Summary Report on *HHF testing of W-monoblock mock-ups made by VITZRONEXTECH and KFE*

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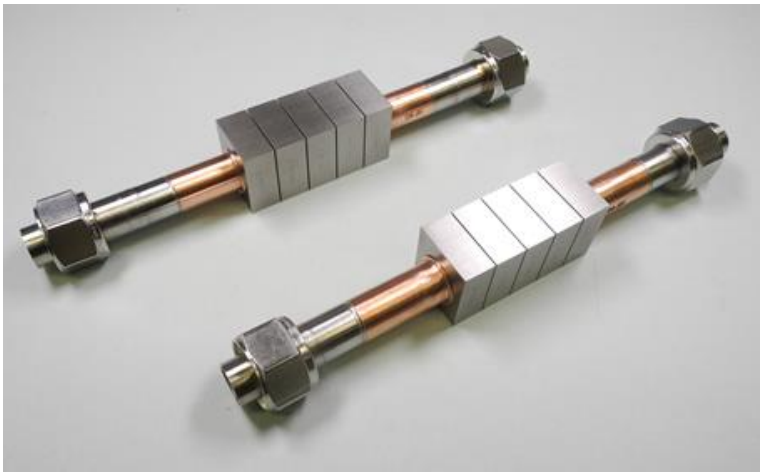
Executive Summary

This report presents results of high heat flux tests performed on two actively water-cooled W monoblock mock-ups designed by KFE (Korea Institute of Fusion Energy) and made by VITZRONEXTECH Co., Ltd. The mock-ups named "HIP #1" and "HRP #1" were tested in the HHF test facility GLADIS at IPP Garching in November 2023. The following tests of both samples are summarized in this report according to the agreed test procedure:

1. Screening tests 6 - 20 MW/m², each loading step 3 pulses with 10 s duration,
   water-cooling parameter for all tests:
   v=12 m/s axial velocity, 15°C inlet, static system pressure of 1MPa,
2. Low cycle fatigue tests, each sample loaded with 100 cycles at 10 MW/m², 10 s duration
3. Cycling tests, each sample loaded with 1000 cycles at 20 MW/m², 10 s duration,

All samples survived in good conditions, no detectable bonding defects, cracks or notable surface modification occurred during the HHF tests. We did not detect any degradation of the mock-ups.



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Abbreviations

HHF	*High Heat Flux*
IR	*Infra red*
W	*Tungsten*
ε	*Emissivity*
T-KLEIB	*One-color pyrometer, type KLEIBER KMGA 740, limit 3500 °C*
T-QKTR	*Two-color pyrometer, with digital quotient calculation, type Maurer QKTRD 1075, limit 1700 °C*

1 Introduction, aim of HHF tests

The HHF tests were performed to support the qualification of actively water-cooled W monoblock mock-ups made by VITZRONEXTECH Co., Ltd. in South KOREA. Sample 1 (HIP #1) was manufactured by hot isostatic pressing, sample 2 (HRP #1) by hot radial pressing.

Fig. 1: Tested samples HIP #1 and HRP #1.

All HHF tests were performed in the H neutral beam test facility [1] at IPP Garching. Compared to the loading in an electron beam test facility by scanning of a high energy electron beam, the test in a neutral beam facility offers a homogenous loading of the sample similar to the expected loading conditions of a fusion experiment.

The HHF tests and documentations were performed according to the agreed test procedure:

1. Screening tests 6 - 20 MW/m², each loading step 3 pulses with 30 s duration
2. Low cycle fatigue test, 100 x 10 MW/m², 10 s duration,

   Before step 1 and after step 2: visual inspection and photographic documentation of the mock-ups, focused on the loaded surface.
   IR images of the low-cycle test will be recorded in the steady-state phase at the end of each pulse and provided as video. Selected IR and CCD images of # 1 and # 100 will be provided.

3. 1,000 cycles 20 MW/m², 10 s duration,
   IR images were recorded in the steady state phase at the end of each pulse, provided as a separate video.

4. Summary report of the performed tests
   Including summary data sheet of the tests, selected IR images of # 1, 100, 250, 500, 750 and 1000.
   Optical images of the loaded surface were taken before start of HHF loading, after 100 cycles 20 MW/m², after cycle 500, 750 and at the end of the test.

2 Loading and cooling conditions of the HHF tests

HHF tests of the two components with cooling water at room temperature were performed. This allowed the use of the vacuum lock system at GLADIS to reduce the operating effort, time and costs. All mock-ups were installed and tested individually in GLADIS. The mock-ups were installed in the horizontal direction, normal to the beam axis.

The actively water cooled mock-ups reached the thermal equilibrium after ~7 s loading, meaning a constant temperature and stress profile across the component. Therefore, all cyclic tests were performed with 10 s loading followed by 50 or 80 s cooling, respectively. The applied hydrogen neutral beam (Gaussian profile with 150 mm FWHM) ensures a simultaneous and homogeneous heating of all monoblocks of the mockups as shown in Fig 2.

This profile was measured during the test campaign to check the applied heat loading on the mock-ups according to the methode which is described in [1].

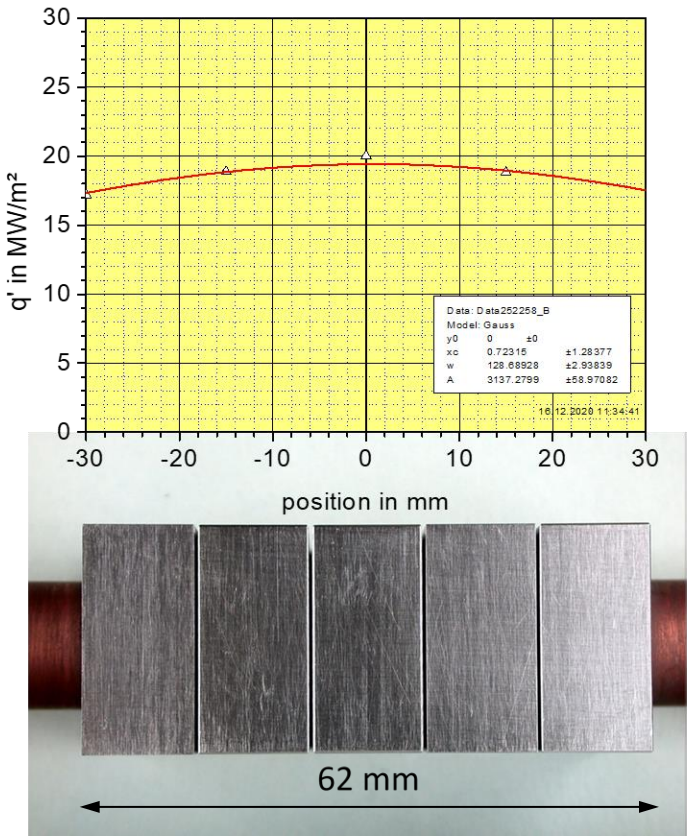

Fig. 2: Applied heat flux profile across the sample shown for the 20 MW/m² loading case.

The variation of the beam and diagnostics parameter is within ± 5 % during the performed tests. The surface temperature of the exposed mock-ups was measured with one- and two-colour pyrometers as well as monitored by an infrared camera Infratec Image IR. The two-colour pyrometer (Ø8 mm focus, λ = 1.4 – 1.75 µm, temperature range 500 °C – 1700 °C) was used as reference for the emissivity (ε) determination of the one-colour pyrometer (Ø22 mm focus, λ = 2.0 – 2.2 µm, temperature range 350 °C – 3500 °C) and the IR camera.

All tests were performed at the following cooling conditions:

- Inlet water temp. 15 °C, axial velocity v=12 m/s, 1 MPa static pressure,
- Calculated local critical heat flux (CHF), > 60 MW/m² corresponds to an allowed loading of the component of about 27 MW/m² (safety factor 1.4).

3 Summary and results of HHF tests

3.1 Screening tests

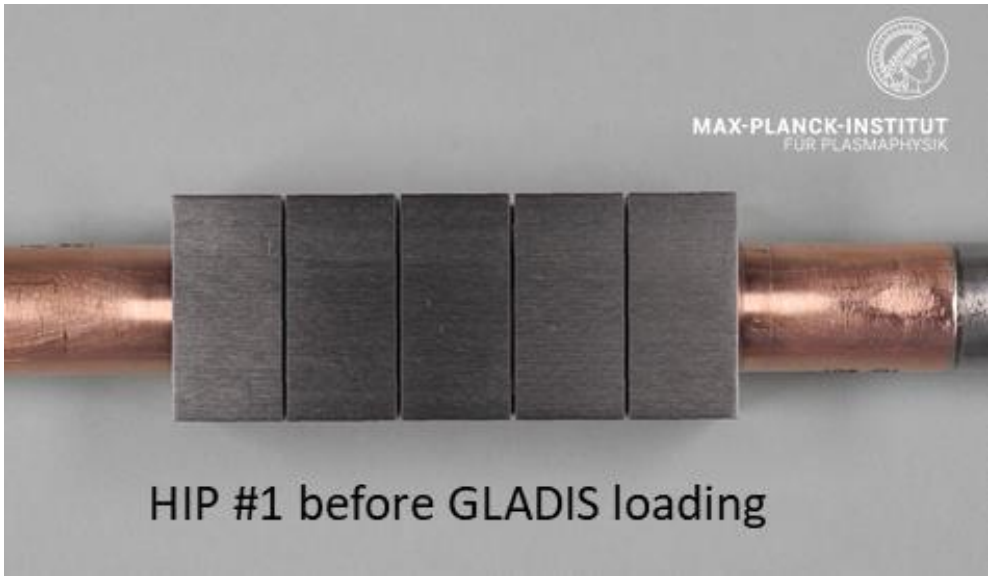

Fig. 3: High heat flux loaded surface of sample HIP #1 before HHF tests.

Fig. 4: High heat flux loaded surface of sample HRP #2 before HHF tests

The results of the pyrometrically measured surface temperature during the screening tests are shown in Fig. 5. Each data point presents the average of 5 pulses typically. The focus of the pyrometers was directed to the centre of block 3.

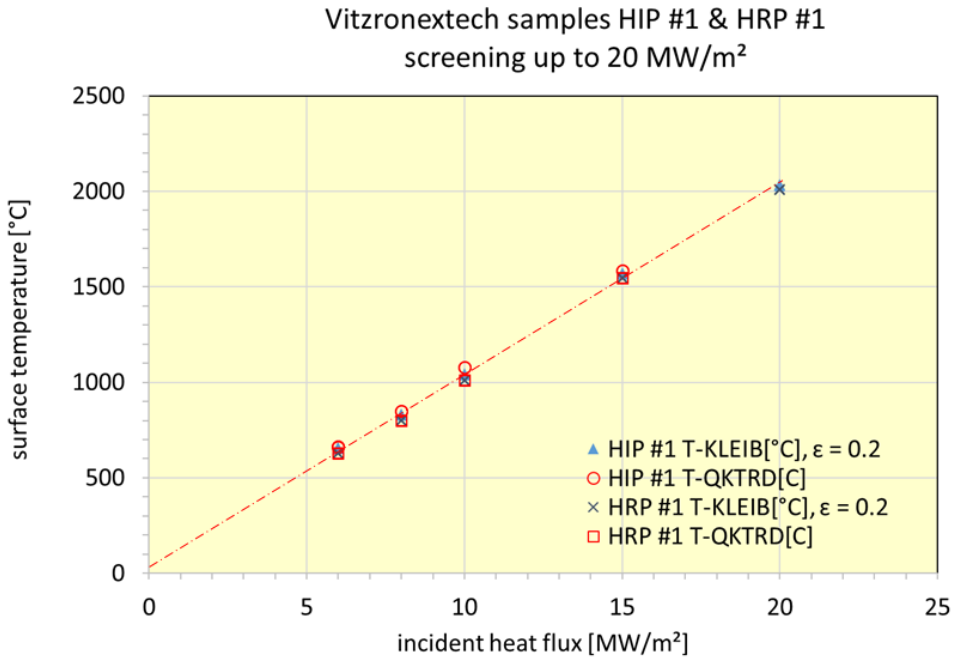

Fig. 5: Summary of the screening test of both samples. The one-colour pyrometer data (T-KLEIB) are recorded with ε= 0.2.

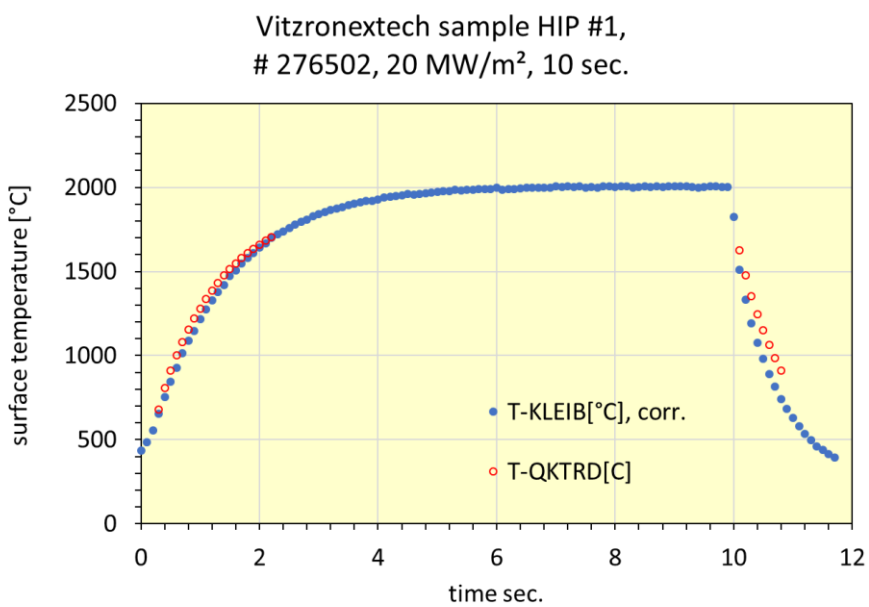

Fig. 6: Pyrometrically measured surface temperatures of sample HIP #1 during the last 20 MW/m² screening pulse. The one-colour pyrometer data (T-KLEIB) are recorded with ε= 0.2.

3.2 10 MW/m² low cycle fatigue tests

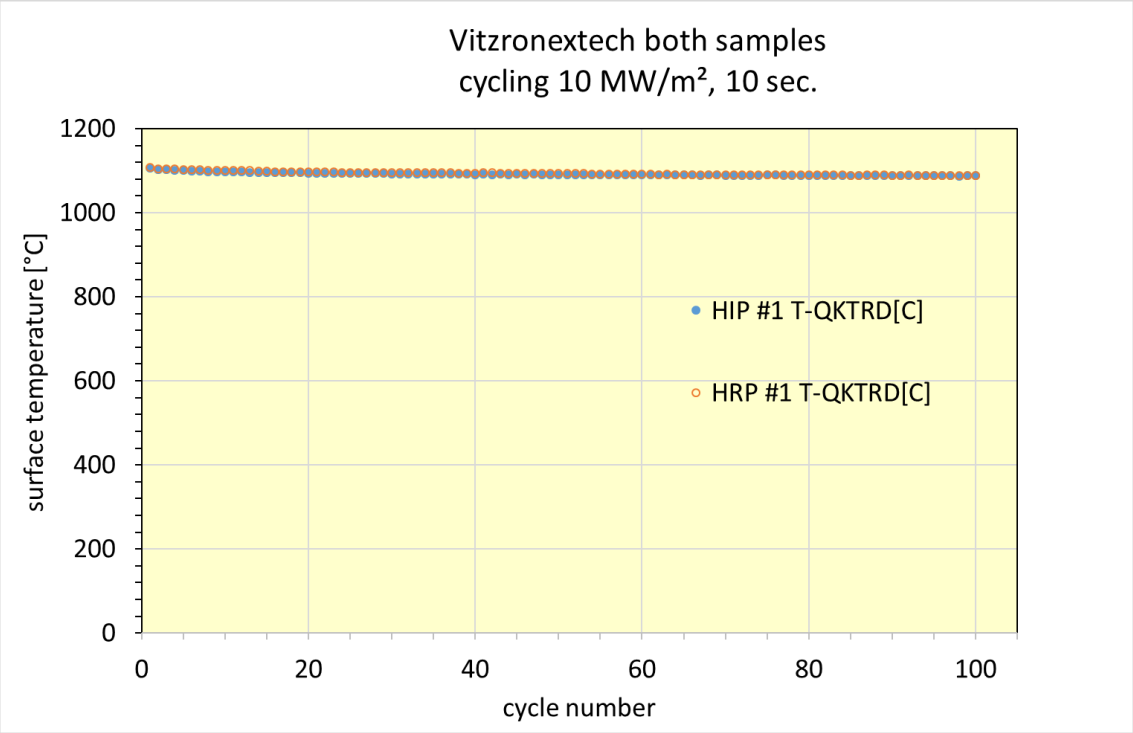

Fig.7: Comparison of pyrometrically measured surface temperatures of both samples during cycling at 10 MW/m². The two-colour pyrometer data (T-QKTRD) are shown.

3.3 1000 x 20 MW/m² cycling tests

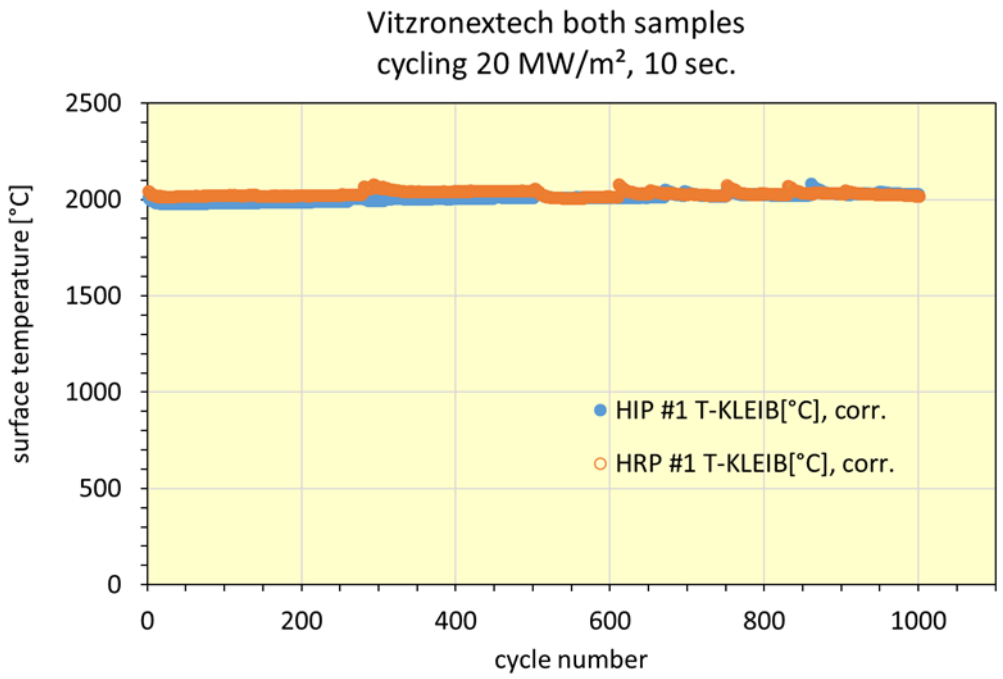

Fig. 8: Comparison of pyrometrically measured surface temperatures of both samples during cycling at 20 MW/m². The two-colour pyrometer data (T-QKTRD) are shown.

3.4 Surface images of 1000 x 20 MW/m² cycles test

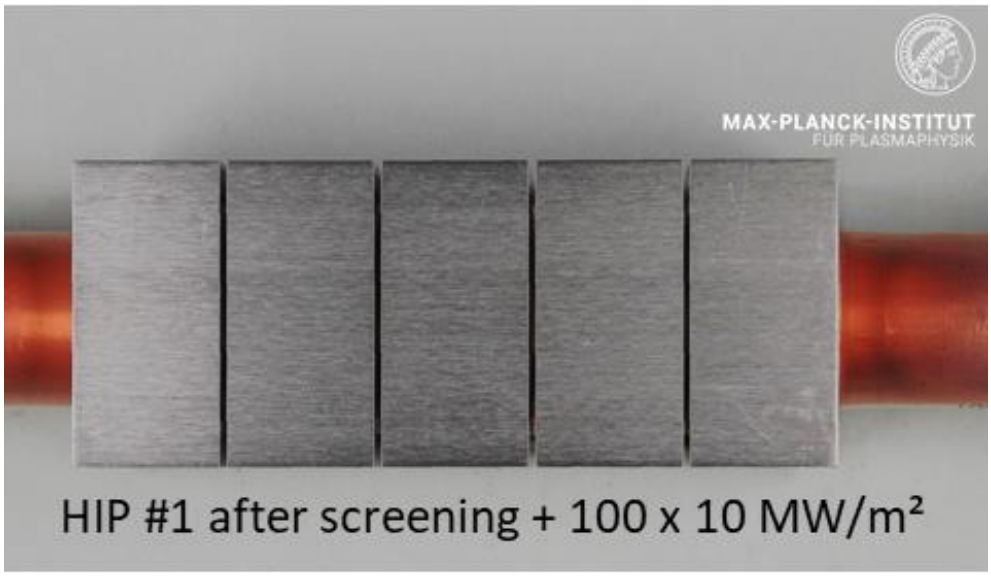

Fig. 9: High heat flux loaded surface of HIP #1 before cyclic 20 MW/m² loading.

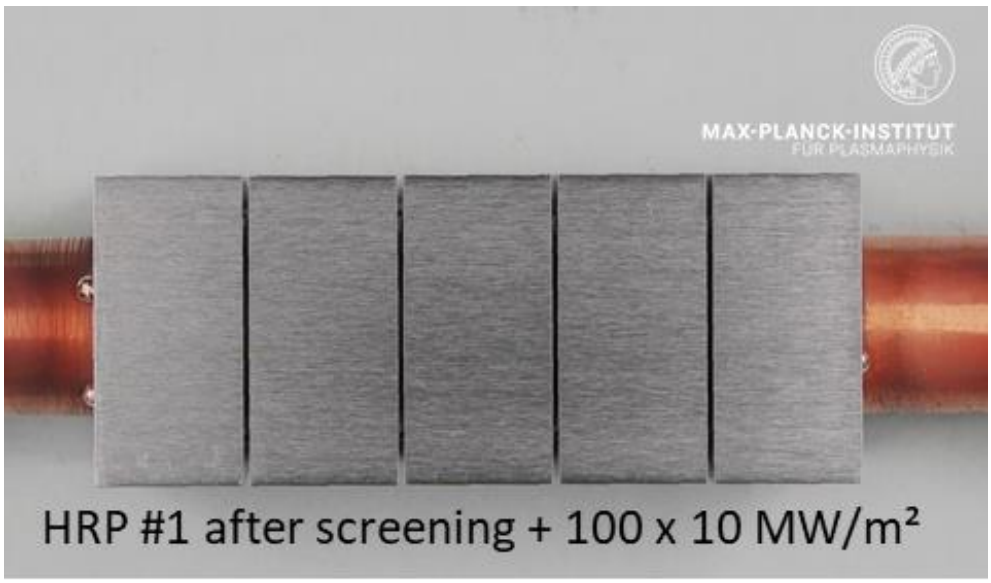

Fig. 10: High heat flux loaded surface of HRP #1 before cyclic 20 MW/m² loading.

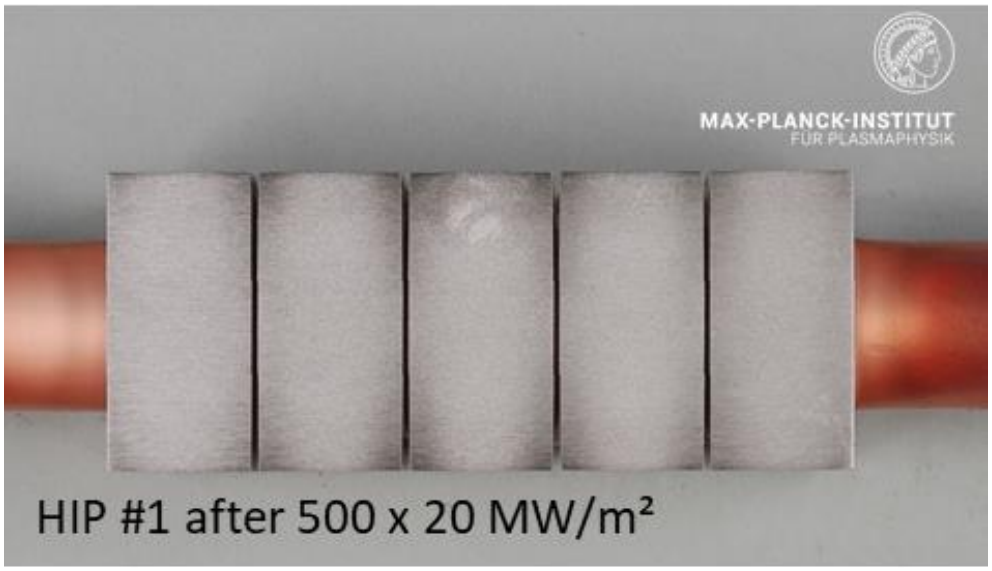

Fig. 11: High heat flux loaded surface of HIP #1 after 500 cycles at 20 MW/m².

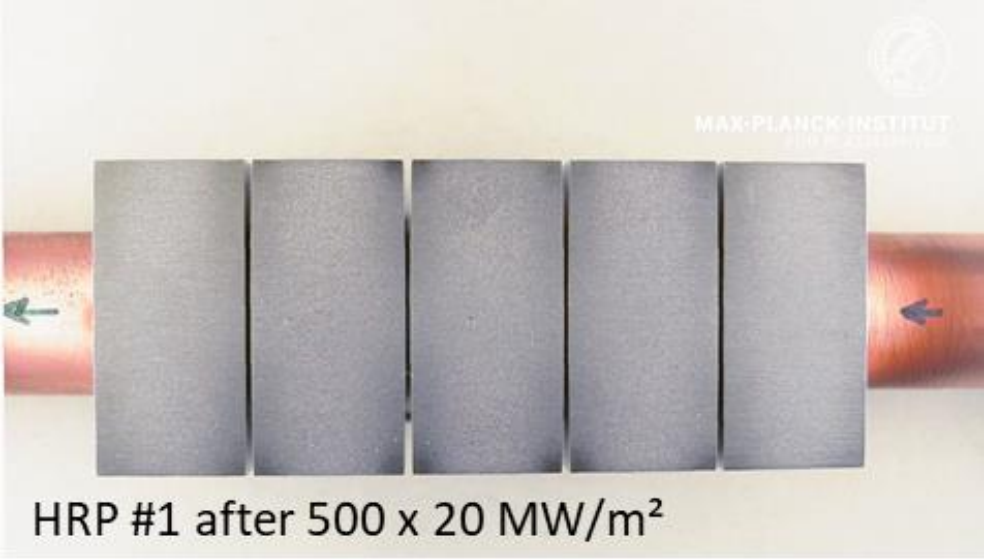

Fig. 12: High heat flux loaded surface of HRP #1 after 500 cycles at 20 MW/m².

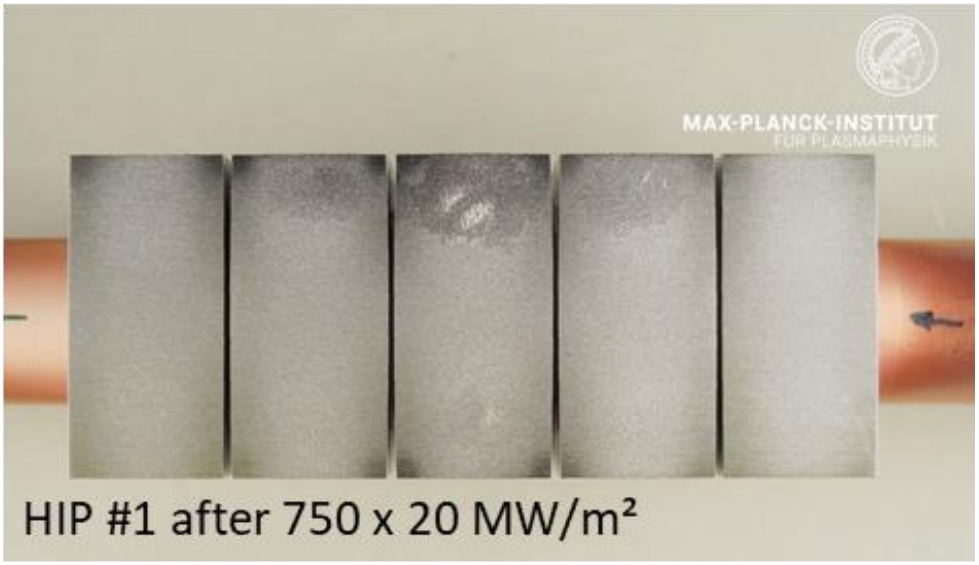

Fig. 13: High heat flux loaded surface of HIP #1 after 750 cycles at 20 MW/m².

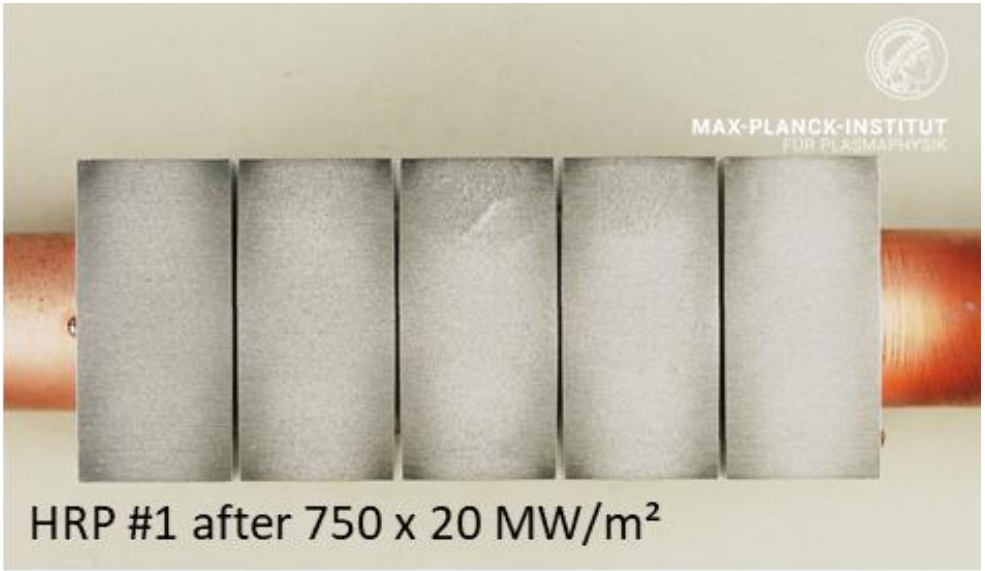

Fig. 14: High heat flux loaded surface of HRP #1 after 750 cycles at 20 MW/m².

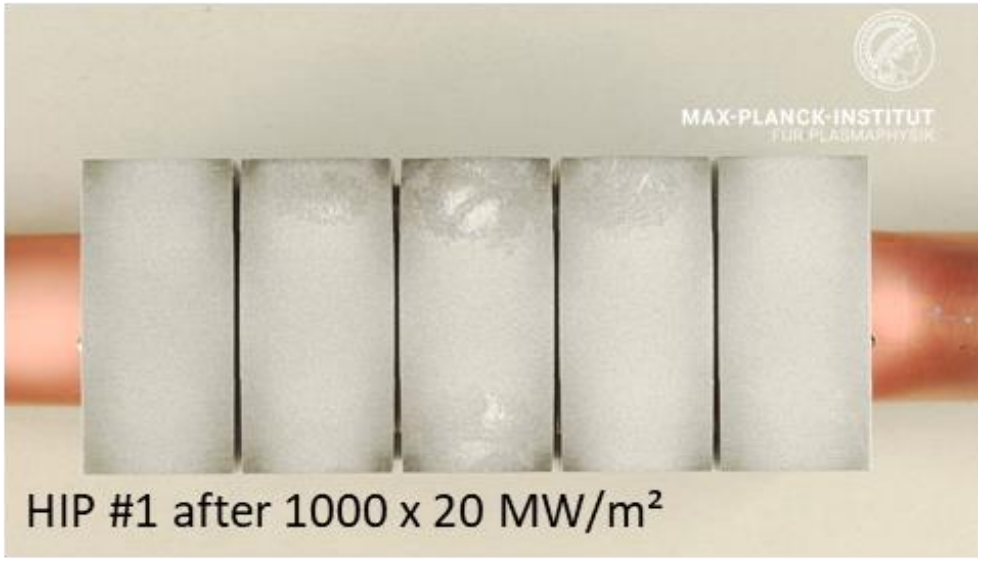

Fig. 15: High heat flux loaded surface of HIP #1 after 1000 cycles at 20 MW/m².

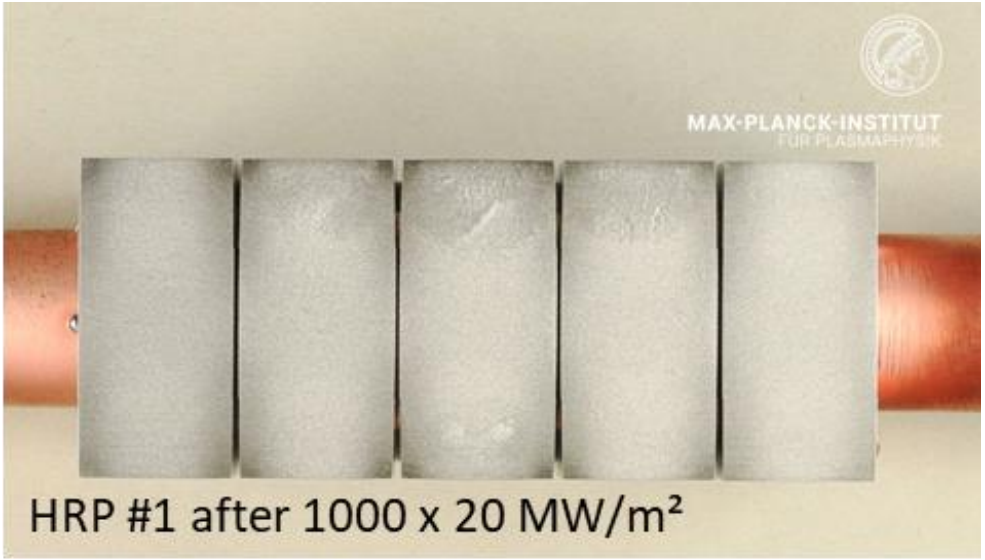

Fig. 16: High heat flux loaded surface of HRP #1 after 1000 cycles at 20 MW/m².

3.5 IR images of cycling at 20 MW/m²

All IR images were taken in the steady state phase at the end of each pulse. The intention is to monitor the temperature distribution of the component and to detect any hot spots as results of defects. The IR images are not appropriate for precisely measuring local temperatures. The images have been individually corrected to match the central block temperature to the corresponding pyrometer data.

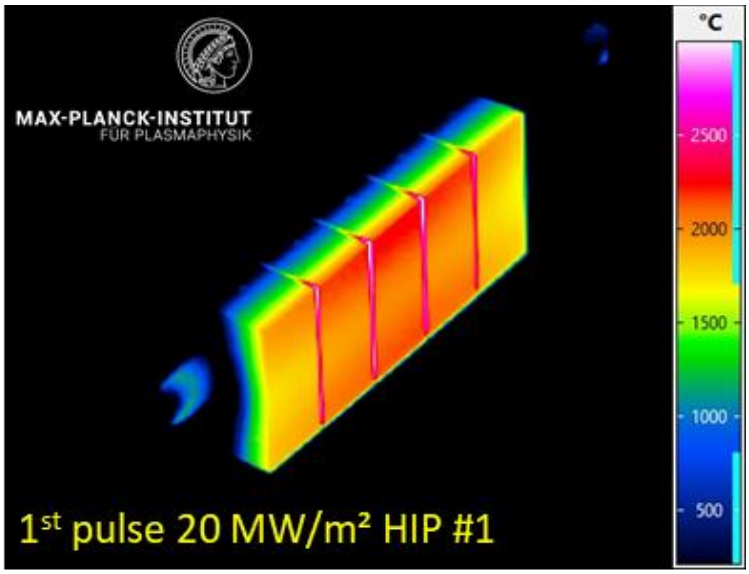

Fig. 17: IR image during 20 MW/m² cycling.

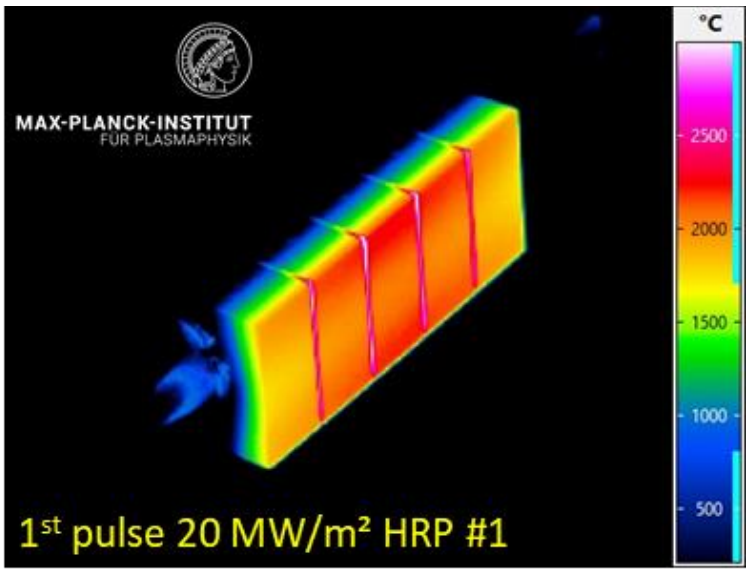

Fig. 18: IR image during 20 MW/m² cycling.

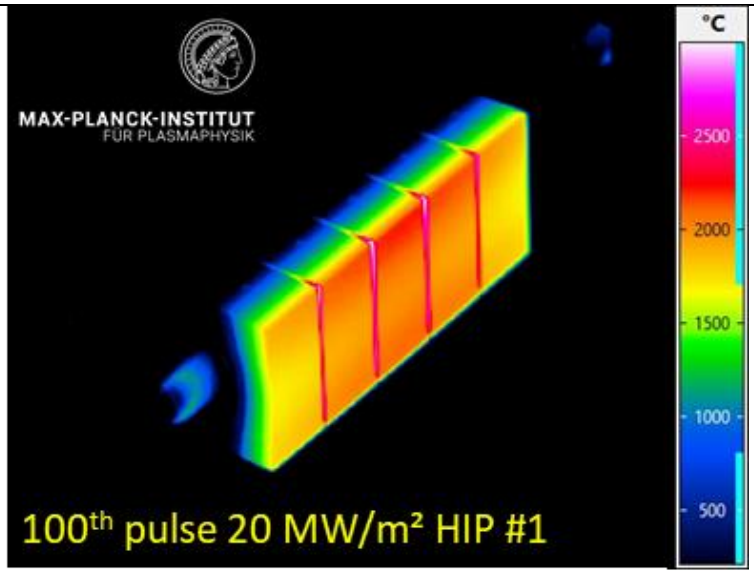

Fig. 19: IR image during 20 MW/m² cycling.

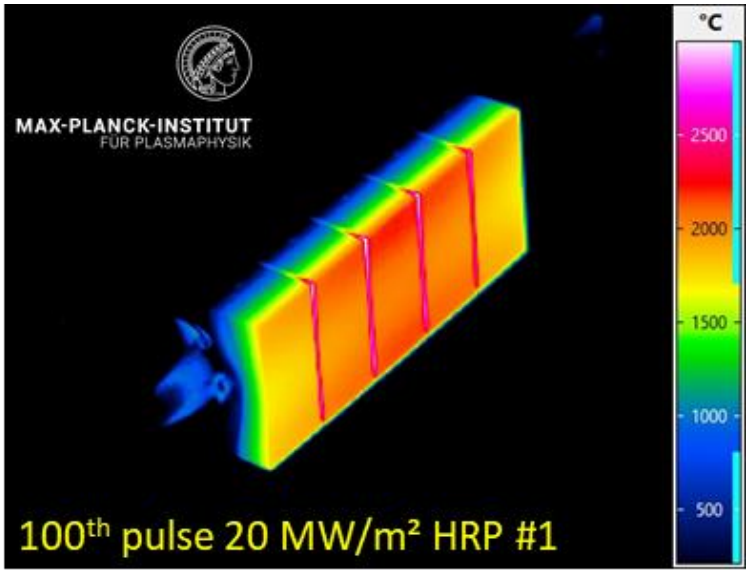

Fig. 20: IR image during 20 MW/m² cycling.

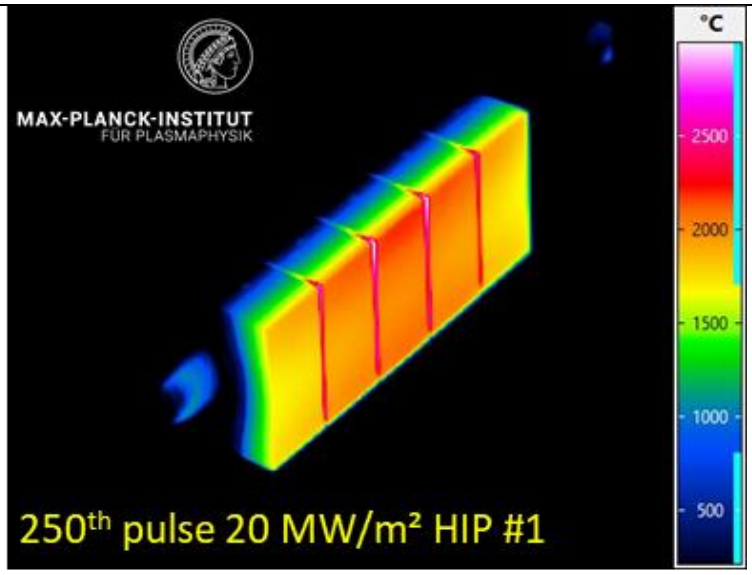

Fig. 21: IR image during 20 MW/m² cycling.

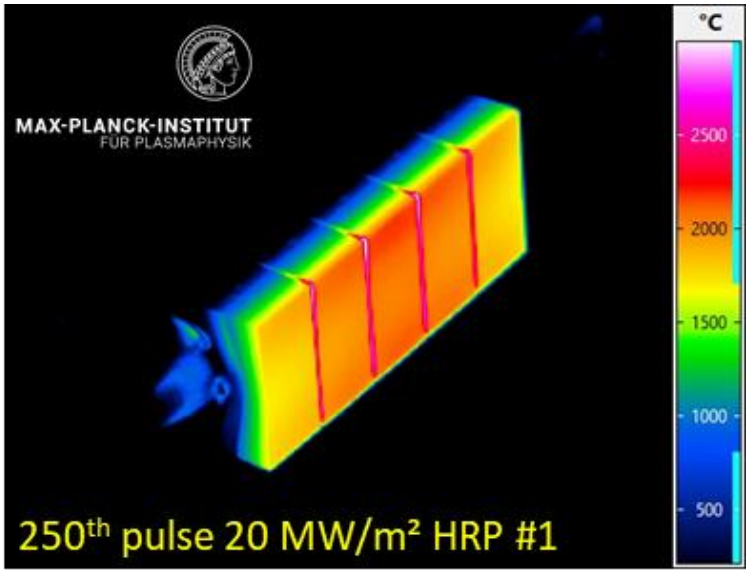

Fig. 22: IR image during 20 MW/m² cycling.

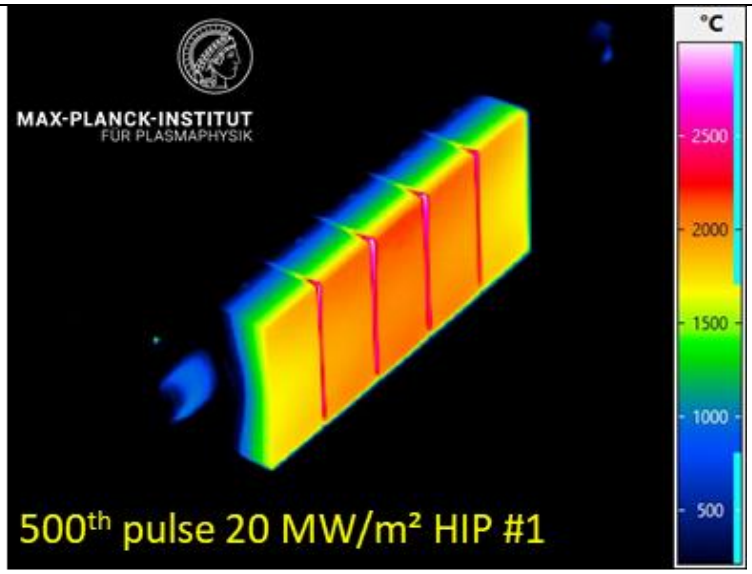

Fig. 23: IR image during 20 MW/m² cycling.

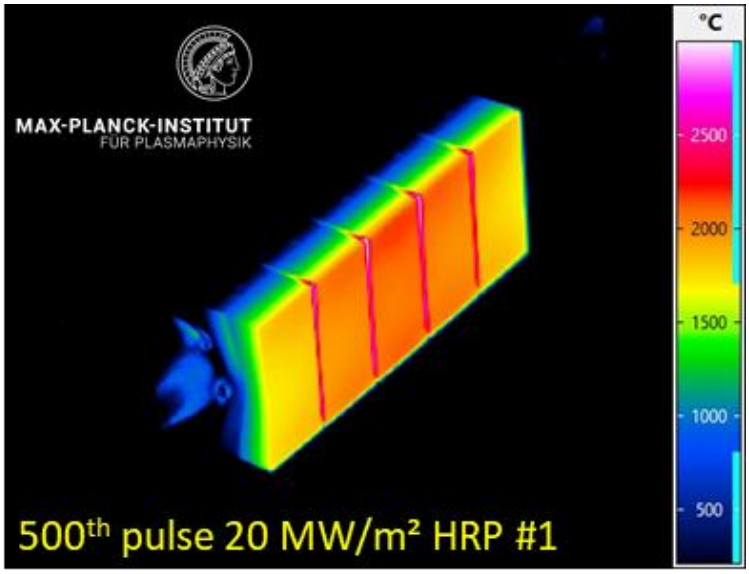

Fig. 24: IR image during 20 MW/m² cycling.

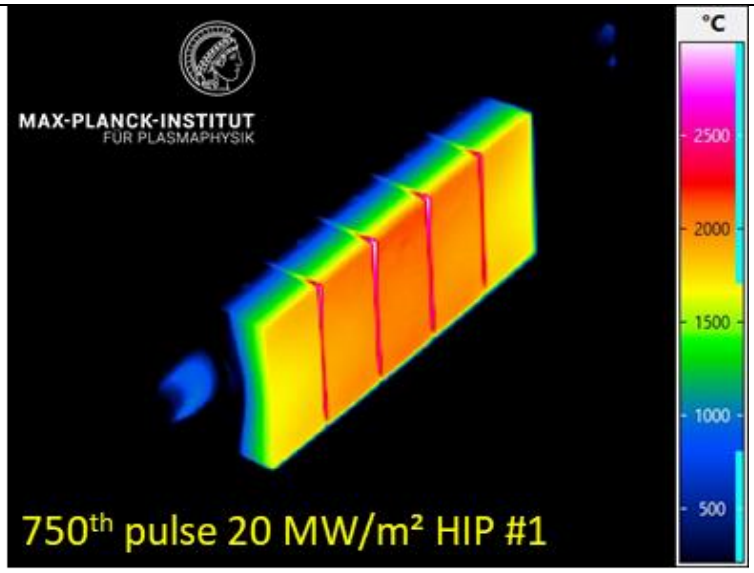

Fig. 25: IR image during 20 MW/m² cycling.

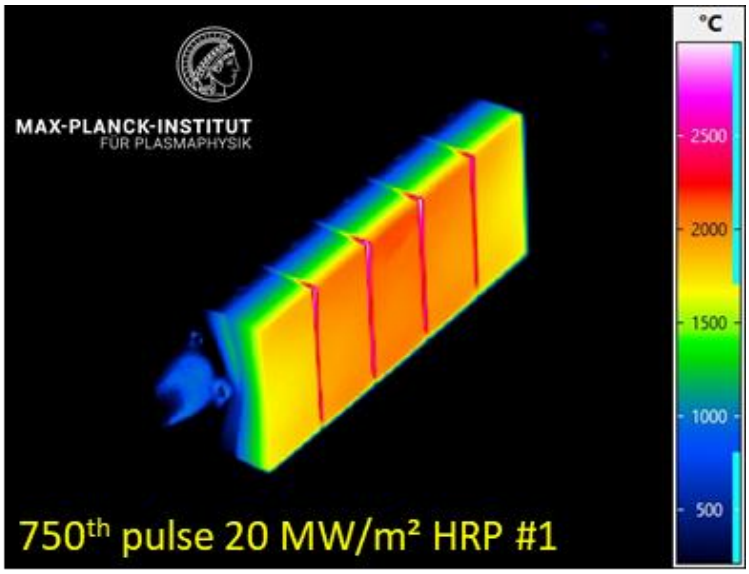

Fig. 26: IR image during 20 MW/m² cycling.

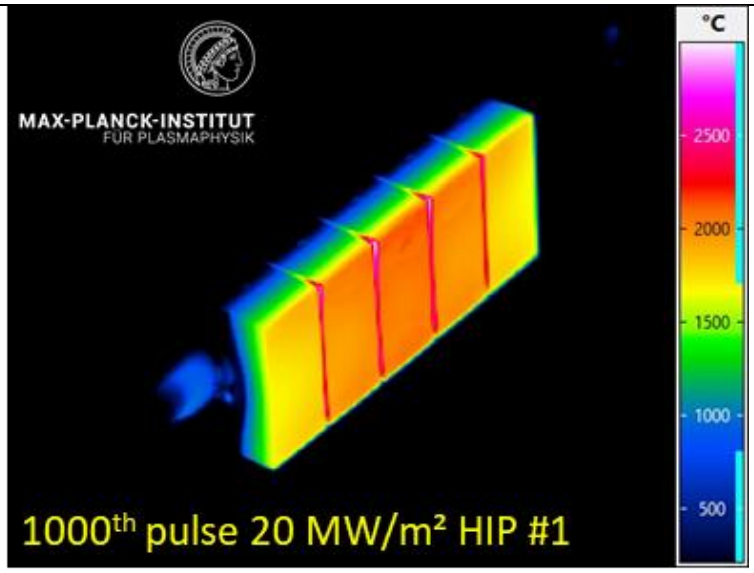

Fig. 27: IR image during 20 MW/m² cycling.

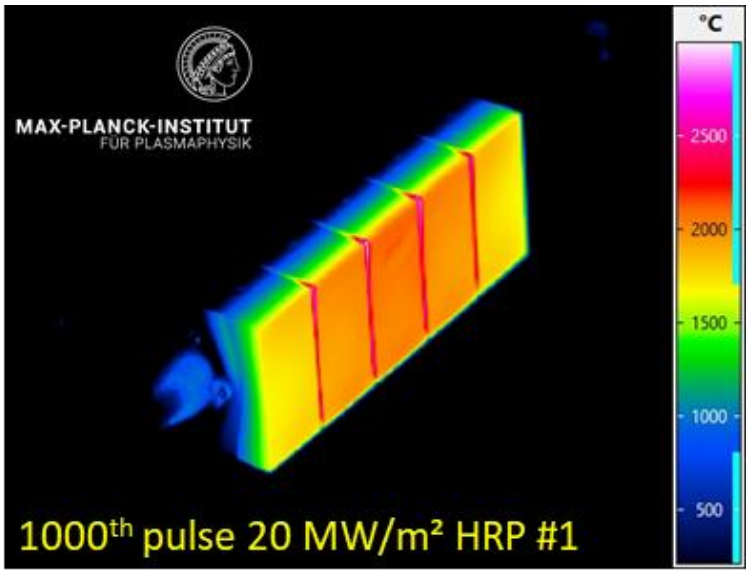

Fig. 28: IR image during 20 MW/m² cycling.

4 Summary

The successful design and manufacturing of W monoblock mock-ups *by VITZRONEXTECH Co., Ltd. and KFE* were confirmed by HHF tests with cyclic heat loading of 1,000 x 20 MW/m², 10 s loading each. The tests were performed in the neutral beam test facility GLADIS at IPP Garching.

- No unexpected defect occurred during cyclic testing of the samples.
- We could not detect any surface cracks of the W monoblocks or notable surface modification occurred during the HHF tests.
- We did not detect any degradation of the mock-ups.

Summary table of main results:
Please consider the mentioned 5 % accuracy of the data.

Loading case, sample	surface temperature, center block 3, °C **aver. value, cycling**	surface temperature, center block 3, °C **max. value, cycling**	surface temperature, center block 3, °C **min. value, cycling**
Cycling 100 x 10 MW/m², HIP #1	1092	1103	1087
Cycling 100 x 10 MW/m², HRP #1	1093	1105	1089
Cycling 1000 x 20 MW/m², HIP #1	2010	2083	1978
Cycling 1000 x 20 MW/m², HRP #1	2030	2079	2006

5 Attachments as files

1. Summary sheet of performed loading “vitzronextech_2023_summary-GLADIS_heg.xlxs”
2. “HIP#1-IR video 1000 x 20 MW/m2.mp4” of collected IR images, recorded in the steady state phase at the end of each pulse during the 1,000 cycles at 20 MW/m² on mock-up HIP #1.
3. “HRP#1-IR video 1000 x 20 MW/m2.mp4” of collected IR images, recorded in the steady state phase at the end of each pulse during the 1,000 cycles at 20 MW/m² on mock-up HRP #1.

6 References

[1] H. Greuner et al. / Journal of Nuclear Materials 367–370 (2007) 1444–1448