SAND2011-3261C

Non-Traditional Surveillance Systems and their Application to Safeguards

May 18, 2011

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International Safeguards and Technical Systems

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Outline

- Common Imaging Systems and the Visible Spectrum
- Imaging throughout the Electromagnetic (EM) Spectrum
  - Reflective Infrared
  - Ultraviolet
  - Thermal
  - X-ray and Gamma Ray
  - Microwave
- Imaging Spectroscopy
- Conclusions

Surveillance in safeguards typically relies on imaging systems sensitive to the visible region of the EM spectrum

- Visible spectrum limited to 400 – 750 nanometers (nm)
- More spectral information is present in the picture to the right than the human eye can see
- This presentation will explore imaging outside of the visible region of the EM spectrum
- Potential to strengthen safeguards activities by offering additional information for improved surveillance measures

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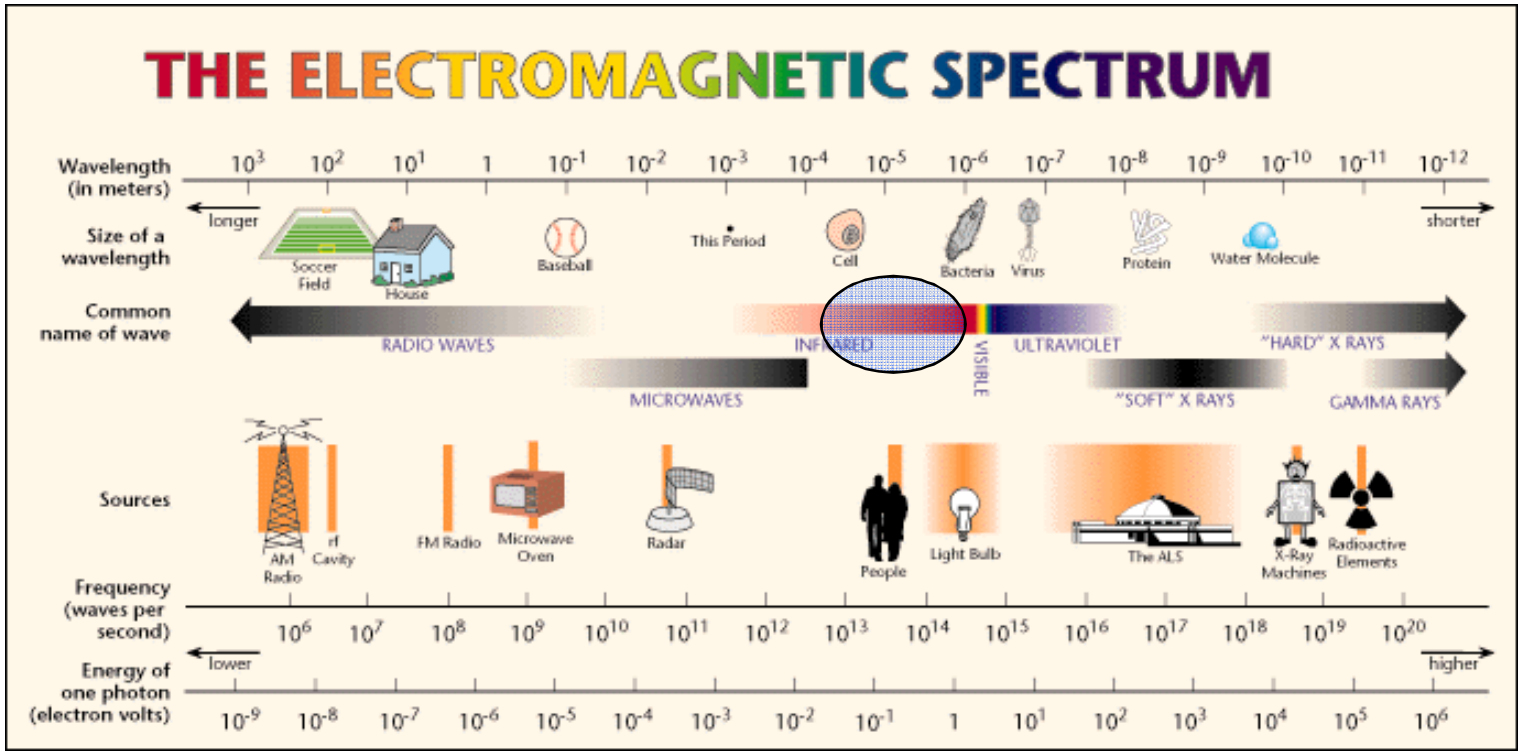
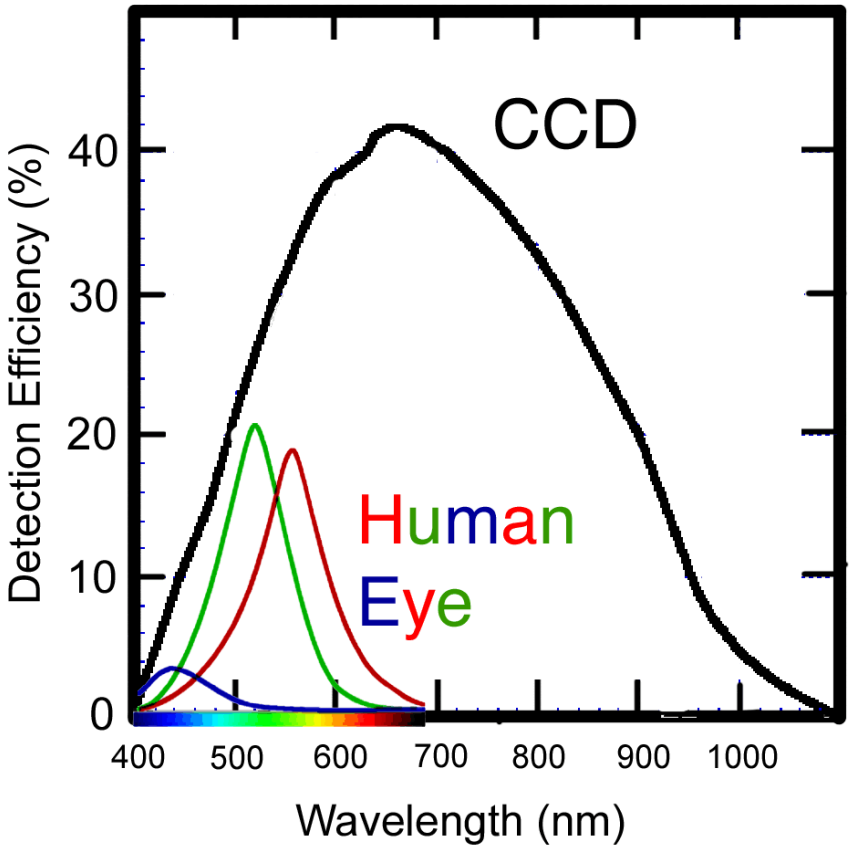
Electromagnetic (EM) Spectrum



In the visible band, detectors measure intensity of optical radiation reflected from a scene

- The image to the right shows the difference in detection efficiency between the human eye and the CCD, or Charge Coupled Device detector commonly found in digital cameras
- CCD is sensitive to radiation outside of visible region; however, it is filtered in digital cameras due to unwanted effects in images
- Source of radiation often broad spectrum (outside visible)



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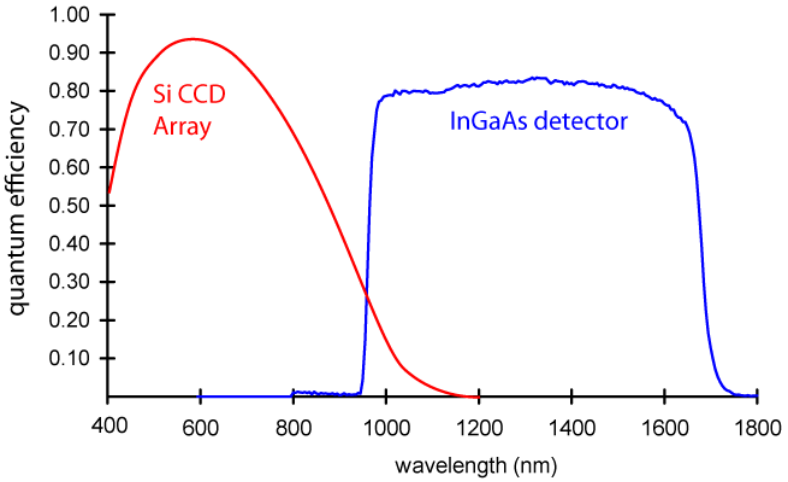
Reflective Infrared

- Near Infrared (NIR): 750 to 1000 nm
  - Common sources of radiation: sun or active illuminators
  - Common detectors
    - Charge Coupled Devices (CCD): 350 to 1000 nm
    - Indium Gallium Arsenide (InGaAs): 900 to 2500 nm (more common to 1700 nm)
  - Applications
    - Common in physical security for low-light scenarios
- Short-wave Infrared (SWIR): 1000 to 2500 nm
  - Common sources of radiation: sun or active illuminators
  - Common detectors
    - InGaAs: 900 to 2500 nm
    - HgCdTe (MCT, Mercury Cadmium Telluride)
    - InSb (Indium Antimonide)
  - Applications
    - Low-light imaging, image enhancement, process control, imaging spectroscopy



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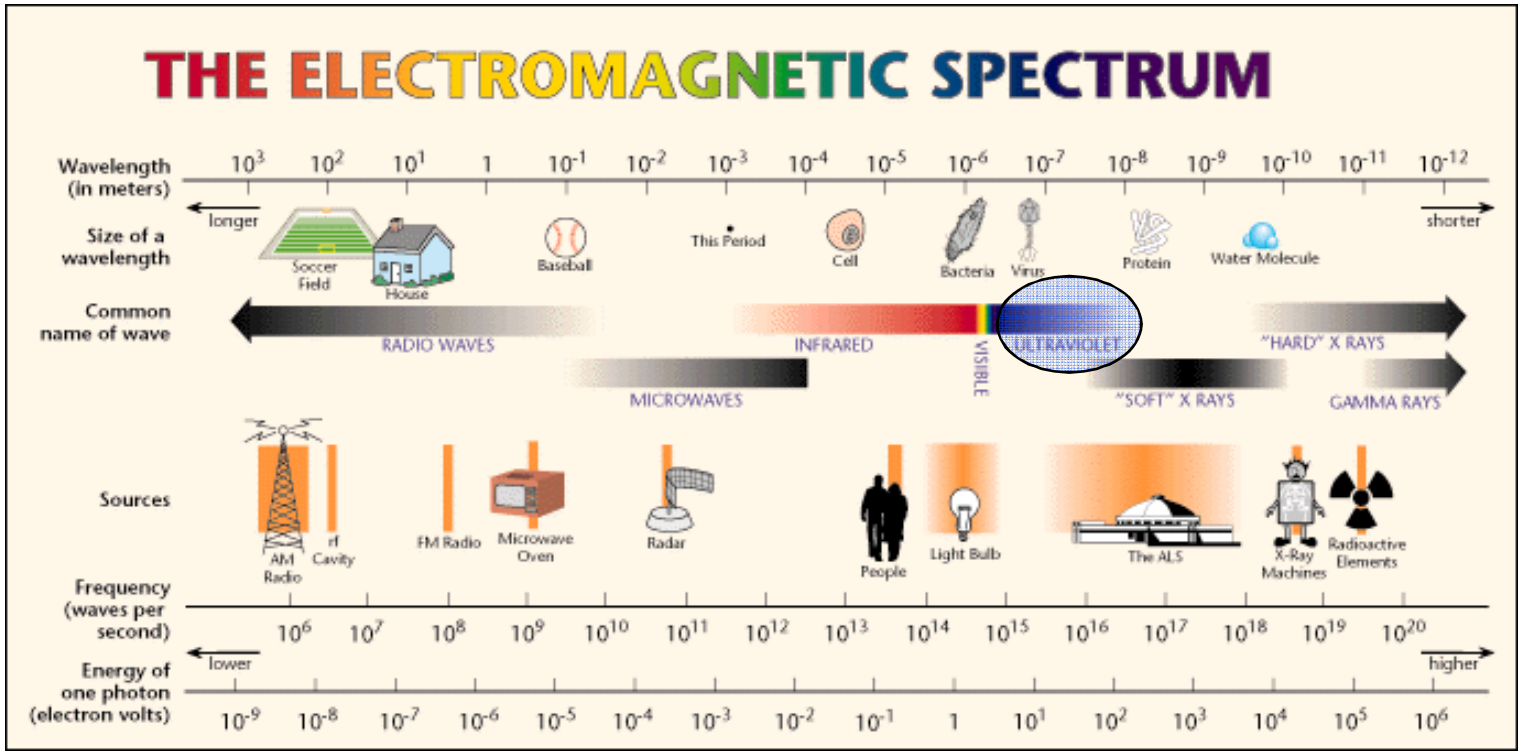
EM Spectrum - Ultraviolet



Ultraviolet (UV)

- UV extends from 10 to 400 nm
- Only 200 to 400 nm is used for imaging
  - Air is opaque below 200 nm
  - Near-UV: 300 to 400 nm
  - Deep-UV: 250 to 280 nm
- UV illumination sources can include sunlight, black lights, UV LEDs, and UV fluorescent lamps
- Technology for near-UV and deep-UV imaging differs

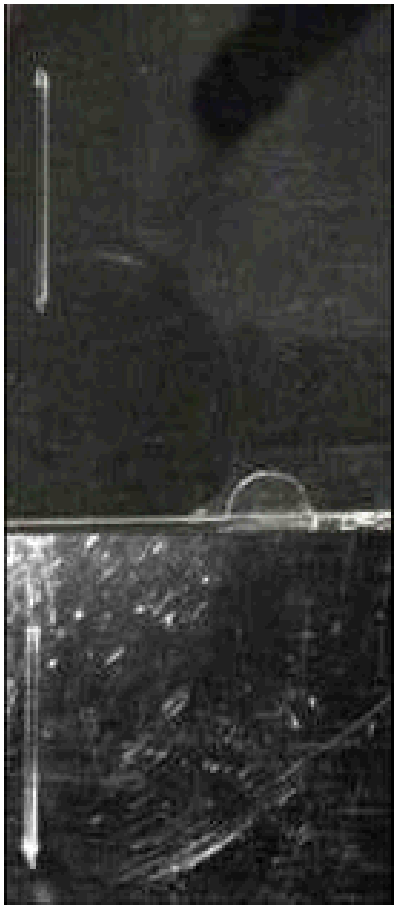
Near-UV versus deep-UV imaging hardware

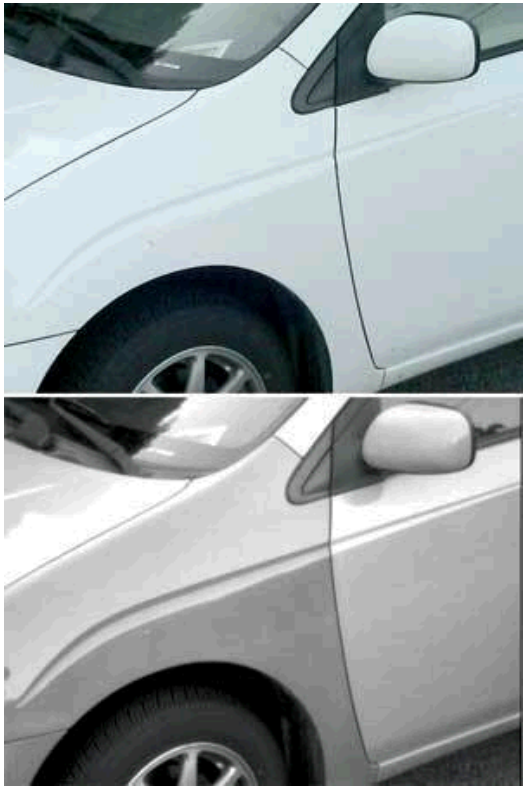
- Digital cameras based on CCD detectors can also be used for near-UV imaging
  - Remove UV blocking filter
  - Standard glass lenses acceptable, but less expensive preferred (no antireflection coating)
- Deep-UV imagers require both special detectors and lenses
  - Detectors: either thin silicon substrates or wave-shifting coatings
  - Lenses: quartz (fused silica) or calcium fluorite

Reflected UV versus UV fluorescence

- Reflected UV
  - Illuminate surface of an object with UV source
  - UV light striking object's surface reflected or scattered, and detected by UV camera
- UV Fluorescence
  - Illuminate surface of an object with UV source
  - Object absorbs the UV excitation and reradiates the light at a longer wavelength for detection by visible or IR cameras

Reflected UV for detecting surface anomalies



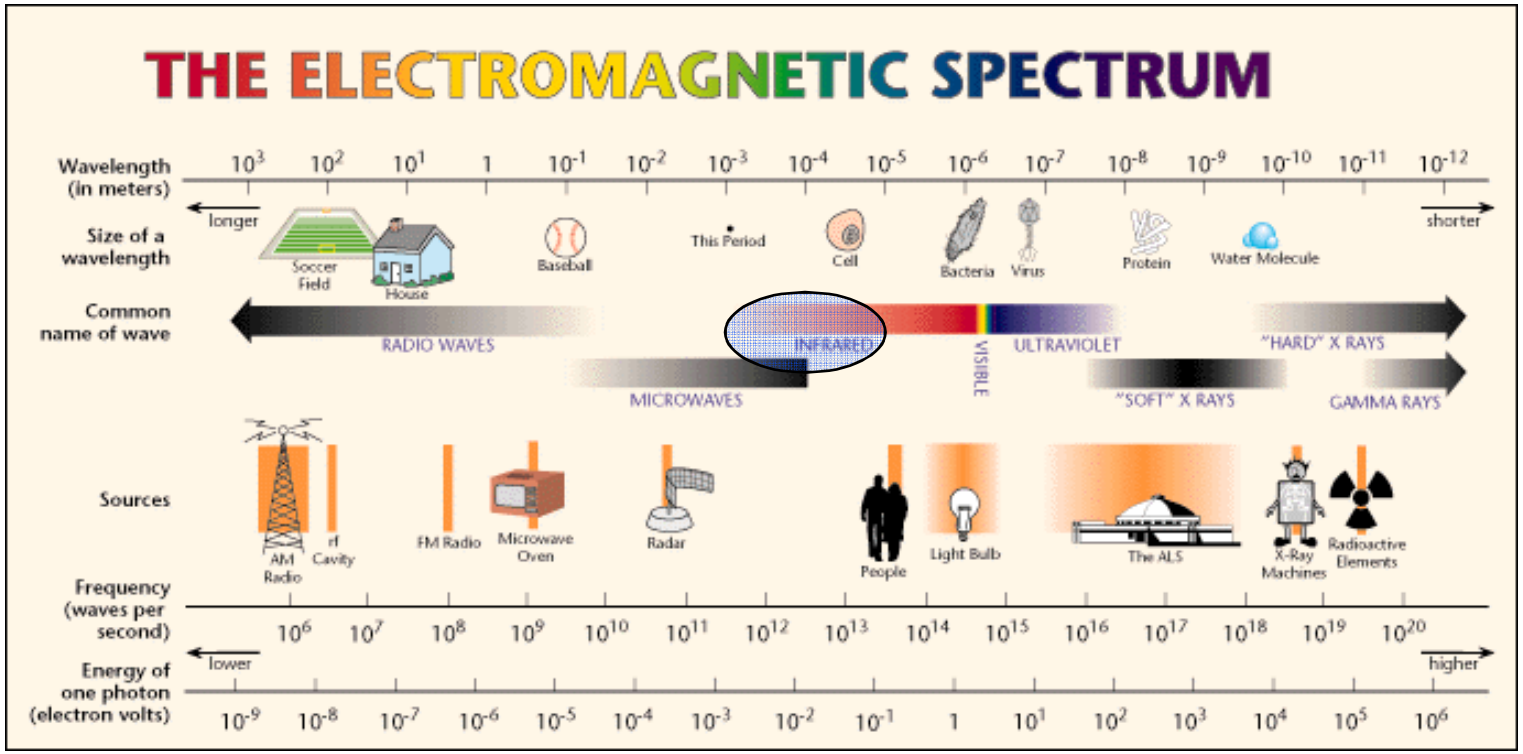


- UV light scattered more readily by material surface features than light of longer wavelengths
- Left: CD jewel case under visible and 365 nm UV light
- Right: Difference in age of car paint under visible and 320 to 400 nm UV band
- Safeguards applications: tamper indication or equipment authentication

UV fluorescence for anti-counterfeit and tamper detection

- Security elements only visible under UV illumination incorporated into high-value assets to validate their authenticity
  - U.S. currency, driver's licenses
- For safeguards, possibly embed fluorescent materials to interact with UV cameras
  - surveilled containment

EM Spectrum - Thermal

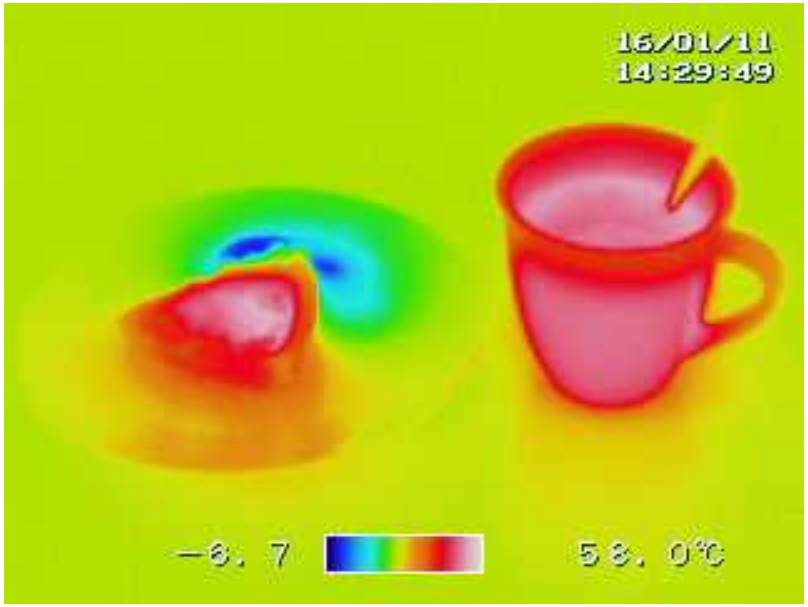


Thermal

- Mid-wave infrared (MWIR): 3.3 to 5 μm
- Long-wave infrared (LWIR): 8 to 14 μm
- Thermal imaging cameras sensitive to temperature differences between objects in these regions due to emission of thermal energy
- From limited and high-cost, to ubiquitous in recent years due to new detector materials and advancements in integrated circuits
  - Microbolometer – uncooled thermal sensor that has allowed for small, lightweight, and low power detectors

Example thermal image

- Image shows coffee, apple pie, and ice cream in the LWIR using a microbolometer- based commercial camera (NEC Thermo Shot)
- Ice cream is at -6.7°C (19.94°F), and the coffee is at 58°C (136.4°F)



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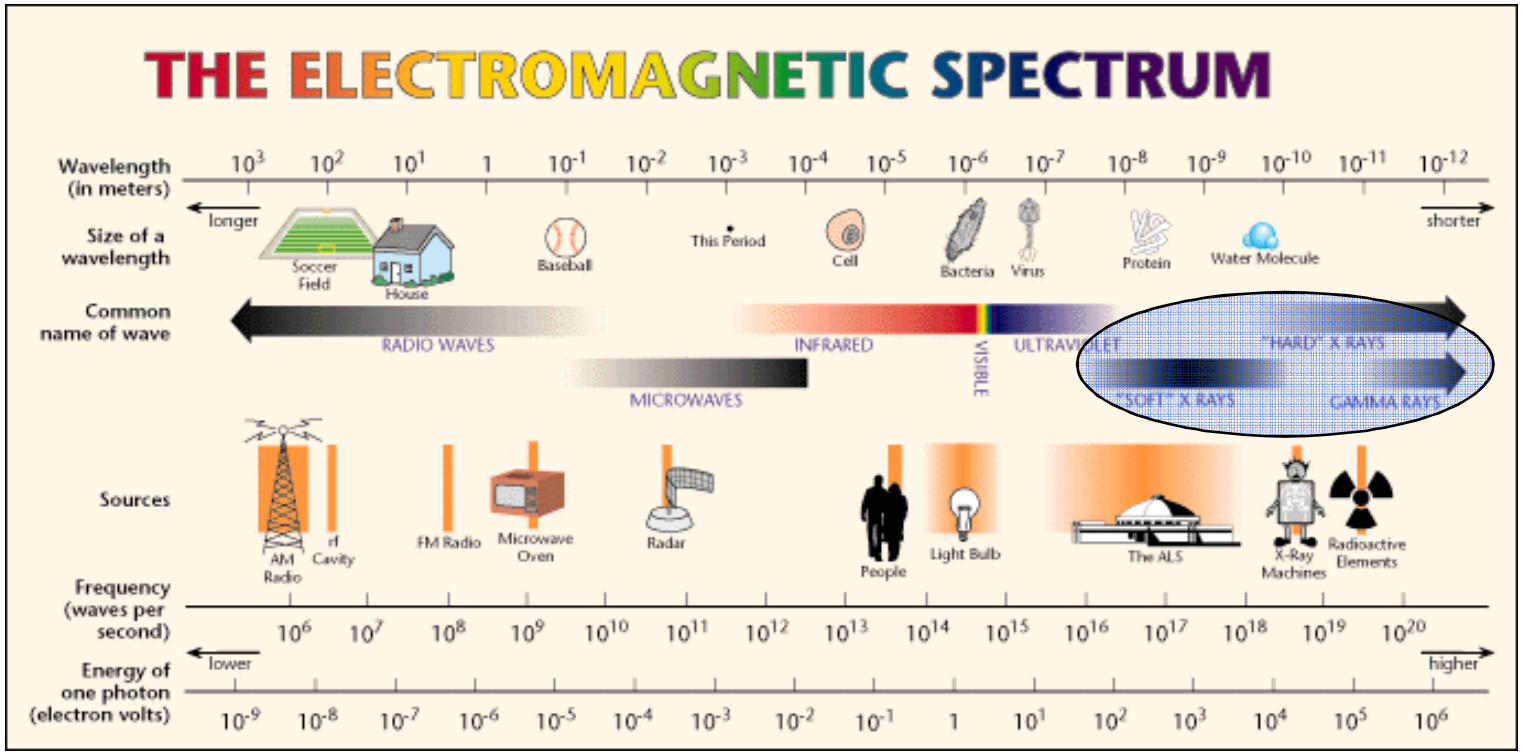
Thermal has become more affordable for security and surveillance

- Images show differences in temperature from thermal radiation emission of objects in scene
  - Does not require auxilliary lighting
  - Allows for imaging in night time and other poor lighting conditions
- Recent U.S. Nuclear Regulatory Commission (NRC) regulations require nuclear facilities to provide continuous 24-hour surveillance of perimeter and thermal imagers are being installed at some facilities

Thermal imaging may detect density variations in materials

- These density variations could be surface or subsurface non-uniformities or defects
- Continuum heat transfer is impeded by the defects or otherwise affected by density variations
- Denser materials retain heat longer than less dense materials
- Heat can be applied by solar loading or brief intense pulses of light
- Infrared cameras can be used to record surface temperature distribution over time
- May support safeguards inspections to determine that equipment and facilities are free from tampering and facilities have not been altered

EM Spectrum – X rays and Gamma rays



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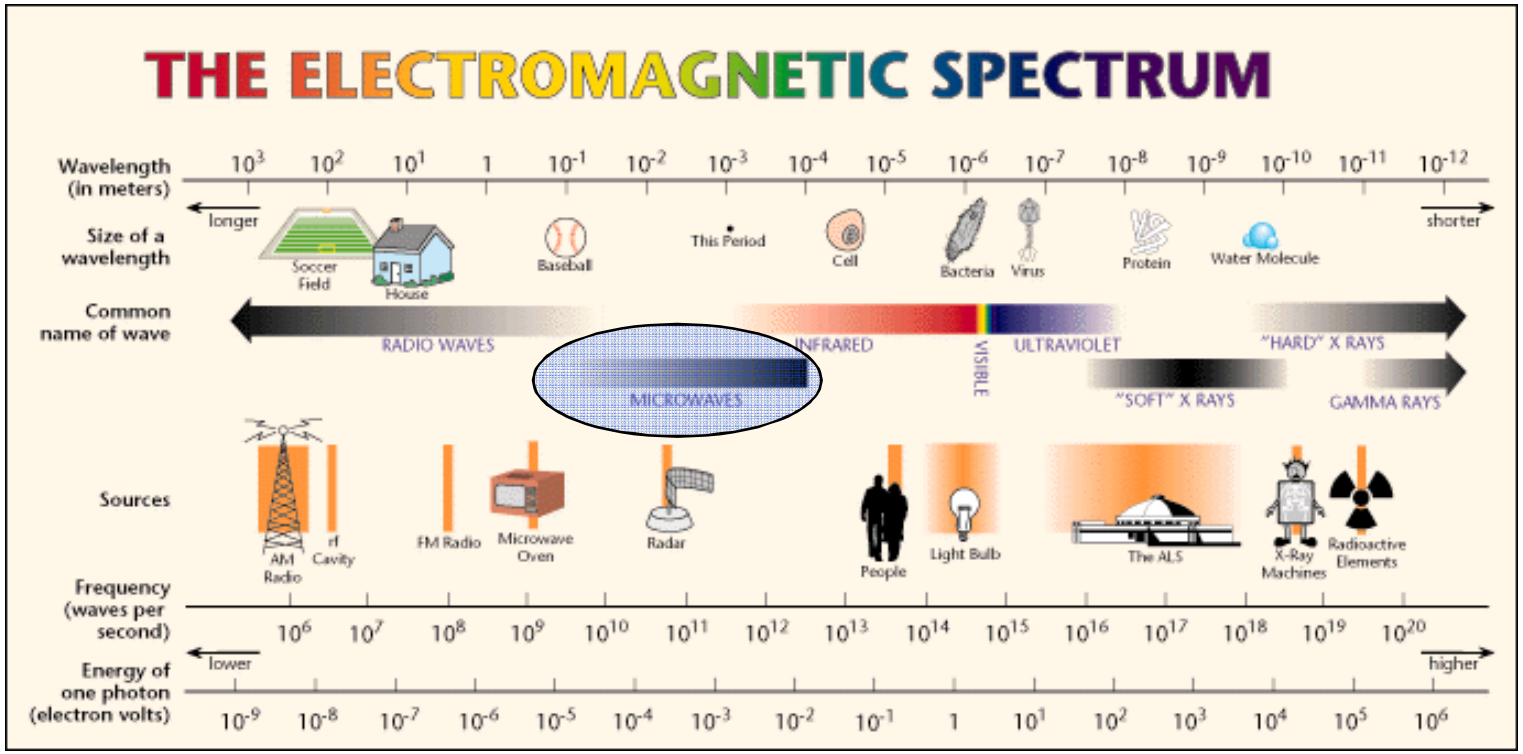
X-ray and Gamma ray

- X-ray: 0.01 to 10 nm
- Gamma ray: less than 0.01 nm
- High frequency, high energy, very short wavelengths
  - Difficult to measure wavelengths in this region so refer to energy of photons, or particles of light that have a particular energy
- Can penetrate all materials
- X-rays can be used for contraband and anomaly detection through walls and containers
  - Regulated for human exposure

Gamma rays

- Can image where x-rays cannot, such as through steel and other dense materials
- Gamma rays are produced by nuclear processes
- Gamma ray spectroscopy currently used in safeguards for identification of different isotopes of radioactive materials

EM Spectrum - Microwaves



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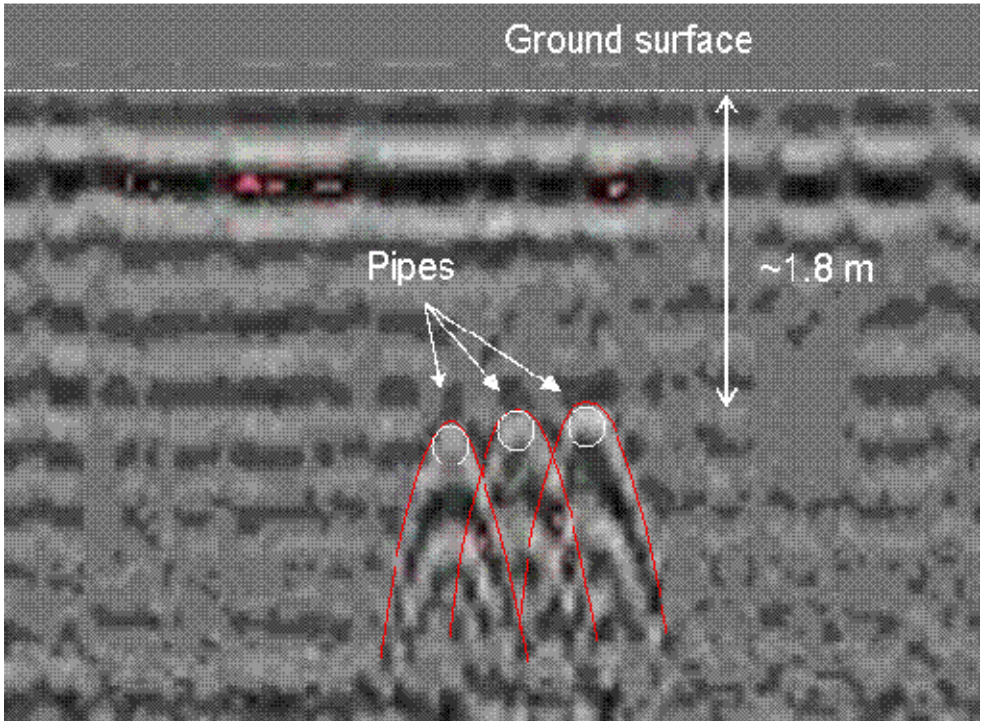
Microwave

- Long wavelengths and low energy: 10 mm to 1 m
- Can penetrate nonconductive materials relatively well
- Ground-penetrating radar for DIV
  - Short pulses sent into a material
  - Reflections off dissimilar material boundaries returned to collection system
  - Frequency of operation is compromise between material penetration depth, object or feature resolution, availability of interference-free frequencies, and antenna and equipment size

Ground-penetrating radar

- Data interpretation not always intuitive
- Many companies are working on 3D renditions and improved visualization



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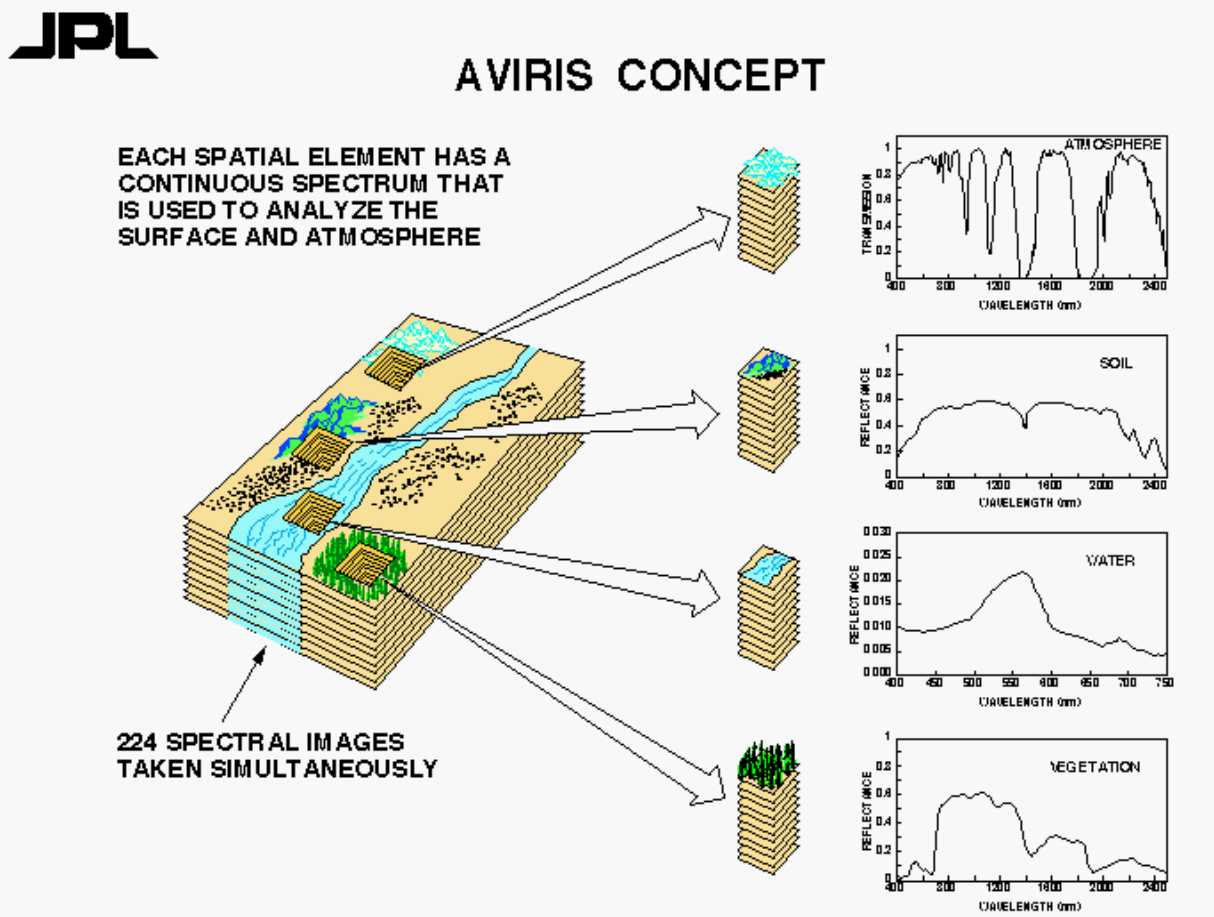
Imaging Spectroscopy

- Materials look different across the EM spectrum because the process by which photons interact with materials varies with wavelength
- With enough spectral resolution of a sensor, objects can be characterized by their "spectral signature" – that is the dependence of photons returned to the sensor on wavelength
- Spectral signature may appear to be a "near continuous response," but really is very narrow contiguous spectral bands
- Imaging spectroscopy has been used as a tool in the laboratory, as well as for geological and environmental studies in the remote sensing field
- However, it has been somewhat limited by its high-computing requirements

Imaging Spectroscopy

- Surveillance of a process
- Leaks, material changes, other anomalies
- Spectral tags for authentication or tamper indication



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Conclusions

- Visible imaging is one of many imaging technologies available
- These technologies are currently and commonly applied in fields other than safeguards
- Adaptation of technologies common to other industries could have potential to strengthen safeguards activities by offering additional information for improved surveillance measures, with less research costs funded directly by the safeguards community
- These technologies will require further evaluation for applicability to safeguards

Questions?

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