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Development of an Electron and Ion Laser Source to Test Radiobiological Effects with Ultra-High Dose Rates

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Limitations of conventional particle-accelerator technology have motivated development of advanced particle-acceleration techniques, such as laser-plasma acceleration (LPA), which could see a broad range of applications—including development of novel approaches for creating clinical microbeams with ultra-high dose rates. Within the past few years, tremendous progress in LPA development has been made (Leemans et al., Phys Rev Lett. 113, 245002 (2014); Steinke et al., Nature 530, 190-193 (2016)).

The Berkeley Laboratory Laser Accelerator (BELLA) facility at the Lawrence Berkeley National Laboratory is an experimental facility for further advancing development of laser-driven plasma acceleration. To advance medically relevant applications, a project is underway to create a platform to understand radiobiological effects of laser-accelerated ion and electron beams for the treatment of cancer. Ultra-high instantaneous dose rates (>40 Gy/s) of 4.5 MeV electron beams have been reported in murine, feline and porcine laboratory studies to completely eradiate tumors while reducing the occurrence and severity of early and late complications affecting normal tissues. Nanosecond intense 5-10 MeV proton pulses of up to ~3 kGy can be generated at the BELLA-PW-laser. In the following years, a proton focusing system to achieve >100 kGy at millimeter spotsizes and a new laser beam line will be implemented. The latter will allow for proton energies >50 MeV.

For electron beams, a 1 Hz repetition-rate with a few MeV ultra-compact electron accelerator capable of generating femtosecond intense pulses is being developed. In both cases, instantaneous peak dose rates are many orders of magnitude greater than with conventional accelerators. Average dose rates can be controlled by adjusting with the laser pulse repetition rate and peak dose rates can be adjusted, e. g. by selection of laser powers, masking and focusing. Peak dose rates can reach very high values in excess of 109 Gy/s during ion or electron radiation pulses with durations of a few nanoseconds.

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