Documentary notebooks - Occupational health and safety - *No. 170, 1 er quarter 1998*

→ *A. Barlier-Salsi, S. Salsi,*
A. Klingler, Environmental Physiology
Department, INRS Research Center, Nancy

Radiation lamps ultraviolet

Quantification of the risks associated with their use

RISKS ASSOC IATED WITH THE USE OF ULTRAVIOLET LAMPS

The aim of the study was to quantify the risks associated with the use of different types of ultraviolet lamps and to define the limits in which they should be used. For this purpose, the spectral irradiance of 30 of these lamps was measured between 200 and 400 nm. Maximum durations of daily exposure were determined for different distances from radiation source. Most lamps produced to be potentially dangerous, making it necessary to wear protective equipment, especially with sources emitting in the UVB and UVC range (200-315 nm). With the other lamps, it is essential not to exceed the daily exposure duration limits.

VS this study aims to quantify the risks associated with the use of ultraviolet lamps and to define their limits of use. To this end, the spectral irradiance of 30 of these lamps was measured between 200 and 400 nm. The maximum daily exposure times were determined for different distances of use. The results show that the majority of lamps are potentially dangerous and that the wearing of protective devices is necessary, more especially with sources emitting in UVBet C (200-315nm). With other lamps, it is essential not to exceed the daily exposure times.

optical radiation ultraviolet radiation UV lamp skin eye injury

optical radiation ultraviolet radiation UV lamp skin eye lesion

L ultraviolet (UV) radiation is optical radiation whose spectral range extends from 100 to 400 nm. The CIE (International lighting) distinguishes three categories of ultraviolet rays: UVA (315-400 nm), UVB (280-315 nm) and UVC (100-280 nm) [1].

The sun is virtually the only natural source of ultraviolet radiation; ultraviolet rays represent about 5% of the total radiation emitted. There is, however, a wide variety of artificial sources. Depending on the type of source, the ultraviolet radiation emitted is considered to be parasitic when it does not contribute to the desired effect (in the case of certain general purpose lamps, welding arcs, etc.) or is then used for its direct effects. It indeed finds many applications in industry for drawing plans, detecting defects, drying inks, chemical synthesis, polymerization of varnishes or glues. UV radiation is also widely used in tanning booths. artificial zage. In the medical field, UV radiation lamps are commonly used in the treatment of certain diseases (psoriasis, eczema, hyperbilirubinia, etc.) and for bacterial disinfection.

While short-term, low-dose exposure to ultraviolet radiation has beneficial effects for the body, prolonged and / or high-dose exposure may have acute or chronic pathological consequences that are directly related to penetration and absorption of this radiation in the structures of the skin and the eye.

For the skin, the immediate direct effects are manifested by the classic sunburn, which has several levels of severity from simple erythema to more significant lesions including pain, blister edema. In the long term, the repetition of actinic skin lesions leads to pathological changes of the skin which may be precancerous lesions or possible genuine skin cancers.

For the eye, the immediate effects are felt by damage to the cornea and conjunctiva (keratoconjunctivitis) symptomatology is well known sand pressure in the eyes, tearing, "red" eye. Visual disability can last from 6 to 24 hours. In the long term, chronic exposure to ultraviolet radiation can lead to clouding of the lens (cataracts).

A bibliographic review, published in 1994 [2,] gives a detailed description of the effects and the different mechanisms of action of ultraviolet rays on the organism. It also identifies the different situations of occupational exposure to ultraviolet rays as well as the commonly used sources of ultraviolet radiation, but does not provide the values of the risk levels associated with the use of these different sources.

The present study therefore proposes to complete this bibliographical summary, by quantifying the risks presented by sources of ultraviolet radiation used in different sectors of activity, by defining their limits of use.

1. Methods and techniques

1.1. Studied lamps

Thirty ultraviolet lamps of different characteristics and powers were studied: 3 supra-actinic lamps, 3 actinic lamps, 5 so-called black light lamps, 12 lamps for tanning and phototherapy, 1 medical fluorescent lamp, 4 germicidal lamps, one lamp for graphic art and a lamp for photochemistry. Their characteristics and fields of use are given in the *table I.*

1.2. Measurement configurations

Ultraviolet radiation was measured on one lamp of each type. Certain tubes have also been studied in other configurations, corresponding in particular to the simultaneous operation of 2 and 4 lamps of the same type.

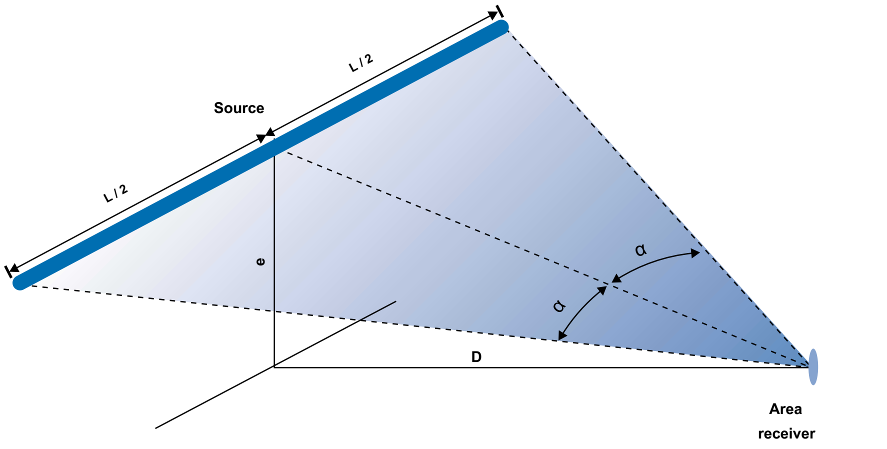

Fig. 1. Configuration of linear sources

1.3. Measured sizes and equipment

The spectral irradiance E_λ was measured between 200 and 400 nm using of an Optronic model OL750 spectroradiometer. This device is equipped with a double grating monochromator, 2 detectors (a photomultiplier and a silicon detector), an amplifier and an integrating sphere.

The spectroradiometer was calibrated from 2 secondary sources, themselves calibrated against NIST (National Institute of Standards and Technology) references. The first source is a deuterium lamp (accuracy varying from 3.8 to 5% depending on the wavelength), the second, a tungsten halogen lamp (accuracy varying from 2.6 to 3.1% depending on the length of the wave).

1.4. Method of measurement and calculation of the spectral irradiance

The spectral irradiance E_λ was measured at a distance varying from 0.25 at 1.5 m depending on the dimensions of the lamps. The distances of use of these sources being very variable, the spectral irradiance was calculated, as follows, for different values of the exposure distance.

If $E_\lambda(D)$ is the irradiance spectral at a distance D, $E_\lambda(D_{my})$ the spectral irradiance at the measuring distance D_{my}, $E_\lambda(D)$ has for expression:

$$E_\lambda(D) = E_\lambda(D_{my}) \frac{G(D)}{G(D_{my})} \qquad (1)$$

where G (D) and G (D_{my}) are respectively the configuration coefficients of the source at distance D and distance from measure of $_{my}$.

In this calculation, two coefficients of configuration have been taken into account:

one relating to linear sources [2] (case of tubes; cf. table I), which has the expression (cf. *fig. 1):*

$$G(D) = \frac{D}{2(D^2 + e^2)}(2\alpha + \sin 2\alpha) \qquad (2)$$

the other corresponding to point sources (case of other sources; see table I), which is written:

$$G(D) = \frac{1}{D^2} \qquad (3)$$

1.5. Assessment method risks

Calculation of exposures and corresponding exposure limit values

All other conditions being equal, the nature and site of the lesions caused by ultraviolet radiation are essentially linked to its wavelength. The assessment of the associated risks therefore requires the determination of the exposures in different spectral domains. Depending on the spectral domain considered, it is the former energy position (H_{UVA}) or the exhibition energy efficient sition (H_{UVeff}). The latter takes into account the relative efficiency spectral tive of ultraviolet radiation on the eyes and skin, S_λ.

TABLE I

VS FEATURES AND AREAS D ' USE OF THE LAMPS STUDYED

Lamp types	Landmarks (power)	Characteristics	Areas of use
Supra-actinic lamps	A1 (20W) A2 (40W) A3 (140W)	Fluorescent tubes	- drawing of plans, - photomechanical reproductions, - treatment of hyperbilirubinia, - various medical treatments.
Actinic lamps	B1 (20W) B2 (40W) B3 (140W)	Fluorescent tubes	- drawing of plans, - photochemical reactors, - insect traps.
Black light lamps	C1 (6W) C2 (18W) C3 (6W) C4 (125W) C5 (125W)	Fluorescent glass tubes Filtering glass bulb called "Blue -Black" Glass bulb deWood	- fault detection, - insect traps, - special effects in the show, - archeology, mineralogy, medicine, biology.
Tanning lamps and phototherapy	D1 (20W) D2 (40W) D3 (40W) D4 (80W) D5 (100W) D6 (40W) D7 (80W) D8 (40W) D9 (80W) D10 (100W) D11 (400W) D12 (300W)	Emission fluorescent tubes intense between 320 and 390 nm Emission fluorescent tubes intense between 313 and 370 nm Reflector fluorescent tubes with intense emission between 313 and 370 nm Fluorescent tubes with reflector with extremely reduced emission in the UVB Quartz metal halide lamp High pressure mercury vapor lamp	- artificial tanning, - treatment of skin diseases, - exposure of photopolymers, - insect traps. - artificial tanning, - treatment of skin diseases, - photochemical processes. - artificial tanning. - artificial tanning, - treatment of skin diseases. - artificial tanning, - treatment of skin diseases, - various medical treatments.
Germicidal lamps	E1 (6W) E2 (9W) E3 (15W) E4 (115W)	Quartz lamps mercury vapor low pressure	- air disinfection, - water purification, - sterilization (hospitals, food industry)
Fluorescent lamp medical	F1 (20W)	Fluorescent tube with intense emission between 400 and 500 nm	- treatment of hyperbilirubinia, - reprography.
Lamp for photochemistry	G1 (125W)	High pressure mercury vapor quartz burner	- photochemistry, - polymerization of glues and varnishes, - spectrometry.
Arts lamps graphics	H1 (125W)	High pressure mercury vapor lamp	- screen printing, - hardening of lacquers, - enlarger, - decorative lighting.

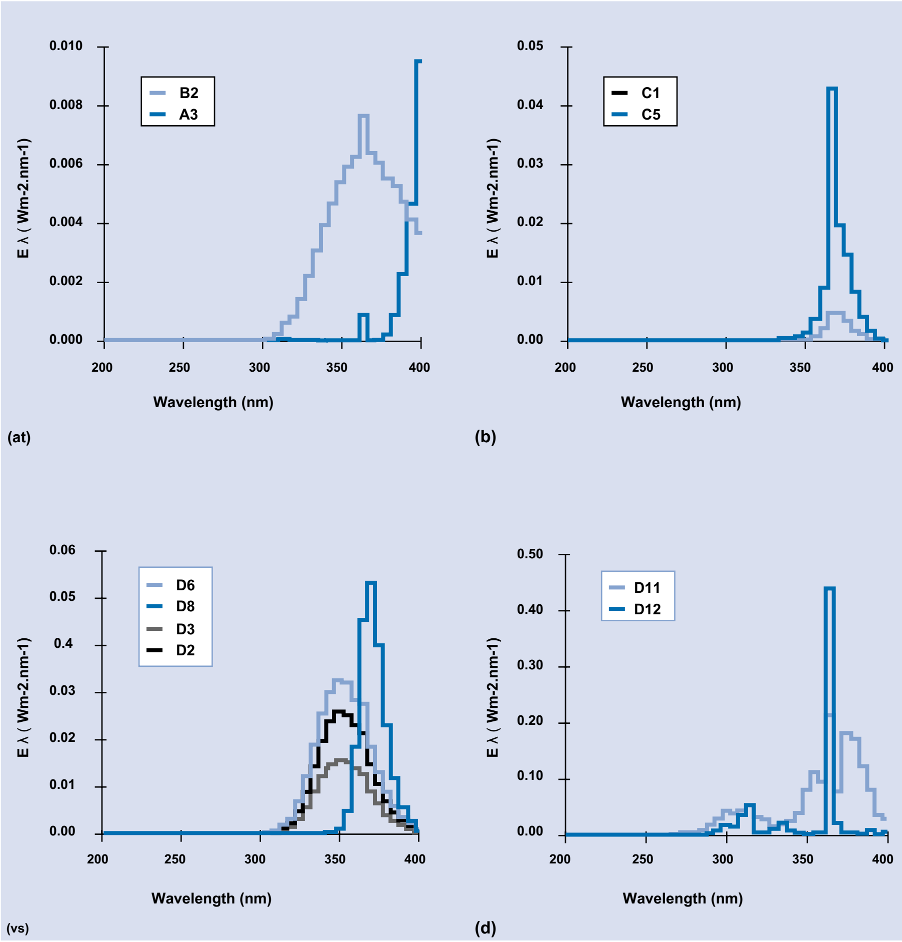

Fig. 2. Spectral distributions of irradiance calculated at 1m from actinic and supra-actinic lamps (a), black light lamps (b) and lamps for tanning and phototherapy (c, d)

TABLE II

M METHOD OF CALCULATING EXPOSURE LEVELS AND CORRESPONDING EXPOSURE LIMIT VALUES

Field spectral	Risks	Effects physiological	Levels exhibition	Values limits exhibition
200 at 400 nm	*SKIN UVeff* *EYE UVeff*	Skin: erythema, effects carcinogenic Eye: keratitis, conjunctivitis	$H_{UVeff} = \sum_{200}^{400} E_{\lambda}\, t S_{\lambda}\, \Delta\lambda$	VLE UVeff = 30 Jm- 2
315 at 400 nm	*EYE UVA*	Eye: cataract	$H_{UVA} = \sum_{315}^{400} E_{\lambda}\, t.\, \Delta\lambda$	VLE UVA = 10^4 Jm $^{-2}$

E_{λ}: Spectric irradiance [W. cm-2. nm-1] - D_{λ}: bandwidth [nm]. S_{λ}: Relative spectral efficiency - t: daily exposure time [s].

These different exposures are then compared with the exposure limit values proposed by the IRPA (International Radiation Protection Association) [4, 5].

The exposure calculation method, the corresponding exposure limit values and the associated risks are presented in the *table II.*

Calculation of risk indices

In order to quantify the risks presented by sources, each exhibition H_x was compared to the exposure limit value corresponding VLE. To do this, a risk index I_x has been defined as follows:

$$I_x = \frac{H_x}{VLE_x} \qquad (4)$$

Thus, a risk index greater than 1 means that the source studied presents a risk in the spectral range considered.

Determination of the limits of use of sources

Given the diversity of sources studied and their different conditions of use, the risk index determined in a particular situation is not sufficient to characterize the risks presented by these sources. It is therefore necessary to calculate for each source, the maximum permissible daily exposure time as a function of the exposure distance in each spectral domain. Thus, at an exposure distance D, the maximum admissible daily exposure time t (D) is expressed as:

for the risks " *SKIN UVeff* "And" *EYE UVeff* "(cf. table II):

$$t(D) = \frac{30}{\sum_{200}^{400} E_{\lambda}(D) . S_{\lambda}. \Delta\lambda} \qquad (5)$$

for the risk " *EYE UVA* "(Cf. Table II).

$$t(D) = \frac{10^4}{\sum_{315}^{400} E_{\lambda}(D). \Delta\lambda} \qquad (6)$$

2. Results

2.1. Energy illumination spectral

The spectral distributions of irradiance calculated at 1 m from the studied sources are shown in *figures 2 and 3*. The performance was limited to one spectrum per type of lamp, that of the lamp 40 W, when this power is available. These graphs show that: the lamps marked D11, D12 (fig. 2d) and G1 (fig. 3d) emit over the entire ultraviolet range,

the emission spectrum of the germicidal lamps E1 to E4 (fig. 3a) is practically limited to a line at 253 nm,

the other types of lamps have a maximum emission in the UVA.

Figure 2c shows the importance of the reflector incorporated in certain tubes on the emission. Indeed, at equal power (40 W), the maximum emission (0.03 W. m- 2) of the reflector tube D6 is twice as high as the maximum emission (0.015 W. m- 2) of tube D3 not fitted with reflector.

2.2. Risk Assessment

The risks presented by the sources were evaluated using the risk indices defined by relation (4). Two risk indices were calculated:

index I UVeff to quantify the risks *SKIN UVeff* and *EYE UVeff*

and the index I UVA to quantify the risk *EYE UVA* (cf. Table II). Indices I UVeff and I UVA were calculated in the situation where the risk is maximum, i.e. at the dis-
minimum exposure strength is 0.50 m and for a maximum daily exposure time, 8 hours. The *figure 4* rep-
feel the clue I UVA according to the index I UVeff for all the sources studied.

This representation of risk indices makes it possible to define 4 zones:

a risk-free zone in the lower left dial,

a zone of maximum risk, risks *SKIN UVeff*, *EYE UVeff* and *EYE UVA* in the upper right dial,

a zone for risk *EYE UVA* in the upper left dial and

a zone for risks *SKIN UVeff* and *EYE UVeff* in the lower right dial.

Thus, the medical fluorescent lamp F1, the filter glass black light lamp C3 and the supra-actinic lamps of 20 and 40W, A1 and A2 do not present any risk. On the other hand, the actinic lamp B3, the lamps for tanning and phototherapy D4, D5, D6, D7, D11 and D12, the lamp for graphic arts G1 and the lamp for photochemistry H1 have all the

risks (*SKIN UVeff*, *EYE UVeff* and *EYE UVA)* associated with ultraviolet radiation.

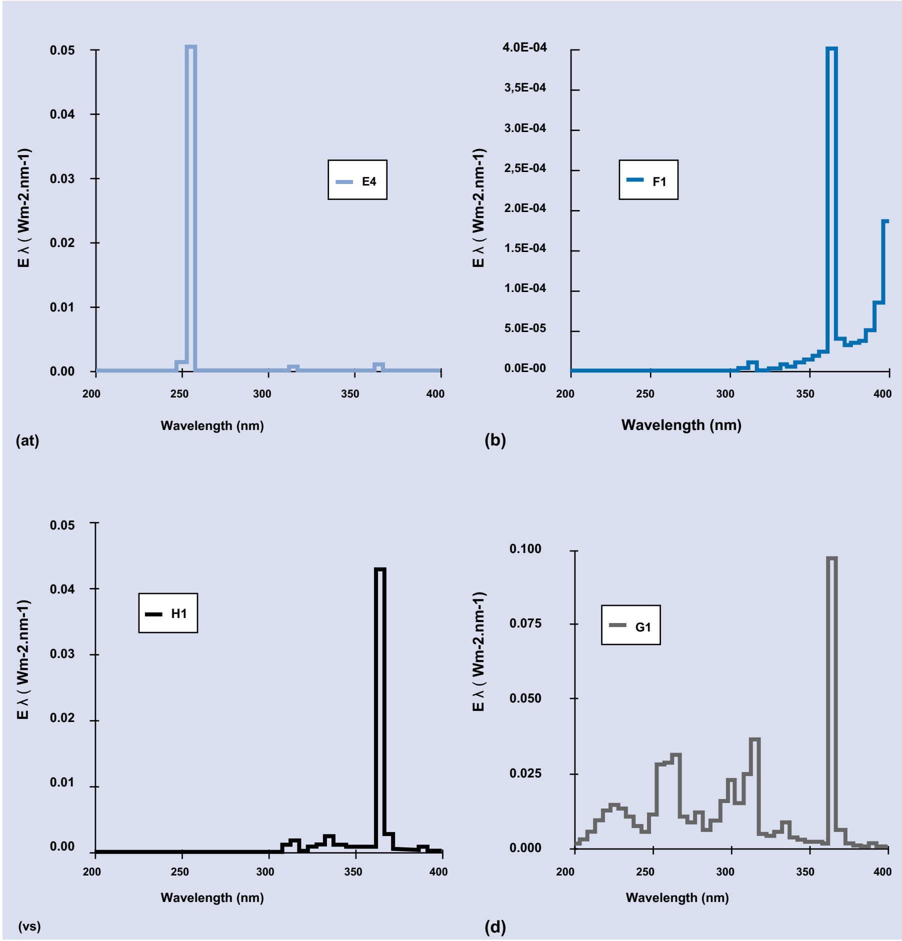

Fig. 3. Spectral distributions of irradiance calculated at 1m from the germicidal lamps (a), the medical fluorescent lamp (b), the lamp for graphic arts (c) and the lamp for photochemistry (d)

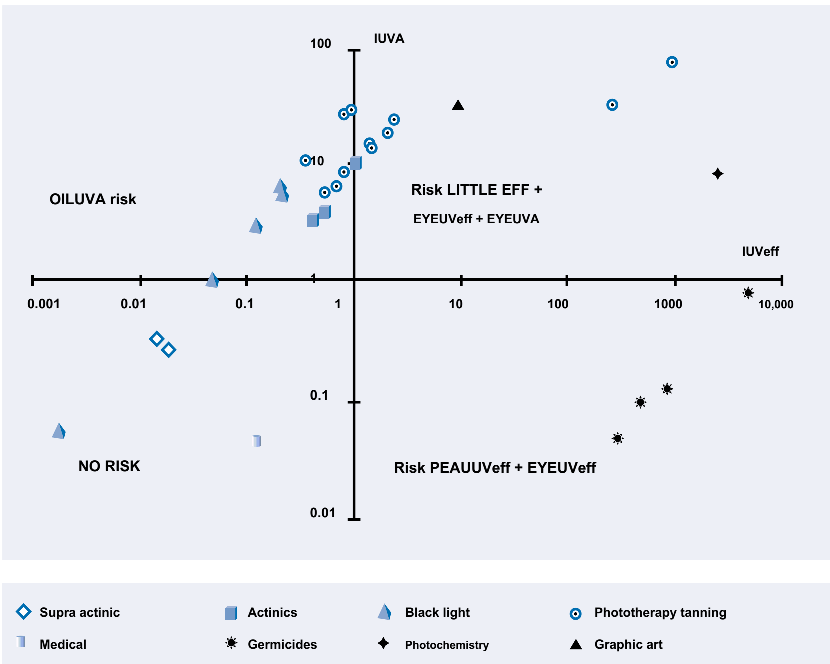

Fig. 4. Risk indices calculated 1m from the source and for 8 hours of daily exposure

Germicidal lamps are located in the risk zone *SKIN UVeff* and *EYE UVeff* and other lamps not mentioned in the area risk *EYE UVA.*

2.3. Limits of use of sources

When the sources present risks under the conditions described above, it is important to determine their limits of use, expressed in the form of distance - duration of exposure curves. The maximum daily exposure times

were calculated using relations (5) and (6) for exposure distances between 0.5 m and 5 m. Limits on the use of sources relating to risks

SKIN UVeff and *EYE UVeff* are represented *figure 5* and those relating to risk *ŒIL UVA figure 6.* Although all fluorescent tubes for tanning and phototherapy rapie present a risk *EYE UVA,* the representation (see fig. 6) was limited to one curve by tube type for clarity.

"SKIN UVeff "And" EYE UVeff "

The risks *SKIN UVeff* and *EYE UVeff (* cf. fig. 5) presented by the lamp for the photo chemistry G1, germicidal lamps, E1 to E4 and lamps D11 and D12 for tanning and phototherapy are very high. The maximum daily exposure times corresponding to an exposure distance of 5 m vary from 5 to 180 minutes depending on the power of these lamps. On the other hand, the maximum daily exposure times determined for the actinic lamp B3, the fluorescent tubes for tanning and phototherapy D4 to D7 and the lamp for graphic arts H1 are between one hour and 8 hours for distances of exposure less than

1.5m. Beyond this distance, these lamps no longer present any risks *SKIN UVeff* and *EYE UVeff.*

"EYE UVA "

For exposure distances greater than 5 m, the sources studied do not present a risk associated with the UVA range (see fig. 6). In other exposure conditions (distance less than 5 m) it is necessary to respect the maximum daily exposure time to work

without risk in front of these sources. So at 0.50 m from the source, the maximum daily exposure times vary from:

1 to 3 hours for the actinic lamp A3 and the black light lamps C2, C3 and C4,

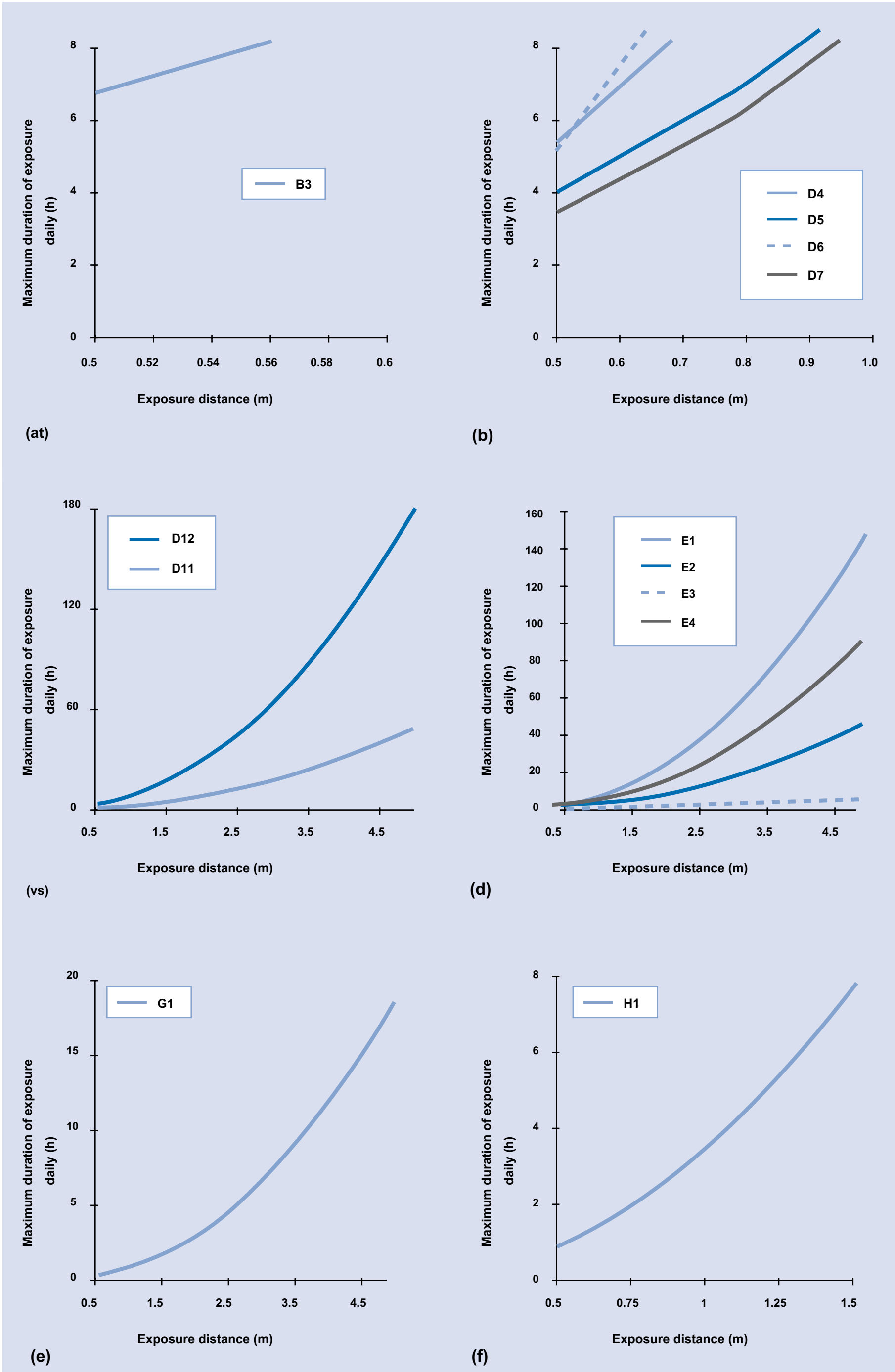

Fig. 5. Limits of use of lamps for SKIN risks UVeff and EYE UVeff:
(a) actinic lamp, (b) fluorescent tubes for tanning and phototherapy,
(c) other lamps for tanning and phototherapy, (d) germicidal lamps, (e) lamps for photochemistry,
(f) lamp for graphic arts

30 minutes to 1h30 for fluorescent tubes for tanning and phototherapy D1 to D10 and the lamp for graphic arts G1,

and are less than 30 minutes for the other lamps for tanning and phototherapy, D11 and D12.

Use of lamps mounted in battery

The results presented above correspond to the use of a single lamp. However, certain types of lamps such as actinic and supra-actinic lamps or lamps for tanning are rarely used alone; in fact, they are more often mounted in a battery of 2, 4 or even 8 lamps. The *figure 7* give an example of

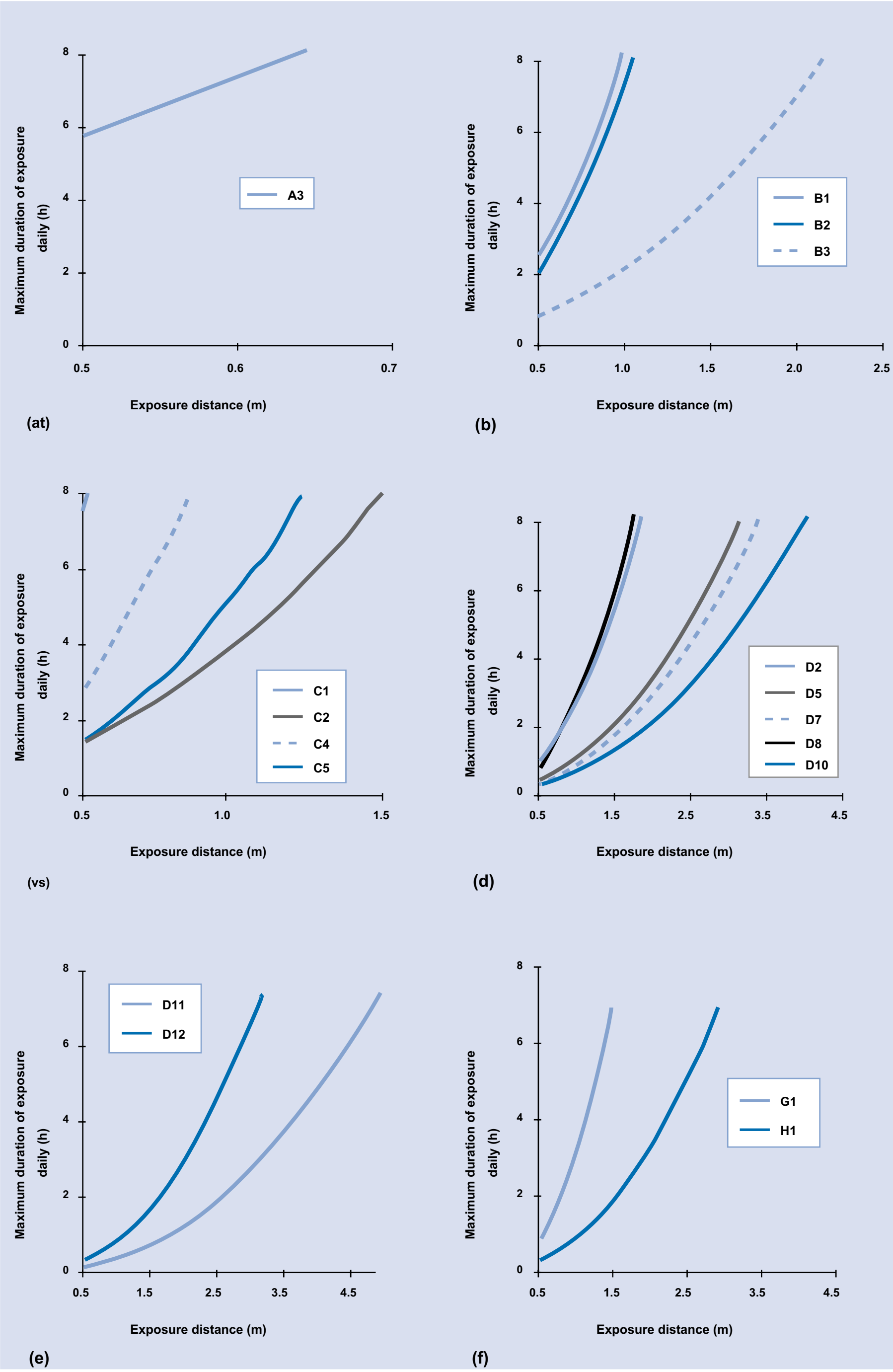

Fig. 6. Limits of use of lamps for the EYE risk UVA:
(a) supra-actinic lamps, (b) actinic lamps, (c) black light lamp,
(d) fluorescent tubes for tanning and phototherapy, (e) lamps for tanning and phototherapy, (f) lamps for graphic arts and photochemistry

actinic lamps (B3) mounted in battery. This figure makes it possible to compare the maximum permissible daily exposure times as a function of the exposure distance for 1, 2 and 4 lamps. So at

0.50 m, the risks *SKIN* $_{UVeff}$ and *EYE* $_{UVeff}$ almost non-existent when using a single lamp, become quite real when using a 4 lamp battery. The maximum daily exposure time which is of the order of 7:30 am for a lamp, is only 1:45 am for 4 lamps.

It is therefore imperative to adapt the results presented to the actual conditions of use, namely the number of lamps in service. A rough estimate of the risk is to divide the maximum permissible daily exposure time for a lamp by the number of lamps used. This calculation is approximate in the as it does not take into account the configuration coefficient of the source. However, the error made having the consequence of increasing the risk, the estimated maximum allowable times are always less than the actual maximum allowable times.

3. Discussion

The importance of the danger, linked to the use of lamps emitting specifically ultraviolet radiation, varies according to their characteristics and according to whether they are accidental or chronic exposures. Accidental exposure to intense sources of ultraviolet radiation results in the appearance of erythema of the skin and keratoconjunctivitis. The effects of such exposure are immediate but remain reversible. On the other hand, the recurrence of cutaneous erythema following chronic exposure can ultimately lead to cancerous lesions [6]. During any chronic exposure, the appearance of an erythema, even slight, must constitute a warning for the user and encourage him to use an adequate protective device in order to avoid the appearance of more serious long-term lesions.

Due to their intense radiation level in the UVB-C range, germicidal lamps often cause accidents. People brought to work near these lamps must therefore wear protective clothing and glasses [7]. When these lamps are used for the disinfection of premises, they must never be operated in the presence of personnel. Likewise, sources used in industrial processes such as actinic, supra-actinic and photochemical lamps are often built into machines and users are generally not exposed to direct radiation from lamps. Rather, the risks associated with the use of lamps for tanning and phototherapy result from chronic exposures. These lamps, often mounted in a battery of 4 or 8 lamps, are likely to cause mild erythema, just perceptible but the repetition of which can be dangerous in the long term. Personnel employed in artificial tanning booths or in phototherapy treatment rooms must pay attention to the duration of exposure to these lamps; if these times exceed the maximum permissible daily exposure times, the

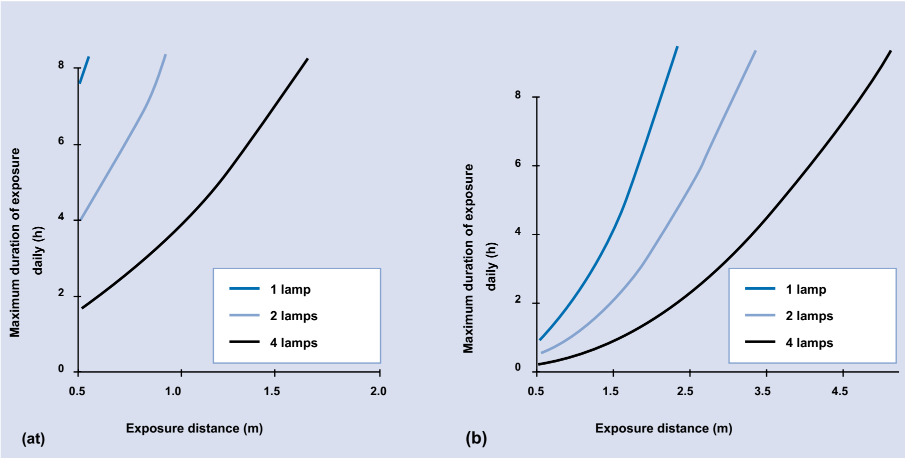

Fig. 7. Limits of use corresponding to 1, 2 and 4 lamps:
(a) SKIN risk $_{UVeff}$ + EYE $_{UVeff}$, (b) EYE risk $_{UVA}$

wearing of protective clothing and eyewear is necessary [8].

Chronic exposure to UVA radiation can also cause clouding of the lens (cataracts). However, the source must be located in the axis of the user's gaze so that the ultraviolet rays emitted are capable of reaching the lens. However, UVA radiation is often accompanied by visible radiation which makes the source dazzling and triggers avoidance reflexes (eyelid reflex, looking away, etc.), which are means of protection.

On the other hand, if the emission is limited to the UVA domain, the risk is real and, moreover, there are no precursor signs of-
ger. Among the lamps studied, only the so-called black light lamps fall into this category of sources which emit very little visible radiation; therefore they present risks associated with UVA. The presence of such lamps in the users' field of vision is therefore to be avoided, especially since their direct radiation is of no interest. In fact, in current applications (fault detection, special effects, etc.) it is the properties of the radiation reflected by the various media that are used.

CONCLUSION

Twenty lamps out of the thirty studied are likely to present risks linked to the emission of ultraviolet radiation. The nature and level of risks vary according to the spectral distribution and the power of the sources but also according to their conditions of use.

The exposure distance, the daily exposure time and the number of lamps in use are three factors to be taken into account in assessing the risk relating to a source of ultraviolet radiation.

Thus, the maximum admissible daily exposure distance-duration curves, established for each type of lamp, determine their limits of use. If the daily exposure times exceed the maximum permissible durations thus determined, it is necessary to wear glasses and / or protective clothing. The extent of the hazard also depends on the nature of the exposure. Beyond accidental exposure, the effects of which are immediate but reversible, chronic exposure appears to be the most dangerous in the long term.

The appearance of even a slight erythema, following the use of ultraviolet radiation lamps, should encourage the user to protect himself, in order to avoid the appearance of more serious long-term lesions.

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NATIONAL RESEARCH AND SECURITY INSTITUTE - 30, rueOlivier-Noyer 75680 Paris cedex 14
Offprint from Documentary notebooks - Occupational health and safety, 1 er quarter 1998, n ° 170 - ND 2074 - 1200 ex. CPPAP No. 804 / AD / PC / DC of 14-03-85. Director of publication: J.-L. MARIE. ISSN 0007-9952 - ISBN 2-7389-0624-9

JOUVE-Paris