UNITED STATES ARMY
ENVIRONMENTAL HYGIENE
AGENCY

ABERDEEN PROVING GROUND, MD 21010-5422

NONIONIZING RADIATION PROTECTION STUDY NO. 25-42-0334-86
OPTICAL HAZARD EVALUATION OF DENTAL CURING LIGHTS
AUGUST - NOVEMBER 1985

Approved for public release; distribution unlimited
The purpose of this report is to evaluate potential ocular hazards associated with the use of dental curing lights and to make recommendations to eliminate exposure of personnel to hazardous levels of optical radiation.
SUBJECT: Nonionizing Radiation Protection Study No. 25-42-0334-86. Optical Hazard Evaluation of Dental Curing Lights, August - November 1985

EXECUTIVE SUMMARY

The purpose and recommendations of the enclosed report follow:

a. Purpose. To evaluate potential ocular hazards associated with the use of dental curing lights and to make recommendations to eliminate exposure of personnel to hazardous levels of optical radiation.

b. Recommendations.

(1) To ensure regulatory compliance, the following recommendation is made. Do not permit unprotected personnel to stare directly into the dental curing lights at distances shorter than 25 cm.

(2) To ensure good radiation protection practice, the following recommendation is made. Provide eye protectors which filter wavelengths below 500 nm to reduce discomfort if desired by individual users or if surface laminar ion is applied.
HSHB-RL

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OPTICAL HAZARD EVALUATION OF DENTAL CURING LIGHTS
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1. AUTHORITY.


2. REFERENCES. A list of references is provided in Appendix A.

3. PURPOSE. To evaluate potential ocular hazards associated with the use of dental curing lights and to make recommendations to eliminate exposure of personnel to hazardous levels of optical radiation.

4. GENERAL.

a. Background. Dental curing (photopolymerization) lights are used to cure resins used for dental restorations (tooth "fillings") and are now found in most Army dental clinics. Previously, resins were cured with near-ultraviolet (UV-A) radiation. Now, most resins are cured with blue light. Most dental curing light units in this study consisted of an enclosed light source (and power supply), which was coupled to a handheld "gun" by a fiber optic cable or light-guide. From the fiber-optic cable or the protruding tip of the "gun," light was directed to the resin to be cured.

b. Evaluated Units. A total of 13 units were evaluated by USAEHA personnel: six at the DENTAC, Fort Bragg, North Carolina; one at the Edgewood Area Dental Clinic, Aberdeen Proving Ground (APG), Maryland; one at Rhodes Dental Clinic, Fort Sam Houston, Texas (as part of USAEHA Survey No. 25-42-0208-86, reference 6); one at the DENTAC, Redstone Arsenal, Alabama; and four at USAEHA, APG. A list of the evaluated units, their identification, and their manufacturer can be found in Appendix B.

Use of company names does not imply endorsement by the US Army, but is intended only to assist in identification of a specific product.
c. Radiometric Terms and Units. A table of commonly used radiometric and photometric terms and units is provided in Appendix C.

d. Instrumentation. A spectroradiometer [employing an Oril double monochromator (2.5-nm bandwidth), a Hamamatsu R212 photomultiplier, an Oril High Voltage power supply, and a Keithley Model 614 Electrometer] was used for the measurements of spectral irradiance. The spectroradiometer was calibrated against a 1000-W FEL-type standard lamp, with calibration traceable to the National Bureau of Standards.

5. FINDINGS.

a. Evaluation. The measured spectral irradiance for 12 of the different types of dental lights is plotted in Appendix D. From these spectral measurements, the following quantities used for the hazard evaluation (in accordance with references 3 and 4) were derived: total irradiance (E), effective UV irradiance (EUV), UV-A irradiance (EuvA), blue-light irradiance (Ea) and IIuminance (E). Furthermore, the blue-light radiance (Le), the thermal-hazard radiance (Lth) and the luminance (Lv) were calculated using the source diameter (D) and the measurement distance (r = 30 cm). The results are shown in Appendix E.

b. Exposure Conditions. During a curing procedure, the dentist is normally not exposed to the light source directly. The light source is a tungsten-halogen lamp whose output is transmitted via a quartz rod or a fiber-optic cable to the tooth under treatment. The dentist can be exposed to reflected light from the tooth or to light that has been transmitted through the transilluminated tooth. Occasionally, if the dentist is curing a preparation on the front teeth from behind, he can view the exposed area of the tip. The calculations in this report assume worst-case conditions: direct exposure to the tip of the curing device and a viewing distance such that the source subtends an angle greater than 11 milliradians. It must be emphasized that the dentist is only occasionally exposed to the tip directly and, during the normal course of a photopolymerization, is only exposed to the reflected or transmitted source (see the following Figure).

c. Special Features. One of the Caulk Prisma-Lite units emitted an audible tone every 10 seconds while the light was on. The Command units were equipped with a timer, adjustable for an on-time between 1 and 30 seconds.

d. Warning Labels. Warning labels were not attached to any of the units.

6. DISCUSSION.

a. Spectral Output. The output of a specific type of curing light can vary within a factor of two, depending on the age of the light source. Some units emit a relatively high portion of their output in the UV-A spectral region. Earlier types of curing lights, like the NUVA-Light, were UV-A lights with very little visible output, whereas the currently used
FIGURE. Use of a Dental Curing Light at the Edgewood Area Dental Clinic, APG. Left photograph shows tip of applicator and right photograph shows applicator in use. The dentist's eyes were more than 50 cm from the tip.
resins are best cured with blue light. The advantage with blue-light-cured (polymerized) resins is a greater and more consistent depth of cure, whereas UV-A radiation provides a more shallow (albeit harder) depth of cure. Generally, a complete curing of a resin takes 30-50 seconds.

b. Potential Hazards. Three potential hazards could exist which require evaluation: UV hazard to the cornea and lens, blue-light retinal hazard, and thermal burn retinal hazard. The measurements revealed that the UV hazard is nonexistent; i.e., no actinic UV radiation was detected and the UV-A emission from all units is sufficiently below the occupational exposure limits to cause harmful effects under normal operating conditions. In effect, the only hazards requiring careful study were the blue-light and thermal hazards. Both of these hazards have their most pronounced adverse effect at short visible wavelengths (blue). The blue-light hazard is dominant for lengthy exposure times (>10 sec) and the thermal hazard is dominant for short exposure times (<10 sec). Only for one of the evaluated units (Command No. 1) was there a theoretical thermal hazard, and then only if one deliberately stares directly into the light at a very close distance (less than 15 cm) and for more than 5 seconds. However, because the luminance (brightness) was also very high, the eye's adhesion response would limit the exposure time to about 0.25 sec and, since a viewing distance of 15 cm is less than the near accommodation point of 25 cm for the normal individual, this is not a realistic viewing situation. It is more likely that an operator would be exposed to the blue-light hazard during normal treatment procedures. Thus, only the blue-light hazard is of practical concern. Therefore, only the maximum stare time, $T_{max}$ [calculated from the blue-light radiance ($L_b$) and the TLV® for this quantity (references 3 and 4)], is shown in Appendix E. It is seen that $T_{max}$ ranges from 4 minutes to more than 100 minutes. Assuming total additivity of blue-light retinal exposures over an 8-hour workday, a total of eight 30-second cures with the light-source (positioned so that the dentist could see the exposed tip) would exceed the occupational exposure limit (TLV). Since the tip is normally directed away from the eye, this is an unrealistic operating condition. Again, since the luminance is high, and since normal treatment times are short, these lights can be considered nonhazardous for both operator and patient when used as intended. Since this study was performed, a scientific article has appeared (reference 7) which suggests eyewear be used; however, this was based upon an assumption of a heavier workload, i.e., 17 to 81 applications a day where the tip would be seen.

c. Reflections. For reasons described in the above paragraph, reflections, either specular or diffuse, can be considered nonhazardous under normal use conditions. Only under excessively heavy use could reflections be of possible concern.

© TLV - Threshold Limit Value established by the American Conference of Government Industrial Hygienists, Cincinnati, Ohio. Use of trademarked names does not imply endorsement by the US Army but is intended only to assist in identification of a specific product.
d. Eyewear, Luminance and Comfort. It is not necessary to use protective eyewear during normal use when operating dental lights. However, since the dental lights' luminance exceeds the maximal comfort luminance of $10^4$ cd/m$^2$ for indoor work, the operator may, for comfort, choose to wear either slightly colored plastic eyewear (sunglass type) or to attach special, small-diameter, clip-on plastic lenses to the protruding tip of the "gun." Under heavy use (e.g., total laminations of front teeth), eye protectors may be advisable when using some units. Both tip shields and spectacles are readily available from various dental supply houses (see reference 8). The cost per spectacle varies greatly, but need not be excessive. For example, Younger Optics, has spectacles at a cost of approximately $15.00 each.

7. CONCLUSION. Dental curing lights can be considered nonhazardous under normal operating conditions for restorative dentistry. The operator may wish to reduce specularly or diffusely reflected luminances by using colored/tinted eyewear or by attaching colored/tinted clip-on plastic shields to the tip of the handheld gun.

8. RECOMMENDATION.

a. Do not permit unprotected personnel to stare directly into dental curing lights at distances shorter than 25 cm (AR 40-46, Cl, paragraph 1-40).

b. Provide eye protectors which filter wavelengths below 500 nm to reduce discomfort if desired by individual users or if surface lamination is applied. (This recommendation is based on good radiation protection practice.)

9. ACKNOWLEDGMENTS. Mr. Paul Eriksen, visiting scientist, Danish National Institute of Occupational Health, Copenhagen, was the principal author for this report and has since returned to Denmark. CPT Willem P. Van de Merwe, Nuclear Science Officer, Laser Microwave Division, was a co-author for this report and has since departed this Agency.

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APPENDIX A

REFERENCES

1. AR 40-5, 1 June 1985, Preventive Medicine.

2. AR 40-46, 6 February 1974, Control of Health Hazards from Lasers and Other High Intensity Optical Sources, CI, 15 November 1978.


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APPENDIX B

IDENTIFICATION OF EVALUATED UNITS

Caulk Prisma-Lite (1)
Model No.: Pr-1, 115V-50/60Hz-3.5A.

Caulk Prisma-Lite (2)
Model No.: Pr-1, SN 25425, 115V-50/60Hz-3.5A.

Caulk Prisma-Lite (3)
Model No.: Pr-1, SN C1636, 115V-50/60Hz-3.5A.

Command (1)
Model No.: NUVA-Lite, SN 15691, 120V-60Hz-1.7A.

Command (2)
Model No.: NUVA-Lite, SN 18228, 120V-60Hz-1.7A.

Command (3)
Model No.: NUVA-Lite, SN 15537, 120V-60Hz-1.7A.

SPECTRA Lite (made in GDR)
Model No.: Spectra light Polymerization Unit, SN 7030-3-362.
Agent: Peatron Corp., P.O. Box 771, Malingford, CT 06492.

Norland Opticure
Model No.: Light Gun UVC 5000, SN A001448

Western Electric
Model No.: 345 Simplex UV Curing light, SN 0092.
Mfg: Archie Solomon Mfg. Corp., 950 Sun Valley Drive, P.O. Box 395, Roswell (Atlanta), GA 30077.

Caulk NUVA-Lite
Model No.: L102, SN 23877, 115V-60Hz-2A.

Midwest Insite
Model No.: 162, SN 13339
Mfg: American Midwest, 901 West Oakton, Des Plains, IL 60018.

Elipar Curing Light
SN: V60438
Mfg: Seefield/Overbau, West Germany.

Optilux Curing Light
Mfg: Demetron Research Corp., 5 Ye Old Road, Dandury, CT 06810.
# Appendix C

### Useful CIE Radiometric and Photometric Terms and Units

<table>
<thead>
<tr>
<th>Radiometric</th>
<th>Photometric</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Term</strong></td>
<td><strong>Symbol</strong></td>
</tr>
<tr>
<td>Radiant Energy</td>
<td>$Q$</td>
</tr>
<tr>
<td>Radiant Energy Density</td>
<td>$u$</td>
</tr>
<tr>
<td>Radiant Flux (Radiant Power)</td>
<td>$P$</td>
</tr>
<tr>
<td>Radiant Exittance</td>
<td>$R$</td>
</tr>
<tr>
<td>Irradiance or Radiant Flux Density (Base Data in Photobiology)</td>
<td>$I$</td>
</tr>
<tr>
<td>Radiant Intensity</td>
<td>$I_0$</td>
</tr>
<tr>
<td>Radiance</td>
<td>$L$</td>
</tr>
<tr>
<td>Radiant Exposure (Base in Photobiology)</td>
<td>$H$</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Luminous Efficacy (of radiation)</td>
<td>$\varepsilon$</td>
</tr>
<tr>
<td>Radiant Efficiency (of a source)</td>
<td>$\eta$</td>
</tr>
<tr>
<td>Optical Density</td>
<td>$D$</td>
</tr>
</tbody>
</table>

1. The units may be altered to refer to narrow spectral bands in which the term is preceded by the word "spectral" and the unit is then per wavelength interval and the symbol has a subscript $\lambda$. For example, spectral irradiance has units of watt*ster$/m^2$ or more often, watt*ster$/m^2*nm$. The watt*ster$/m^2$ is the preferred unit and "ster" is the preferred word for "steradian". The SI unit of wavelength is nanometer (nm).

2. Popular prefixes for power units are: milli (m), micro (\mu), nano (n), pico (p), femto (f), and atto (a).

3. At the source $L = \frac{dE}{d\Omega}$ and at a receptor $L = \frac{dE'}{d\Omega'}$. SI units are Wsr$^{-1}$, Wsr$^{-1}$m$^{-2}$, Wsr$^{-1}$m$^{-2}$nm$^{-1}$, Wsr$^{-1}$m$^{-2}$nm$^{-2}$, and Wsr$^{-1}$m$^{-2}$nm$^{-2}$um$^{-1}$. The watt*ster$/m^2$ is the preferred unit and "ster" is the preferred word for "steradian". The SI unit of wavelength is nanometer (nm).

4. $E_0' = E_0$ at 555 nm.

5. $P_s$ is electrical input power in watts.

6. $\lambda$ is the wavelength. $A$ is the area of pupil in mm$^2$.  

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APPENDIX D

SPECTRAL IRRADIANCE OF 12 of 13 OF THE DENTAL CURING LIGHTS
APPENDIX E
MEASURED AND CALCULATED RADIOMETRIC AND PHOTOOMETRIC QUANTITIES USED TO DESCRIBE THE OUTPUT OF DENTAL CURING LIGHTS

<table>
<thead>
<tr>
<th>Source</th>
<th>D (mm)</th>
<th>E$_{LACM}$ (0.3 m)</th>
<th>E$_{LACM}$ (0.3 m)</th>
<th>E$_{UV}$ (0.3 m)</th>
<th>E$_{V}$ (0.3 m)</th>
<th>F$_{v}$ cm$^{-2}$</th>
<th>E$_{LACM}$Sr$^{-1}$</th>
<th>E$_{LACM}$Sr$^{-1}$</th>
<th>T$_{MAX}$ (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caulk Prisma-Lite (1)†</td>
<td>5</td>
<td>48</td>
<td>ND</td>
<td>0.07</td>
<td>12</td>
<td>41</td>
<td>1.9x10$^6$</td>
<td>0.060</td>
<td>0.61</td>
</tr>
<tr>
<td>Caulk Prisma-Lite (2)‡</td>
<td>5</td>
<td>88</td>
<td>ND</td>
<td>0.24</td>
<td>46</td>
<td>95</td>
<td>4.9x10$^6$</td>
<td>0.21</td>
<td>2.1</td>
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<tr>
<td>Caulk Prisma-Lite (3)†</td>
<td>5</td>
<td>71</td>
<td>ND</td>
<td>0.05</td>
<td>37</td>
<td>73</td>
<td>3.5x10$^6$</td>
<td>0.17</td>
<td>1.7</td>
</tr>
<tr>
<td>Command (1)§</td>
<td>5</td>
<td>190</td>
<td>ND</td>
<td>3.3</td>
<td>95</td>
<td>220</td>
<td>1.0x10$^6$</td>
<td>0.43</td>
<td>4.6</td>
</tr>
<tr>
<td>Command (2)§</td>
<td>5</td>
<td>120</td>
<td>ND</td>
<td>3.6</td>
<td>58</td>
<td>110</td>
<td>5.2x10$^5$</td>
<td>0.27</td>
<td>2.8</td>
</tr>
<tr>
<td>Command (3)§</td>
<td>5</td>
<td>110</td>
<td>ND</td>
<td>2.2</td>
<td>46</td>
<td>110</td>
<td>5.0x10$^5$</td>
<td>0.22</td>
<td>2.8</td>
</tr>
<tr>
<td>SPECTRA-Lite§</td>
<td>5</td>
<td>24</td>
<td>ND</td>
<td>0.90</td>
<td>12</td>
<td>37</td>
<td>3.7x10$^5$</td>
<td>0.030</td>
<td>0.31</td>
</tr>
<tr>
<td>Norland Opticure$^*$</td>
<td>7</td>
<td>130</td>
<td>ND</td>
<td>61</td>
<td>43</td>
<td>92</td>
<td>2.2x10$^5$</td>
<td>0.10</td>
<td>1.1</td>
</tr>
<tr>
<td>Western Electric$^*$</td>
<td>7</td>
<td>26</td>
<td>ND</td>
<td>16</td>
<td>6.4</td>
<td>0.57</td>
<td>1.3x10$^5$</td>
<td>0.015</td>
<td>0.16</td>
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<tr>
<td>Caulk NUVA-Lite§</td>
<td>10</td>
<td>9.4</td>
<td>ND</td>
<td>0.1</td>
<td>8.4</td>
<td>0.55</td>
<td>6.3x10$^5$</td>
<td>0.0043</td>
<td>0.044</td>
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<tr>
<td>Midwest Insite**</td>
<td>5</td>
<td>202</td>
<td>ND</td>
<td>0.45</td>
<td>21</td>
<td>414</td>
<td>1.9x10$^5$</td>
<td>0.096</td>
<td>1.3</td>
</tr>
<tr>
<td>Elipta**</td>
<td>7</td>
<td>81</td>
<td>ND</td>
<td>0.00</td>
<td>56</td>
<td>63</td>
<td>1.5x10$^5$</td>
<td>0.13</td>
<td>1.3</td>
</tr>
<tr>
<td>Demetron Optilux††</td>
<td>9</td>
<td>--</td>
<td>ND</td>
<td>--</td>
<td>--</td>
<td>73</td>
<td>3.2x10$^5$</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

* The permissible exposure time is given in minutes
† Evaluated at USAHA; bulb close to burnout
‡ Evaluated at Fort Bragg, North Carolina
§ Evaluated at Fort Sam Houston, Texas
$ Evaluated at USAHA; new unit
** Evaluated at USAHA; old unit
†† Evaluated at Redstone Arsenal, Alabama
ND = not detectable
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