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Understanding and Mitigating Visual Glare Impacts and Hazards from Solar Energy Systems

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SAND2019-

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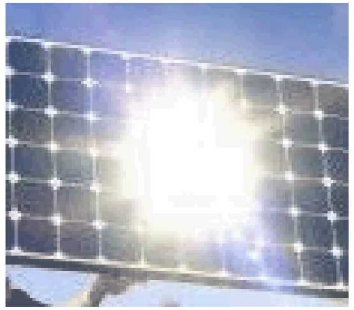
Outline – Solar Energy Glare

- Background & motivation
- Physics of glare & ocular hazards
- Mitigating glare – state of the science
- Research needs


Glint and Glare

- **Glint and glare may cause unwanted visual impacts**
  - Pilots, air-traffic controllers, workers, motorists
- **Potential visual impacts**
  - Distraction
  - Temporary after-image (flash blindness)
  - Veiling
  - Retinal burn

Definitions

Glint: Momentary flash of light

Glare: Continuous source of excessive brightness

Road sign on Massachusetts State Route 2

Examples of Glare from Solar Technologies

Photovoltaics

Manchester-Boston Regional Airport – View from ATCT

PV panels on residence in Colorado

Concentrating Solar Power (CSP)

Heliostats and Central Receiver at Sandia Labs, Albuquerque, NM

Dish Collectors at Sandia

Parabolic Trough Collectors at Kramer Junction, CA

Examples of Glare from Solar Technologies

Glare observations from C-12 cockpit at Kramer Junction, CA
(from Air Force Flight Test Center 412 TW at Edwards AFB, approval #13166)

Glare observed from airport traffic control tower at Manchester-Boston Regional Airport (May 2012). The $3.5M array had to be tarped.

New Federal Policy

- U.S. Department of Transportation, Federal Aviation Administration (78 FR 63276, October 23, 2013)
  - "...the FAA requires the use of the SGHAT to demonstrate compliance with the standards for measuring ocular impact stated above for any proposed solar energy system located on a federally-obligated airport."
  - "All sponsors of federally-obligated airports who propose to install or to permit others to install solar energy systems on the airport must attach the SGHAT report, outlining solar panel glare and ocular impact, for each point of measurement to the Notice of Proposed Construction Form 7460-1."

DoD Guidance on Glare and SGHAT

- DoD Memo June 11, 2014
- DoD Instruction 4165.57 revised March 12, 2015

OFFICE OF THE UNDER SECRETARY OF DEFENSE
3000 DEFENSE PENTAGON
WASHINGTON, DC 20301-3000

ACQUISITION, TECHNOLOGY AND LOGISTICS

JUN 1 1 2014

MEMORANDUM FOR ASSISTANT SECRETARY OF THE ARMY (INSTALLATIONS, ENVIRONMENT, AND ENERGY)
ASSISTANT SECRETARY OF THE NAVY (ENERGY, INSTALLATIONS, AND ENVIRONMENT)
ACTING ASSISTANT SECRETARY OF THE AIR FORCE (INSTALLATIONS, ENVIRONMENT AND LOGISTICS)

SUBJECT: Glint/Glare Issues on or near Department of Defense (DoD) Aviation Operations

In conjunction with the Department of Energy (DOE), the Federal Aviation Administration (FAA) has determined that glint/glare from some types of solar renewable energy systems could result in ocular impact to pilots and/or air traffic controllers, and thus potentially compromise the safety of the air transportation system. Glint is defined as the momentary flash of bright light, while glare is a continuous source of bright light. The FAA interim procedures require commercial airport operators who receive airport operations funding from FAA to conduct glint/glare studies for solar renewable energy systems on or near their airports. While commercial aviation has generally more rigid landing procedures, DoD flight procedures are more varied due to multiple military aircraft types and training requirements. Thus, FAA's interim guidance should only be used as a guide for consideration.

As part of the Office of the Secretary of Defense (OSD) review of solar renewable energy projects, the Directorate of Facilities Energy & Privatization (FE&P) will review your mission compatibility assessments, including the potential for glint/glare. Solar renewable energy projects using the authority found in 10 U.S.C., § 2922a or in 10 U.S.C., § 2667 (Enhanced Use Lease) will require the SGHAT analysis for OSD review/approval/certification. For renewable energy projects that do not require OSD approval (e.g. renewable energy included in Military Construction (MILCON): Facilities Sustainment, Restoration, and Modernization (FSRM); Energy Savings Performance Contract (ESPC); Utility Energy Services Contract (UESC); or Energy Conservation Investment Program (ECIP) projects), OSD encourages a mission compatibility assessment include glint/glare as applicable. The use of the SGHAT is optional, and other glint/glare tools may be used.

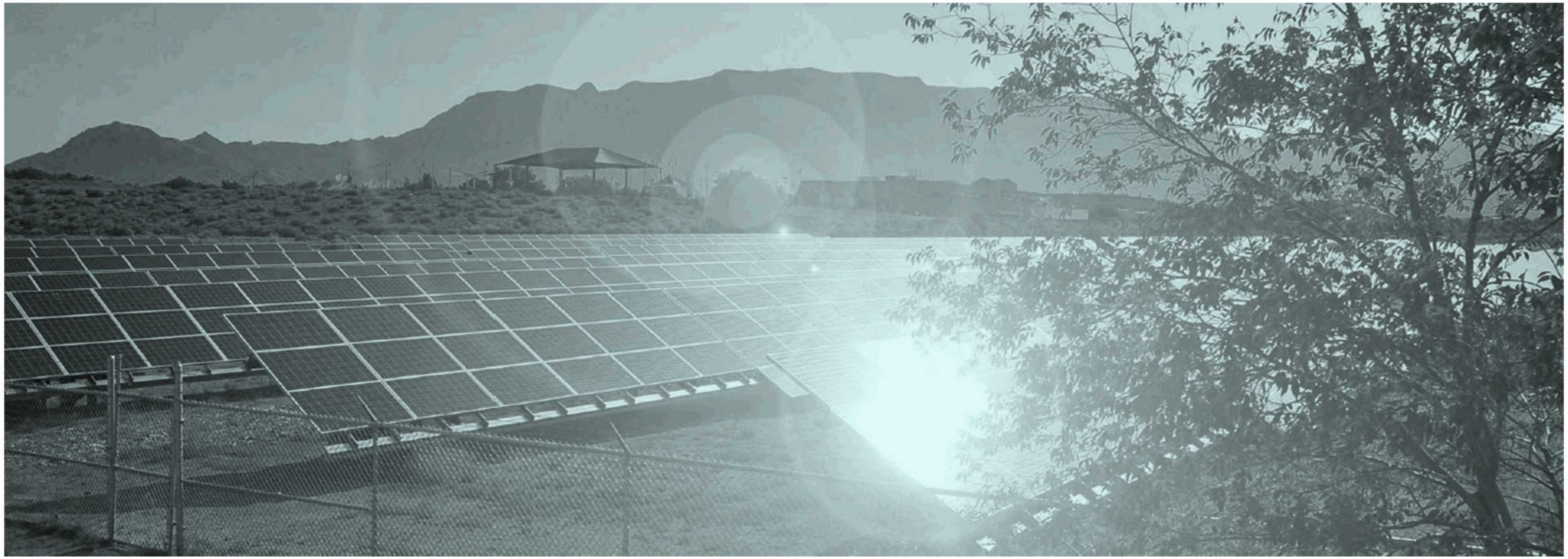
Should your staff have questions, please contact Ms. Sara Streff, FE&P at 571-372-6843 or Mr. Steve Sample, SCH at 703-571-0067.

John Conger
Acting Deputy Under Secretary of Defense
(Installations & Environment)

Need

Need models, tools, and methods to mitigate glare and address federal and local policies requiring quantification of glare impacts from solar energy installations...

while maximizing annual energy production



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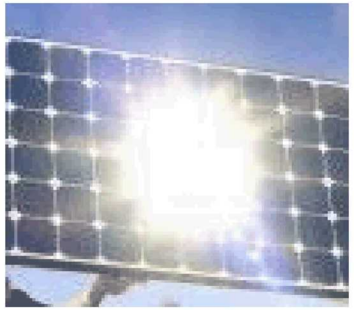
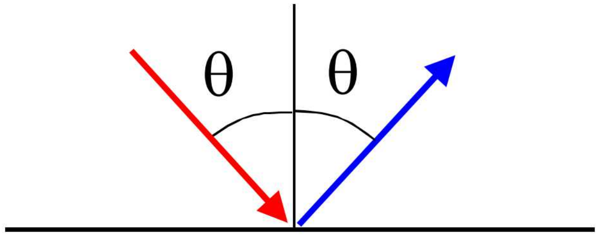
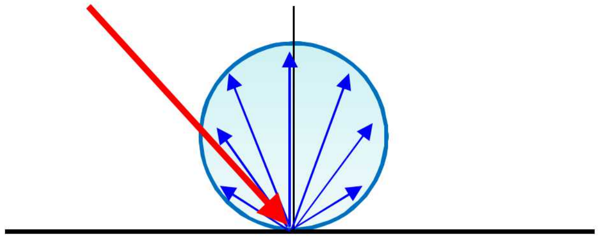



Types of Reflection



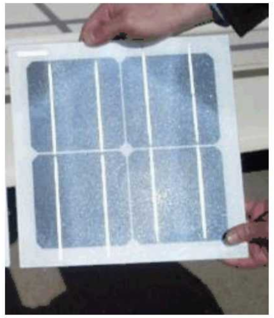
Specular Reflection

Polished Surfaces
(e.g., mirrors,
smooth glass)

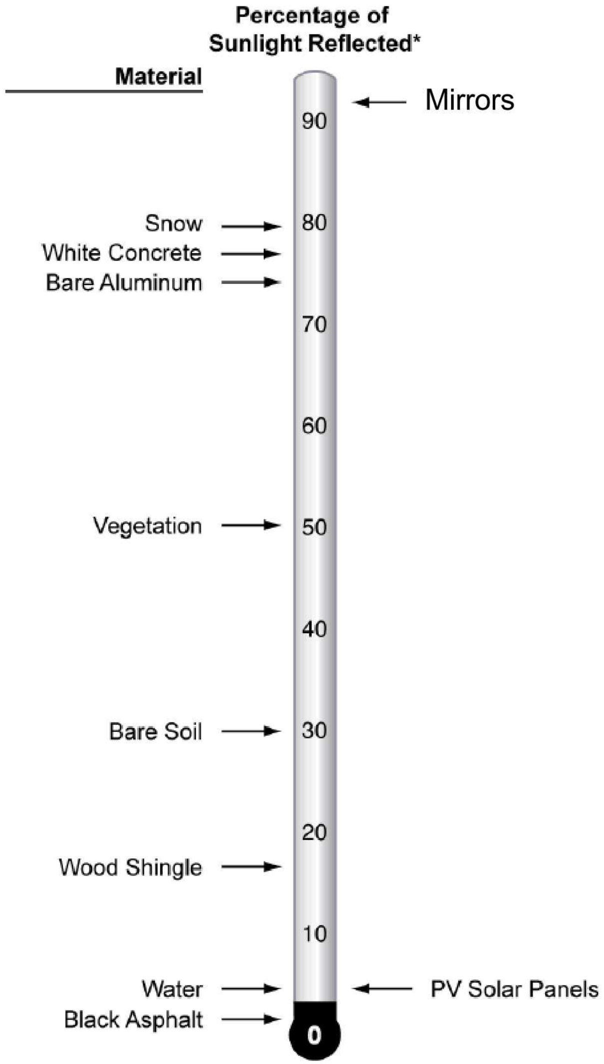


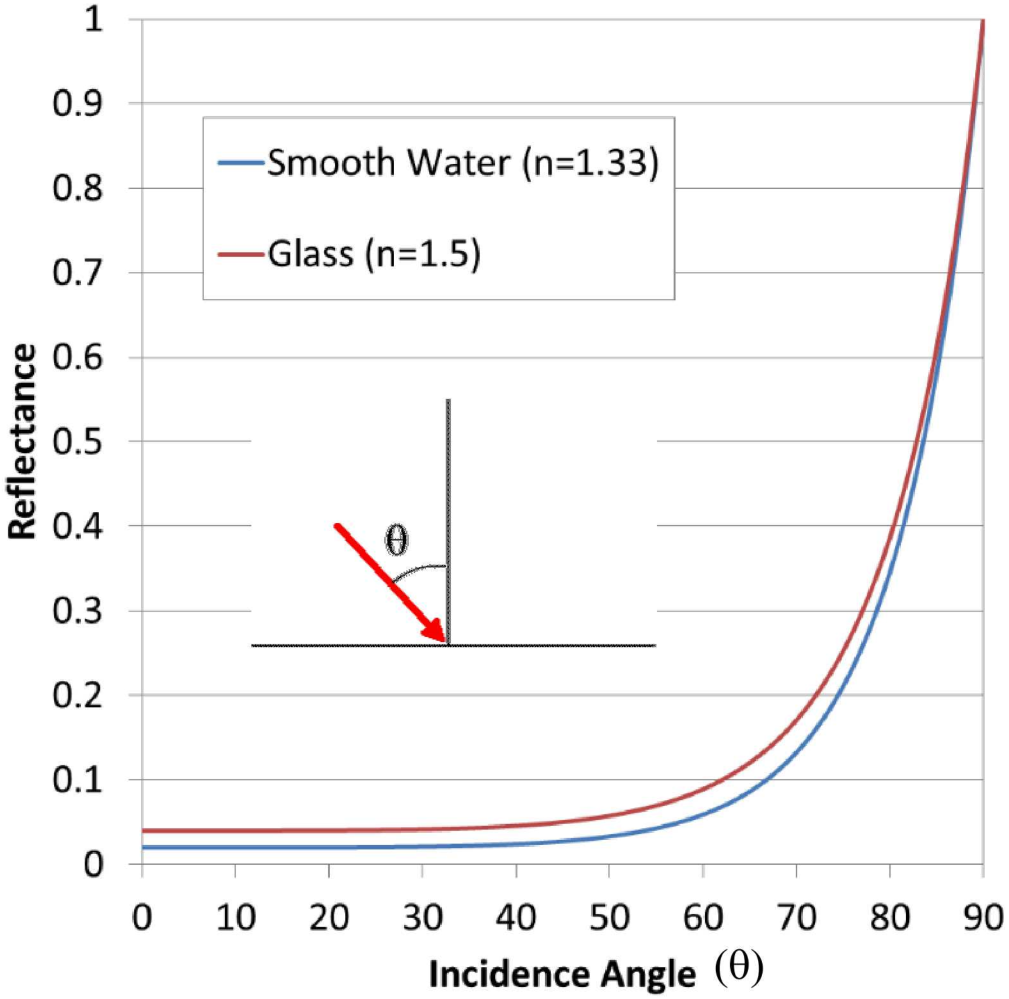
Diffuse Reflection

Rough Surfaces
(e.g., receivers, textured
glass, snow, pavement)



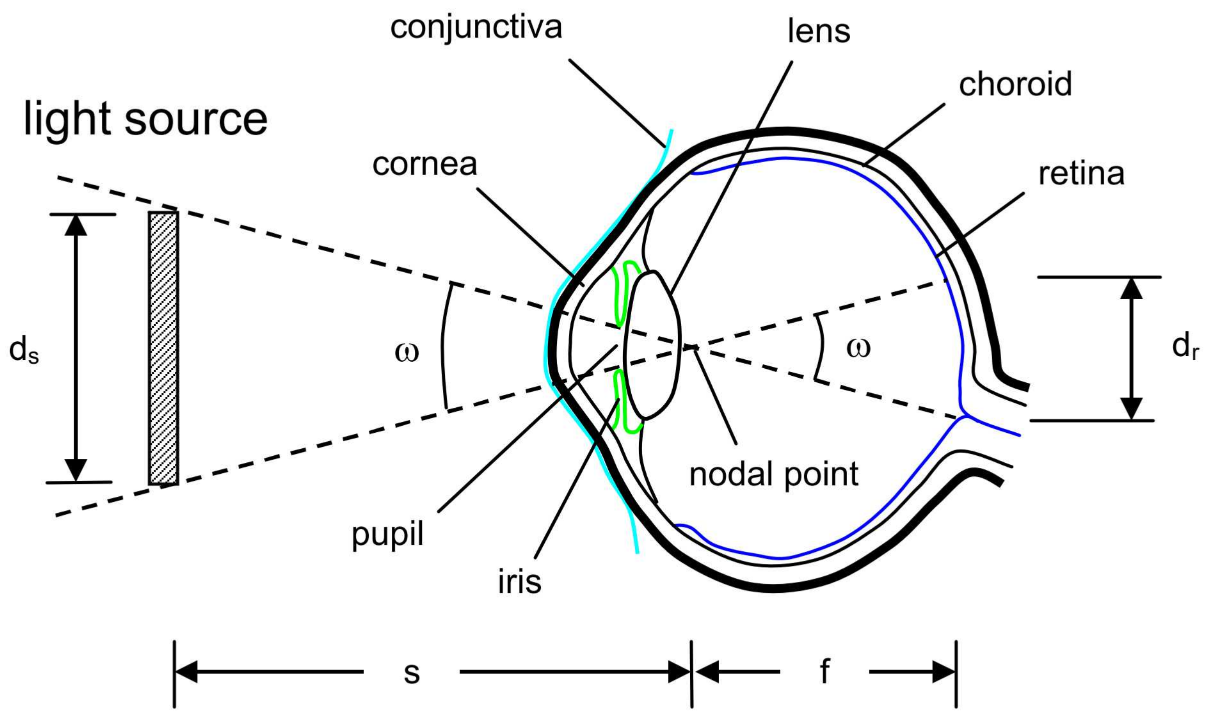
Reflectivity





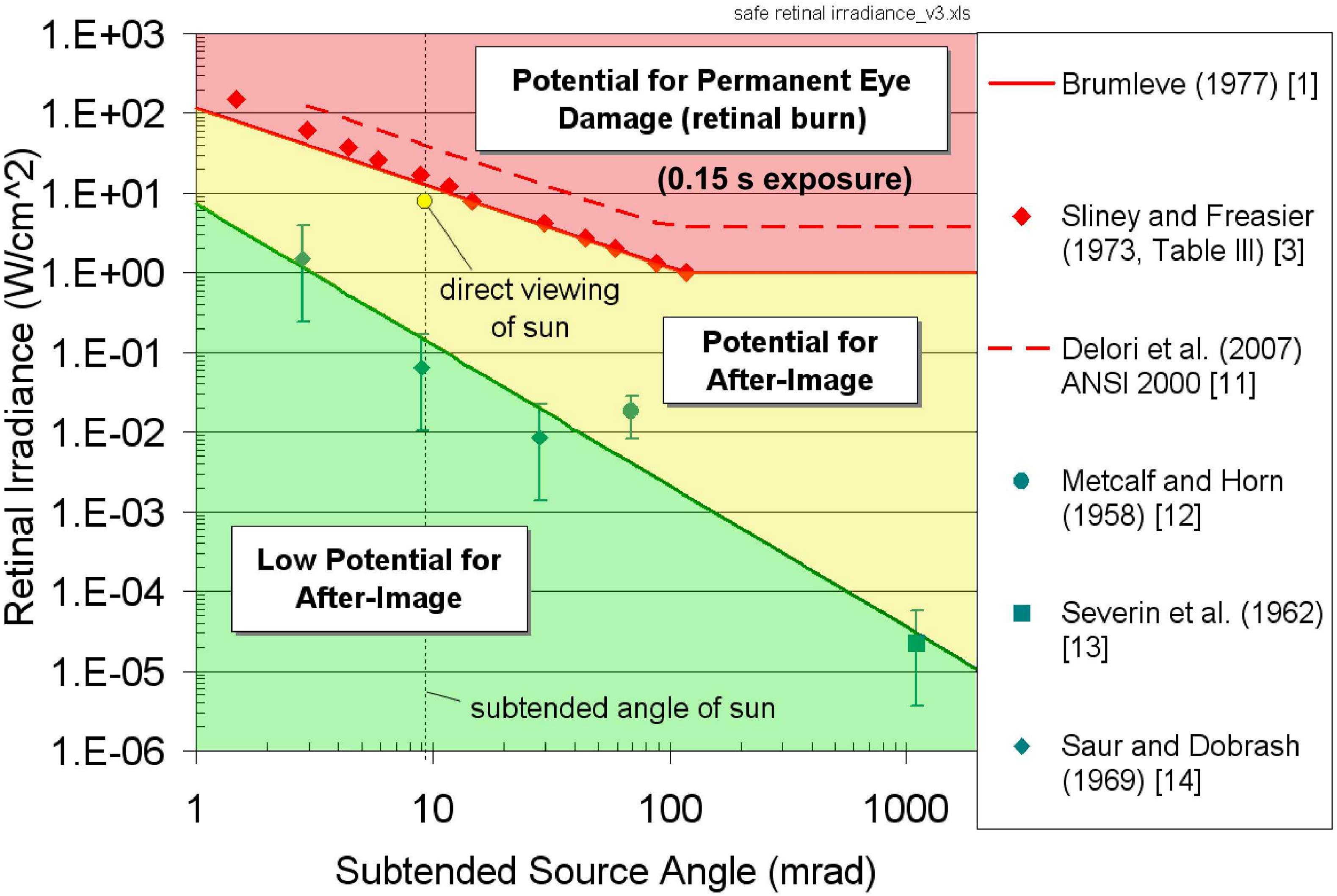
Adapted from ACRP Synthesis 28 "Investigating Safety Impacts of Energy Technologies on Airports and Aviation"

Impact of Light Entering the Eye



- Need to calculate
  - Power entering eye
    - Function of irradiance at the cornea (front of eye)
  - Subtended angle of glare source (size / distance)

Potential Ocular Impacts



Equations and analysis methods detailed in Ho et al. (2010, 2011)

Testing the Impact of Solar Glare

- Testing glare potential and ocular impact
- FAA flight simulator tests
  - Impact of angle and duration of glare
- Impact of PV surface texturing or coatings
  - Reflectivity vs. incidence angle

Decreasing ocular impact / increasing energy absorption


Proceedings of the ASME 2015 Power and Energy Conversion Conference
PowerEnergy2015
June 28-July 2, 2015, San Diego, California

PowerEnergy2015-49481

ASSESSMENT OF PHOTOVOLTAIC SURFACE TEXTURING ON TRANSMITTANCE EFFECTS AND GLINT/GLARE IMPACTS

Julius Yellowhair and Clifford K. Ho

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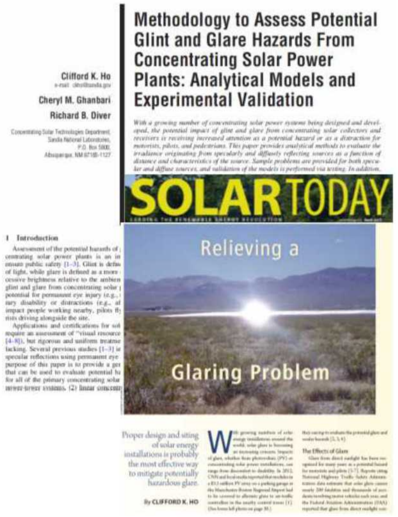
ABSTRACT

1. INTRODUCTION

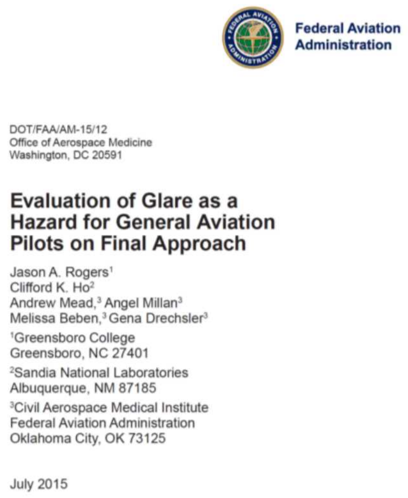
NOMENCLATURE


Methodology to Assess Potential Glint and Glare Hazards From Concentrating Solar Power Plants: Analytical Models and Experimental Validation

Clifford K. Ho
Cheryl M. Ghanbari
Richard B. Diver

SOLAR TODAY

Relieving a Glaring Problem


Federal Aviation Administration

DOT/FAA/AM-15/12
Office of Aerospace Medicine
Washington, DC 20591

Evaluation of Glare as a Hazard for General Aviation Pilots on Final Approach

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Andrew Mead,[3] Angel Millan[3]
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July 2015

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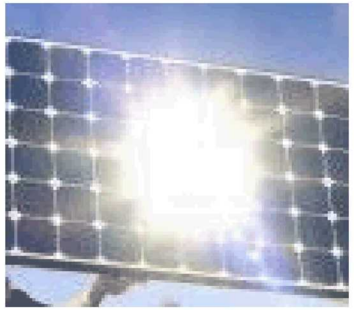
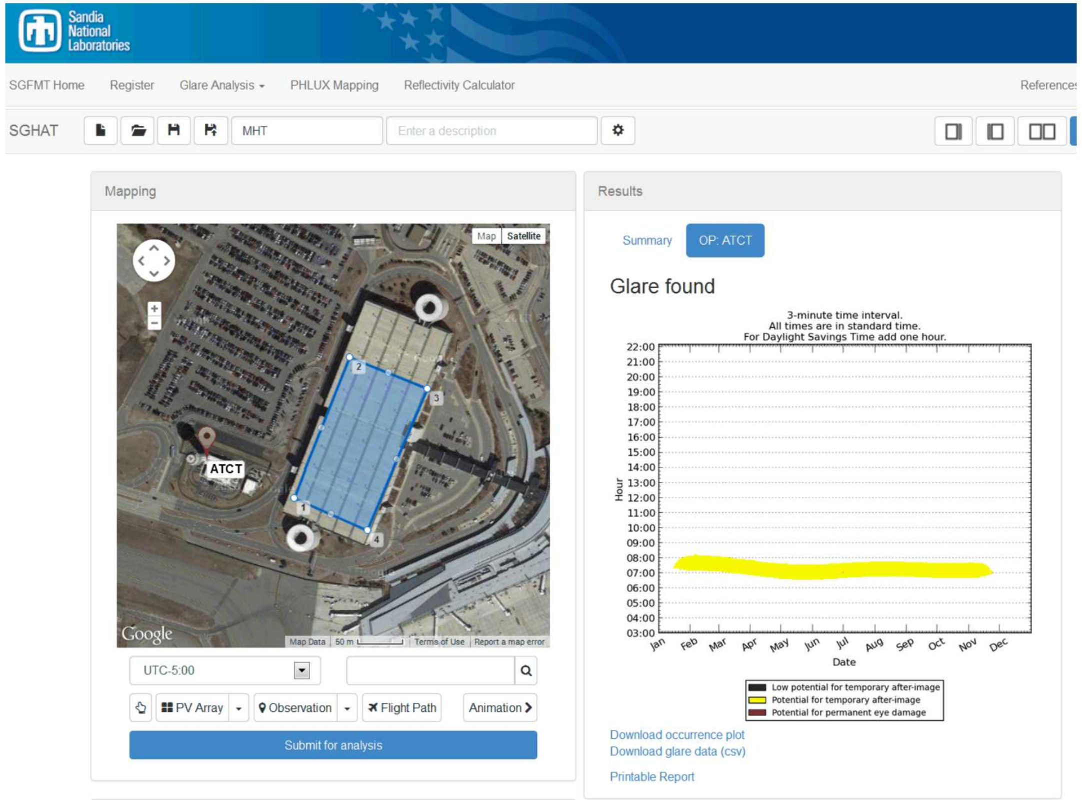



Solar Glare Hazard Analysis Tool

- Web-based software that predicts impacts of glare and annual energy production from photovoltaic arrays



- Uses interactive Google Maps
- Very fast annual simulations
- Optimizes energy production

www.sandia.gov/glare

Mitigation of glare while maximizing energy production

Azimuthal Angle (degrees)	Elevation Angle (degrees)	Relative Annual Energy Production
180	43	100.0%*
200	20.6	93.9%**
120	40	88.9%
120	50	87.2%
110	20.6	82.4%
110	30	85.0%
110	40	84.7%
120	60	83.7%
110	50	82.8%
130	70	81.5%
100	30	80.9%
100	20	80.8%
100	40	79.9%
110	60	79.3%
120	70	78.3%
100	50	77.6%
90	20	77.5%
210	80	76.9%
90	30	76.4%
220	80	75.8%
90	40	74.5%
110	70	74.2%
100	60	74.1%
130	80	74.0%
90	50	71.8%
120	80	71.3%
100	70	69.2%
90	60	68.1%
110	80	67.7%
90	70	63.4%
100	80	63.2%
90	80	57.8%

- Use SGHAT to identify PV array configurations that produce no glare
- Choose design that maximizes energy production

*Maximum energy production; produces glare to ATCT
**Current configuration; produces glare to ATCT

SGHAT Impact

Solar Industry

Reprinted with permission from the June 2013 issue

Glare Factor: Solar Installations And Airports

The FAA is looking into how PV arrays affect pilots and air traffic control operations.

Stephen Barrett

The success of the solar industry as a whole has obscured a small but impressive and growing business in solar photovoltaic projects at airports. The partnership between airports and solar is a logical one, given the open landscape, availability of buildings and land to site projects, and proximity to large electricity loads that airports provide. Airport managers have also recognized the business advantages of solar power as an alternative revenue source and in providing long-term cost savings. In addition, public policy benefits to municipal, county and state government agencies that manage airports and have set greenhouse gas reduction goals offer a real and purposeful basis for these projects.

But airports, as entry points for world air travel, present very unique challenges to solar developers. The Federal Aviation Administration (FAA) must ensure safe and efficient air travel. Safety is paramount, and

mary purpose. Recent observations of glare from solar projects have ush- ered in an in … from the air … the FAA, wl … less receptiv … The centr … when rulin … project is: W … Over the … FAA, with … Department … developed a … potential im … ticle review … authority ov … isting the re … ing glare m … example den … are being ap

U.S. Department of Transportation

Federal Aviation Administration

Regulatory authority

Solar developers working at or near an airport might wonder whether they need FAA approval at all. The answer is not always clear.

When a project is proposed on airport property, the FAA has broad authority. The airport, as recipient of FAA funds for infrastructure improvements, is responsible for

(referred to as Part 77) and environmental laws (e.g., National Environmental Policy Act).

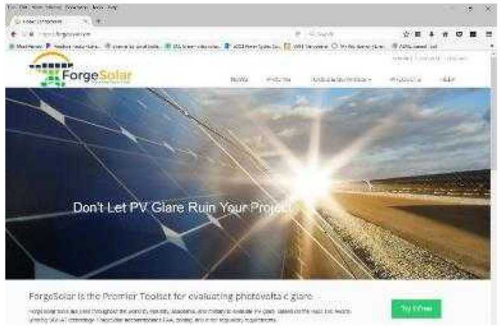
If a private developer seeks a long-term lease of airport land, additional requirements will apply, including assessing the project's compatibility with the airport master plan and documenting that lease payments meet the FAA's fair market value test.

The FAA's airspace review has traditionally focused on whether or not the project presents a physical obstruction of airspace, which has been a permitting challenge for the wind

the nation's airspace layer and automatically trigger FAA review.

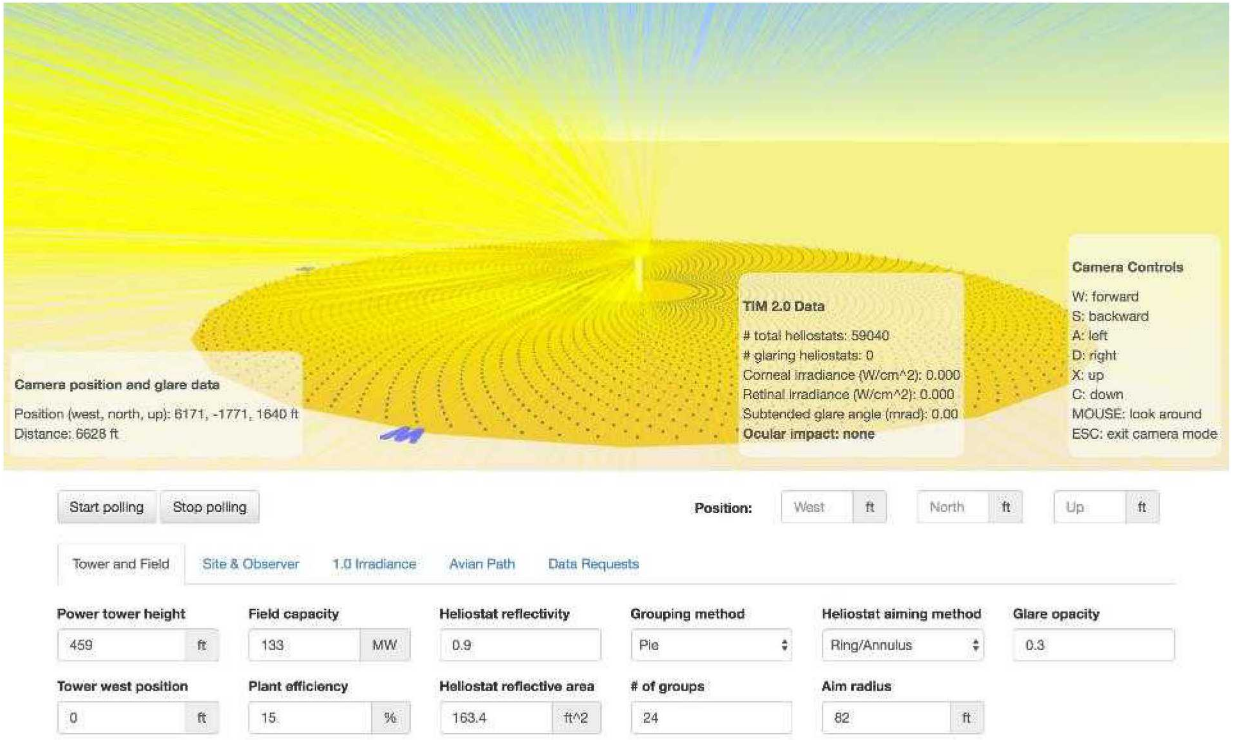
Concerns about glare are specific to on-airport activities, but "how close is too close" has not been defined. Because answering this question will be case-specific, a developer should contact the airport as a part of its stakeholder outreach program. If the airport expresses con-

- Over 6,000 registered users in over 60 countries
- 2013 R&D 100 Award
- New federal policy issued in 2013 mandates use of SGHAT
- SEIA promoting SGHAT through national webinars
- Articles in solar trade magazines promoting use of SGHAT
- Licensed to ForgeSolar



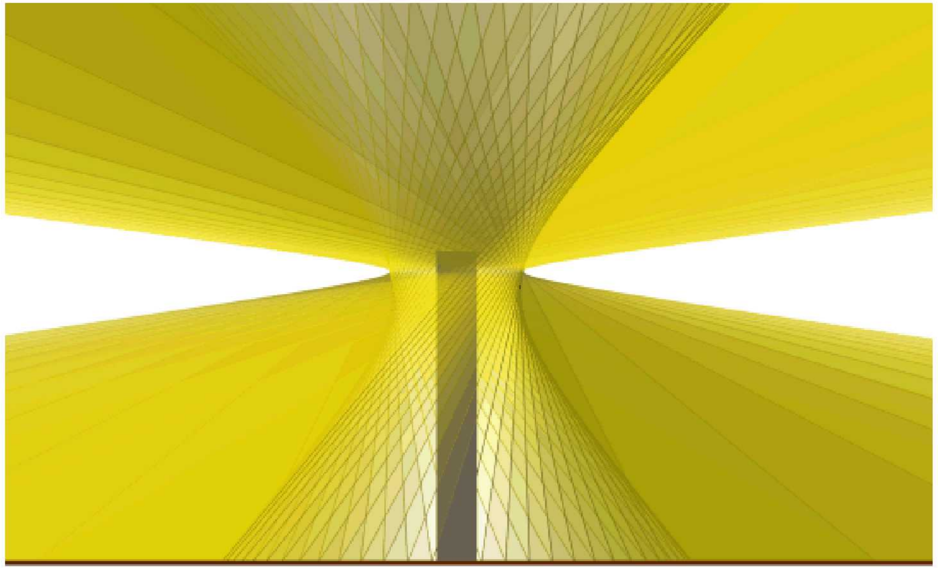
Tower Illuminance Model (TIM)

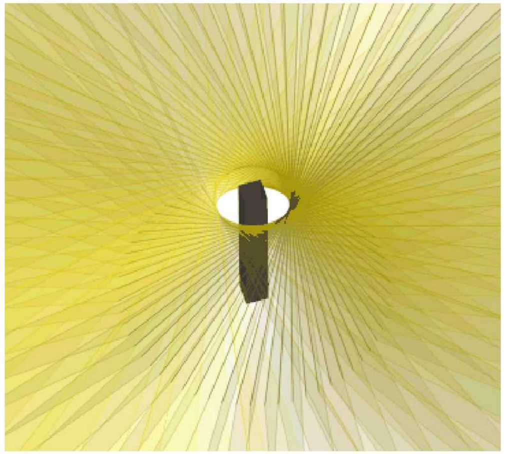
- Evaluates glare and avian flux hazards for different heliostat aiming strategies for CSP
  - Use keyboard buttons to “fly” through heliostat field



www.sandia.gov/glare

Glare from Heliostats in Standby Mode



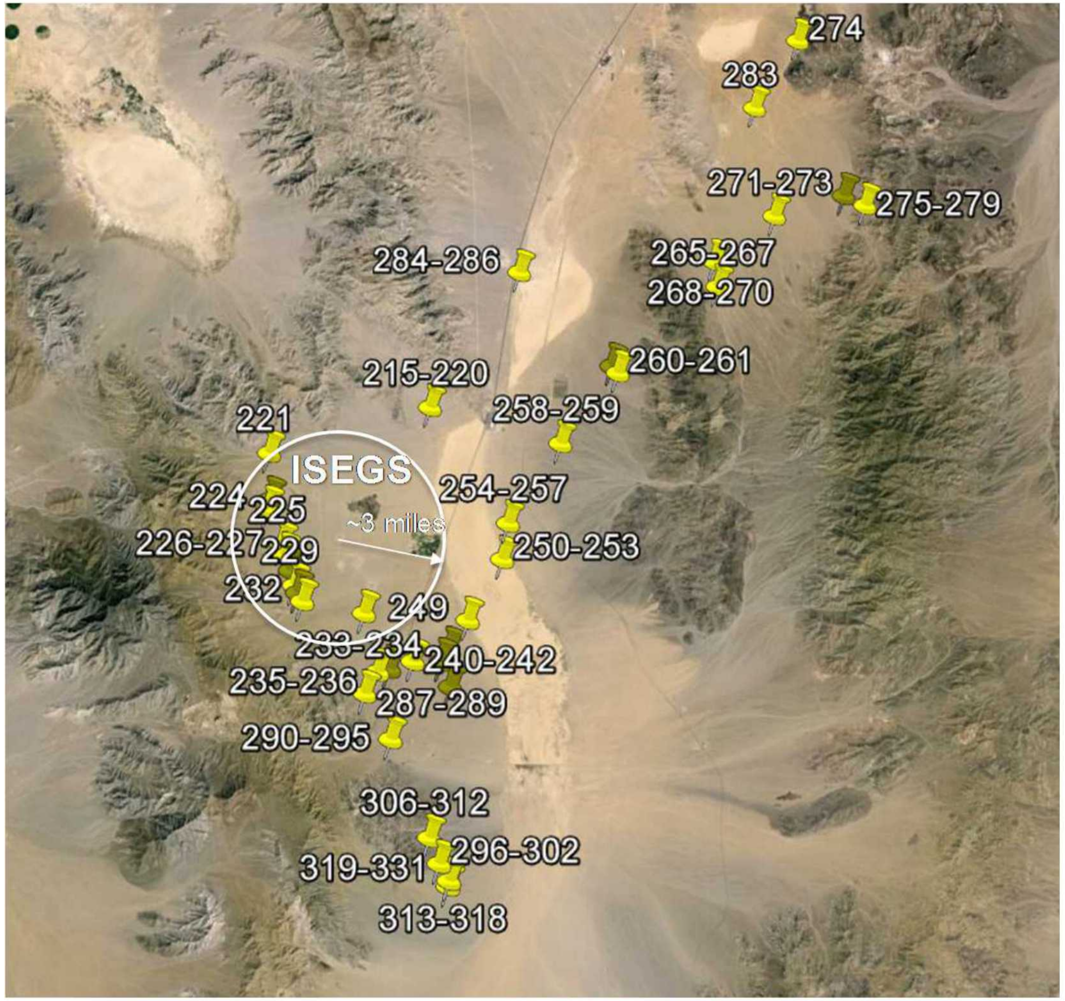


Helicopter Flyovers of Ivanpah Solar Plant

April 2014, July 2014, March 2015, May 2018

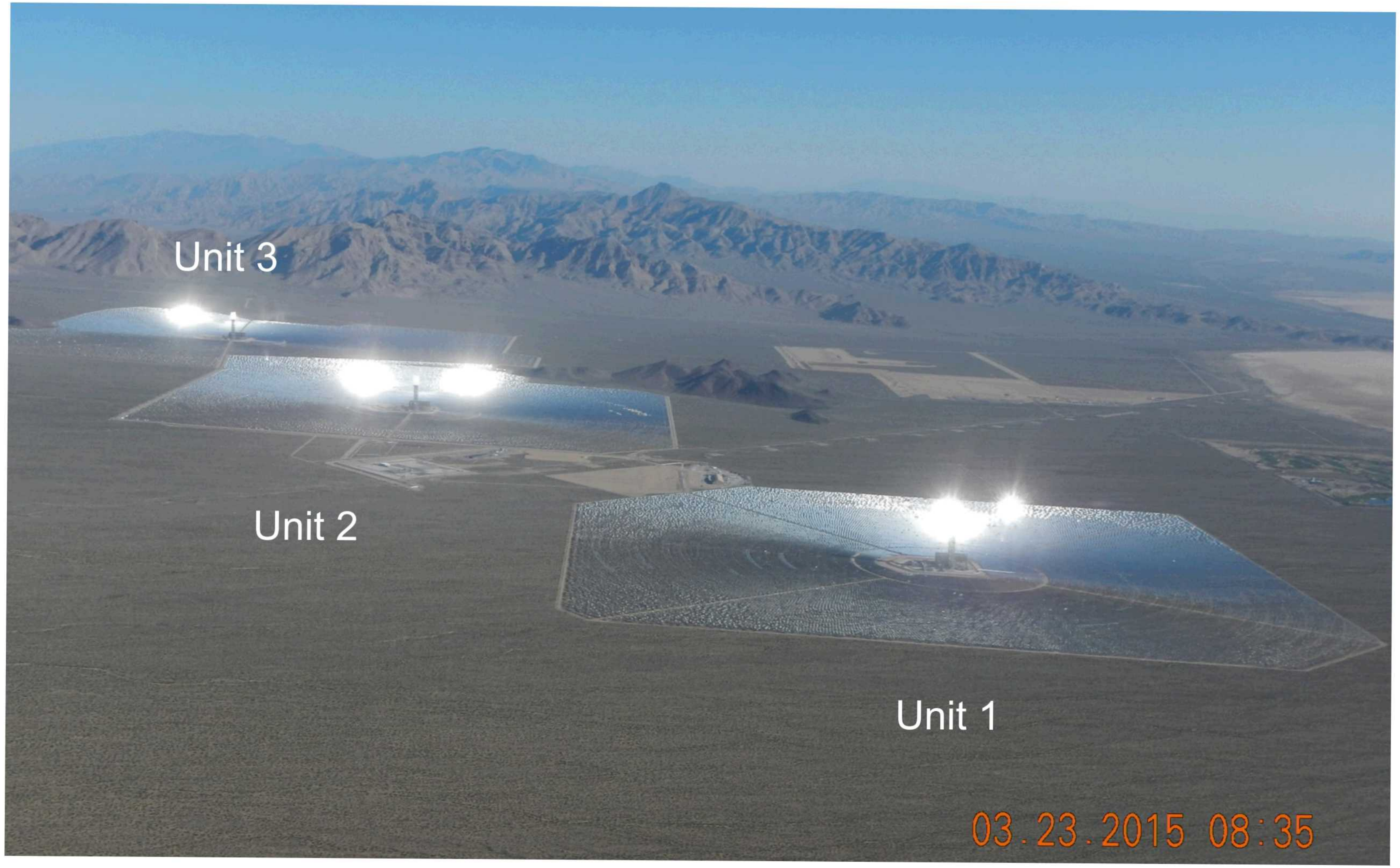
Objective: Quantify glare at Ivanpah and suggest mitigation measures

July 2014 Flyover



Aerial Glare Photographs

Looking north, 8:35 AM (PDT), March 23, 2015, ~4 - 5 miles away



Aerial Glare Photographs

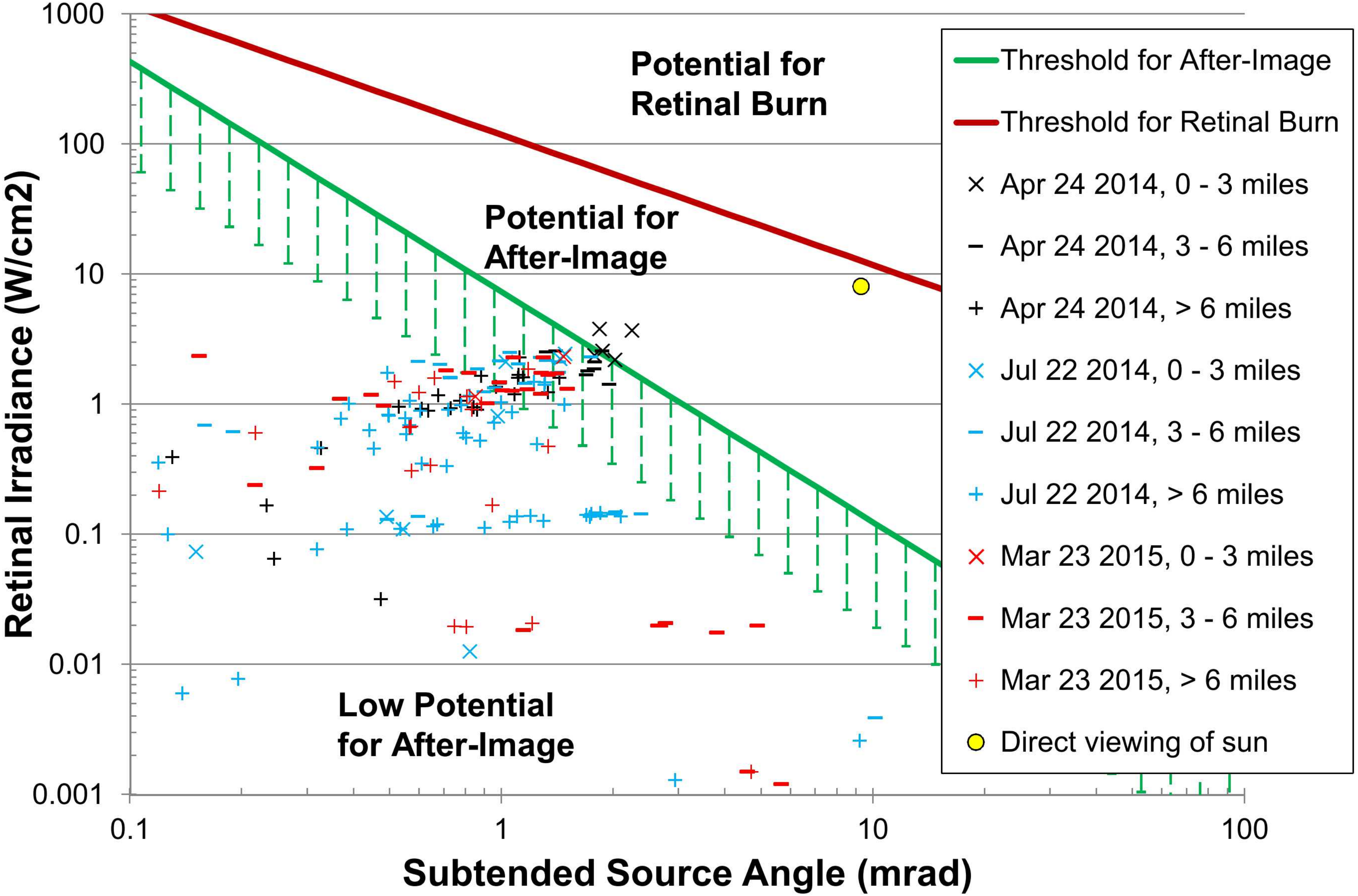
Looking northwest, 8:39 AM (PDT), March 23, 2015, ~3 – 4 miles away

Unit 2, 1/4000s, f/32

Aerial Glare Photographs

Looking southwest, 8:53 AM (PDT), March 23, 2015, about 14 miles away

Ocular Hazard Analysis



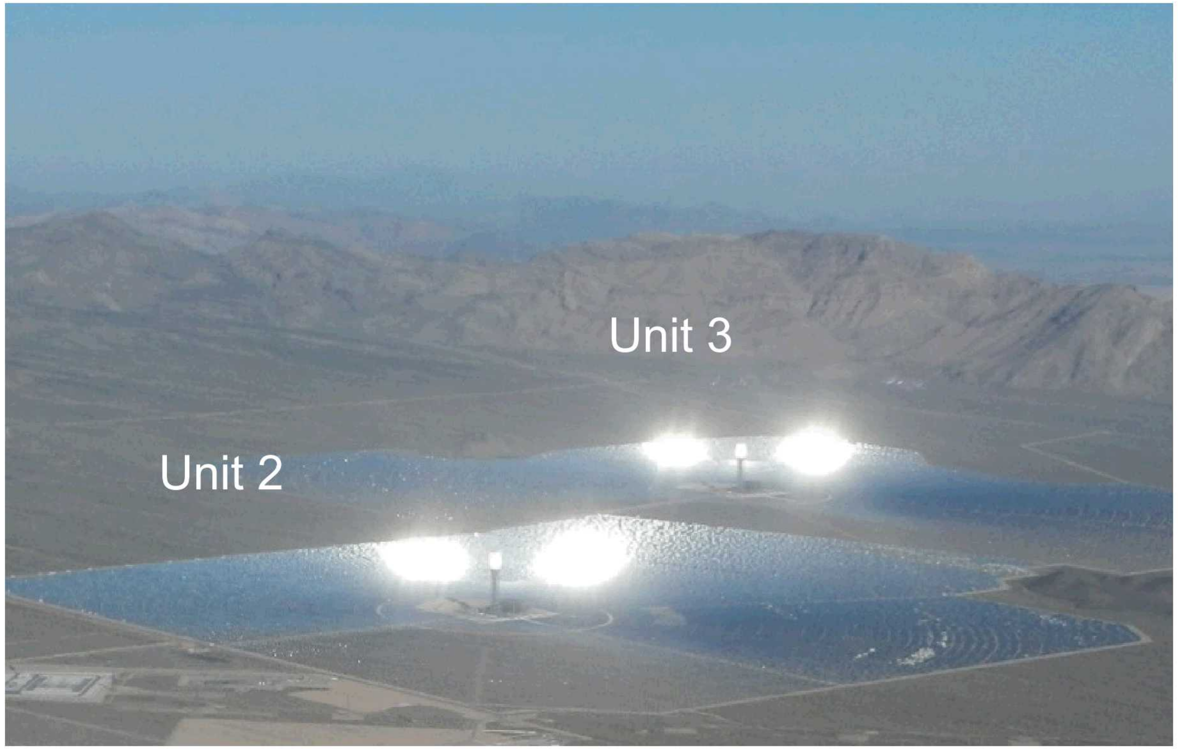
Suggested Mitigation Measures

- Limit the number of heliostats in standby mode
  - Predict need for standby heliostats based on cloud cover or other factors
  - Bring heliostats up to standby position near receiver sequentially only as needed
- Implement dynamic aiming strategy and reflect light either straight up or toward the ground (depending on slew time to target)
- Increase the number of aim points near the receiver during standby and have adjacent heliostats point to different locations to disperse visible glare
- Reduce number of standby heliostats that face directly toward the sun; these produce the most glare
- Incorporate a glare shield near the receiver for heliostats in standby mode
  - Perhaps the shield can serve as a preheater
- Improve tracking and positioning algorithms to reduce the number of "rogue" heliostats

Aerial Glare Photographs

Looking northwest

March 23, 2015



May 18, 2018

Fewer heliostats in standby and more dispersed standby aiming strategy reduced visible glare

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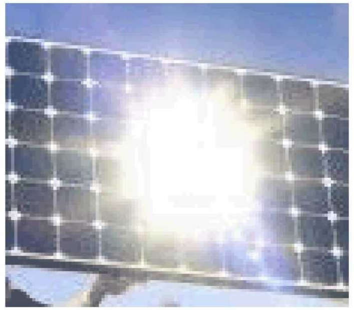


Research Needs

- Validation of glare/avian hazard mitigation tools
- Development and testing of materials and methods that reduce glare for PV and CSP
- Technoeconomic studies of glare-mitigation technologies
  - Evaluation of trade-offs between glare mitigation and performance/cost

Helicopter flyovers of NSTTF (left) and Ivanpah CSP (right)

Decreasing ocular impact / increasing energy absorption

Conclusions

- Glare from solar energy systems can cause visual impacts
  - Reflections from glass PV modules and CSP mirrors
- Federal (FAA, DoD) and local policies implemented to prevent adverse glare from solar energy installations
- Tools and safety metrics have been developed
  - SGHAT evaluates glare PV systems; design tool to mitigate glare while maximizing energy production
  - TIM evaluates glare/avian hazards from CSP systems
  - Tools can be used to address federal and local requirements (www.sandia.gov/glare)
- Research needs
  - Additional validation
  - Materials development to reduce glare while increasing energy production
  - Technoeconomic analyses

Acknowledgments

- Funding from DOE Solar Energy Technologies Office
  - Chris Nichols, Michele Boyd
- Federal Aviation Administration
  - Bill Petrak and Chris Hugunin
- Sandia and NREL Colleagues
  - Cianan Sims, Julius Yellowhair, Tim Wendelin

Questions?

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