Radiation generation in high power laser applications

Simon Bohlen[1,*]

[1]Deutsches Elektronen-Synchrotron DESY, Notkestraße 85, 22607 Hamburg, Germany

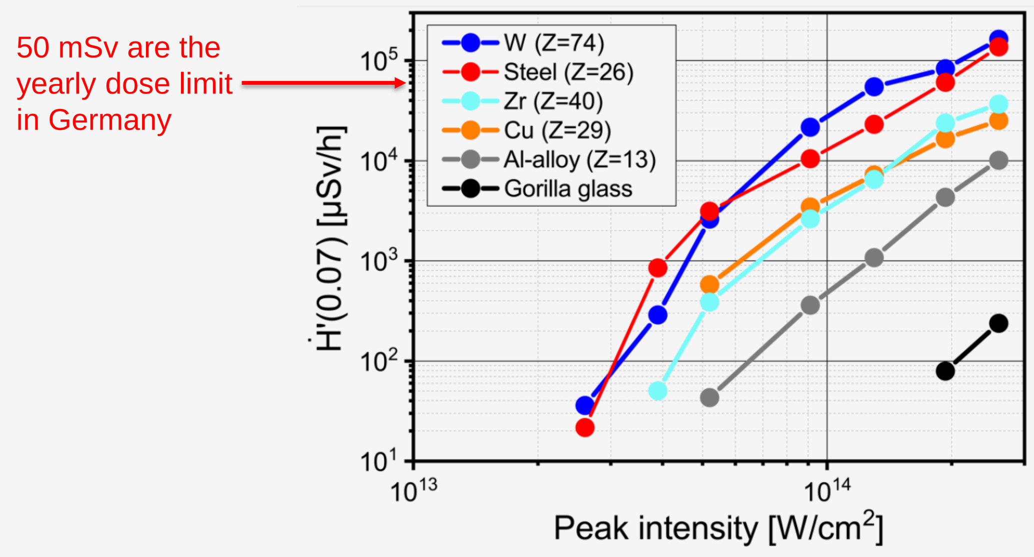
D3
Radiation
Safety

Lasers with femtosecond pulse durations have become readily available and are used in numerous applications from material processing to plasma-based accelerators. Often, the lasers are focused to small spot sizes, exceeding intensities of 10^{13} W/cm^2 and thus the ionization threshold in most materials. As this can lead to the production of x-rays, national law in Germany made it mandatory to monitor the dose rate if this intensity threshold is exceeded. At Deutsches Elektronen-Synchrotron DESY, research has now started to further investigate and understand the production of x-rays in different materials or gases to enable safe working conditions and compliance with the legal framework while maintaining the flexible workflow required at universities and research institutes. This poster gives an overview of existing research on this topic, shows plans for the research at DESY and invites to discuss implications for future work in the development of plasma accelerators.

Measurement of radiation dose in solid materials

Most measurements are for material processing using ultrafast lasers[1]

- Moderate peak intensities can lead to high dose rates in material processing.
- The average energy of these lasers is often similar to that of lasers used for plasma acceleration.
- Low power beams can have enough energy to create ionising radiation if focused down.
- Nevertheless, generation of radiation no threat for most applications[2].



Dose rate from 40 W laser for different Materials (10µm, 100µJ, 400kHz). Image from [1]

Impact on plasma-acceleration setups

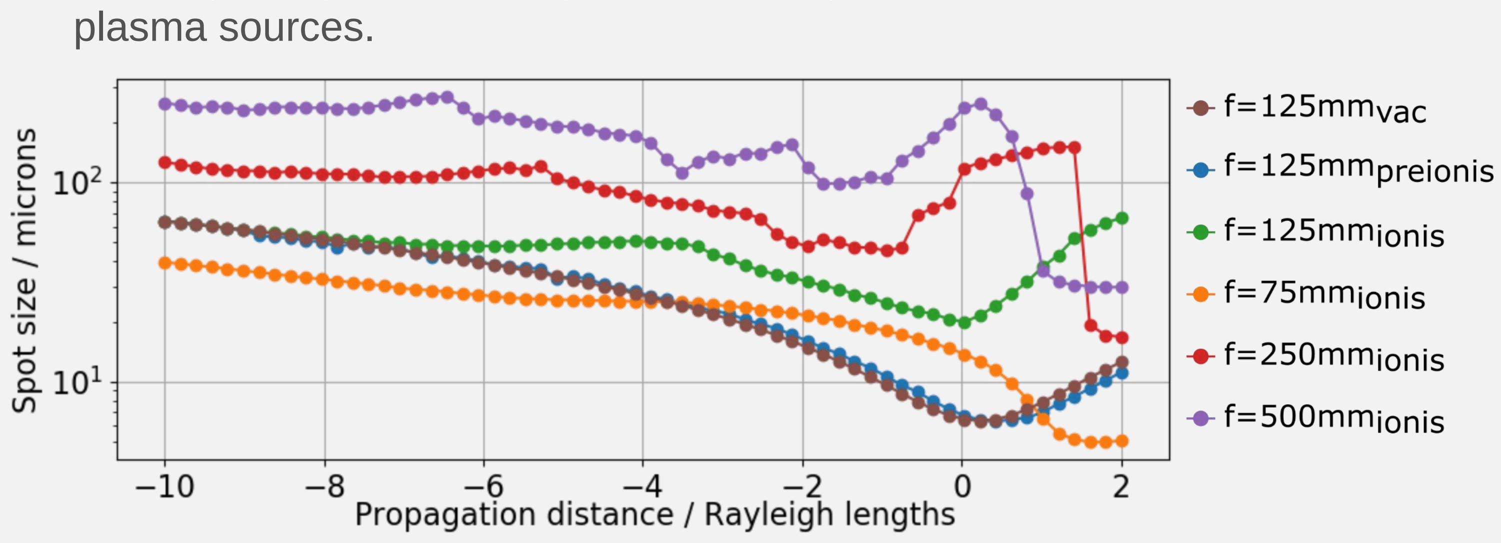
Regulations relevant for future laser technology and applications

- Intensities of 10^{13} W/cm^2 can be easily exceeded, e.g. when broadening the spectrum in hollow-core fibres or mulipass cells.
- Working permits might be required for the use of standard laser installations such as spatial filters.
- Imaging using lenses can create foci exceeding the intensity threshold.
- Regulations might be specified based on working conditions in material processing, ignoring requirements for research environments.
- Measurements required to define relevant parameter space.

Common goals for radiation safety and plasma acceleration

Understanding of plasma generation essential for both fields

- The focusing dynamics of the laser need to be understood:
  - Ionisation diffraction and self-focusing need to be simulated.
  - Scaling laws for approximation of intensity required.
  - Experimental study of plasma generation and dynamics needed.
- Study of femtosecond phenomena.
- Plasma generation and heating effects influence radiation generation.
- Investigation of plasma dynamics at high repetition rates.
- Usability as light source e.g. for hard x-rays in combination with laser plasma sources.

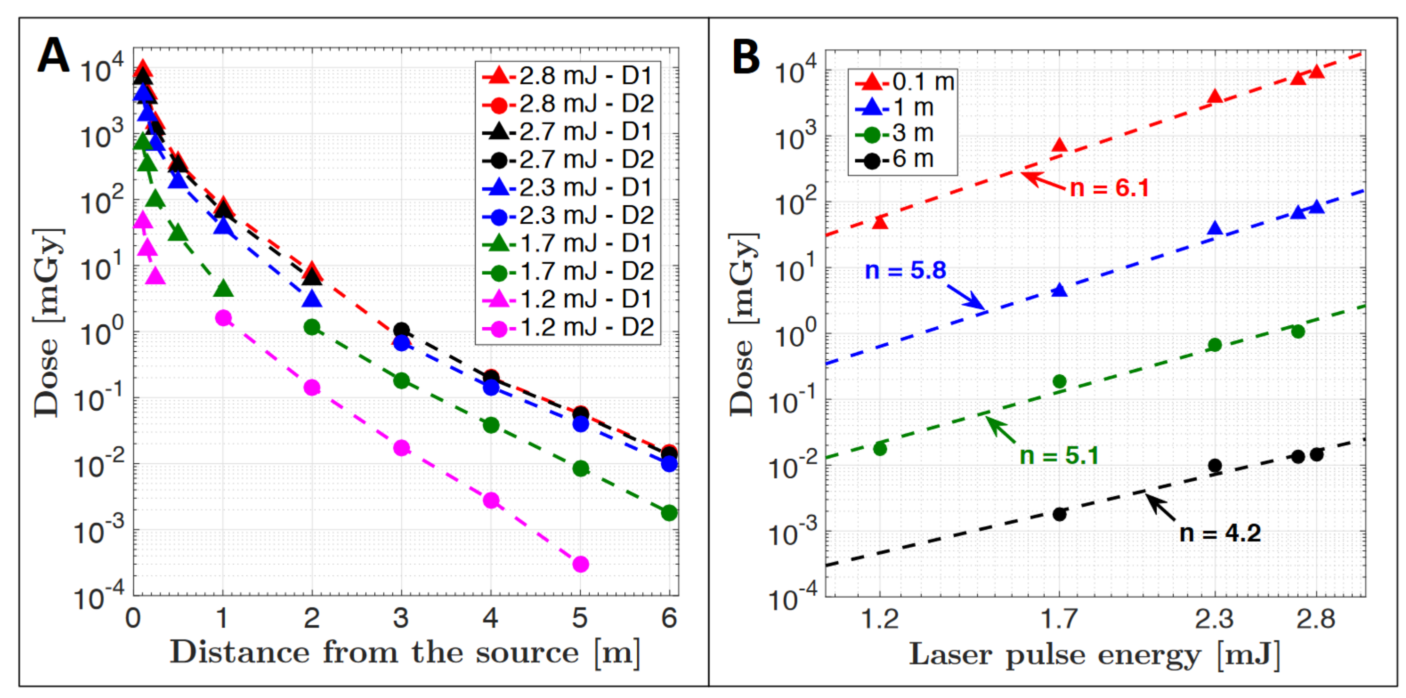


Simulation of ionisation diffraction and self focusing, courtesy of Kristjan Põder

Measurement of radiation dose in air

Deadly radiation dose from few Joules of laser energy[3]

- Using tight focusing even small laser energies can create large doses.
- Setup in Canada used 6000 pulses (1 minute) with an energy of 2.8 mJ per pulse to create a dose of 10 Gy by focusing in air.
- The vacuum intensity estimated at $I_0 \approx 10^{19}$ W/cm^2 at full power.
- Assuming full body exposure, lethal doses can be accumulated within minutes, even at distances of 1m from the focus.
- Significant production of high-energy x-rays can be assumed due to relevant doses at distances of several meters.

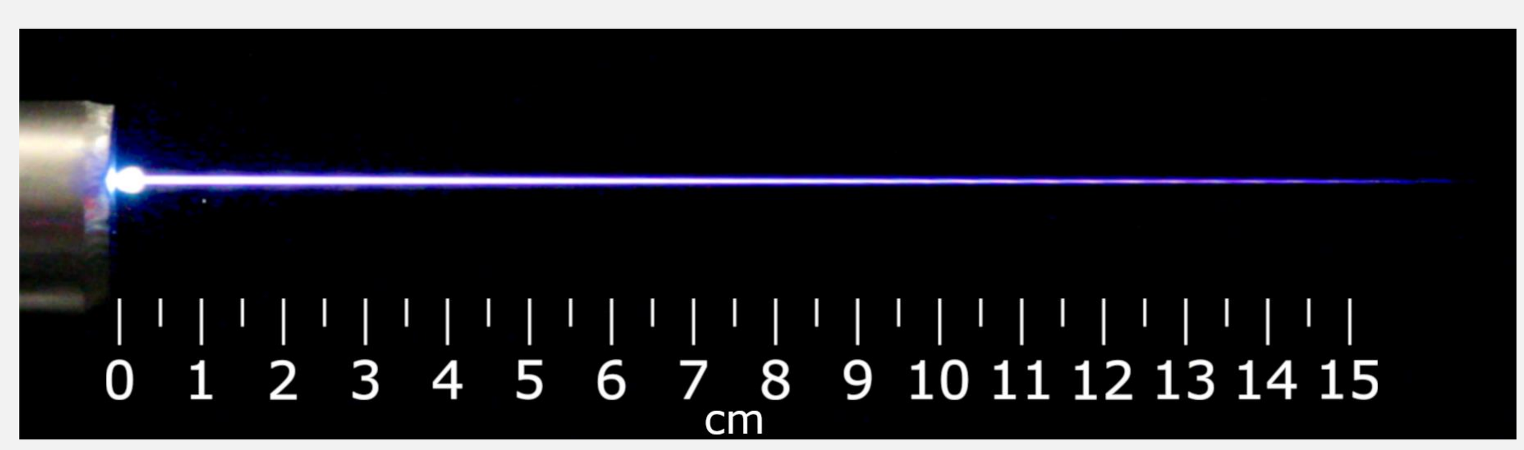


Measured radiation doses for 1 minute at 100 Hz with laser focus in air. Image from [3]

Challenges for dose monitoring

Development of new detectors for femtosecond x-ray pulses required

- Short x-ray bursts are challenging for existing detector technologies and often lead to pile-up.
- Dose rates can vary over serveral orders of magnitude.
- Low x-ray energies require monitoring of dose rates close to experiments due to attenuation in ambient air.
- Development of new detector technologies might be required for dose rate measurements.
- First tests of fluorescence-based detectors for femtosecond x-ray pulses ongoing at DESY.



Fluorescence of 0.67 keV photon beam at XFEL

Summary

Safe high power laser applications without radiation

- Laser intensities above 10^{13} W/cm^2 can lead to the generation of x-rays when hitting material or gases.
- Dependency on many laser parameters and the target material lead to huge parameter space and make predictions difficult.
- Understanding of fundamental (plasma) processes required to maintain flexible working conditions in safe way.
- Monitoring of the radiation required to enable safe working environments.
- Femtosecond nature of the produced x-rays make precise measurement of radiation doses challenging.

References

[1] H. Legall et al., *Review of x-ray exposure and safety issues arising from ultra-short pulse laser material processing*, J. Radiol. Prot. **41** R28, (2021)

[2] R. Weber and T. Graf, *X-ray emission during materials processing with ultrashort laser pulses - A serious problem?*, Procedia CIRP **111** 844–849, (2022)

[3] S. Vallières et al., *High Dose-Rate Ionizing Radiation Source from Tight Focusing in Air of a mJ-class Femtosecond Laser,* arXiv:2207.05773, (2022)

* Contact: simon.bohlen@desy.de | d3.desy.de

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