An accurate experimental benchmark of bremsstrahlung for radiotherapy quality beams

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Outline

• Experiment
• Monte Carlo geometry
• Results
  – Accuracy
  – Timing
• Conclusions
Thick-target bremsstrahlung measurement at 10-30 MV

- Bremsstrahlung yield: photons per unit solid angle per unit energy interval
- Targets: Be, Al, Pb, thickness is CSDA range
- Yield on beam axis, Al and Pb, 10, 15, 20, 25 and 30 MV
- Yield at 15 MV, Be, Al and Pb at 0, 1, 2, 4, 10, 30, 60, 90
- Back angle in progress
Target and detector geometry

- 0.3 cm radius electron beam normally incident on 0.013 cm Ti, 0.01 cm Si TCM, 0.005 cm SS window (10), target BCM
- 8x10” NaI, 1” Pb collimator
Data processing

- Subtract pile-up spectrum and bkg
- Add counts lost to pulse pile-up
- Unfold detector response
- Add counts lost to attenuation and detector efficiency
- Collimator effect
Thick-target bremsstrahlung benchmark measurements

- “Forward-directed bremsstrahlung of 10- to 30-MeV electrons incident on thick targets of Al and Pb”, BA Faddegon, CK Ross, DWO Rogers, Medical Physics 17(5):773-785, 1990
Monte Carlo simulation: 15 MeV electrons on Be/Al/Pb target

- Geant4
- New geometry: scoring sphere around beamline and target developed by M. Asai
- New scoring developed by T. Aso
- Installation and support by J. Perl
- EGSnrc with BEAM user code from NRCC
- Revised scoring
Effect of target chamber on 15 MV bremsstrahlung yield

Ratio yield with no stainless steel window to that with window

- Be - Geant
- Al - Geant
- Pb - Geant

Ratio of bremsstrahlung yield vs. Angle (degrees)
Bremsstrahlung Fluence versus Direction

MC with target chamber out to 10 degrees, no target chamber 30 and 60 degrees

Experimental uncertainty: 5% on beam axis (0 degrees)
3% relative uncertainty at different angles

- Be - EGS (3.8% higher than mst on axis)
- Al - EGS (4.3% higher)
- Pb - EGS (1.7% higher)
- Be - Gnt7.1 (10% lower than mst on axis)
- Al - Gnt7.1 (9% lower)
- Pb - Gnt7.1 (5% higher)
- Be - Gnt8.0 (20% lower than mst on axis)
- Al - Gnt 8.0 (18% lower)
- Pb - Gnt 8.0 (6% lower)
Bremsstrahlung Fluence Ratio, MC/measurement

MC with target chamber out to 10 degrees, no target chamber 30 and 60 degrees

Experimental uncertainty: 5% on beam axis (0 degrees)
3% relative uncertainty at different angles

Fluence Ratio

Angle (degrees)

Be - EGSnrc
Al - EGSnrc
Pb - EGSnrc
Be - Geant 7.1
Al - Geant 7.1
Pb - Geant 7.1
Be - Geant 8.0
Al - Geant 8.0
Pb - Geant 8.0
15 MV Pb, 0 degrees

Geant fluence normalized to match 0 degree measurement at peak

- Measurement
- EGSnrc with target chamber
- Geant 4.7.1, with chamber
- Geant 4.8.0, no chamber

Fluence (MeV sr⁻¹)

Energy (MeV)
15 MV Al, 0 degrees

Geant fluence normalized to match 0 degree measurement at low energy
15 MV Be, 0 degrees

Geant fluence normalized to match 0 degree measurement at low energy

Fluence (MeV sr⁻¹)

Energy (MeV)

- Measurement
- EGSnrc: target chamber
- Geant 4.7.1: target chamber
- Geant 4.8.0: no chamber
Timing Comparison

No Bremsstrahlung Splitting
Geant 4.7.1/EGSnrc

Bremsstrahlung Splitting x 100
Geant 4.8.0/EGSnrc
Conclusions: 15 MV thick-target brem

• Need to improve bremsstrahlung cross-sections
  – Yield on axis (10-20%)
  – Angular distribution, eg, 15-30% low at 10 degrees
  – Energy spectra for low-Z targets, eg, ratio fluence at 10 MeV to 1 MeV 30% low for Be and Al

• Low energy physics + 8.0 multiple scattering, etc, may be less accurate all Z (10%), slower high-Z (due to lack of Russian Roulette in brem split?)

• Timing pretty good with bremsstrahlung splitting employed
  – Slow for low-Z targets by factor of 3, more for high-Z