Vapour Shielding of Liquid-metal CPS Based Targets Under ELM-like And Disruption Transient Loading

IGOR GARKUSHA, V.A. Makhlai, Yu.V. Petrov, S.S. Herashchenko, M.S. Ladygina, N.N. Aksenov, O.V. Byrka, V.V. Cheboratev, N.V. Kulik, V.V. Staltsov and S. Pestchany*

National Science Center „Kharkov Institute of Physics and Technology“, 61108, Kharkiv, Ukraine

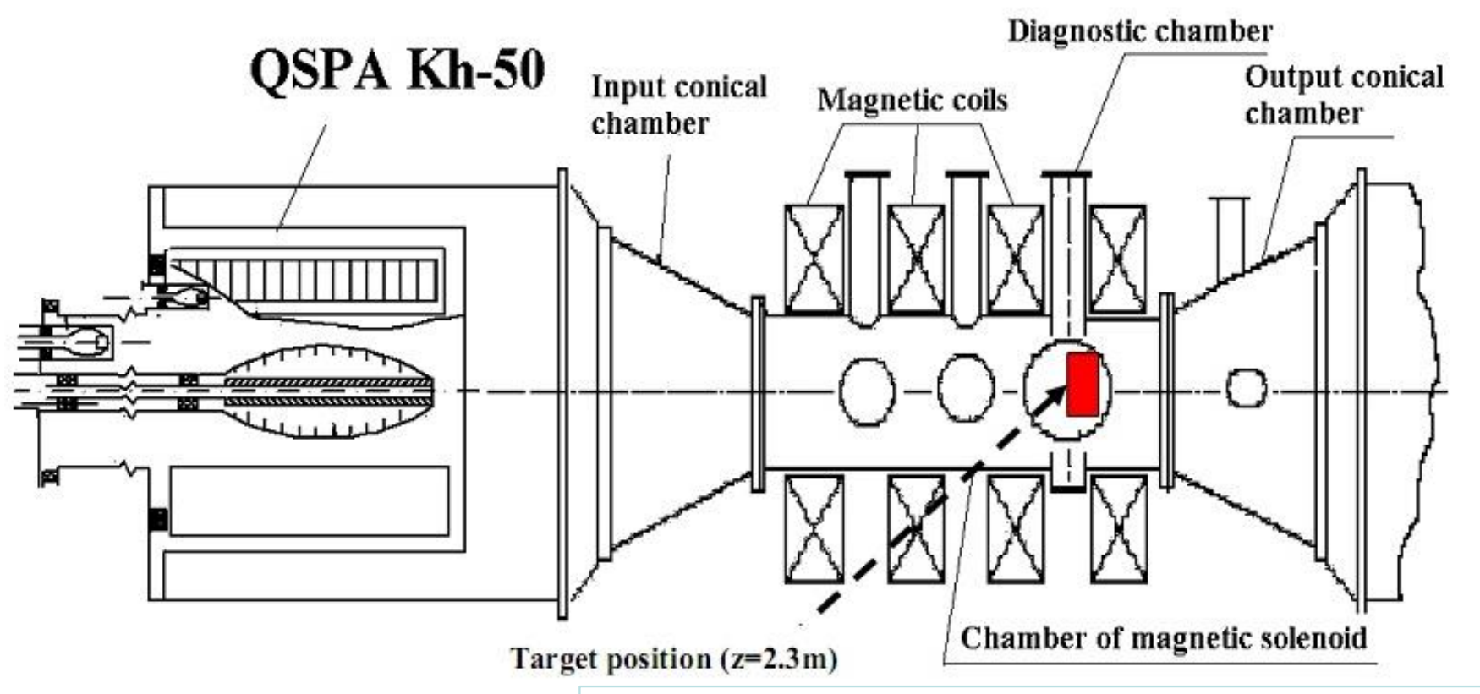
**Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Karlsruhe, Germany*

Motivation

One of the key risks for the DEMO tokamak performance is high energy density transients (disruption and ELM). Capillary porous systems filled with liquid metal (Li, Sn) are considered now as an alternative approach for plasma-facing components of heavily loaded divertor in a fusion reactor. Among the favorable effects for LM divertor approach could be strong vapor shielding of exposed surfaces, which decrease essentially both the resulting surface load and erosion. Different PSI devices are used to analyze the material response to extremely high particle and heat fluxes. This paper presents experimental studies of plasma-surface interactions during powerful QSPA plasma impacts to the Sn CPS structures in conditions, simulating disruption and ELM-like loads.

Experimental facilities, samples and diagnostics

QSPA Kh-50



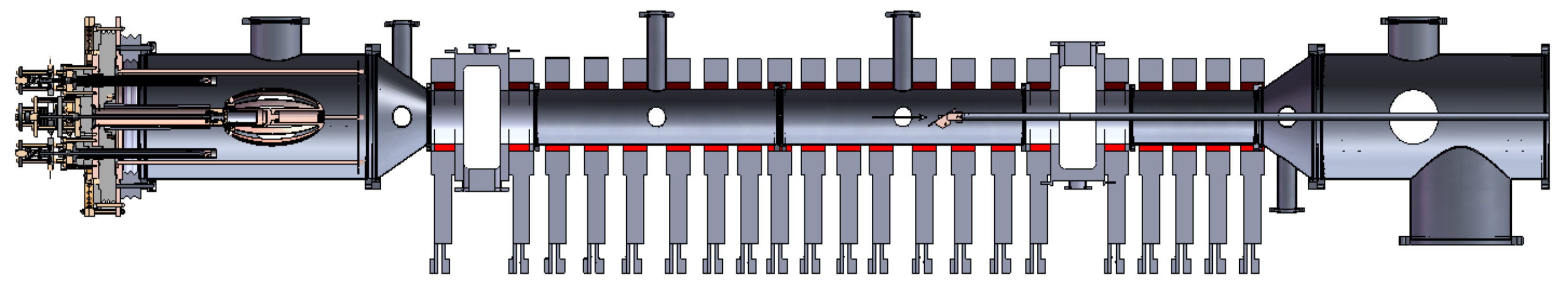
Plasma energy density	0.1–2.2 MJ/m²
Plasma load duration	0.25 ms
Diameter of plasma stream	15 cm

Diagnostics

- ❖Calorimetry
- ❖Optical emission spectroscopy
- ❖High-speed digital camera PCO AG

QSPA-M

V A Makhlai et al *2020 Phys. Scr. T171, 014047*

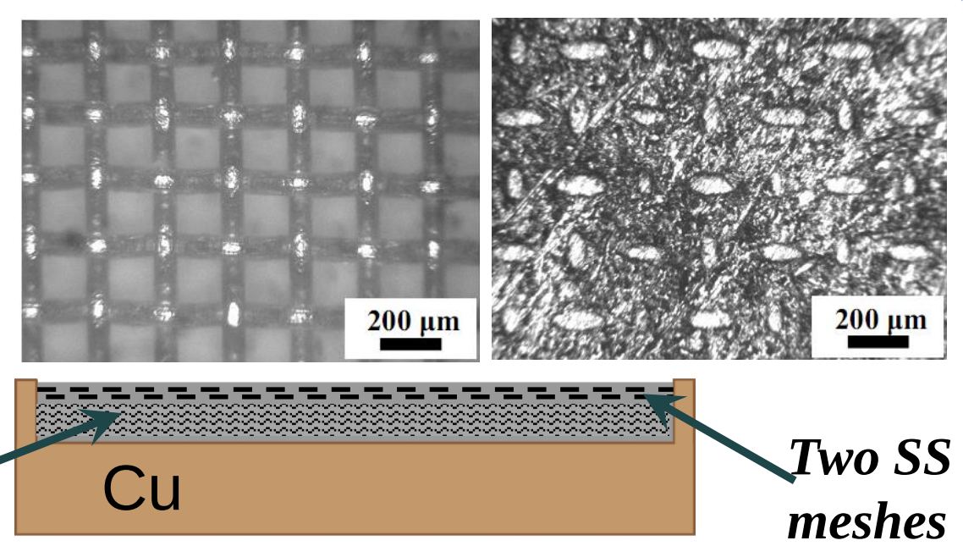


Plasma energy density	0.1-1 MJ/m²
Plasma load duration	0.1 ms
External magnetic field	0.8 T
Diameter of plasma stream	6 cm

I.E. Garkusha *et al 2017 Nucl. Fusion 57, 116011;*
I.E. Garkusha *et al 2019 Nucl. Fusion 59, 086023*

CPS based Sn

SS mesh wetted by Sn. Average cell size – 150x150 μm; Wire thickness – 90 μm



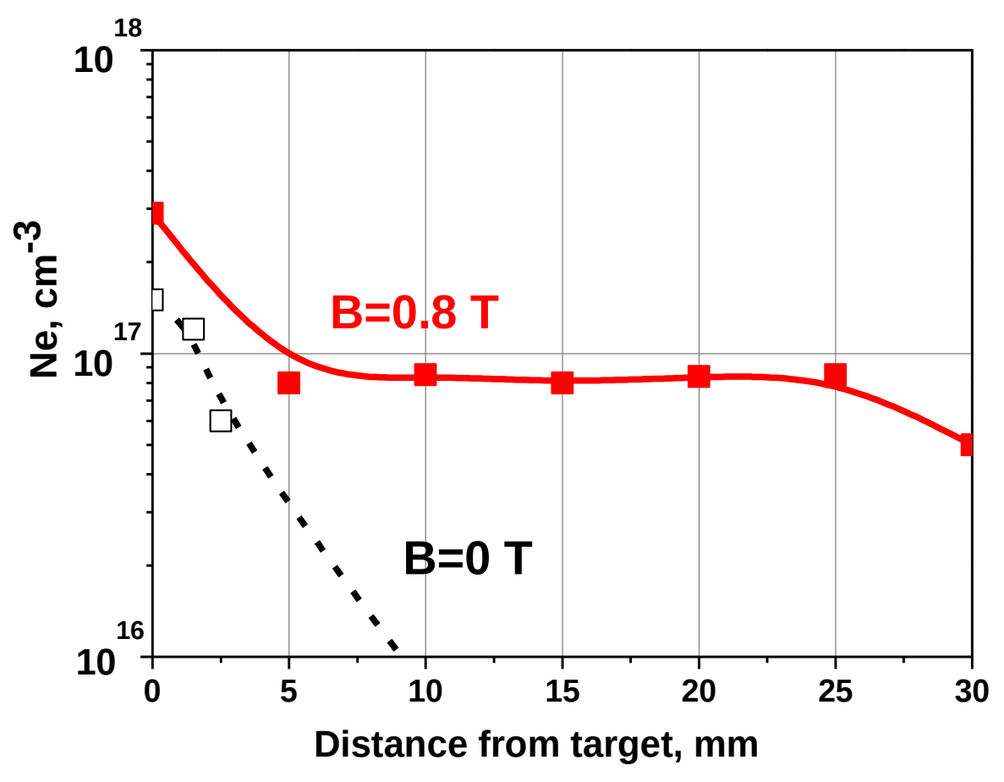
Porous structure made of SS wire

Two SS meshes

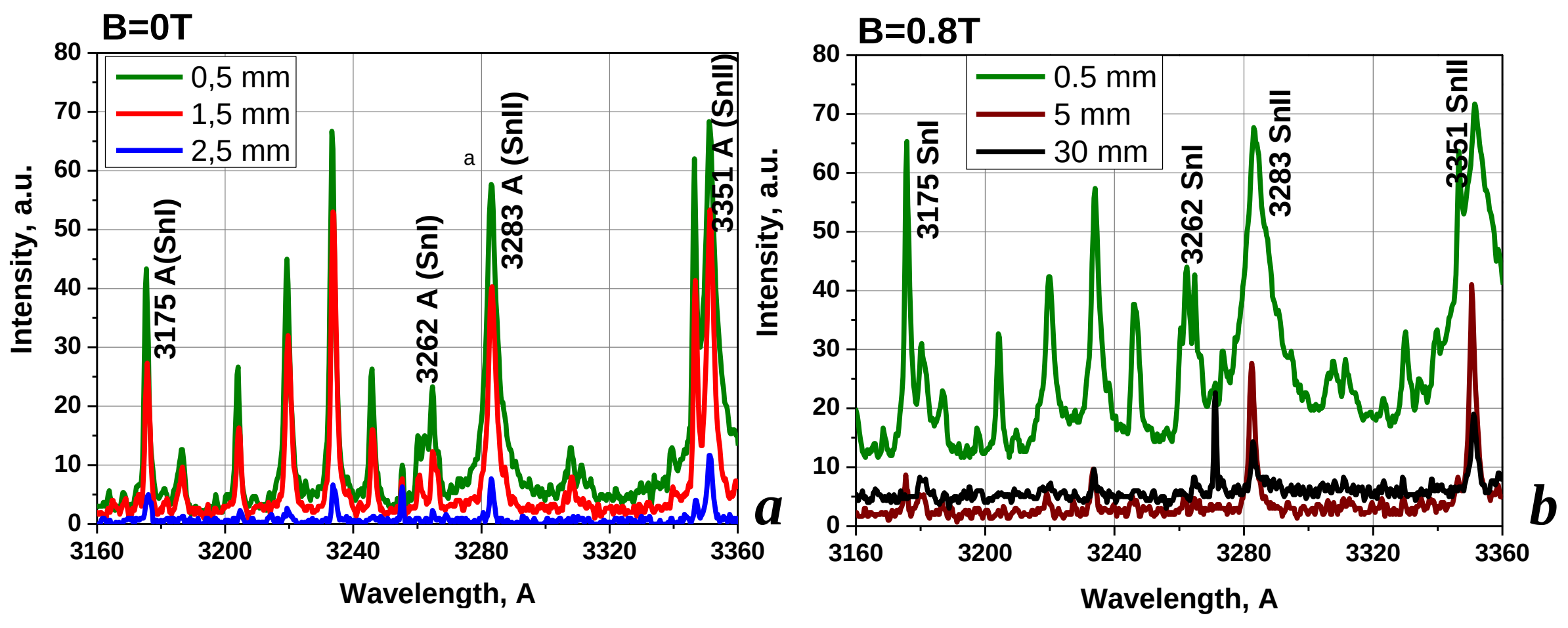
Schematic cross-section view of the target

Spectroscopy studies

- The plasma electron density was estimated using Stark broadening of spectral lines Sn II (3283 Å).
- The shielding layer is thinner without a magnetic field due to the plasma flows around the target.
- Shielding layer size increases in magnetic field. Sn lines are detected at essentially longer distances in magnetic field.
- This dense plasma shield is completely not transparent for the impacting plasma, being considerably larger than the particle free path length.



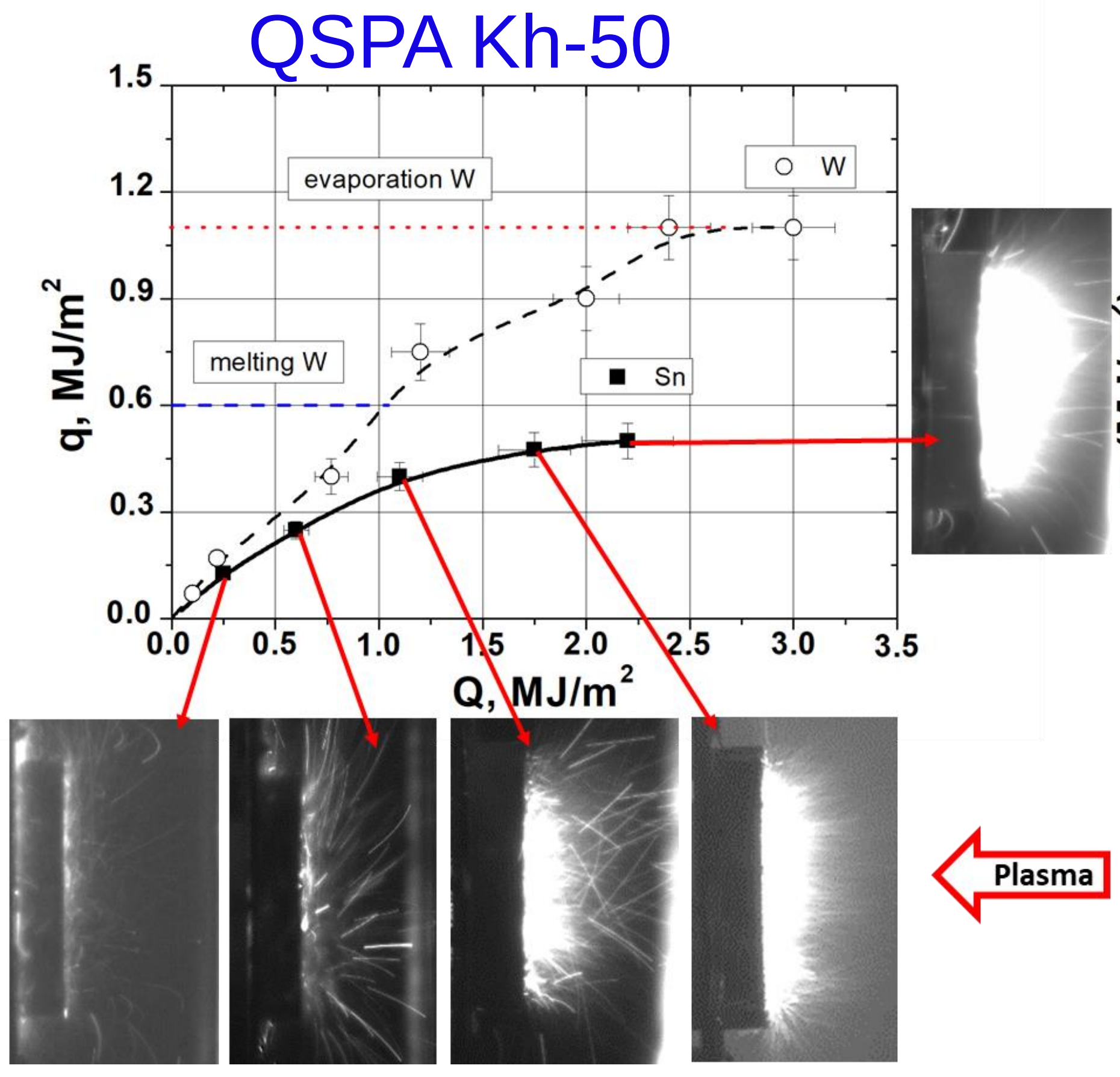
Distributions of electron density in shielding layer vs. the distance from the Sn target surface, Q=0.75 MJ/m² in QSPA-M



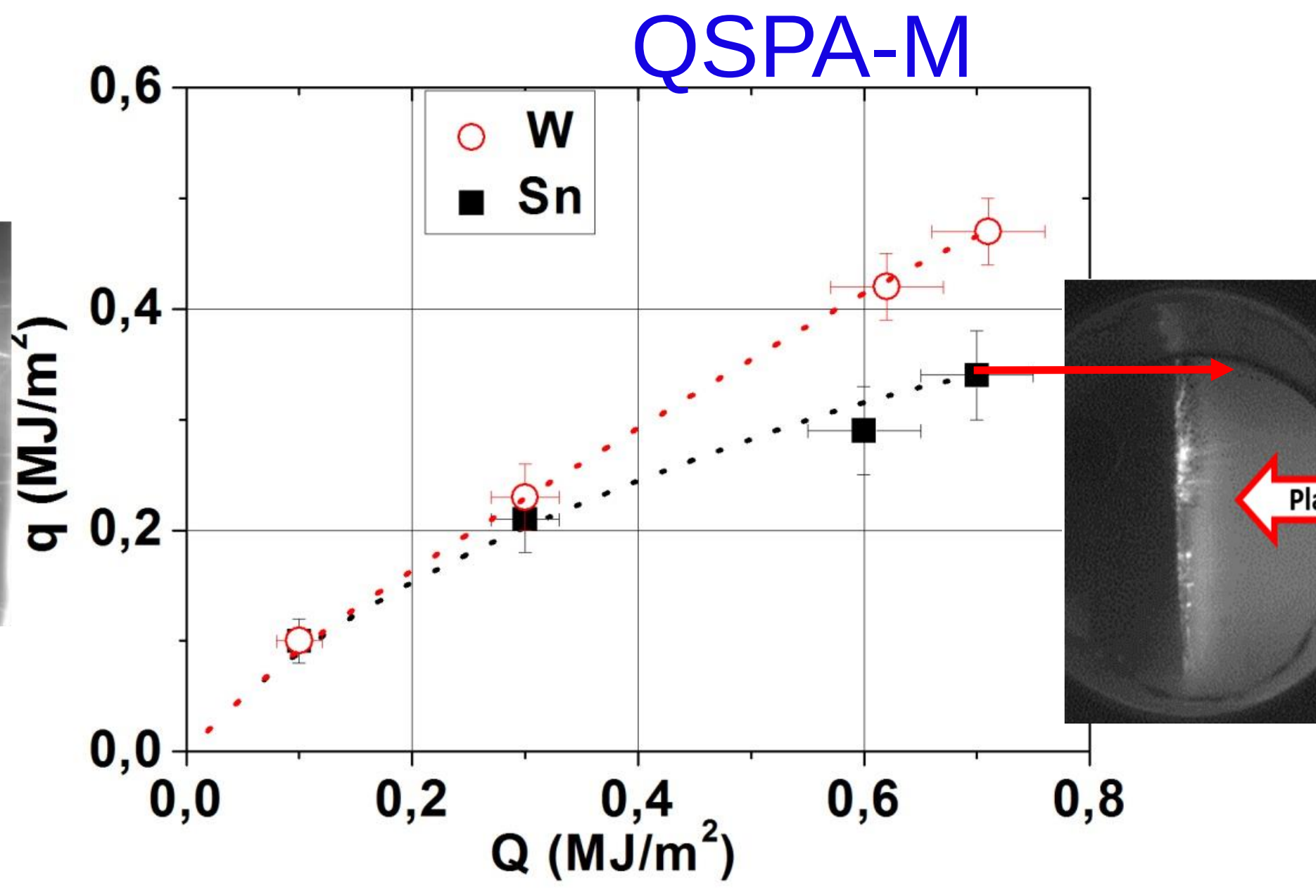
Behavior of spectra intensity and tin spectral lines versus distance from Sn-target at B=0 T (a) and B=0.8 T (b)

Measurements of energy density

QSPA Kh-50

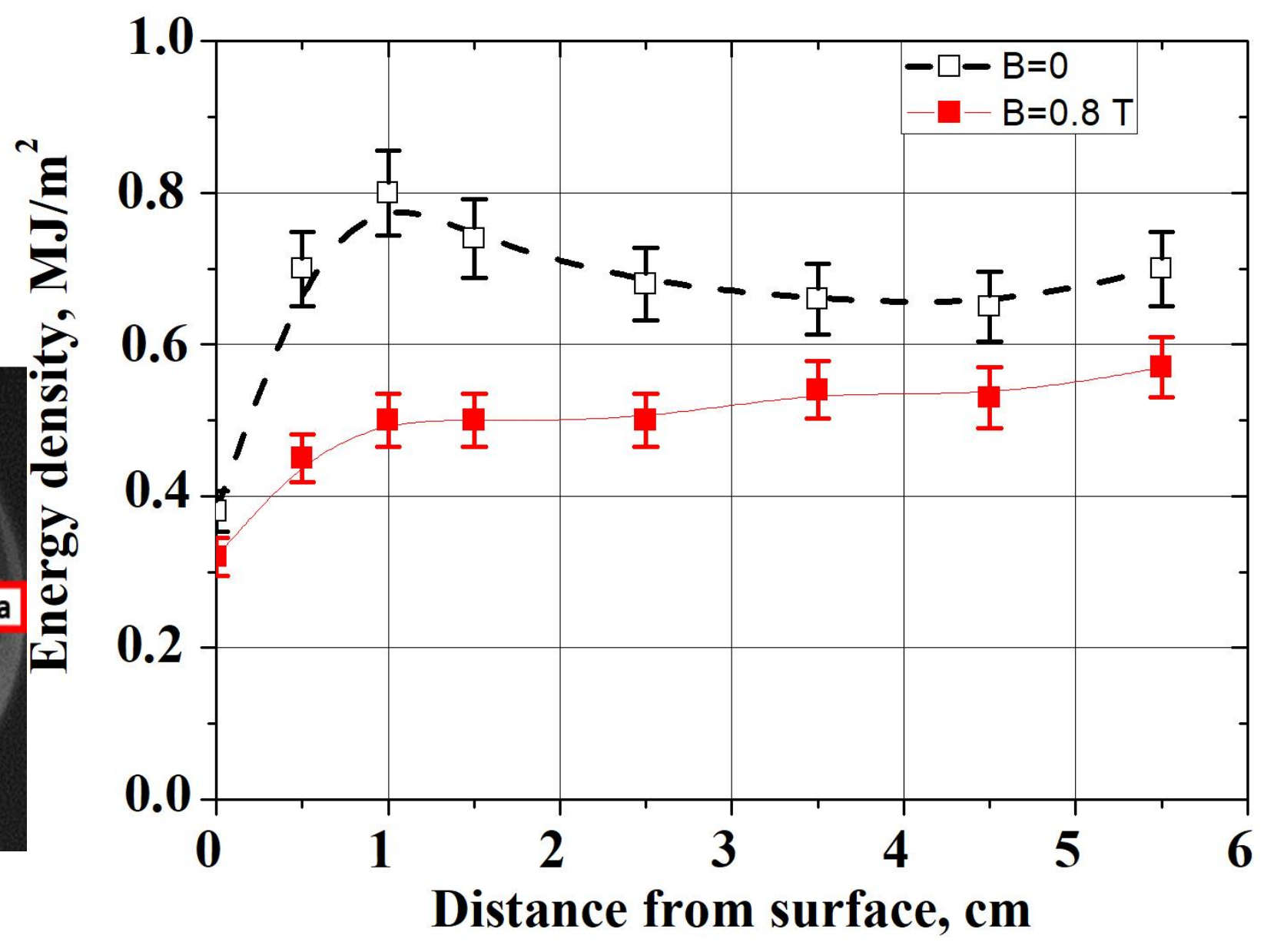


QSPA-M



Energy density absorbed by the CPS target vs. the energy density in impacting plasma stream and corresponding frames from high-speed camera for varied heat loads.

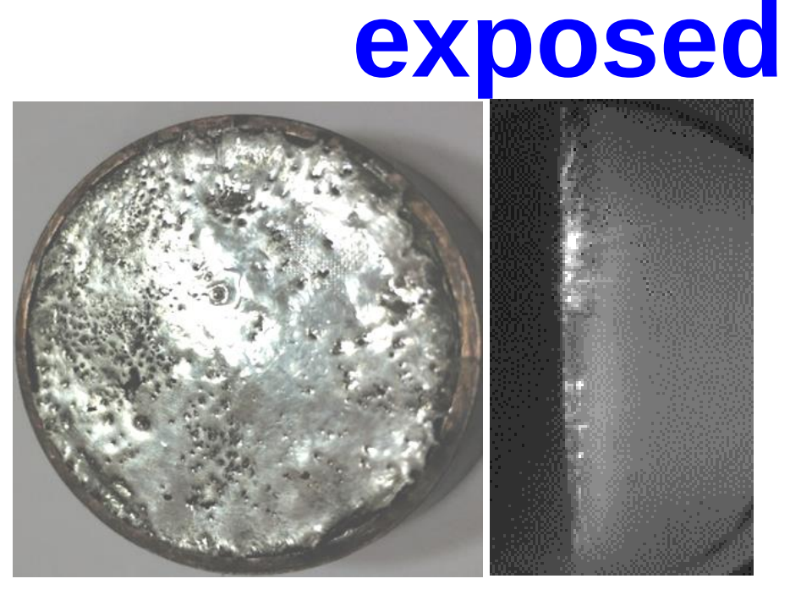
Energy density delivered to the CPS tin target is reduced in comparison with similar measurements, performed for flat tungsten surface in identical conditions.



Distributions plasma energy density in shielding layer vs. the distance from the CPS target surface, Q=0.75 MJ/m²

Only a part of the plasma energy is transferred to the target surface through the shielding plasma layer.

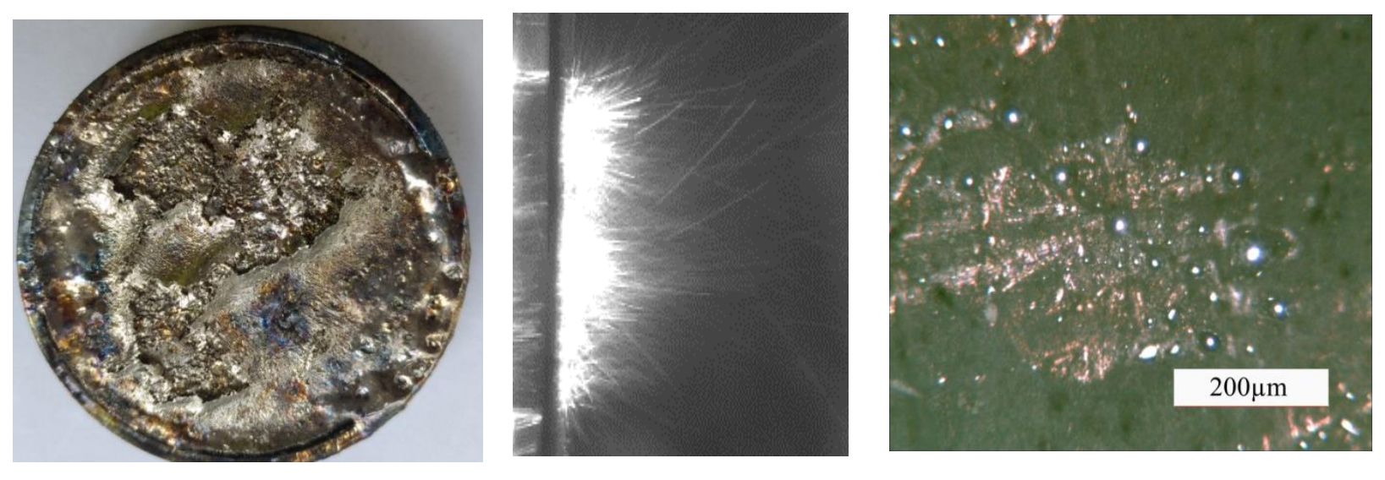
Damaging and erosion of exposed surfaces

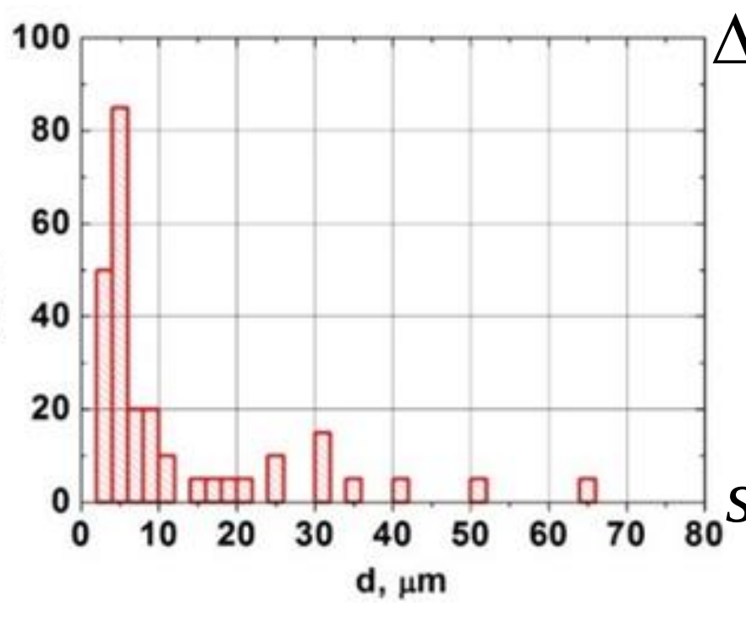


QSPA-M

Q= 0.75 MJ/m²
Δm≈0.05 mg/cm²pulse

QSPA Kh-50

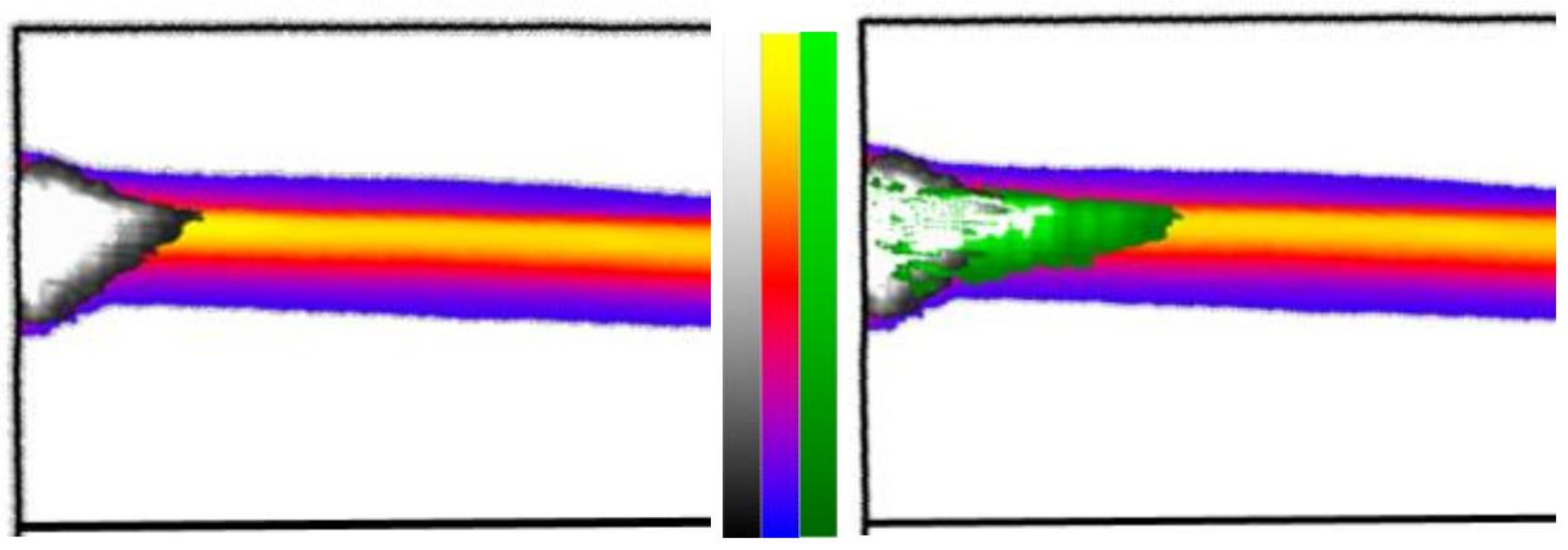




Δm≈ 6.85 mg/cm² pulse

An optical macro-image and size distribution of particles re-deposited upon the CPS target surface exposed to plasma pulses of 1.8 MJm⁻².

Results of numerical simulation



Left panel shows 2D distributions of Sn plasma density (black-white colour scale) and H plasma density (blue-red-yellow scale) in the shielding layer for the QSPA shot of Q=0.75 MJ/m². Right panel shows distribution of Sn plasma radiation intensity (green scale) on top of the Sn and H densities, shown in the left panel. Maximum electron density in the Sn shield is 10^{17} cm^{-3} and $2\cdot10^{16}$ cm^{-3} in the free H plasma stream.

Conclusions

- ✓ *Vapour shielding of liquid-metal Sn capillary porous structures under ELM-like and disruption transient loading has been studied in complementary simulation experiments using QSPA-M and QSPA Kh-50 experimental facilities.*
- ✓ *The thickness of the shielding layer increases in a magnetic field. The spectral lines of Sn were registered only in a very thin plasma layer < 0.5 cm from the surface at B=0, but in the magnetic field of 0.8 T Sn spectrum was recognized at 3 cm from the exposed surface. The electron density in plasma shield is 5-10 times higher than in impacting plasma stream.*
- ✓ *Plasma exposures of Sn CPS target with QSPA plasma load < (0.5 MJ/m²) do not trigger the generation of erosion products. For the heat load > 0.5 MJ/m², but < 1 MJ/m² single dust particles traces have been registered. Further increase of heat load leads to the splashing of eroded material. For ELM-like impacts rather weak melt motion was observed on the target surface. A moderate particle splashing is attributed to the heat loads up to 1 MJ/m².*
- ✓ *First comparison of obtained experimental results on vapour shielding of Sn CPS with available data from numerical simulation using the TOKES code demonstrates the qualitative correspondence between the simulated and measured electron density in the plasma shield.*

KIPT
Kharkov Institute of Physics and Technology

IPP

KIT
Karlsruhe Institute of Technology

“Work performed under EUROfusion WP DTT1-LMD “

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 and 2019-2020 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.