Optical Radiation Hazard Analysis

1. General

This report constitutes a hazard analysis of the Wildfire model WF-400S/F, 400-watt (400-w) black-light UV-A ultraviolet lamp/projection-lens system developed by Wildfire for use in the entertainment industry for special effects and to provide ultraviolet illumination of fluorescent markers. The projection lighting system contained an Osram Type Ultramed 400-W ultraviolet lamp within an interlocked housing, a parabolic reflector to collimate the beam and a UV-A transmitting filter which blocked visible and UV-B radiant energy. The unit could be placed in either a narrow-beam or wide-beam mode.

2. Hazard Analysis

This analysis is based upon measurements of total and UV-spectral-band irradiance of a representative unit (S.N. 1051). This report shows that this light source does not pose a realistic hazard to the eye or skin when used for its intended purpose. The report clarifies safety issues related to exposure of more sensitive individuals and recommends warning statements, which should be provided, to the user of this light system. It should be noted that the WF-400 unit does not pose any more significant hazard than most "black-light" sources used in entertainment, science and industry.

a. Potential Hazard to the Cornea and Lens

(1) UV-B Exposure. The IL 1700 radiometer and UV-hazard detector used for measurements of actinic UV-B radiation provided an "effective irradiance" by use of a spectral weighting filter which was designed to fit the ACGIH/IRPA action spectrum for UVR hazard analysis. This filter/detector effectively eliminated the lengthy process of using the spectral irradiance of the WF400 source and mathematically weighting it against the S_{λ} spectral sensitivity function of ACGIH/IRPA.

There were trace amounts of UV-B radiation ($\lambda < 315$ nm) which were detected at the top ventilation louvers (an "effective irradiance" of 0.2 µW / cm^2 at 1 cm). Exposure to this level would be permitted up to 4 hours by ACGIH and IRPA recommendations. This is a totally unrealistic exposure duration.

Within the main beam along the beam axis, the IL 1700 instrument provided maximal values of effective irradiance $E_{\in ςς}$. For example, 0.4 µW / cm^2 was measured at 10 cm in front of the filter/faceplate. The permissible exposure duration $t_{NAΩ}$ is the time calculated to reach a total effective exposure dose (radiant exposure) of 3 mJ / cm^2 in any one day. Therefore, $t_{NAΩ}$ is the dose of 3 mJ / cm^2 divided by the measured effective irradiance $E_{\in ςς}$, and for 0.4 µW / cm^2 $t_{NAΩ}$ is: 7,500 s, or 2 hours and 5 minutes. Measurements were made within the beam along the main beam axis at many distances from the lighting system out to a distance of 200 cm. Examples of some of the measured UV-B effective irradiances were: 1.4 µW / cm^2 at the filter (lens) face, 0.4 The effective irradiance fell below the 8-hour exposure limit of 0.1 µW / cm^2 at approximately 30 cm (1ft.). Since the source at close range is discomforting to look into, it is totally unrealistic to assume that anyone would stare into the source at such a close exposure distance for such a long duration.

UV-A Exposure. The current EL of ACGIH and IRPA for UV-A exposure of the eye (to protect the cornea and lens) is: 1 J/cm^2 within any one day (or within any 1,000 s in one day in old standards). From a practical standpoint, at close range the EL applied to exposure durations of less than 1000 s (16.6 min.) will be the limiting case since the EL of 1 mW / cm^2 would apply for unrealistically lengthy exposures. However it should be recognized that in some future revisions, there may be a further "cap" placed upon the UV-A irradiance for extremely lengthy exposure durations exceeding 10,000 s (2.8 hours). Whatever occurs, it is unlikely that a revision will affect the current safety evaluation of the WF-400, since output irradiances will exceed 1 mW / cm^2 in the near field of the source. A maximum axial beam irradiance measured immediately in front of the WF-400 source was: 12 mW / cm^2 at the surface of the lens. This irradiance exceeds the 1 J / cm^2 in 83s (1 minute, 23 seconds). However, this is a totally unrealistic viewing distance, as the source is discomforting to stare into. At 10 cm from the filter lens, the irradiance is 8 mW / cm^2 and this leads to safe exposure duration of 125 s (2 hrs. and 5s). at a realistic exposure distance of 1 m from the lamp (about 3 ft. from the lens), the irradiance is only 80 μW / cm^2 , leading to a safe exposure duration of 12,500 s = 3.5 hours. It is totally unrealistic to imagine such long exposures just in front of this type of spotlight where the useful application distance is at least 10ft. (3 m).

b. Potential Hazards to the Skin

A maximum axial beam UV irradiance measured immediately in front of the source was: 12 mW / cm^2 at the filter surface and 8 mW / cm^2 at 10 cm from the filter lens. This irradiance could just be felt, but could never pose a thermal hazard to the skin. However as noted above, the permissible exposure duration to actinic, UV-B radiation in the beam is 2 hours and 5 minutes at 10 cm and over 8 hours at 30 cm (1ft.). It is quite unrealistic to assume that anyone would place their skin so close for such a long time. Therefore, for normal skin, there is no realistic risk of exceeding occupational exposure limits for Ultraviolet radiation (UVR). For individuals taking photosensitizing drugs, this duration would be reduced, but even here, lengthy exposures at such a close range would be rare.

c. Potential Retinal Hazard to a Viewer without a Lens

A far more complex hazard analysis relates to evaluating the hazard to a person who is "aphakic" i.e., a person who has had his or her crystalline lens removed—normally because of cataract surgery and has not had a UV-absorbing plastic intra-ocular lens (IOL) surgically implanted. This population is quite small, and is estimated to be less than one in 1,000 persons in the USA. However, very young children have normal lenses, which do not completely filter out UV-A, and this population should be considered.

To obtain an estimate of the potential retinal hazard the source was measured with an International Light Radiometer Model IL 700 with a Model 8ED033 UV-A detector head and the flash distance of the WF-400 reflector was determined visually. The flash distance is that location along the beam axis where the reflector appears fully filled with light (Sliney and Wolbarsht, 1980). Since the lamp was tubular in shape and not circularly symmetric with respect to the beam axis, the projection system did not have a singular flash distance. The source appeared purple with a violet halo, and was somewhat discomforting to stare into even at 5 m (about 16 ft.) where the lengthwise dimension of the lamp filled the reflector. I measured a total UV-A irradiance of 0.1 Mw / cm^2 at the apparent flash distance of 5.0 meters from the source. The diameter of the reflector was 20 cm and about 20% of the reflector area was filled, i.e., 63 cm^2 .Hence the solid angle is 63 cm^2 / $(500)^2$ =0.25 msr. Hence the radiance L was: (6.3 Mw / cm^2) / (0.25 msr) = 0.04 W / (cm^2. sr). After the spectral radiance of the lamp is weighted by the aphakic UV hazard function, the effective radiance L-eff can be estimated to be approximately 0.2 W / (cm^2.sr). The TLV is: 100 J / (cm^2.sr) / L-eff. Hence the maximum exposure duration $t_{NA\Omega}$ will be approximately 500 seconds (8 minutes, 20 s) in any one day. This is an unrealistically long duration to stare into a discomforting source.

The above calculations clearly show that the warning statement should address the safety of the aphakic individual. Based upon current knowledge, any young child, aphakic or pseudophakic person whose retina is exposed to a significant level of UV-A will have a strong aversion response, since the retina will provide a strong and uncomfortable visual sensation to UV-A if this radiant energy reaches the retina.

d. Potential Hazard to the Retina of a Normal Individual

Current UV Els assume that a purely UVR source does not pose a potential hazard to the normal (phakic) person, since the crystalline lens absorbs so much UVR. However, it may be worthwhile to examine the actual retinal exposure dose to a normal person viewing the Wildfire source at close range. In the normal person, only approximately 0.3% to 1% of UV-A radiant energy reaches the retina, after most is absorbed in the crystalline lens and there is little if any precipitation. Furthermore, the lens fluoresces and this provides an additional veiling glare. When I looked into the Wildfire source it was not comfortable to look at, which certainly confirmed that a significant visual stimulus was reaching the retina. If we assume that the UV-A transmittance of the lens is as much as 1%, than we can estimate that the above-calculated phakic hazard $t_{NA\Omega}$ is extended by 100 times to: 50,000 s, or more than 8 hours in any one day for a person staring into the source at very close range. Although no EL exists today for such exposure, it is not unreasonable to assume that this could be a future development. From this calculation there is no reason to suggest that cumulative exposures to the far lower retinal irradiances when in use would be of any real concern. Assessing this risk will require measurements of beam irradiance as a function of distance.

e. Maximum Reasonable Exposure Duration

The most important aspect in any practical hazard analysis of the Wildfire UV source is the determination of the worst reasonable case for human exposure for the eye and skin. At present there is no generally agreed upon method of making this determination in practical applications. Most experts would agree with the time used in all laser safety standards, for infrared exposure, i.e., 10 s should apply here. However, it is as yet unclear just how discomforting viewing the Wildfire source really is for most people.

3. System Safety Requirements

The unit should have an interlock to assure that the lamp cannot be turned on if the UV-A filter is removed. To assure that the front filter door cannot be opened when the lamp is operating, there is an electrical interlock which turns off the lamp. This was tested on the Wildfire unit and it was functioning.

4. Conclusions

This report shows that this light source does not pose a realistic hazard to the eye or skin when used for its intended purpose. This report has considered safety issues related to exposure of more sensitive individuals, which suggests that warning statements should be provided to the user of this light system to warn against extensive exposure of photosensitized individuals. To place the findings of this study in perspective, it should be noted that the WF-400S/F unit does not pose any more significant hazard than most black-light sources used in entertainment, science and industry.

David H. Sliney, Ph.D.