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Development of 3D-printed radiotherapy shielding for superficial radiotherapy

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Disclosure

- The presenter has advised that the following presentation is subject to **no** conflicts of interest and has **nothing** to disclose.
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Introduction

Patient specific cut-outs / masks / shields are used in kilovoltage radiotherapy to collimate the field.

Historically these have been Pb, of sufficient thickness to reduce the dose to ≤5% of the open field dose.

Patient-specific shields made manually.

The thicknesses of Pb required to achieve this are presented in various text books without much explanation. Some values are intended for air-kerma shielding calculations, not patient dose.

Source	Pb thickness (mm) and beam quality
Archer	0.1 (50 kV), 0.2 (70 kV), 0.4 (100 kV), 0.5 (125 kV), 0.6 (150 kV)
Hansen	0.95 (≤ 150 kV), 1.9 (≥140 kV)
Khan	0.2 (1 mm Al HVL), 0.3 (2 mm Al HVL), 0.4 (3 mm Al HVL), 1.0 (1 mm Cu HVL), 2.0 (3 mm Cu HVL), 2.5 (4 mm Cu HVL)
Mayles	0.5 (≤ 90 kV), 1 (≤ 140 kV)

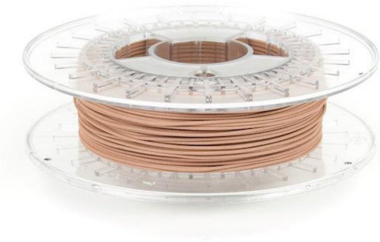
Introduction

There is incentive to remove Pb from workflows and develop solutions that allow patient-matched shields to be developed without moulding.

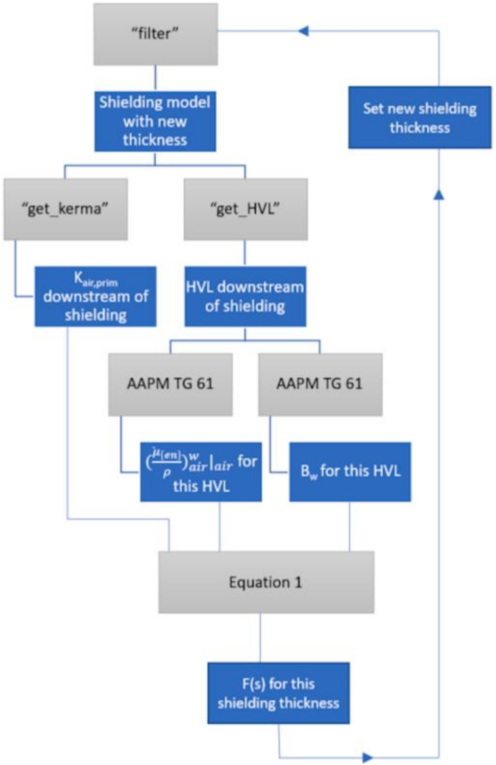
3D printing with optical scanning is a potential solution. PLA/metal composite filaments exist. But how thick does the material need to be?

Unfortunately, the calculation of thickness for nonstandard shielding materials is complicated by

- polyenergetic spectrum of kV beams,
- characteristic absorption edges,
- production of photon scatter, fluorescence and electrons specific to the material and energy,
- effect of beam hardening on dose to surface downstream (i.e. change in water backscatter).



Modelling



SpekPy software allows simple simulation of spectra and air-kerma (per mAs) for x-ray tube systems. SpekPy achieves this using user-supplied kV, target, geometry, filtration and material data.

Modelling shielding material as filtration in SpekPy allows the iterative characterisation of air kerma & beam quality (as HVL mm Al or Cu) downstream of variable thickness of shielding.

AAPM TG61 data can then be referenced to calculate dose to water from kerma and shielded "HVL", by interpolation of backscatter factors and mass absorption coefficient ratios.

These calculations were used to calculated transmission factors:

$$F(s) = \frac{D_{\text{shielded}}}{D_{\text{open}}} \approx \frac{\left(K_{\text{air,prim}}\; B_w\; \left[\left(\overline{\mu}_{\text{en}}/\rho\right)^{w}_{\text{air}}\right]_{\text{air}}\right)_{\text{shielded}}}{\left(K_{\text{air,prim}}\; B_w\; \left[\left(\overline{\mu}_{\text{en}}/\rho\right)^{w}_{\text{air}}\right]_{\text{air}}\right)_{\text{open}}}$$

Modelling

SpekPy transmission factor calculations were performed for Pb and the two 3D printable materials, for all energies on the RBWH WOmed T-300 unit.

Material composition was approximated from nominal % by weight indicated by the filament manufacturers. Filaments were assumed to be “pure” mixes of Cu or W, and $(C_3H_4O_2)_n$.

Calculations achieved using Python (numpy, scipy and pandas, with SpekPy functions).

Material	Composition (%wt)	ρ (g cm^{-3})
Lead sheeting	100% Pb	11.3
Cu-PLA filament	80% Cu, 20% PLA	3.9
W-PLA filament	92% W, 8% PLA	7.8

Beam	V_{tube} (kV)	Filtration (mm)				1st HVL	2nd HVL
		Be	Al	Cu	Sn		
1	70	3.0	0.9	–	–	1.20 mm Al	2.09 mm Al
2	100	3.0	2.1	–	–	2.90 mm Al	4.90 mm Al
3	100	3.0	3.7	–	–	4.13 mm Al	6.16 mm Al
4	100	3.0	0.8	0.2	–	6.28 mm Al	7.80 mm Al
5	300	3.0	1.3	1.0	–	2.44 mm Cu	3.72 mm Al
6	300	3.0	0.8	1.6	–	2.97 mm Cu	3.92 mm Al
7	300	3.0	0.8	2.6	0.5	3.88 mm Cu	4.41 mm Al

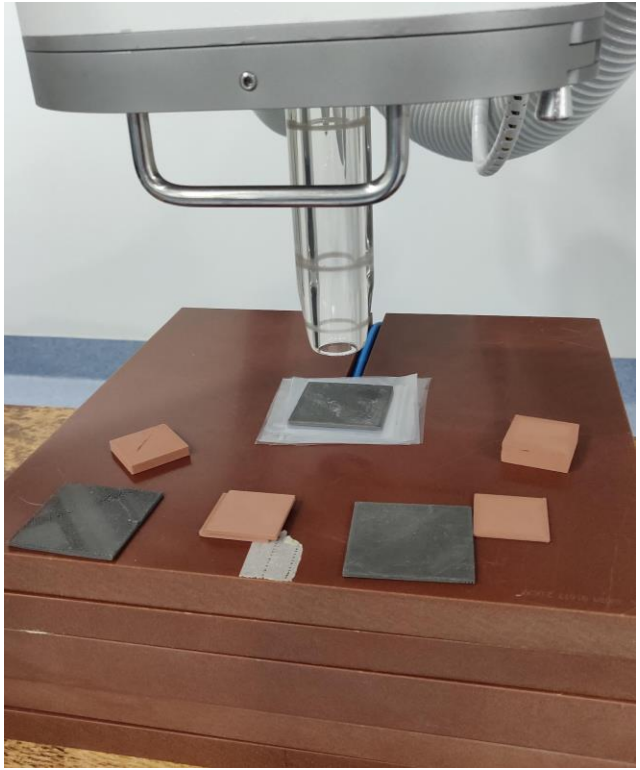
Measurements

For evaluation of calculations, test shielding slabs were printed and transmission factors measured. Transmission factors were measured at the surface of a Virtual Water phantom with an Advanced Markus chamber, with and without variable thicknesses of shielding.

$$F(s) = \frac{M_{\text{shielded}}}{M_{\text{open}}}$$

A stand-off 3 cm was used to allow shielding to be added and removed.

For all measurements, sufficient low-density polyethylene was added to eliminate electron dose enhancement (resulting from excess electron production in shielding material compared to water, due to higher density).

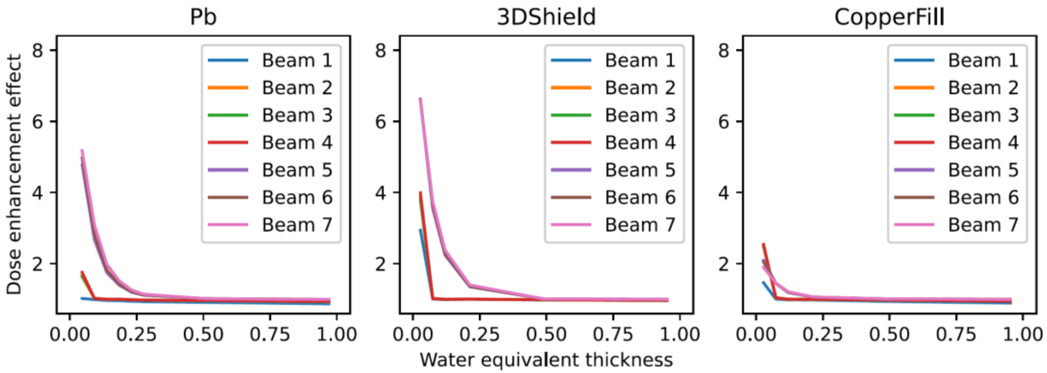


Measurements

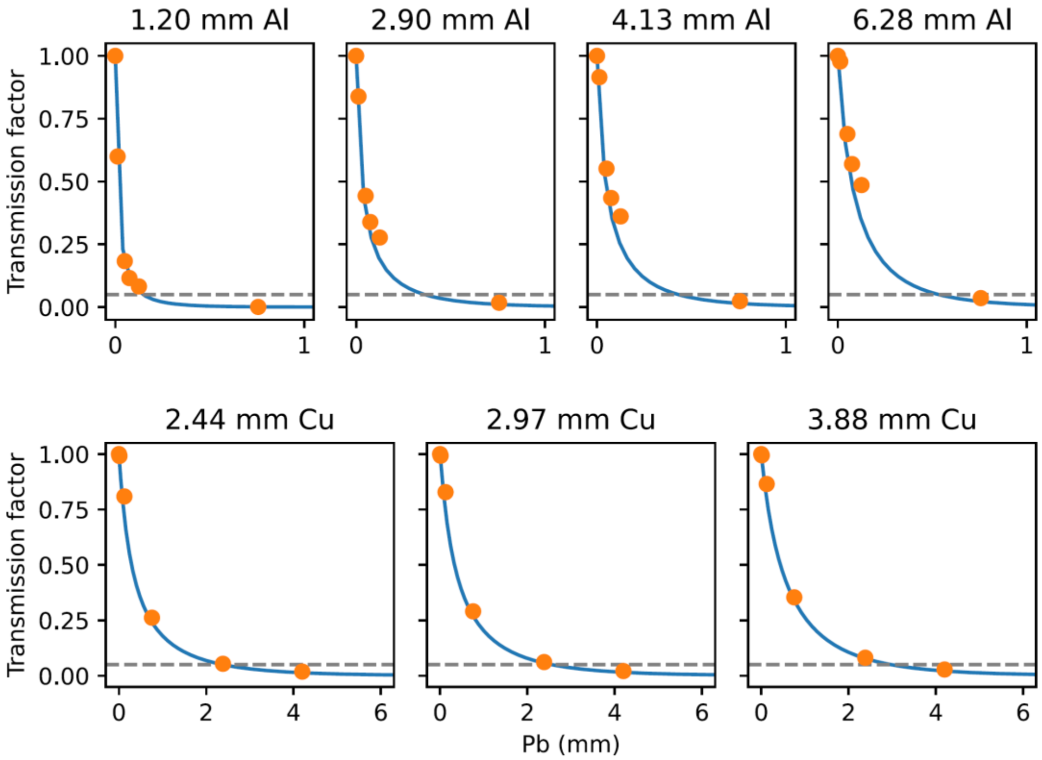
The peak energy electrons produced by the kilovoltage beams used in this study were 70, 100 and 300 keV. The continuous slowing down approximation (CSDA) ranges of electrons of these energies are 0.078, 0.143 and 0.842 mm in water, respectively.

Dose enhancement effect shown below, for three materials, with different thickness of LDPE. CSDA is a conservative over-estimate. The thickness of the epidermis ranges from 0.05 - 0.4 mm.

Thickness used was ~0.2 mm for superficial and ~0.5 mm for orthovoltage.



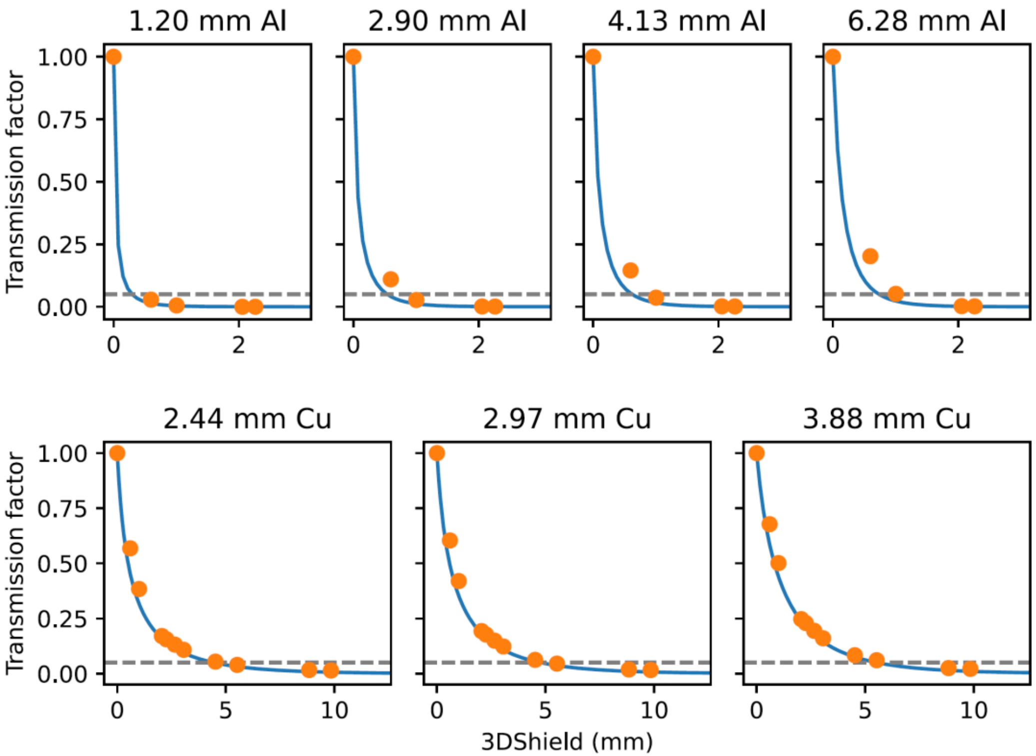
Results



Results for Pb, where blue line is calculated, orange is measured.

5% transmission requires thicknesses of 0.2-0.6 mm for superficial energies, and 2.2-2.7 mm for orthovoltage energies.

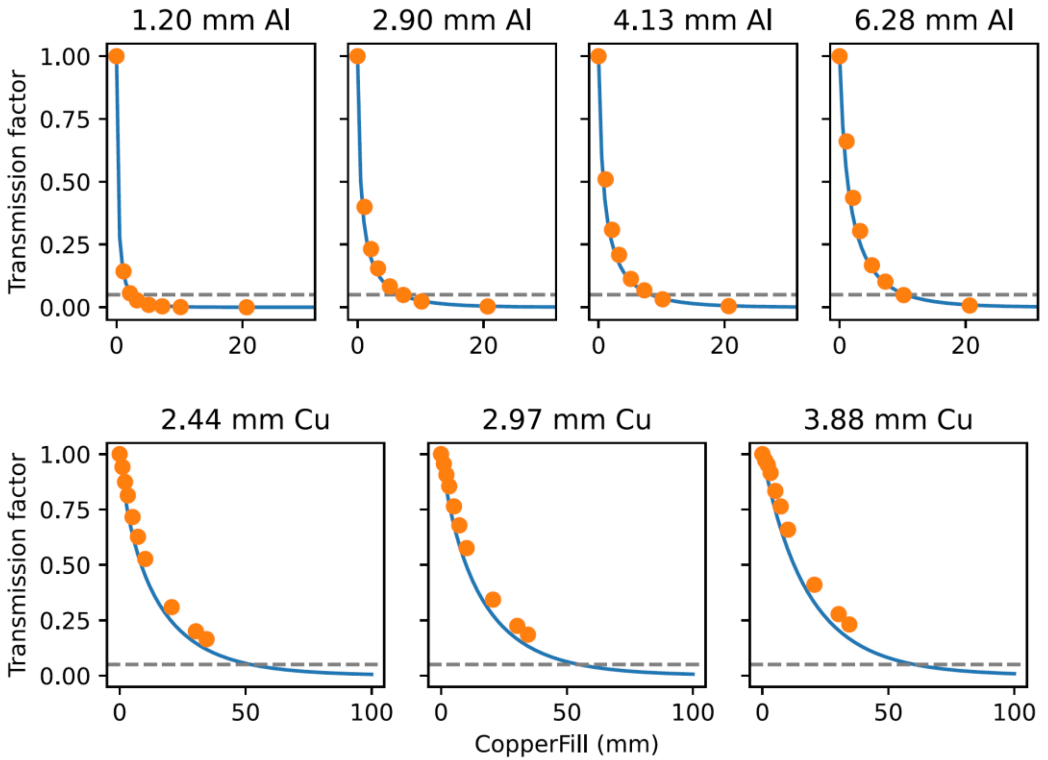
Results



Results for W-PLA, where blue line is calculated, orange is measured.

5% transmission requires thicknesses of 0.2-0.6 mm for superficial energies, and 2.2-2.7 mm for orthovoltage energies.

Results



Results for Cu-PLA, where blue line is calculated, orange is measured.

5% transmission requires thicknesses of 2-10 mm for superficial energies, and more than 5 cm for orthovoltage energies!

Conclusion

The calculated transmission factors generally underestimated the values obtained by physical measurements. **Why?** The approach used is not inclusive of secondary photon scatter, fluorescent photon production, or electron effects.

For Pb, the mean difference was 2.6% between measurements and calculations. Deviations were greater for printed materials.

The conservative addition of 1 mm (superficial) and 2 mm (orthovoltage) of additional material would be sufficient to ensure <5% transmission, from value calculated for 5%.

Results calculated for lead were consistent with published recommendations.

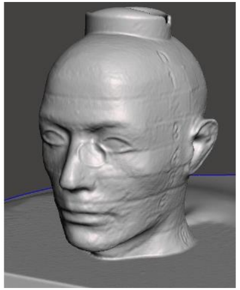
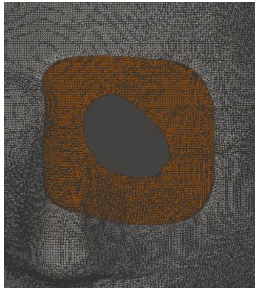
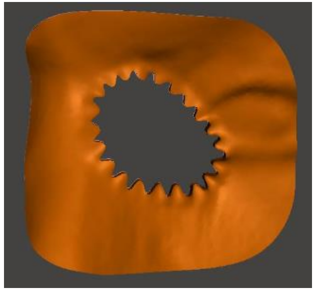
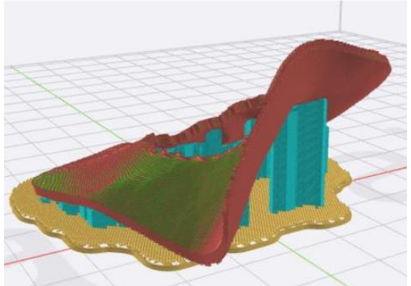
Calculated and measured shielding thicknesses for 5% transmission factor.

Beam	V_{tube} (kV)	HVL	Calculated thickness (mm)			Measured thickness (mm)		
			Pb	W-PLA	Cu-PLA	Pb	W-PLA	Cu-PLA
1	70	1.20 mm Al	0.2	0.3	1.9	0.2	0.6	2.4
2	100	2.90 mm Al	0.4	0.6	5.7	0.6	0.9	7.2
3	100	4.13 mm Al	0.5	0.6	6.8	0.6	1.0	8.5
4	100	6.28 mm Al	0.6	0.8	8.0	0.7	1.1	10.1
5	300	2.44 mm Cu	2.2	4.0	48.5	2.6	4.8	60.3
6	300	2.97 mm Cu	2.3	4.2	50.9	2.8	5.3	63.3
7	300	3.88 mm Cu	2.7	4.9	56.4	3.2	6.3	69.8

Conclusion

The two printable materials have potential use for radiation shielding, however, Cu-PLA is inappropriate for orthovoltage beams due to thickness required, and Rapid 3DShield is relatively expensive.

Monte Carlo simulation could be used to verify estimates. However the iterative calculation of dose to water for variable thickness of shielding with Monte Carlo would be less efficient than the method used in this study. The proposed method could be used to inform Monte Carlo simulations.


Conclusion

See related EPSM presentations:

- Wed morning, Crowe - Characterisation of Artec Leo 3D scanner for radiotherapy applications
- Wed afternoon, Simpson-Page - Changing Penumbras: Assessment of variation in kV lead shield penumbra
- Wed afternoon, Crowe - Commissioning a Monte Carlo model of a kilovoltage radiotherapy unit

Work described in:

S. B. Crowe, P. H. Charles, N. Cassim, S. K. Maxwell, S. R. Sylvander, J. G. Smith, T. Kairn (2021) Predicting the required thickness of custom shielding materials in kilovoltage radiotherapy beams, *Physica Medica* **81**: 94-101