Observations and Assessments of Glare from Heliostats and Trough Collectors: Helicopter Flyover and Drive-By Sightings

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Abstract

This paper presents observations and assessments of glare from heliostats and parabolic trough collectors. A helicopter flyover of heliostats at the National Solar Thermal Test Facility in Albuquerque, NM, revealed that when the heliostats were placed in a standby mode with an aim point ~30 m to the east of the top of the tower, a strong glare could be observed from the mirrors of the heliostat over 1700 m (> 1 mile) away. Ocular hazard analyses showed that the retinal irradiance and subtended angle of the glare was sufficient to cause a temporary after-image, which was consistent with observations. Glare was also observed from the Nevada Solar One trough plant along Highway 95 in Nevada. Evaluations of the digital images showed that the glare was comprised of discrete, uniformly spaced reflections, which are believed to come from the bellows shields spaced every few meters along the receiver tube. Concentrated sunlight from the collector mirrors can reflect off the bellows shields away from the collector toward an observer. Theoretical analyses showed that the measured irradiance and subtended source angle of the glare source was sufficient to cause a low to moderate potential for after-image. A simple mitigation for this type of glare is to use a diffuse paint or coating on the bellows shield, or to design the geometry of the bellows shields to prevent stray light and reflections from leaving the collector.

1. Introduction

Glint and glare from concentrating solar power (CSP) plants is receiving increased attention from federal agencies in the United States. Glint is defined as a momentary flash of bright light, while glare is defined as a more continuous source of excessive brightness relative to the ambient lighting. Both the U.S. Air Force and the Federal Aviation Administration (FAA) have raised concerns regarding the potential for negative impacts from glint and glare on pilots and the associated impact on training missions, airports, and general aviation. The Air Force has expressed concerns that glare from heliostats and tower receivers at CSP plants proposed near the Nevada Test and Training Range will impact pilots, limiting the space and time available for their training missions. Both the Air Force and the FAA have also expressed concerns regarding the potential impact of glare and other sources of interference from CSP plants located near airports and runways, especially during critical phases of flight such as takeoff and final approach. The FAA has indicated that they intend to provide guidance and rulings regarding these potential impacts after they gather information from scientists and other agencies, including the Air Force. Until then, the FAA has recently stated that their default position will be to disallow any new solar energy installations near airports.

2. Approach

This paper provides observations and assessments of glare from actual CSP sites. This study builds upon previous studies that developed models and tools to evaluate potential glint and glare hazards from concentrating solar collectors or receivers during short-term exposures [1]-[3].[1] Hazards evaluated include the potential for permanent eye injury (e.g., retinal burn) and temporary visual impairment (e.g., after-image). The methods and models developed in those studies are applied to recent observations of glare from heliostats during a helicopter flyover of the National Solar Thermal Test Facility (NSTTF) at Sandia

[1] Additional studies have also been performed to investigate the impacts of long-term exposure to glare from solar concentrator systems [4].

National Laboratories in Albuquerque, NM (Figure 1), and from parabolic trough collectors at the Nevada Solar One plant along an adjacent highway (Highway 95) (Figure 2). The helicopter flyover of the NSTTF at Sandia was performed on November 10, 2010. The 200+ heliostats at the site were aimed at a standby point approximately 30 m to the east of the top of the tower while the helicopter was positioned at various points south of the tower. Digital photographs of the glare were taken to quantify the irradiance and ocular impacts using the methods described in Ho et al. [2]. On June 29, 2010, digital photographs of glare emanating from the parabolic trough collectors at Nevada Solar One were taken along Highway 95 just before noon (Pacific daylight time). The glare "traveled" along the collectors as we drove along the highway, which was nearly two miles away from the trough collectors. The digital photographs were analyzed to quantify the irradiance and ocular impacts using the methods described in Ho et al. [2].

Figure 1. Left: Preparing for a helicopter flyover of the National Solar Thermal Test Facility at Sandia National Laboratories in Albuquerque, NM. Right: Observations of glare from heliostats placed in a standby position aimed ~30 m to the east of the top of the tower (11/10/2010).

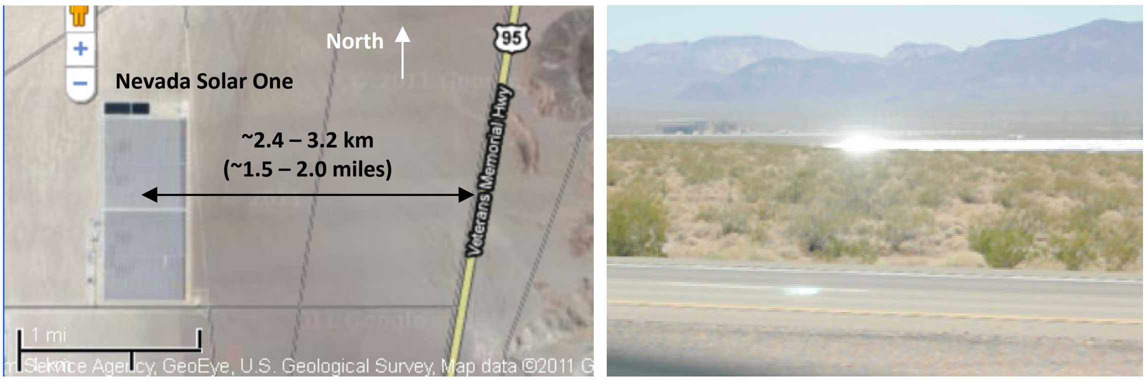

Figure 2. Left: Location of Nevada Solar One relative to Highway 95 (about 20 km south of Boulder City, NV). Right: Photograph of glare emanating from Nevada Solar One observed along Highway 95 (6/29/10).

3. Results and Discussion

3.1. Helicopter Flyover of the NSTTF Heliostat Field

Results of the helicopter flyover revealed that specular reflections from heliostats can produce a source of bright glare at large distances (>1000 m). Photographs of glare (see Figure 1) from a heliostat at ~1,700 m (just over a mile) away from the helicopter were analyzed using the web-based glare analysis tool and methods described by Ho and Khalsa [3]. The helicopter was hovering at approximately 580 m above ground level (2,300 m above mean sea level) and about 1,600 m south of the heliostat field.

A temporary after-image was experienced by the author after viewing the glare source directly, which was consistent with model predictions [2]. The ocular hazard plot and normalized irradiance received from the glare source are shown in Figure 3. The retinal irradiance received from the reflections off the heliostat was less than that caused by one sun during the flyover, and the subtended angle of the glare was also less than that of the sun. Because the focal lengths for heliostats are typically long (greater than several hundred meters), and because the observer will typically be at least one focal length away from the tower receiver (where the heliostats are focused), the irradiance received by the observer will likely be less than one sun due to the divergence of the reflected rays. In this particular case, the focal length of the heliostat was ~300 m, and the distance between the camera and the heliostat was ~1,700 m (nearly six times the focal length). However, if the observer is near the focal length of the heliostat, irradiances greater than one sun are possible. If multiple heliostats are aimed at an observer away from the tower receiver, the irradiance can be greater than one sun. However, the risk of this occurring can be significantly reduced if safe operating procedures and precautions are implemented to prevent multiple heliostats from focusing at locations beyond the tower that may be intercepted by aircraft.

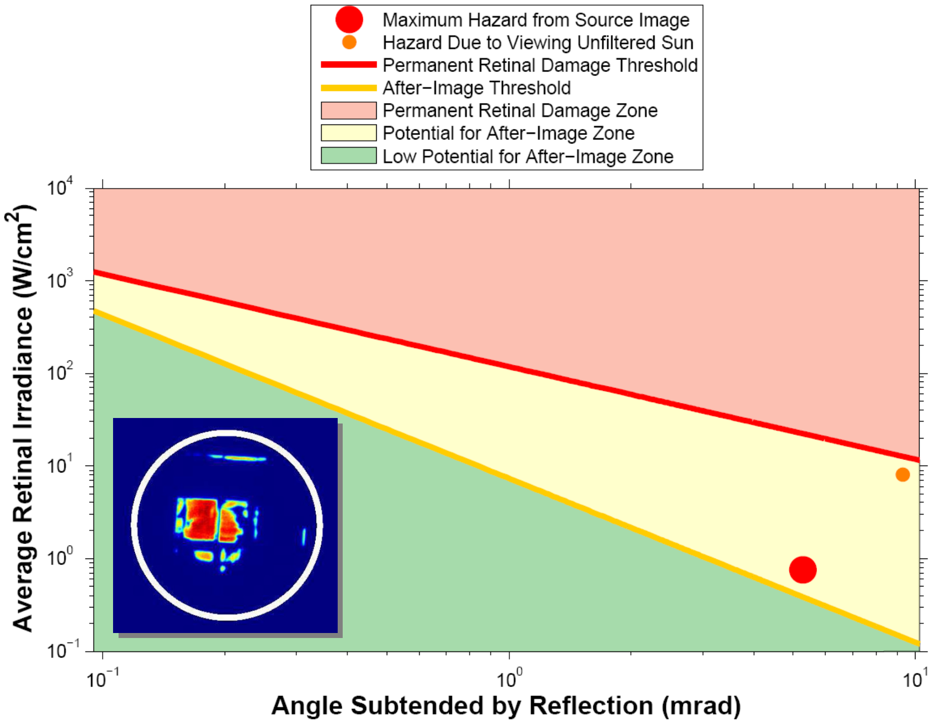

Figure 3. Hazard analysis plot of glare observed from a heliostat ~1700 m (just over a mile) away from the helicopter. The circled area of the inset image is the evaluated region of the glare source.

3.2. Glare from the Nevada Solar One Trough Plant

The digital photographs of the glare from the parabolic troughs at Nevada Solar One were evaluated to determine potential ocular hazards. Figure 4 shows that the retinal irradiance (which was less than that caused by viewing the sun directly) and subtended source angle (which was greater than that of the sun) caused by the glare yields a low to moderate potential for after-image (the point lies near the threshold between low and high potential for after-image). This was consistent with actual observations by the author. The author noted a temporary after-image, but only after viewing the glare for prolonged periods (several seconds). The subtended source angle of the glare was larger than the subtended angle of the sun because of additional scatter from the source of the glare, which we believe to be from the stainless steel bellows shields along the receiver tube.

The bellows shields are reflective cylindrical shields approximately 20-30 cm in length that are located approximately every ~4 m along the receiver tube. The digital images clearly revealed that the glare was comprised of many discrete sources that corresponded to the location (and separation distance) of the bellows shields (see inset in Figure 4). The reason the glare was so bright was because concentrated sunlight from the collector was reflecting off the bellows shields toward Highway 95 to the east (see Figure 5). The intensity increased towards solar noon as the collector rotated into a position that allowed more sunlight from the collector to reflect off of the bellows shield to the east toward Highway 95. The Air Force performed simulated landings over the parabolic trough plant at Kramer Junction, CA, and they also observed a bright glare that was likely caused by this effect. A simple mitigation for this type of glare is to use a diffuse paint or coating on the bellows shield, or to design the geometry of the bellows shields to prevent stray light and reflections from leaving the collector. Schott Solar has designed collars that can serve as the bellows shields and will reflect the sunlight back to the receiver tube instead away from the collector (Figure 6).

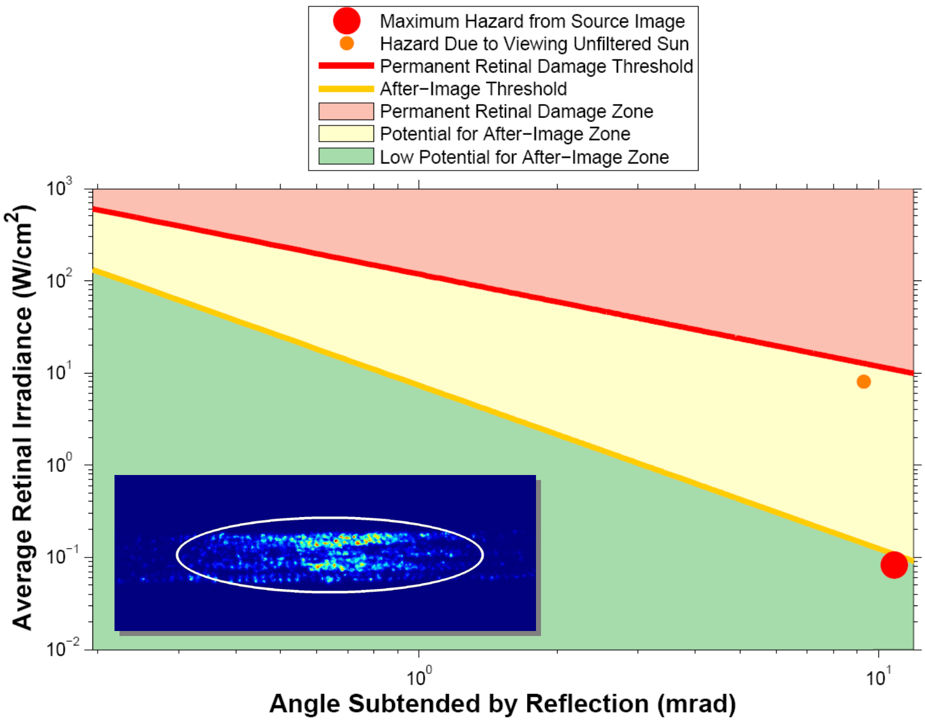

Figure 4. Hazard analysis plot of glare observed from Nevada Solar One ~2.5 km away on Highway 95. The circled area of the inset image is the evaluated region of the glare source, which shows that the glare is comprised of discrete, uniformly-spaced reflections.

Figure 5. Photographs of bellows shields uniformly spaced ~4 m along the receiver. Concentrated sunlight from the mirrors can reflect off the bellows shields away from the collector.

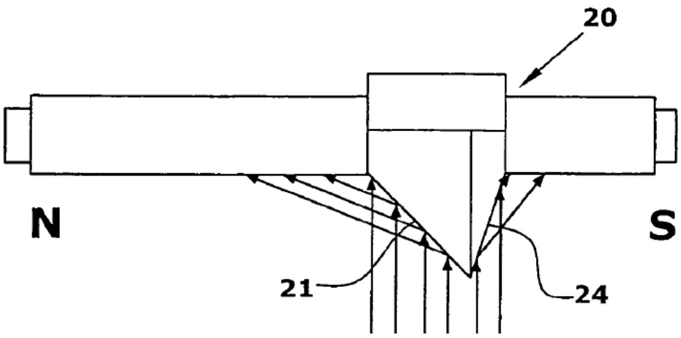

Figure 6. Schematic of a design for a bellows shield that reflects light from the parabolic trough mirrors toward the receiver tube [5].

3.3. Conclusions

This paper has presented observations of glare from heliostats and parabolic troughs. A helicopter flyover of heliostats at the National Solar Thermal Test Facility in Albuquerque, NM, revealed that when the heliostats were placed in a standby mode with an aim point ~30 m to the east of the top of the tower, a strong glare could be observed from the mirrors of the heliostat over 1700 m (> 1 mile) away. A temporary after-image was experienced by the author after viewing the glare source directly, which was consistent with model predictions of ocular hazard using the method described in Ho et al. [2]. The glare was primarily confined to a single heliostat since a single aim point was used, and beams from multiple heliostats would diverge past the aim point. Risks associated with glare from multiple heliostats can be significantly reduced if procedures and precautions are implemented to prevent multiple heliostats from focusing at locations beyond the tower that may be intercepted by aircraft.

Glare was observed from the Nevada Solar One trough plant along Highway 95. Evaluations of the digital images showed that the glare was comprised of discrete, uniformly spaced reflections. We believe that these reflections come from the bellows shields spaced every few meters along the receiver tube. Concentrated sunlight from the collector mirrors can reflect off the bellows shields toward Highway 95 to the east. The glare that was observed from 2.4 – 3.2 km away was sufficient to cause a temporary after-image when viewed for several seconds. Theoretical analysis [2],[3] showed that the measured irradiance and subtended source angle of the glare source was sufficient to cause a low to moderate potential for after-image. A simple mitigation for this type of glare is to use a diffuse paint or coating on the bellows shield, or to design the geometry of the bellows shields to prevent stray light and reflections from leaving the collector [5].

These evaluations are intended to support ongoing assessments of the occurrence and potential impacts of glare at CSP plants. Quantified evaluations, along with appropriate models and tools, will assist the Air Force, FAA, and other agencies to assess potential impacts of glare for their applications and needs. In the absence of this information, these agencies have stated that they will assume the worst, which will have negative implications for siting and permitting of solar energy installations.

Acknowledgments

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