High Heat Flux Testing of PFCs for SPARC

Presented at the INFUSE Workshop 2020

TK Gray[1], D Brunner[2], T. Henderson[2], A Kuang[3], ML Reinke[2], RL Romesberg[4], GS Showers[4], DE Wolfe[4], DL Youchison[1], and D Yuryev[2]

[1]Oak Ridge National Laboratory

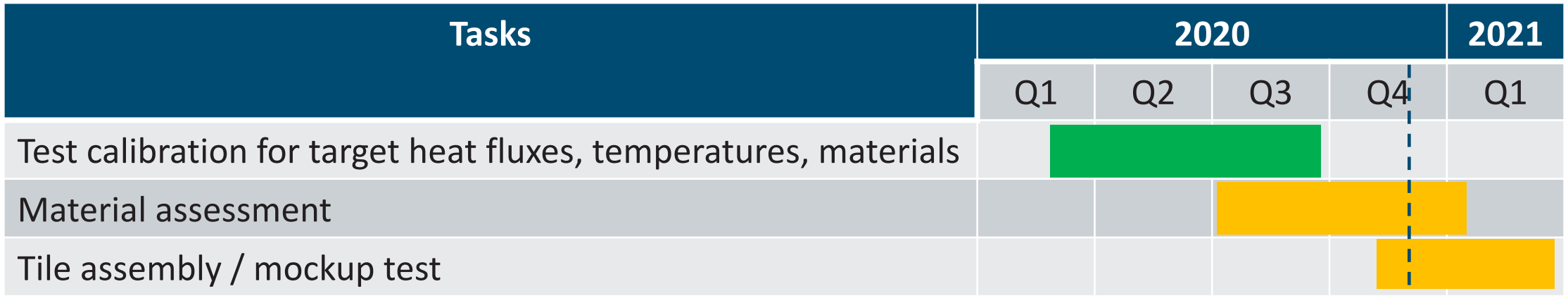
[2]CFS

[3]PSFC/MIT

[4]Applied Research Laboratory, Penn State University

High Heat Flux (HHF) Programmatic Goals

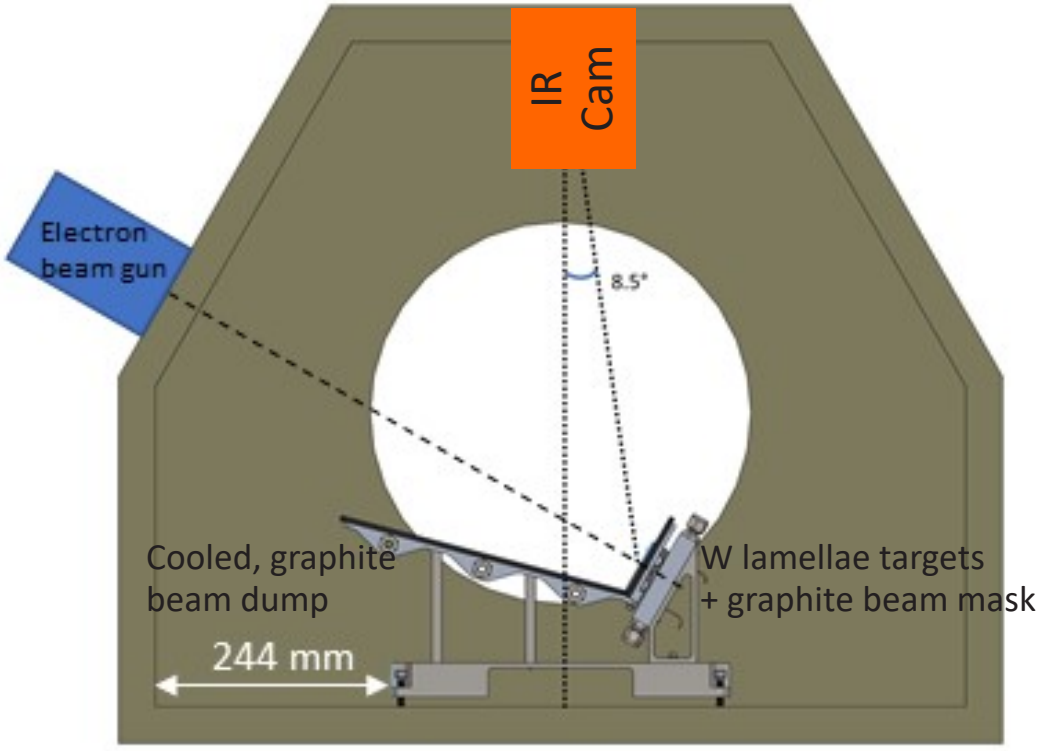
- SPARC is a short-pulse (10 s), high power density tokamak to demonstrate net fusion energy
- Baseline divertor operation is to sweep the strike point over inertially cooled divertor (>100 MW/m^2 divertor surface heat flux)
- INFUSE project aims to
  1. Inform the divertor plasma-facing material choice (form of carbon or tungsten tile)
  2. Demonstrate that the plasma-facing component can survive under SPARC-relevant cyclic heat loading

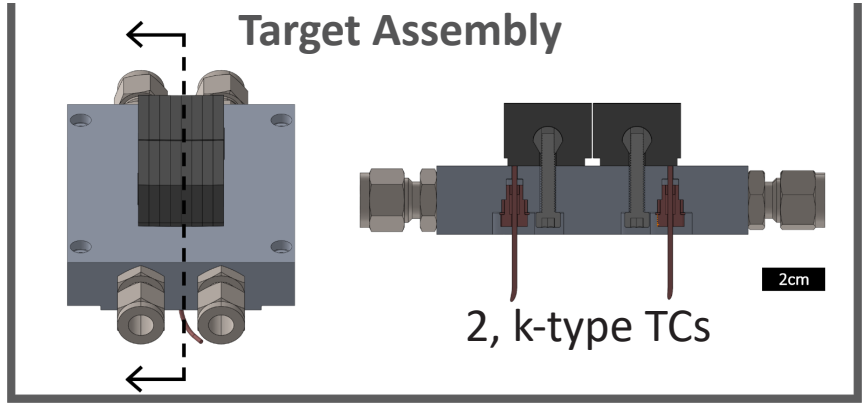


Overview of E-beam Facility and Testing Setup

- 6, 17 kV electron beams available
  - $I_{beam} \leq 2$ A
- Target block and beam dump both actively cooled
  - Water flow rate: 2.2 – 2.4 gpm
- IR Camera: FLIR SC4000
  - 100 Hz, 320x256 pixels
  - 50 mm lens, ND2 filter
  - In-situ + bench top BB calibration

E-beam Sciaky Facility





Desired e-beam scenario

- Mimic desired strike point sweep envisioned for SPARC
- Defined as a “sweep-cycle” at a given I_{beam} for 10 sec total
  - 10 strike-point sweeps on target
  - Hoped to vary speed of sweep
    - Default of 0.5 m/s → 0.1 m/s
  - Targets allowed to cool between sweep cycles (< 200 C)
- Beam spends most of time on the dump (0.8 sec)
- Chose C-Mod W lamellae for preliminary round of HHF testing
  - Heat flux handling ability of W is risky

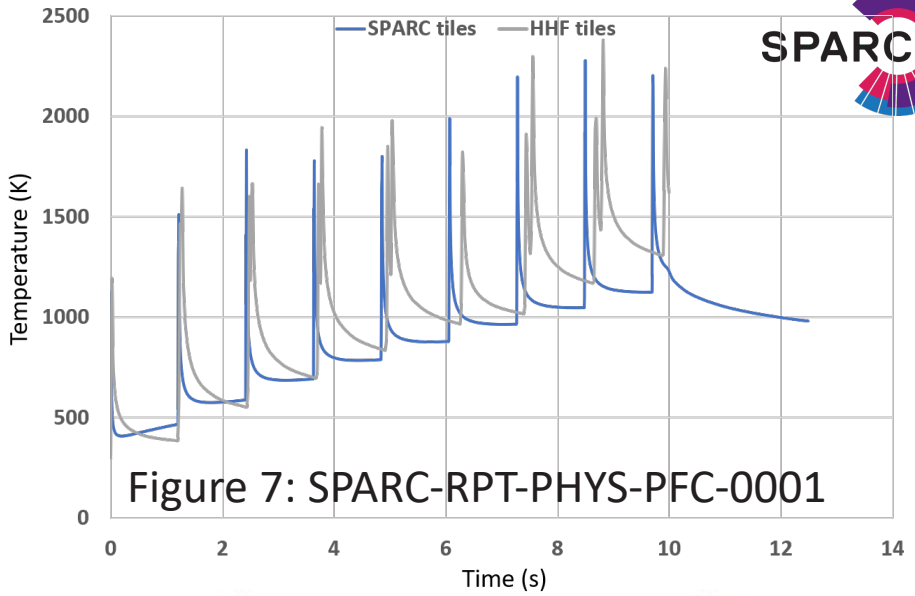
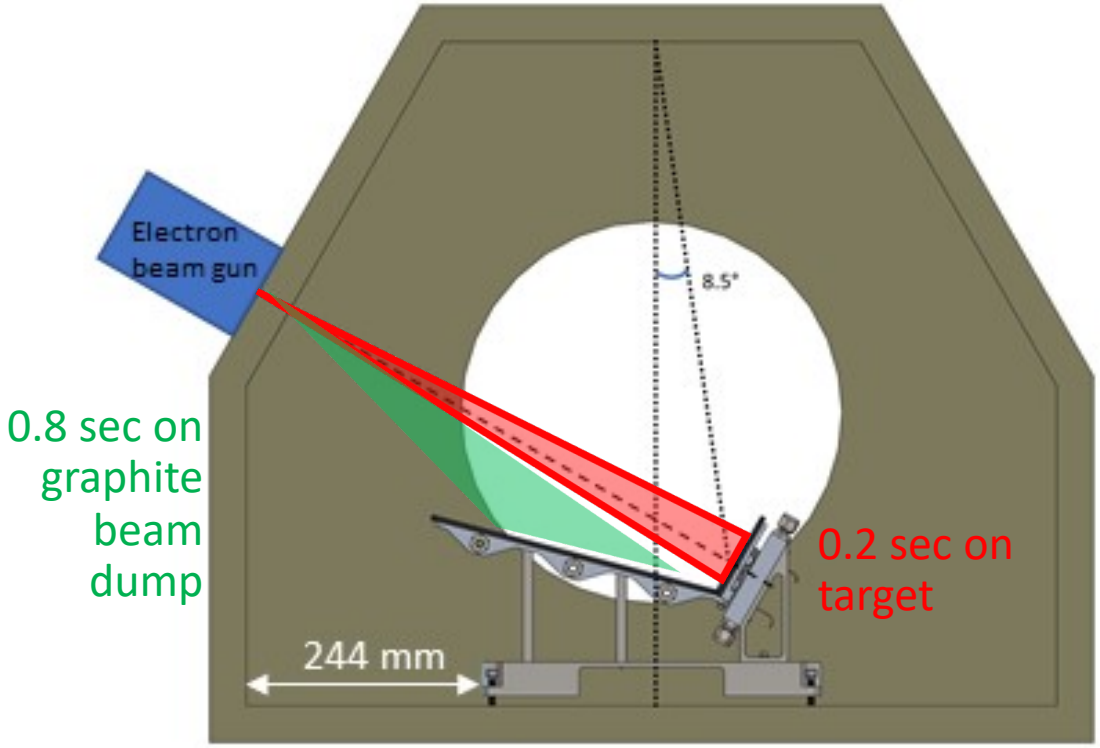
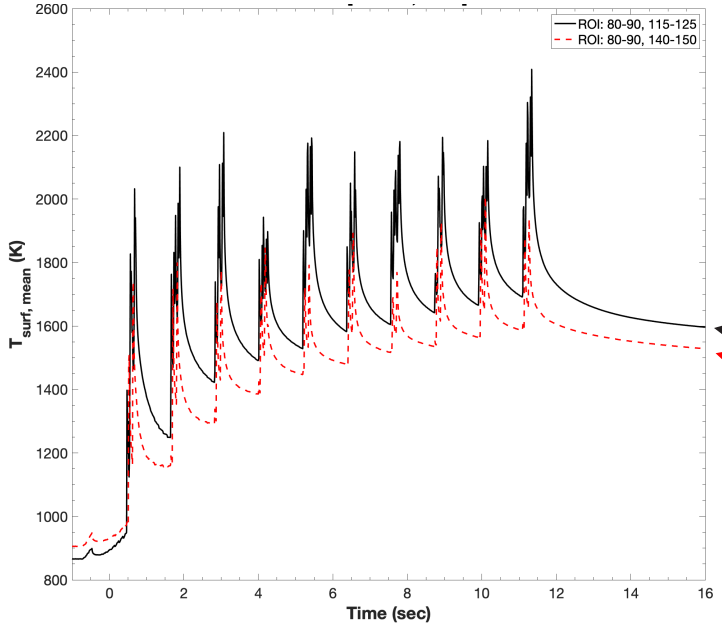


Figure 7: SPARC-RPT-PHYS-PFC-0001

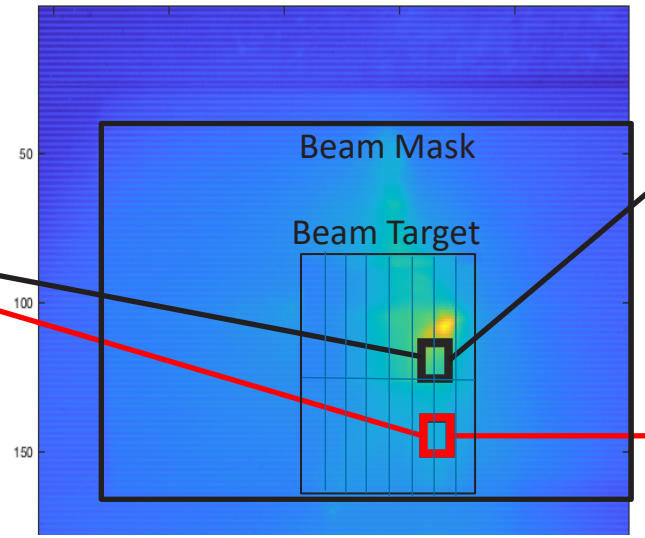


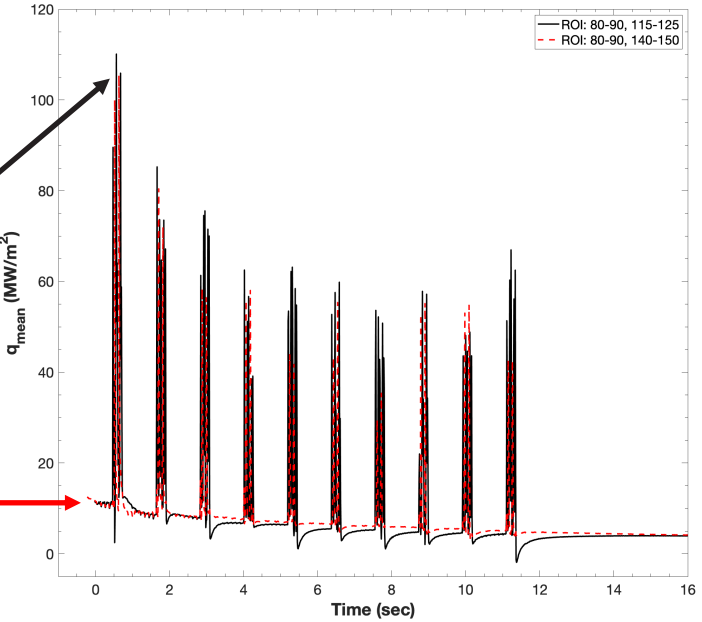
Measured T_{surf} similar to expected from simulations

- Peak q” = 110 MW/m^2
  - I_{beam} = 2000 mA
  - Semi-infinite estimation
  - Drops for successive sweeps
- Preliminary q"$_{estimate}$ = 130 MW/m^2 assuming f_{abs} = 0.3
  - 34 kW e-beam (17 kV @ 2 A)
  - f_{abs} = 0.2 – 0.25 if 110 MW/m^2 estimate is accurate



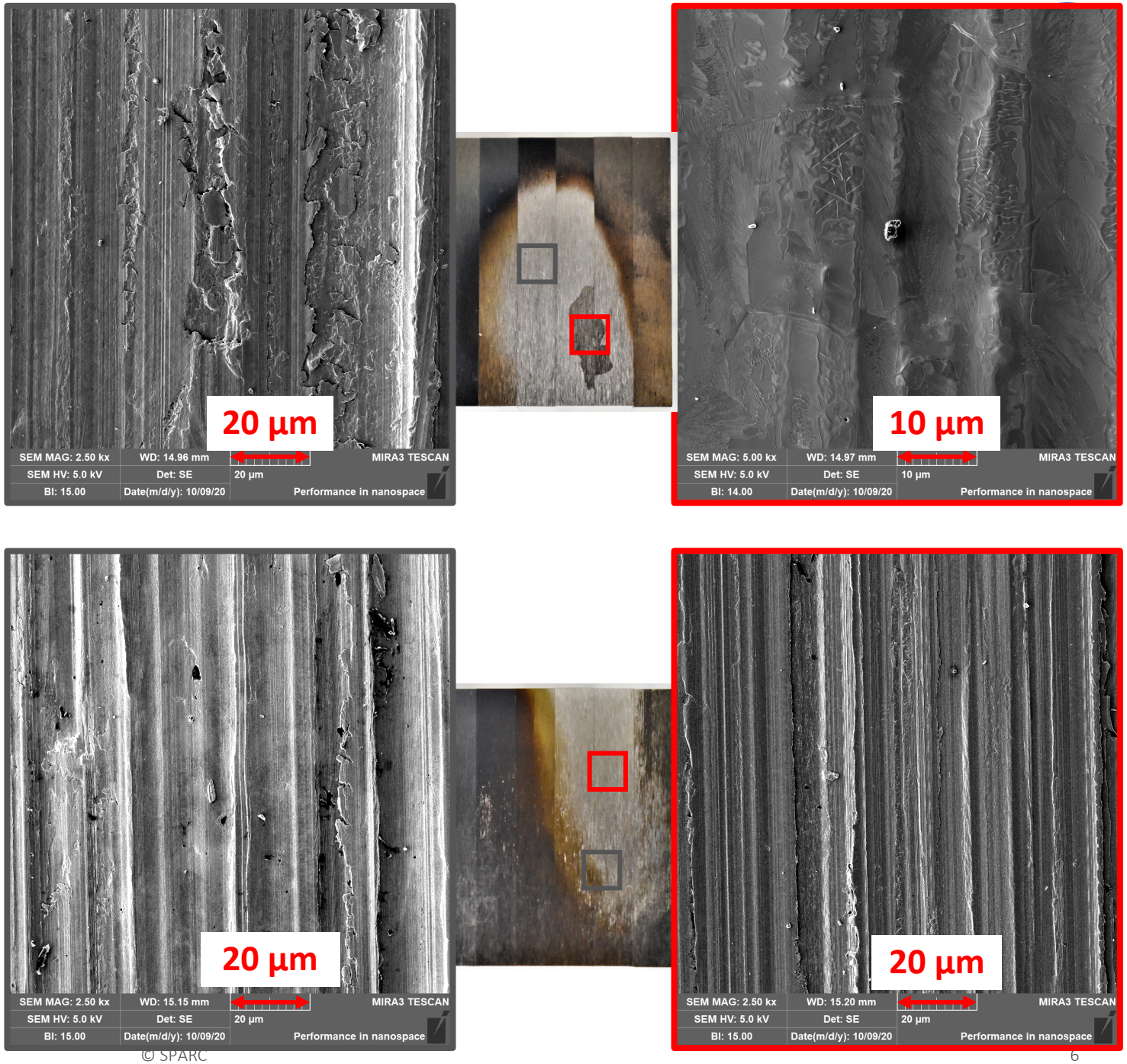
IR View of Mask and Target





Minimal damage to W tiles

- Tiles were C-MOD era PFCs
  - Surface re-ground and polished
  - Dominate surface features from that process
- Overall, no cracking observed down to 20 micron scale
- SEM from melt region shows possible surface melting and cracking
  - 10 micron scale



Summary of Results and Next Steps

- Sciaky facility achieved:
  - e-beam spot size ~ 10 mm DIA at high I_{beam} (> 1250 mA)
  - E-beam sweep speed of 0.2 m/s
  - T_{surf} comparable to expected SPARC divertor temperatures
  - Controllable heat fluxes of 50 – 100 MW/m^2
- With sufficient beam sweeping, W melting can be minimized
- Evidence of small, crack network at 10 micron scale after exposure to 100 MW/m^2 heat flux
- Next steps:
  - Data analysis from exposure testing, confirm replication of SPARC-relevant fluxes.
  - Complete detailed plan for PFC mockup tests
  - Build PFC mock-ups of CDR-level tile design and perform tests

Impacts on SPARC

- HHF tests provide critical information to guide design and selection of SPARC plasma-facing materials
- CFS now has access to facility to test prototypes at SPARC-relevant levels. This complements theoretical analysis and projection based on publications or lower heat flux tests
- CFS and ORNL can now move on to HHF Testing of integrated PFC module
- Aim is to have results to inform PDR, scheduled for July 2021

2019 INFUSE Programs on the SPARC Timeline

Divertor Component Testing

OAK RIDGE National Laboratory

Divertor Plasma Simulations

Lawrence Livermore National Laboratory

Divertor CDR

Materials Downselect

Plasma Facing Components PDR

2020 (Q4) | **2021 (Q1)** | **2021 (Q2)** | ... | **2025**

Toroidal Field CDR

Central Solenoid CDR

Limiter CDR

Central Solenoid Model Coil PDR

SPARC commissioned

Alpha Particle Diagnostics

PPPL PRINCETON PLASMA PHYSICS LABORATORY

Superconducting Cable AC Loss and Quench Detection

BROOKHAVEN NATIONAL LABORATORY