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Shielding factors for traditional safety glasses

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Presentation outline

- Background to project
- Scope
- Experimental investigations
- Monte Carlo investigations
- Implications and future work

Project outline – protecting the eye

- A number of studies have suggested that the development of cataracts may occur following exposure to significantly lower doses of ionizing radiation than previously considered.
- CNSC is proposing the following amendments to the *Radiation Protection Regulations*:
  - to change the equivalent dose limit for the lens of an eye for a Nuclear Energy Worker from the current limit of 150 mSv to 50 mSv in a one-year dosimetry period
  - to add a new dose limit for the lens of an eye for a Nuclear Energy Worker of 100 mSv in a five-year dosimetry period
- The purpose of this research project is to assist CNSC staff in developing regulatory guidance in the area of reducing dose to the lens of the eye.
- **Specifically, the study is focused on researching the shielding factor offered by traditional safety glasses and prescriptive eyewear that are commonly used in the industry, or readily available for purchase and use.**

Scope of work - experimental

1. kV x-rays	
Energies	Sufficient energies in the range **15 keV to 65 keV (**effective energy) to characterize the energy dependence of shielding factors
Measurements (a)	Simple attenuation measurements Form - planar sheet, **Measurements to be carried out in-air**, Detector: standard ionization chamber with sensitive size consistent with eyeball Measurements at multiple angles in range 0-90 degrees
Measurements (b)	Characterization of eye wear shielding **At least 5 types of eyewear** readily available in Canada and meeting CSA Z94.3 standard Geometry as for planar sheets
2. Y-90/Sr-90 beta source	
Energy	Y-90/Sr-90 beta source (end-point energy = 2.28 MeV)
Measurements (a)	Same as for kV x-rays above
Measurements (b)	Same as for kV x-rays above

Scope of work – Monte Carlo calculations

1. kV x-rays	
Energies:	**Simulated beams should match as closely as possible the experimental beams**
Calculations (a)	Simple attenuation measurements Form - planar sheet **Simulated geometry to match experimental measurements** “Detector”: air kerma will be scored with and without the shielding material present.
Calculations (b)	Simulation of eye wear shielding **Simplified models** based on 2-D curvature (e.g., portion of a cylinder) will be used.
2. Beta source	
Energy	Standard spectrum for Y-90/Sr-90 beta source (end-point energy = 2.28 MeV).
Calculations (a)	Same as for kV x-rays above
Calculations (b)	Same as for kV x-rays above, augmented with mono-energetic electron beams in range 700 keV to 10 MeV.

Materials investigated

Three materials were investigated:

Polycarbonate (Makrolon™), CR-39, and Trivex (TVX31).

The respective base monomers for three materials are:

bisphenol-A,

diethyleneglycol bis allylcarbonate (ADC)

urethane.

- Polycarbonate: ρ = 1.15 g cm^{-3} (± 0.5 %)
- CR-39 ρ = 1.27 g cm^{-3} (± 2.4 %)
- TVX31 ρ = 1.07 g cm^{-3} (± 1.5 %)

All the types of eyewear investigated in this work had polycarbonate lenses

Eyewear types investigated

Selection based on:

i) easy availability

ii) difference in geometry

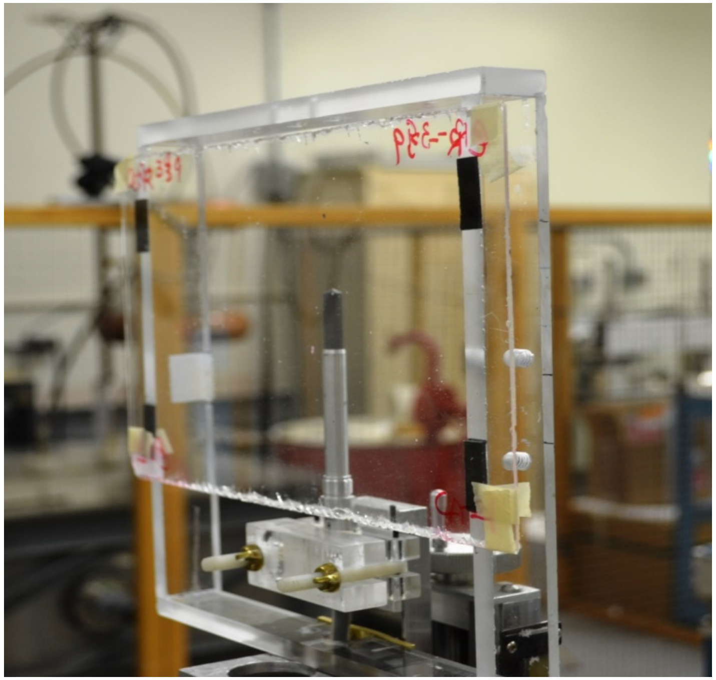
Not necessarily representative but a variety of sizes/shapes

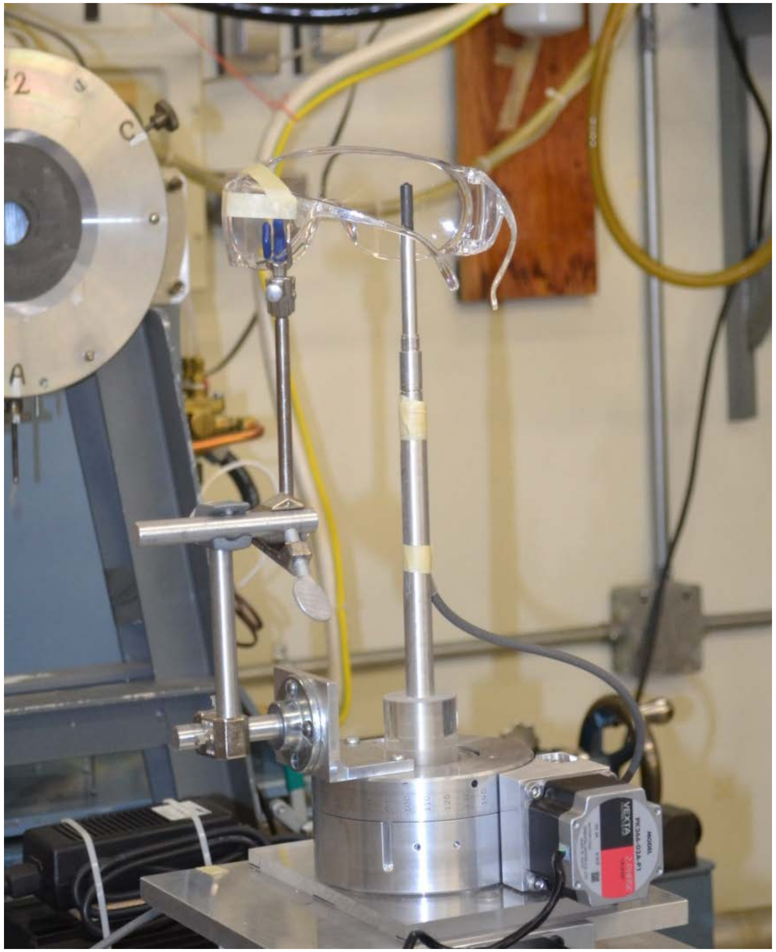
Eyewear	Minimum thickness (mm)	Maximum thickness (mm)
#1	2.1	2.3
#2	2.2	2.3
#3	1.7	2.2
#4	2.1	2.9
#5	1.5	2.5
#6	1.7	2.1

Experimental setup - kV x-rays

NRC primary x-ray calibration facility

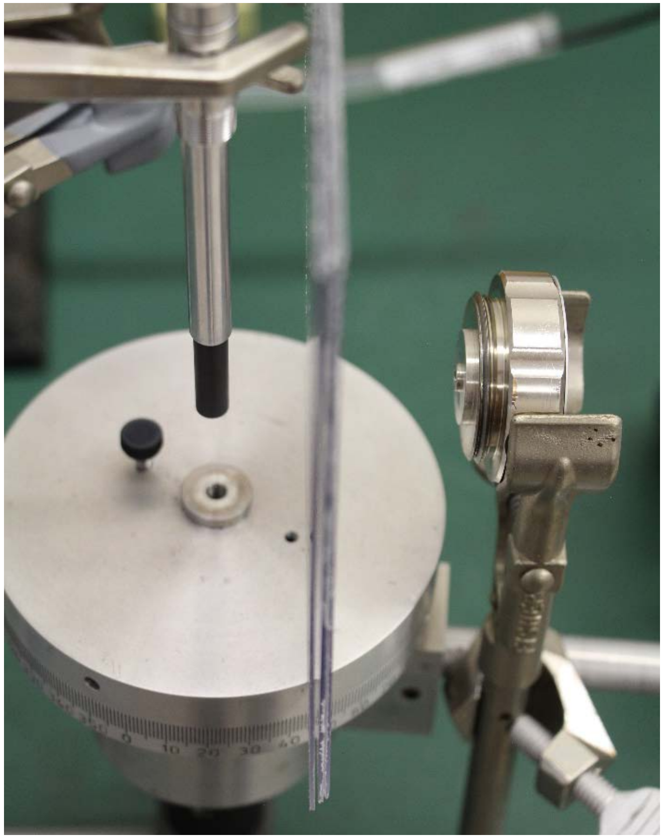
Tube kVp	HVL	E_{eff} (keV)
30	0.39 mm Al	15.7
50	1.44 mm Al	25.0
80	3.56 mm Al	35.4
135	0.60 mm Cu	64.8



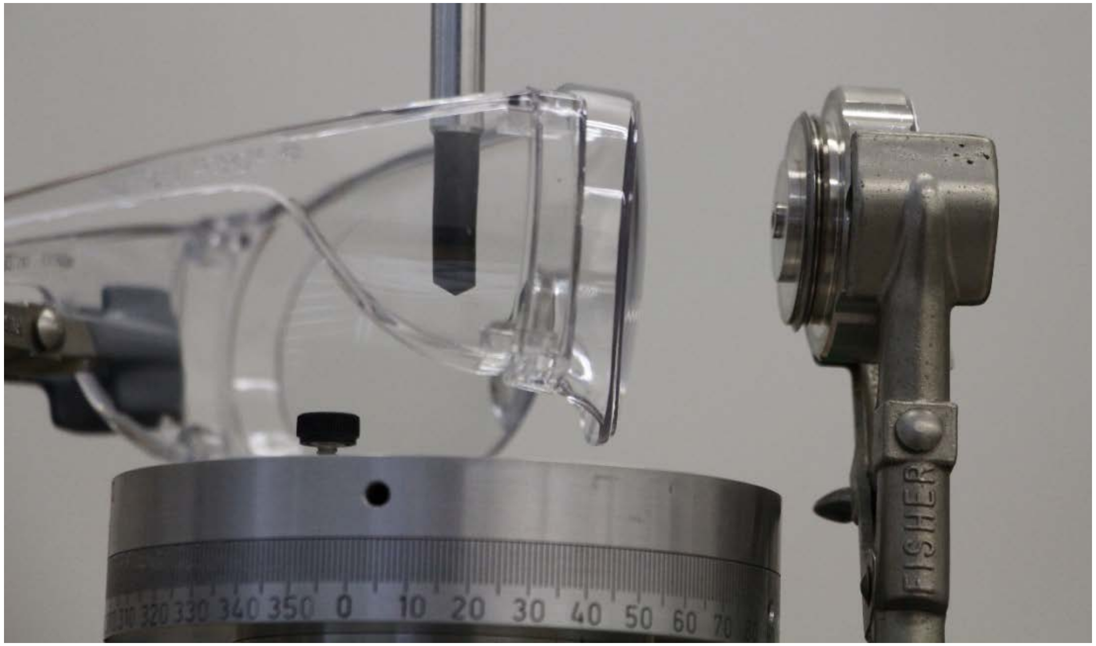


Source fixed, shielding rotated

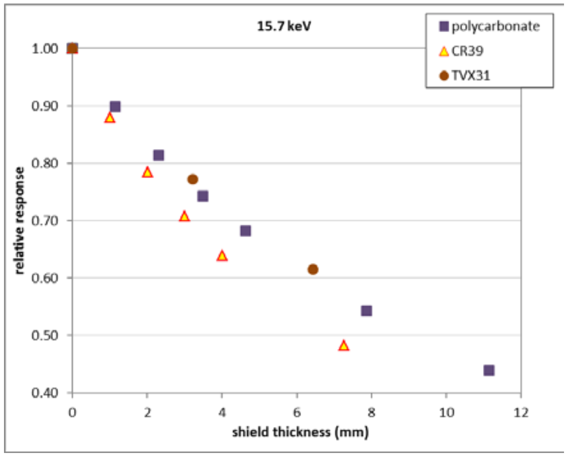
Experimental setup – Sr-90

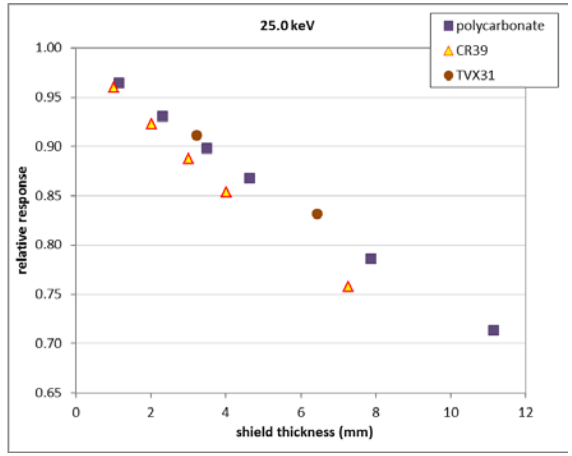


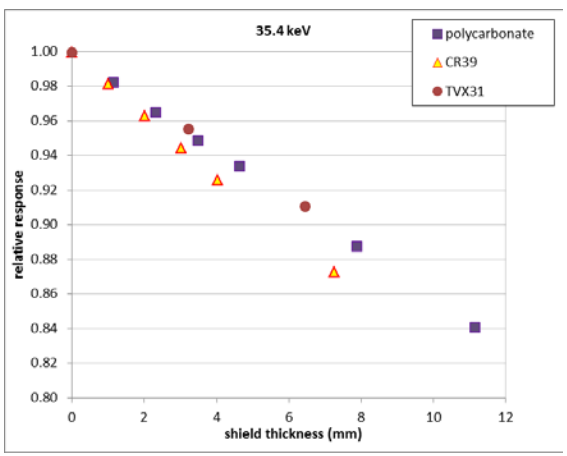
PTW 48010 check source used
Weak, so short source-detector distance
Shielding fixed, source rotated

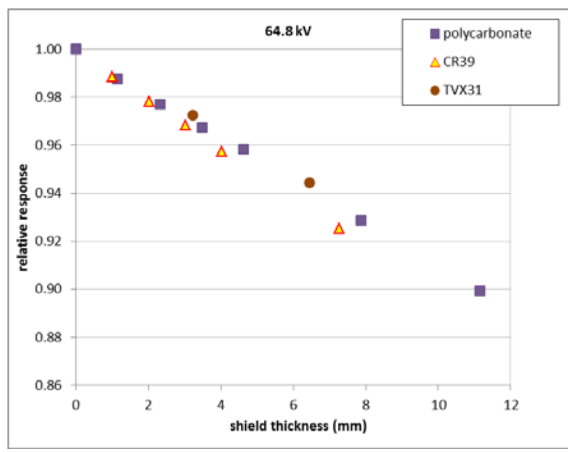


Experimental results – planar sheets

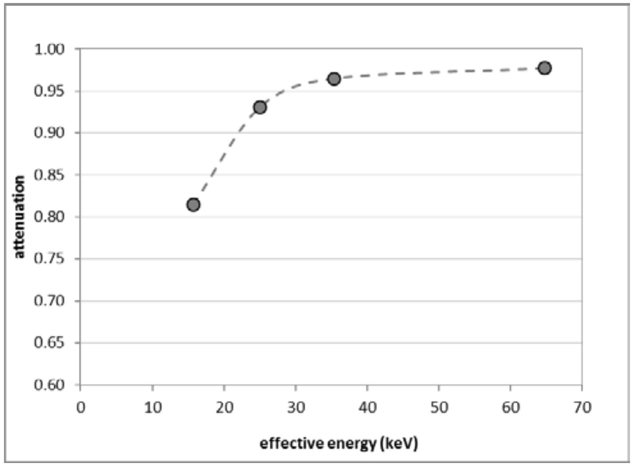






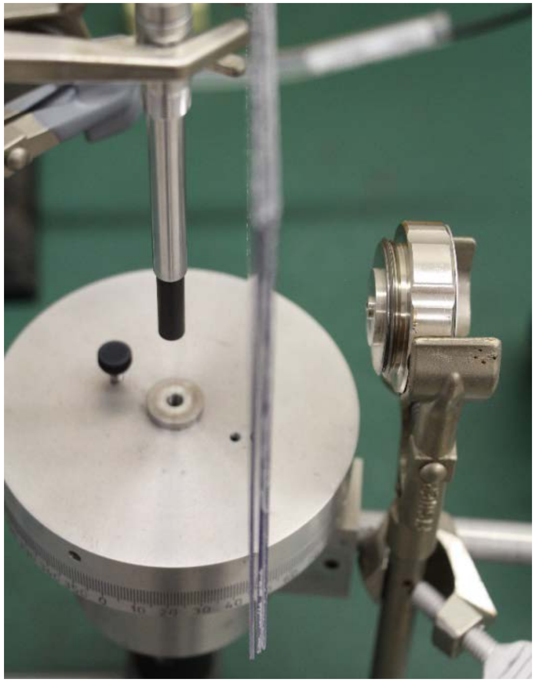


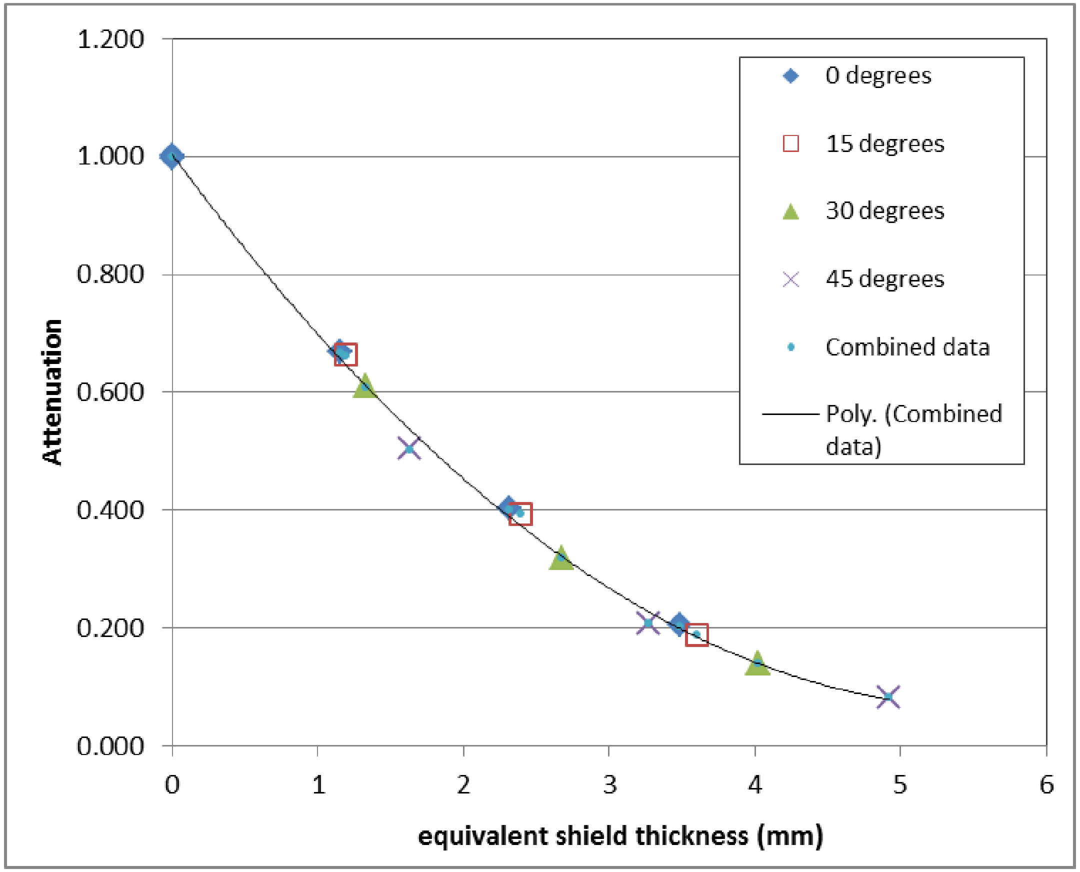
Small, consistent difference between materials



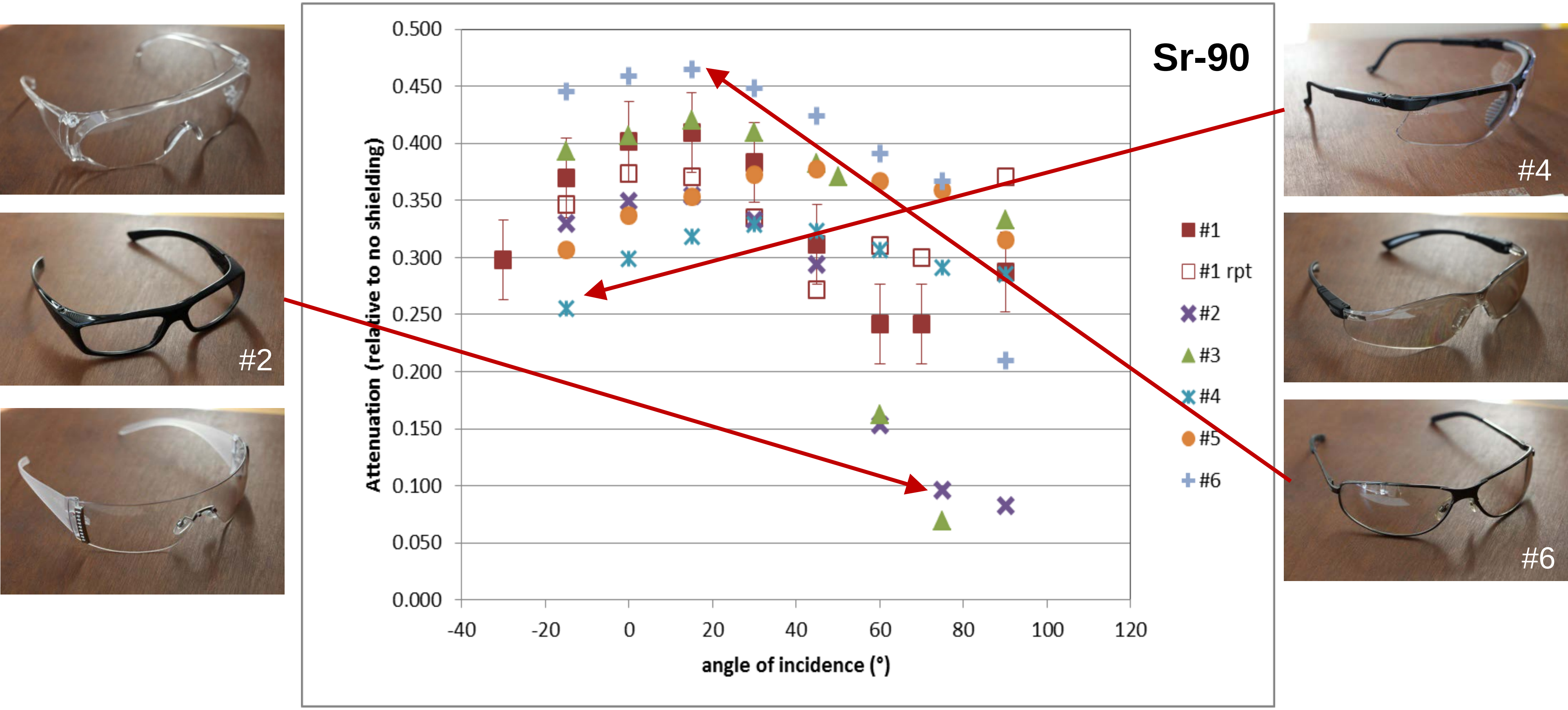
2.3 mm polycarbonate sheet

Experimental results – effect of rotation



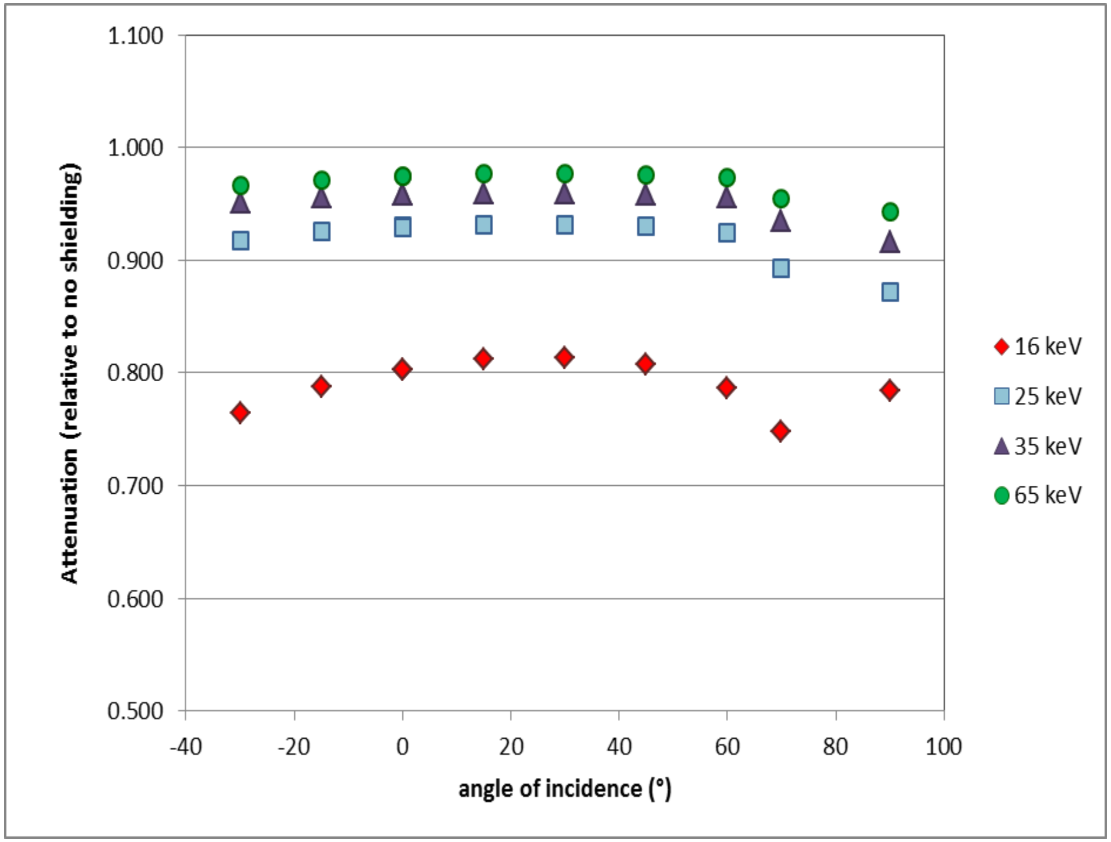


Experimental results – eyewear models



Shielding factor (1/attenuation) ~ 2.5-3

Experimental results – eyewear models



kV x-rays

Little variation with angle

Experimental results – eyewear models

Eyewear type	Effective photon energy (keV)			
	64.8	35.4	25.0	15.7
	Attenuation factor (relative to no shielding)			
#1	0.98	0.96	0.93	0.81
#2	0.98	0.96	0.93	0.80
#3	0.97	0.95	0.93	0.79
#4	0.96	0.95	0.91	0.76
#5	0.97	0.95	0.92	0.79
#6	0.97	0.96	0.93	0.81
Mean	**0.970**	**0.954**	**0.924**	**0.793**
Std dev	**0.5%**	**0.6%**	**1.0%**	**2.3%**

Little or no protection for all kV x-ray beams

Monte Carlo investigations

- Using EGSnrc
- Need geometries and compositions for accurate simulations
- Not easy to get definitive compositions of commercial materials

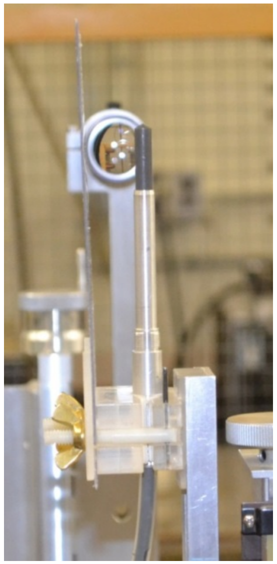
Material	ρ ($g\ cm^{-3}$)	Elemental composition (%)			
		H	C	N	O
Polycarbonate	1.15	6	76	-	19
CR-39	1.274	7	53	-	41
Trivex (TVX31)	1.074	9	55	8	28

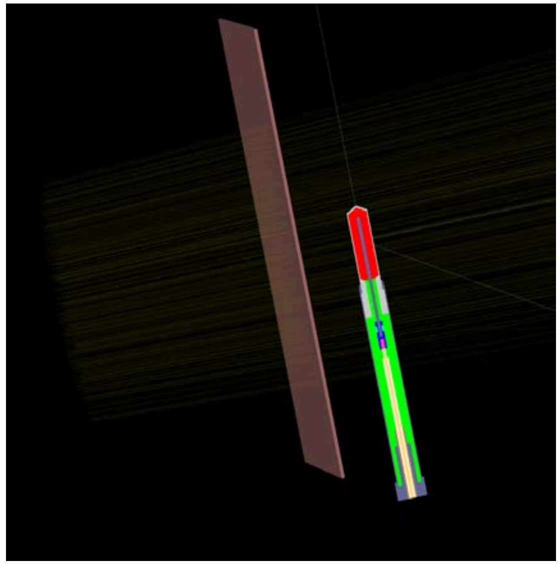
Note there are both density and atomic number differences

Monte Carlo investigations – kV x-rays

- BEAMnrc applications for the NRC x-ray tubes, compiled as shared libraries, are used as particle sources for the C++ EGSnrc application **cavity.**
- Default transport parameters are used in the simulations and particles are followed until their energy falls below a cut-off of 1 keV.
- The application is used to model the NE2571 Farmer-type ionization chamber and compute ratios of D_{gas} with and without the attenuating sheets of materials *on-the-fly*.
- Variance reduction techniques such as photon splitting and range rejection with Russian roulette are used to increase calculation efficiency.
- A large number of histories are simulated in order to achieve 1σ statistical uncertainties in the attenuation values of less than 0.1 %.

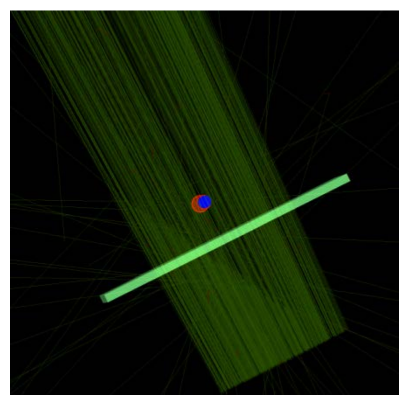
Monte Carlo investigations – kV x-rays

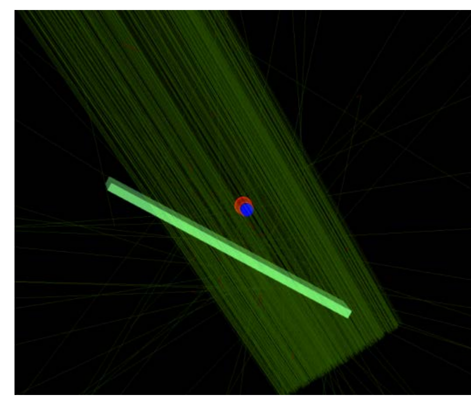




- Accurate simulation of experimental geometry
- NE2571 chamber modelled in detail

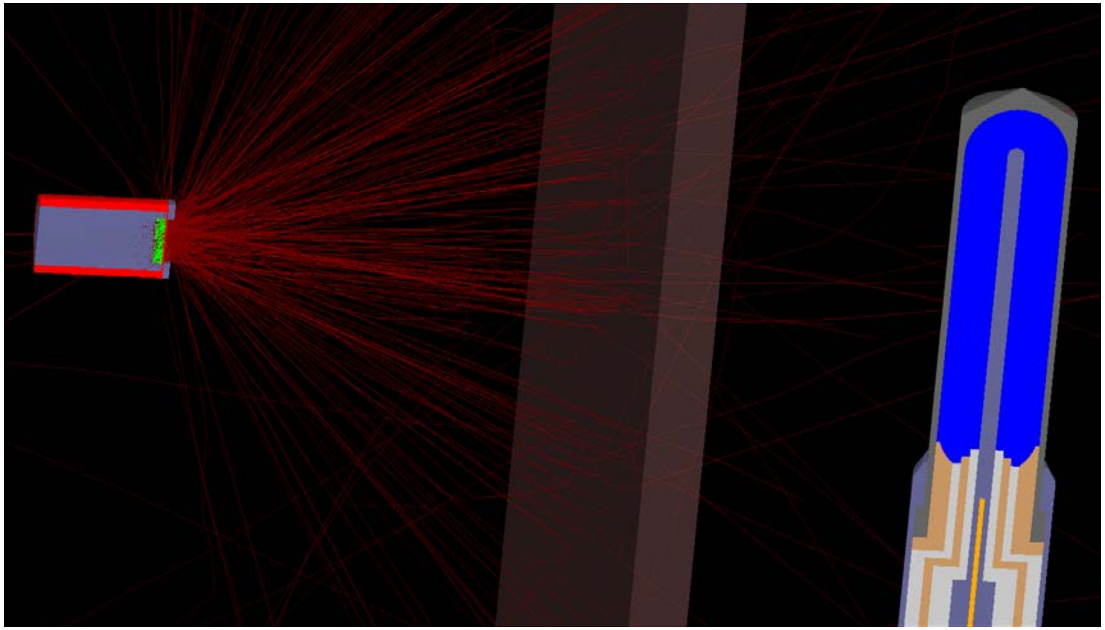
- sheets of materials were rotated around the chamber axis by the desired angle





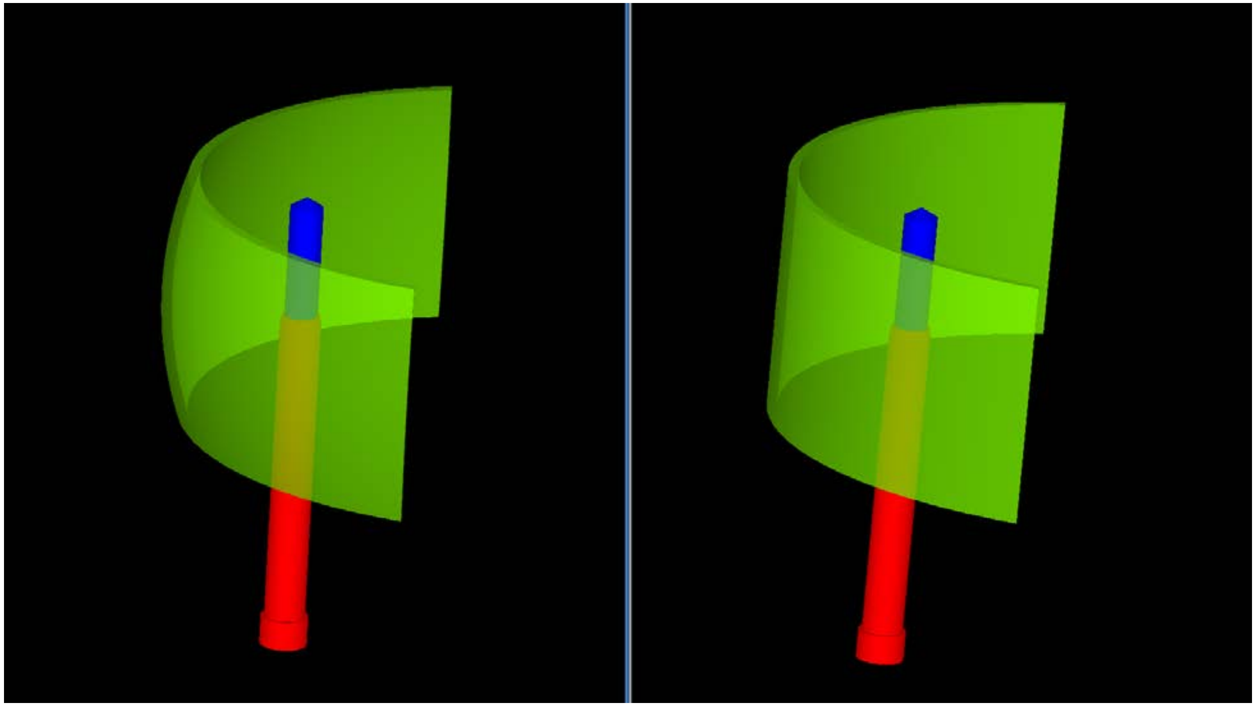
Monte Carlo investigations – Sr-90 source

- Geometry modelled in detail
- Source geometry built from information provided by manufacturer
- Source rotated around chamber (as for experiment)

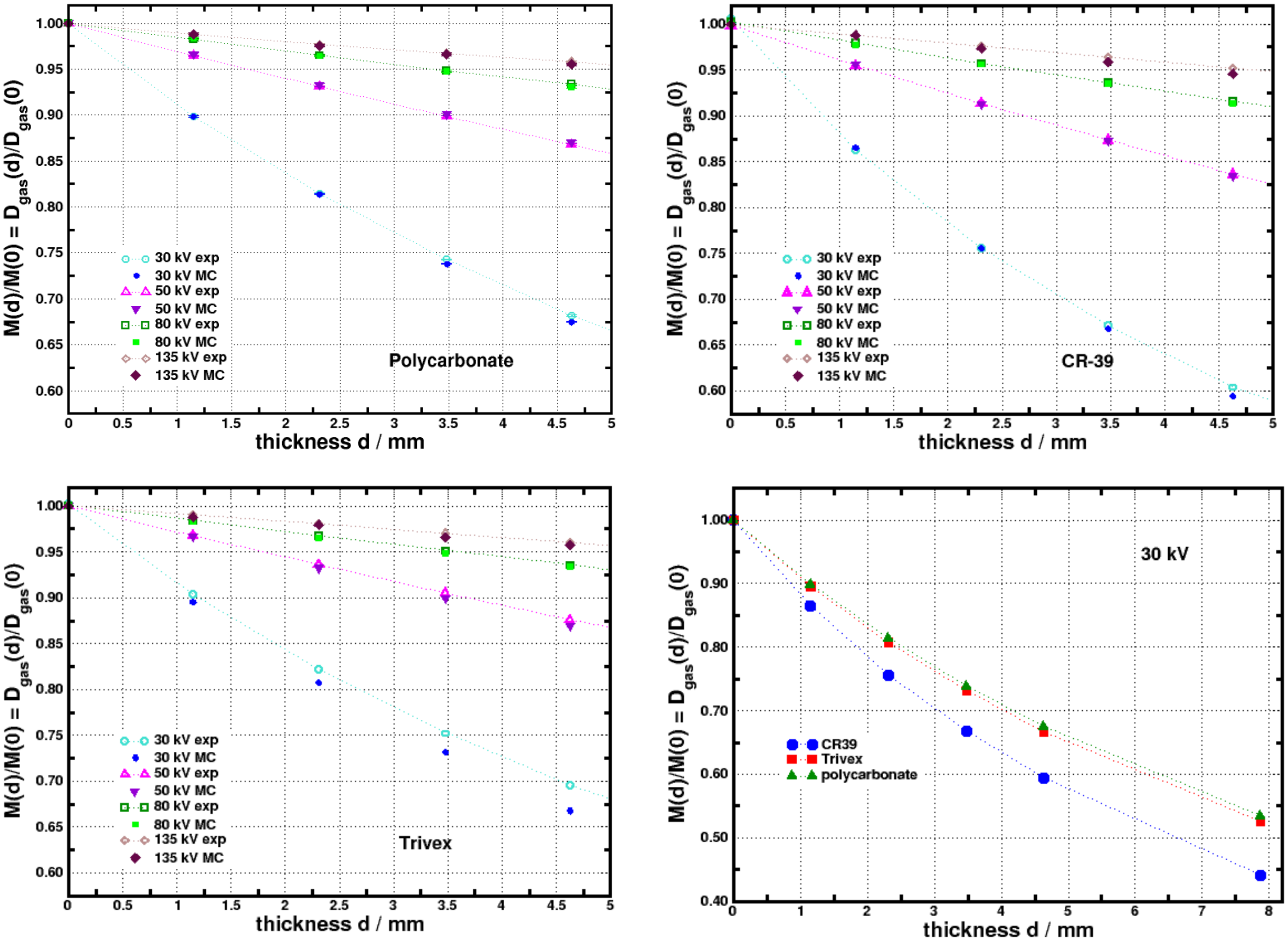


Monte Carlo investigations – eyewear models

- Detailed geometrical modelling of different eyewear models is beyond the scope of this work.
- Instead, simplified eyewear models are used
- Two polycarbonate eyewear models were used for the MC calculations, one made out of a <u>cylindrical slice</u> and the other using a <u>spherical slice.</u>



Monte Carlo results – planar sheets: x-rays



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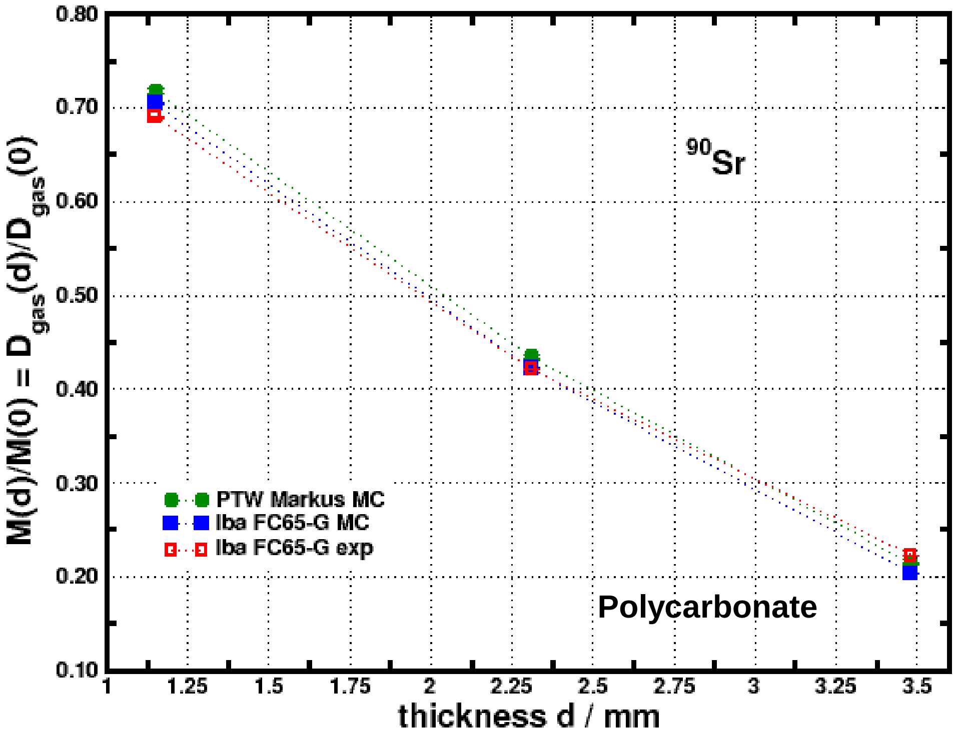
Monte Carlo results – planar sheets: Sr-90



- Short source-detector distance likely to make experiment and/or simulations sensitive to small geometry details
- Not actually the case
- Good agreement between measurement and simulation
- Little dependence on detector

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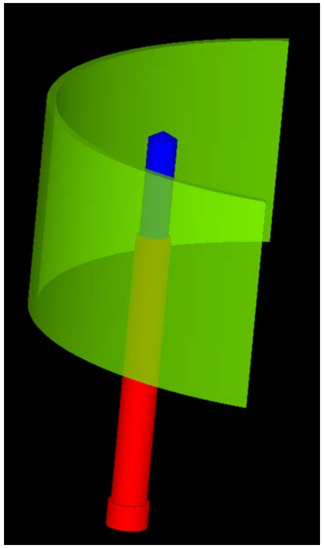
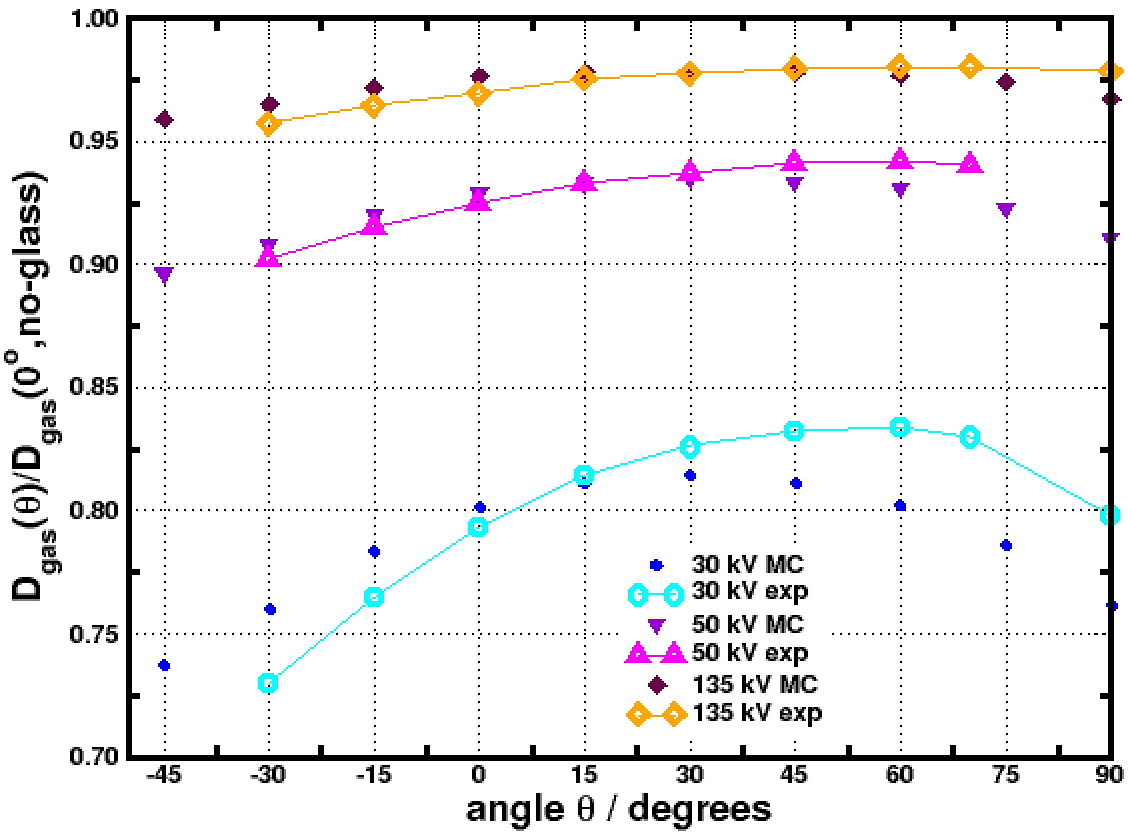
Monte Carlo results – comparison with experiment





Good agreement considering simplicity of MC model

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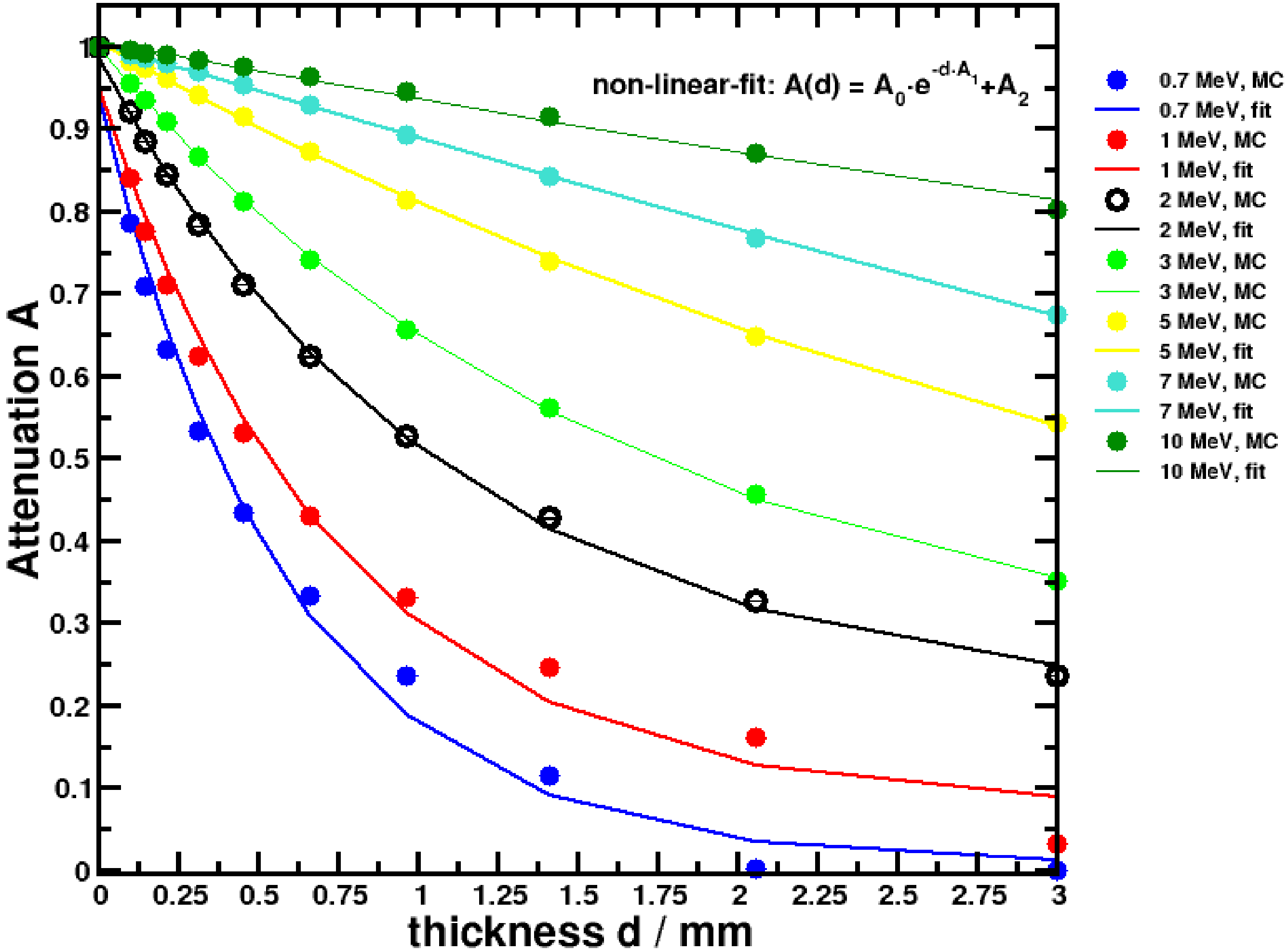
Summary

- Measurements and calculations provide detailed characterization of the shielding properties of standard protective eyewear
- As might be expected, the standard thickness of polycarbonate:
  - does not provide meaningful shielding for kV x-rays,
  - provides some protection for beta rays (factor ~ 3)
- Experience gained from measurements and developing accurate Monte Carlo simulations can be used in future investigations of more realistic radiation protection scenarios:
  - Situation-specific radiation sources
  - Complex geometries (source, room, person)

Thank You

Monte Carlo results – planar sheets: mono-energetic beams



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