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Monte Carlo optimization of the target configuration for bremsstrahlung x-ray production in flash radiotherapy

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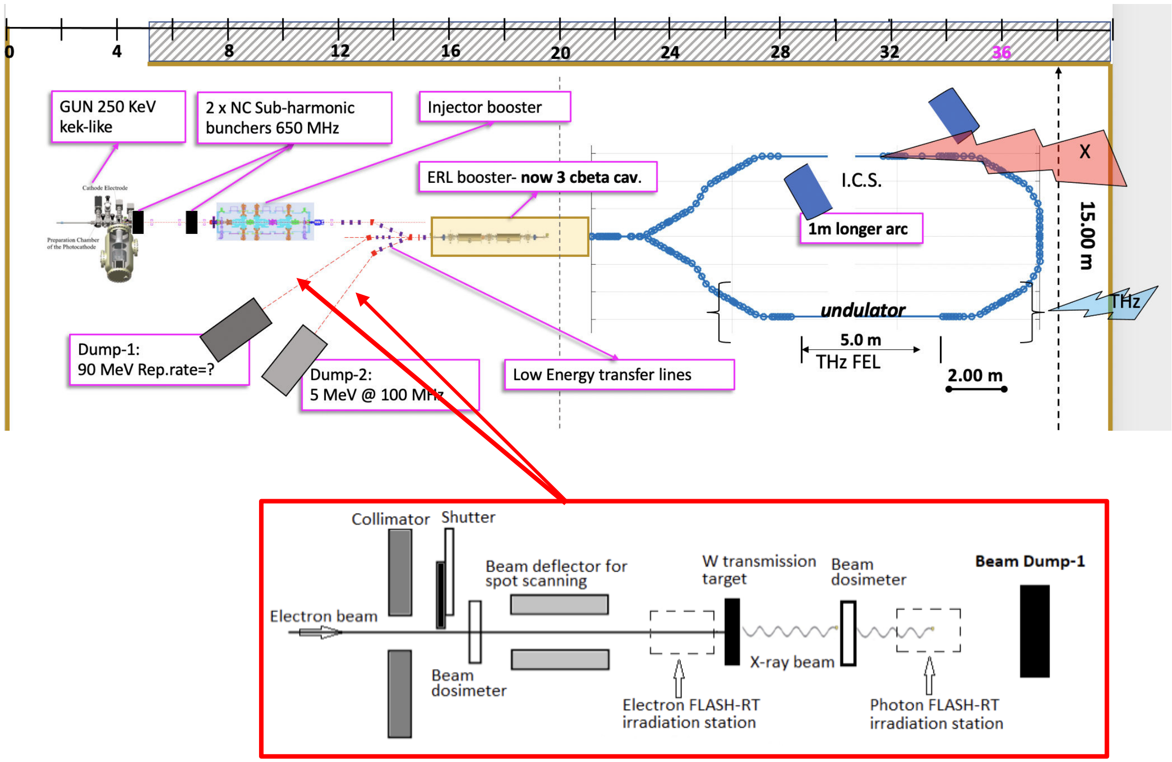
High-flux BriXSino electron beam for X-ray production



Flash radiotherapy is an innovative and promising teraphy for oncological lesion treatments which relies on high dose delivered at high rate in a small time lapse (>40 Gy/s water dose). Investigations are mainly confined to radiotherapy with electrons and protons, with the extension to x-ray photon beams limited to two factors: 1) limited photon output dose rate of conventional linacs with electron beam currents in the order of 0.1 mA; 2) thermal load constraints on the electron beam target for electron currents > 1 mA (limit temperatures for W/Cu target = 1500 ° C/500°C).

Thermal limits of current linac anodes

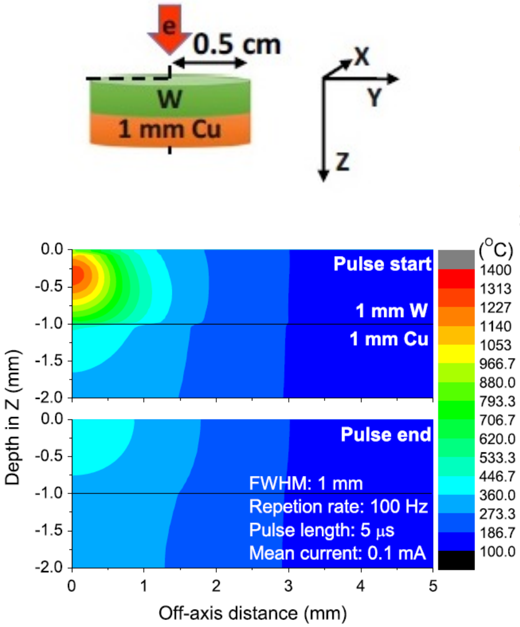


FIG. 5. 2D contour plot of the temperature distribution at the start (top) and end (bottom) of each electron pulse, when the target has reached its equilibrium state. Electron beam parameters: FWHM of 1 mm, pulse length of 5 µs, repetition rate of 100 Hz, and mean current of 0.1 mA. At the start of each temperature pulse, all the energy of the electron pulse is deposited and the target reaches its highest temperature. At the end of each temperature pulse, copper removes the maximum amount of heat and the target reaches its lowest temperature before repeating the cycle. Both W and Cu are 1 mm thick in this model, and the black line indicates the boundary between the two materials. [Color figure can be viewed at wileyonlinelibrary.com]

TABLE I. Electron beam parameters used for temperature and dose calculations.

arameter	Value
eam energy (MeV)	10
eam FWHM (mm)	0, 0.2, 0.5, 1, 2, 3
lean current (mA)	0.1, 0.2
ulse length (µs)	5
epetition rate (Hz)	100, 200, 400, 800

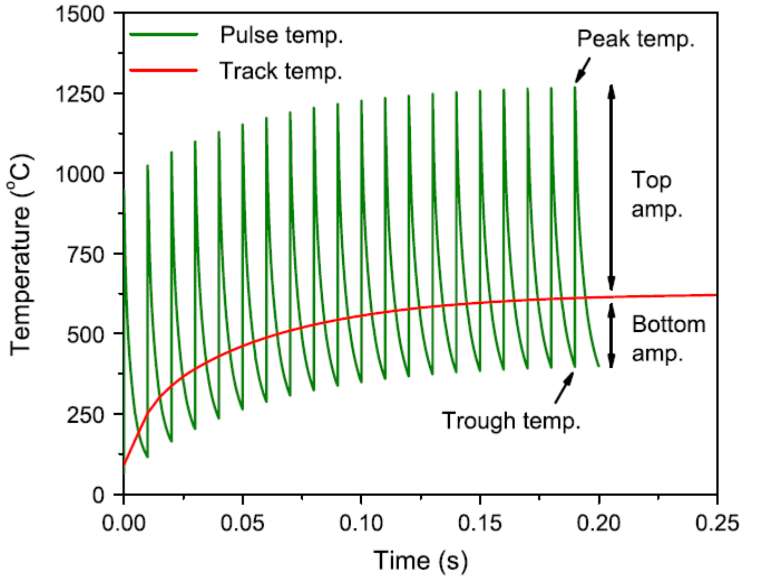
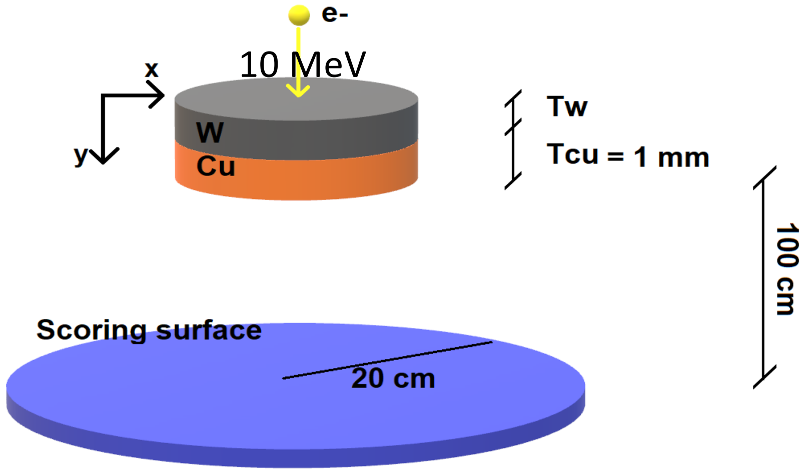


FIG. 3. Concepts used to characterize the transient temperature behavior of a target under repeating heat loads. The green saw shape curve is the transient temperature. The red curve is the track temperature, which is calculated by using an averaged heating load. The top amplitude is the difference between the peak and track temperatures. The bottom amplitude is the difference between the track and trough temperatures. [Color figure can be viewed at wileyonlinelibrary.com]

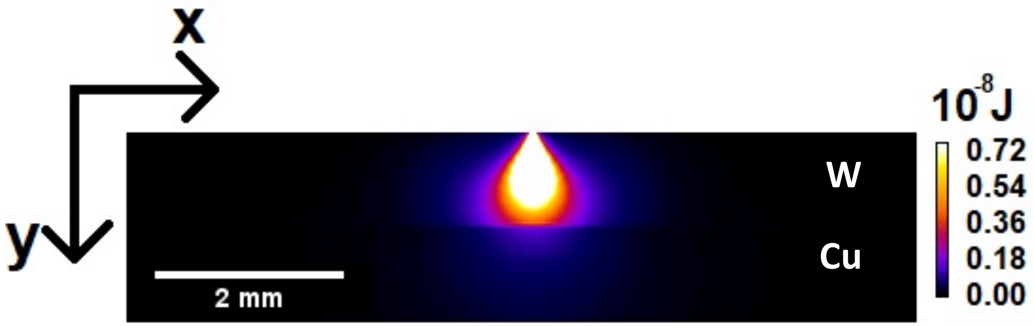
Data from: Wang, Jinghui, et al. "Thermal limits on MV x-ray production by bremsstrahlung targets in the context of novel linear accelerators." *Medical physics* 44.12 (2017): 6610-6620.

Simulated setup for x-ray production with the BriXSino high brilliance source



Simulation setup for investigating the heat load of the tungsten target for bremsstrahlung X-ray production with <10 MeV electron beam. The tungsten target is thermally backed by a copper layer.

Voxel side = 0.020 mm; electron range cutoff threshold = 0.010 mm. Number of electrons launched in the simulation = 10^9.

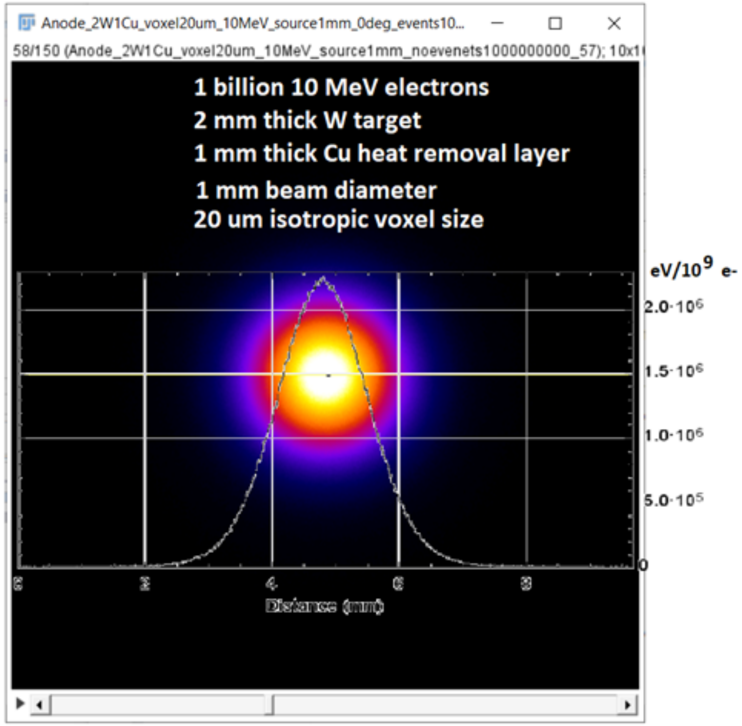


Coronal slice of the scored energy deposit map in the W/Cu materials.

Target dose distribution and produced spectrum

MV photons radiative loss/collisional loss (bremsstrahlung)
for 10 MeV electrons slowing down in W: ca. 50%

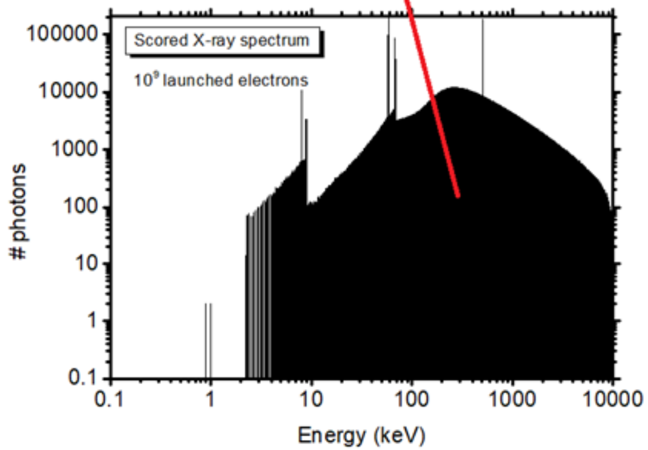
This preliminary test shows the energy distribution on a W target coupled with a Cu heat removal layer. The shown section is perpendicular to the electron beam direction. On the right, the photon spectrum at 1 m from the target is shown, indicating a total photon yield of 0.14 ph/e-.



10 e- pulses
at 100 MHz

1.0×10^9 electrons (10 MeV)

1.4×10^8 photons



10 MeV, 5 mA electron beam
(50 kJ/s)

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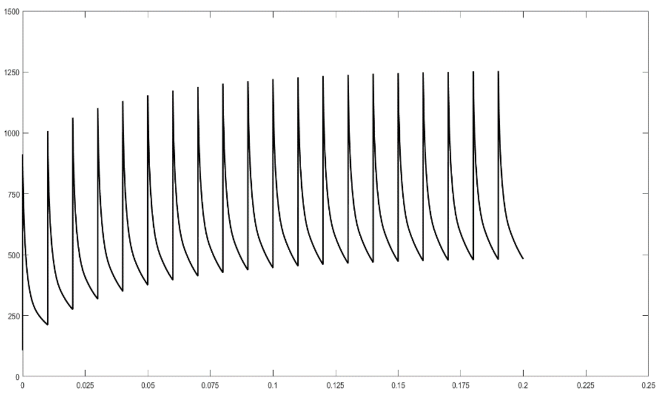
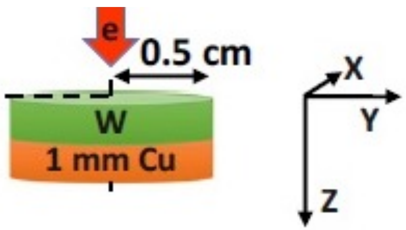
Thermal load and dose in BriXSino configuration

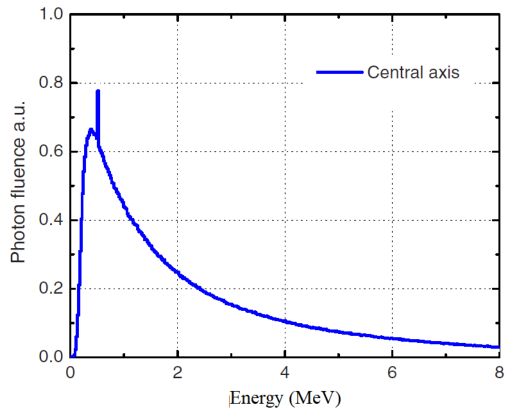
Temperature over the time:
Max target temperature (1200 °C)
for 10^9 electrons/pulse at 100 Hz





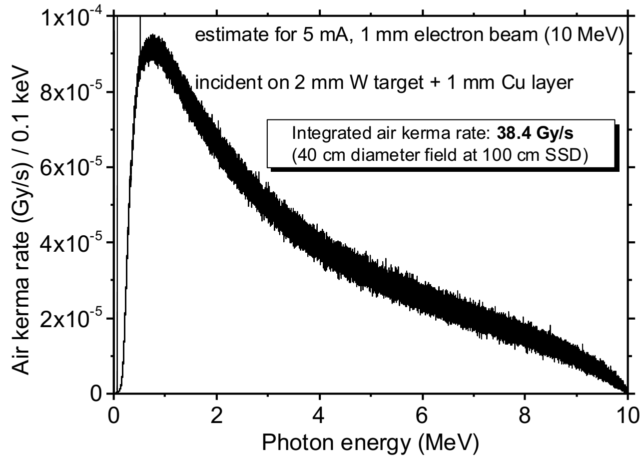
On following the scored air kerma (right) on a 20 cm radius circular surface at 1 m from the target, with the indication of the estimated kerma rate (38.4 Gy/s). On the left, a literature analysis of the photon fluence on a similar study

Literature



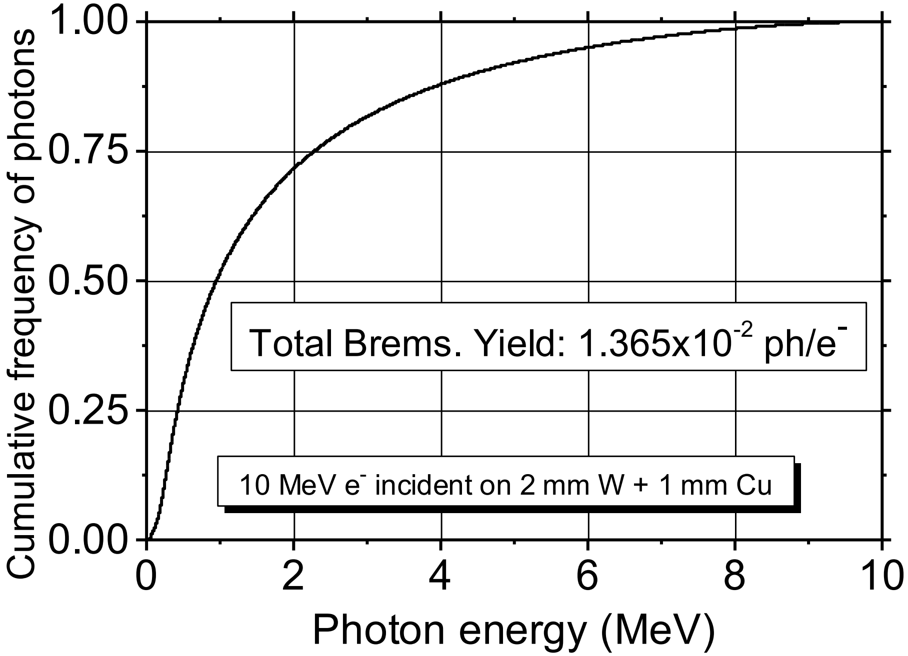
Monte Carlo simulated x-ray spectra on the central beam axis of unflattened 10 MV beams provided by an Elekta linac. More details concerning the MC simulations w.r.t. this figure can be found in Dalaryd *et al.* (Ref. 32).

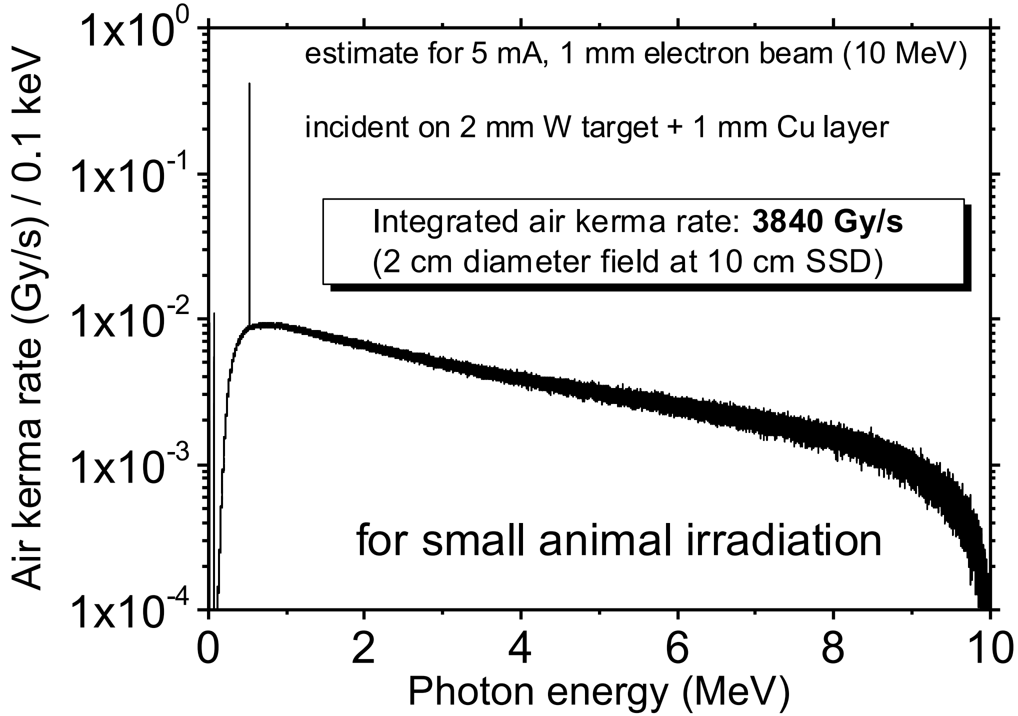
Our Geant4 simulations



*Literature data from: Wang, Jinghui, et al. "Thermal limits on MV x-ray production by bremsstrahlung targets in the context of novel linear accelerators." *Medical physics* 44.12 (2017): 6610-6620.

Cumulative fluence at the scoring surface





The cumulative fluence a the scoring surface shows that 50% of the generated photons have energy higher than 1 MeV

Estimated kerma rate spectrum @ 10 cm from the collimator

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IV Geant4 International User Conference 2022, 24–26 October 2022, Napoli (Italy)

Thanks for your attention

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