EUROfusion

PRD-9.TEST.01-T005-D001(2022)

Update and Plans KIPT for 2023

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PRD LMD kick-off meeting | 20.03.2023

KIPT

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Outline

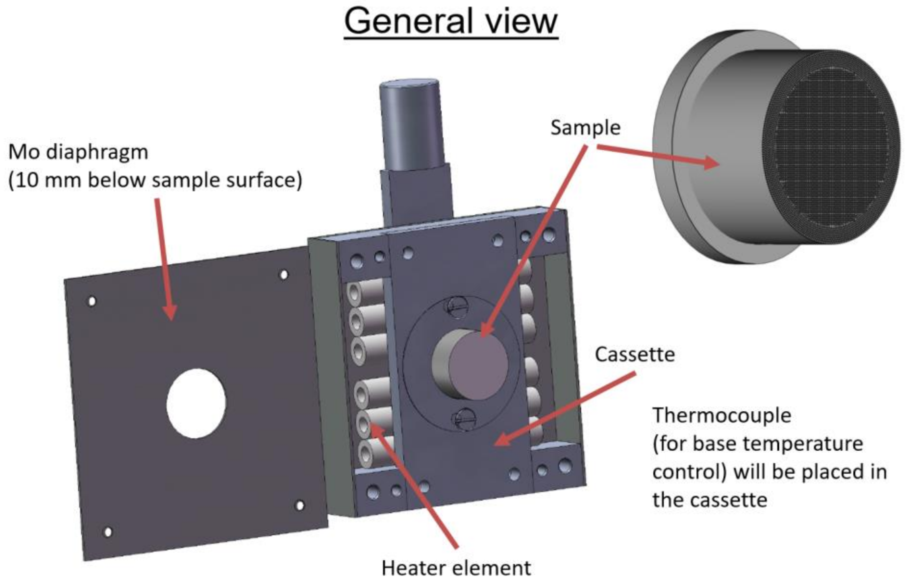
- Introduction
- Experimental facilities and samples
- Experimental results
  - Analysis of the damaging CPS samples exposed at different base temperatures.
  - Evaluation of overall resilience and stability of CPS samples after plasma pulses.
- Summary
- Future plans

Introduction

- Liquid metals mock-ups were proposed as alternative of full tungsten divertor for DEMO.
- Extrapolation of the disruptions/ELMs erosion effects obtained at the present-day tokamaks to the transient peak loads of next step fusion devices (ITER and DEMO) remains uncertain.
- Special investigations on material behavior at the relevant transient loads are thus very important.
  - Disruption testing of mock-up samples

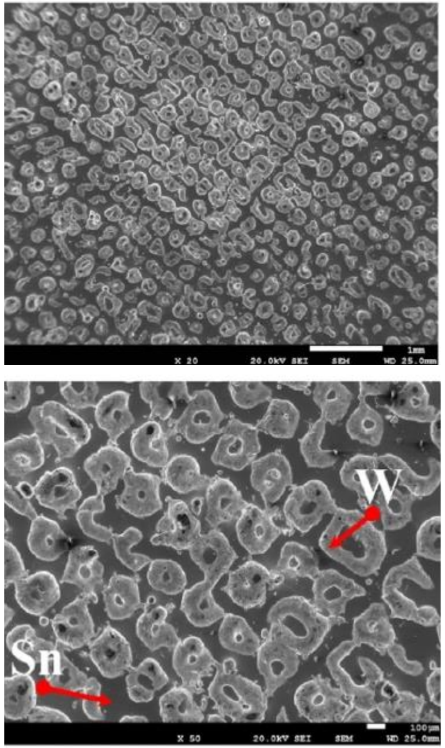
Task PRD-9.TEST.01-T005-D001 (2022)

Samples



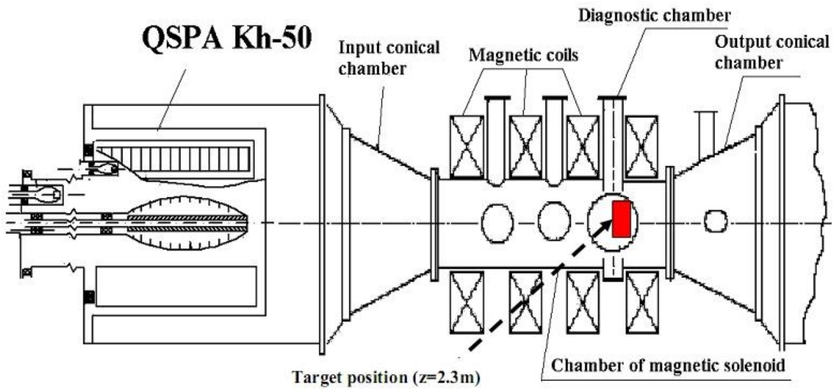
CPS cylindrical samples of 25 mm in diameter and 17 mm in height were provided by Peter Rindt, DIFFER.
P. Rindt et al, *Nucl. Fusion* **59** 054001, 2019

The holder for prototypes/samples was prepared.



SEM images with different magnifications of the initial surface of the CPS target.

Experimental facility – QSPA Kh-50



Energy density ρ_w = up to 30 MJ/m^2,
Plasma pulse duration $\tau \approx 0.25$ ms;
P_{max} = (3-18) bar, n = (0.2-5) 10^{16} cm^{-3}; B_0 =0.54 T ($\beta \approx 0.3 \ldots 0.4$);
Diameter of plasma stream- 15 cm

Test conditions	
Energy density in plasma stream, [MJ/m^2]	up to 3
Number of pulses	100
Base temperature, [T °C]	~ 300 °C , ~ RT

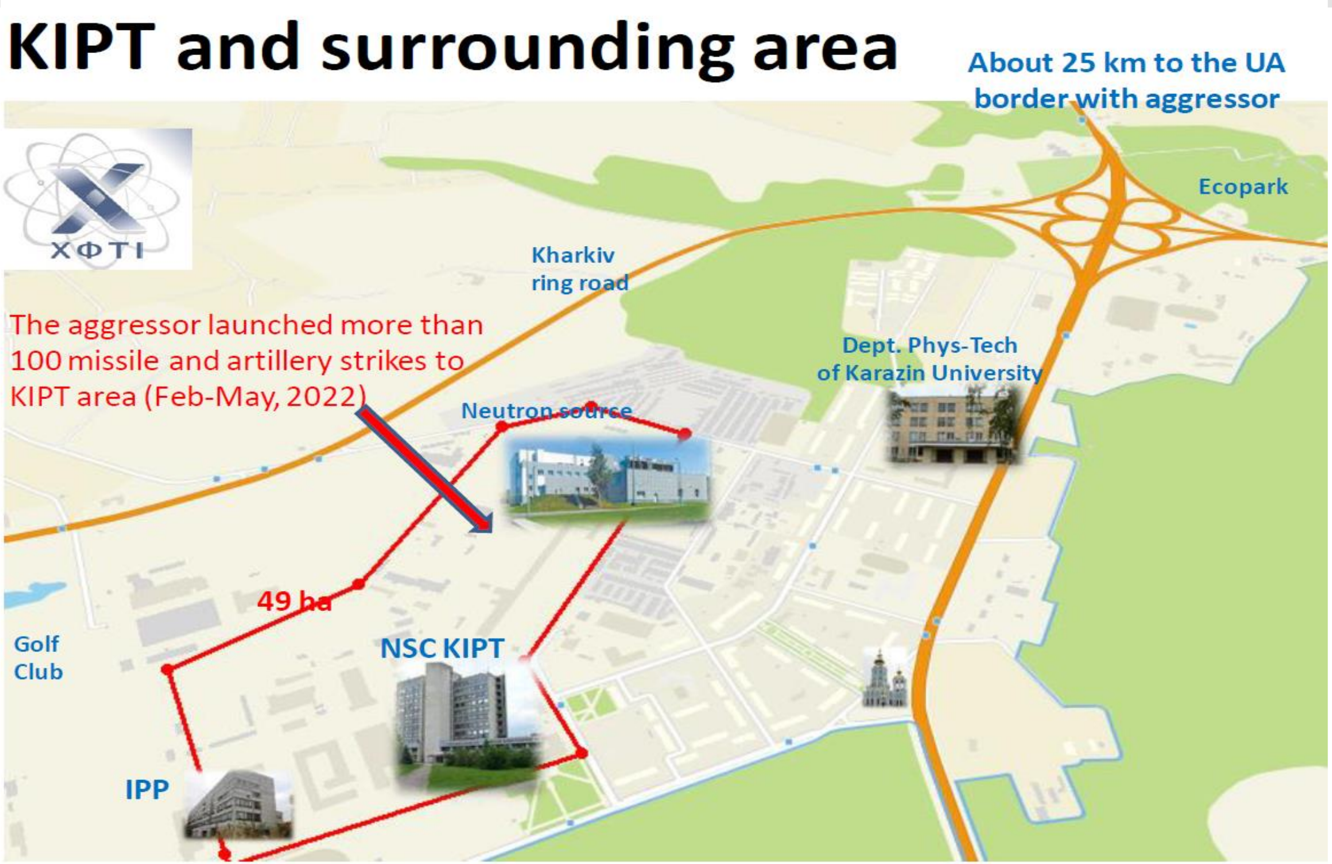
I.E. Garkusha *et al* 2021 *Nucl. Fusion* **61** 116040
S.S. Herashchenko et al. Fus. Eng.& Des. 190 (2023) 113527

Diagnostics

- Calorimetry
- High-speed digital camera PCO AG
- SEM EDXA

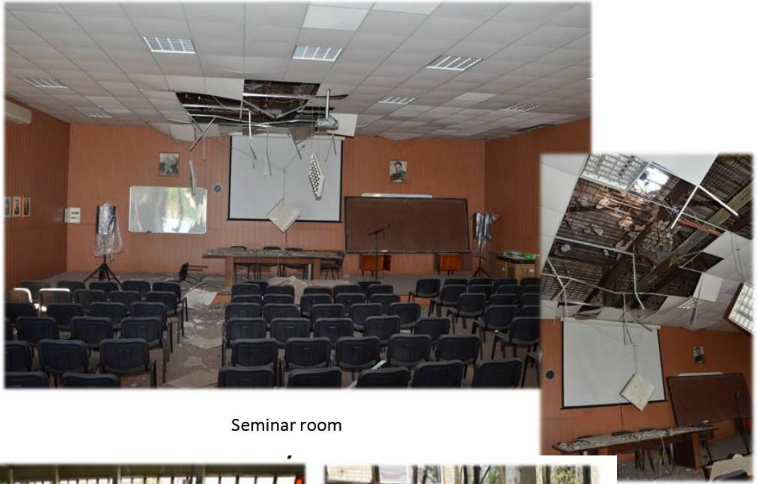
Experiments were performed only during few weeks in January-February 2022

Update on KIPT Status



Science magazine covered Kharkiv's response to the attacks in the article HERO CITY, Science Vol.378, Issue 6624, p 1036.

Update on IPP KIPT Status



Seminar room

Stellarator hall inside
Facilities still alive!

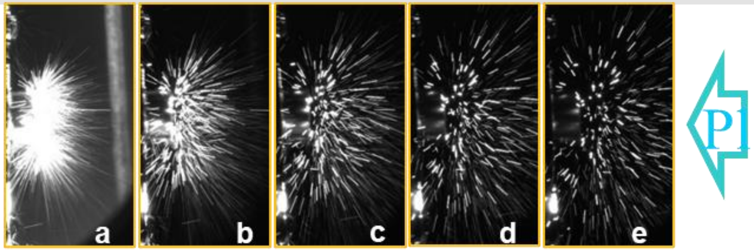
QSPA hall

Both QSPA facilities are survived !

- Experiments were stopped at the end of February 2022.
- Team works remotely and have conducted repairs on the institute's damaged buildings and facilities

EUROfusion-news F*ebruary 24, 2023*
https://euro-fusion.org/eurofusion-news/eurofusion-stands-in-solidarity-with-research-in-ukraine/

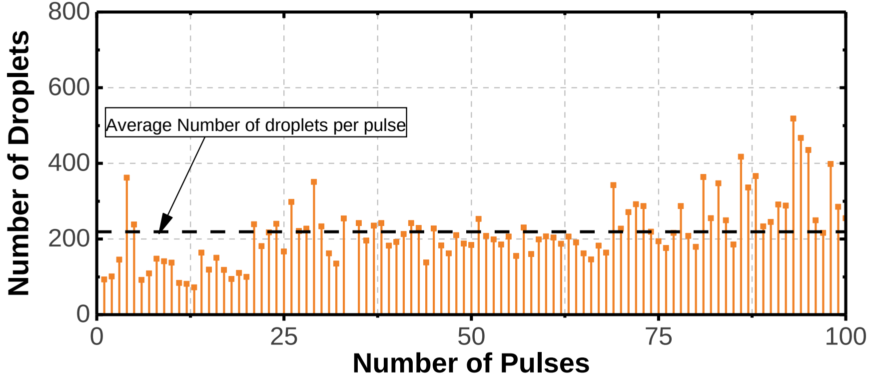
Erosion of pre-heated CPS targets



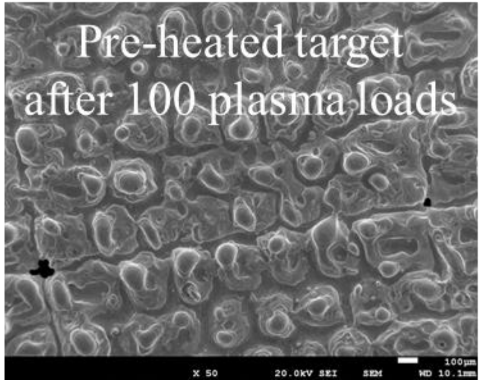
Pre-heated. T_{surf} ~300°C

Images of the PSI after 100 plasma pulses

The images correspond to 1.2-2.4 ms (a); 2.4-3.6 ms (b); 3.6-4.8 ms (c); 4.8-6 ms (d); 6-7.2 ms (e) after the start of the PSI interaction ($t_{exposure}$=1.2 ms).



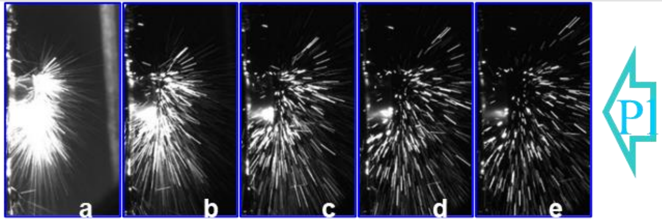
Number of ejected particles v.s number of plasma pulses



SEM image of exposed surface

- Average number (about 210) of ejected particles per plasma pulse is approximately the same in the course of plasma pulses from 20 till 80.
- Few single cavities are recognized on exposed surfaces due to splashing of molten material.
- Cavernous are further filled by melted material at next pulses but new one could appear too.

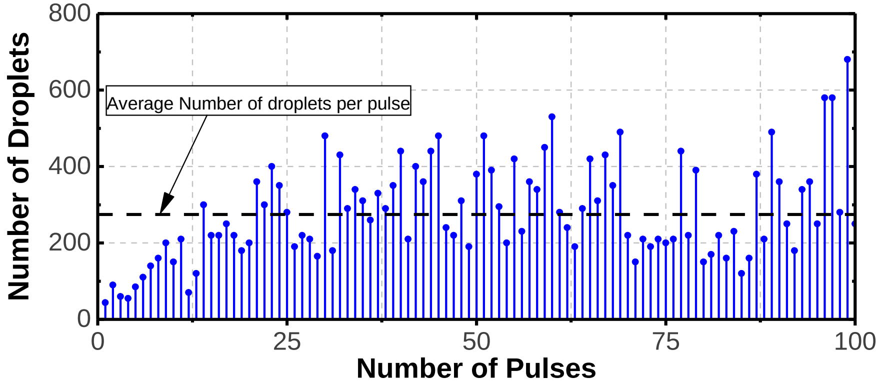
Erosion of non-preheated CPS target



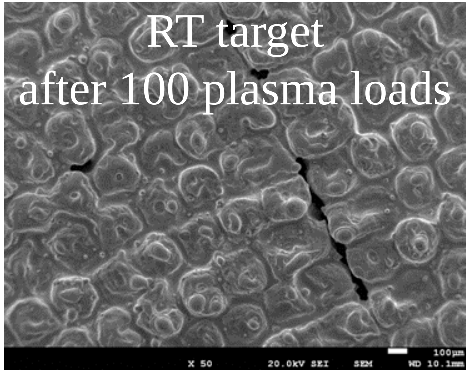
Non pre-heating. T_{surf} ~ RT

<u>Images of the PSI after 100 plasma pulses</u>

The images correspond to 1.2-2.4 ms (a); 2.4-3.6 ms (b); 3.6-4.8 ms (c); 4.8-6 ms (d); 6-7.2 ms (e) after the start of the PSI interaction ($t_{exposure}$=1.2 ms).



Number of ejected particles v.s number of plasma pulses

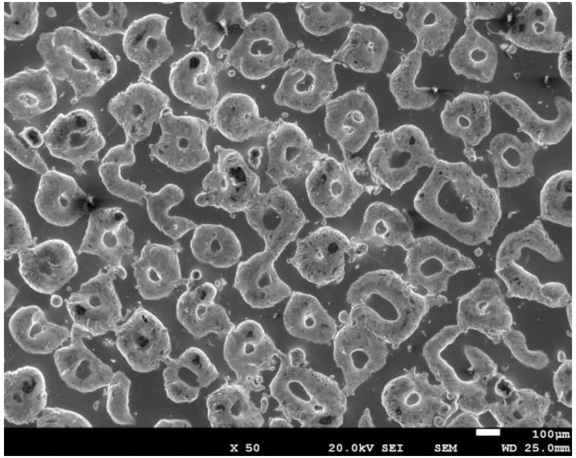


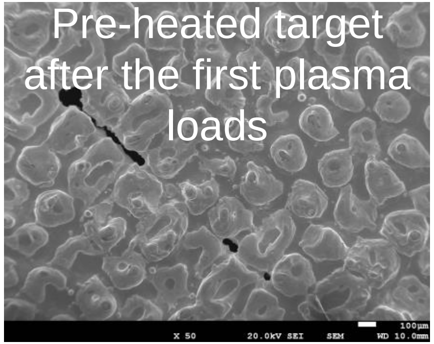
SEM image of exposed surface

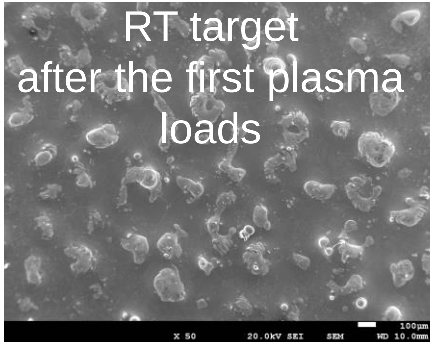
- Number of ejected particles essentially varied from pulse to pulse. In average, about 280 particles ejected per plasma pulse.
- Cavernous are arisen on exposed Sn surfaces due to splashing of molten material

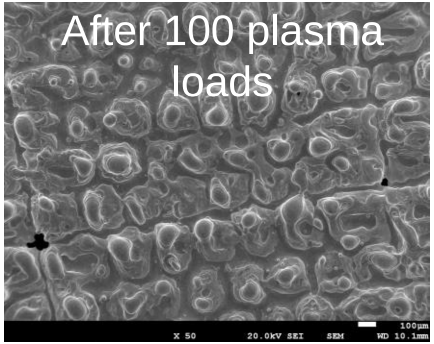
SEM images of CPS targets

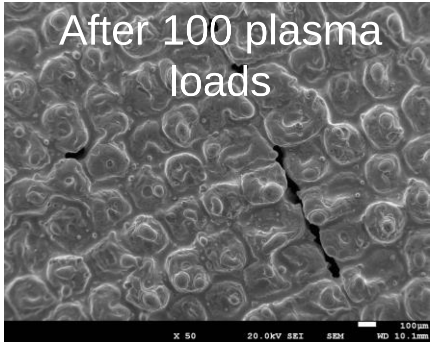
Initial







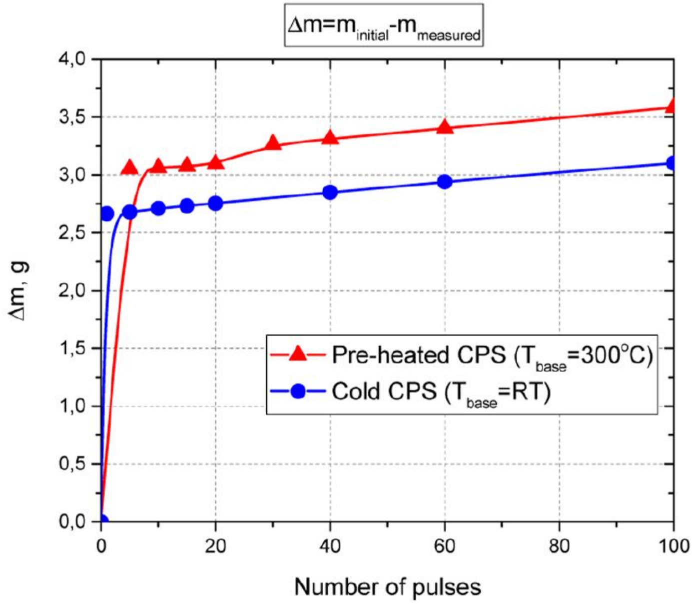




- Cavernous are arisen on exposed Sn surfaces due to splashing of molten material
- Such cavities (if near each other) may originate the cracks with width up to 30 µm.

Mass losses during the experiment

Pre-heated CPS1 **T_{surf} ~300°C**	**Cold CPS2** **T_{surf} ~ RT**
$m_{initial}$=98.13875 g	$m_{initial}$=98.1973 g
Mass losses of the samples **after the first plasma pulses**	
After 5 pulses: Δm=3.0541 g	After 1 pulse: Δm=2.6645 g
Summary mass losses of the samples **after 100 plasma pulses**	
Δm=3.58475 g	Δm=3.1013 g
Accuracy of the measurements: ± 0.000015 g	



- The main mass losses occur during the first plasma pulses.
- Linear growth of mass losses is observed after the first pulses

SUMMARY

- During short company in Jan-Feb 2022, QSPA exposures of Sn CPS samples have been performed at the different initial temperature (at room temperature and at 300 °C) of samples.
- 3D-printed W CPS filled by Sn withstood 100 QSPA plasma impacts with an energy density of ~3MJ/m^2 without the drastically damages to the W base. The CPSs remain wetted by the Sn during following exposures.
- Plasma exposures of CPS samples are triggered ejection of droplets/dust from the surface. Decreasing of average number of ejected particles is recognized for preheated sample surface (at least in the course of 100 plasma pulses).
- Results were presented at SOFT-2022 and published in Fus.Eng.Des in Feb. 2023.
- The facility time within this WP PRD-9 (about 15 days) was used fully during first half of February 2022.
- Other experiments were stopped by KIPT after 24 February 2022 due to the war in Ukraine.

Plans for 2023

- Plasma exposures of CPS targets would be possible not earlier than in second half of 2023 due to the war in Ukraine.
- Works to be performed in 2023 year :
  - Analysis of the damaging CPS samples exposed at different base temperatures will be continued.
  - Study of mechanisms responsible for the particles ejection (both in liquid and solid state).
  - Collection of solid dust as well as splashed droplets.
  - Characterization of dust/droplets particles ejected from exposed CPS surfaces. Estimation of start-up time of the droplets/dust from the surfaces

- Deliverables:

  Evaluation of primary mechanisms of the damaging of CPS structure under the transient plasma loads.

  Characterization of ejected liquid and solid particles.

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Determination
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Inclusion