Radiation safety for high power laser applications

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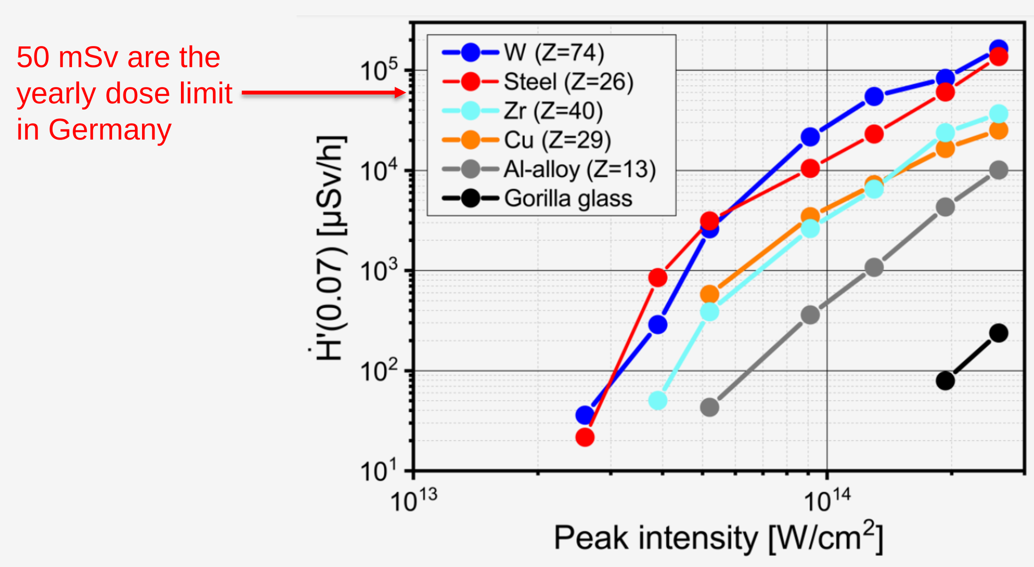
Radiation
Safety

Ultra-short lasers with femtosecond pulse durations have become readily available and are now used in numerous applications such as material processing or plasma-based accelerators. In most cases, these lasers are focused to small spot sizes, exceeding intensities of 10^{13} W/cm² 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 from all laser setups exceeding this intensity threshold. At DESY, research has now started to further investigate and understand the production of x-rays in different materials and 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 studies already conducted 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]

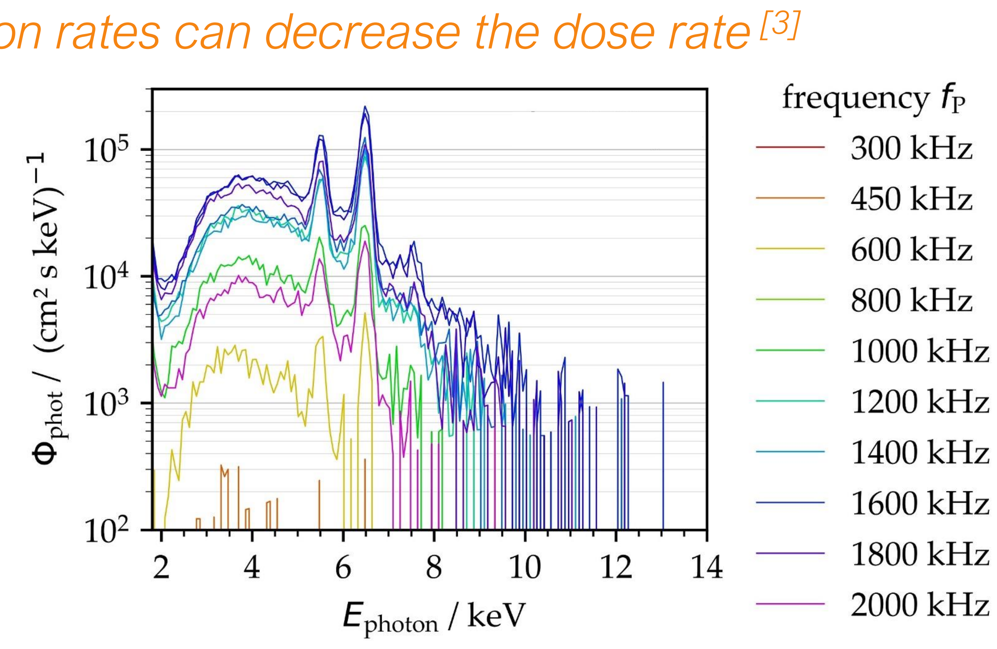
- In material processing, already moderate peak intensities can lead to high dose rates.
- The average energy of these lasers is often similar to that of lasers used for plasma acceleration.
- Already low power or alignment beams can have enough energy to create ionizing radiation if focused down.



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

Knowledge of plasma physics essential for predictions

High repetition rates can decrease the dose rate [3]



Radiation dose as function of repetition rate. Image from [3]
Maximum at 1600 kHz, dose drops at 2000 kHz.

- The dose rates depend on many laser properties (energy, repetition rate, pulse duration, contrast, …) and the target material.
- Overcritical densities can reduce the dose rates for high repetition rates.
- Non-linear effects such as self-focusing in air plasmas can change properties of laser beam.
- Overlap with many areas of general plasma physics, plasma accelerators and plasma fusion

Impact on plasma-acceleration setups and outlook

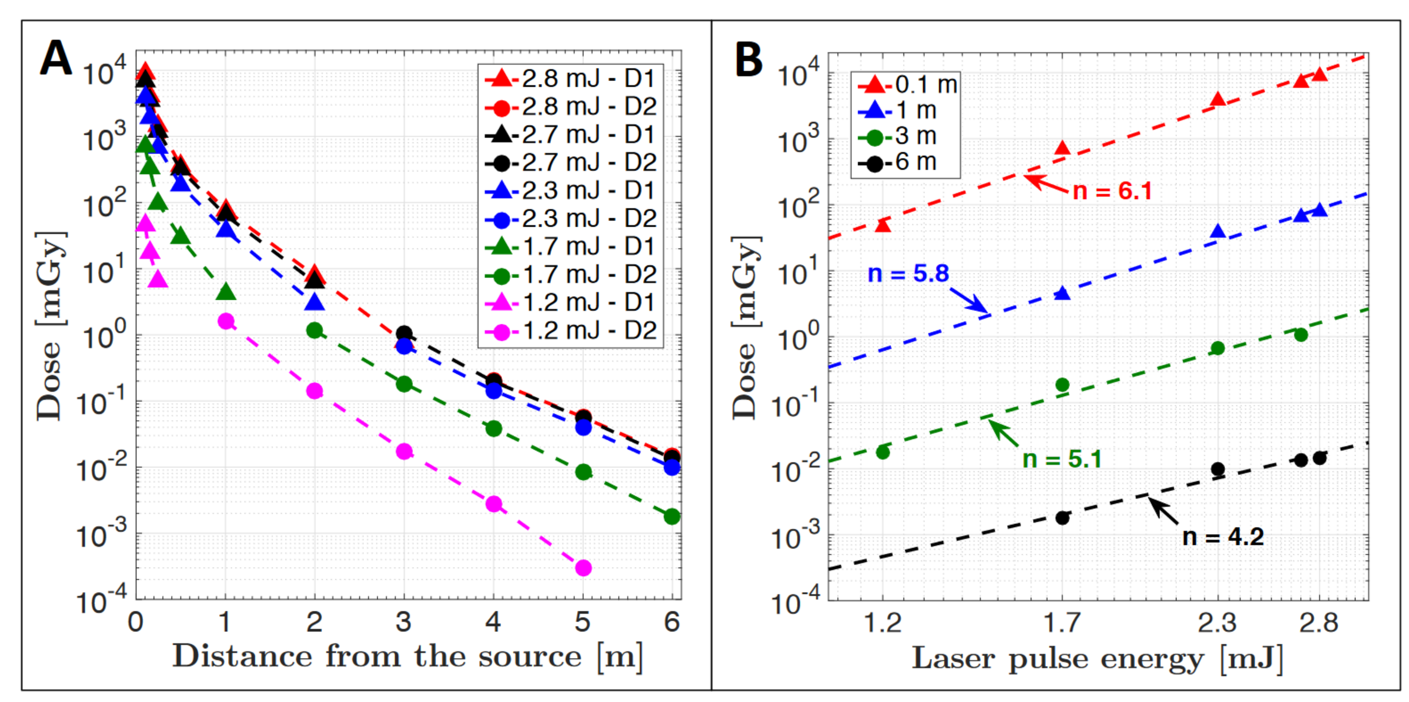
Regulations relevant for future laser technology and applications

- Intensities of 10^{13} W/cm² can be easily exceeded, for example when broadening the spectrum in hollow-core fibres or mulipass cells.
- Working permits might be required for the use of 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

Measurement of radiation dose in air

Deadly radiation dose from 280mJ laser energy[2]

- Using tight focusing even small laser energies can create large doses.
- Setup in Canada used 100 pulses (1 minute) with an energy of 2.8 mJ per pulse to create a lethal dose of 10 Gy by focusing in air.
- The intensity reached $I_0 \approx 10^{19}$ W/cm² at full power.
- Even at distances of 1m lethal doses can be accumulated within minutes.
- Relevant doses at distances of several meters implies significant production of high-energy x-rays

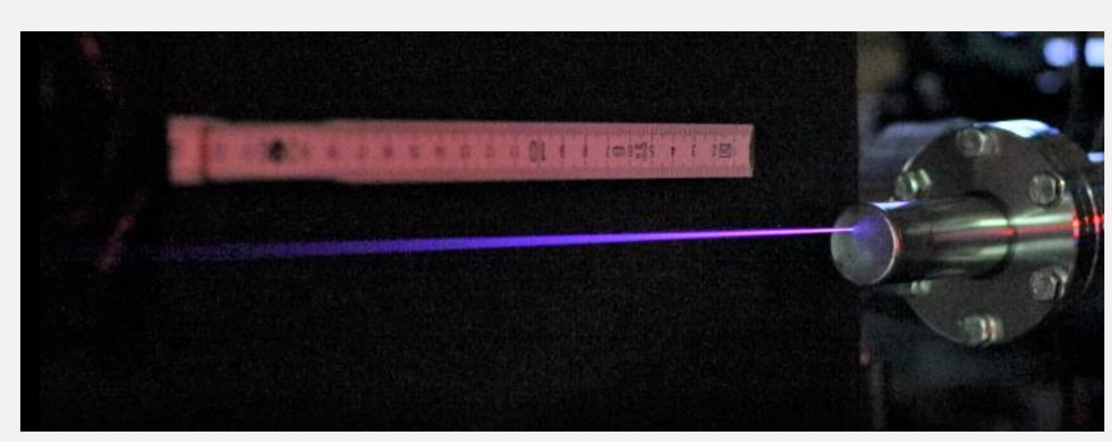


Measured radiation doses for 1 minute at 100 Hz with laser focus in air. Image from [2]

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 2.7 keV photon beam at XFEL

Summary

Safe high power laser applications without radiation

- Laser intensities above 10^{13} W/cm² can lead to the generation of x-rays when hitting material or gases.
- Monitoring of the radiation required to enable safe working environments.
- Femtosecond nature of the produced x-rays make precise measurement of radiation doses challenging.
- 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.

Refrerences

[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] 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)

[3] J. Schille et al., *Study on X-ray Emission Using Ultrashort Pulsed Lasers in Materials Processing*, Materials, 14, 4537 (2021)

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