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X-ray Security Imaging on Personal Dosimetry

July 2024

Derek Tian Lewis, Connor Cronin Williams, Seth J Kanter

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Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

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X-ray Security Imaging on Personal Dosimetry

Derek Lewis[1,2,*], Connor Williams[1,*], Seth Kanter[1]

[1]***Idaho National Laboratory***, *Radiological Engineering, Radiological Controls & Emergency Management, Idaho Falls, ID, 83415*

[2]***Georgia Institute of Technology***, *Department of Nuclear & Radiological Engineering and Medical Physics, Atlanta, GA, 30318*

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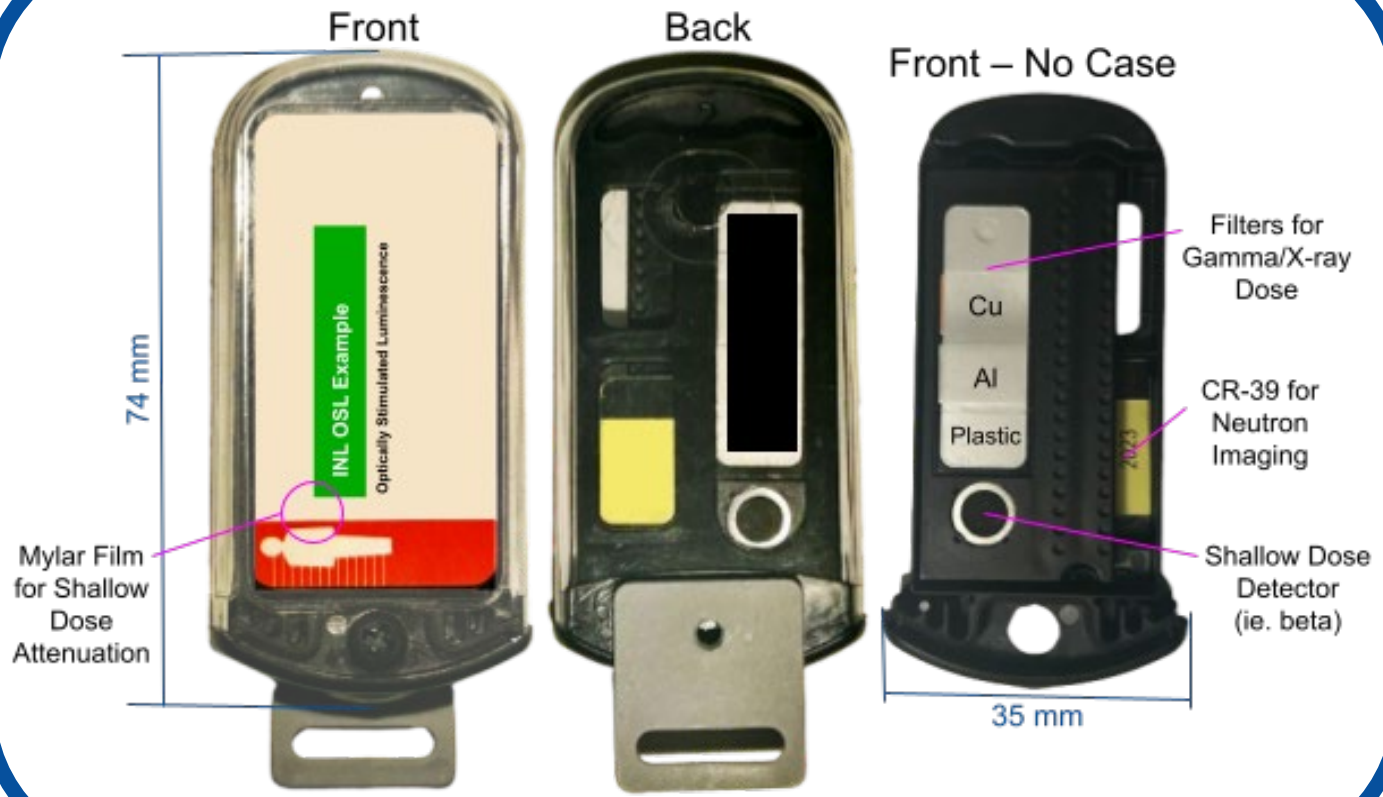
Idaho National Laboratory

www.inl.gov

*For more information: dlewis310@gatech.edu | connor.williams@inl.gov

Optically Stimulated Luminescence (OSLs)

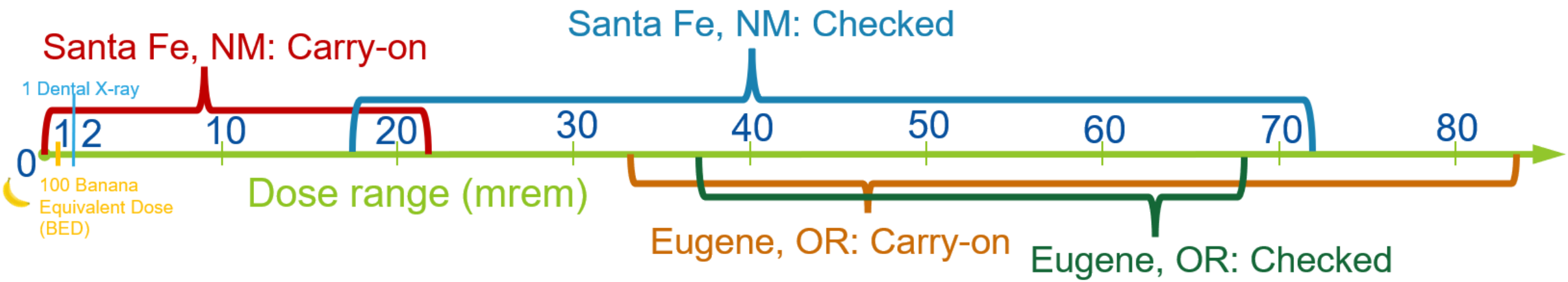


- A type of **Personal Dosimeter**
- Occupational **Dose Records**
- Mandated by Federal Regulations

Optically Stimulated Luminescence (OSLs)

Advancing X-ray Imaging Technology in Airports

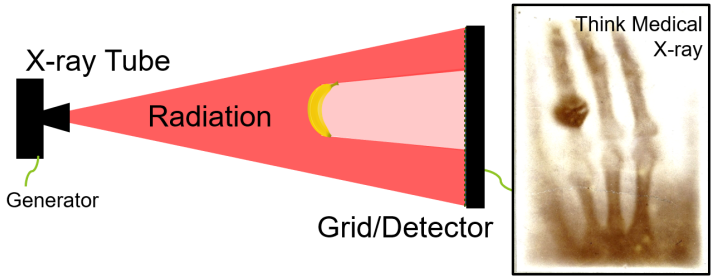
Preliminary trials show **high variance**!



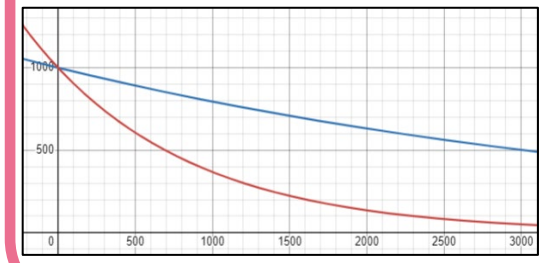
… but why?

Advancing X-ray Imaging Technology in Airports

Low Dose Single X-ray **Projection**:



Dual Energy (DE) X-ray Projection:

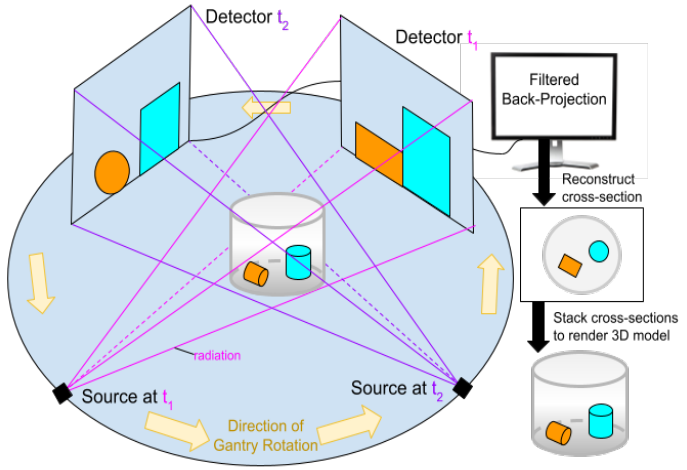


Attenuation is dependent on photon **energy** and the medium's ***Z_{eff}*** *(atomic number)*

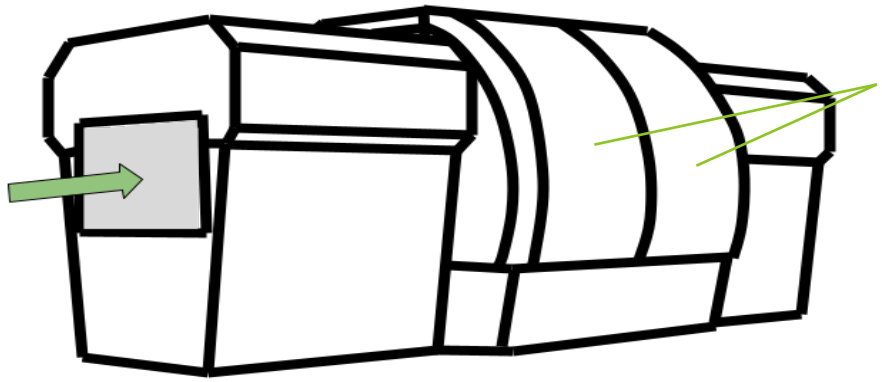
We can **characterize** materials by solving for their Z_{eff}
(Unfortunately, water and explosives' Z_{eff} are very close)

1974 — 2001 — More Dose! — 2024

Computed Tomography (CT)



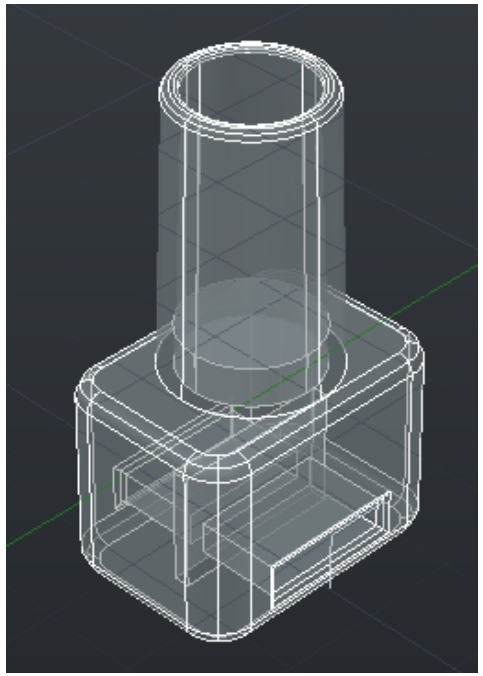
DE CT uses the Z_{eff} and **volume-density** to distinguish between liquids and explosives:



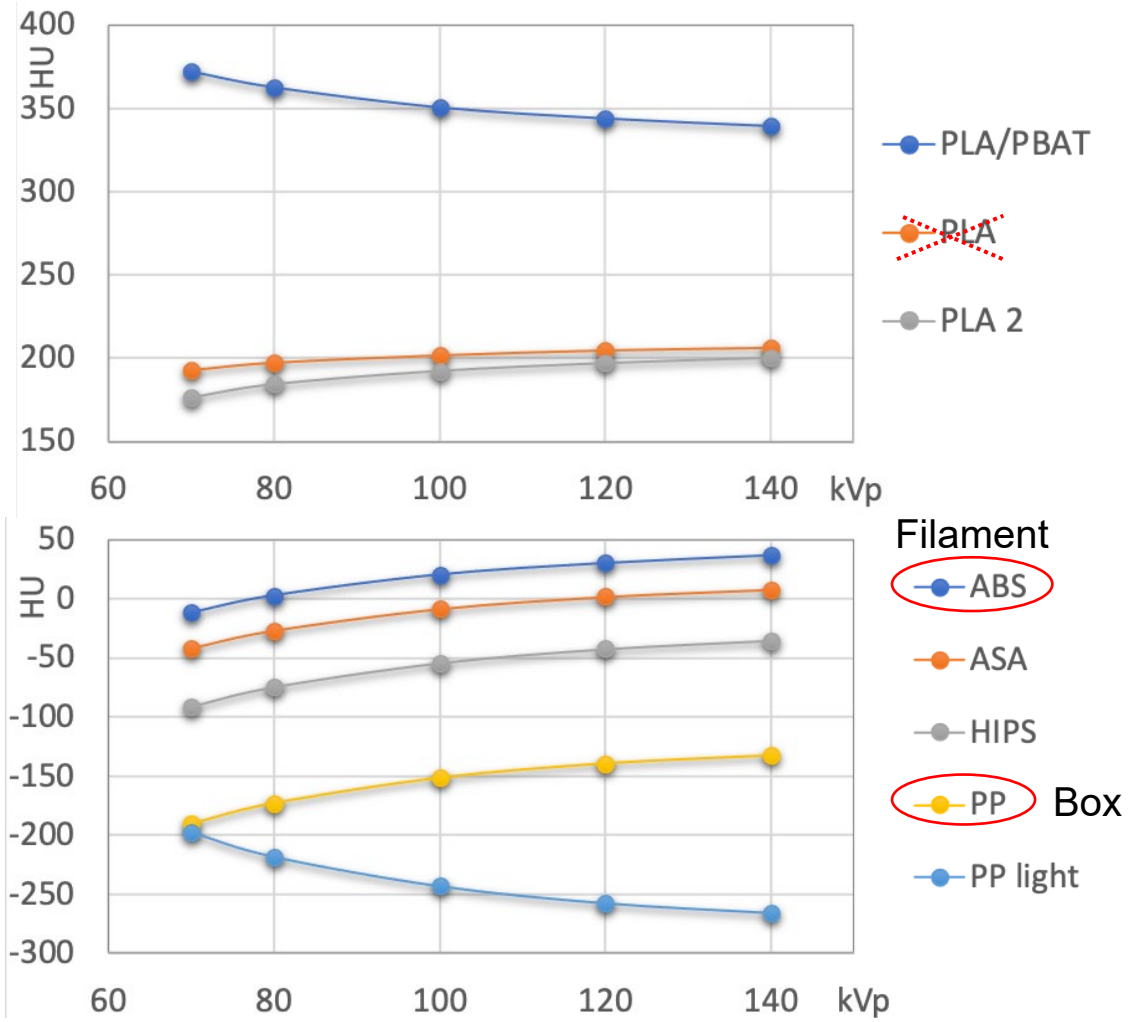
DE CT Carry-ons

Methods

- 3D Modeling, Printing, and Theory



Attachment for OSL clip



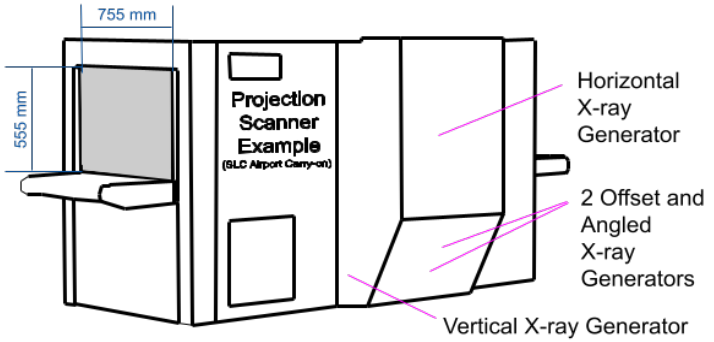
[1]Ma X, et al. (2021). Classification of x-ray attenuation properties of additive manufacturing and 3D printing materials using computed tomography from 70 to 140 kVp. Frontiers in Bioengineering and Biotechnology, 9: DOI=10.3389/fbioe.2021.763960 ISSN=2296-4185

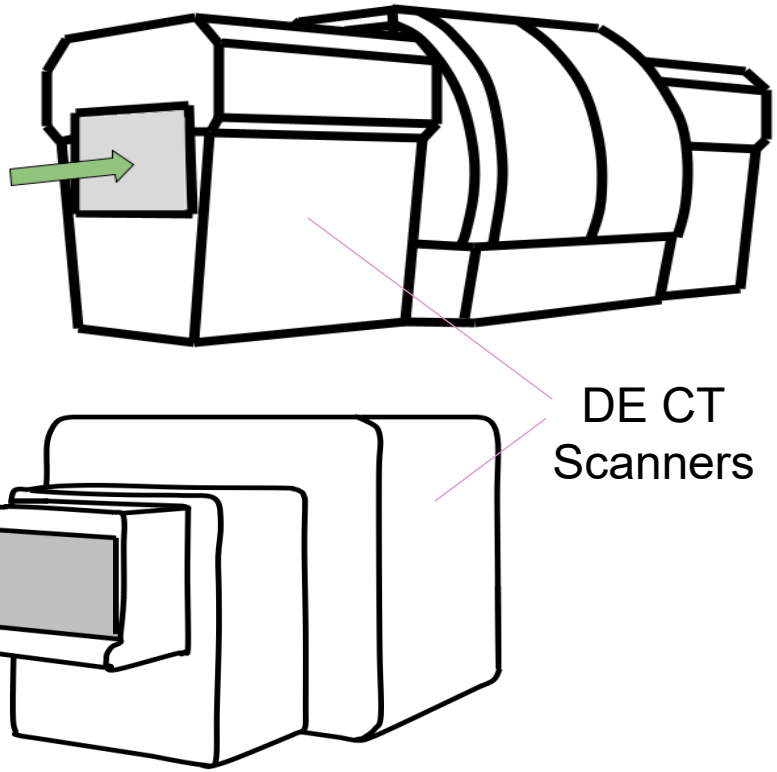
Methods – SLC Tests





- **300 OSLs**
  - **Cross-section**
  - **Luggage**
  - Reference Bag Shielding
  - Orientation
- Scintillation Detector
  - X-ray Spectrum
  - Dose vs. Time

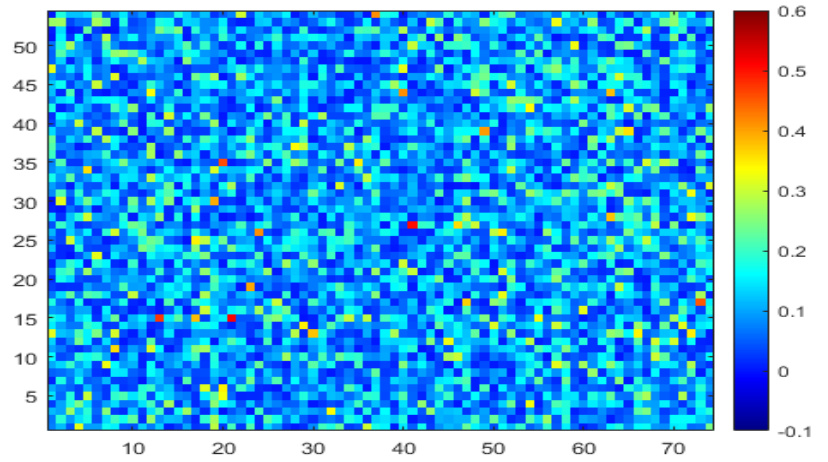




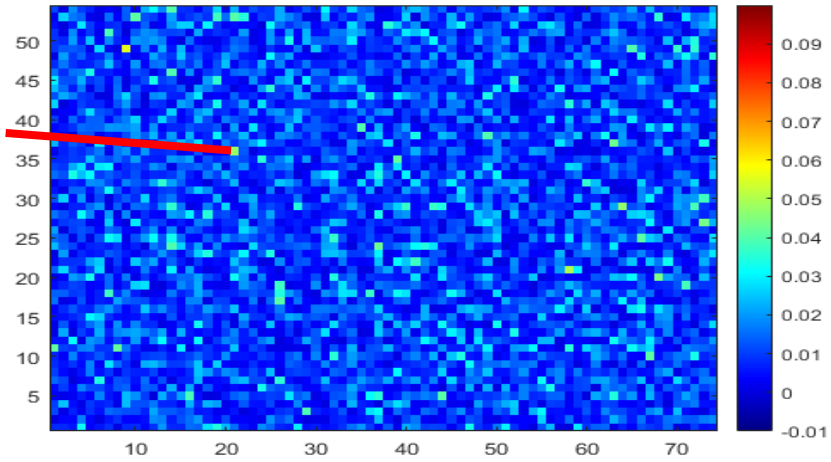
Theoretical Predictions – Projection Imaging

Resonance

1 mm^2 Interference Pattern Averaged Over cm^2



0.1 mm^2 Interference Pattern Averaged Over cm^2

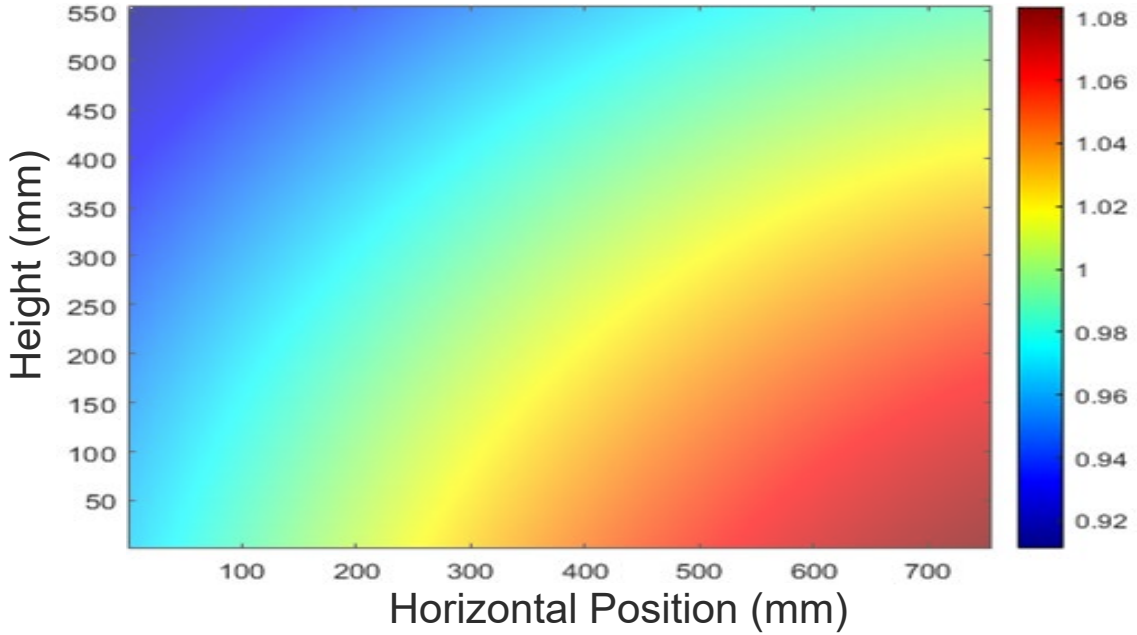


Short wavelength resonance is mitigated by the size of the OSL detector (1 cm^2)

Near Uniform Dose

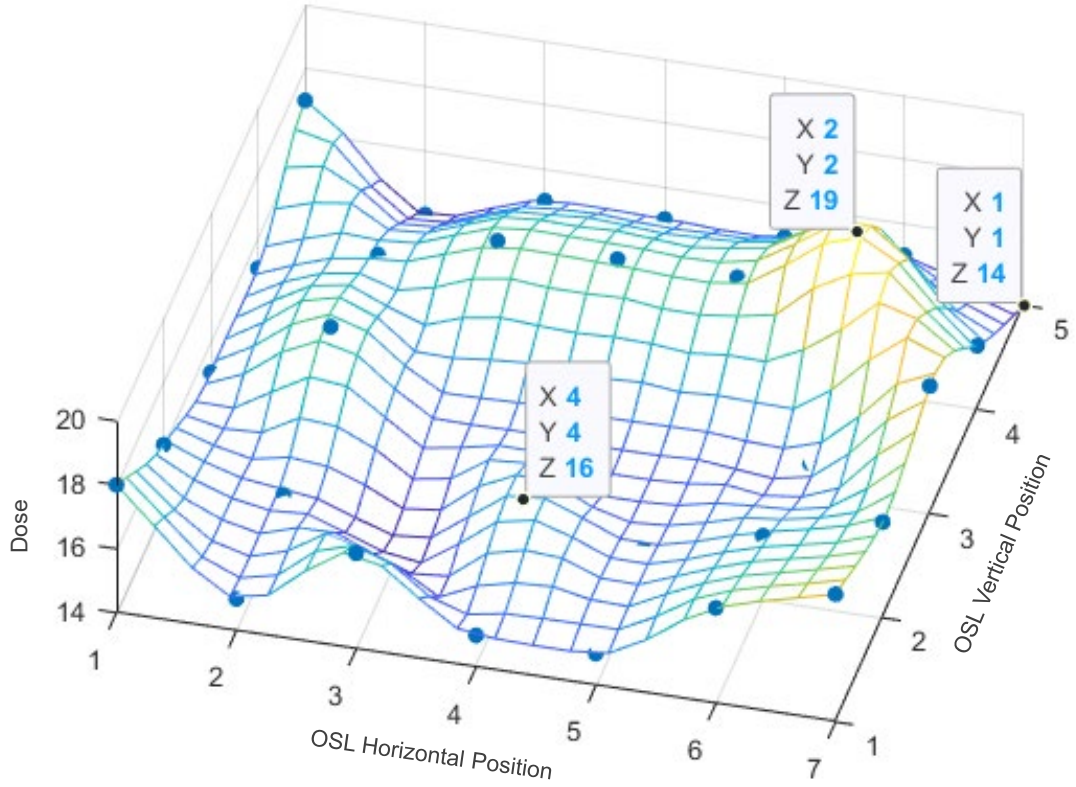
Cross-sectional Dose Relative to Average

(No Inverse Square)



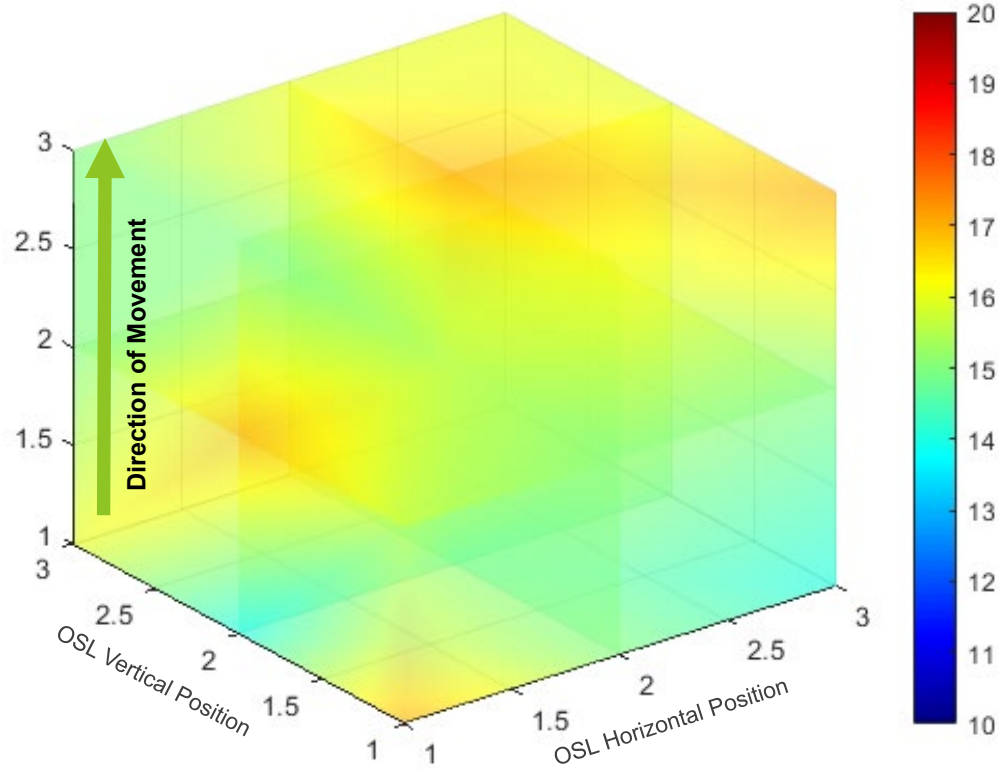
Experimental Findings – Projection Imaging

Cross-sectional Dose†† (mrem)



Suggests **normal distribution**

Luggage Dose†† (mrem)



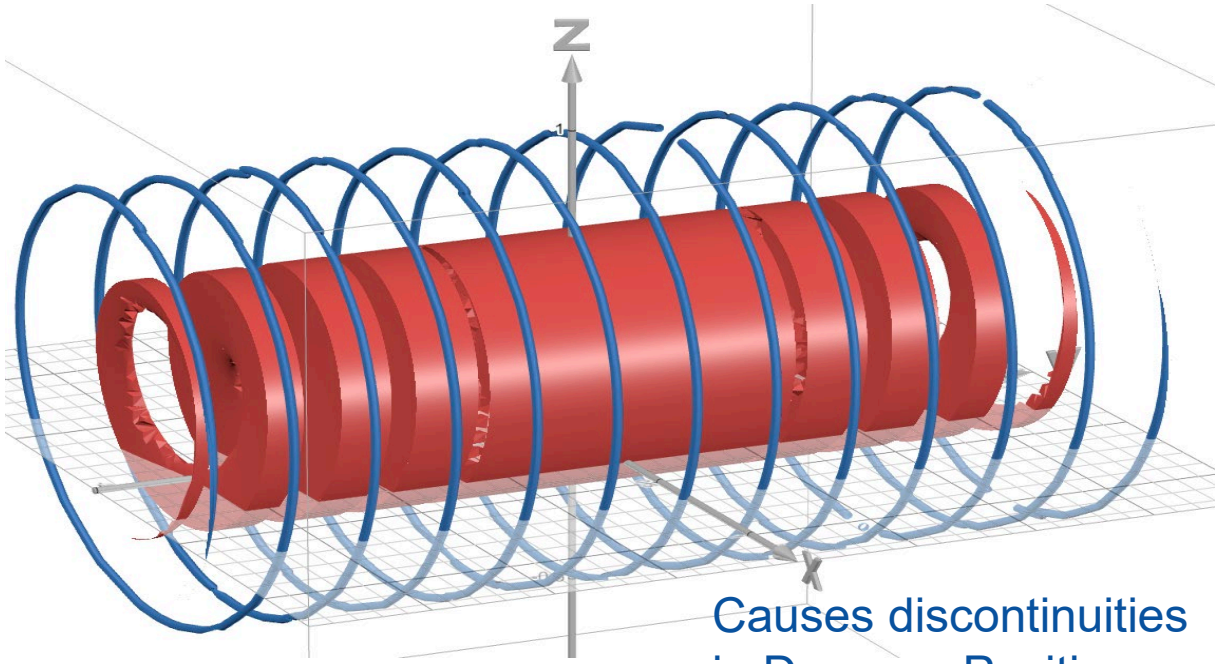
Dose appears to be **independent of position**

††Interpolated

Theoretical Predictions – CT Imaging

Time (*y*-axis) Dependence of X-rays Incident on Cross-section (*xz*-plane)

Relative path of source depicted in blue



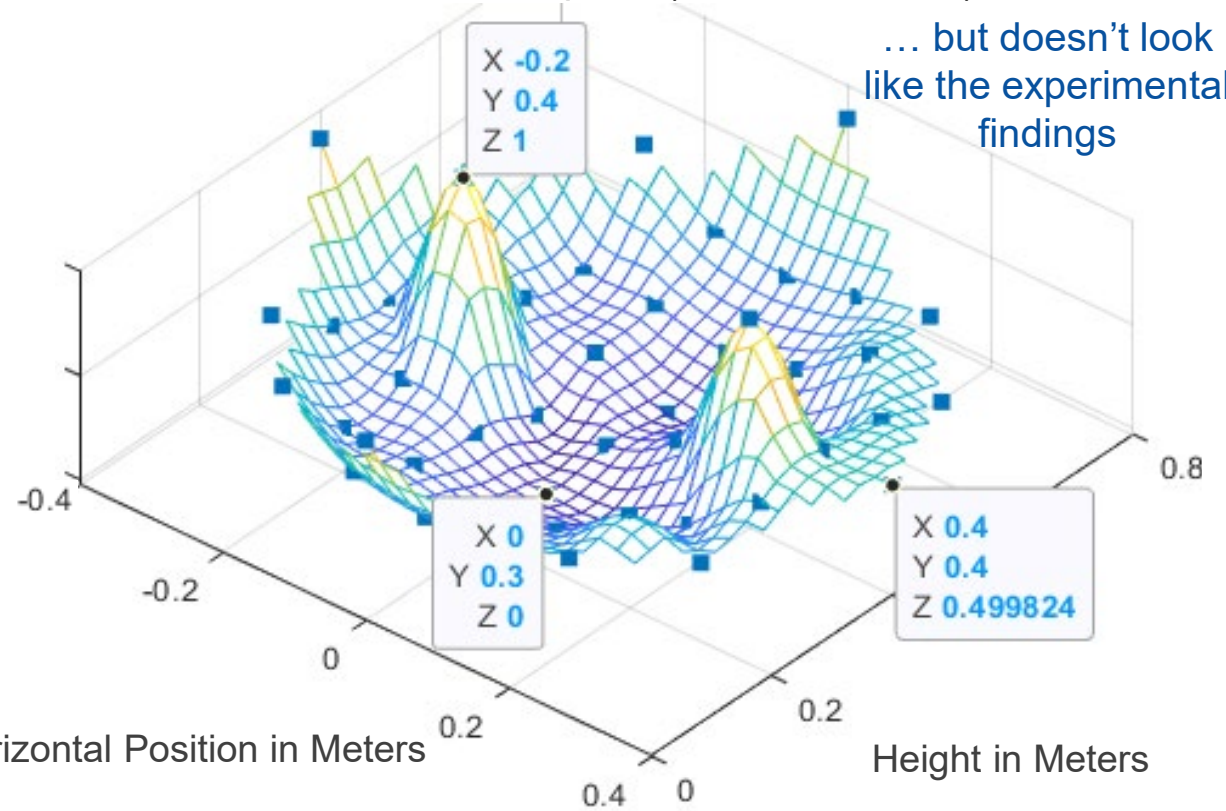
Causes discontinuities in Dose vs. Position

$$\pm 2\pi t \cot(\Theta_A) \leq \omega\sqrt{(R\cos(\omega t) - x)^2 + (R\sin(\omega t) - z)^2}$$
$$x^2 + z^2 \leq r_{in}^2$$

Range of Cross-sectional Dose††

With Inverse Square (10 cm Precision)

… but doesn't look like the experimental findings



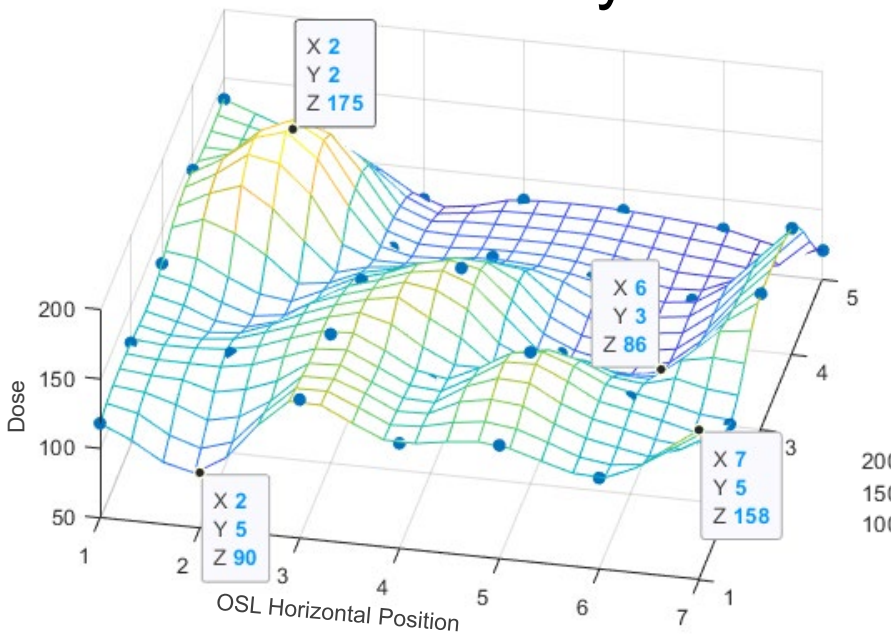
$$\text{Dose}(x,z) \propto \sum_{n=1}^{k/2} \int_{t_{2n-1}}^{t_{2n}} \left(\frac{e^{-\mu\sqrt{((R\cos(\omega t)-x)^2+(R\sin(\omega t)-z)^2+(vt)^2)}}}{(R\cos(\omega t)-x)^2+(R\sin(\omega t)-z)^2+(vt)^2}\right)dt)$$
$$\text{when } \pm\omega\sin(\Theta_A)\sqrt{-2\cos(\omega t)Rx - 2\sin(\omega t)Rx + R^2 + x^2 + z^2} - 2\cos(\Theta_A)\pi t = 0$$

††Interpolated

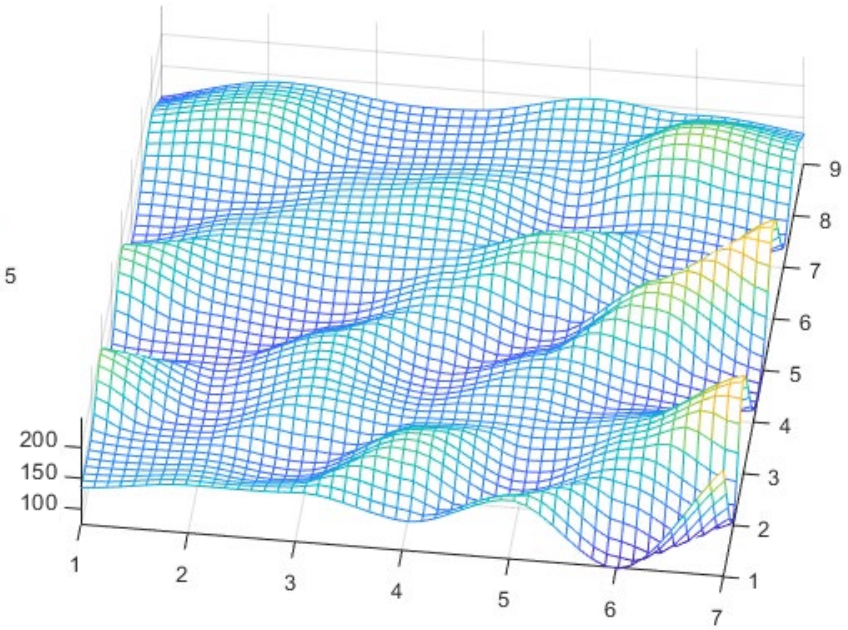
Experimental Findings – CT Imaging

Cross-sectional Dose†† (mrem)

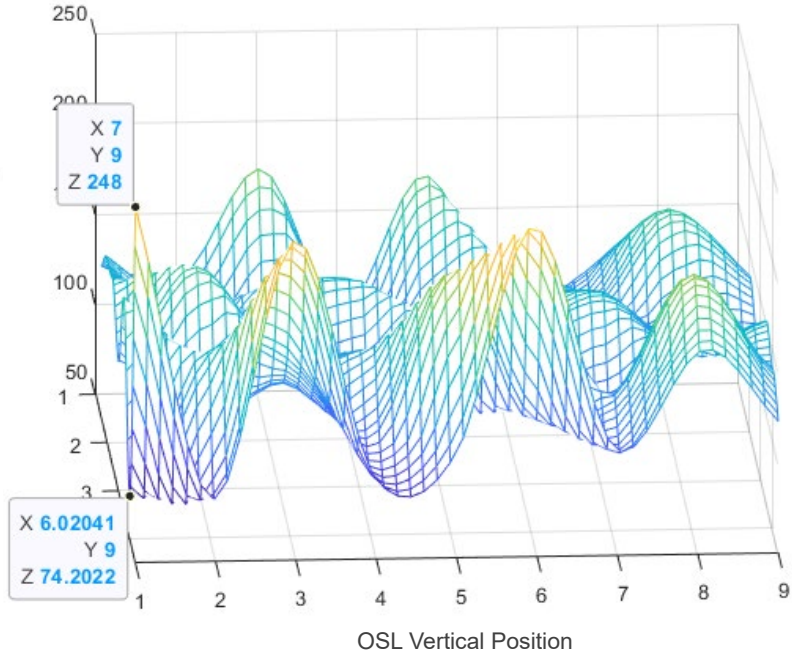
CT Carry-on



CT Checked



CT Checked - View 2



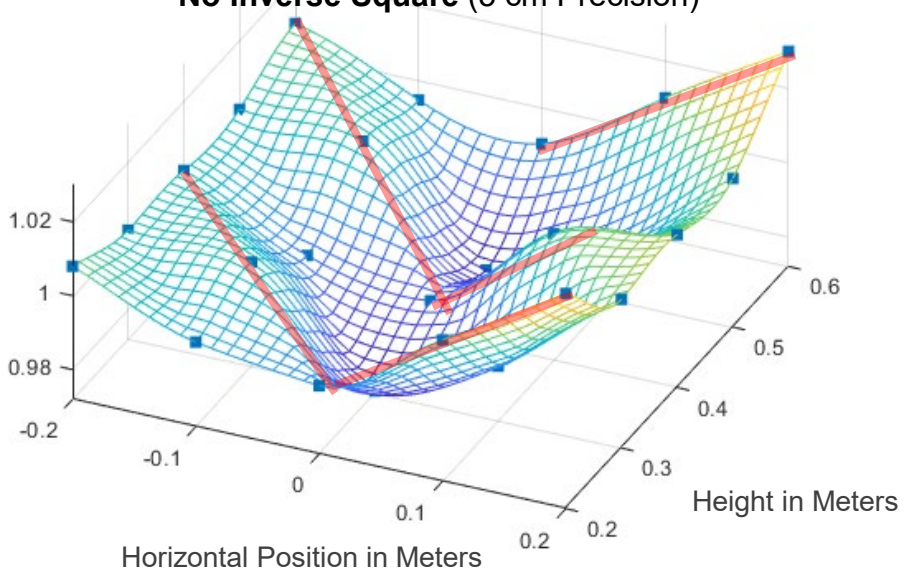
Suggests **normal distribution**

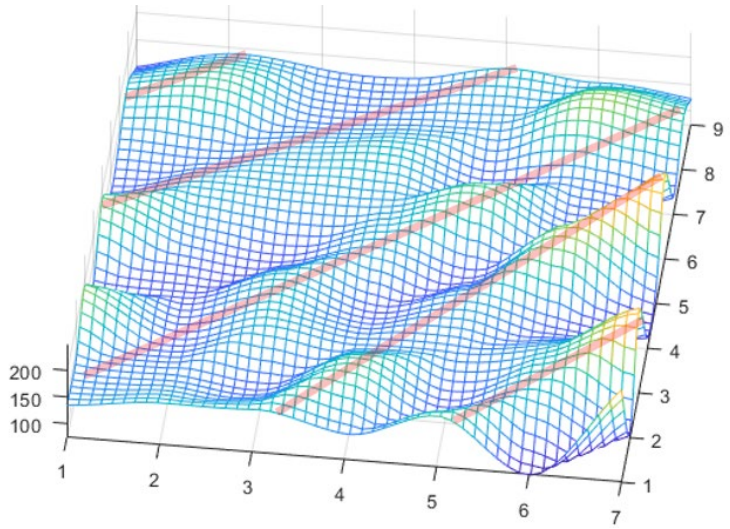
††Interpolated

Theoretical and Experimental Comparison – CT Imaging

Cross-sectional Dose Relative to Average††

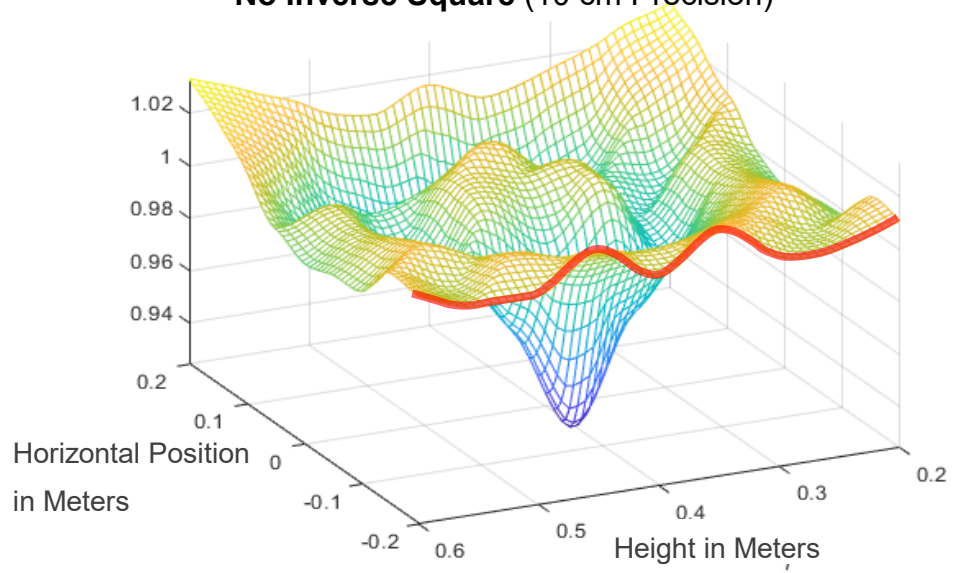
No Inverse Square (5 cm Precision)

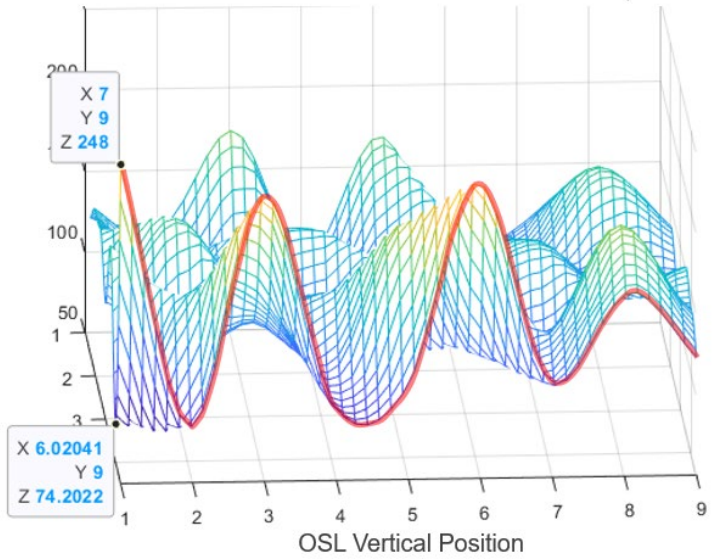




Cross-sectional Dose Relative to Average††

No Inverse Square (10 cm Precision)



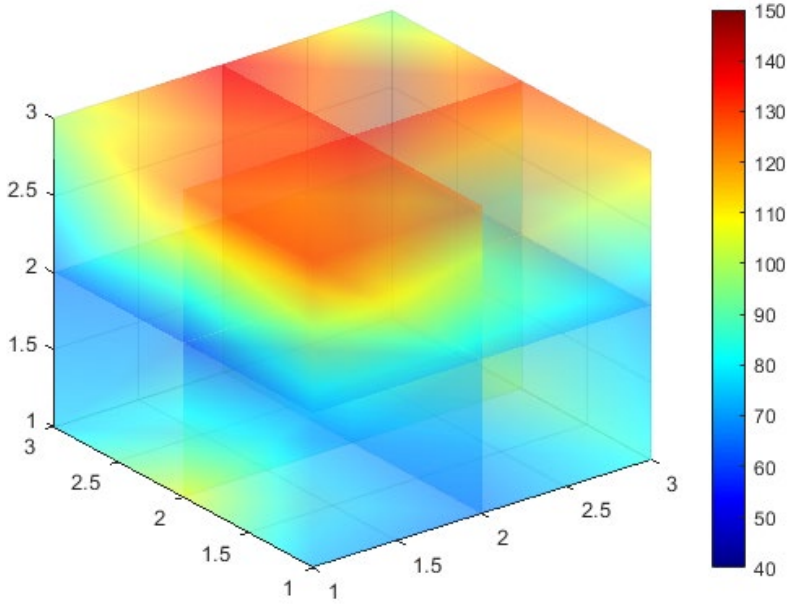


††Interpolated

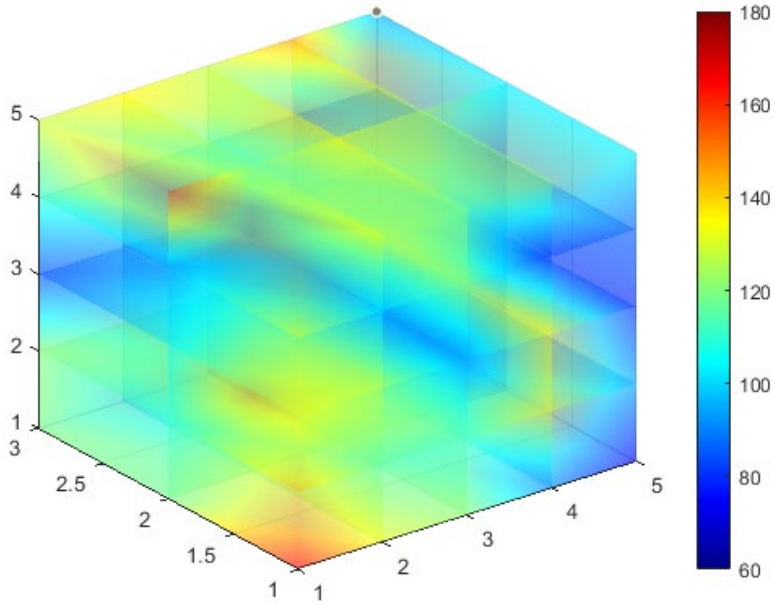
Experimental Findings – CT Imaging

Luggage Dose†† (mrem)

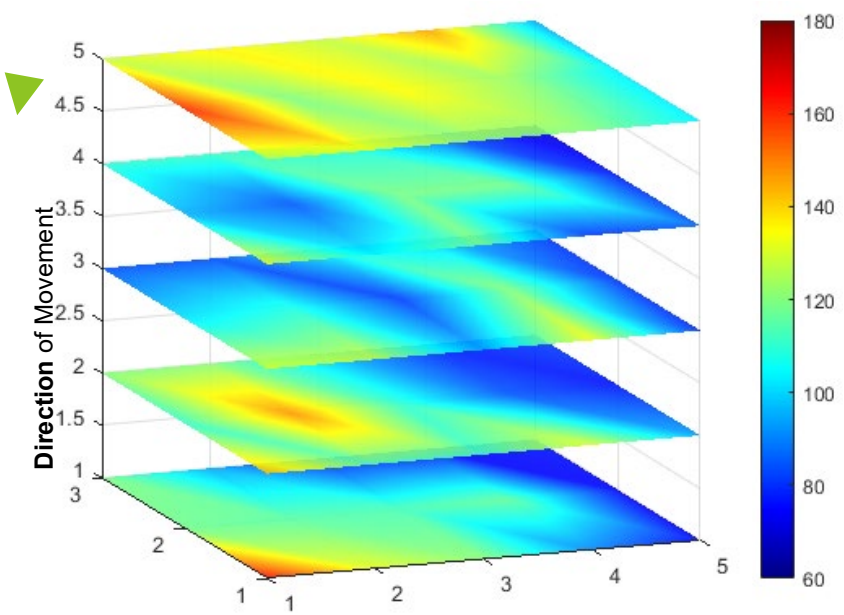
CT Carry-on



CT Checked



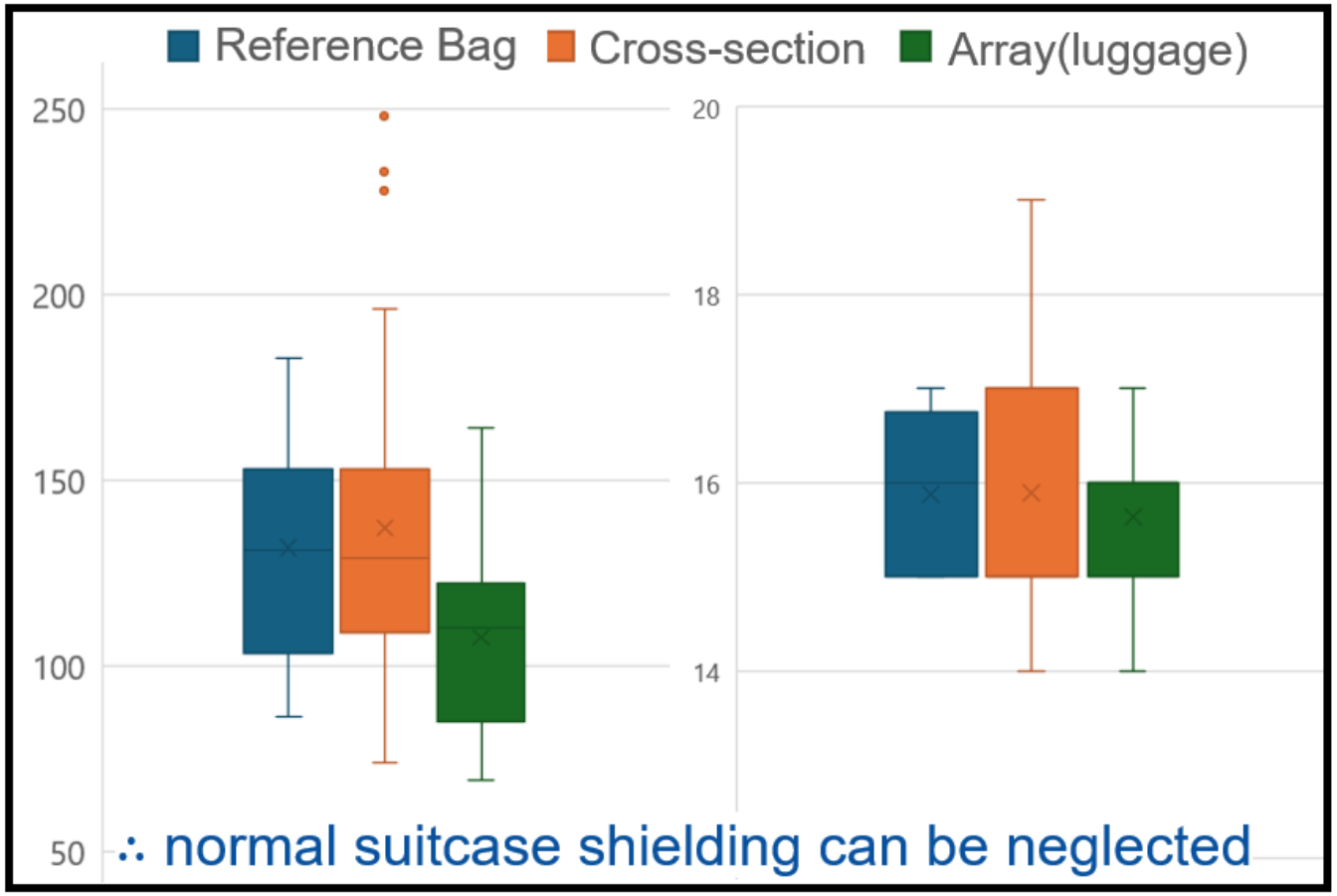
CT Checked - View 2

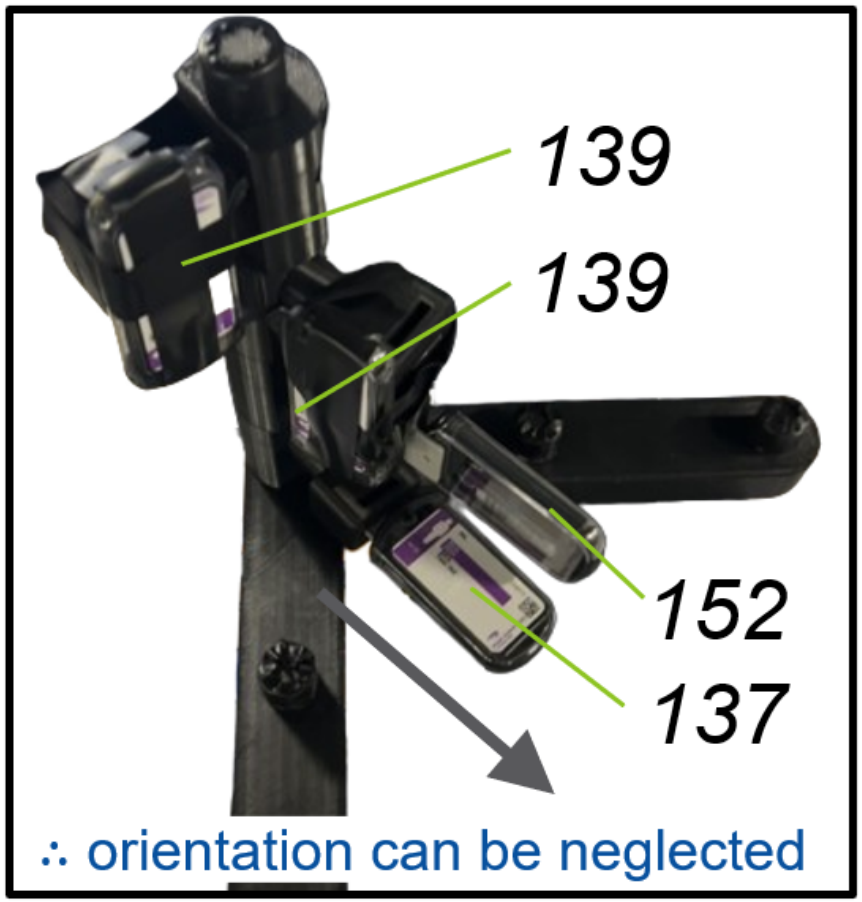


Dose appears to be **independent of position**

††Interpolated

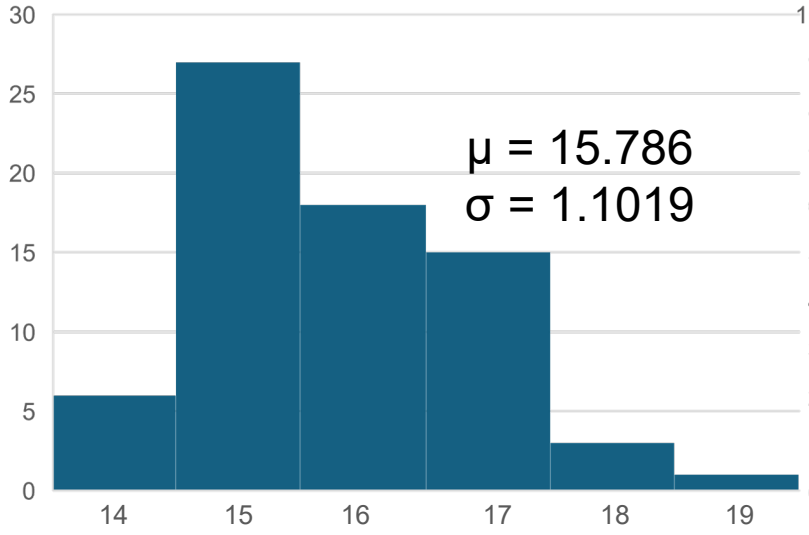
Attenuation and Orientation Tests



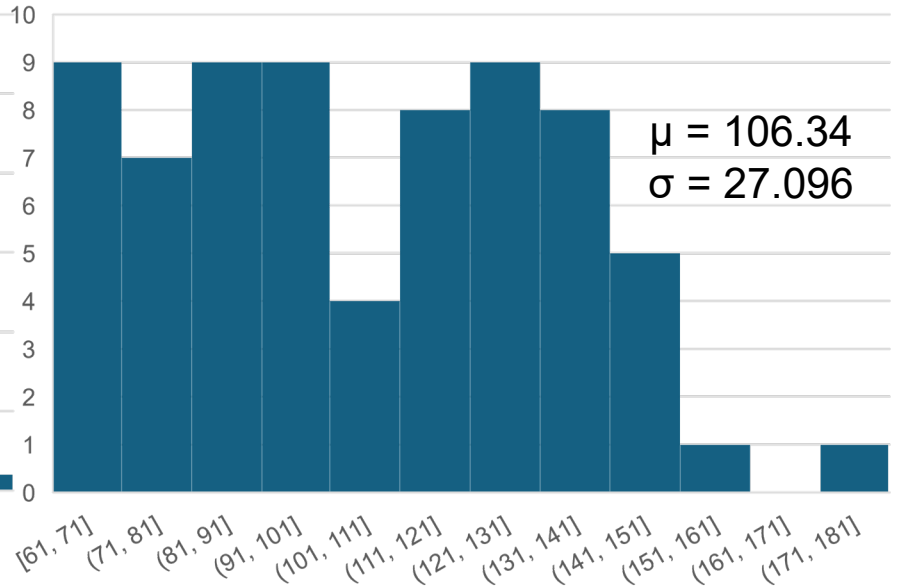


Recommendations for Radiological Control

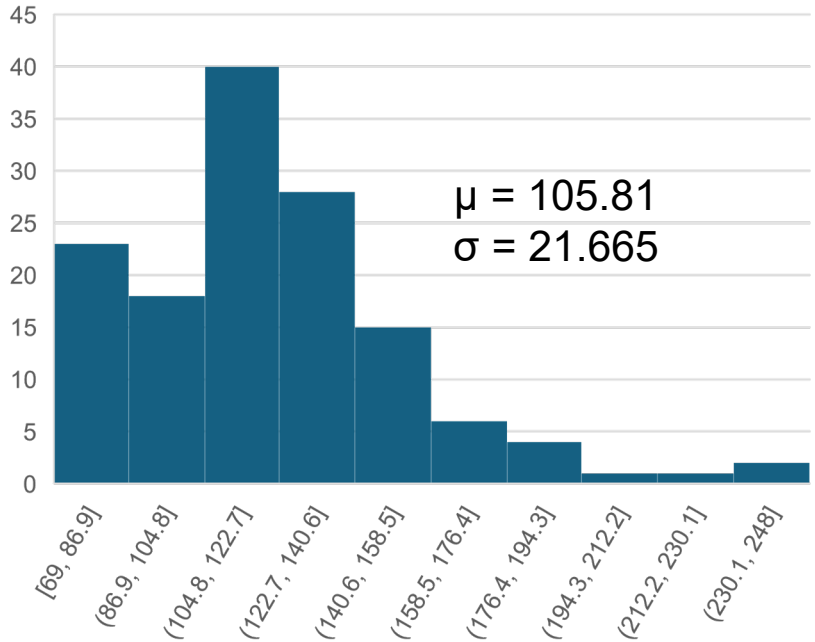
Projection Carry-on:
13.5 mrem§



CT Carry-on:
52.2 mrem§



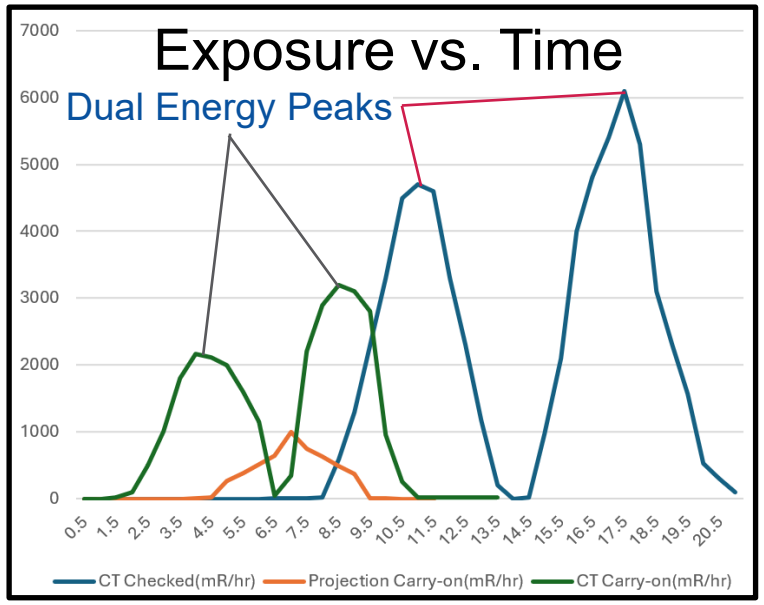
CT Checked:
62.5 mrem§



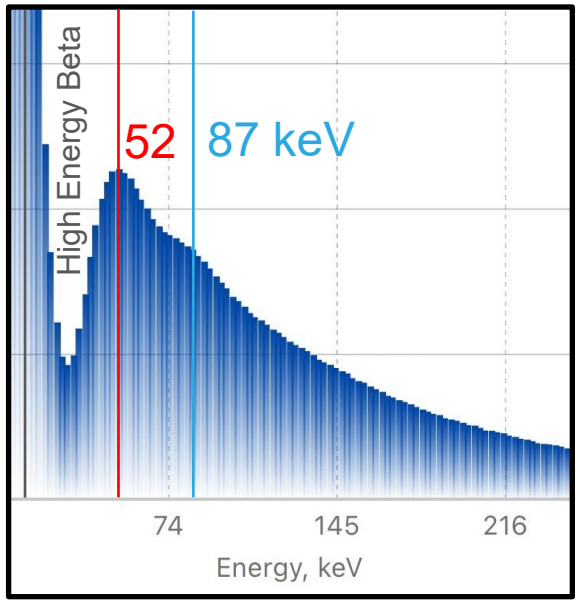
§**With 97.5% confidence** that the true mean dose is greater than the recommendation

Limitations and Future Works

Additional Airports & Scanners



Shallow Dose Variance in CT



Proprietary and Security Concerns

Acknowledgements

References

- [1]Ma X, et al. (2021). Classification of x-ray attenuation properties of additive manufacturing and 3D printing materials using computed tomography from 70 to 140 kVp. Frontiers in Bioengineering and Biotechnology, 9: DOI=10.3389/fbioe.2021.763960 ISSN=2296-4185

Questions

dlewis310@gatech.edu | connor.williams@inl.gov

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