Investigating the use of alanine-based chip cards for emergency personal dosimetry, following ionizing radiation exposures

A Monte-Carlo modelling experiment, investigating dose uncertainties due attenuation by the wearer

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CIRMS 2026 — Need

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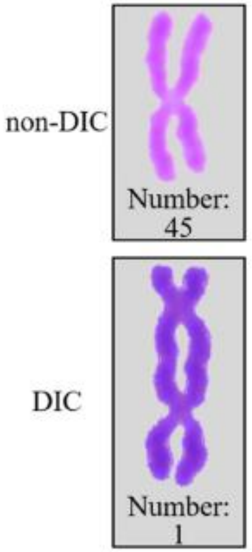
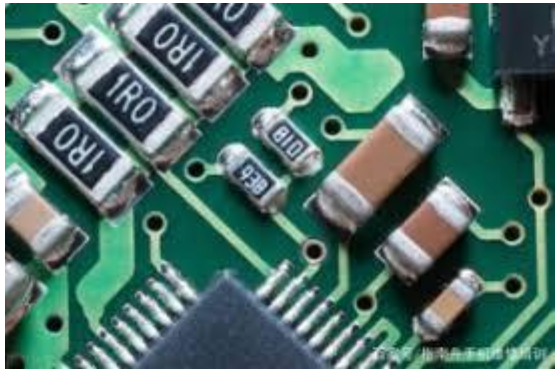
Progress in **emergency response to mass-casualty exposures** is currently blocked because we lack **capacity for large-scale biological/physical dosimetric measurements**, which prevents **rapid population dose estimates**.

Background

- In the event of a large-scale radiological exposure, identifying absorbed dose to potentially exposed individuals (>1Gy) is imperative
- Biological dosimetry resources are limited, and have a wait time (72+ hours)
- Currently, physical ‘fortuitous’ dosimetry is centred around measuring mobile phone transistors/resistors
  - Requires destruction of the device
  - Time consuming

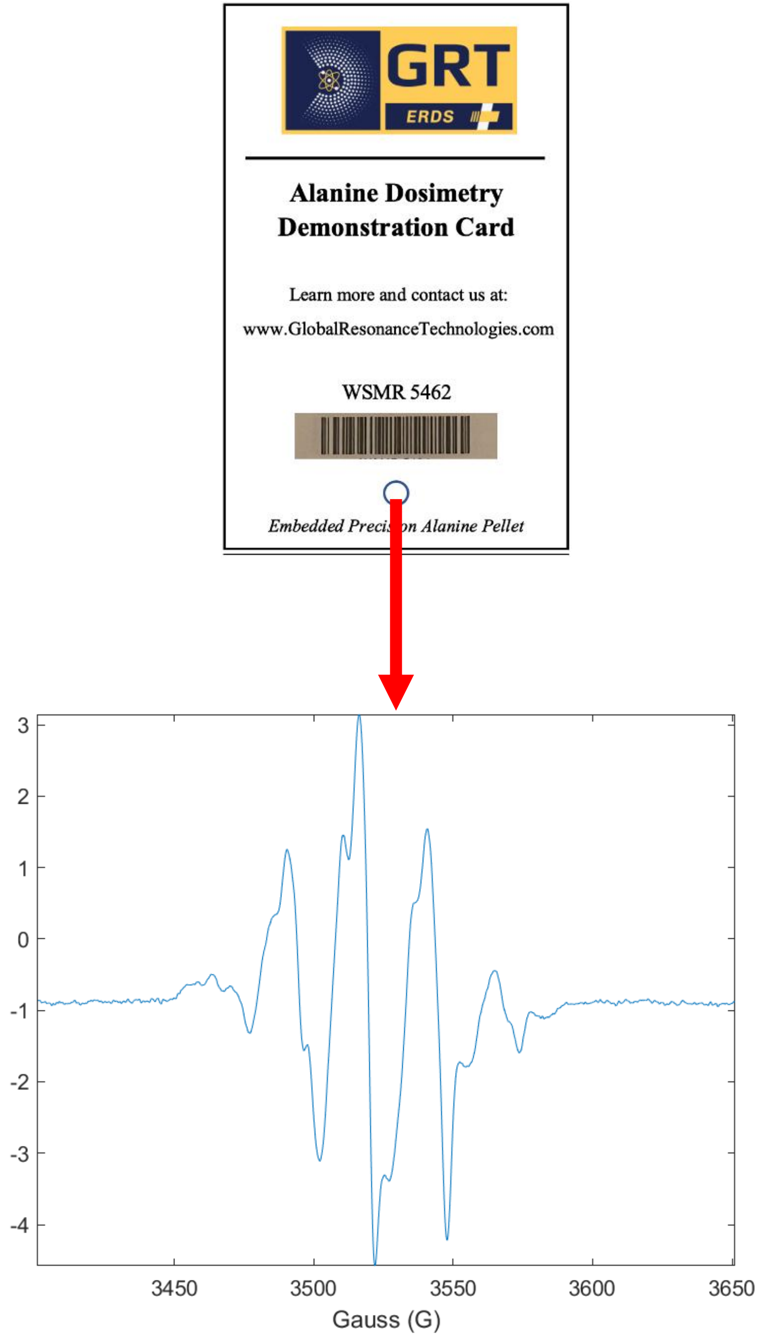




Concept

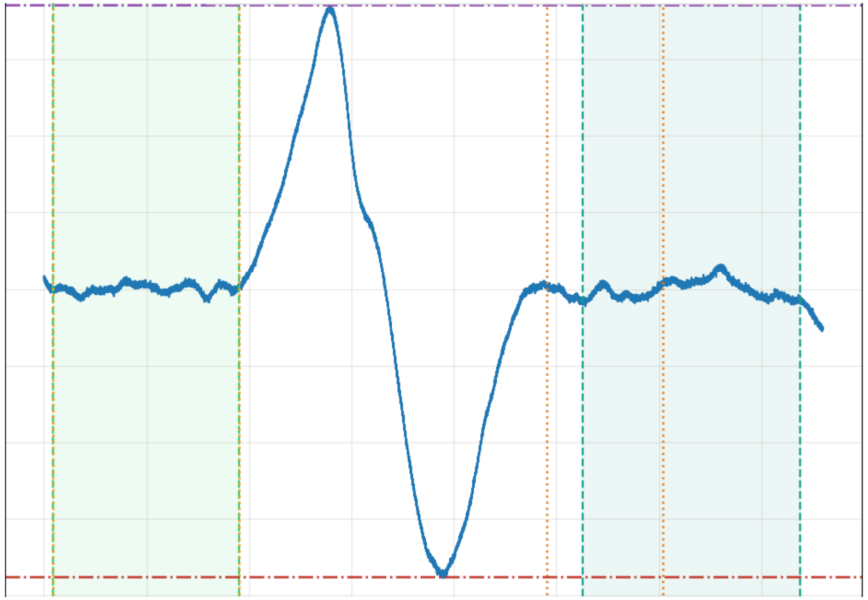
- Implementing a consistent, inexpensive, physical dosemeter across the population would allow:
  - Rapid triage
  - No ‘culturing’ delay

- Alanine, a radiosensitive amino acid, could be laminated in ID cards to enable this
  - When measured by electron spin resonance, it’s signal amplitude is proportional to dose



Project aim

- Develop a ‘card reader’ ESR spectrometer for reading clinically relevant doses



270Gy alanine ESR spectrum from current reader prototype; SNR ~ 125

- ***Conduct computational modelling to explore intrinsic uncertainties in a dose measured***
  - ***If the reader was perfect, would the dose reading be perfect?***

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Motivation

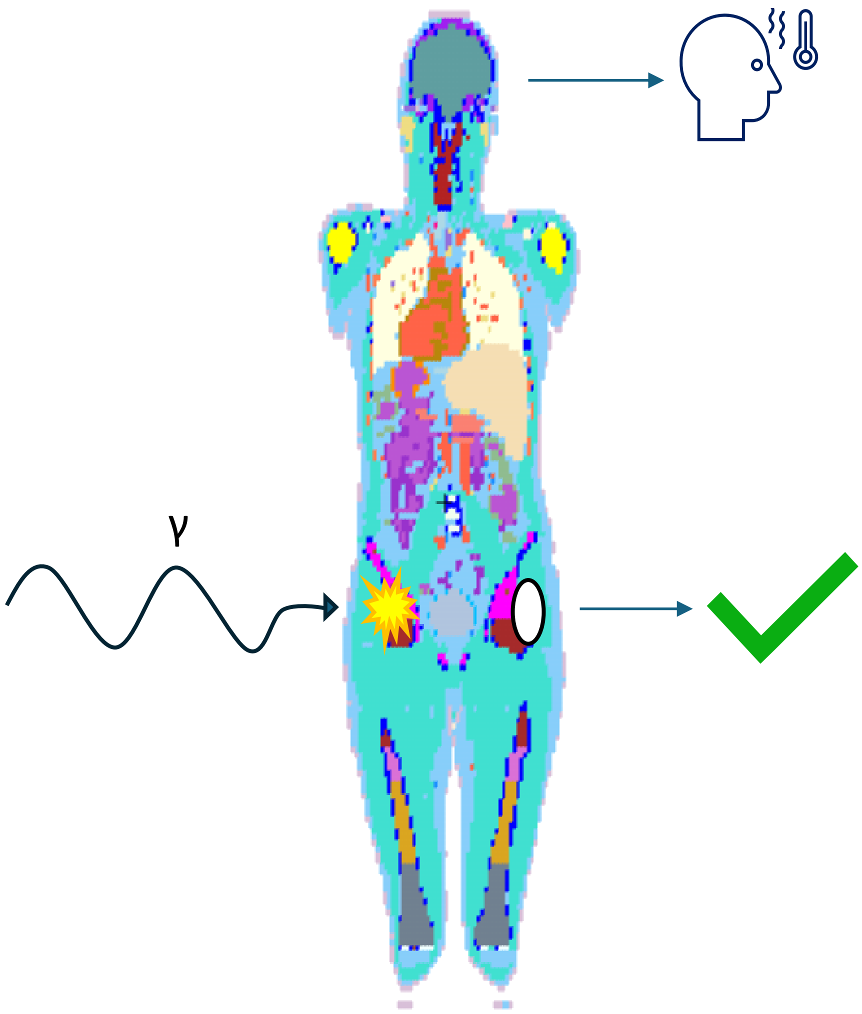
- ICRU94 – advice on physical dosimetry in emergencies
  - ‘For large-scale, acute exposure events, the quantity to be reported in initial-phase dose assessment for individuals simply be presented as “absorbed dose.”’

Motivation

- For 0.4MeV photons:
  - Half value layer (HVL) of cortical bone ~3.6cm
  - Tenth value layer (TVL) of cortical bone ~12.1cm

⇒ An individual may shield their own dosemeter from radiation

  - Could be incorrectly triaged as healthy (according to physical methods)
  - This effect could be around a 50%-90% reduction in dose measurement

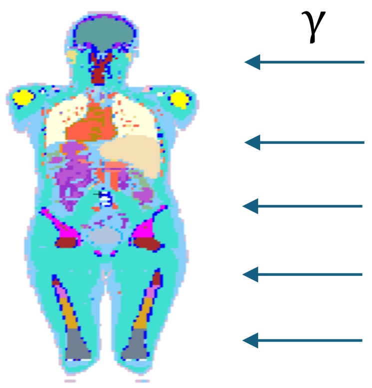


HVL and TVL calculated with NIST reference data:
https://physics.nist.gov/PhysRefData/XrayMassCoef/ComTab/bone.html

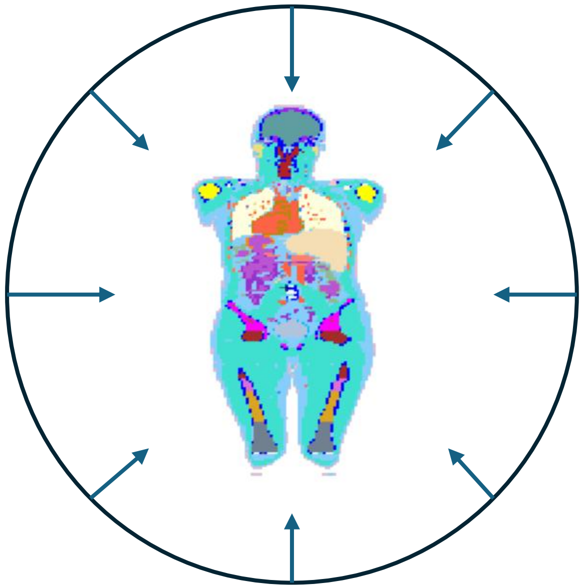
Methodology

We consider 2 exposure geometries:

- Short-timescale, plane parallel (improvised nuclear device or detonation)
  - Question: What is the maximum attenuation the wearer can shield their dosemeter by?

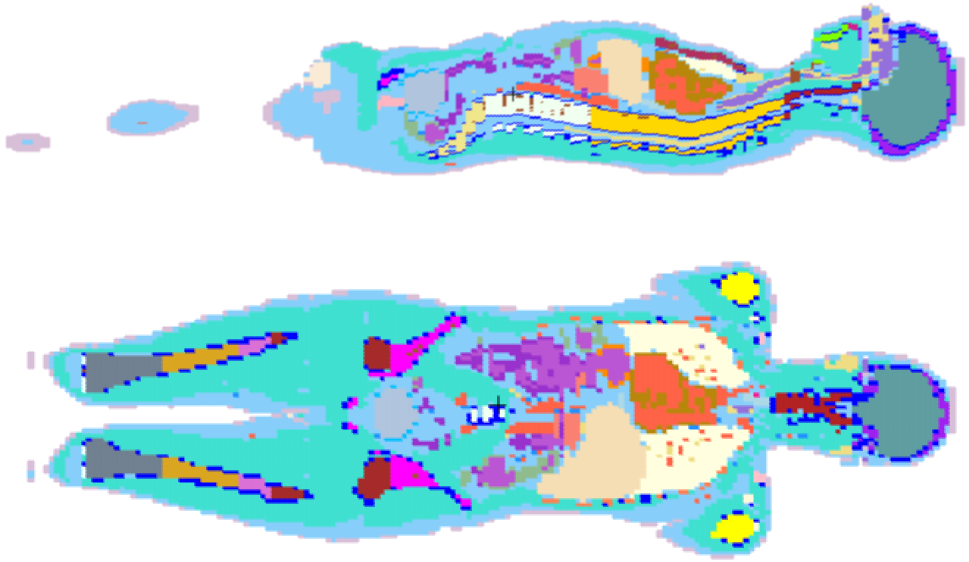


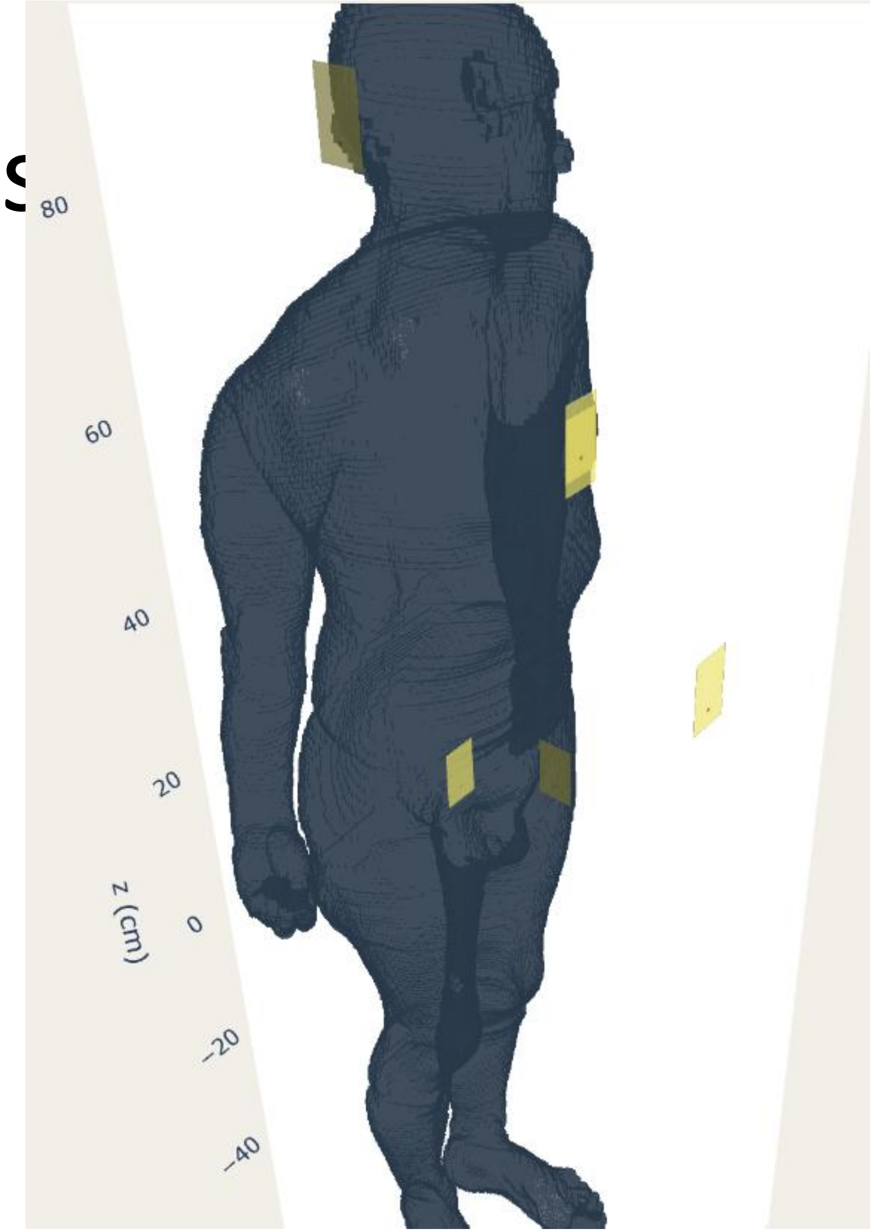
- Longer-timescale exposures (RDDs, fallout, in-place device):
  - *Isotropic – isotropically emitting sources on a spherical surface*
  - *Rotational – sources on a spherical surface emitting towards the phantom*
  - Question: What is the average attenuation an individual shields their dosemeter by?



Methodology – Short exposures

- Experiments were conducted in MCNP 6.3, with the ICRP 110 male voxel phantom
- Alanine cards were paced in 6 positions on the phantom

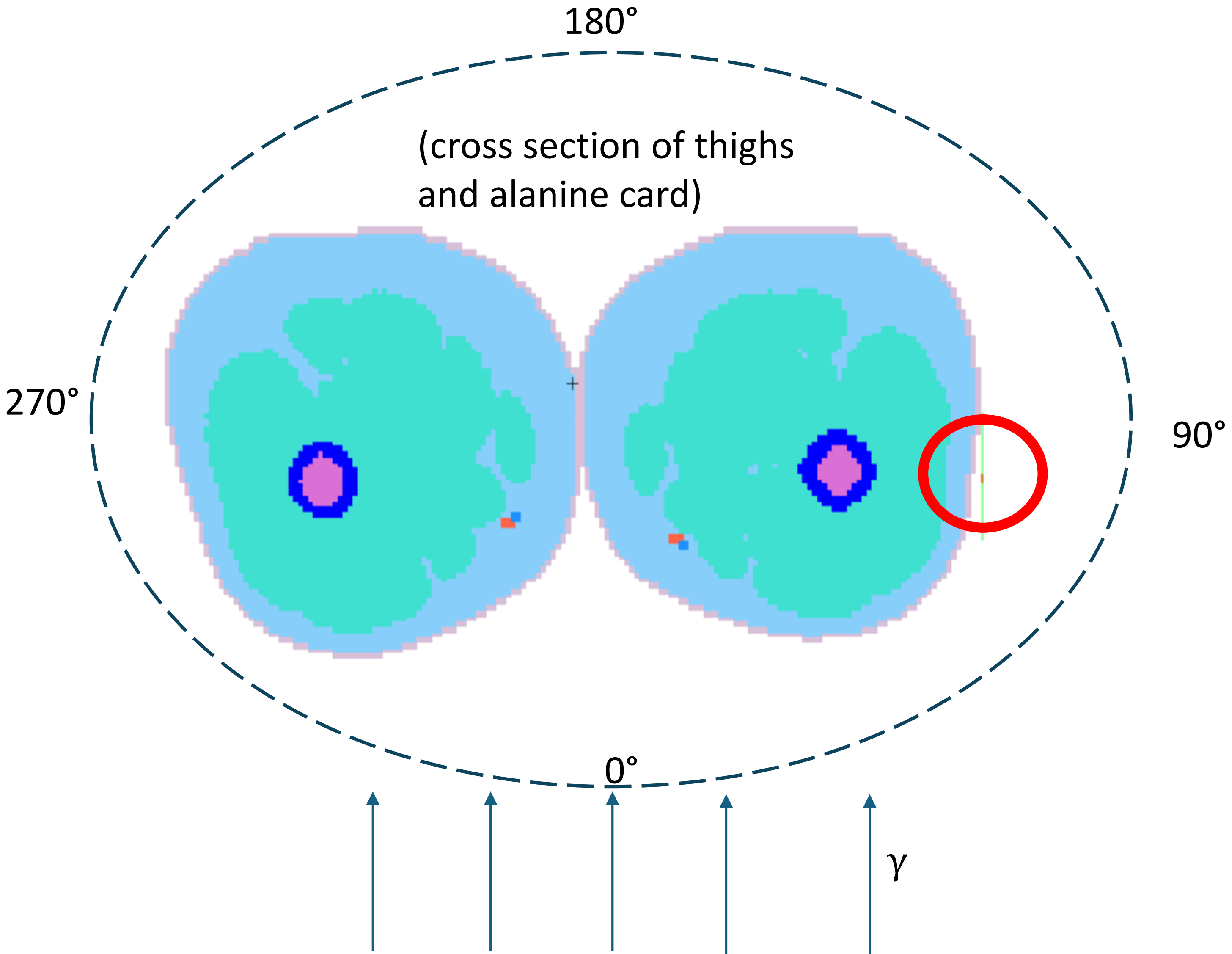




Graphical rendering of only the surface of the phantom (+pellets) for plotting

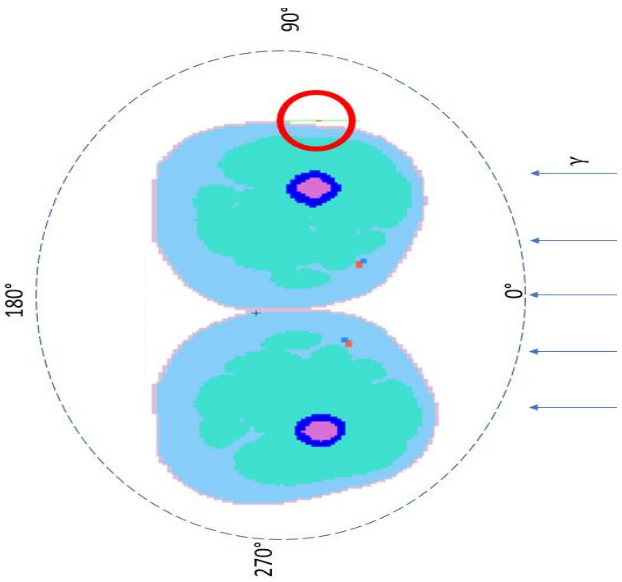
Methodology – Short Exposures

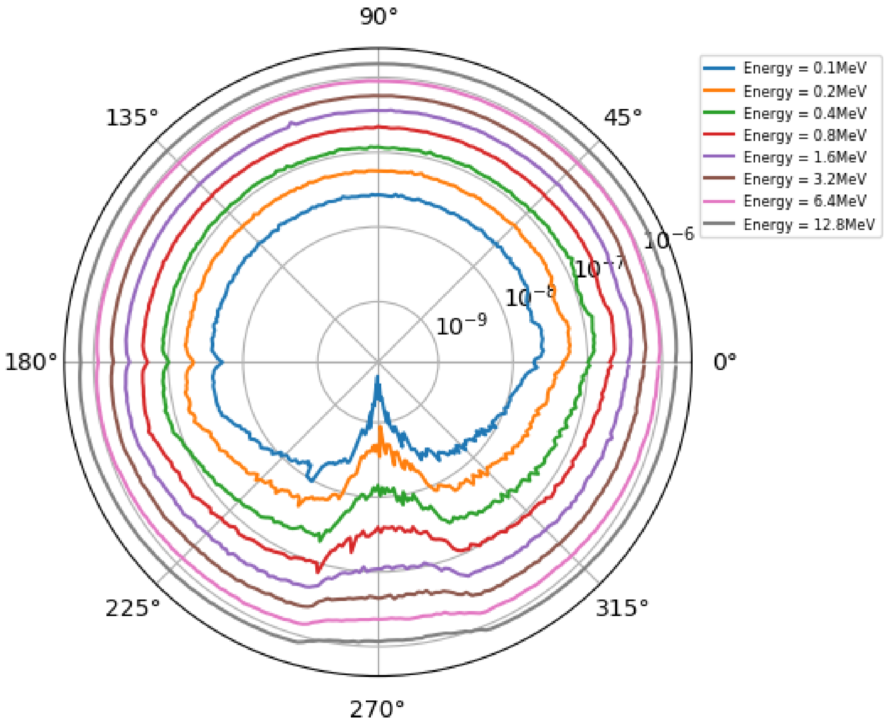
- Plane parallel source rotated in 1° steps around phantom
- Energy varied from 0.1 MeV to 12.8 MeV
- Recorded dose to the alanine pellet, not the phantom
- Computation time chosen so most statistical uncertainties for attenuated positions were below 20%.



Raw data – Short Exposures

- For each (position, energy), we calculated:
  - Maximum dose (average of largest 10% of points)
  - Minimum dose
- Value of interest – Max/Min ratio
  - Maximum possible attenuation of measured dose due to body attenuation

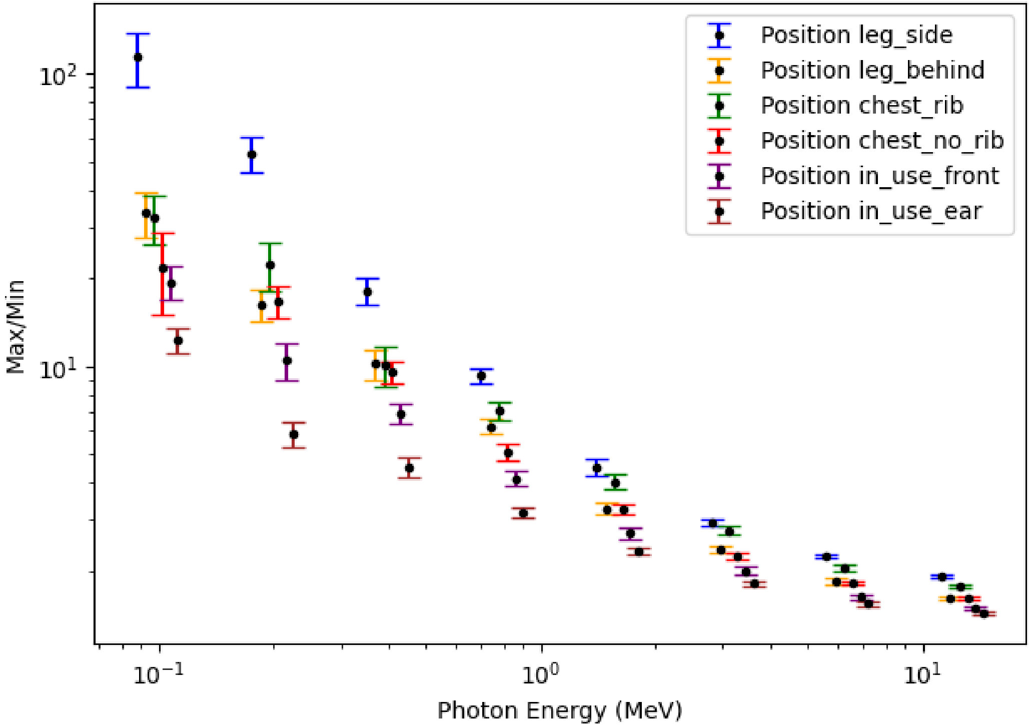




Side leg position: Measured dose vs source angle

Results – Short Exposures

- For photon energies of 0.1-0.4 MeV:
  - Dose to pellet can be reduced by 100x-10x due to body-attenuation
- Ratio drops exponentially with increasing photon energy
- At 12.8 MeV:
  - $Max/Min < 2$

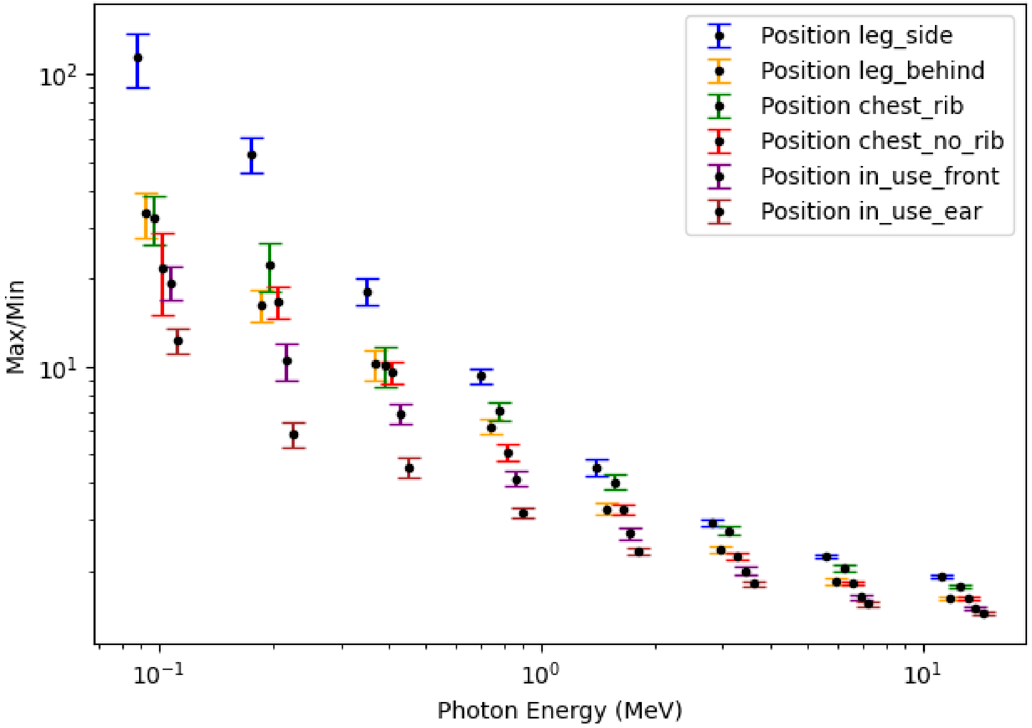


Maximum / Minimum measured dose vs photon Energy for each dosemeter position

Interpretation – Short Exposures

- Below 1 MeV:
  - Most positions are unattenuated
  - Some dosemeters will measure at least 10x less dose than the wearer – if facing an ‘unlucky’ direction
  - Individual dosemeters are not reliable indicators of dose for directional exposures

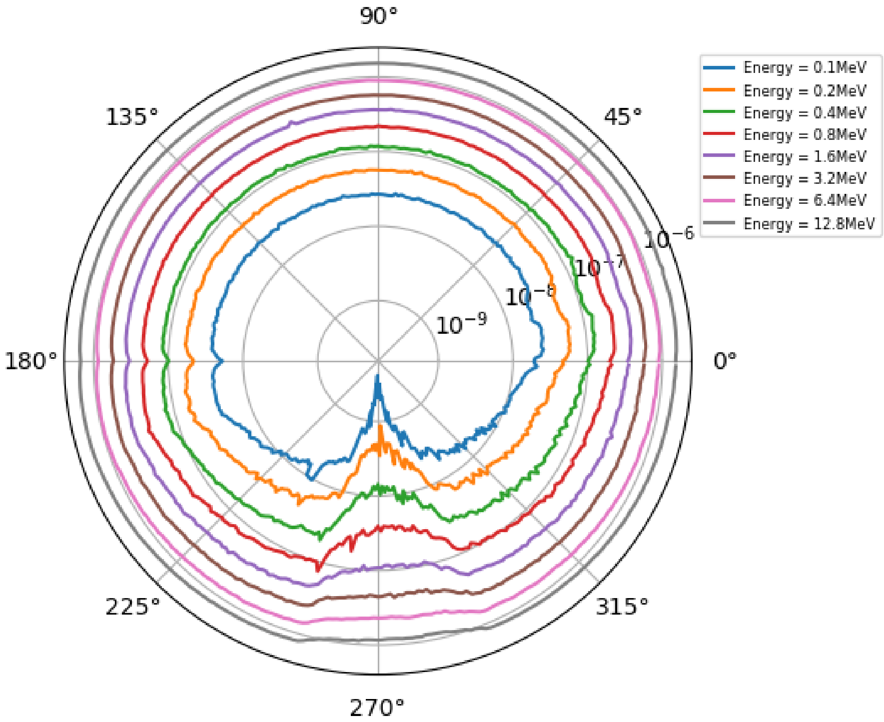
⇒If location of individuals at time of exposure is known, geographical clustering of individuals could solve this issue



Maximum / Minimum measured dose vs photon Energy for each dosemeter position

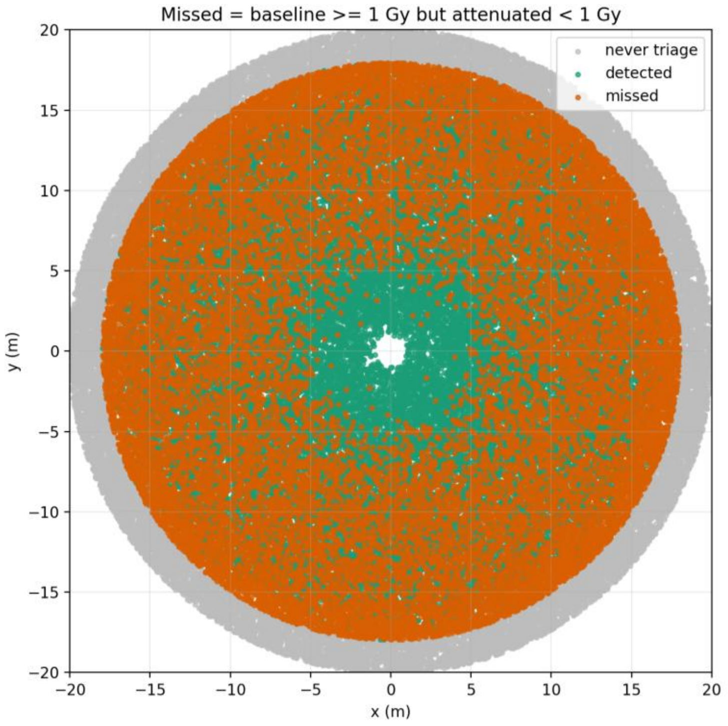
Interpretation – Other Data Visualisation

- We can simulate a set of points receiving $1/r^2$ distributed doses
- Simulated people randomly facing different directions:
  - Sampled random (card pos, angle) from the 6x360 dose vs angle data
- Create a 'map' of people missed from triage
- Calculate theoretical miss-rate
  - Percentage of (card positions, orientations) that would result in not being detected

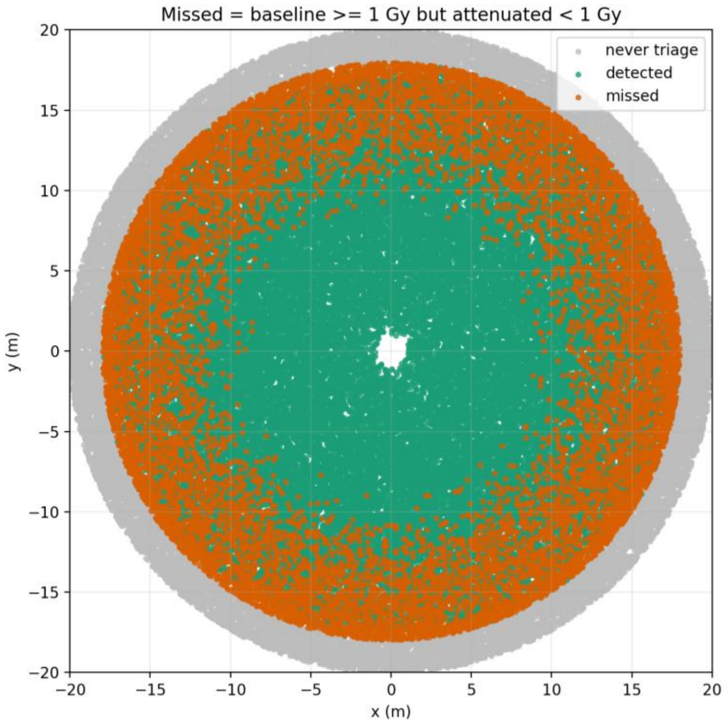


Side leg position: Measured dose vs source angle

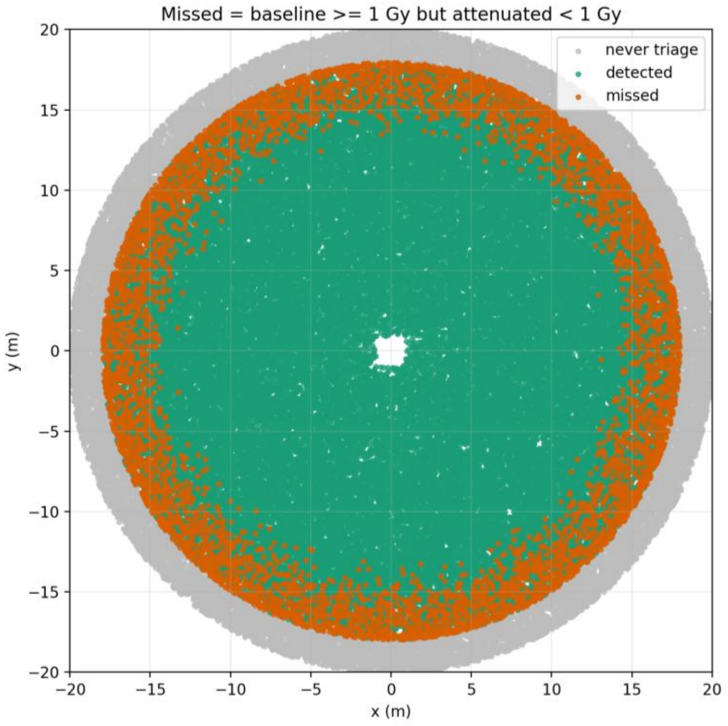
Dose map of people facing in random directions with pellet worn in random position



0.1MeV



1.6MeV

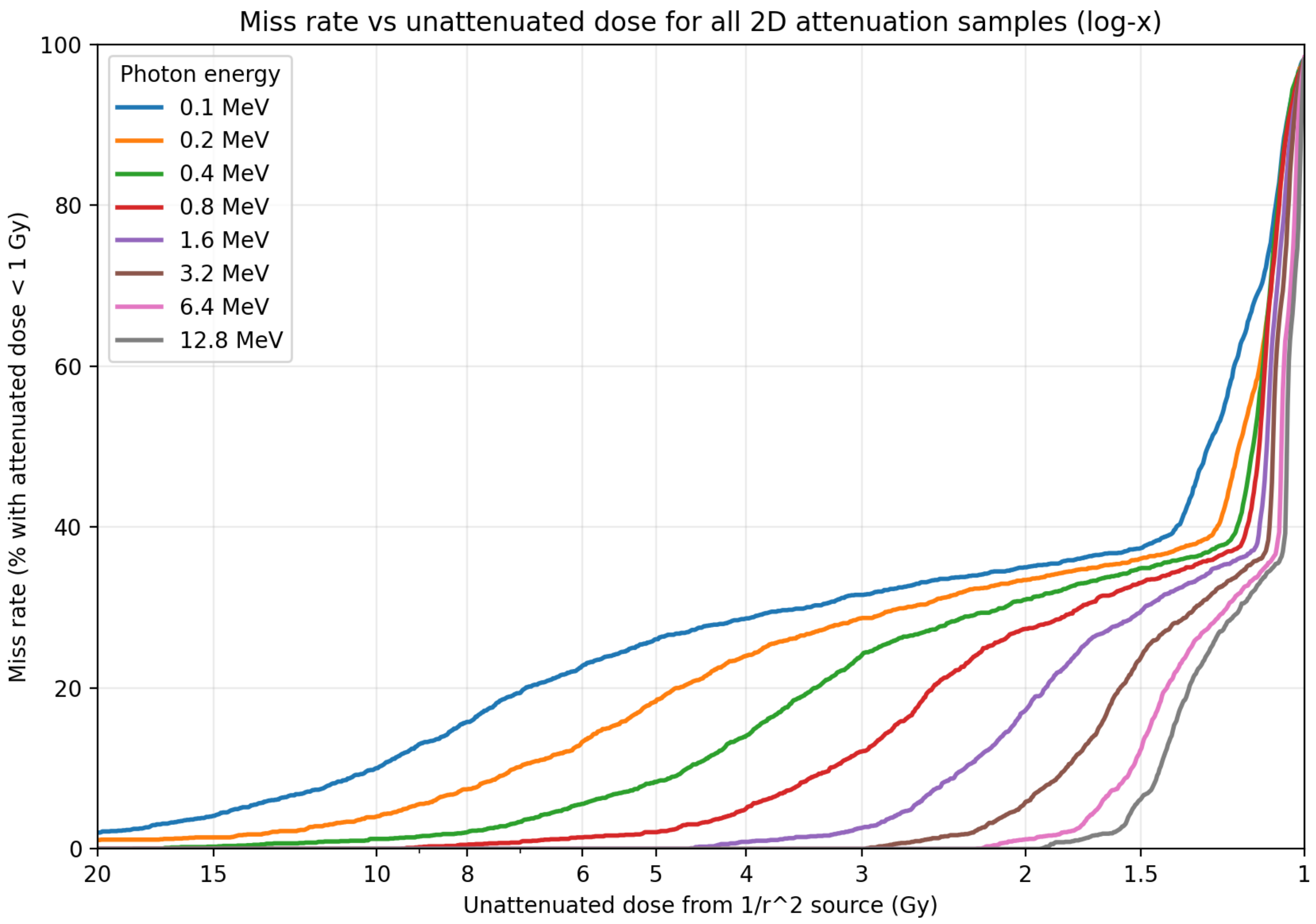


12.8MeV

Raw measurement miss-rate

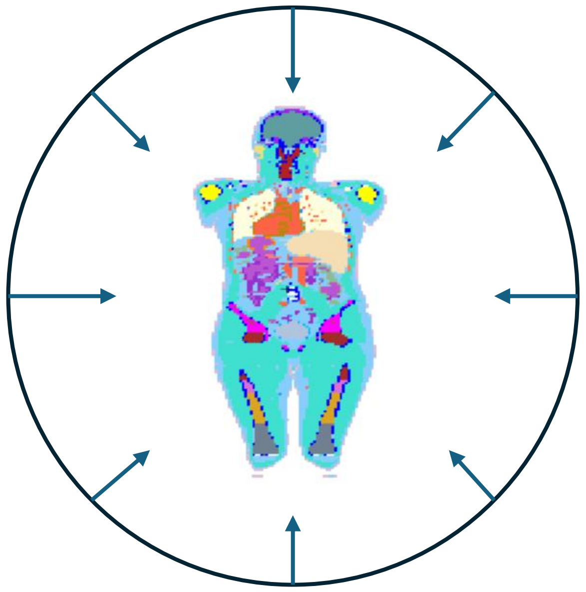
- For each photon energy
  - Percentage of 6x360 attenuated points below triage level 'missed'

- Clustering could help identify those over 1.5Gy, for a triage threshold of 1Gy
  - Reliably always take highest dose in an area
  - *Dose measurements can only be reduced*



Methodology – Long Exposures

- Longer-timescale exposures:
  - ***Question: What is the average attenuation an individual shields their dosemeter by?***



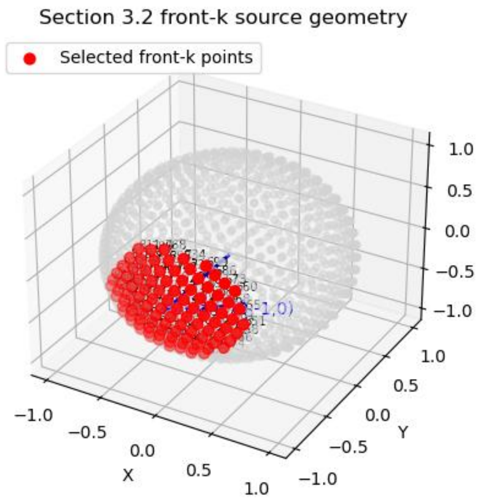
1. What is the conversion from a laboratory measurement with an X- ray source to an isotropic exposure?
2. What is the variation of dose measurement depending on where the dosemeter is worn?

Methodology – Long Exposures

Individually simulated 1,000 sources (isotropic and plane parallel) on a sphere

- Used an average of the 10% most forward sources as a ‘lab’ X-ray source
- Used the average of all points as an isotropic source

$$Correction = \frac{D_{lab}}{D_{iso}}$$



Caption depicting ‘lab’ chosen source positions

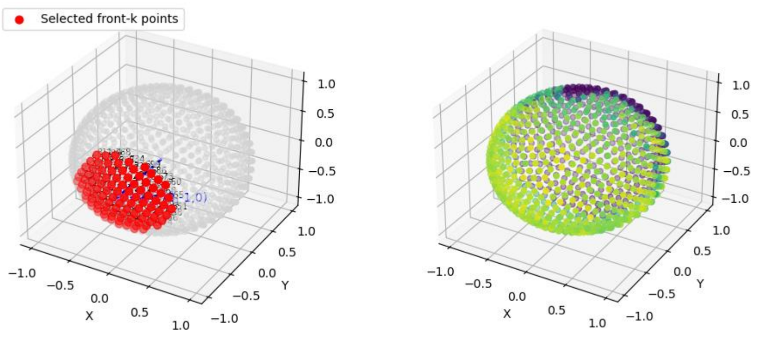
Results – Long Exposures

1) Lab-to-isotropic conversion

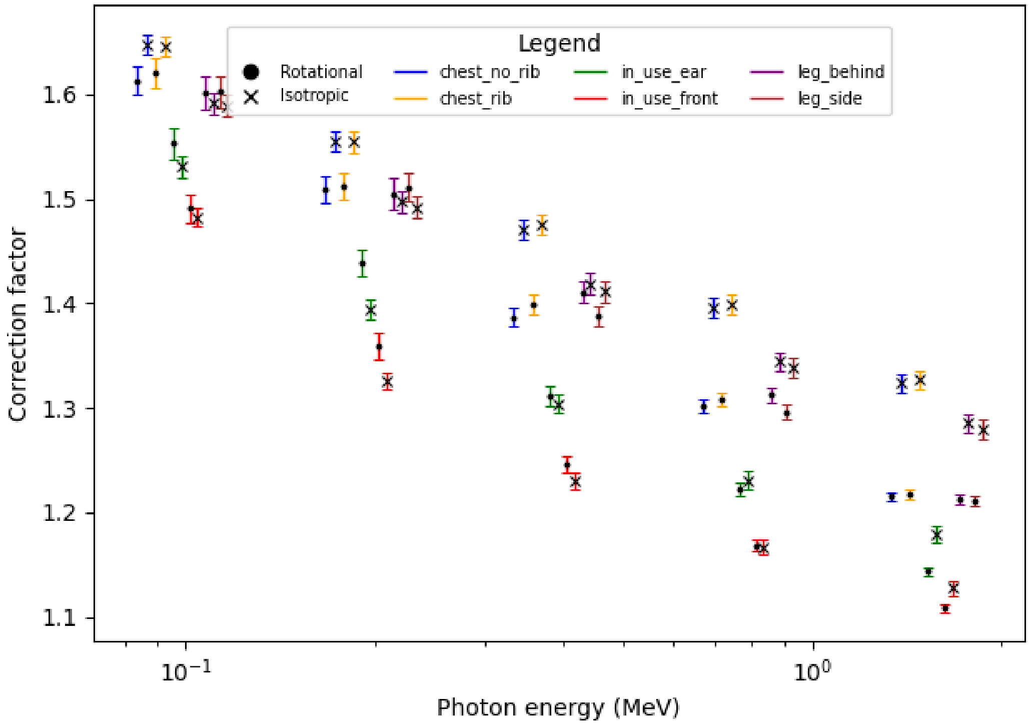
- An energy-dependent factor from ~1.7 to ~1.3 could be multiplied with dose measurements, to calibrate to lab irradiations

2) Position variability

- Measured dose **does** depend on dosemeter position
    - Taking the largest correction factor would ensure this doesn't affect triage



(left) plot of source positions, and highlighted 'lab' sources; (right) colourplot of dose vs 3-D source position for the chest dosemeter



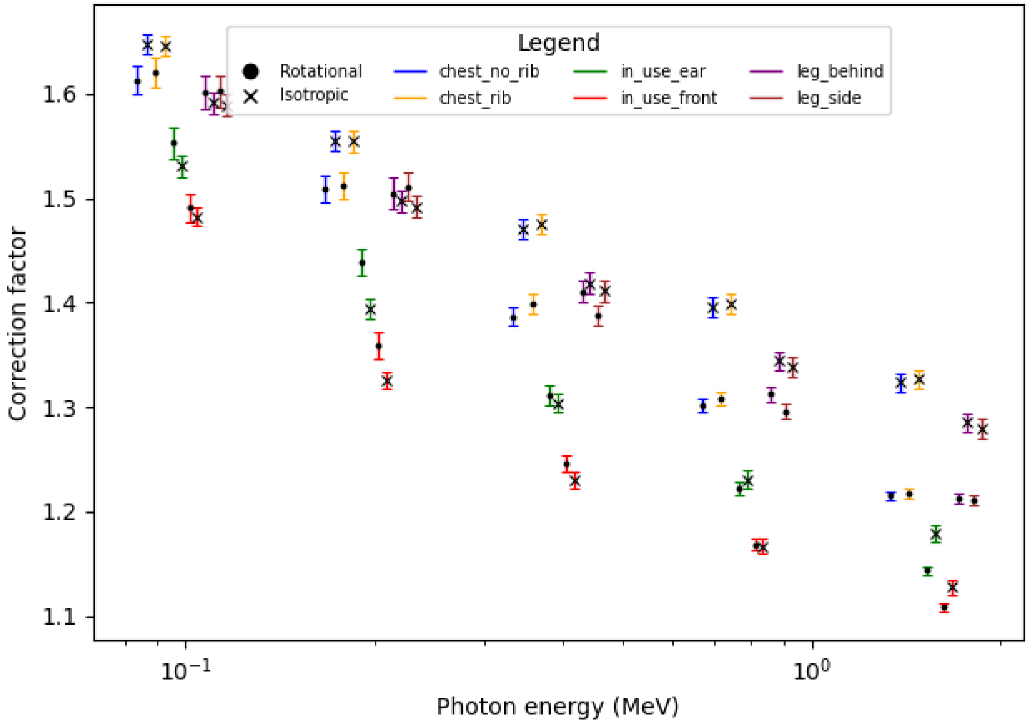
Plot of correction factor vs photon energy for each dosemeter position

Results – Long Exposures

- Supported by effective dose conversion coefficients in ICRP 116
- By taking ratio of conversion coefficients for AP / ISO (anterior posterior / isotropic):
  - ~1.8 @ 0.1MeV
  - 1.36 @ 1.117MeV

Conversion coefficients include body weighting factors

** ICRP, 2010. Conversion Coefficients for Radiological Protection Quantities for External Radiation Exposures. ICRP Publication 116, Ann. ICRP 40(2-5).*



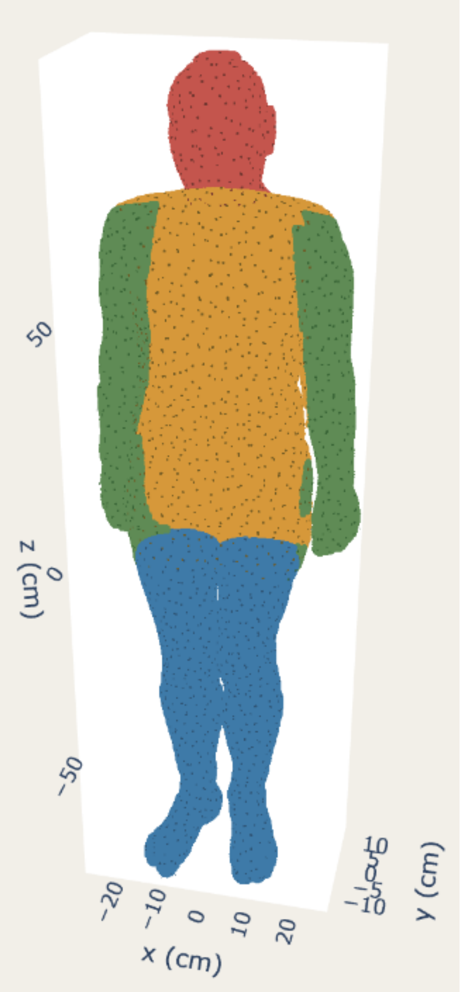
Plot of correction factor vs photon energy for each dosemeter position

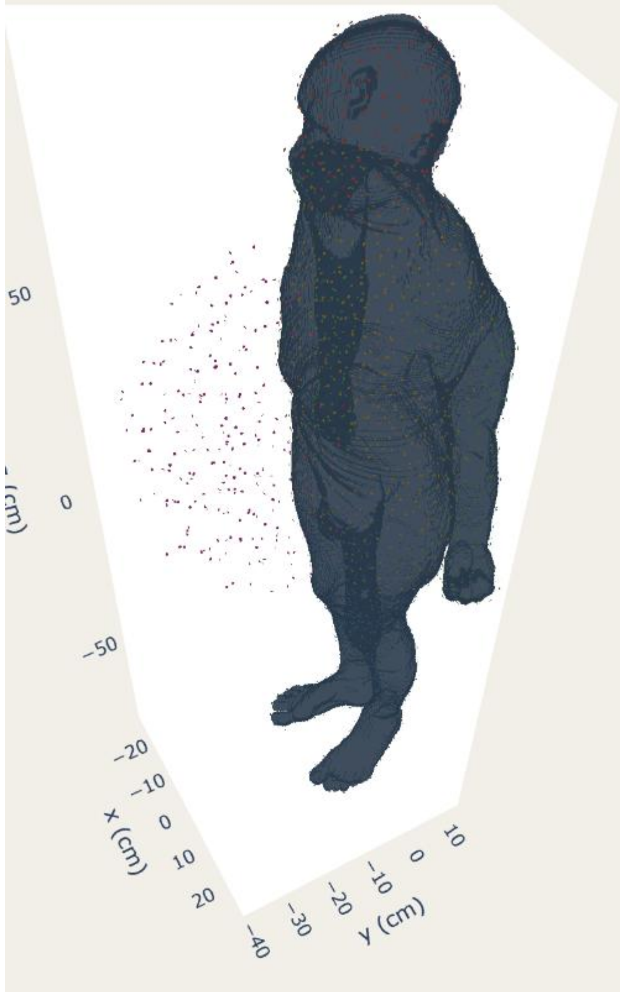
Methodology – Long Exposures

2) Estimating variation in measured dose with respect to pellet position

- Phantom surface covered with pellets separated by 2cm
- Held in-front pellets packed in a hemisphere on the phantom

Results not yet available – long computer time required





Conclusions

- Alanine cards worn by members of the public could provide accurate dose estimates
- For long, isotropic exposures: a correction factor should be applied to capture all dosemeter positions
- For short-timescale, or fixed position directional exposures: an ensemble of dose measurements + geographic position information would be required
- Some in-place devices will likely sit between these regimes - averaging assumptions are important