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The Effects of Focal Parameters on Optical Detection of Radiation Measurements

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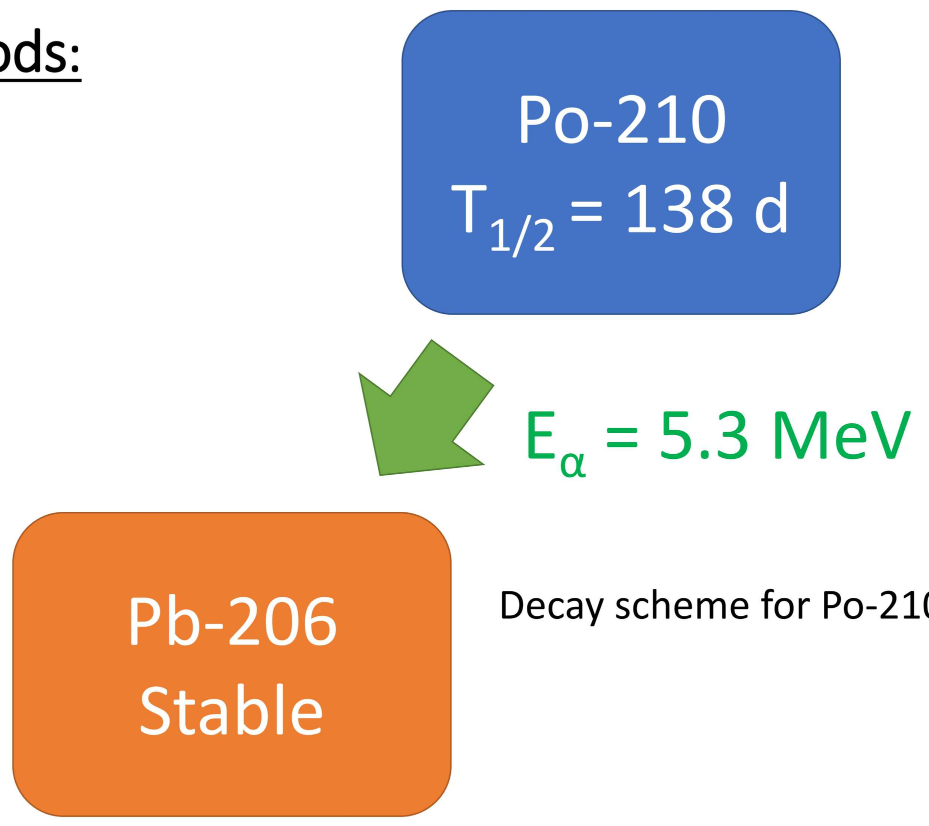
Abstract:

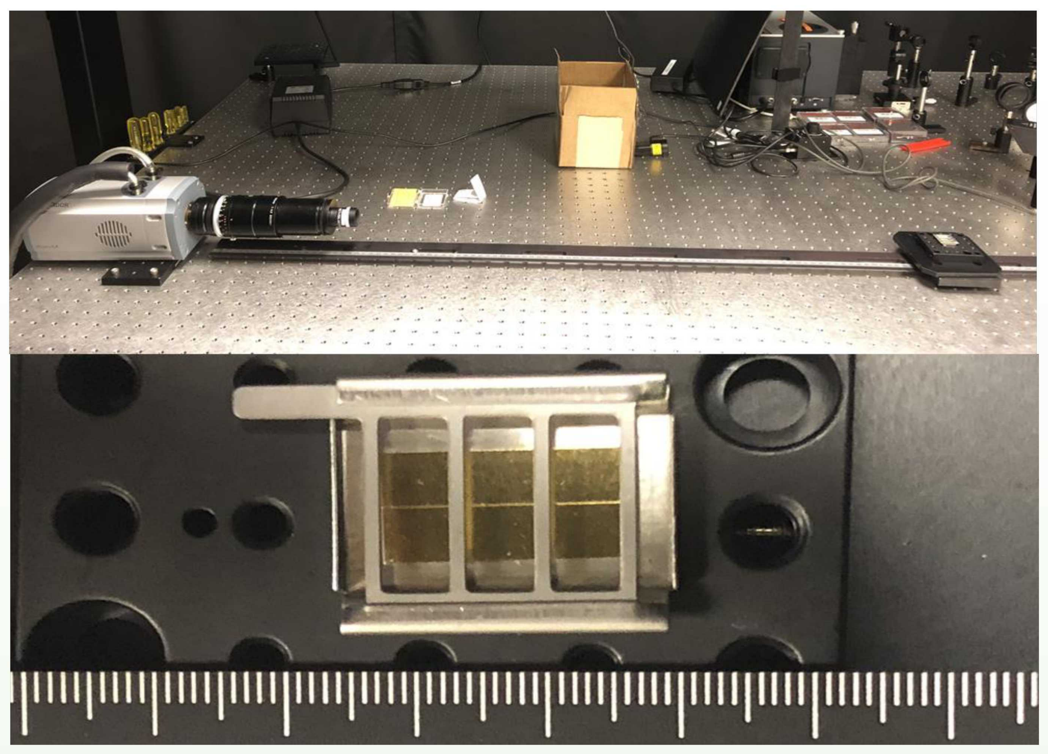
Optical Detection of Radiation (ODR) is a technique to sense ionizing radiation in the atmosphere based on optical signatures emitted by atmospheric molecules ionized or excited by the radiation. The volumetric nature of the light (UV) source associated with an ionizing radiation source complicates ODR. Since optical sensors and systems focus at a single distance, the focal length, much of the light produced by such a volumetric source will be out of focus to varying degrees. As light goes out of focus, the uncertainty regarding its source location and intensity increases. This issue becomes increasingly prevalent both for radiation sources with a longer attenuation length (i.e., gamma vs. alpha), and as depth of field decreases. In addition, if ODR is to be used to find and identify unknown radioactive sources, it is likely that the source will be out of focus. Determination of the presence of radiation by optical detection has been frequently demonstrated (qualitative analysis), however, quantitative dose mapping and determination of a source's distance from the camera has been hindered partly by the uncertainties described above. A thorough understanding and measurement of the convolution of signal with the camera response as the source moves from the point of focus is necessary to move forward with applications of ODR. This report details experimental methods of obtaining the relationship between focal length and the Signal to Noise Ratio (SNR) of images taken of a radiation dose field at a constant distance and describes a potential exploitation of this relationship to determine the location of an unknown alpha radiation source.

Methods:

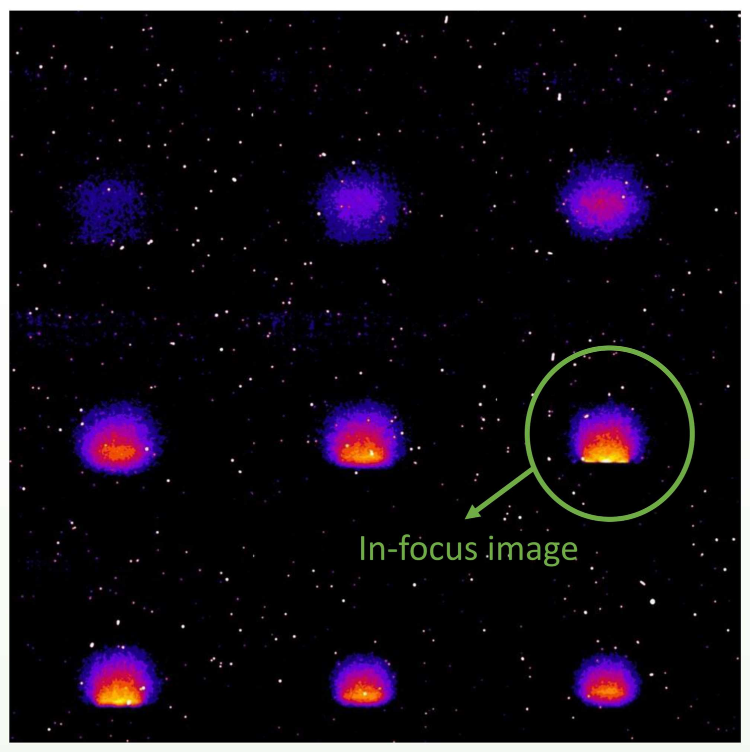
- Light sources, including both UV LED point sources and Po-210 alpha sources, were positioned on an optics table and imaged using an Andor iKON camera.
- With no room lighting, sets of images were acquired with varied parameters, to include focal length, aperture, and source position.
- Images were processed to calculate the average signal pixel value, signal to noise ratio (SNR) and signal size



Decay scheme for Po-210



Above: Andor iKON in sample acquisition set-up
Below: a 500 µCi Po-210 source used

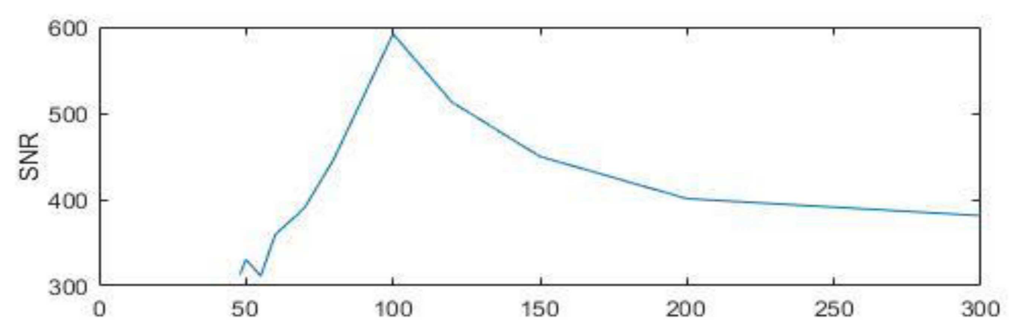


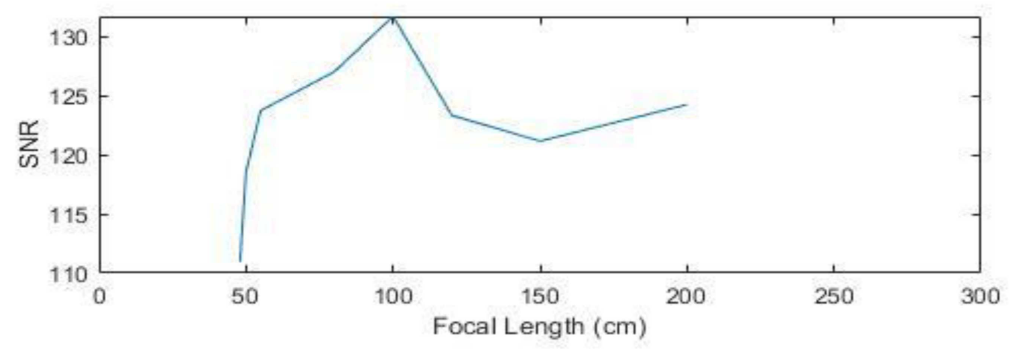
Images of 500 µCi "stamp" source, 80 cm from camera, acquired for 30 min. From left to right, top to bottom: f = 50, 55, 60, 70, 80, 100, 120, 150, 200 cm.

Introduction and Background:

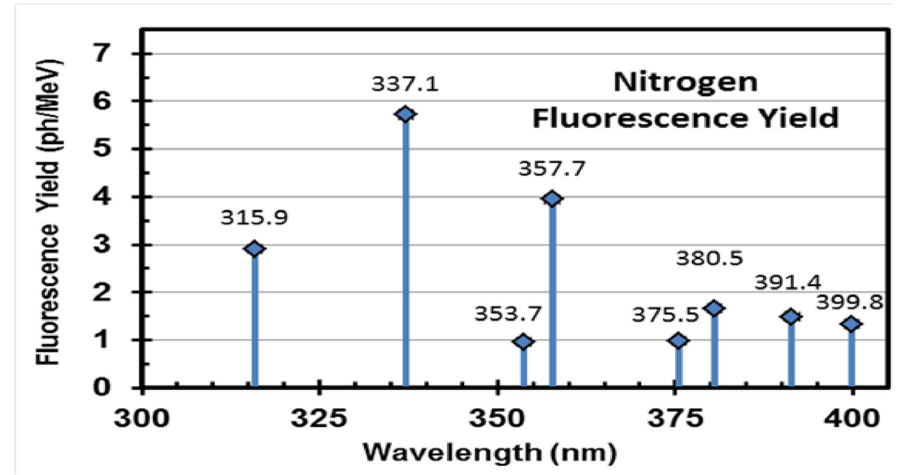
Traditional radiation detection systems function by collecting the direct radiation emitted by a nucleus, so the distance from the source at which the detector can operate is limited by the range of the initial radiation [1]. Thus, a capability to measure secondary effects of radiation, which have longer ranges than the initial radiation, is desired. Ionizing radiation excites and ionizes molecules in the air, which then deexcite and emit optical photons in the UV spectrum. These photons can be imaged to produce an accurate radiation dose field.

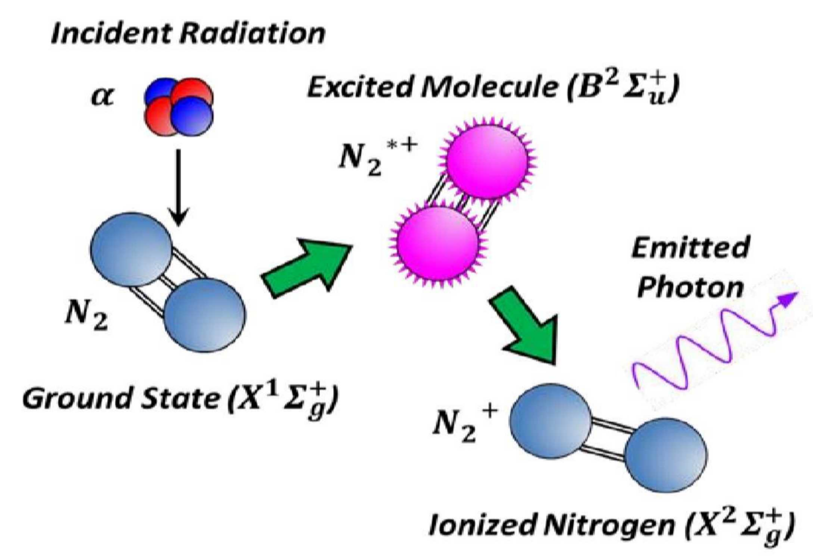
Optical images are integrated along the axis of the lens, and since radioactive sources of optical light are volumetric, optical dose field images are integrations of out-of-focus signal; this is a major problem for ODR, but also a unique feature which may be exploited for certain applications.



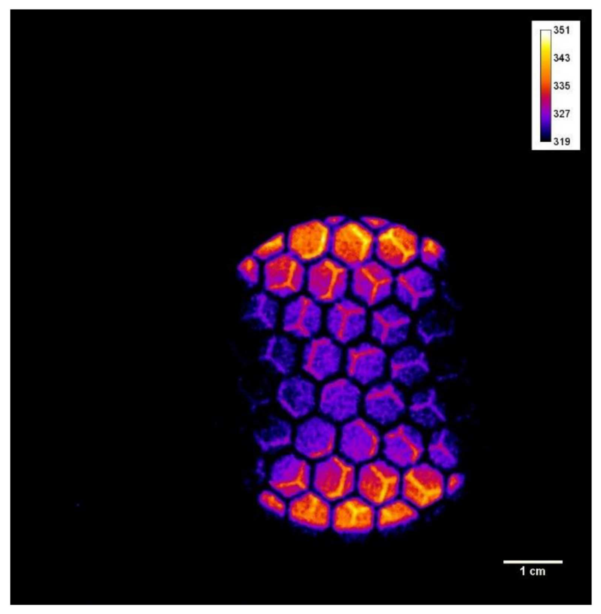


Above: SNR for images of the LED source at 1 m, various foci
Below: SNR for images of the Po-210 "can" source at 1 m, various foci





Above: Nitrogen fluorescence spectrum due to alpha radiation [2]
Below: a sample nitrogen ionization/excitation scheme [2]



Left: ~5 mCi Po-210 "can" source
Right: Dose field image produced by this source

Results and Further Work:

- Clear trends were observed in the relationships between SNR and focal length for both the LED source and the Po-210 sources.
- These trends can be exploited to locate a radioactive source from a no a priori knowledge basis, from the following method:
  1. From a stationary camera position and with a variable focus lens, take images at many known focal lengths within the region of interest.
  2. Process images to determine SNR of each image.
  3. The focal length used for the image which has the highest SNR is the approximate axial location of the source.
- The issue of overwhelming UV background from solar and man-made sources is still a significant issue for realistic field applications of this technique, so this work should be repeated to examine the less intense solar-blind region of air radioluminescence.

Acknowledgements:
My mentor, Jeff Martin, has been hugely influential on me and this project, and advised me to carry out most of this work. I also want to thank Rick Harrison, whose lab and equipment I used to conduct this research, and with whom I always have the most stimulating conversations in that lab.

References:
[1] Knoll, G. (2010). *Radiation Detection and Measurement.* Ann Arbor, MI: Wiley and Sons
[2] Harrison, R. K., et. al (2015). New radiological material detection technologies for nuclear forensics: Remote optical imaging and graphene-based sensors. Sandia National Laboratories. doi: 10.2172/1214453

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