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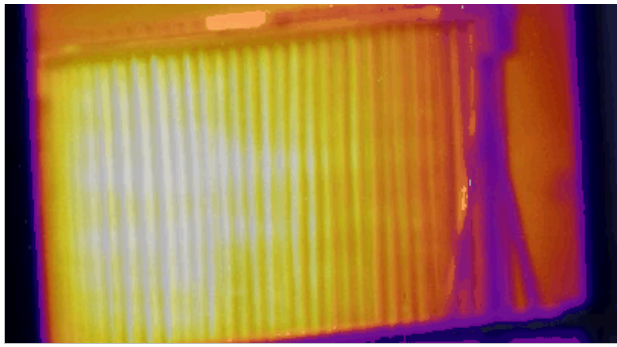

1) Post-Detonation Nuclear Forensics from Prompt Signatures and 2) Optical Detection of Radiation

Dr. Jeffrey B. Martin, Nuclear Forensics R&D Dept.

Sandia National Laboratories

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

2/19/2015

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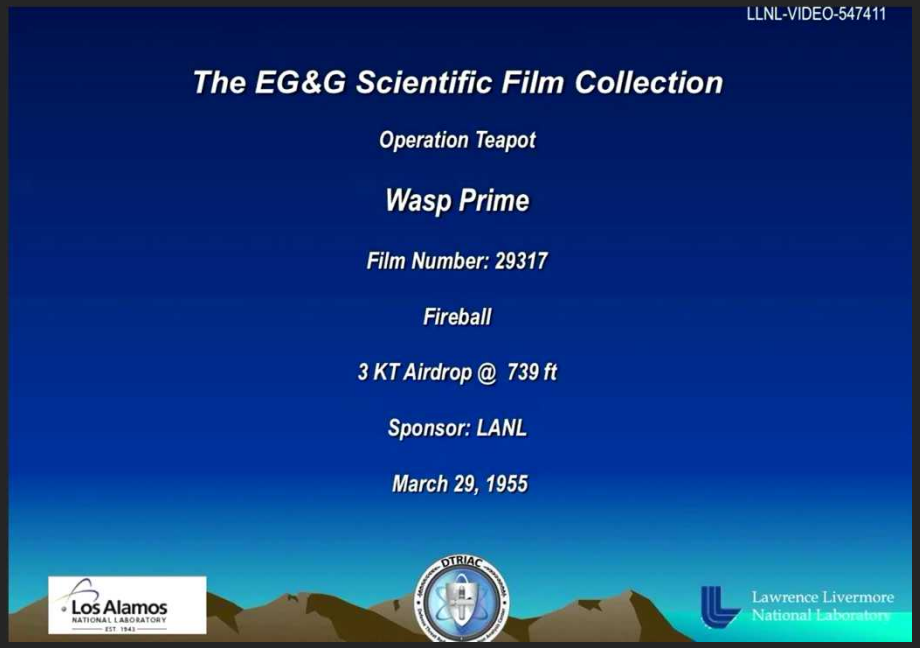
Above Ground Nuclear Test Films

Provide a Tutorial for Nuclear Forensics Signals and Signatures



Name		Yield	Height of burst		Scaled		
Test	Series	(kt)	(ft)	(m)	HOB (m)	Deployment	Date
Wasp Prime	Teapot	3	739	225	153	Airdrop	3/29/55
Climax	Upshot-Knothole	61	1334	407	103	Airdrop	6/4/53

The US conducted 1030 nuclear tests and
210 of them were above ground tests
like the two captured in these films

Fall out from nuclear surface detonation provides key information but is not prompt

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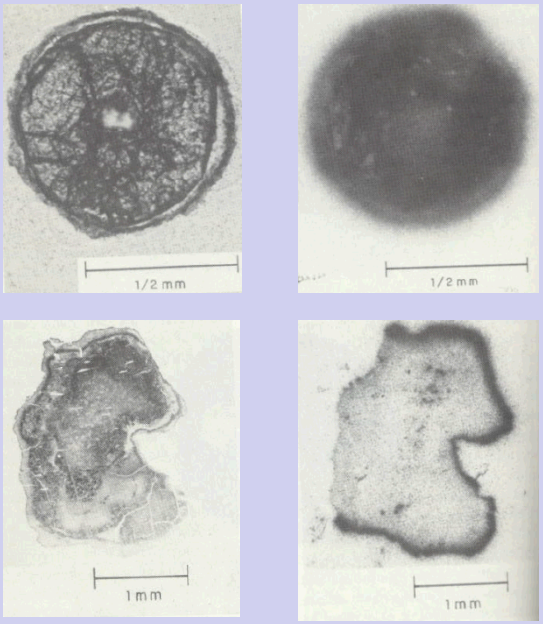
Fall out from nuclear surface detonation



Photographs (left) and autoradiographs (right) of fall out particles recovered from ground-surface shots in the Pacific from *The Effects of Nuclear Weapons* by Glasstone and Dolan.

Fall out

- Is unique to a nuclear detonation in the atmosphere
- Creates enormous radiation dose fields
- And can be provide information about the detonation, because
  - Short-lived man-made isotopes are created by fission in the nuclear detonation

Picture of International Monitoring System radionuclide station from Comprehensive Test Ban Treaty Organization (CTBTO) brochure

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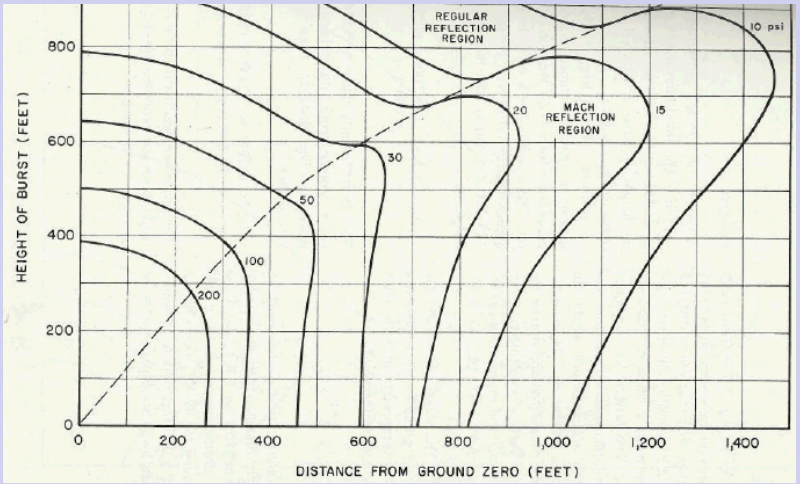
Overpressure pulse from nuclear detonation in the atmosphere

Overpressure created by nuclear detonation



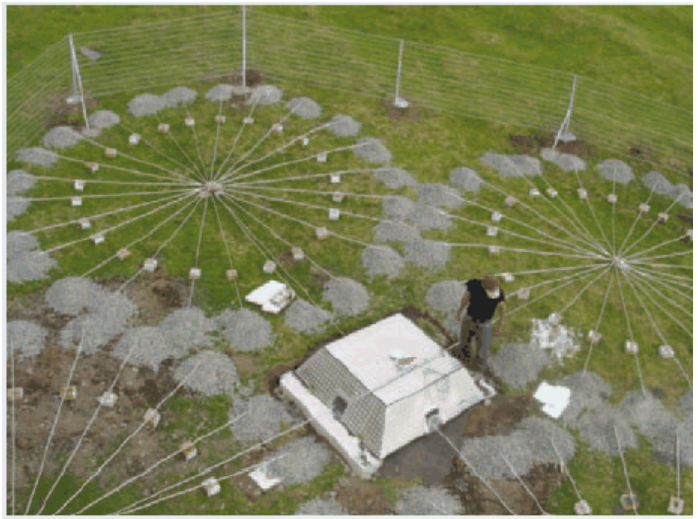
Peak over pressure on the ground for a 1-kiloton burst from *The Effects of Nuclear Weapons* by Glasstone and Dolan.

The overpressure at a given distance from ground zero scales with the third root of the yield, W, in kilotons (kt)

- $W^{1/3} = d/d_1$

Overpressure travels as an acoustic wave in the atmosphere

- Creating damaging shock waves
- And can provide information about the detonation, because
  - The amplitude and character of the acoustic waves are related to the yield
  - Both overpressure and infrasound



ARRAYS OF INFRASOUND STATION IS49, TRISTAN DA CUNHA, UNITED KINGDOM.

Picture of International Monitoring System infrasound sensor station from CTBTO brochure

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Seismic signals from nuclear surface detonation

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Seismic signals from surface-interacting nuclear detonation

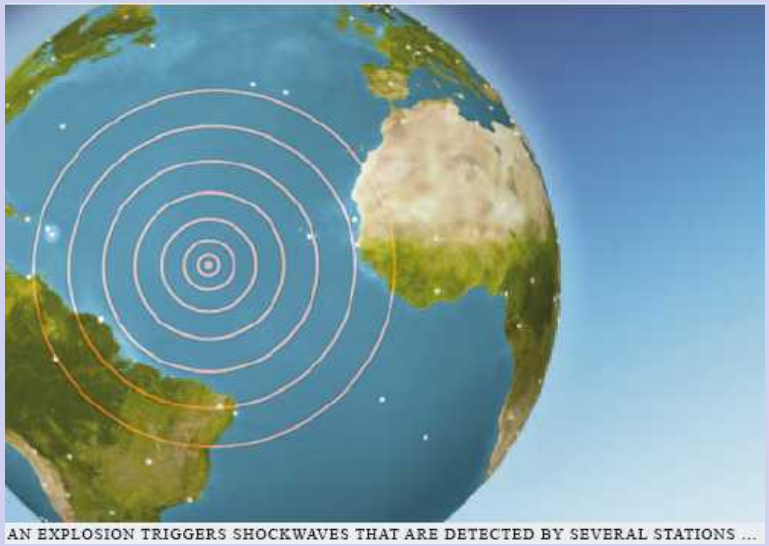

Illustration of seismic signals radiated by a detonation from CTBTO brochure

Seismic shock waves, like overpressure, travel as acoustic waves

- They can cause damage to building foundations and other underground structures and infrastructure
- And can provide information about the detonation, because
  - The character of the seismic waves is related to the yield of the device

Picture of International Monitoring System seismic sensor station from CTBTO brochure

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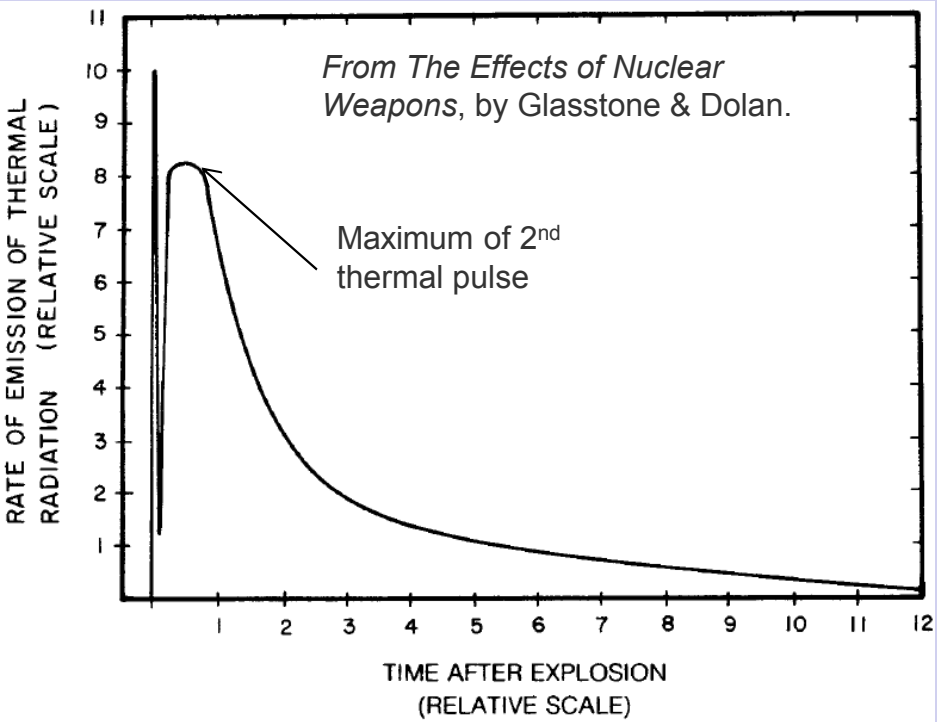
Emission of thermal energy from an atmospheric nuclear detonation



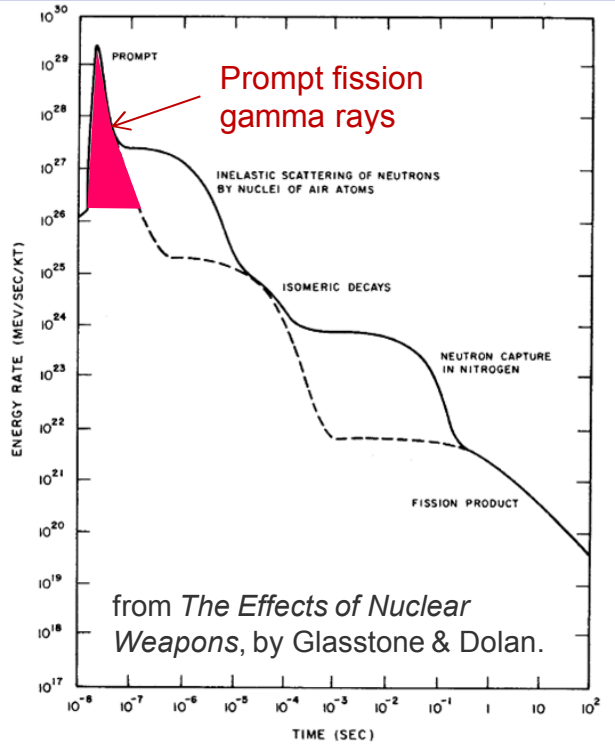
Thermal output of the fireball comes in two pulses, which

- Is unique to a nuclear detonation in the atmosphere
- Creates tremendous thermal damage via fire ignition and skin burns
- And is directly related to the yield, W (in kt), of the device

  - $P_{max} \approx 3.18\ W^{0.56}$ (kt/sec)
  - $t_{max} \approx 0.0417\ W^{0.44}$ (sec)

Initial nuclear radiation from an atmospheric 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

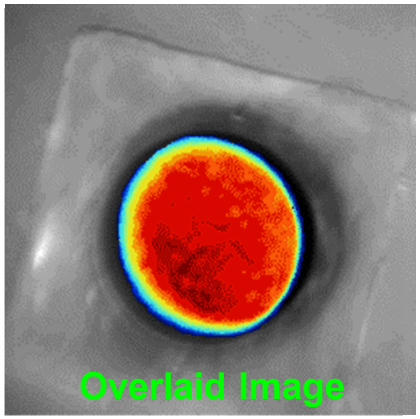
- Like the thermal pulse, unique to a nuclear detonation in the atmosphere
- Creates enormous radiation dose fields
- And can be provide information about the detonation fissions, because
  - A fraction of the gamma rays are promptly emitted in the fission reaction

Prompt post-detonation nuclear forensics summary

- A nuclear detonation creates and releases many types of energy which result in “nuclear weapons effects”
  - Examples we reviewed include: overpressure, ground shock, thermal and gamma radiation
- At longer ranges these effects can become measureable signatures and signals which can be used to characterize the detonation
- The CTBTO already uses several in its International Monitoring System
  - Infrasound and seismic signals are prompt signals that inform the IMS its role of characterizing nuclear detonations
- We see that thermal and gamma radiation also have useful properties for characterizing nuclear detonations

Optical Detection of Radiation

Dr. Jeffrey B. Martin
Dr. Richard K. Harrison
Sandia National Laboratories



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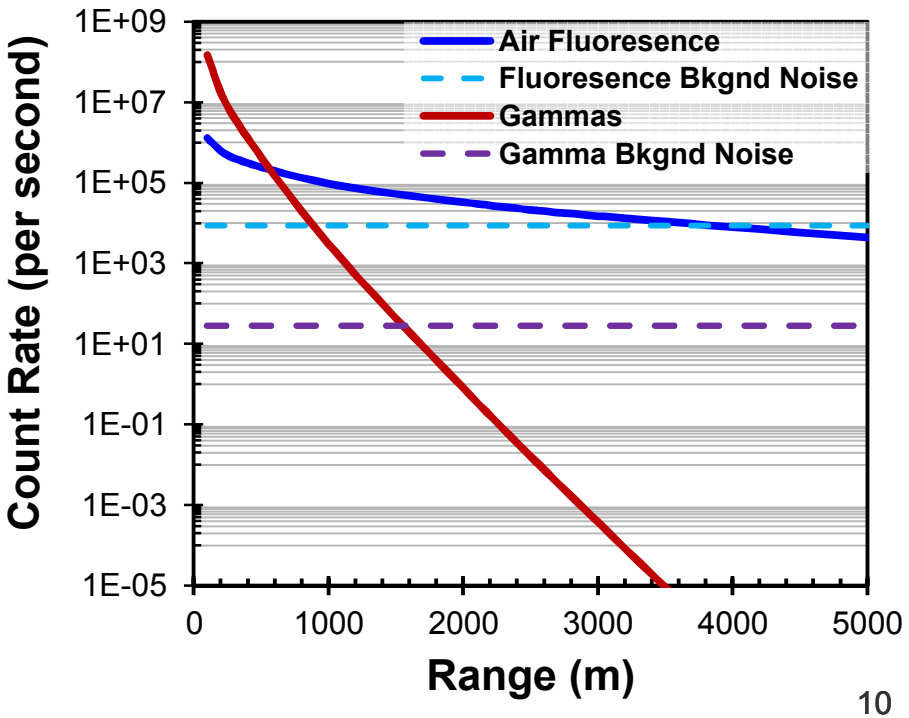
Optical Detection of Ionizing Radiation

- 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



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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

Phenomenology of Optical Radiation Detection

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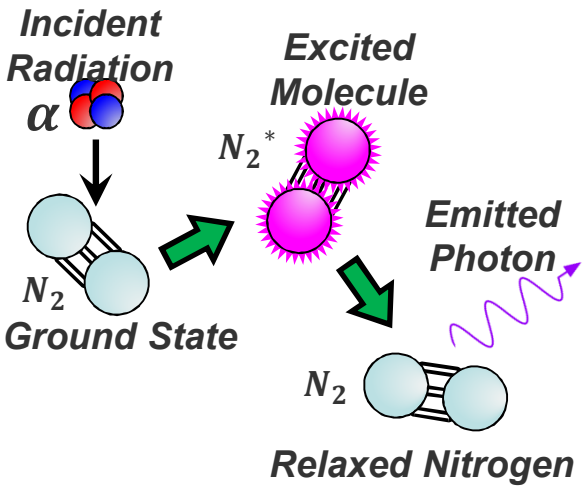
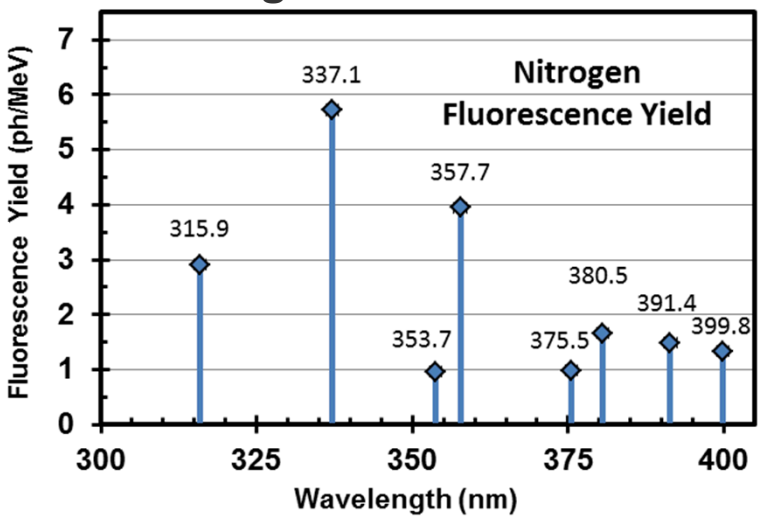
- Ionizing radiation interacting with nitrogen generates excited molecular states.
- These molecules can de-excite through emission of UV photons at characteristic wavelengths

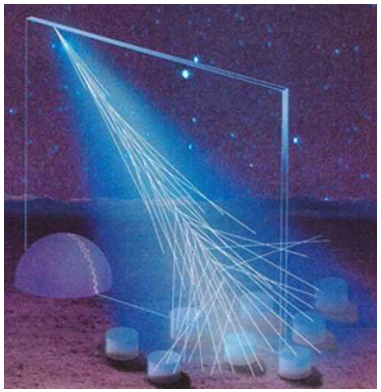


Nitrogen Emission Lines

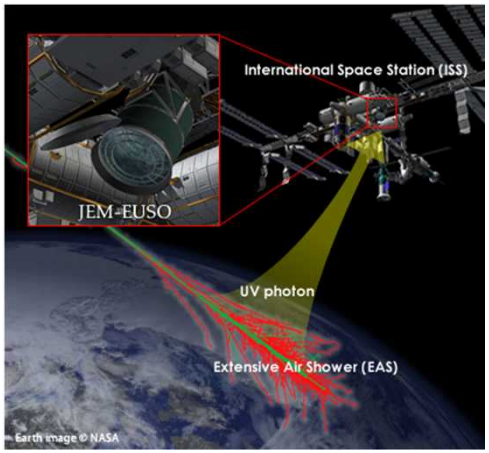


~17 photons per MeV deposited

Pierre Auger Observatory



JEM-EUSO Mission



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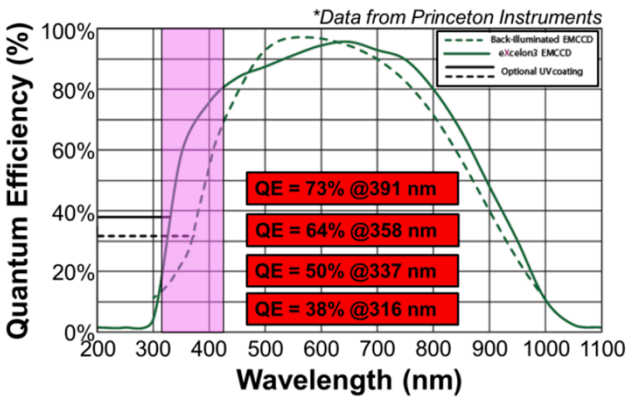
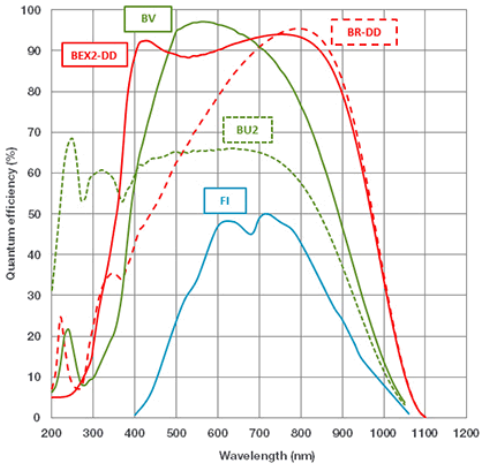
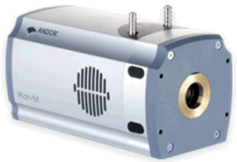
Optical Rad. Detection: Why Sandia? Why Now?

- Sandia's experience with satellites, optics, atmospheric transport and prompt forensics provides new perspective
- 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

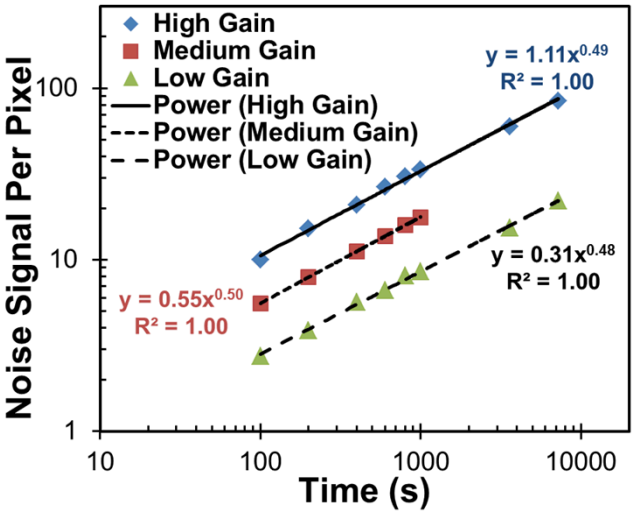
High UV Quantum Efficiency







Shot-Limited Noise



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Optically Detecting Radiation from an Alpha Source

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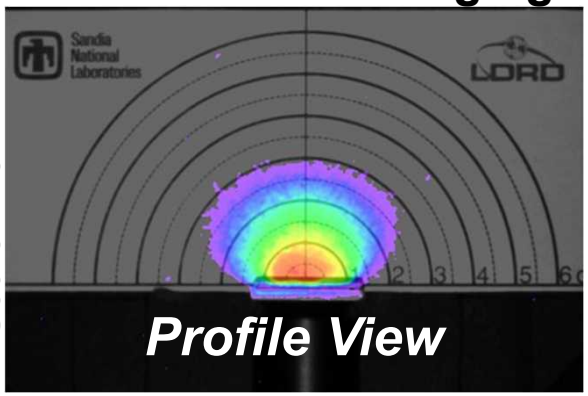
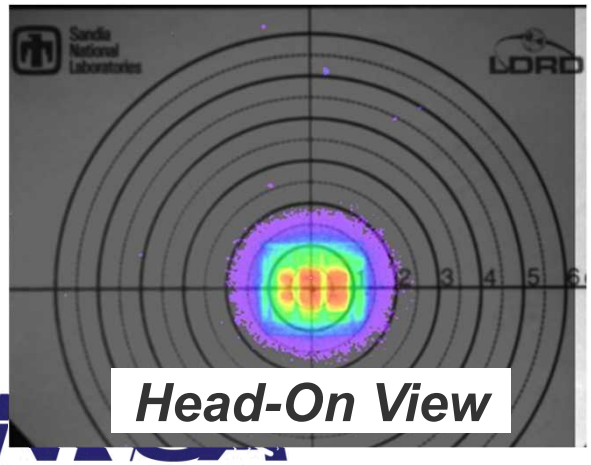
- UV photons were detected far beyond the dosed region
- Radiation range in air could be directly imaged
- UV emission highest where strongest radiations fields expected
- Dose rates, shielding and exposure time all affect radiation imaging

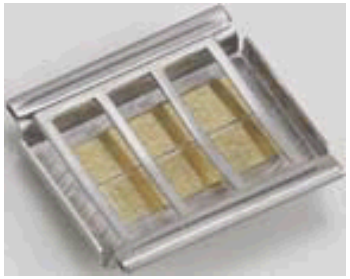
Radiation Field Imaging



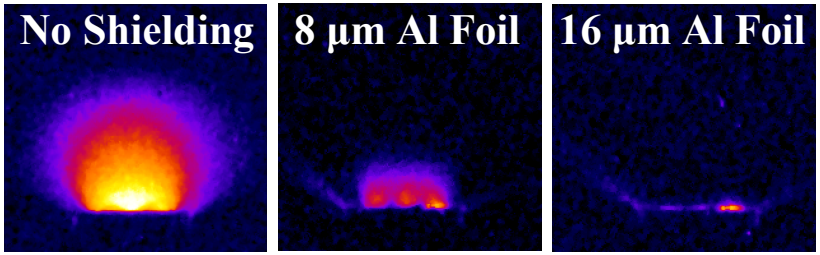
*Scale in cm



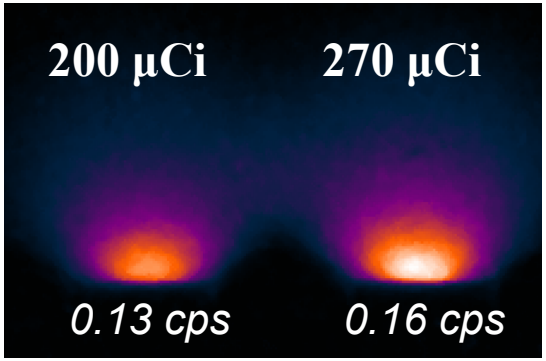
500 µCi Po-210



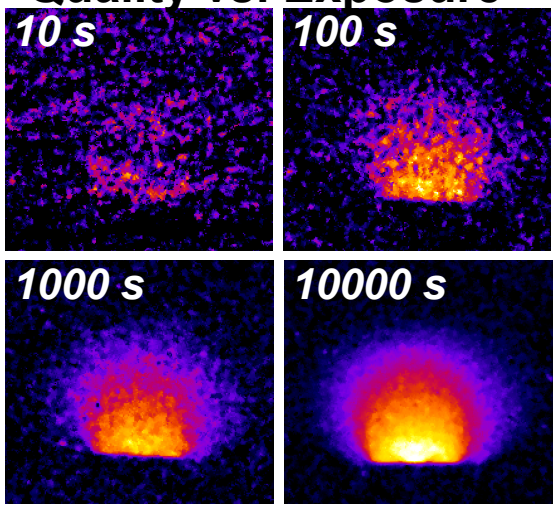
Effect of Shielding and Energy



Dose Discrimination



Quality vs. Exposure



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Optical Alpha Radiation Detection Outdoors

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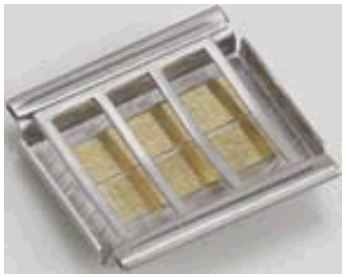
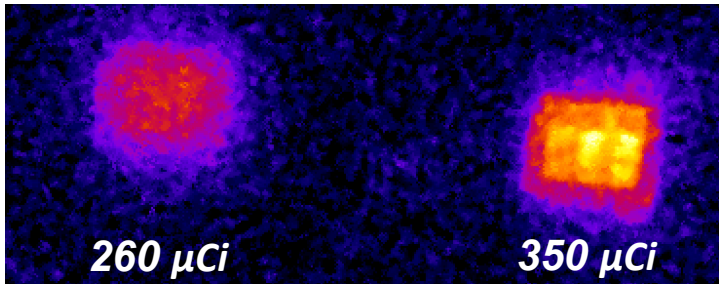
- Pathfinder system developed to evaluate optical detection possibilities
- Radiation imaged at 500× primary range at night with man-made background

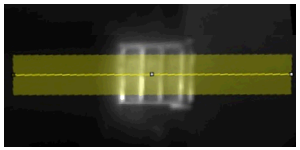
Po-210 Alpha Source



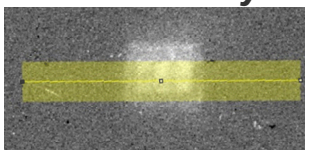
Head-On View



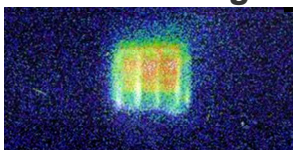
360 nm LED Lit



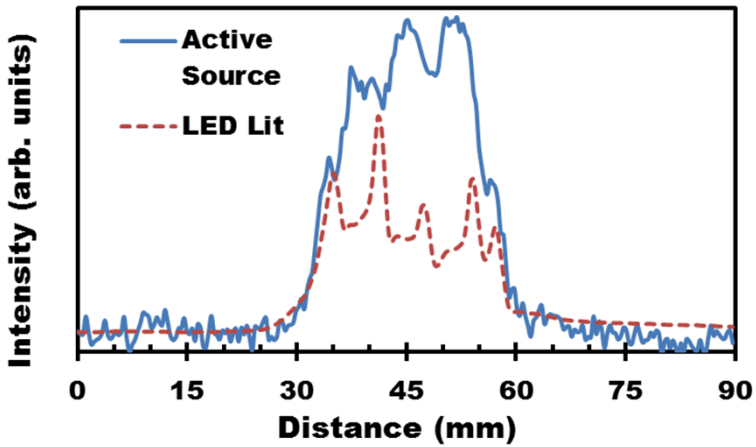
UV Intensity



Overlaid Image



Profile of UV Intensity and LED Lit Structure



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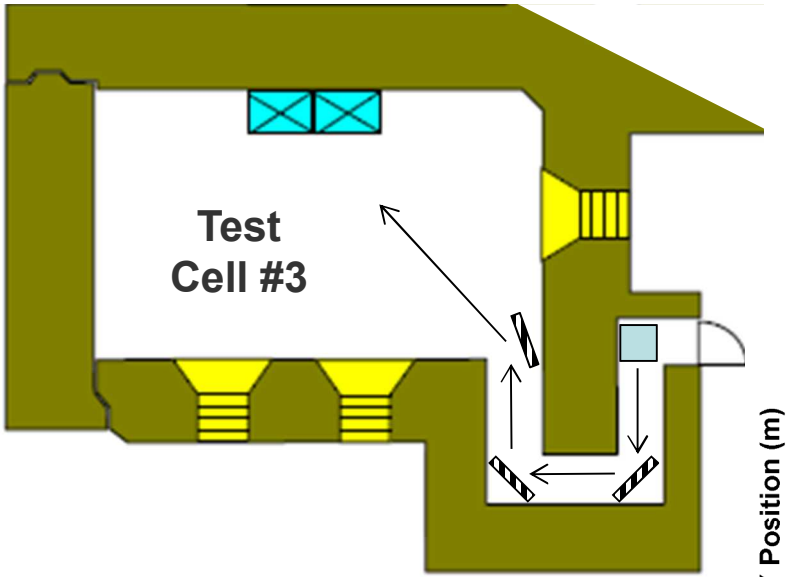
Optical Gamma Radiation Detection Indoors: Planning

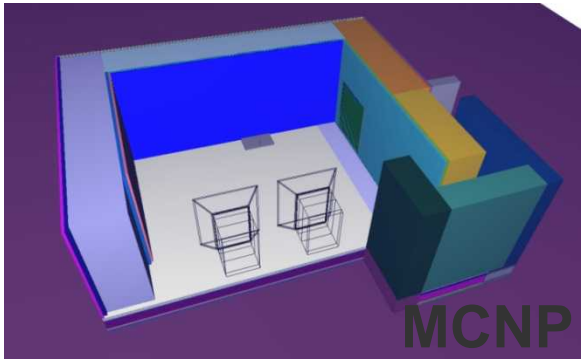
- Detecting neutral particle radiation–induced fluorescence would be a major step towards practical optical detection for nuclear forensics
  - Much more challenging because of much larger ranges and lower energy deposition attenuation coefficients
- Sandia's Co-60 Gamma Irradiation Facility was identified as a testing site for proposed gamma radiation imaging

GIF

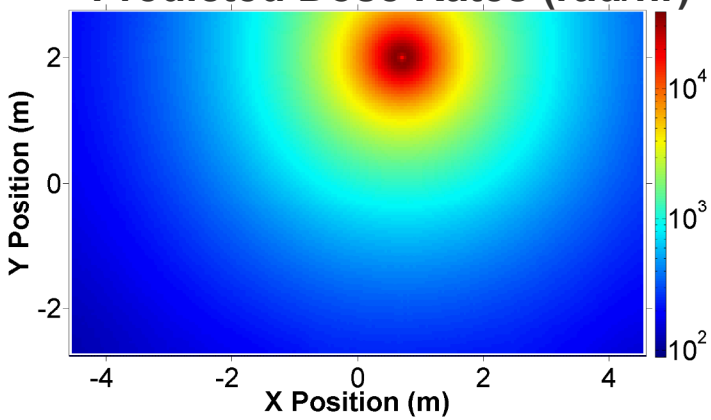
UV Lenses

Test Layout





Predicted Dose Rates (rad/hr)



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Optical Gamma Radiation Detection Indoors: Set-up

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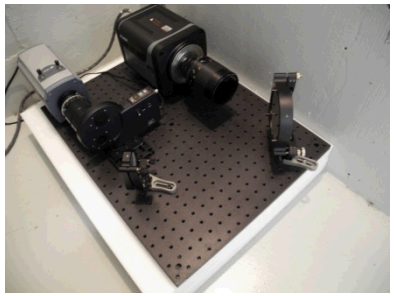
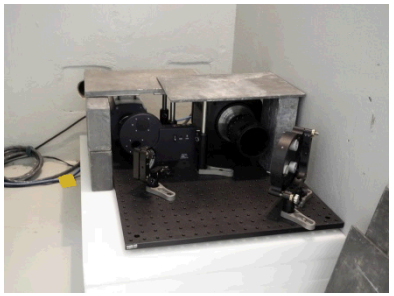
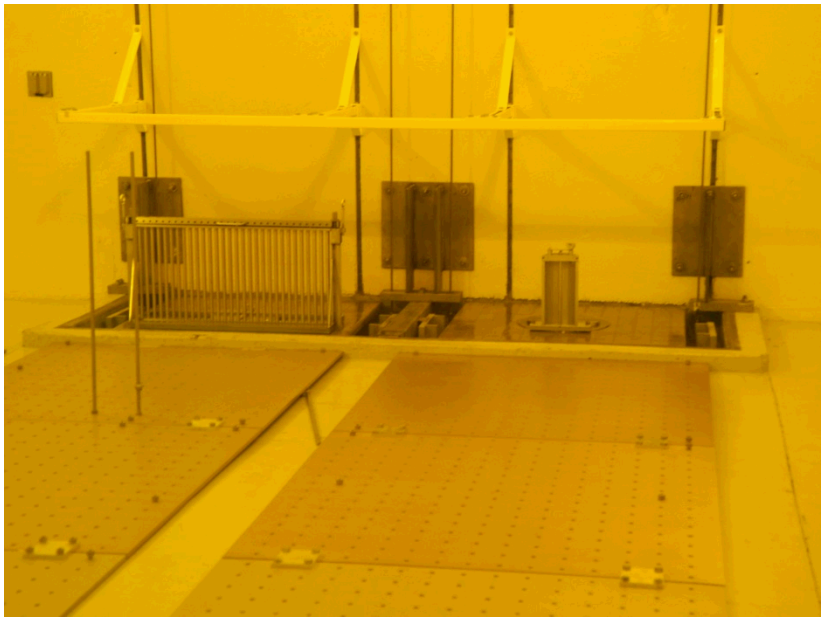
- Test concept: limit radiation dose to camera using mirrors, multiple scatters, distance and shielding
- Image around corners to detect radiation fields near Co-60 pins
  - Two options: single pin (160 Ci) and linear array (223 kCi)
- Detect regions around pin to detect optical emission and dose rates



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Optical Gamma Radiation Detection Indoors: Initial Results

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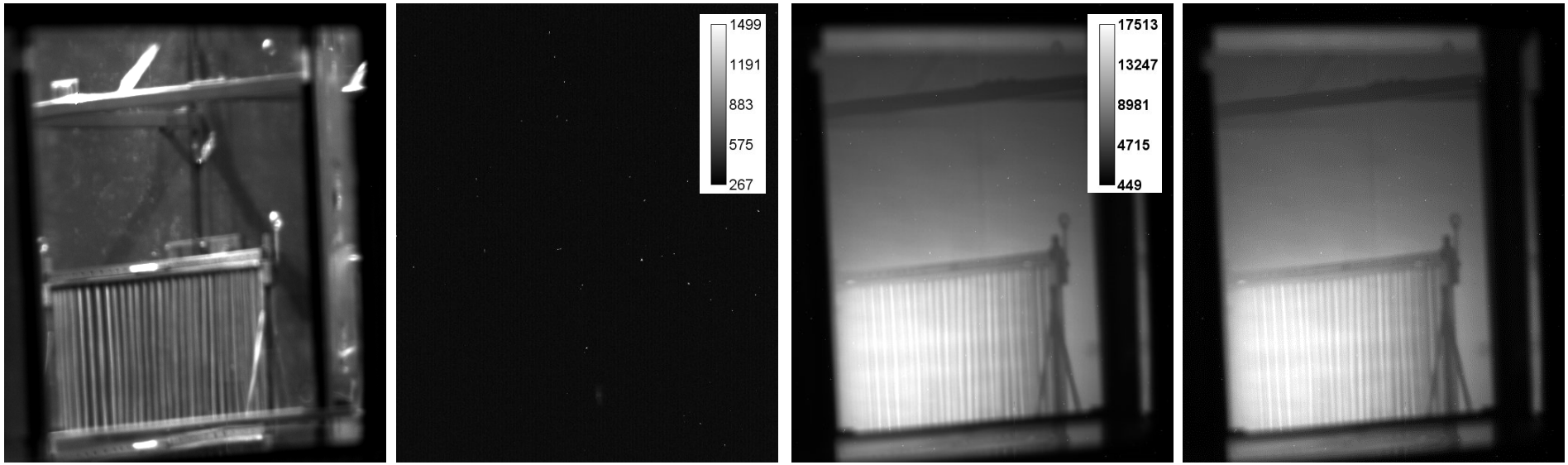
- Initial results conclusive – high radiation fields (10^6 rad/hr) were imaged from a 0.006 rad/hr location using UV-filtered imaging system
  - Linear array could be detected in as little as 3 seconds with 1” lens
  - Single pin emission overwhelmed by Cherenkov from linear array
- Image interpretation can be non-intuitive for volume light source
- Possible application of radiation facility dose mapping

Lights On | Background | Signal | Bkg. subtracted



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Optical Gamma Radiation Detection Indoors: Analyzed Results

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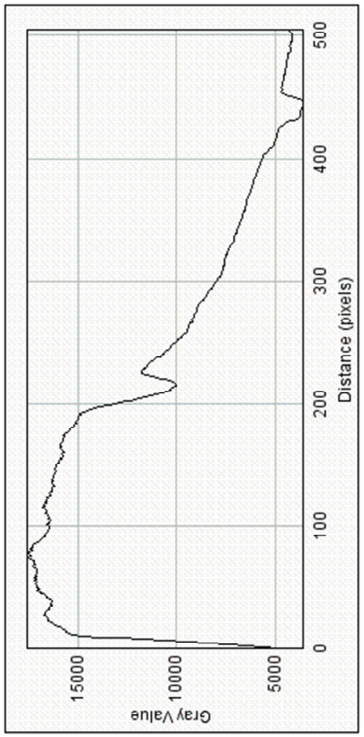
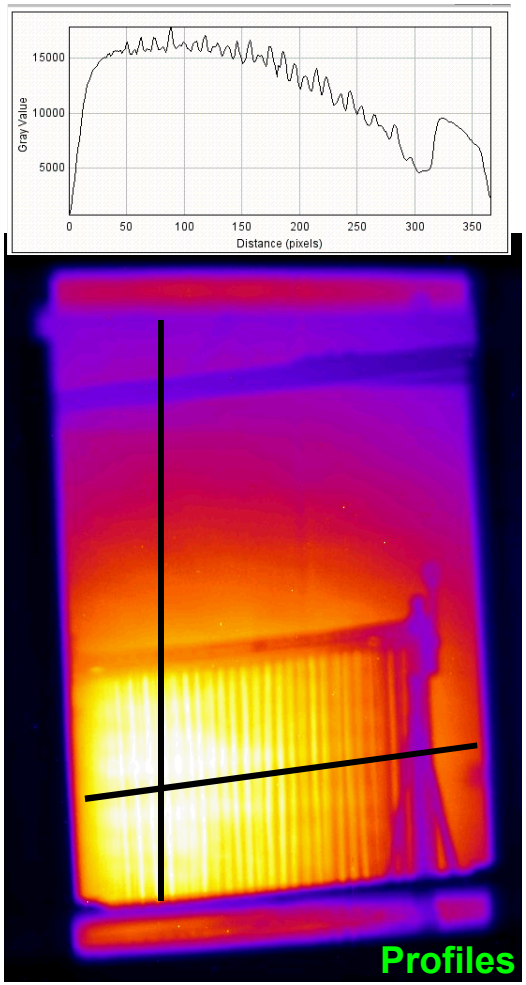
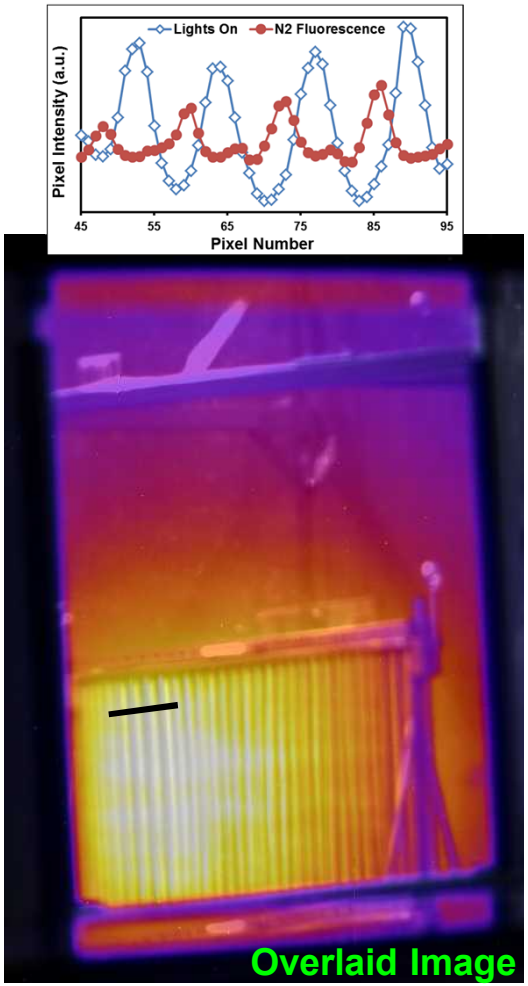
- Light emission decays away from linear pin array with distance
- Overlaid image shows that detected signal is highest between the pins
  - Corresponds to longer optical path over which light is emitted



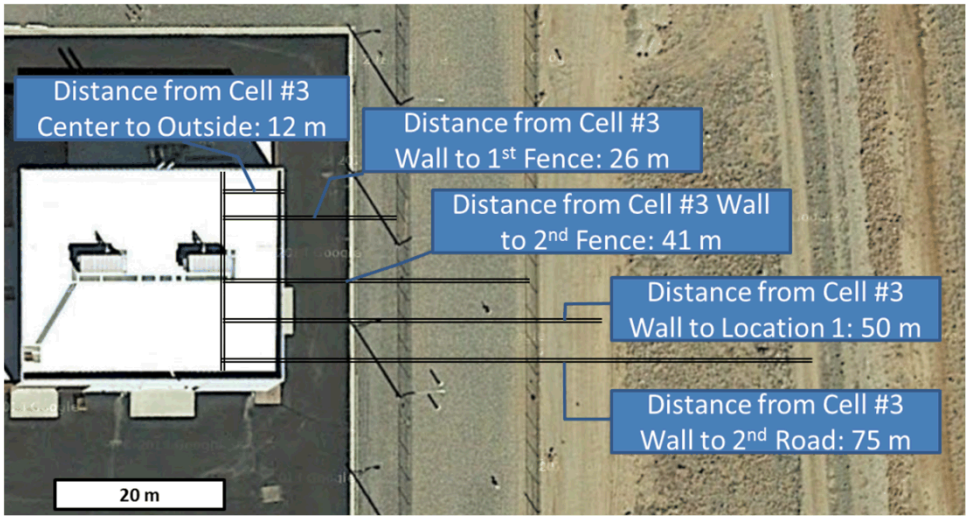




Optical Gamma Radiation Detection Outdoors: Set-up

- 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

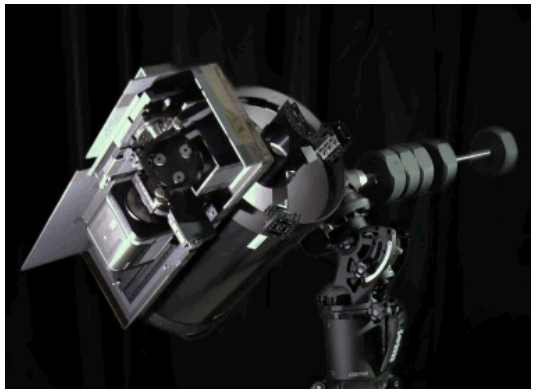
Images of Location and Mobile Platform



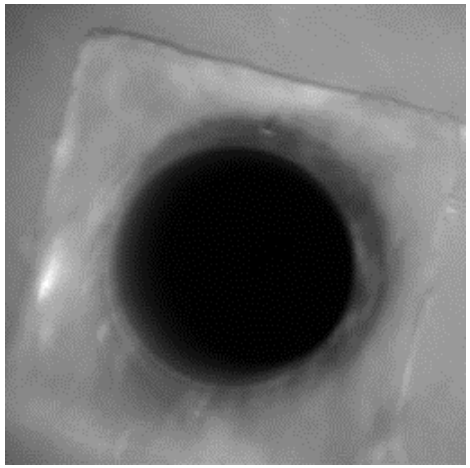
Optical Gamma Radiation Detection Indoors: Initial Results

Sandia National Laboratories

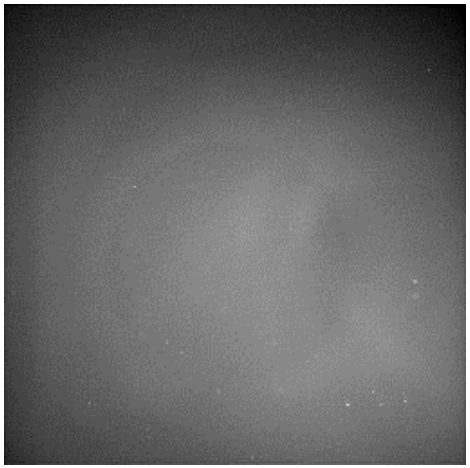
- Distance: 75 m
- Exposure Time: 1 hour
- Source Activity: 110 kCi
- Dose Rate (Cell): >10 krad/hr
- Dose Rate (Camera): <0.2 mrad/hr
- 14” Telescope Collection Area
- Filter = 390 ± 7.5 nm (>90% transmission)



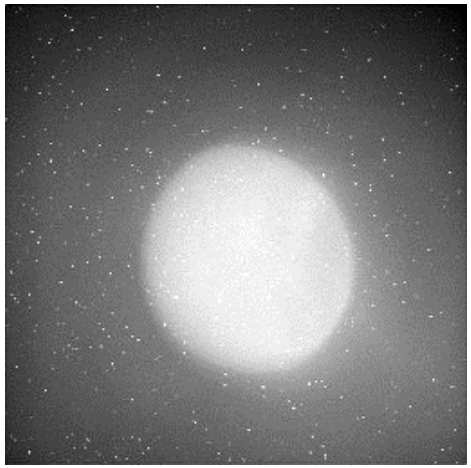
Outer Lights On



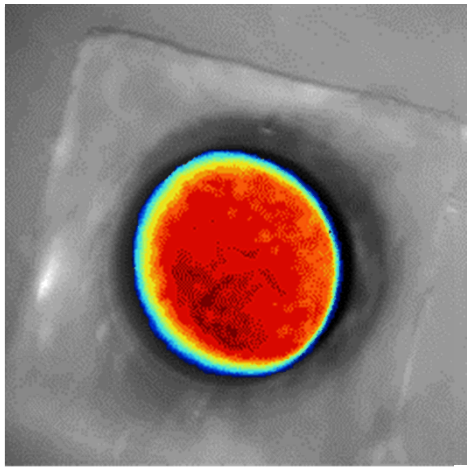
Background



Sources Up



Subtracted, Filtered and Overlaid



Optical detection of radiation summary

- Optical radiation imaging correlates UV photons from ionized nitrogen with radiation dose in air
- This effect provides a powerful technique for long-range detection far beyond the range of primary radiation
- Radiation imaging has been demonstrated indoors and outdoors with charged and neutral particles

Lab Overview

Sandia National Laboratories

- **Sandia National Labs**
  - Multi-program lab operated by Lockheed Martin for the Department of Energy
  - One of three NNSA labs

- **Nuclear Forensics at Sandia National Labs**
  - Expertise in optical sensing has led to research in prompt forensics
  - Other projects include investigations of alternative signatures, numerical simulations of nuclear detonations, surrogate debris development, neutron interrogation, and ground-based systems.

- **Past and Current Tech. Nuclear Forensics Academic Collaborations**

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National Nuclear Security Administration