SAND2014-17265PE

Evaluation of Glare at the Ivanpah Solar Electric Generating System – 2nd Flyover on July 22, 2014

Exceptional service in the national interest

Sandia National Laboratories

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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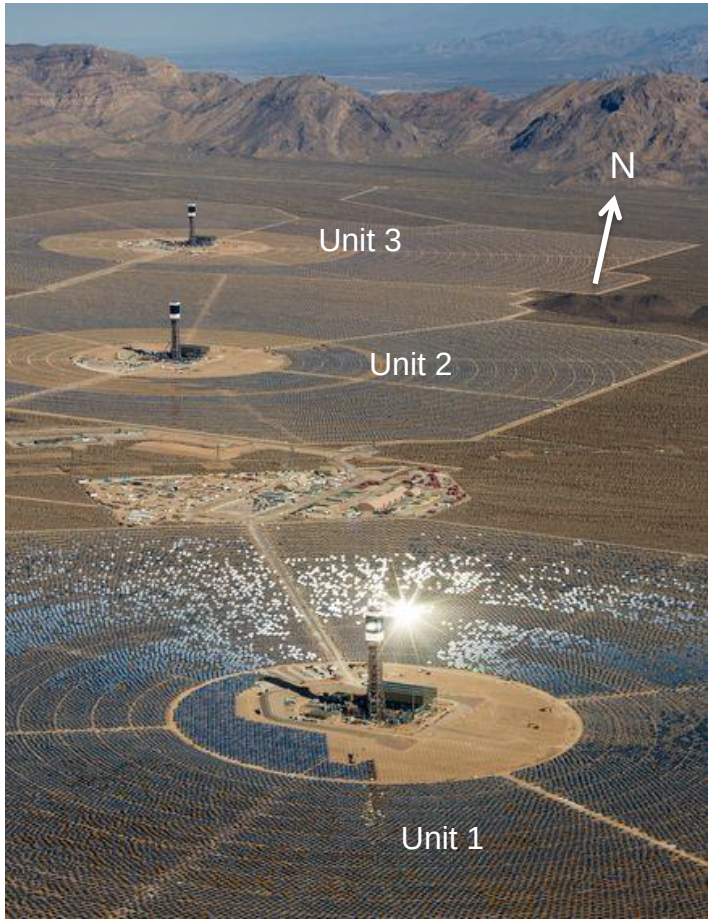
Overview

- Background and Objectives
- Aerial Glare Monitoring
- Next Steps

Ivanpah Solar Electric Generating System

- Three power tower units
  (377 MW (net) / 392 MW (gross)
  - Unit 1: 126 MW
  - Unit 2: 133 MW
  - Unit 3: 133 MW
  - Each tower 140 m (459 ft) tall
- 173,500 heliostats
  - 2 mirrors/heliostat: 15.2 m^2
- Direct steam receiver (22 m tall x 17 m wide + ~16 m of white shielding)
- Dry-cooling
- 14.2 km^2 (3500 acres) on public desert land in southern California
- Owners: NRG Energy, Google, and Brightsource Energy



Previous Aerial Surveys of Glare

- April 24, 2014 – Sandia National Laboratories
  - Heliostats in standby mode can cause glare to aerial observers
  - Glare from heliostats can cause after-image at far distances (up to 6 miles in our helicopter surveys); similar to briefly looking at sun
  - Glare was visible from multiple heliostats in standby mode
  - The glare from the illuminated receiver was small compared to the glare from the standby heliostats
  - Ground-based drive-by surveys did not reveal ocular hazards
  - Suggested mitigations measures for heliostats in standby mode
- May 8, 2014 – CEC Staff and Contractors
  - Observed glare from “direct solar reflections from the heliostats (DSRH)” in standby mode that were sufficient to result in “disability glare” that can compromise visual performance and flight safety
  - Suggested mitigation measures for heliostats in standby mode

Glare from Heliostats in Standby Mode

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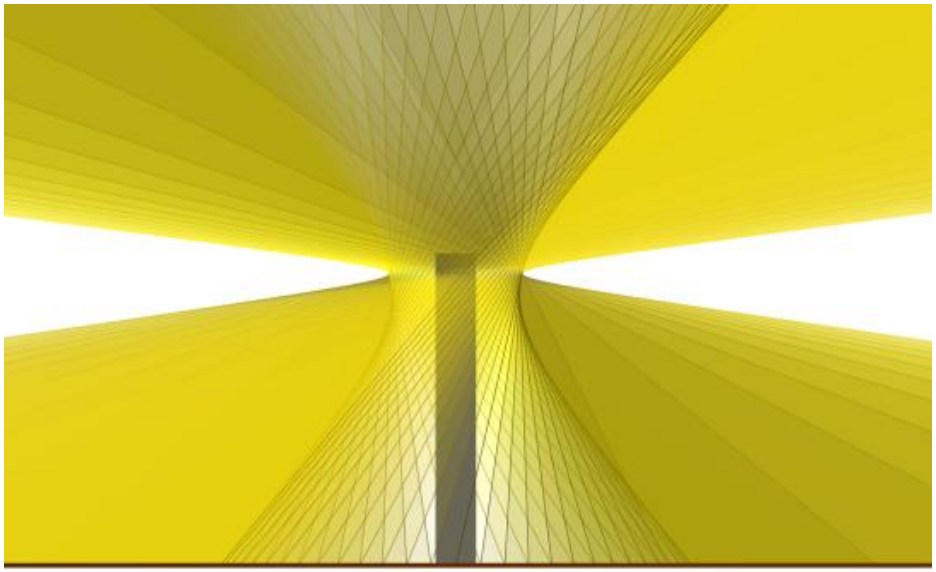

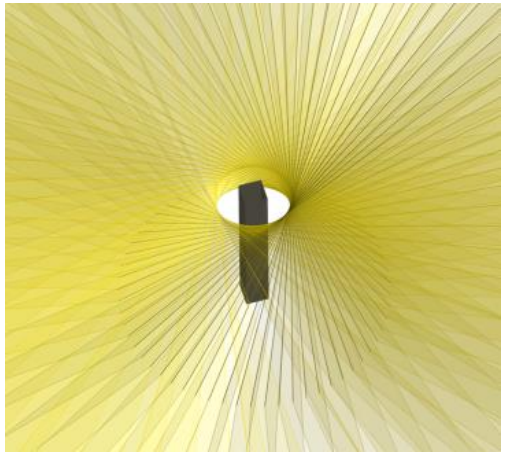

Suggested Mitigation Measures

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- Limit the number of heliostats in standby mode
  - Predict need for standby heliostats based on cloud cover or other factors
  - Position some heliostats vertically in proper azimuth position to reduce time to slew to target
  - Bring heliostats up to standby position near receiver sequentially only as needed
- Increase the number of aim points near the receiver during standby and have adjacent heliostats point to different locations to disperse the visible glare
- Incorporate a glare shield near the receiver for heliostats in standby mode
  - Perhaps the shield can serve as a preheater for the water
- Improve tracking and positioning algorithms to reduce the number of “rogue” heliostats

Heliostat Standby Aiming Strategies

(Personal communication – Nitzan Goldberg, Brightsource Energy, 7/22/14)

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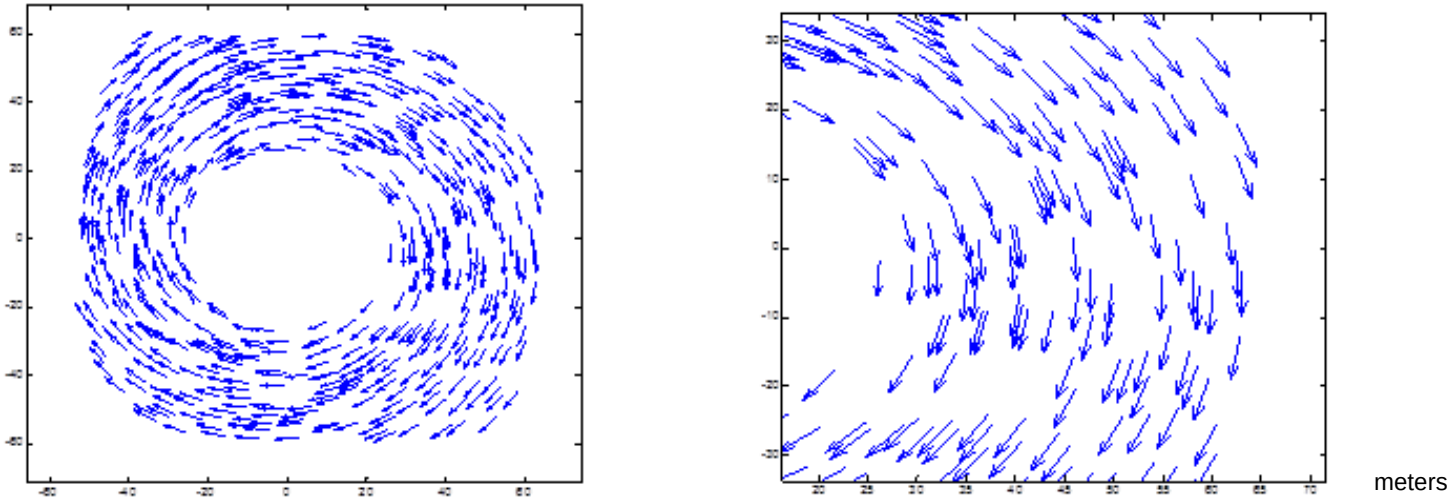
- Option 1 (original)
  - Standby points are as close to the receiver as possible
  - Each heliostat as its own aim point depending on azimuth and distance
  - Each heliostat aims to the left side of the receiver



Quiver plots showing flux vectors near the receiver from a sample of heliostats for Option 1

Heliostat Standby Aiming Strategies

(Personal communication – Nitzan Goldberg, Brightsource Energy, 7/22/14)

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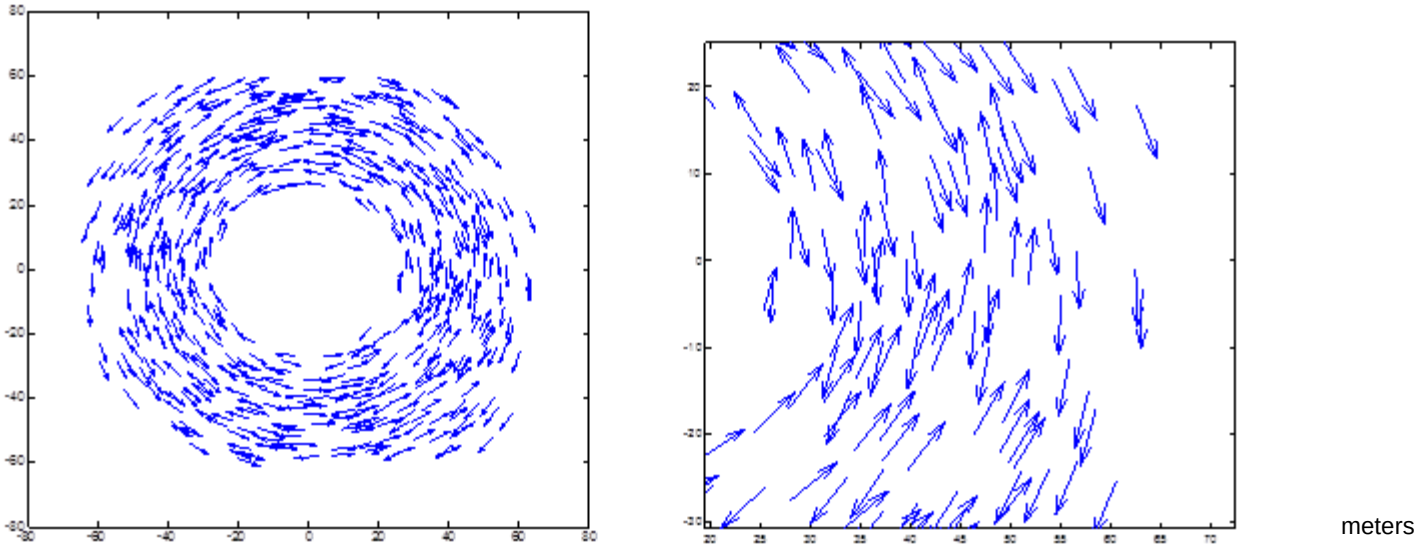
- Option 2 (Unit 1 during April 24 flyover?)
  - Standby points are as close to the receiver as possible
  - Each heliostat as its own aim point depending on azimuth and distance
  - Aiming is to both sides of the receiver



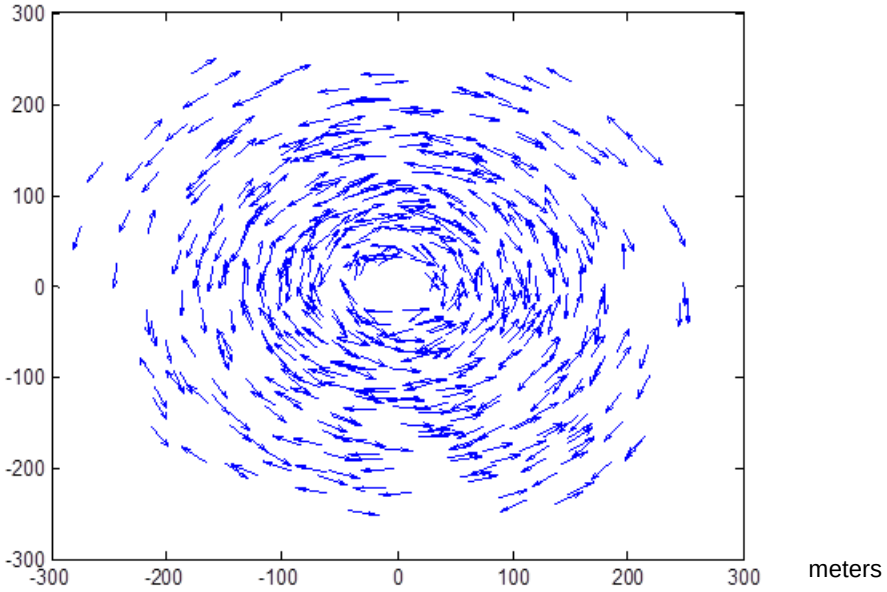
meters

Quiver plots showing flux vectors near the receiver from a sample of heliostats for Option 2

Heliostat Standby Aiming Strategies

(Personal communication – Nitzan Goldberg, Brightsource Energy, 7/22/14)

- Option 3 (Units 1 and 2 during July 22 flyover)
  - Spread standby points to reduce flux density in air around receiver and to disperse the observable glare
  - Aiming is to both sides of the receiver



Quiver plots showing flux vectors near the receiver from a sample of heliostats for Option 3

Objective

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- Sandia performed a second aerial survey on July 22, 2014
  - First aerial survey was performed on April 24, 2014
- Objective was to evaluate impact of changes made to standby aiming strategies employed at Units 1 and 2 (Unit 3 was unchanged)
  - Units 1 and 2 employed standby aiming strategy similar to Option 3
  - Unit 3 employed standby aiming strategy similar to Option 1

Overview

- Background and Objectives
- Aerial Glare Monitoring
- Next Steps

Aerial Monitoring Photo Locations

July 22, 2014 (~11:00 AM – 12:50 PM)

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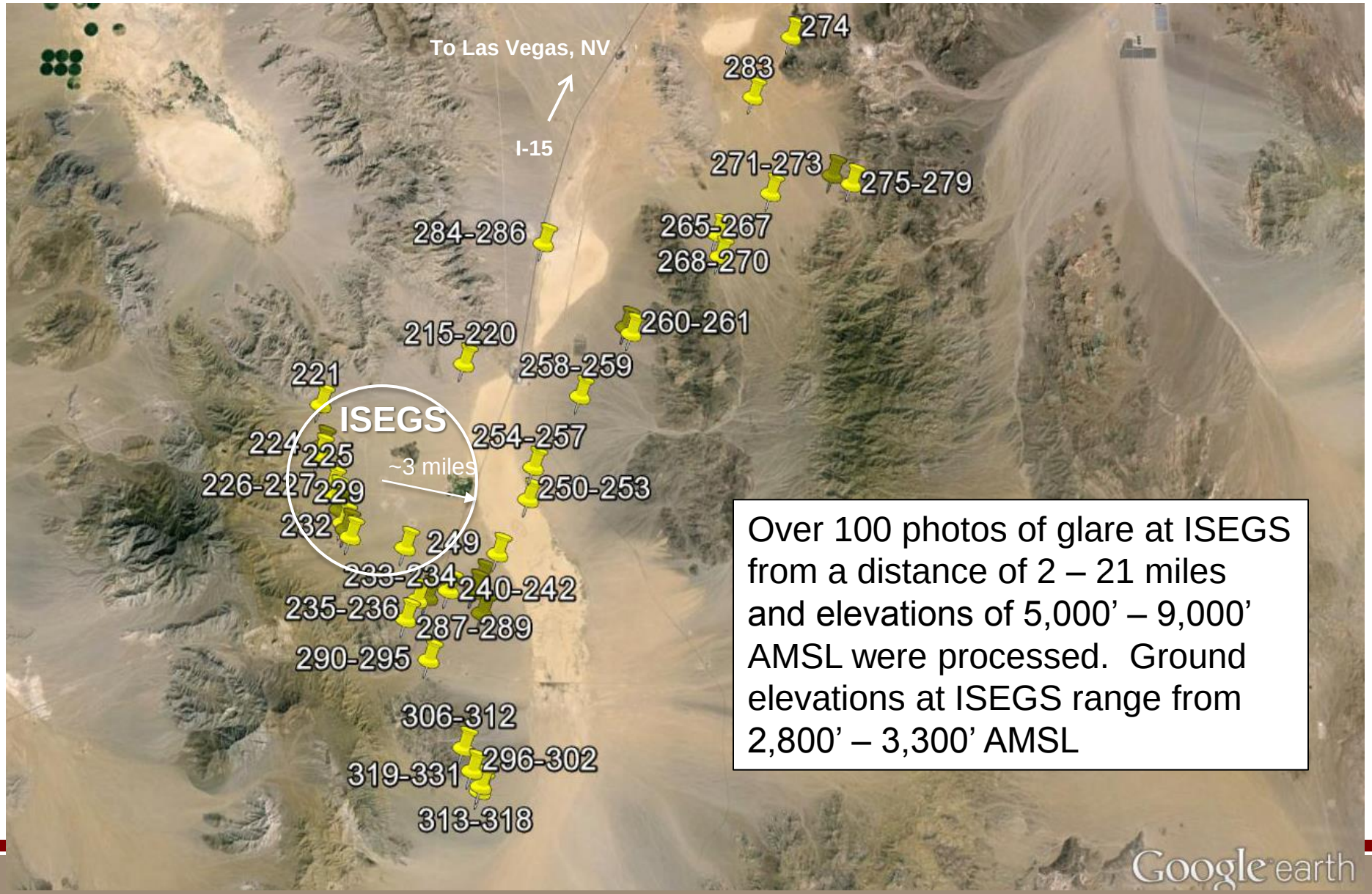


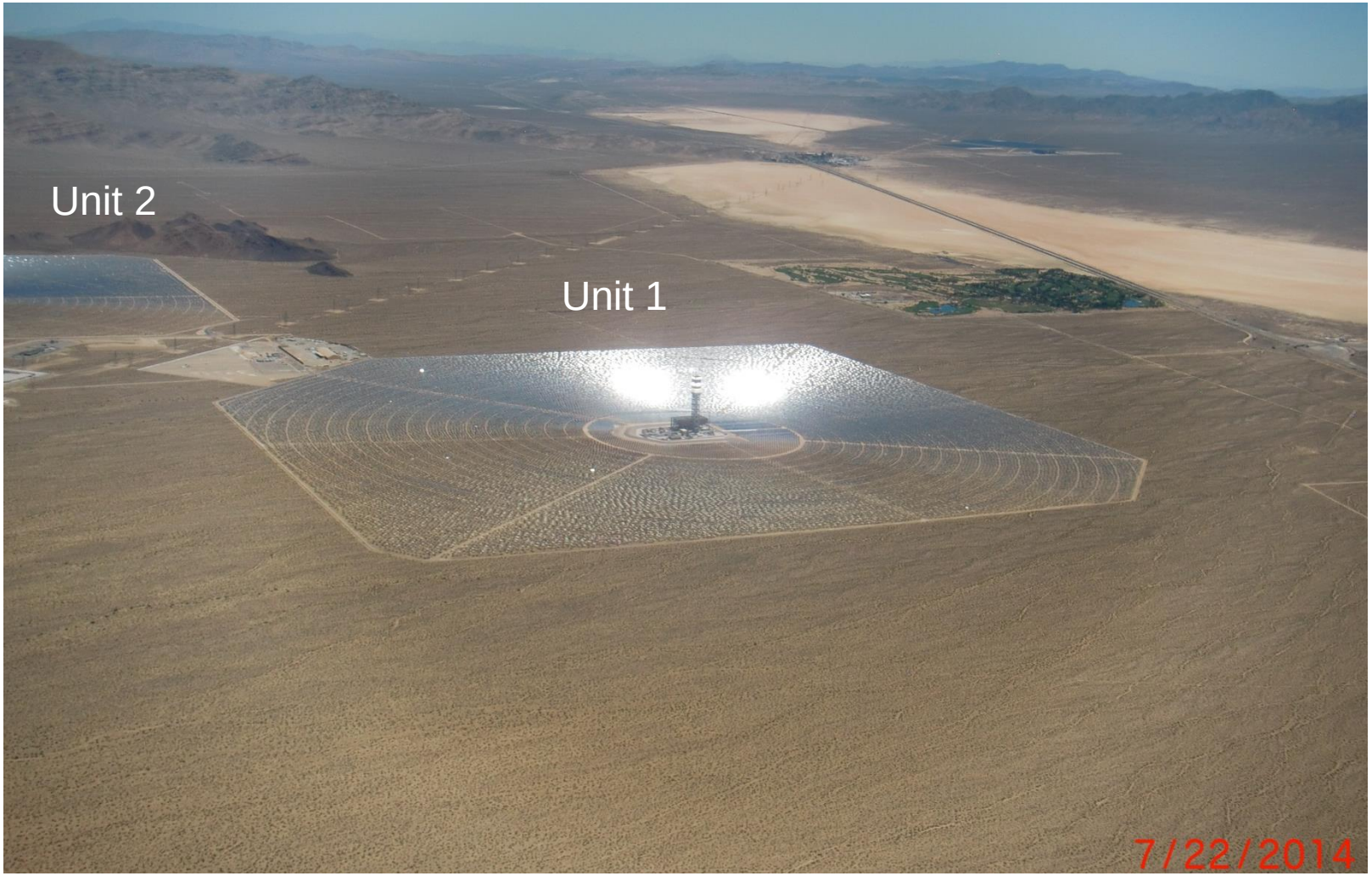
Over 100 photos of glare at ISEGS from a distance of 2 – 21 miles and elevations of 5,000' – 9,000' AMSL were processed. Ground elevations at ISEGS range from 2,800' – 3,300' AMSL

Aerial Glare Photographs

Looking Southeast, ~1 – 4 miles away
11:20 AM (PDT), July 22, 2014

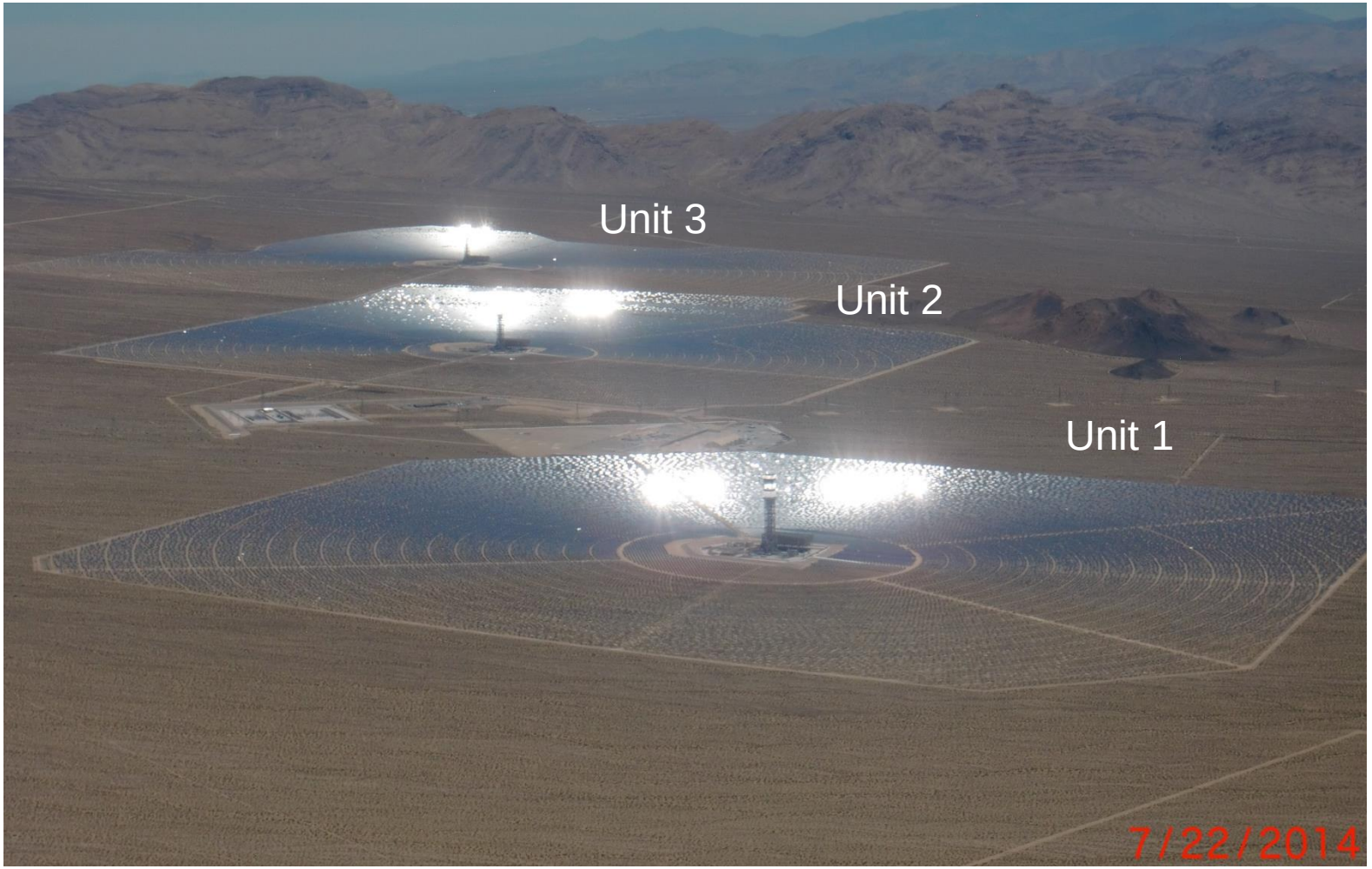
Aerial Glare Photographs

Looking Northeast, ~2 – 3 miles away
11:29 AM (PDT), July 22, 2014



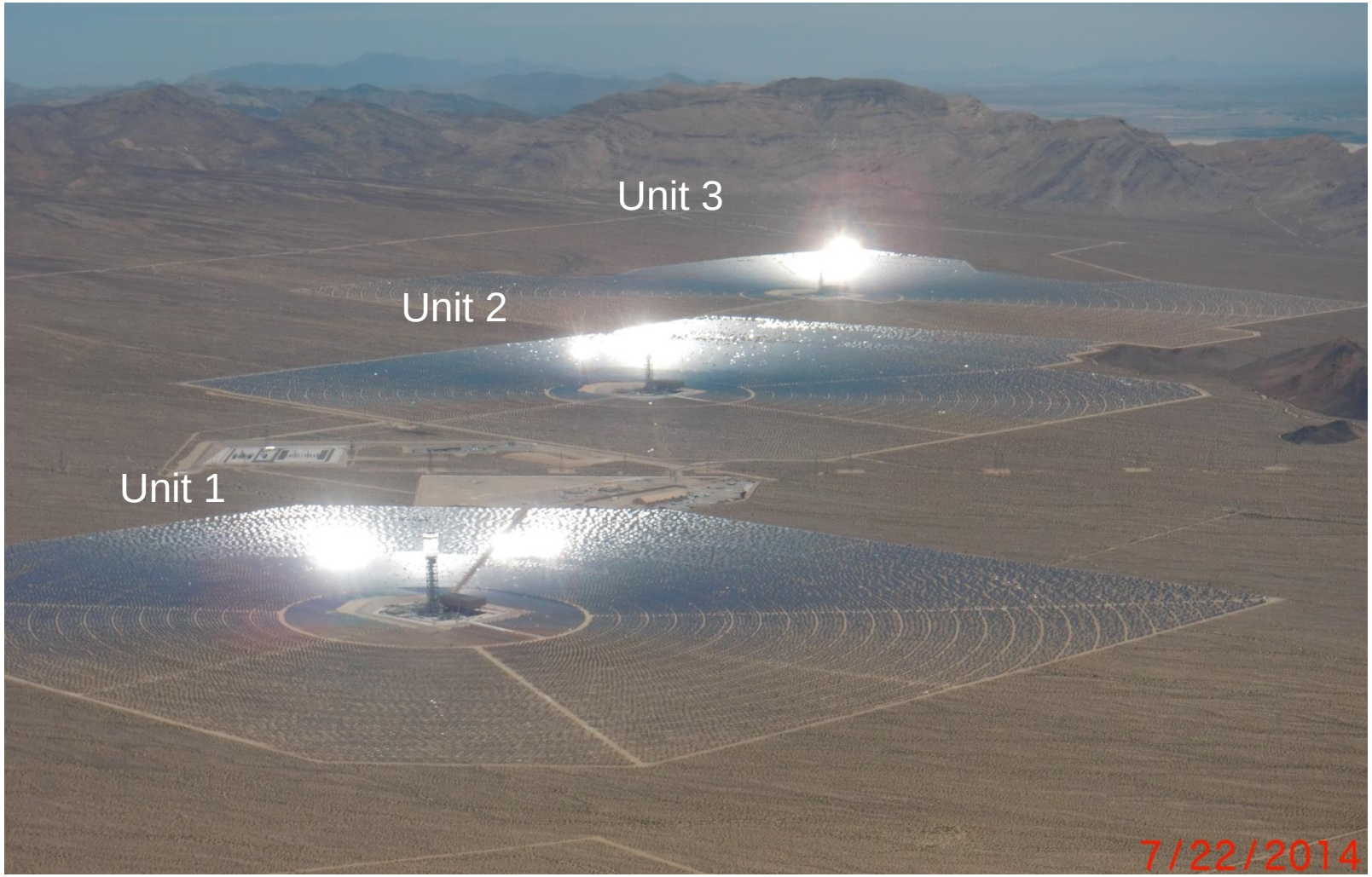
Aerial Glare Photographs

Looking North/Northwest, ~5 – 6 miles away
11:33 AM (PDT), July 22, 2014



Aerial Glare Photographs

Looking Northwest, ~3 – 5 miles away
11:38 AM (PDT), July 22, 2014



Aerial Glare Photographs

Looking West/Northwest, ~5 – 6 miles away
11:40 AM (PDT), July 22, 2014

Aerial Glare Photographs

Looking West/Southwest, ~7 – 8 miles away
11:48 AM (PDT), July 22, 2014

Aerial Glare Photographs

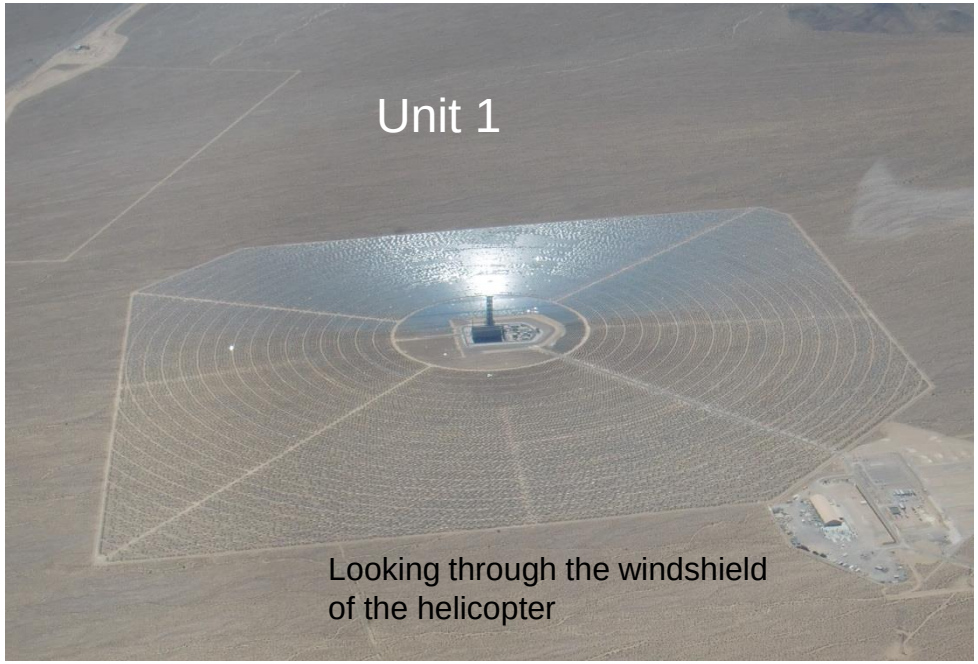
Looking Southwest, ~16 – 17 miles away
12:00 PM (PDT), July 22, 2014

Aerial Glare Photographs

Looking South/Southwest, ~9 – 10 miles away
12:17 PM (PDT), July 22, 2014

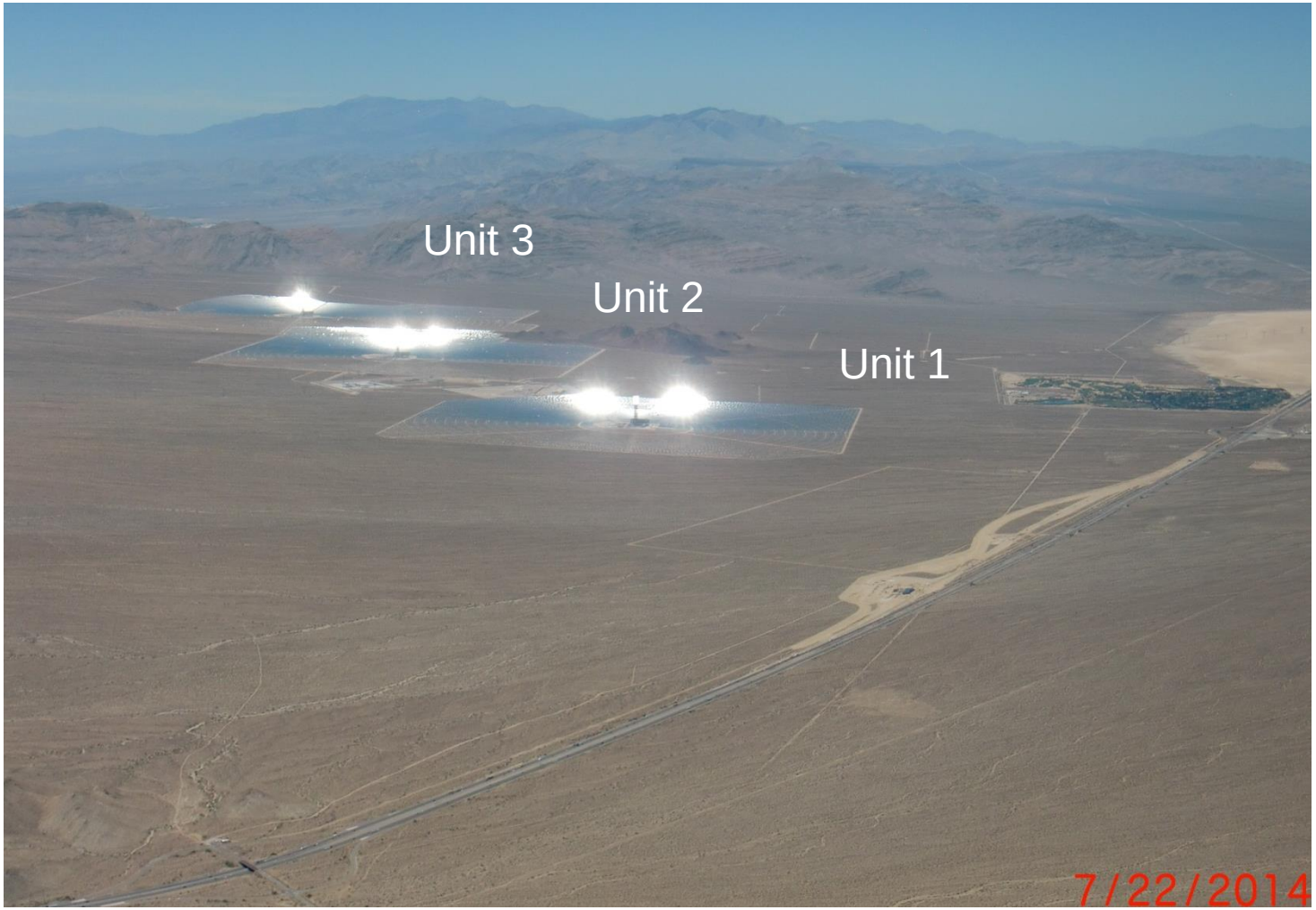
Aerial Glare Photographs

Looking South, ~1 – 2 miles away
12:21 PM (PDT), July 22, 2014



Aerial Glare Photographs

Looking North/Northwest, ~6 – 9 miles away
12:31 PM (PDT), July 22, 2014



Aerial Glare Photographs

Looking North/Northwest, ~7 – 10 miles away
12:40 PM (PDT), July 22, 2014

Unit 1 – Looking North/Northwest ~3 – 4 miles away

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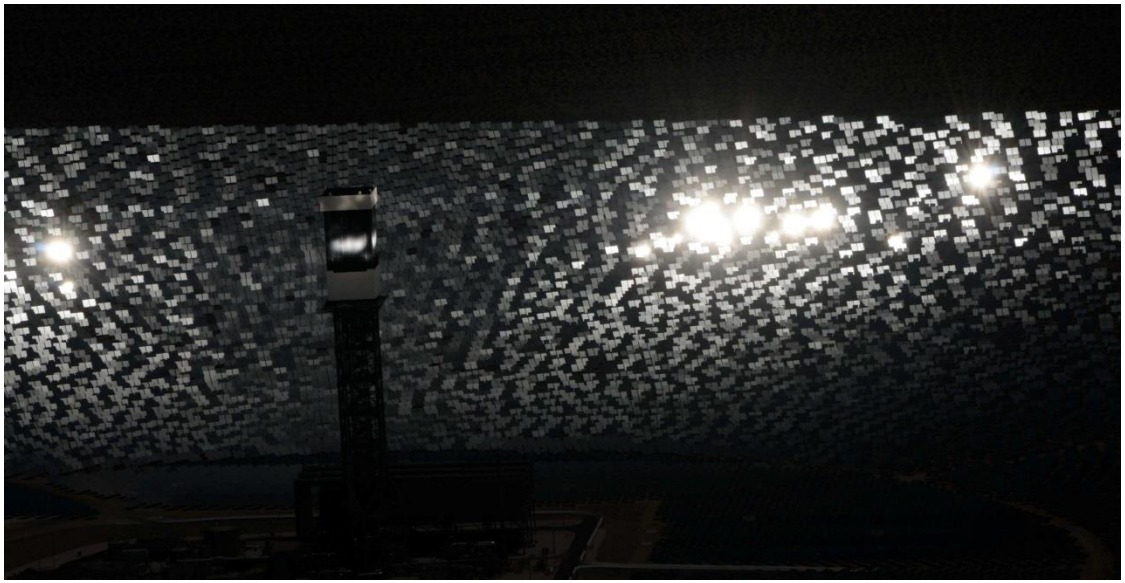
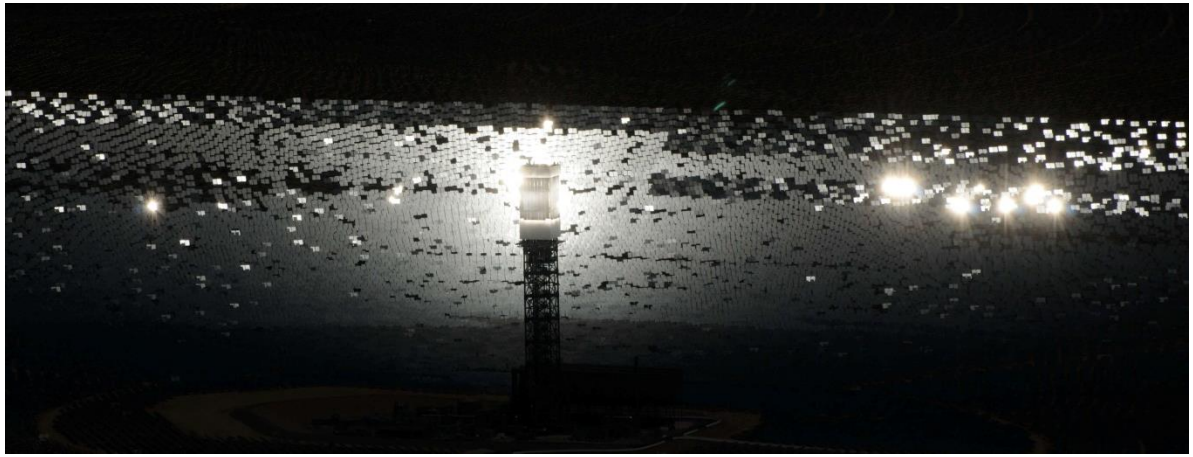


~11:31 AM (PDT)

DSC237 (no filters),
1/3200s – f/32
Brightest points are saturated

DSC235 (~60X filtering),
1/3200s – f/32
No saturation

Unit 2 – Looking North/Northwest ~5 miles away



~11:30 AM (PDT)

DSC238 (no filters),
1/3200s – f/32
Brightest points are saturated

DSC236 (~60X filtering),
1/3200s – f/32
No saturation

Unit 3 – Looking North/Northwest, ~7 miles away

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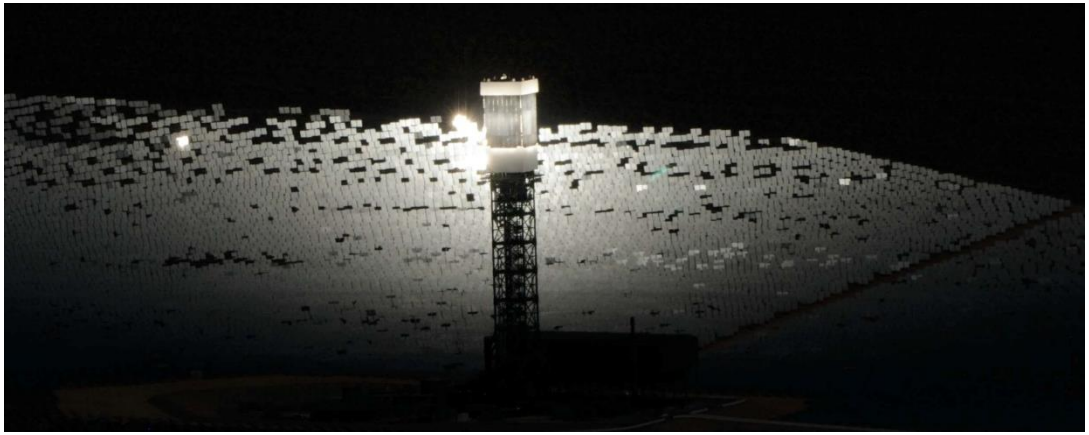
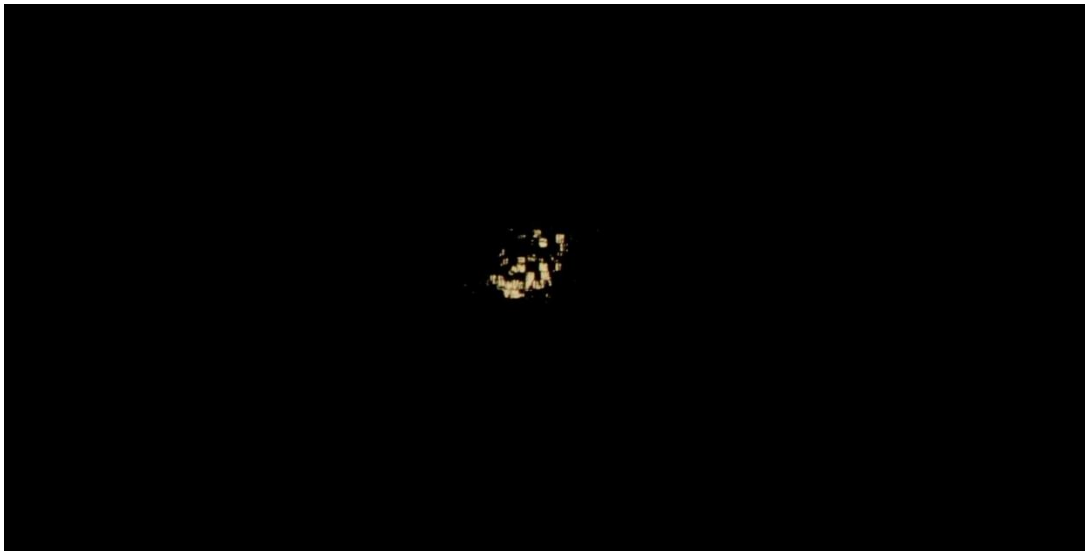


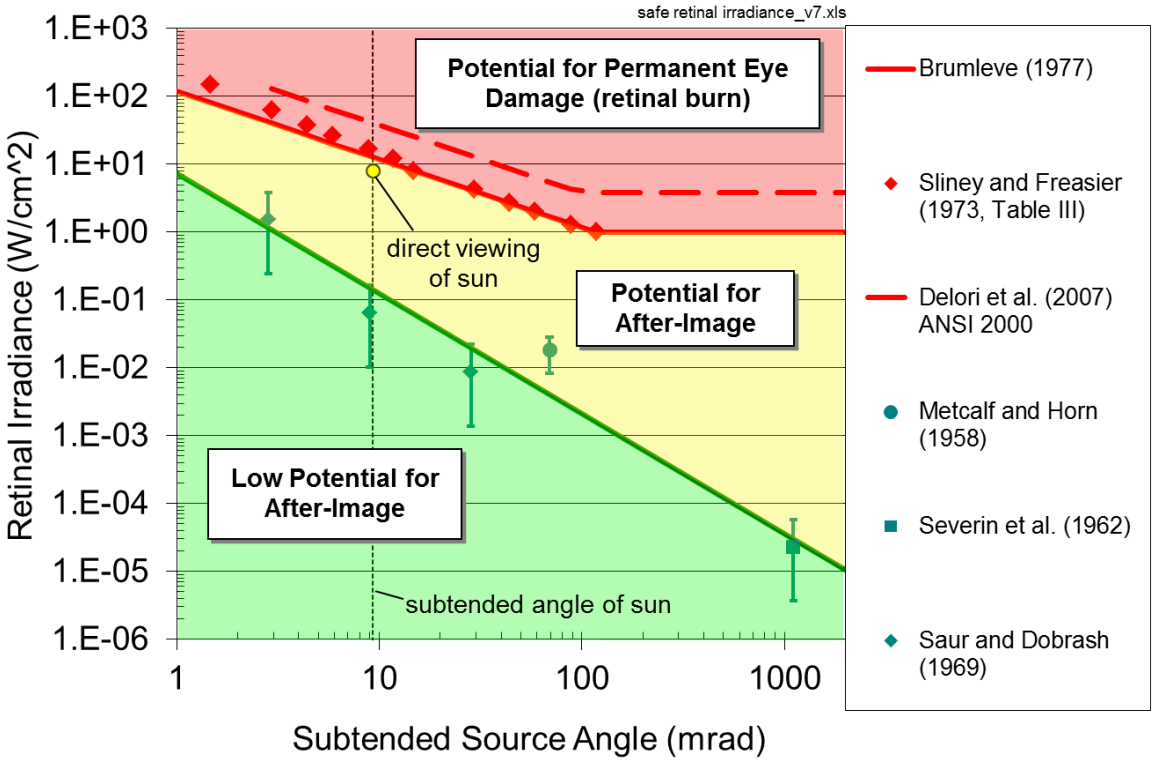
~11:32 AM (PDT)
DSC239 (no filters), 1/3200s – f/32
Brightest points are saturated



~11:38 AM (PDT)
DSC246 (~4096X filter), 1/3200s – f/32
No saturation

Ocular Hazard Analysis

- Use image of sun and DNI to scale irradiance and subtended angle of glare from heliostats



From Ho et. al (2011)

Ocular Hazard Analysis

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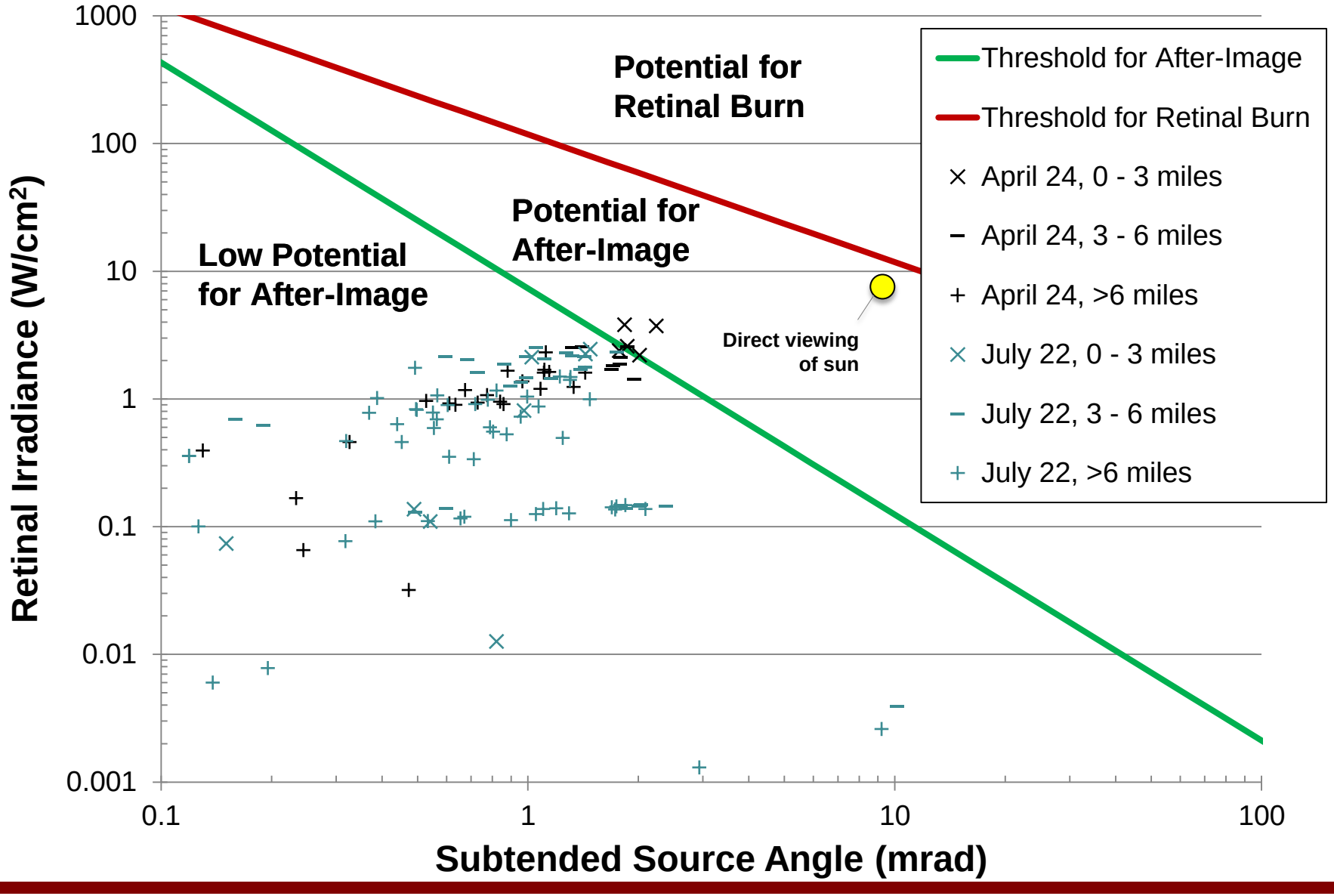
Sampling from over 100 glare images

Image	DNI (W/m^2)	Tower Unit	Approximate Distance to Glare Source (miles)	Average Retinal Irradiance (W/cm^2)	Total Subtended Glare Angle (mrad)	Ocular Impact
DSC 0233	1000	1	1.9	2.118	1.024	Low Potential for After-Image
DSC 0221	1000	3	2.4	0.810	0.976	Low Potential for After-Image
DSC 0224	1000	2	2.8	0.137	0.489	Low Potential for After-Image
DSC 0229	1000	1	3	1.766	1.428	Low Potential for After-Image
DSC 0250	1000	1	4.2	2.518	1.054	Low Potential for After-Image
DSC 0218	1000	3	4.5	2.037	0.685	Low Potential for After-Image
DSC 0240	1000	2	5.2	1.450	1.158	Low Potential for After-Image
DSC 0304	1000	2	6.5	0.985	0.777	Low Potential for After-Image
DSC 0252	1000	3	6.6	1.751	0.492	Low Potential for After-Image
DSC 0258	1000	1	7.2	1.493	1.221	Low Potential for After-Image
DSC 0289	1000	3	7.3	0.139	1.195	Low Potential for After-Image
DSC 0291	1000	2	7.3	0.137	1.101	Low Potential for After-Image
DSC 0305	1000	3	8.1	0.634	0.440	Low Potential for After-Image
DSC 0306	1000	1	8.7	0.137	2.092	Low Potential for After-Image
DSC 0285	1000	2	9.7	0.553	0.803	Low Potential for After-Image
DSC 0260	1000	1	9.9	0.821	0.498	Low Potential for After-Image
DSC 0264	1000	3	10	1.013	0.388	Low Potential for After-Image
DSC 0265	1000	1	14	0.590	0.554	Low Potential for After-Image
DSC 0271	1000	3	16.8	0.119	0.671	Low Potential for After-Image
DSC 0272	1000	1	16.9	0.110	0.384	Low Potential for After-Image
DSC 0282	1000	2	18.9	0.357	0.119	Low Potential for After-Image
DSC 0280	1000	3	19	0.467	0.320	Low Potential for After-Image
DSC 0274	1000	3	21	0.110	0.534	Low Potential for After-Image

Ocular Hazard Analysis



Summary of Glare Monitoring

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- New heliostat standby aiming strategies were implemented for Units 1 and 2 (“Option 3”)
  - Unit 3 was unchanged (“Option 1”)
- Flyover on July 22, 2014, showed that the points of glare from Units 1 and 2 were more spread out than Unit 3
- Ocular hazard analysis showed “low potential for after-image” for all photos of Units 1, 2, and 3
  - However, I thought that the glare was still bright enough to cause complaints
  - Time of day for July 22 flyover was later (close to noon) than April 24 survey, which was ~9 AM (PDT)
- Need to consider additional standby aiming strategies and protocols

Overview

Sandia National Laboratories

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- Next Steps

Next Steps

- Hold meeting with CEC, NRG, Brightsource, Sandia, and other stakeholders to review results and discuss path forward
  - New standby aiming strategies?
  - New standby procedures?
    - Number of heliostats in standby has been reduced (<10,000 per unit)
    - No longer bringing 100% of heliostats to standby during startup
  - Possibility of glare shields?
  - Reduce number of heliostats in standby on the same side as the sun
- Implement new aiming strategies
  - Perform additional flyovers to characterize impact
- Identify optimal solution
  - Revise Heliostat Positioning Plan for review and approval