulum; f/l, 100 mm; detector, PMT Side window S20 multi-alkali; input optics, quartz light guide (L = 180 cm); cosine corrector; field of view with angular opening of 80° for measures on surface portions or luminous sources.

The measurement configuration is of fundamental importance in evaluating laboratory exposure to represent individual exposure. The use of a detector having an efficiency depending on radiation incidence angle in agreement with cosine law is therefore optimal. For skin exposure evaluation, the detector was oriented along the orthogonal direction of the surface of the body exposed, whereas for eye exposure, it was oriented along the visual line. In this situation, eye exposure strongly depends on the geometric factors that characterize it, in the presence of a large source, the 80° sight field was applied on the detector to simulate the eye span.

In measures with optical radiation using a spectrometer, each component (input and dispersive optics, detector and electronics) introduces an error that has to be added to the uncertainties associated with calibration and those introduced by the operator (10). Considering error sources and the radiometer uncertainty of 5% (1 sigma) (direct measure), the overall uncertainty of each evaluated data is ±10% (1 sigma).

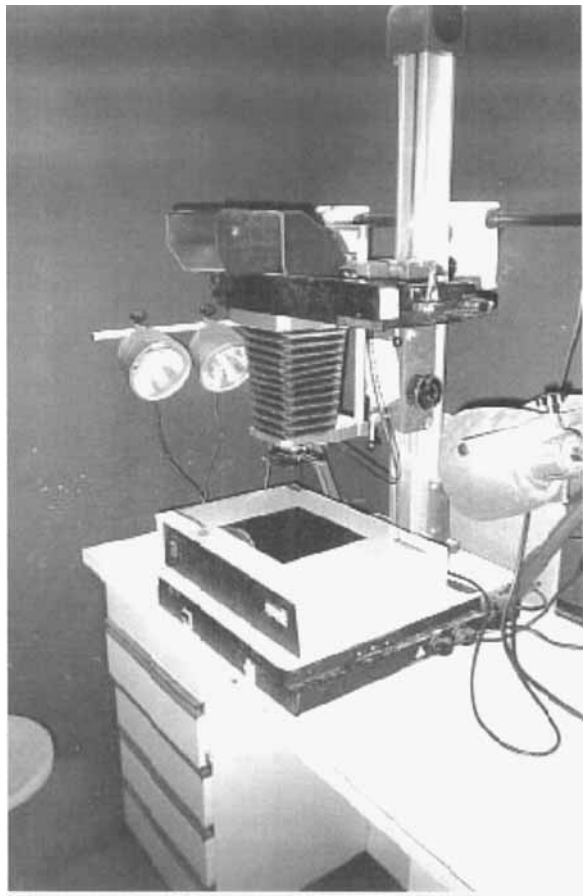

Figure 2. Fluorescent lamps for diagnostic methodologies and characterization of biological structures, genetics and biochemical area.

RESULTS

The levels of total and effective irradiance of each source are summarized in Tables 2–4. For every source, many spectra have been collected because the use modalities can significantly involve several exposure levels if referred to different organs: hands, eyes and face. Sources are identified with the code previously defined and reported in Table 1, where measures have been carried out on the same source in various positions, "hands" indicates skin and hand exposure and "eyes" indicates eyes and face exposure.

Risk assessment and maximum time permitted

The maximum time of permitted daily exposure has been estimated for each source on the basis of effective irradiance. ICNIRP EL are observed for unprotected eyes and skin if the conditions (1), (2) and (3) are observed.

$$E_{\text{eff}} t \leq 30 \text{ J m}^{-2} \qquad (1)$$

where E_{eff} is effective irradiance (W m^{-2}) and t is exposure time (s). Condition (1) is based on the fact that during a period of 8 h, the corresponding value of effective radiation exposure for unprotected skin and eyes, E_{eff}, does not exceed 30 J m^{-2}.

Table 2. Total and effective irradiance of chemical area sources*

Source code and position	E_{tot} (240–400) (Wm^{-2})	E_{tot} (315–400) (Wm^{-2})	E_{eff} (240–315) (Wm^{-2})	E_{eff} (315–400) (Wm^{-2})	E_{eff} (240–400) (Wm^{-2})	% UV-A	% UV-B	% UV-C
L3102	8.30×10^{-3}	5.63×10^{-3}	5.11×10^{-4}	2.17×10^{-6}	5.14×10^{-4}	68	32	0
L3652	4.00×10^{-3}	4.02×10^{-3}	0.00	5.08×10^{-7}	5.08×10^{-7}	100	0	0
LHG-1	5.72×10^{-3}	3.23×10^{-3}	1.24×10^{-3}	5.33×10^{-7}	1.24×10^{-3}	57	11	32
LHG-2	1.89×10^{1}	1.79	2.42×10^{-2}	2.23×10^{-3}	2.65×10^{-2}	57	11	32
L2542	4.77×10^{-2}	1.79×10^{-3}	2.17×10^{-2}	2.66×10^{-7}	2.18×10^{-2}	91	5	4
L3653	3.30×10^{-2}	3.27×10^{-2}	5.28×10^{-5}	6.68×10^{-6}	5.96×10^{-5}	99	1	0
LB254	2.99×10^{-1}	1.81×10^{-3}	1.42×10^{-1}	6.27×10^{-7}	1.42×10^{-1}	1	6	93
LBAN	4.05×10^{-3}	1.42×10^{-3}	1.26×10^{-3}	3.99×10^{-7}	1.26×10^{-3}	35	19	46
TLC—Hands	1.84	—	8.16×10^{-1}	1.25×10^{-5}	8.16×10^{-4}	4	6	90
TLC—Eyes	2.55×10^{-2}	1.17×10^{-3}	1.16×10^{-2}	1.38×10^{-7}	1.16×10^{-2}	4	6	90
CHINO—Hands	2.01×10^{-2}	—	1.70×10^{-3}	3.27×10^{-6}	1.70×10^{-3}	83	4	13
CHINO—Eyes	1.57×10^{-2}	1.25×10^{-2}	1.62×10^{-3}	2.45×10^{-6}	6.22×10^{-3}	83	4	13
MER—Hands	1.10×10^{-1}	—	1.64×10^{-3}	2.23×10^{-5}	1.67×10^{-3}	96	2	2
MER—Eyes	2.43×10^{-2}	2.11×10^{-2}	1.54×10^{-3}	4.43×10^{-6}	1.55×10^{-3}	96	2	2
HG—Eyes	4.35×10^{-2}	4.20×10^{-2}	1.31×10^{-4}	6.93×10^{-6}	1.39×10^{-4}	97	3	0
HG—Hands	5.35×10^{-1}	5.72×10^{-1}	1.25×10^{-3}	8.99×10^{-4}	1.35×10^{-3}	97	3	0

*Where the exposure was not uniform, the body portion that is exposed to UVR is indicated beside the source code.

For eyes, a separate condition (2) has to be satisfied in the bandwidth of 315–400 nm:

$$E_{tot}t \leq 10\,000 \text{ J m}^{-2} \quad (2)$$

where E_{tot} is total irradiance not weighted (W m^{-2}) and t is exposure time (s). The value 10 000 J m^{-2} corresponds to a radiation exposure limit, EL, reported over a period of 8 h.

Considering that generally UV irradiation can occur over the whole spectrum, 180–400 nm for eyes and skin, the corresponding exposure duration cannot exceed time, t_{max}, obtained with condition (3):

$$t_{max} = \frac{1}{\frac{E_{eff(180-315)} + E_{eff(315-400)}}{30} + \frac{E_{tot}}{10\,000}} \quad (3)$$

Risk assessment methodology given in Eq. (3) is more restrictive than ICNIRP requirements; in fact, it combines two limits, which ICNIRP intended to be used separately (effective UVR on the cornea and UV-A on the lens). The authors used the more conservative Eq. (3) because laboratory exposures are too changeable, making it impossible to consider each specific situation (*e.g.* the same worker can use various sources emitting different UVR spectra).

Maximum time limits (in seconds or in hours, minutes and seconds) are detailed in Tables 5–7 ("—" indicates irradiance data lower than limits, where exposure does not exceed time limits reported for a working day). On the basis of these times and considering the modalities of source use, a qualitative index of health risk level was assessed (N = negligible, M = medium, H = high) and reported in the last column of Tables 5–7.

Protective measurements

Preventive and protective measures. UVR exposure varies depending on the equipment characteristics and on use modalities. In areas where workers are staying, exposures depend on type and power source and exposure intensity, covering source characteristic and shielding (complete or partial), source–eye/skin operator distance, geometry of workplace relative to source, duration of daily use, work modalities and technology used. The reduction of risk is possible by means of intensity attenuation of radiation fields, reduction of exposure times, increase of source–operator distance, shieldings, elimination of undue exposure of staff not assigned to those specific activities and use of personal protective equipment (PPE) (11).

According to the preventive philosophy, protective measures have to be applied in this order: engineering and collective measures (*e.g.* source enclosure or shielding), administrative and managerial (behavioral measures) and as a last resort, the use of PPE.

Table 3. Total and effective irradiance of genetics and microbiological area sources*

Source code and position	E_{tot} (240–400) (Wm^{-2})	E_{tot} (315–400) (Wm^{-2})	E_{eff} (240–315) (Wm^{-2})	E_{eff} (315–400) (Wm^{-2})	E_{eff} (240–400) (Wm^{-2})	% UV-A	% UV-B	% UV-C
T320—Hands	4.33×10^{1}	4.29×10^{1}	6.37×10^{-3}	9.12×10^{-3}	1.55×10^{-2}	99	1	0
T320—Eyes	1.32×10^{1}	1.31×10^{1}	1.76×10^{-3}	2.73×10^{-3}	4.50×10^{-3}	99	1	0
CAP	9.99×10^{-2}	9.70×10^{-2}	1.52×10^{-3}	1.10×10^{-5}	1.53×10^{-3}	97	1	2
TGEN1—Hands	2.81×10^{1}	1.29×10^{1}	3.73	8.04×10^{-3}	3.74	46	54	0
TGEN1—Eyes	2.62	1.16	3.34×10^{-1}	7.70×10^{-4}	3.35×10^{-1}	44	56	0
TGEN2—Eyes	9.87	9.69	5.08×10^{-3}	1.66×10^{-3}	6.76×10^{-3}	98	2	0
TGEN2—Eyes	4.49×10^{-2}	4.88×10^{-2}	0.00	1.53×10^{-6}	1.53×10^{-6}	100	0	0
SANTAO1—Eyes	8.84×10^{-3}	5.82×10^{-3}	1.54×10^{-3}	1.15×10^{-6}	1.54×10^{-3}	66	9	26
RAN	1.39×10^{-4}	1.30×10^{-4}	4.93×10^{-6}	5.38×10^{-9}	4.94×10^{-6}	94	4	3
DEL	2.08×10^{-2}	2.07×10^{-2}	3.29×10^{-5}	2.31×10^{-6}	3.52×10^{-5}	100	0	0

*Where the exposure was not uniform, the body portion that is exposed to UVR is indicated beside the source code.

Table 4. Total and effective irradiance of biological area sources*

Source code and position	E_{tot} (240–400) (Wm^{-2})	E_{tot} (315–400) (Wm^{-2})	E_{eff} (240–315) (Wm^{-2})	E_{eff} (315–400) (Wm^{-2})	E_{eff} (240–400) (Wm^{-2})	% UV-A	% UV-B	% UV-C
PATL—Hands	2.64×10^{1}	2.64×10^{1}	1.34×10^{-3}	3.24×10^{-3}	4.59×10^{-3}	100	0	0
PATL—Eyes	1.06×10^{1}	1.05×10^{1}	6.38×10^{-4}	1.31×10^{-3}	1.95×10^{-3}	100	0	0

*Where the exposure was not uniform, the body portion that is exposed to UVR is indicated beside the source code.

Operating rules and control measures. The main procedures to ensure staff and student protection are listed below (11,12).

(1) Engineering and physical safety measures.
   a. To position UV sources in specific lodgings.
   b. To verify that observation windows are made of stable materials and absorb the UV band.
   c. When the source irradiates outside the work area, adequate shielding is needed to avoid exposure of staff not involved in the activity. It is necessary to isolate the exposure area.

(2) Managerial safety procedures.
   a. Areas in which UV sources are used should be indicated by warning signs.
   b. Researchers have to carry out periodic checks of safety device functionality (emergency buttons, *etc.*). They have to ensure that the safety system checks and maintenance operations are carried out periodically, particularly lamp covering and reflector (it is necessary to keep it clean to avoid material deposition altering radiation filtration) and eventual cooling systems (*e.g.* high-pressure lamps) maintenance.
   c. Authorized staff (and students) shall be trained and informed by the laboratory manager on type and characteristics of UV source used; UVR organ targets (skin and eyes), physiopathological situations that can involve a level of unacceptable risk and health effects associated with UV exposure; prevention and protective measures; specific operating procedures (SOP) for safe use of UV sources, with particular attention to safe behavior; PPE use and care; periodic safety checks and maintenance of UV equipments; safety warnings; procedures in emergency situations; health surveillance (if required).
   d. Researcher, in collaboration with the University Safety Service, chooses PPE and supplies them to potentially exposed staff, who, in turn, are obliged to use them (see point 4).

(3) Behavioral safety measures.
   a. To limit exposure time of the body, or parts of it, depending on research activity.
   b. To observe maximum exposure times not to exceed EL.
   c. Situations in which it is not possible to use PPE, shall be restricted to exceptional cases.
   d. To always use light containers and source screens.
   e. To avoid possible openings that could give rise to UV exposure near other workplaces also.
   f. To stay at a maximum distance from the source.
   g. In areas in which there are UV sources, to carry out the necessary operations only, avoiding unjustified radiation exposures.
   h. Workers and students have to communicate variations in their personal health conditions, involving UV exposure.
   i. The researcher shall prepare SOP for safety conditions that must be observed by all workers.

(4) Personal Protective Equipment.
   a. In the laboratory, target organs of UVR are skin and eyes. For skin, the most effective safety measure is to cover the skin wearing gown, muffs and gloves. UVR penetration through the coat varies depending on the weft of material webbing, the more closely woven is the material, the greater is the protection. High protection is associated with materials such as cotton and, given in the same sort of fabric, darker colors absorb more UVR than light colors (2,13).
   b. When face masks or glasses are assigned to more than one person, they must to be disinfected after every use.
   c. For eyes, the most effective means of protection is to wear glasses or masks (or both) (the latter also protects face skin). The choice of glasses must take account the following factors: spectral distribution of UV source, exposure intensity in the workplace, property of transmission of materials and their stability, glasses and mask design.
   d. For some high-pressure lamps subject to breakage risk, eyes and face must be protected with PPE-like masks resistant to fragments of lamp covering breakage.
   e. Glasses are only effective when the source is predominantly UV-A; if UV-B or UV-C radiations are significant,

Table 5. Maximum times and risk index of chemical area sources*

Source code and position	Exposed part†	Maximum time (s)	Maximum time h	min	s	Risk
L3102	S–E	56576	—	—	—	Negligible
L3652	S–E	2387072	—	—	—	Negligible
LHG-1	S–E	23996	6	39	56	Negligible
LHG-2	S	1134	0	18	54	Medium
L2542	S	1379	0	22	59	Medium
L3653	S	503356	—	—	—	Negligible
LB254	S–E	211	0	3	31	High
LBAN	S–E	23647	6	34	7	Negligible
TLC—Hands	S	16	0	0	16	High
TLC—Eyes	S–E	2592	0	43	12	High
CHINO—Hands	S	1495	0	24	55	High
CHINO—Eyes	S–E	18072	5	1	12	Negligible
MER—Hands	S	272	0	4	32	Negligible
MER—Eyes	S–E	18625	5	10	25	Negligible
HG—Eyes	S–E	113524	—	—	—	Negligible
HG—Hands	S	22255	6	10	55	Negligible

*Where the exposure was not uniform, the body portion that is exposed to UVR is indicated beside the source code.

†The column "exposed part" indicates the organs, S = skin, E = Eyes/Face, which are compared with exposure limits and calculated maximum exposure times.

Table 6. Times and risk index of genetics and microbiological area sources*

Source code and position	Exposed part†	Maximum time (s)	Maximum time h	min	s	Risk
T320—Hands	S	1931	0	32	11	High
T320—Eyes	S–E	683	0	11	23	High
CAP	S–E	16439	4	33	59	Negligible
TGEN1—Hands	S	8	0	0	8	High
TGEN1—Eyes	S–E	89	0	1	29	High
TGEN2—Eyes	S–E	838	0	13	58	High
TGEN2—Eyes	S–E	202805	—	—	—	Negligible
SANTAO1—Eyes	S–E	19260	5	21	0	Negligible
RAN	S–E	5629806	—	—	—	Negligible
DEL	S–E	308227	—	—	—	Negligible

*Where the exposure was not uniform, the body portion that is exposed to UVR is indicated beside the source code.
†The column "exposed part" indicates the organs, S = skin, E = Eyes/Face, which are compared with exposure limits and calculated maximum exposure times.

as in research laboratories, the facial skin will have to be covered using specific mask.

DISCUSSION

Results obtained in this survey carried out at research laboratories show that the use of sources of incoherent UVR can be a nontrivial risk for researchers, technicians and students. It is important to note that EL suggested by ICNIRP and used in this study does not protect against stochastic effects.

Regarding the EL, the effective and total irradiance levels have produced evidence that, potentially, the risk from UV exposure exists especially in association with apparently innocuous sources, particularly if they are used without specific safety procedures. Table 8 shows UV lamps for which risk is not negligible if the worker does not use safety procedures and PPE.

In particular, risk to unprotected skin and eyes is important with chromatography viewers and with transilluminators used for subcellular observation of biological activities. The latter could in fact involve a high risk for eyes because the activity needs that the lamp is positioned upward and that operator manipulates the gel with the lamp switched on. The protection from UV sources however can be easily realized by using PPE, both for skin and eyes. Also, the spark high-pressure lamps can involve a significant risk, but this source is shaped in such a way that the presence of the operator is not necessary.

Table 7. Times and risk index of biological area sources*

Source code and position	Exposed part†	Maximum time (s)	Maximum time h	min	s	Risk index
PATL—Hands	S	6536	1	48	56	Negligible
PATL—Eyes	S–E	891	0	14	51	Medium

*Where the exposure was not uniform, the body portion that is exposed to UVR is indicated beside the source code.
†The column "exposed part" indicates the organs, S = skin, E = Eyes/Face, which are compared with exposure limits and calculated maximum exposure times.

Table 8. Source type at medium and high risk (when not protected)

Area	Source	Source code
Chemical	Hg high-pressure lamp	LHG, LBAN
	Hg medium-pressure lamp	LB254
	TLC plate viewer	TLC, CHINO
Genetics and microbiological	Transilluminator	T320, TGEN, SANTAO1
	Germicide hood (eye position)	CAP
Biology	Animal pound lamp	PATL

The operation with UV lamps can also be carried out by students, who cannot be considered expert workers; so their operation might demand times exceeding those calculated using limits adopted in this study. Safety procedures detailed in this study refer to training and information, prevention and protection measures, including PPE use.

In conclusion, in a research laboratory, there are some situations that can be important if operators (particularly students) are not adequately trained and informed on the risks, safety procedures and the use of PPE.

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