HAZARD ANALYSES OF GLINT AND GLARE FROM CONCENTRATING SOLAR POWER PLANTS

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Abstract

Because of the increased interest in deploying concentrating solar power systems, glint and glare from concentrating solar collectors and receivers is receiving increased attention as a potential hazard or distraction for motorists, pilots, and pedestrians. This paper provides a summary of previous analyses to evaluate glint and glare from concentrating solar power plants. In addition, a review of the physiology, optics, and damage mechanisms associated with ocular radiation is provided. A summary of safety metrics and standards is also compiled from the literature to evaluate the potential hazards of calculated irradiances from glint and glare. Previous safety metrics have focused on prevention of permanent eye damage (e.g., retinal burn). New metrics are introduced in this paper for temporary flash blindness, which can occur at irradiance values several orders of magnitude lower than the irradiance values required for irreversible eye damage.

Keywords: glint, glare, retinal irradiation, retinal burn, flash blindness

1. Introduction

Assessment of the potential hazards of glint and glare from concentrating solar power plants is an important requirement to ensure public safety. Glint is defined as a momentary flash of light, while glare is defined as a more continuous source of excessive brightness relative to the ambient lighting. Hazards from glint and glare from concentrating solar power plants include the potential for permanent eye injury (e.g., retinal burn) and temporary disability or distractions (e.g., flash blindness), which may impact people working nearby, pilots flying overhead, or motorists driving alongside the site.

Applications and certifications for solar thermal power plants often require an assessment of "visual resources" at the site, but these requirements typically focus on aesthetic qualities and standards. Certifications also require an evaluation of general health and safety issues associated with the site, but rigorous and uniform treatment of glint and glare are lacking. The purpose of this paper is to summarize previous analyses and provide general assessment methods that can be used to evaluate potential hazards of glint and glare for all of the primary concentrating solar power (CSP) technologies: (1) power tower systems, (2) linear concentrator systems (e.g., parabolic troughs, linear Fresnel), and (3) dish/engine systems.

2. Review of Previous Assessments

The following sections summarize previous assessments that were conducted to evaluate potential glint and glare hazards from power towers, linear receivers, and dish collector systems. Figure 1, Figure 2, and Figure 3 show photographs of observed specular and diffuse reflections from these different types of systems.

2.1 Power Towers

Brumleve [1],[2] provided some of the earliest analyses of eye hazards associated with central receiver technologies. Analytical models were developed to assess light intensities and hazardous ranges of single and multiple coincident heliostat beams at ground level and in the air space above a central receiver facility at Sandia National Laboratories in Albuquerque, New Mexico. Distances were calculated to ensure safe retinal irradiance levels (based on work from Sliney and Freasier [3]), and results showed that retinal irradiance from single heliostat beams exceeded the safe limits only within a short range (up to 40 m) within the focal distance of the heliostat. For heliostats with focal distances greater than 270 m, the safe retinal limits were never exceeded. The safe number of multiple coincident beams was also calculated as a function of distance, focal length, and projected area density of the multiple collectors on the retina. Based on these analyses, exclusion zones (restricted areas) and beam control techniques were recommended to minimize the potential hazards from single and multiple heliostat beams during operation.

Brumleve [2] also used video techniques during helicopter flyovers and at ground level to determine retinal irradiance, image size, and receiver brightness for the 10 MW_e solar thermal central receiver pilot plant in Barstow, California. Safe limits were not exceeded in the airspace above an altitude of ~240 m, which is the lowest allowable altitude for aircraft near the 91-m tall receiver tower. It was also found that the receiver was not bright enough to constitute an eye hazard during momentary viewing.

The probability of multiple heliostat beams randomly crossing in the airspace above the proposed Ivanpah Solar Electric Generating System in California was calculated in an application submitted to the California Energy Commission [4]. In the application, they showed that the probability of a sufficient number of heliostat beams (8) crossing at the same point to exceed safety limits at an altitude of 1000 m was infinitesimally small.

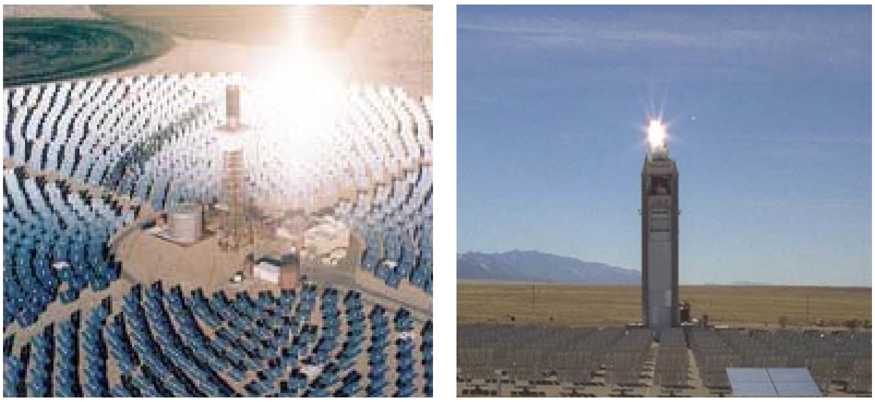

Figure 1. Left: Specular reflections from heliostats at Solar One (10 MW_e Power Tower, Daggett, CA). Right: Diffuse reflections from receiver panel (National Solar Thermal Test Facility, SNL, NM).

2.2 Linear Concentrators

Glint and glare analyses have been performed for the proposed Carrizo Energy Solar Farm in San Luis Obispo County, California, which consists of nearly 200 lines of compact linear Fresnel reflector systems [5]. Diffuse reflection from the receiver pipes and spillage intensity from the reflectors were evaluated. Results showed that unsafe beam intensities could be posed to pedestrians within ~18 m of the perimeter fence; therefore, privacy slats in the perimeter fence were proposed. Other scenarios associated with reflected light were not found to be likely hazards.

An application for certification of the Victorville 2 Hybrid Power Project [6] included a letter from the California Department of Transportation, Division of Aeronautics, that conducted flyovers of existing parabolic trough plants at Kramer Junction and Harper Lake in Southern California. The glare and flash was found to be similar to the reflection over a smooth water surface. In addition, a letter from the chief operating officer of the Kramer Junction facility stated that the observed reflections originated primarily from the receiver tubes and that the glare has not been a distraction to pilots in nearly 20 years of operation.

A recent application for certification of the San Joaquin Solar 1 & 2 project submitted to the California Energy commission included a glint and glare analysis for their proposed parabolic trough plant [7]. The analysis evaluated the diffuse reflection from the receiver pipes (heat collection elements), and they concluded that the diffusely reflected sunlight from the receiver pipes would be 150 times less than the intensity of the sun and therefore not a hazard. The beam intensity caused by specular reflection from the mirrors was also considered to evaluate potential glare when the parabolic troughs were being rotated from stow position to tracking position. Results showed that the beam intensity could be unsafe for pedestrians within 60 feet from the plant perimeter (although details of the calculations and metrics were not provided), so privacy slats in the perimeter fence were recommended.

Figure 2. Specular and diffuse reflections from linear receiver tube (left) and trough field (aerial view, right) at Kramer Junction (150 MW_e Parabolic Trough, Mojave Desert, CA).

2.3 Dish/Engines

A qualitative glint and glare analysis of dish/engine systems for the SES Solar Two Project was conducted as part of the application for certification that claimed that distracting, blinding, or hazardous glint or glare effects should not be a problem [8]. However, detailed analyses of the potential for hazardous reflections during off-axis positions (e.g., during stowing, start-up, or abnormal operations) was not performed.

Ghanbari and Diver [9] developed a mathematical model to investigate the maximum viewing time of diffuse reflections from a dish receiver aperture plate (see Appendix). The maximum viewing time was based on exposure limits for optical radiation published by the American Conference of Governmental Industrial Hygienists (ACGIH) [10]. Their results showed that diffusely reflected radiation from the receiver did not pose hazards for retinal thermal damage, retinal photochemical injury, and infrared radiation damage.

In 1980, Sliney evaluated hazards of the reflected sunlight from the point-focus collectors at the JPL/Edwards test site [11]. He first analyzed the hazards from viewing the sun directly and concluded that the natural blink response of 0.1 – 0.2 seconds is adequate to protect viewers from thermal retinal and photochemical injury. However, prolonged staring at the sun when it is high in the sky or viewing it, unfiltered, through a magnifier such as binoculars or telescopes will result in thermal retinal damage. He then analyzed viewing of reflected sunlight from a point-focus collector. Sliney concluded that if an observer is less than one focal length away from a single facet on a point-focus collector, even for short exposures, injury could occur. However, when a dish is tracking the sun, it is virtually impossible for anyone, worker or observer, to be less than one focal length for any one facet. The situation that is of greater concern is when the dish is not tracking the sun but is in an off-axis position that could still reflect sunlight onto a worker or observer. In these cases, however, the reflected sunlight would not emanate from the entire dish, but rather from an individual facet, and observers would not be exposed to reflections that are more dangerous than the sun itself.

Figure 3. Left: Specular reflections from stowed parabolic dish collectors. Right: Diffuse light emanating from dish receiver aperture. (National Solar Thermal Test Facility, SNL, NM)

2.4 Discussion of Previous Analyses

In the previous analyses of glint and glare for concentrating solar thermal power plants, permanent eye damage was used as the metric to determine safe retinal irradiance values. The safe retinal irradiance thresholds were based on retinal burn tests performed on rabbits [3]. In the next section, additional metrics are discussed, including temporary flash blindness. Data from past research on flash blindness and recovery times from after-image disability are reviewed to provide additional quantitative metrics that may be used for glint and glare evaluations of concentrating solar thermal power plants.

3. Ocular Irradiation and Safety Metrics

3.1 Anatomy of the Eye

Figure 4 shows an illustration of the human eye and how an image is projected onto the retina. Light rays enter through the cornea and pass through the pupil, which can vary in aperture size from 2 – 3 mm for a sunlight-adapted eye to 7 – 8 mm for a dark-adapted eye. The rays pass through the lens and converge at a nodal point behind the lens. The image is then inverted and projected onto the retina, a distance approximately 1.7 cm behind the nodal point in healthy eyes.

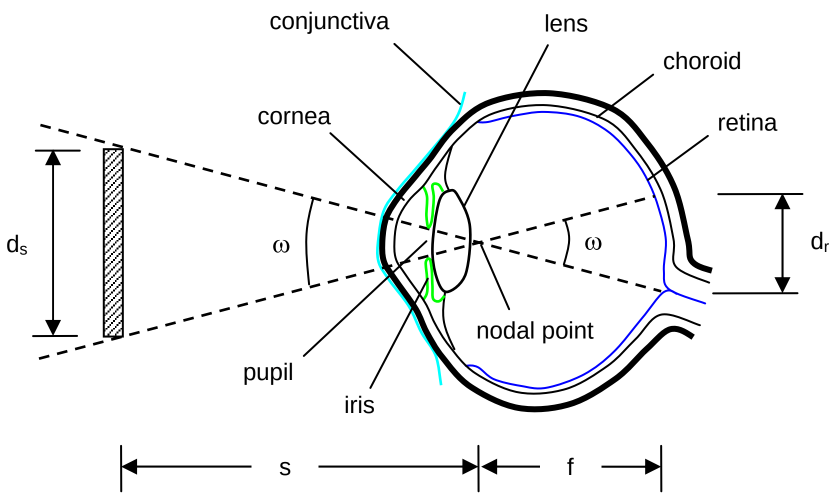

Figure 4. Image projected onto the retina of a human eye.

Potential damage to the eye depends on a number of factors including the source radiance, source angle (size and distance to eye), duration of exposure, and wavelength. The spectral distribution of sunlight is heavily weighted in the visible bandwidth (400 – 700 nm), but the eye can pass wavelengths between 400 and 1400 nm to the retina. The lens of the eye is a strong absorber of wavelengths less than 400 nm [3]. At lower wavelengths, UV-B and UV-C radiation are absorbed in the cornea and conjunctiva, and sufficient doses can cause keratoconjunctivitis (welder's flash) and photokeratitis (snow blindness) [3],[12]. Solar retinitis and eclipse blindness are caused primarily by photochemical damage (rather than thermal injury) in the visible spectrum between 380 and 580 nm. Between 580 and 1400 nm, photothermal damage predominates over photochemical damage. Because the blink response of the eye is rapid (0.15 – 0.2 s) [3], exposure to reflected sunlight is expected to be short in duration.

3.2 Retinal Irradiance

The retinal irradiance (power per unit area) can be calculated from the total power entering the pupil and the retinal image area. The area projected onto the retina (assuming circular images) can be determined from the source angle (ω), which can be calculated from the source size (d_s) and distance (s), and the focal length (f), as follows (refer to Figure 4):

$$d_r = f\,\omega$$

$$\text{where } \omega = d_s / s \tag{1}$$

Eq. (1) assumes that the arc and the chord of a circle are the same for small angles. At a source angle, ω, of 60°, the error in d_r is ~5%. If the irradiance at a plane in front of the cornea, E_c (W/m^2), is known, the power entering the pupil can be calculated as the product of the irradiance and the pupil area (the diameter of the pupil, d_p, adjusted to sunlight is ~2 mm). The power is then divided by the retinal image area and multiplied by a transmission coefficient, τ (~0.5 [11]), for the ocular media (to account for absorption of radiation within the eye before it reaches the retina) to yield the following expression for the retinal irradiance:

$$E_r = E_c\left(\frac{d_p^2}{d_r^2}\right)\tau \tag{2}$$

If the source radiance, L (W/m^2/sr) is known, the corneal irradiance in Eq. (2) can be determined by multiplying the radiance by the subtended solid angle of the source, Ω (sr):

$$E_c = L\Omega = L\frac{A_s}{s^2} \approx L\left(\frac{\pi}{4}\omega^2\right) \tag{3}$$

and the retinal irradiance can be calculated directly from the radiance as follows:

$$E_r = \frac{\pi L \tau}{4}\left(\frac{d_p}{f}\right)^2 \tag{4}$$

It should be noted that Brumleve [1] includes an additional coefficient (ν) to account for the fraction of solar irradiance between 400 and 1400 nm, but this has been included in the transmission coefficient, τ, above. As an example, the retinal irradiance caused by viewing the sun directly can be calculated using Eqs. (1) and (2) with E_c = 0.1 W/cm^2, d_p = 0.002 m, f = 0.017 m, ω = 0.0093 rad, and τ = 0.5, which yields a retinal irradiance, E_r, of ~8 W/cm^2. Note that the retinal irradiance is significantly higher than the irradiance at the entrance of the eye. For applications involving images of the sun, the retinal irradiance can be converted to corneal irradiance using Eqs. (1) and (2) with d_p = 0.002 m, f = 0.017 m, ω = 0.0093 rad (sun shape), and τ = 0.5, yielding the following approximate relation: $E_c = 0.0125E_r$.

3.3 Safety Metrics

Safety metrics relevant to optical radiation and the prevention of permanent eye damage are reviewed and presented in this section. In addition, previous studies pertaining to flash blindness are also presented since temporary flash blindness is potentially hazardous to motorists or pilots. Other consequences from glint and glare such as discomfort and distraction have been evaluated in the literature [13],[14], but the subjective impacts of discomfort and distraction glare are not considered in this paper.

3.3.1 Safe Retinal Irradiance Values from Retinal Burn Data

Sliney and Freasier [3] presented maximum permissible retinal irradiance levels (W/cm^2) based on retinal burn data using rabbits. Brumleve [1] used this data to develop a convenient metric for safe retinal irradiance, E_{rs} (W/cm^2) based on retinal image size, d_r (m), assuming circular images and a 0.15 second exposure (typical blink response):

$$E_{rs} = \frac{0.002}{d_r} \quad \text{for } d_r < 0.002 \text{ m}$$

$$E_{rs} = 1 \quad \text{for } d_r \geq 0.002 \text{ m} \tag{5}$$

Eq. (5) has been used by several analyses of glint and glare for concentrating solar thermal power plants [4],[5],[7]. However, the calculated safe retinal irradiance value that was used in these analyses is based on specific properties of a heliostat (e.g., reflectivity, beam divergence) reported by Brumleve [2] that may not be generally applicable to other collector systems. The safe retinal irradiance value for viewing the sun directly can be calculated using Eq. (5) and the subtended angle of the sun (~9.3 mrad) to calculate the retinal image diameter. The safe retinal irradiance value is 12.7 W/cm^2, which is about 1.6 times greater than the retinal irradiance experienced from viewing the sun directly (~8 W/cm^2). Note that the retinal irradiance is greater than the corneal irradiance (or "irradiance at the eye") because of the smaller image area projected onto the retina (relative to the pupil size). The equivalent safe corneal irradiance for a subtended angle of 9.3 mrad is 0.16 W/cm^2 or 1600 W/m^2.

3.3.2 ANSI 2000 Standard

More recently, Delori et al. [15] provide a concise formulation and summary of the American National Standards Institute (ANSI) Z136.1-2000 Standard for the protection of the human eye from laser exposure. They note that the recommended exposure limits for lasers and broadband sources (such as the sun) are not substantially different. Delori et al. [15] present maximum permissible power levels entering the pupil as a function of exposure duration, wavelength, and source angle. For brief exposures (0.15 – 0.2 s), Table 3 in Delori et al. [15] provides the following expression for the maximum permissible power level, *MP* (W):

$$MP = 6.93 \text{x} 10^{-4}\, C_T\, C_E\, P^{-1}\, t^{-0.25} \tag{6}$$

where C_T is a function of wavelength (ranges between 1 and 40 at wavelengths between 400 and 1400 nm), C_E is a function of the source angle (6.2 for an angle of 9.3 mrad subtended by the sun), P is a pupil factor that is a function of exposure time and wavelength (ranges between 1.8 and ~1 for wavelengths between 400 and 1400 nm), and t is the exposure time (s). Using solar-radiance spectrally weighted values for the coefficients provided by Delori et al. [15] and an assumed exposure duration of 0.15 seconds yields a maximum permissible power at the pupil of ~0.008 W and maximum retinal irradiance of ~40 W/cm^2 for direct viewing of the sun (which corresponds to a safe corneal irradiance of ~0.5 W/cm^2 or 5000 W/m^2). This value is about three times greater than the safe retinal irradiance values proposed by Brumleve [1],[2] for direct viewing of the sun. The difference is probably due to several factors including the use of different factors of safety (up to an order of magnitude or more) in the calculations.

3.3.3 ACGIH Threshold Limit Values

Spectrally weighted exposure limits for optical radiation have also been published by the American Conference of Governmental Industrial Hygienist (ACGIH) [10]. These limits are called Threshold Limit Values (TLVs) and are calculated from spectrally weighted radiometric values of radiance or irradiance. TLVs are evaluated for (1) retinal thermal damage, (2) photochemical injury from chronic blue light exposure, (3) and infrared radiation damage.

3.3.4 Flash Blindness

Flash blindness results from bleaching of retinal visual pigments caused by bright (high luminance) sources of light. Photometric units are used to characterize the levels of brightness (or luminance) (lumens/m^2/sr) or illuminance (lumens/m^2) that cause flash blindness. Most people have experienced flash blindness after viewing a flash bulb from a camera or a bright light in a darkened room. A number of tests were performed by the U.S. Air Force to assess the visual recovery times for individuals exposed to bright flashes of light, primarily to determine how long it would take for pilots to read their instrument panels after being exposed to illumination from nuclear blasts [16],[17]. These studies found that visual recovery times ranged from 4 – 12 seconds for illuminance values ranging from ~650 – 1,100 lumens/m^2. For light emitted within the solar spectrum, this corresponds to approximately 7 – 11 W/m^2 of solar irradiance at the eye.

Additional tests were performed by Saur and Dobrash [18] to determine visual recovery times of individuals after being exposed to simulated sun reflections. They found that recovery times ranged from 0.8 – 2.7 seconds for illuminance values ranging from 120 – 280 lumens/m^2. Based on the solar spectrum, this is equivalent to approximately 1 – 3 W/m^2 of solar irradiance at the eye.

From these data, it appears that a solar irradiance on the order of 1 – 10 W/m^2 or $1x10^{-4}$ – $1x10^{-3}$ W/cm^2 at the eye is sufficient to cause temporary flash blindness. Assuming that this solar irradiance originates from an image that subtends a similar angle to the sun (9.3 mrad) with d_p = 0.002 m, f = 0.017 m, and τ = 0.5, the minimal retinal irradiance values that can cause flash blindness is ~0.01 – 0.1 W/cm^2. Comparing these solar irradiance values against the metrics used for calculating irreversible eye damage (e.g., Eqs. (5) or (6)) shows that flash blindness can occur at irradiances that are several orders of magnitude less than the irradiance metrics used for irreversible eye damage.

3.3.5 Summary of Safety Metrics

Figure 5 summarizes the safe irradiance values and flash blindness metrics discussed above for a 0.15 s exposure. As the subtended source angle increases, the safe retinal irradiance threshold decreases because of the increased size of the retinal image area, and, hence, increased energy applied to the retina. The metrics proposed by Brumleve [1] for safe retinal irradiances appear to be more conservative relative to the other standards plotted. The potential for flash blindness shown in the plot was based on corneal irradiance values of $1x10^{-4}$ – $1x10^{-3}$ W/cm^2 from the above studies, and the retinal irradiance was then determined using Eqs. (1) and (2) with d_p = 0.002 m, f = 0.017 m, and τ = 0.5 (the average retinal irradiance was plotted and the error bars represent the maximum and minimum values). The plotted retinal irradiance values for potential flash blindness appear reasonable when compared to retinal irradiance values of several common sources of light reported by Sliney and Freasier [3]: incandescent bulb (~10^{-4} W/cm^2), pyrotechnic flare (~10^{-3} W/cm^2), tungsten filament (~10^{-2} W/cm^2). Depending on the subtended source angle, the retinal irradiance that causes flash blindness can be 2 – 4 orders of magnitude less than the safe retinal irradiance metrics to prevent irreversible //eye damage.

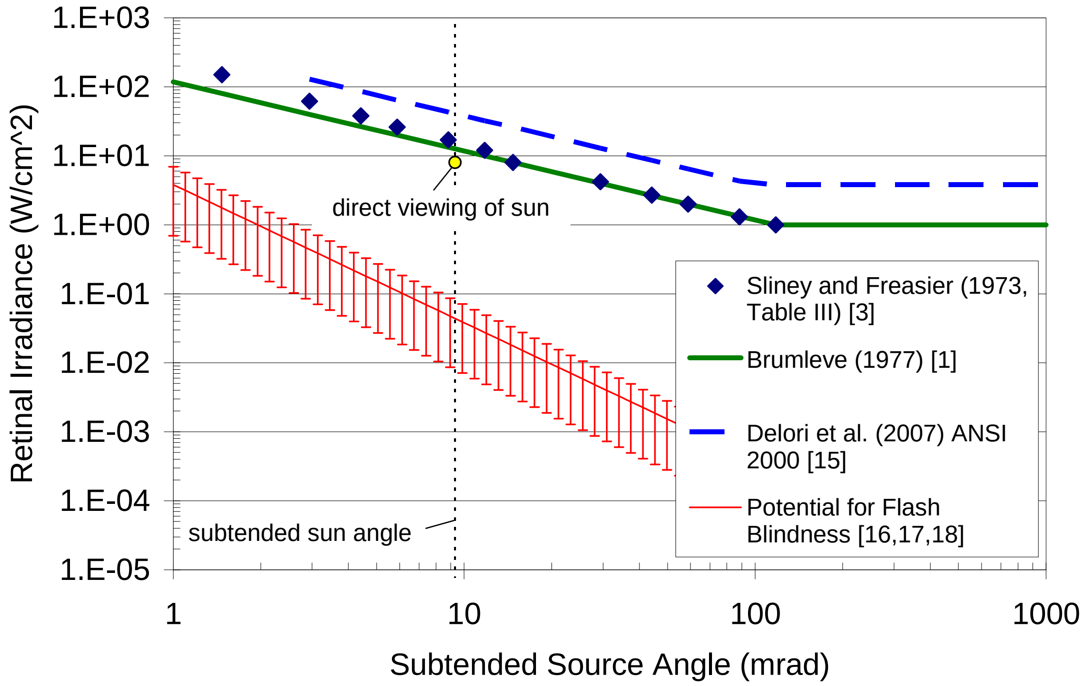

Figure 5. Retinal irradiance metrics as a function of subtended source angle for 0.15 s exposure (typical blink response time). Sliney and Freasier [3], Brumleve [1], and Delori et al. [15] provide safe retinal irradiance values to prevent irreversible eye damage. The range of retinal irradiances that can induce flash blindness is from several data sources [16], [17], [18].

4. Summary and Conclusions

This paper has presented methods to evaluate potential glint and glare hazards from specularly and diffusely reflected sunlight from concentrating solar collectors. First, a review of previous data and standards was performed to summarize metrics used to determine safe retinal irradiances as a function of subtended source angle (or retinal image size). These metrics were all based on preventing permanent eye damage, so a new metric that represents the potential for temporary flash blindness was introduced. The potential for temporary flash blindness can occur at irradiances several orders of magnitude lower than irradiances required for irreversible eye damage. Analytical models were then derived to calculate irradiances from both specular and diffuse sources. In addition, an example of irradiance calculations using a ray-tracing computational model was presented.

The methods and equations presented in this paper can be used to calculate irradiances from various concentrating solar collector systems (e.g., heliostats, dishes, troughs, receivers). These calculated irradiances can then be used to calculate the retinal irradiance using equations in Section 3.2. Finally, the calculated retinal irradiance can be compared against the safe retinal irradiance metrics provided in Section 3.3 to evaluate potential glint and glare hazards. Based on the configurations and operation of the various concentrating solar technologies, potential glint and glare hazards that should be considered include the following:

- Power Towers
  - Specular reflections from heliostats when they are moving from stowed to tracking positions, in standby mode, or are not focused on the receiver
  - Diffuse reflections from the receiver
- Linear Collectors
  - Specular reflections from the mirrors when they are moving from stowed to tracking and from specular reflections off the ends of the trough or mirrors when the sun has a low

elevation angle (e.g., reflections from the north end of a north-south field when the sun is low in the southern horizon).
    - Diffuse and specular reflections from receiver tubes
- Dish/Engine Systems
    - Specular reflections from mirror facets when the dish is off-axis (e.g., moving from stow to tracking)
    - Diffuse reflections from the receiver aperture

The impact of multiple coincident beams (i.e., from adjacent collectors or receivers) was not considered in this study. Brumleve (pp. 27-32) [1] provides a discussion of the impact of multiple sources that can be used together with the results of this study. In general, multiple sources can increase the retinal image size. In addition, the retinal irradiance may or may not increase depending on whether the projected retinal images overlap, which depends on the positions of the sources relative to the observer. For example, if two beams enter the eye but do not overlap, the affected retinal image area is increased, but the irradiance (W/cm^2) is the same as that from a single beam. If the two beam are nearly coincident and form a coalesced image on the retina, the retinal image size is about the same but the irradiance increases.

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References

[1] Brumleve, T.D. (1977). Eye Hazard and Glint Evaluation for the 5-MW_t Solar Thermal Test Facility, SAND76-8022, Sandia National Laboratories, Livermore, CA.

[2] Brumleve, T.D. (1984). 10 MWe Solar Thermal Central Receiver Pilot Plant: Beam Safety Tests and Analyses, SAND83-8035, Sandia National Laboratories, Livermore, CA.

[3] Sliney, D.H, and Freasier, B.C. (1973). Evaluation of Optical Radiation Hazards, *Applied Optics*, 12(1), 1-24.

[4] Carrier, J. (2008). Beam Safety Design Parameters, Data Response Attachment DR89-1, Appendix A, Data Response Set 1A. Dated on 1/14/2008, CH2MHILL, Ivanpah Solar Electric Generating System, Application for Certification (07-AFC-5), Submitted to California Energy Commission, http://www.energy.ca.gov/sitingcases/ivanpah/documents/applicant/DR_1a/2008-01-14_ISEGS_DR_SET_1A.PDF.

[5] Carrizo Energy, LLC (2008). Responses to CEC Data Requests (#1-78), Application for Certification (07-AFC-8), Carrizo Energy Solar Farm, Submitted to California Energy Commission, http://www.energy.ca.gov/sitingcases/carrizo/documents/applicant/2008-02-27_DATA_RESPONSES_1-78.PDF.

[6] City of Victorville, (2008). Victorville 2 Hybrid Power Project, Application for Certification (07-AFC-1), submitted to California Energy Commission, www.energy.ca.gov/sitingcases/victorville2/documents/.

[7] San Joaquin Solar 1 & 2 – Application for Certification Volume 2, Appendix L, "Glint and Glare Study," http://www.energy.ca.gov/sitingcases/sjsolar/documents/applicant/afc/AFC_volume_02/.

[8] SES Solar Two, LLC (2008). SES Solar Two Project, Application for Certification (08-AFC-5), submitted to California Energy Commission.

[9] Ghanbari, C.M. and Diver, R.B. (1994). Glint Hazard Assessment, Sandia National Laboratories Internal Memo, April 21, 1994.

[10] American Conference of Governmental Industrial Hygienists (ACGIH) (1992-1993). Threshold Limit Values for Chemical Substances and Physical Agents.

[11] Sliney, D.H., (1980). An Evaluation of the Potential Hazards of the Point Focusing Solar Concentrators at the JPL-Edwards Test Site, Report submitted to the Jet Propulsion Laboratory (JPL Consulting Agreement No. JF 714696), California Institute of Technology, Pasadena, CA.

[12] Hoover, H.L., (1986). Solar ultraviolet irradiation of human cornea, lens, and retina: equations of ocular irradiation, Applied Optics, 25(3), 359-368.

[13] Osterhaus, W.K.E., (2005). Discomfort glare assessment and prevention for daylight applications in office environments, Solar Energy, 79, 140-158.

[14] Iwata, T. and K. Kimura, (1990/1991). Discomfort Caused by Wide-source Glare, Energy and Buildings, 15-16, 391-398.

[15] Delori, F.C., R.H. Webb, and D.H. Sliney, (2007). Maximum permissible exposures for ocular safety (ANSI 2000), with emphasis on ophthalmic devices, J. Opt. Soc. Am. A, 24(5), 1250-1265.

[16] Metcalf, R.D and R.E. Horn, (1958).Visual Recovery Times from High-Intensity Flashes of Light, Air Force Aerospace Medical Research Lab, Wright Air Development Center Technical Report 58232.

[17] Severin, S.L. N.L. Newton, and J.F. Culver, (1962). An Experimental Approach to Flash Blindness, *Aerospace Medicine*, 1199-1205.

[18] Saur, R.L. and S.M. Dobrash, (1969). Duration of Afterimage Disability after Viewing Simulated Sun Reflections, *Applied Optics*, 8(9), 1799-1801.