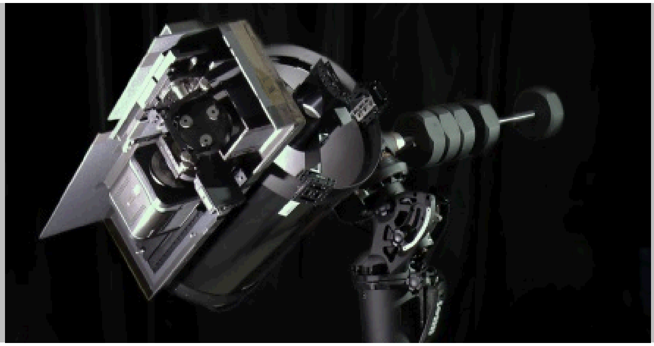
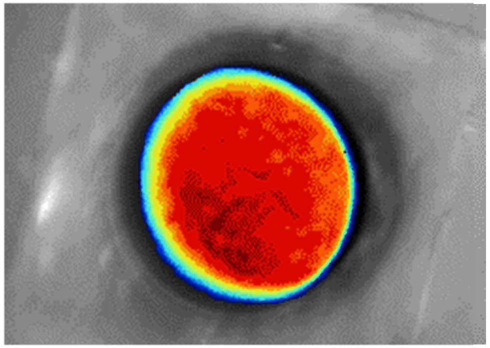
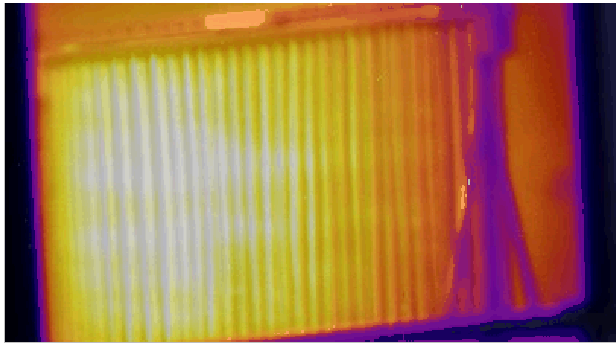
SAND2016-3752C

Exceptional service in the national interest

Sandia National Laboratories







Using Optical Nitrogen Fluorescence to Detect and Characterize Ionizing Radiation in the Atmosphere

Dr. Jeffrey B. Martin,
R.K. Harrison, J. Choi, J.A. Gariano,
D.K. Wiemann and E.G. Winrow

Sandia National Laboratories

4/28/2016

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Optical Detection of Radiation Overview

- Optical radiation imaging correlates UV photons from ionized nitrogen with radiation dose in air

- This same phenomenon
  - Is used in ultrahigh energy cosmic ray astronomy
  - Creates the aurora
  - And is the source of “Teller Light” from an atmospheric nuclear detonation

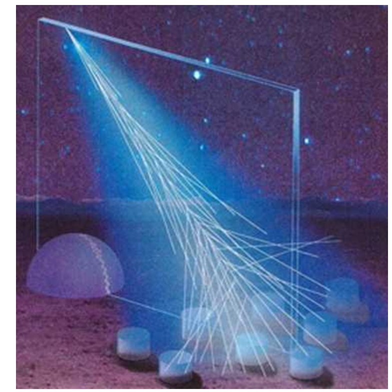
- This effect provides a powerful technique
  - For long-range detection far beyond the range of primary radiation
  - And characterizing spatial distribution of radiation dose in air

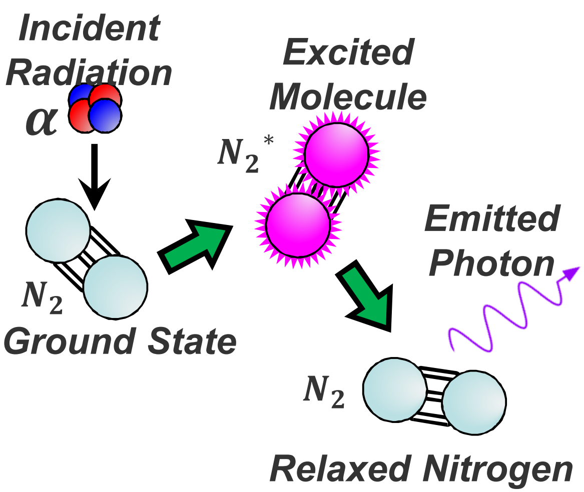
- Radiation imaging has been demonstrated indoors and outdoors with charged and neutral particles

Phenomenology of Optical Radiation Detection

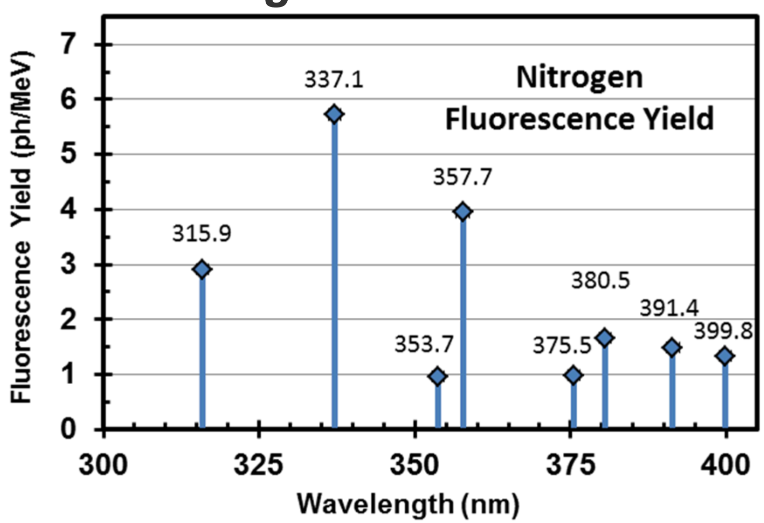
- Ionizing radiation interacting with nitrogen generates excited molecular states.
- These molecules can de-excite through emission of UV photons at characteristic wavelengths

Pierre Auger Observatory



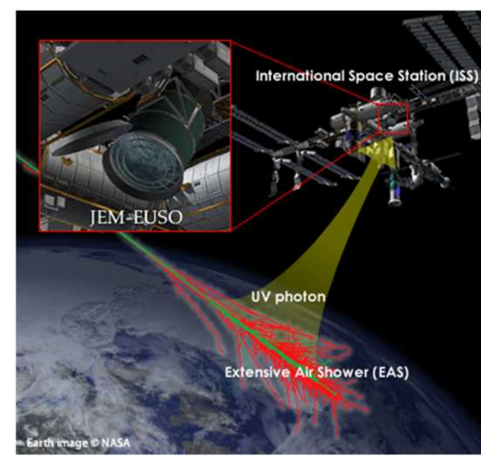


Nitrogen Emission Lines



~17 photons per MeV deposited

JEM-EUSO Mission



Nitrogen Fluorescence Can Be Source of Auroral Light

Auroral light is caused by

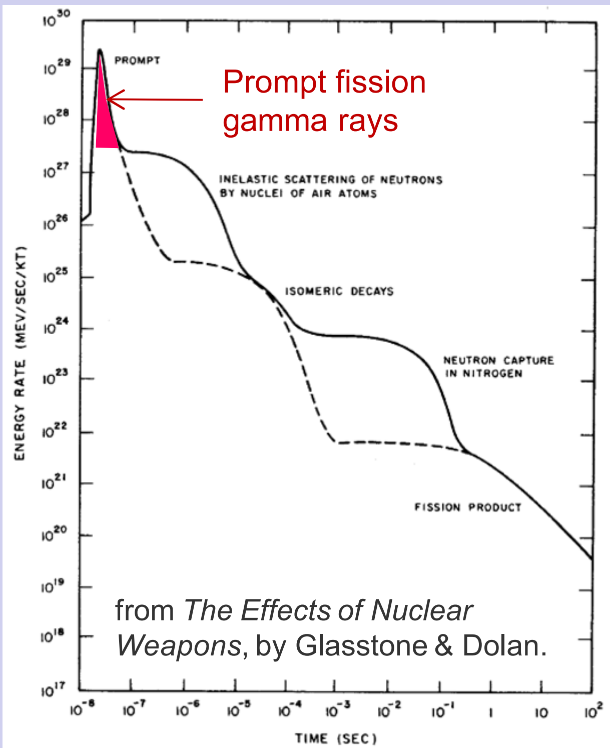
- Collisions between energetic charged particles from the sun
- And gaseous molecules in the Earth's atmosphere

Aurora colors

- The most common green color is produced by oxygen molecules located at about 60 miles altitude
- Nitrogen produces blue or purple auroral light

Teller Light Generation from a Nuclear Detonation

Gamma rays emitted from nuclear detonation



Calculated time dependence of the gamma-ray energy output per kiloton energy yield from a hypothetical nuclear explosion. Dashed line refers to explosion at very high altitude.

Initial gamma ray radiation is

- Unique to a nuclear detonation in the atmosphere
- Creates enormous radiation dose fields
- And can be provide information about the detonation fissions, because
  - A fraction of the gamma rays are promptly emitted in the fission reaction
- Gammas generate Compton scatter electrons which ionize and excite nitrogen molecules
  - Excited nitrogen molecules fluoresce
  - ic

Optical Detection of Ionizing Radiation

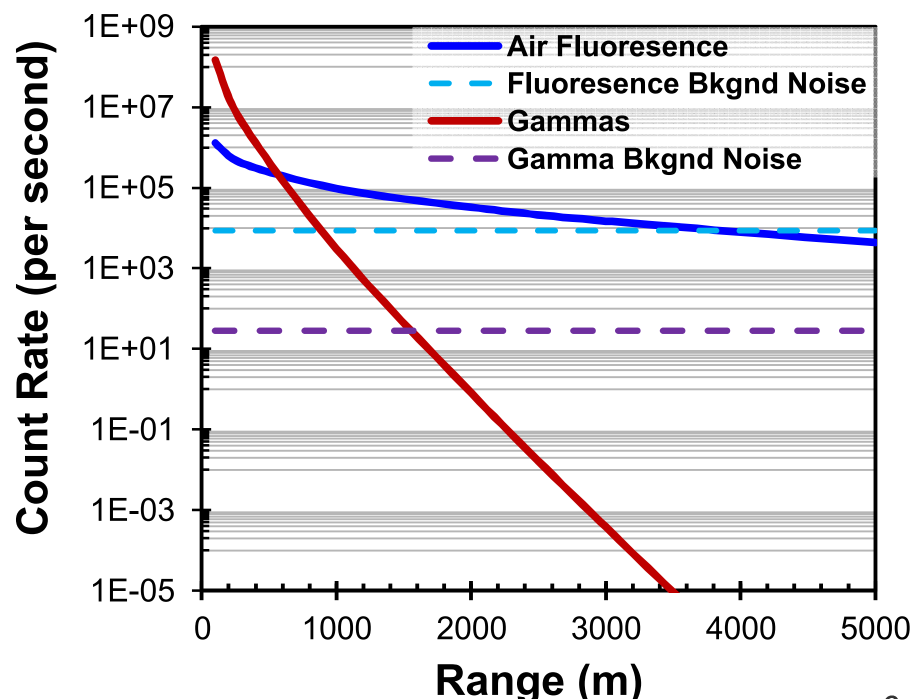
Sandia National Laboratories

- Ionizing radiation is rapidly attenuated in the atmosphere, limiting remote detection.
- Ionizing radiation interacting with the air also causes near-UV nitrogen fluorescence.
- UV signal can be remotely observed with UV-optical telescopes to detect radiation

Radiation	Air Attenuation Length (m)
Alpha	0.05
Beta	5
Neutron	50
Gamma	150
UV Photons	2500*

*MODTRAN Calculation

Est. count rate from 100 Ci Co-60 source in 1-m dia. optical detector and 1-m dia. gamma-ray detector



Potential Applications

- **Optical detection of radiation has several key advantages over conventional detection methods**
  - Long distance remote detection possible
  - Inherently direction sensitive
  - Can detect radiation without receiving dose
  - Does not require direct line-of-sight to radiation source

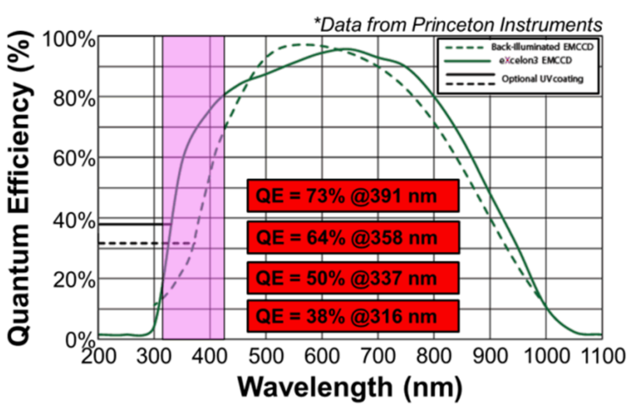
- **These advantages could enable new capabilities for nuclear forensics and related missions**
  - Improve searching speed for radiation dispersal devices
  - More rapid collection for post-det. plume or fallout
  - Reduce dose to personnel by identifying high radiation regions
  - Assist in test ban treaty monitoring with remote surveillance

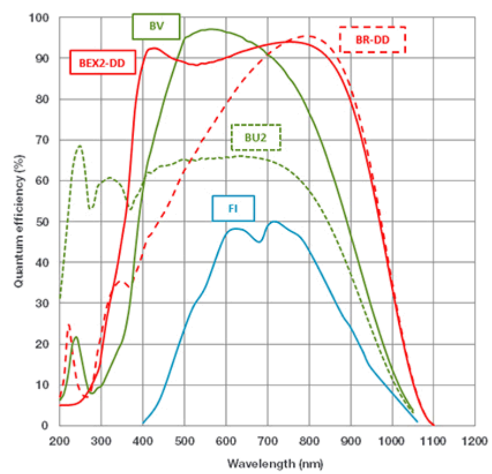
Optical Rad. Detection: Why Now?

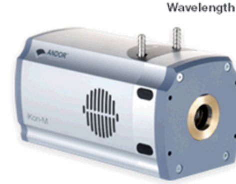
Sandia National Laboratories

- Recent game-changing improvements in CCD technology have dramatically improved UV imaging sensitivity
  - Back-illumination geometry has enabled UV QEs > 60%
  - Improvements in Peltier cooling reduces noise in the field
- Sandia has experience with satellites, optics, atmospheric transport and broad application perspective

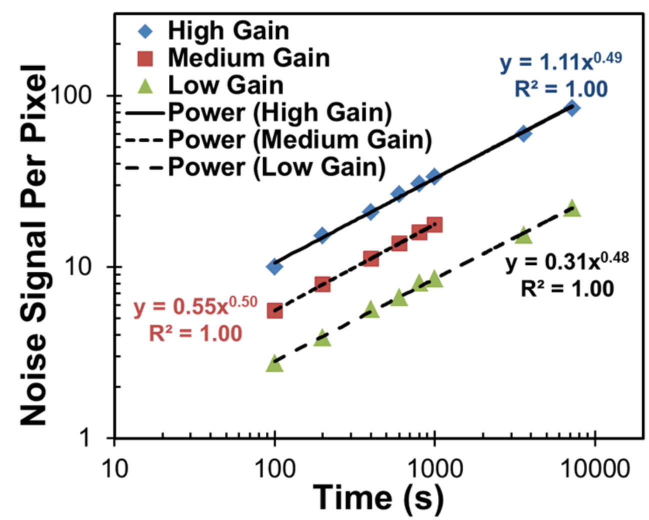
High UV Quantum Efficiency







Shot-Limited Noise

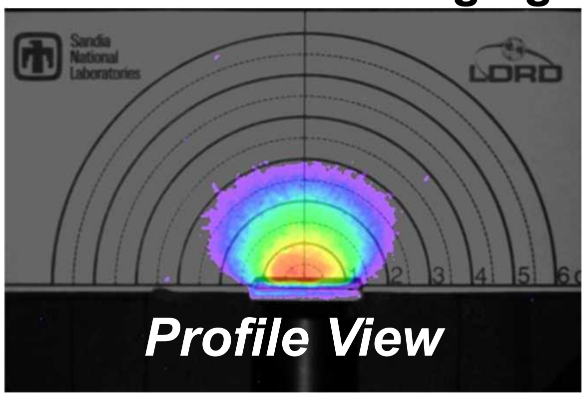


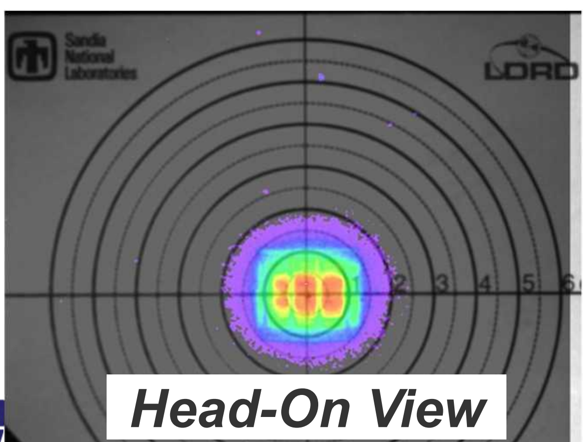
Optically Detecting Radiation from an Alpha Source

- UV photons were detected far beyond the dosed region
- Radiation range in air could be directly imaged
- UV emission highest where strongest radiations fields expected
- Dose rates, shielding and exposure time all affect radiation imaging

Radiation Field Imaging

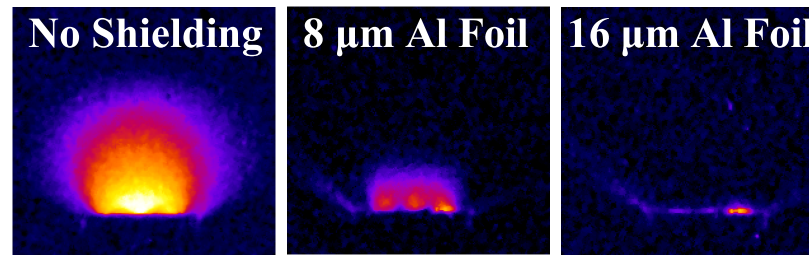
*Scale in cm



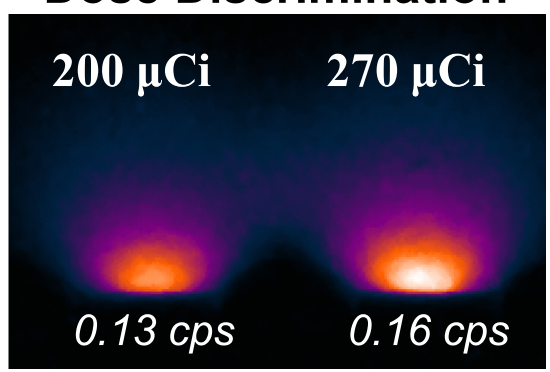


500 µCi Po-210

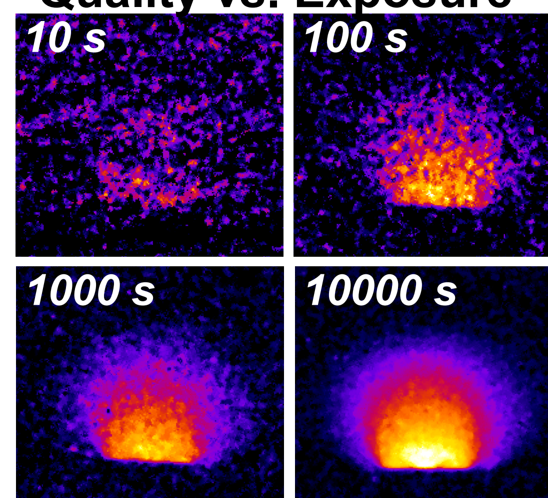
Effect of Shielding and Energy



Dose Discrimination



Quality vs. Exposure

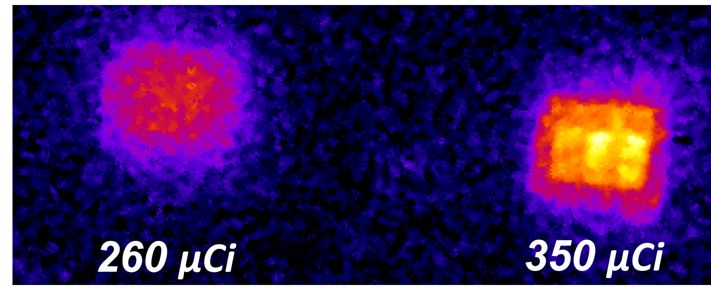


Optical Alpha Radiation Detection Outdoors

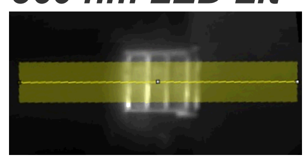
- Pathfinder system developed to evaluate optical detection possibilities
- Radiation imaged at 500× primary range at night with man-made background

Po-210 Alpha Source

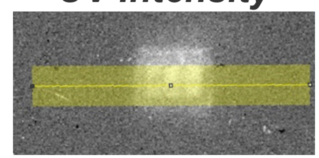
Head-On View



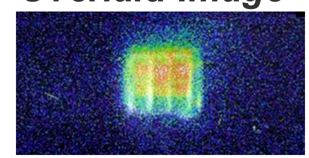
360 nm LED Lit



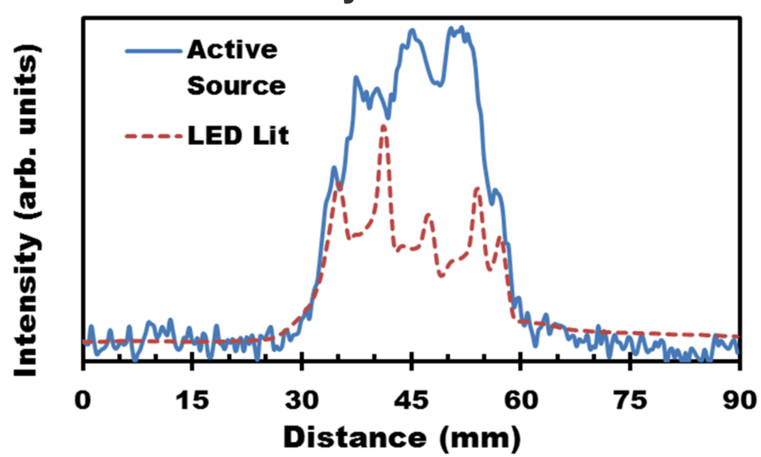
UV Intensity



Overlaid Image



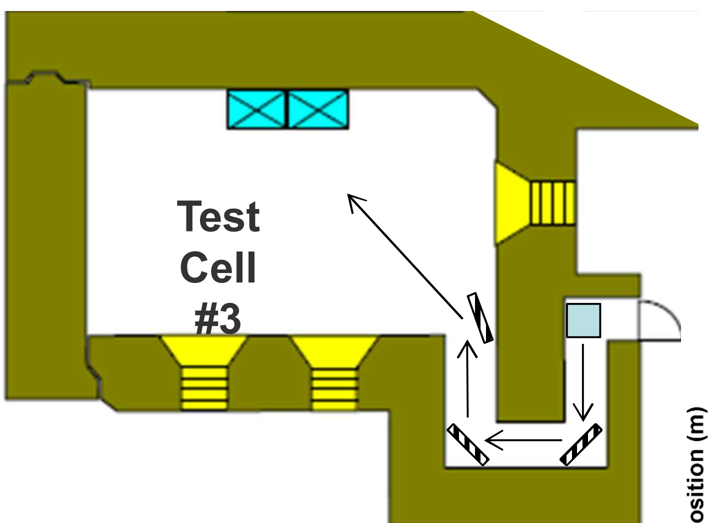
Profile of UV Intensity and LED Lit Structure

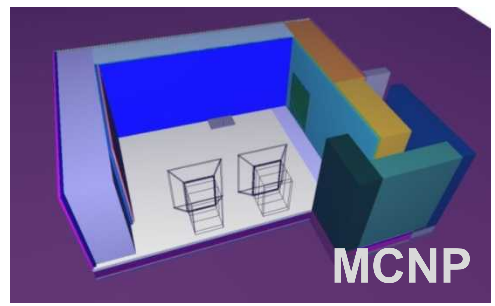


Optical Gamma Radiation Detection Indoors: Planning and Set-up

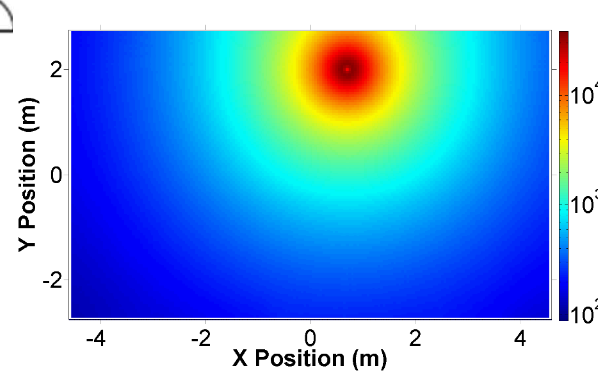
- Sandia's Co-60 Gamma Irradiation Facility was identified as a testing site for proposed gamma radiation imaging
- Test concept: limit radiation dose to camera using mirrors, multiple scatters, distance and shielding
- Image around corners to detect radiation fields near Co-60 linear array (223 kCi)
- Detect regions around pin to detect optical emission and dose rates

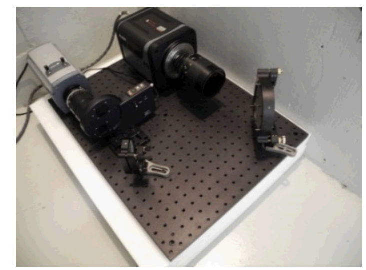
Test Layout





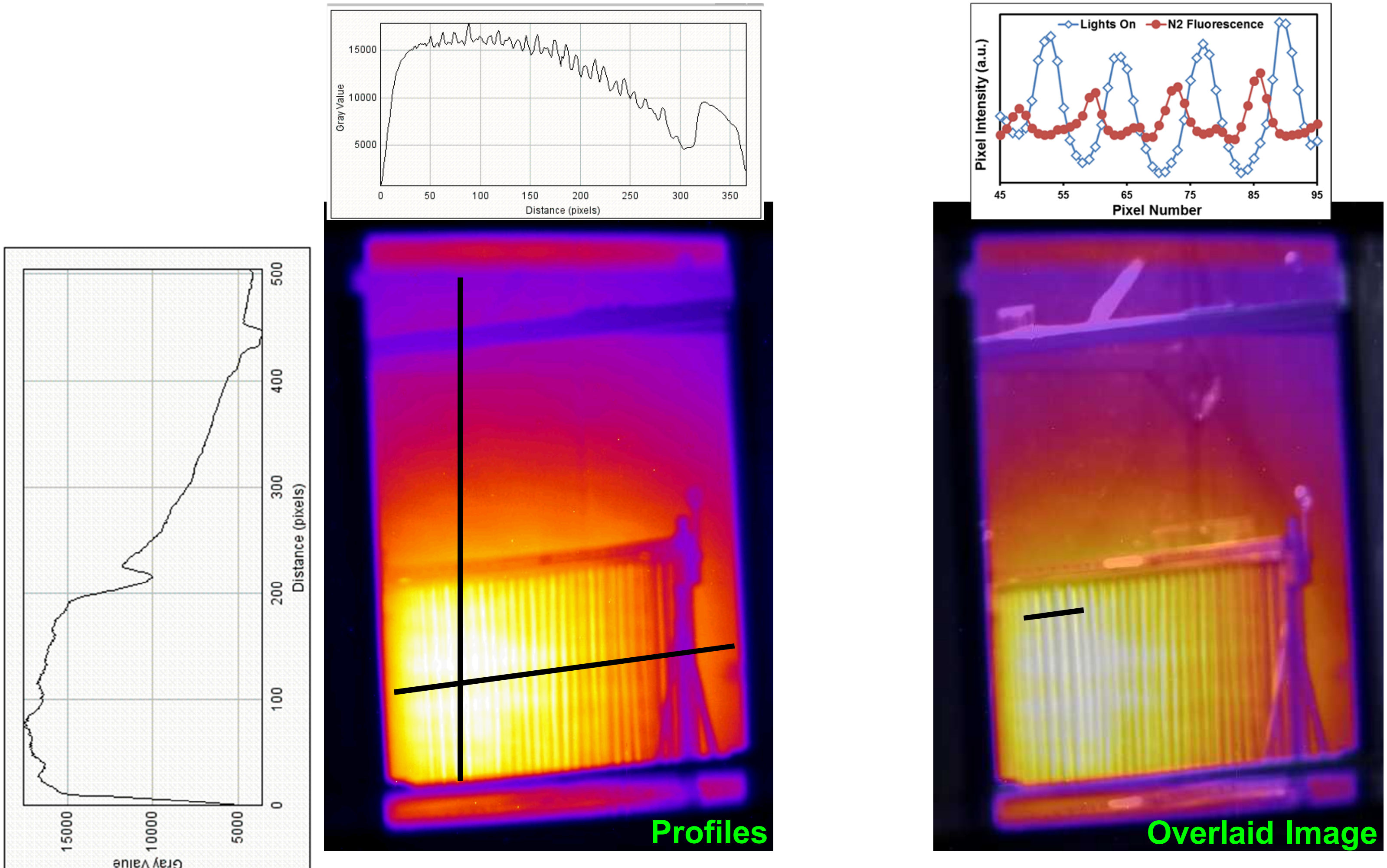
Predicted Dose Rates (rad/hr)





Optical Gamma Radiation Detection Indoors: Analyzed Results

- Light emission decays away from linear pin array with distance
- Overlaid image shows that detected signal is highest between the pins
  - Corresponds to longer optical path over which light is emitted

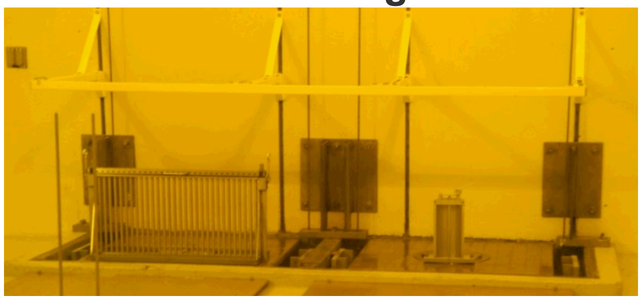


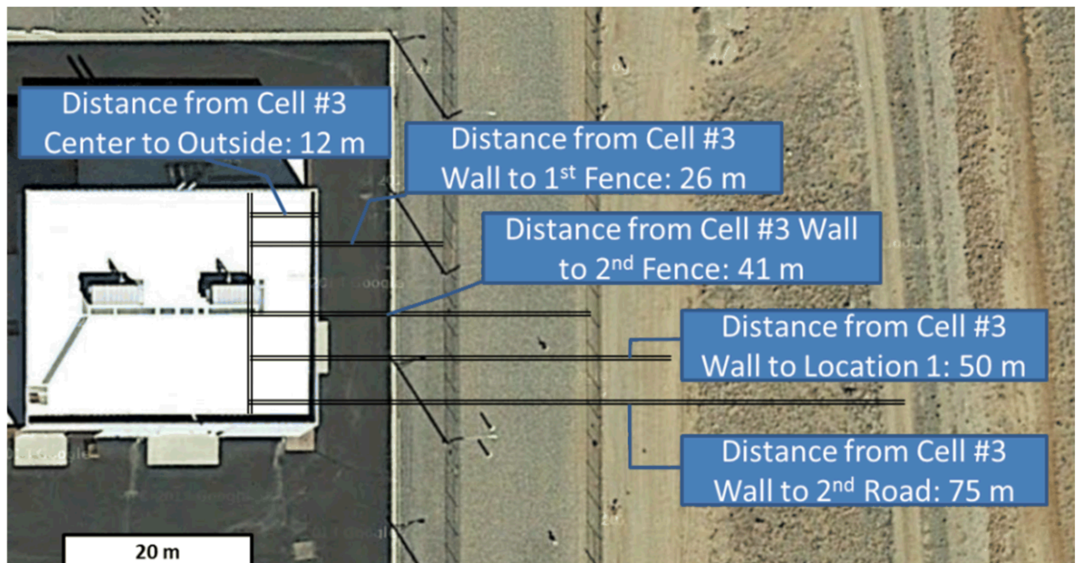
Optical Gamma Radiation Detection Outdoors: Set-up

Sandia National Laboratories

- Plan: Detect radiation from a low-dose remote location via optical path through ducts into high radiation region within the cell
- Goal: Demonstrate optical radiation detection for gammas in outdoor conditions

Images of Location, Source, Mobile Platform

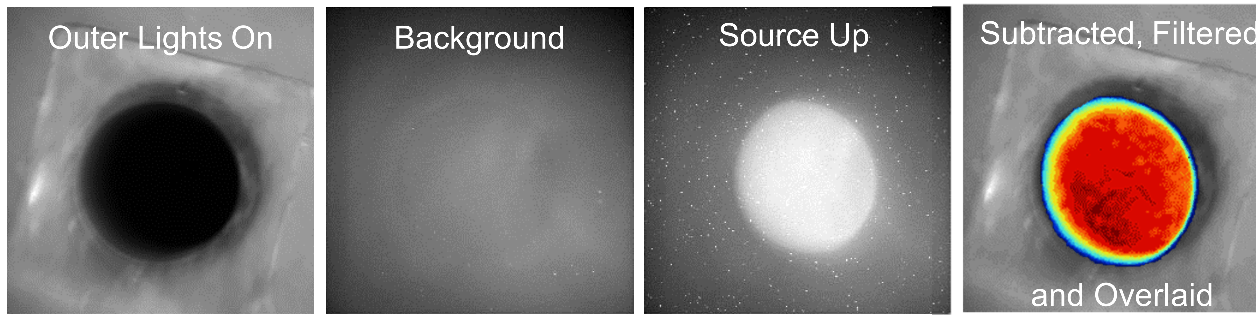


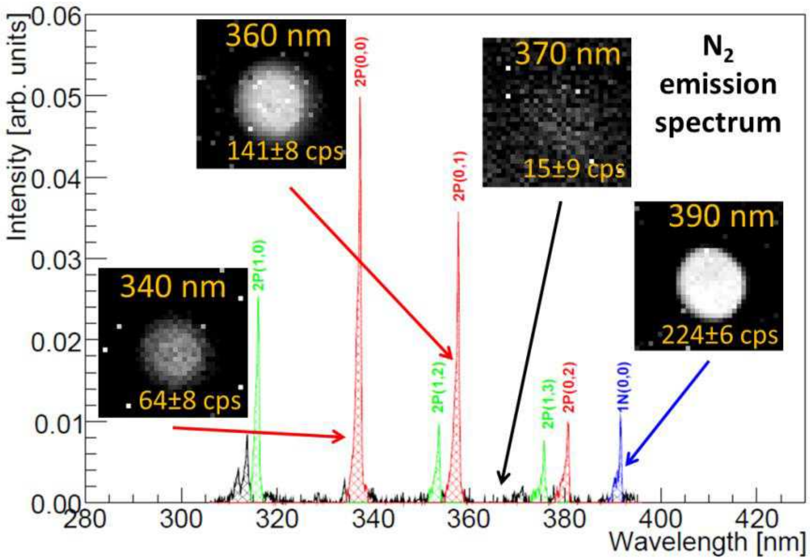


NNSA National Nuclear Security Administration

Optical Gamma Radiation Detection Outdoors: Initial Results

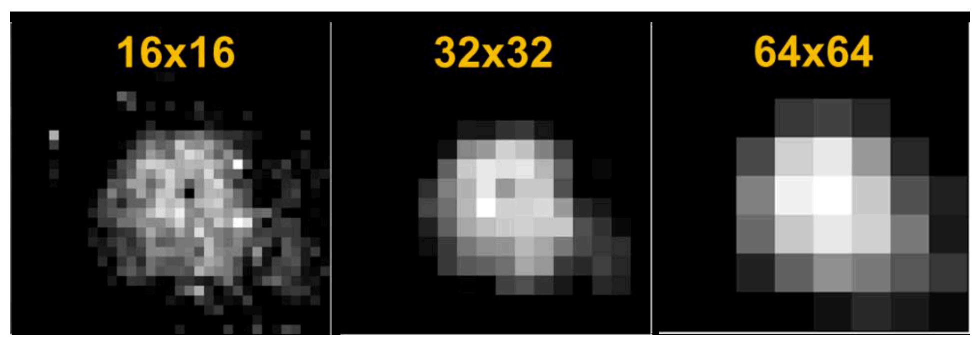
- Distance: 75 m
- Exposure Time: 1 hour
- Source Activity: 110 kCi
- Dose Rate (Cell): >10 krad/hr
- Dose Rate (Camera): <0.2 mrad/hr
- 14” Telescope Collection Area
- Filter = 390 ± 7.5 nm (>90% transmission)





Nitrogen spectrum with multispectral ODR images
Overlaid images from GIF with 110 kCi source on optical emission spectrum of nitrogen fluorescence

Optical radiation detection as a function of bin size in pixels
Image at left shows scene with outer lights on. Three right images show background-subtracted, thresholded and binned signals for 1 hr exposure with 150-Ci Co-60 pin from 75 m away



Optical Detection of Radiation Overview

- Optical radiation imaging correlates UV photons from ionized nitrogen with radiation dose in air

- This same phenomenon
  - Is used in ultrahigh energy cosmic ray astronomy
  - Creates the aurora
  - And is the source of "Teller Light" from an atmospheric nuclear detonation

- This effect provides a powerful technique
  - For long-range detection far beyond the range of primary radiation
  - And characterizing spatial distribution of radiation dose in air

- Radiation imaging has been demonstrated indoors and outdoors with charged and neutral particles