

THE EFFECTS OF RADIATION ON THE EYE IN INDUSTRIAL ENVIRONMENTS

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Abstract — Occupational diseases and harmful effects on the human body industry were concerns in many scientific papers over time. Since the vision is one of our senses responsible for the comfort and quality of life, is very important to know what are the factors that can lead to decreased quality of vision, to try to prevent and, where appropriate, to investigate and find solutions for ocular recovery. In this spirit, present paper shows how electromagnetic radiation can influence human vision and ocular physiopathology, to find solutions for optimal identification of the problems and highlight the methods for prevention and correction that the optometrists can use in such cases. The optometric protocol presented accentuates the important steps that the optometrist must make them in identifying and correcting problems.

Keywords — Electromagnetic radiation, Eye protection, Occupational diseases, Optometric protocol.

I. AN OVERVIEW ABOUT ELECTROMAGNETIC RADIATION

IN terms of classical theory, electromagnetic radiation, the flow of energy at the universal speed of light through free space or through a material medium in the form of the electric and magnetic fields that make up electromagnetic waves such as radio waves, visible light, and gamma rays [1]. In such a wave, time-varying electric and magnetic fields are mutually linked with each other at right angles and perpendicular to the direction of motion. An electromagnetic wave is characterized by its intensity and the frequency of the time variation of the electric and magnetic fields [2] (Fig. 1).

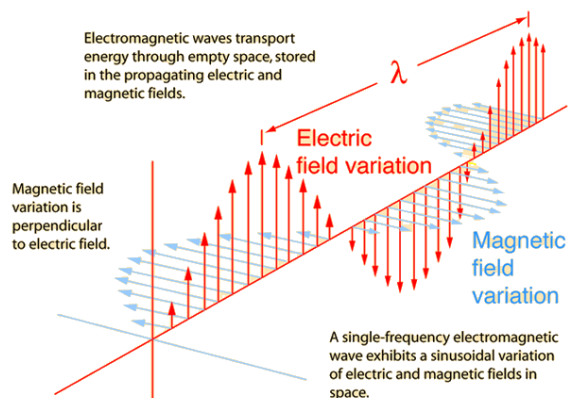


Fig. 1. Electromagnetic radiation [2]

Generically, electromagnetic spectrum is formed by radio waves, microwaves, infrared, visible light, X-rays and gamma rays. Their applications are presented in Fig. 2.

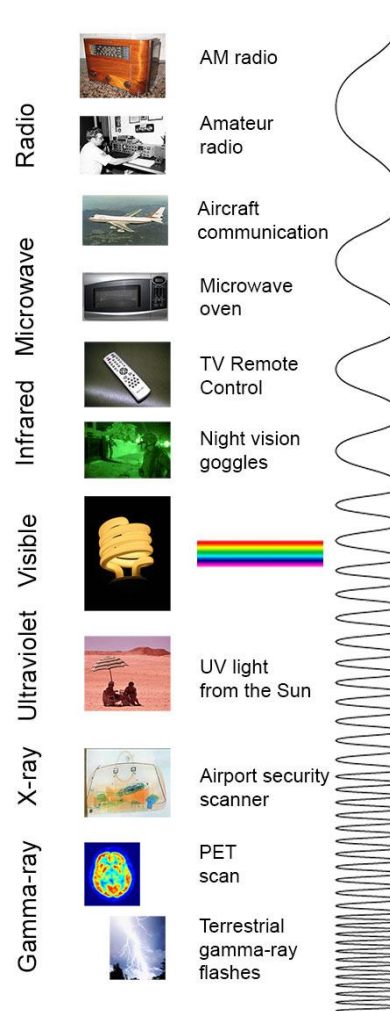


Fig. 2. The electromagnetic spectrum from lowest energy/longest wavelength (at the top) to highest energy/shortest wavelength (at the bottom) [3]

Radio waves are a type of electromagnetic radiation with wavelengths in the electromagnetic spectrum with frequencies from 300 (GHz) to at least 3 (kHz). The wavelengths are ranging from 1 (mm) to 10^8 (mm). Their velocity of this waves, like all the other type form this

spectrum, is actually the speed of light. This type of waves is made naturally by lightning or by astronomical objects (stars) and artificially for fixed and mobile radio communication, broadcasting, radar and other navigation systems, communications satellites, computer networks and other many applications. Human eye cannot receive this kind of waves.

Microwaves are a form of electromagnetic radiation with wavelengths ranging from 10^3 (mm) to maximum 1 (mm), with frequencies between 300 (MHz) at 10^3 (mm) and 300 (GHz) at 1 (mm). This broadband includes UHF and EHF (millimeter waves), and various sources use different boundaries. In all cases, microwave includes the entire SHF band 3-30 (GHz), or 10-100 (mm) at minimum, with RF engineering often restricting the range between 1 and 100 (GHz) (300 and 3 (mm)) [4]. Micro-waves are available in infrared and optical window frequency ranges, but also have a more technical meaning in electromagnetics and circuit theory (some discrete resistors, capacitors, and inductors used with lower-frequency radio waves). In techniques, distributed circuit elements and transmission-line theory are more useful methods for design and analysis. Microwave technology is extensively used for point-to-point telecommunications such as spacecraft communication and much of the world's data, TV, and telephone communications are transmitted long distances by microwaves between ground stations and communications satellites or in microwave ovens and radar technology.

Infrared (IR) is invisible radiant energy, electromagnetic radiation with longer wavelengths than those of visible light, extending from the nominal red edge of the visible spectrum at 700 (nm) with frequency 430 (THz) to 1 (mm) at 300 (GHz). Human eye can see IR up to at least 1050 (nm) only in some experiments [5]. It is divided into three sub-ranges: IR-A, or near infrared (from 780 to 1400 (nm)); IR-B or far infrared (1400 to 3000 (nm)); IR-C (3000 to 10000 (nm)). Most of the thermal radiation emitted by objects near room temperature is infrared. This type radiation is used in industrial, scientific and medical applications: night-vision devices using active near-infrared illumination allow people or animals to be observed without the observer being detected in darkness, infrared astronomy uses sensor-equipped telescopes to detect objects such as planets, and infrared thermal-imaging cameras are used to detect heat loss in insulated systems, to observe changing blood flow in the skin, and to detect overheating of electrical apparatus [6]. Other application include: short-ranged wireless communication, spectroscopy, environmental monitoring, industrial facility inspections, and remote temperature sensing thermal efficiency analysis. [7]

The *visible spectrum* is the part of the electromagnetic spectrum that is visible to the human eye. Radiation from this range of wavelengths is called visible light or simply light. A normal human eye responds to wavelengths from

about 390 (nm) to 700 (nm) with frequency approximately to a band of 430–790 (THz) [8]. Specific wavelengths within the spectrum correspond to a specific color based upon how humans typically perceive light of that wavelength. The long wavelength end of the spectrum corresponds to light that is perceived by humans to be red and the short wavelength end of the spectrum corresponds to light that is perceived to be violet. Other colors within the spectrum include orange, yellow, green and blue. There are only three primary colors (red, green, blue). The remaining colors are actually combinations of these. Depending on the health of the eye and brain, as well as artistic sense, the human eye can see different colors and shades thereof [8].

Ultraviolet (UV) light is an electromagnetic radiation with a wavelength from 400 (nm) to 10 (nm). In most of cases, this range of spectrum is not visible for human eye, but in some cases with special medicine conditions young people can see ultraviolet down to wavelengths of about 310 (nm), and people with aphakia (missing lens) can also see some UV wavelengths [5]. Insects and some kind of birds can see in the top of the UV spectrum (near visible light). UV radiation is naturally present in sunlight, and is artificially produced by electric arcs and some special lights such as short wave ultraviolet lamps, mercury-vapor lamps, ultraviolet lasers, plasma, tanning lamps and black lights. Anatomical effects of UV from the human body are greater than simple heating effects because was scientific demonstrated that UV radiation derive from its interactions with organic molecules (such as human cornea and skin) [8]. The eye is most sensitive to damage by UV in the lower band at 265–275 (nm). The most common affections are photokeratitis, cataracts, pterygium and pinguecula. In extreme cases retina can be damaged (especially from exposure in artificial UV) [9]. Protective eyewear is beneficial to those exposed to ultraviolet radiation (such as sunglasses or protection eyeglasses) [10].

X-radiation (X-rays) is a form of electromagnetic radiation with a wavelength in range from 0.01 (nm) to 10 (nm), corresponding to frequencies in the range 3×10^{16} (Hz) to 3×10^{19} (Hz) and energies in the range 100 (eV) to 100 (keV). Generally, X-radiation is referred to with terms Röntgen radiation, after Wilhelm Röntgen, who discovered them. X-rays with photon energies above 5–10 (keV) are called hard X-rays, while those with lower energy are called soft X-rays [11]. Due to their penetrating ability, hard X-rays are widely used to image the inside of objects, as in medical radiography and airport security. Other applications of X-rays include: crystallography (including the study of the DNA), astronomy (study of X-ray emission from celestial objects), microscopic analysis (to produce images of very small objects), fluorescence (X-rays are generated within a specimen and detected), industrial radiography (inspection of industrial parts), industrial computed tomography (to produce three-dimensional representations of components both externally and

internally), paintings and photographs, spectro-microscopy, airport security (luggage scanners), border control truck scanners use X-rays for inspecting the interior of trucks, X-ray cosmetics and so on [12]. X-rays can produce burning in the human body tissues, including eye.

Gamma radiation (gamma rays) refers to electromagnetic radiation of an extremely high frequency and therefore consists of high-energy photons. Gamma rays typically have frequencies above 10^{19} (Hz) and therefore have energies above 100 (keV) and wavelengths less than 10^{-12} (m). Gamma rays are ionizing radiation, and are thus very dangerous for the human body. Natural sources of gamma rays on Earth include gamma decay from naturally occurring radioisotopes, and secondary radiation from atmospheric interactions with cosmic ray particles. Also, gamma rays can be produced by a number of astronomical processes [4]. Gamma rays cause damage at a cellular level. They are penetrating tissues, causing diffuse damage throughout the body. Medical literature shows that the low levels of gamma rays cause a stochastic health risk, which for radiation dose assessment is defined as the probability of cancer induction and genetic damage and the high doses produce effects, severe acute tissue damage that is certain to happen [9].

II. INFRARED RADIATION EFFECTS ON EYE

As is shown in [13], most of people enjoy the heating effect of infrared from the sun, but, in the same time, most of the industrial sources of infrared with high temperature furnaces are harmful for the human eye, such as in the glass and steel industries. In industrial activities are using arc lamps, electric radiant heaters or some type of laser (YAG or carbon dioxide laser) which also give off infrared (Fig. 3). Evidently, IR-C is the most dangerous for the human eye, because of the higher wavelength, farthest from the visible spectrum (the most safe and healthy for ocular media).

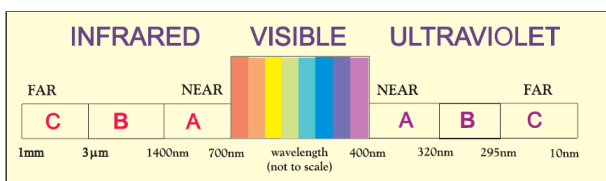


Fig. 3. Electromagnetic spectrum that affect eye [13]

Radiations cause different changes in cellular structure. Depending of the medical condition infrared is absorbed by most of important ocular structure. As the studies provided by the literature shows, the energy of infrared radiation is lower than visible light or ultraviolet radiation. Because the infrared radiation raises the overall temperature in the anterior eye, the most vulnerable tissues at this radiation are in cornea and aqueous humour. Crystalline absorb some small part of this radiation, vitreous another part, so the part that reach the retina is smaller, but very important in ophthalmology.

According [13], in the IR-C domain of infrared, cornea absorbs the wavelengths greater than 3000 (nm) and most radiation with a wavelength above 1400 (nm). This ocular layer is very important because is gateway thru the eye. Also, the crystalline lens absorbs radiation between 900 (nm) and 1400 (nm) (IR-A) and the retina absorbs most of the remaining infrared with a wavelength less than 1400 (nm) (IR-A) (Fig. 4). As is the layer where the image is formed, the retinal cells must be better protected from harmful effects of radiation. Cataracts and retinal burns from exposure to industrial sources (e.g. xenon lamps, infrared lasers and metal arc inert gas welding) are the most important problems that must be analyzed in ocular protection and ergonomics [14].

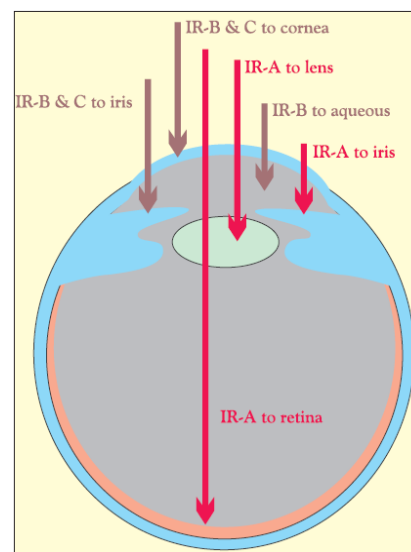


Fig. 4. Infrared radiation absorbed by the ocular tissues [13]

A. The effects of the IR on ocular structure

According [13], the most important harmful effects on eye are:

Eyelids. The most common affections on the eyelid range from mild reddening to third degree burns and, in extreme cases, death of the skin, when are exposed to very high levels of infrared delivered over a short period of time or to low levels of infrared over a long period. Infrared eyelid affections are hardly ever found in the industrial applications.

Cornea. Because the cornea transmits 96% of incident infrared in the range 700-1400 (nm), the level of damage to occur is quite high, especially in the range of 750-990 (nm). The radiation effects on the cornea from this type of radiation involve protein coagulation of the front and middle layers (the epithelium and stroma). At higher dose of IR, damage to the cornea produces immediate pain and vascularization. Eventually, the burn can causes ulcers, which leads to loss of transparency and opacification.

Iris. Depending on the degrees of pigmentation, the iris can absorbs between 53% and 98% of incident infrared in the 750-900 (nm) range. In long exposure, the

most common medical affections are swelling, cell death, hyperaemia and pupillary miosis. The higher wavelengths can cause inflammations and burns.

Lens. The crystalline transmits wavelengths higher than (1400 nm) selected by the cornea and aqueous humour. The most common affection is cataract, which is associated with certain types of occupations involving prolonged exposure to IR.

Retina. The energy radiation that is reaching the retina is absorbed by the epithelium. Depending on some factors (pupil size, the optical quality of the retinal image, exposure duration, size of the retinal image, quality of the retina), high infrared energy causes a rise in temperature and some kind of damage. In industrial applications, the radiant power and the exposure duration are essential. Also, the retinal pigmentation is very important, that is the cause that the most common damages are burns and depigmentation.

B. Industrial environment

Medical studies show that workers in specialty glass and steel industry, working at very high temperatures are exposed to radiation up to 600 times higher. They can develop over time cataracts and eye burns. It was shown that in all cases of senile cataract, subjects were exposed to IR radiation more than 10 years [15]. The explanation would mean that the heating tissue above the normal temperature increases the metabolic rate, which could then lead to premature ageing and eventually at cataract, as a result of accumulation of chemicals. According [13], the most recent article demonstrates that there is a clear occupational risk of developing cataract earlier as a result of exposure to infrared radiation, but that study has not been able to establish a correlation between the density of opacity and the total infrared expose to radiation.

TABLE I OCULAR SYMPTOMS IN INDUSTRIAL APPLICATIONS [13]		
Wave-lengths (nm)	IR sources	Symptoms
400-700	Sun, arc lamps, flash and incand. lamps	Photophobia Problems on scotoma Macular degeneration
488, 514.5	Argon ion laser	Intense blue or green flash without pain or shock Color vision problems a scotoma
530, 586, 648	Krypton ion laser	Green, yellow or red flash
632.8	Helium neon laser	Intense red flash
694.3	Ruby laser	Brilliant red flash with some pain Vitreous hemorrhage Red appearance with blindness
Multiple 400-780	Dye laser	Color dependent on wavelength tuned

III. ULTRAVIOLET RADIATION EFFECTS ON EYE

Sunlight reaches the eye directly thru the sky or by

diffusing reflection from objects or from the ground. Direct radiation is the least important in ocular pathology, because of the involuntary protection (people cannot look at the sun directly). Scattered light, from the sky and the ground, is much more important. Light scattered in the atmosphere depends from the quality of the air, weather and altitude. In addition, some of the artificial sources create a potential risk to eyes.

The most common categories you will see are UVA (long-wave UV and black light), UVB (mid-wave UV) and UVC (shortwave UV and germicidal light) (fig. 3). In science and industrial areas there is a lot of application: irradiation, purification and sterilization (UVC); medicine and cosmetics (UVA and UVB); identifying gems (UVA and UVC); ultraviolet astronomy (all ranges of UV); WWII airplane safety (UVA) and pest control (UVA).

Every artificial light source emits some UVA radiation. The main sources are incandescent lamps and gas discharge lamps and lasers. As is described in [16], commonly used lamps which emit significant amounts of UVA are medium pressure and high pressure mercury vapor lamps and xenon arc lamps, or combinations of these with other gases. Low pressure mercury discharge lamps (or cold quartz lamps) emit more than 90% of their radiant output at 253-257 (nm), while medium pressure mercury lamps, riche 365 (nm). As photochemical lamps, these are used as sources in UV photo-biological application. In high pressure (hot quartz lamps), these lamps emit in 250-400 (nm) range, are used in dermatological photobiology and phototherapy. High pressure xenon arc lamps emit radiation in the range of 170 (nm) through infrared region. They can be used in combination with xenon and give even more UV emission. These are commonly used in photography, printing and visual beacons. Fluorescent lamps are low pressure discharge tubes where a phosphor is coated inside the tube. When used with a glass enclosure that transmits the UV, they are used as sunlamps, emitting both UVA and UVB [16].

When the radiation reaches the biological cells, energy is absorbed. The damage from UV is photochemical, the process is not accompanied by a considerable increase in temperature and the effects can occur after long exposure.

The various ocular structures have a role in filtering out harmful radiation: the cornea (epithelium) absorbs UVC and UVB at maximum 270 (nm) and the healthy crystalline lens absorbs UVB mostly in range of 295-315 (nm). From the ocular point of view, the major effect of this additional UV radiation increase the risk of corneal and conjunctival conditions (pinguecula, some type of keratitis, pterygium), uveitis, on lens can cause cataract or some retinal problems, like solar retinopathy and macular degeneration [17].

IV. SPECIAL OPTOMETRIC PROTOCOL

The classical optometric protocol includes some steps

necessary to identifying the problems and solutions to correction and prevents (Fig. 5): medical records completion and anamnesis analysis (medical history), optometric investigations and tests (external eye exam, eye refraction measurements, determining visual acuity, intraocular pressure measurement, complementary tests) and establish the method of correction and eventually prevention. If after investigations, optometrist identifies or suspects any pathological condition, must recommend an ophthalmologic medical advice.

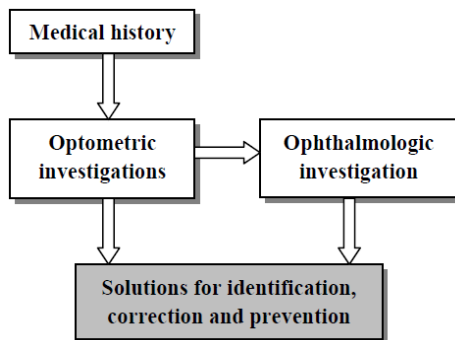


Fig. 5. General optometric protocol

A. Investigations and problems identification

For people working in industrial environments with electromagnetic radiation harmful, investigative protocol should include data and additional exams:

1) *Medical history.* In addition to the normal data are collected in the coming cabinet must emphasize age (it can provide additional data related to health and its ocular refraction), profession and work place (especially if they work in environments polluted by IR and UV), duration of exposure to the radiation, previous or current symptoms (ocular or general), ocular pain, lifestyle (leisure time exposure to radiation otherwise - computer, TV, solar etc.).

2) *Additional test and exams.* First optometrist will carefully study the anterior segment of the eye and its annexes. It will follow stains or burns on the eyelids, eyelashes or eyebrows, inadequate staining or yellowing of the eyes with redness their excessive tearing or asynchronous movement of the eyeballs. Schirmer II test will be done to evidence the dry eye syndrome that can be caused by exposure to radiation. Tracking the pupillary reflex is required to identify possible disease appeared after the work environment. In case of dangerous radiation exposure is required to do these additional tests: determination of intraocular pressure, color vision testing and determination of field. On slit lamp can see any disease of the eyelids, cornea, conjunctiva and lens opacities.

3) *Tests will evidence the issues arising from exposure to radiation.* In case of serious illness will recommend medical specialist. If diseases are mild, it will be recommend solutions as described below.

B. Discussions on ocular protection

A variety of means exist to protect eyes against UV, in the form of spectacles, contact lenses, gas permeable

hard lenses, intraocular lenses, goggles, shields, or helmets that use absorptive or reflective filters to control the undesirable radiation (Fig. 6).

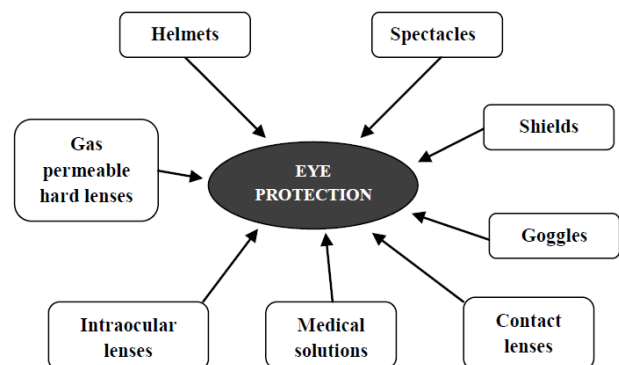


Fig. 6. Principal methods to eye protection from radiation

The most important and most usual method of protection remains the spectacle lenses. There are lens with filtering role, absorbing or light protection. *Filter lens* is characterized by selective transmission of certain wavelengths and ability to absorb part or all parts of the electromagnetic spectrum. Optical filters may therefore two different roles [10]:

1) *Protective role to reduce or cancel the harmfulness of certain wavelength, and/or to attenuate the light energy that enters the eye;*

2) *Stimulating role transmitting certain wavelength selective perception to improve their central (red to put to rest and maintain the system scotopic/photopic system function enough to keep the central visual acuity, or orange-yellow hue stimulating foveal neurosensory elements and perifoveale and they are used in organic retinian ambliopia).*

Polymer lenses absorb UV more efficiently than clear transparent ophthalmic glass. Depending of the material, the lenses have different grade of attenuation. Most manufacturers incorporate UV-blocking agents into ocular devices (eyeglasses lens or contact lenses) in an effort to reduce the hazard [13]. These absorbers need not alter the color of the lens even that an almost perfectly clear ophthalmic lens can still absorb almost all harmful UV. The three main colors used are: green, brown and gray [10]. The shade of green may be regarded as almost universal protective average ultraviolet absorption with the visible portion of the spectrum and a strong absorption of infrared. The shade of gray is a remarkable pro-defense against ultraviolet and may correspond to aspiration inconvenience for use on snow with relatively large visible area which contrasts mitigate risk. Brown shade is relatively less effective in the UV, but it has an important average absorption in the visible radiation, which makes it useful in areas with strong intensity without excess UV and IR - tropical countries. Photochromatic lenses are the private property of having a variable absorption depending on the intensity of radiation that passes reversible property indefinitely. They can be gray or brown. The disadvantage is that the

colored lenses material of which they are made does not absorb light rays evenly. This disadvantage can be removed by using the treated lens.

Application of colored layers or antireflection is performed in special vacuum evaporation method. The process can be applied to all types of eyeglass lenses - color treatment is carried out by submitting the same work cycle of a color and a thin layer antireflection coating. Eyeglasses lens glare treatment is performed by depositing, in the same working cycle, of an antireflection layer on both surfaces of the lens. Absorptive lenses are useful for those working in artificial light, for absorbing a large part of the infrared and avoid eye fatigue. For filtering capacity optical lens characteristic is this: the outer surface of these lenses is glossy and reflective, and the inner surface attenuates light rays. The outer surface of the lens is sprayed a thin layer of silver, gold or platinum on the order of micrometers. Depending on the thickness of the metal, ability attenuation lens can be 25%, 50% or 75%. Metal layers give different shades of glass lenses. For example, if the layer is gold, lens color is green-yellow, green or blue-green. If the layer is silver color is light blue, blue-violet or dark blue. In case of the platinum layer, the lenses have brown-gray color.

Light protection lenses protect eye, not only by the phenomenon of light absorption, but also by reflectance phenomenon. These lenses have the appearance of the mirror because the outer surface is sprayed coating with a thickness of the order of microns. The outer surface of lens is not transparent but reflective. There are two types of glass with reflective surface glass one-color game (the yellow color of the reflective glass, which is sprayed on the surface of the cathode, nickel or silver glass obtained by sputtering cobalt) and game-color glass (pulverized glass nickel-cobalt). A colored lens must fulfill the following conditions: reduce radiation intensity, avoid fatigue and absorbs almost uniform colors and tones of the color of the visible spectrum without major modification of the objects and nature [10].

Industrial protective lenses are designed to protect the eye from harmful light rays, the light too strong, dust, acids or shrapnel. The light sources have a different temperature, and therefore use different protection glass. Thus, in the case of electric arc welding temperature is about 3600 (°C), and varies depending on the electric current. In the case of ultraviolet light, the maximum permissible radiation ray having a wavelength of 250 (nm) was 0.041×10^6 (erg/cm²), and for the infrared, irradiation is allowed to 2.2×10^6 (erg/cm²). The radiation exceeding these values should be reduced with protective glasses.

For arc welding, 10% represent UV, 30% is in visible spectrum and 60% of the total energy released is infrared. In the case of welding flame, the temperature is 1500-1800 (°C), in this case, the energy of the irradiation is about 1/16 of the energy released in the event of irradiation and arc welding is the maximum value for the

wavelength of 1500 (nm). Therefore, in the case of the weld is sufficient flame protection through a light filter, while the arc welding requires both filter and a reflective protection. In industry are used two types of glass: protective glasses colorless, transparent, flat, with one or two layers of protection or colored glass protection, flat, with one or two coatings. Spectacles containing reflective metallic coatings and materials that filter out IR and UV are the ideal means.

V. CONCLUSION

As a general conclusion, the optometrist must identify, investigate and find solutions for preventive and corrective affections from exposure to harmful radiation at work. He must be the first to identify occupational diseases arising in such cases and recommend a specialized medical consultation.

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