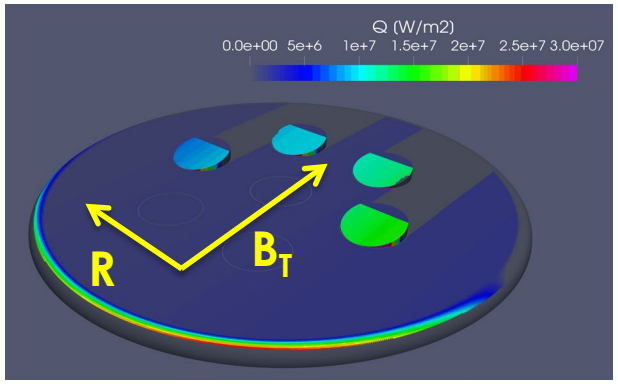
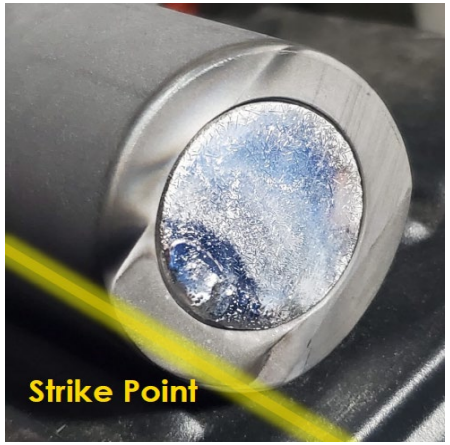
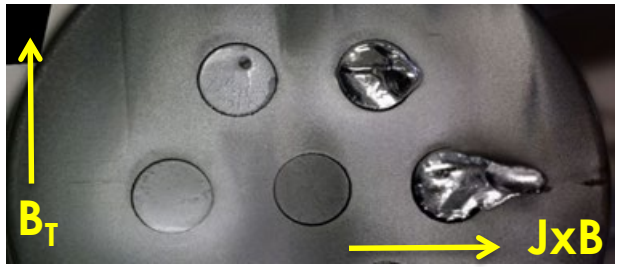
Plasma-Materials Interactions (PMI) Overview

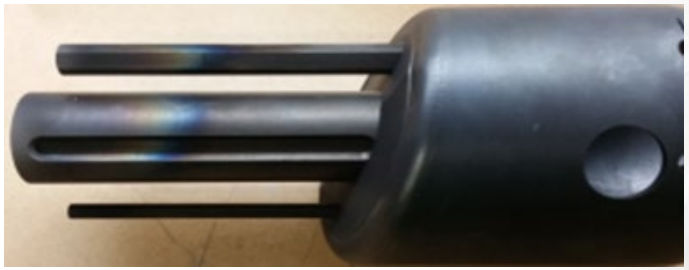
D. Rudakov and G. Sinclair

on behalf of the PMI Topical Area

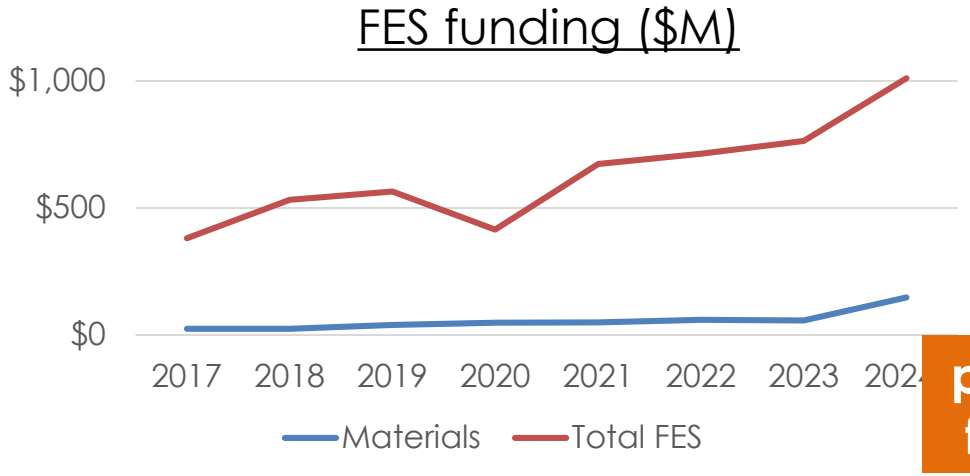


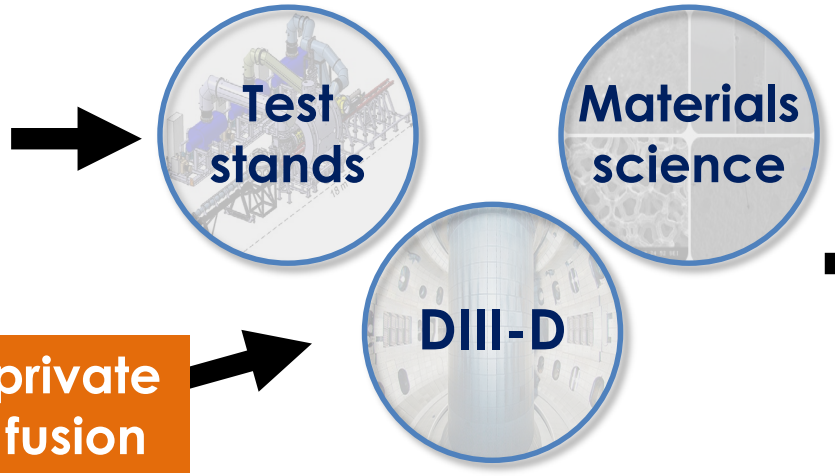






Plasma facing component development has been recently identified as one of the greatest challenges for fusion energy





F. Najmabadi et al., FED (2006)

- **Reactor-relevant plasma facing components (PFCs) remain an immense gap with low historic investment**
- **160% increase in FY24 FES funding request for materials science acknowledges the urgency and scale of this challenge**
- **Development of PFC technologies has been identified as a high priority for privately-funded efforts**
- **Robust PFC qualification requires integrated testing in a fusion environment**
  - DIII-D specifically identified in recent community plan for testing advanced solid PFCs

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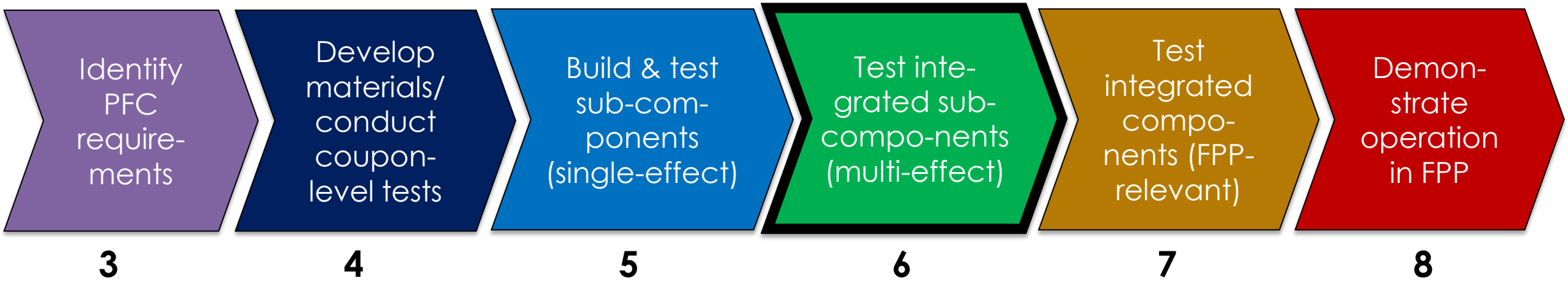
DIII-D is uniquely equipped to qualify low TRL technologies in an integrated fusion environment

- **DIII-D has been conducting integrated testing of coupon-sized samples for 30 years**
  - compatible with user facility model (public and private)
  - works in concert with test stands and fundamental materials research
- **Addressing remaining challenges requires shift from physics to technology**
  - Adopt technological readiness level (TRL) system appropriate for component development

PFC Technology Readiness Level



DIII-D will conduct expanded testing to advance solid PFCs to TRL of 6 over the next 5 years

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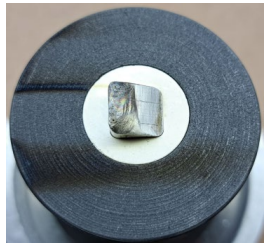
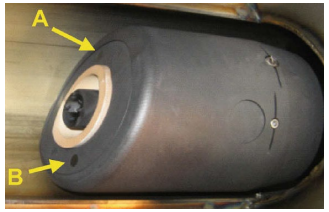
Existing and upcoming PMI studies tools at DIII-D

Existing



Divertor Material Evaluation System (DiMES)

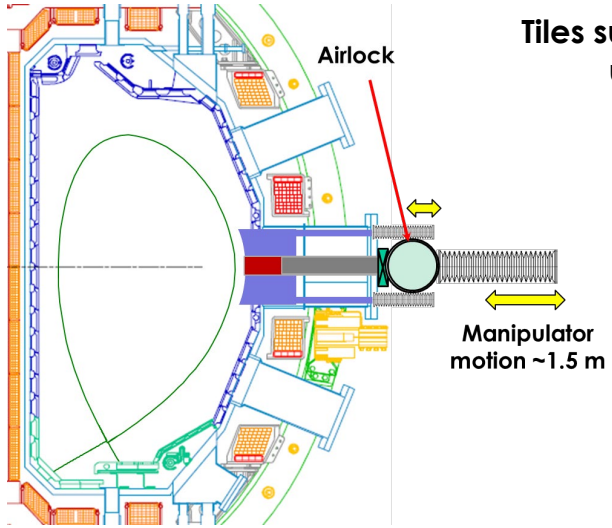


Midplane Material Evaluation Sample (MiMES)

Injection of impurity granules and powders (thrust proposal by F. Effenberg)

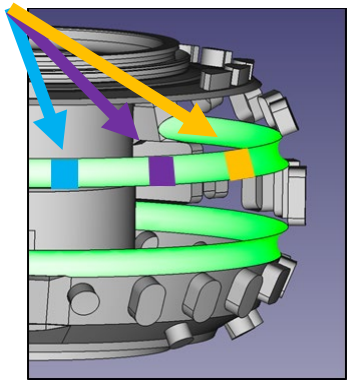
Modeling of local PMI processes (erosion, deposition, hydrogenic retention) and global impurity transport

Upcoming

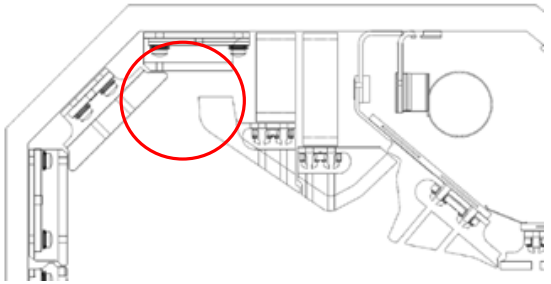


Wall Interaction Tile Station (WITS)

Tiles supplied by users



Toroidal limiters



W-coated SVR divertor

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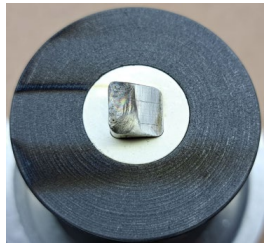

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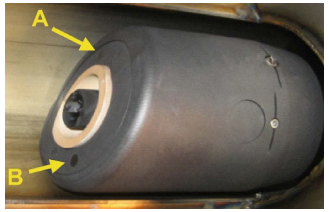

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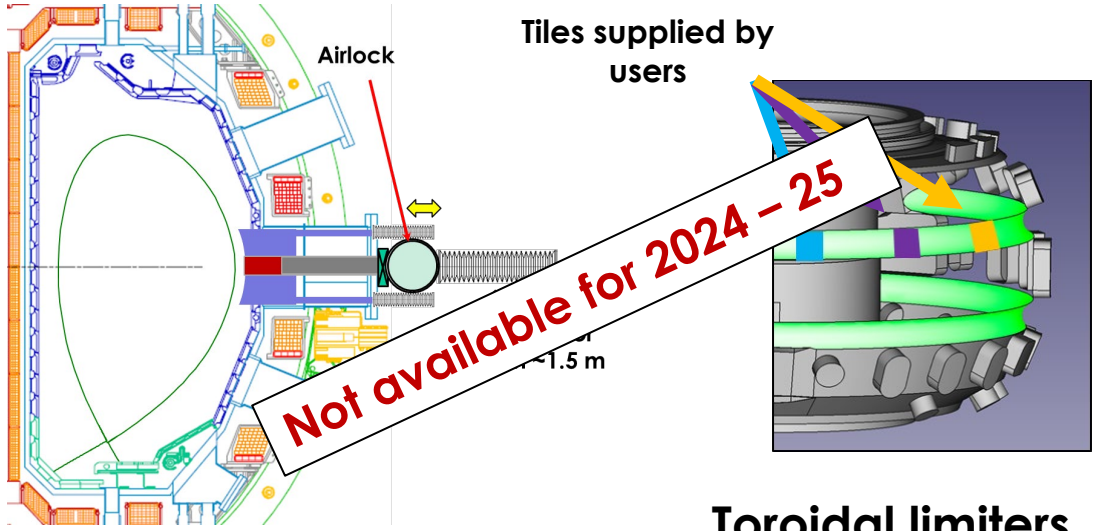

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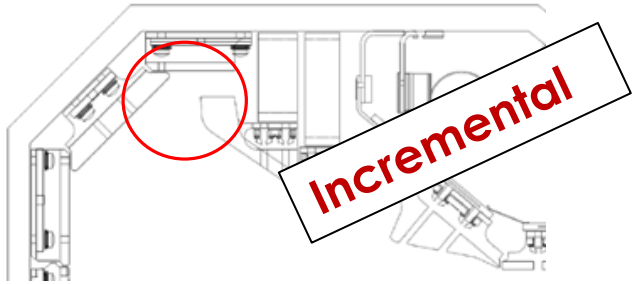

W-coated SVR divertor

For now we will concentrate on the existing capabilities for the proposed thrusts

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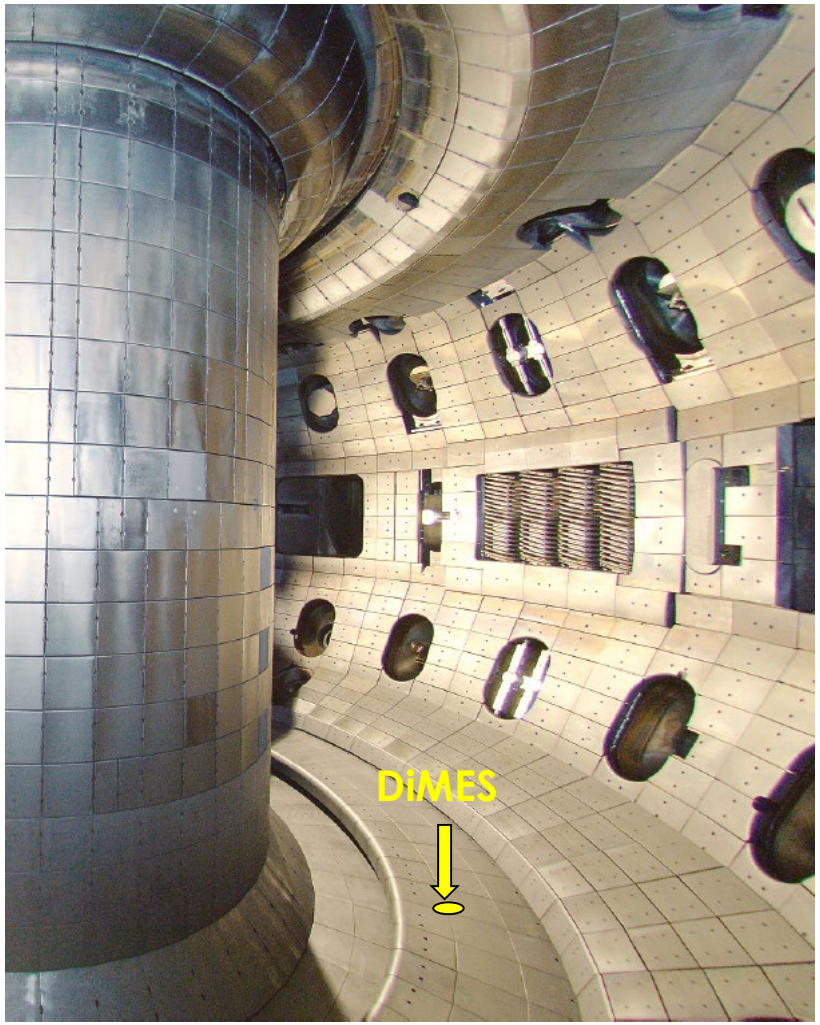
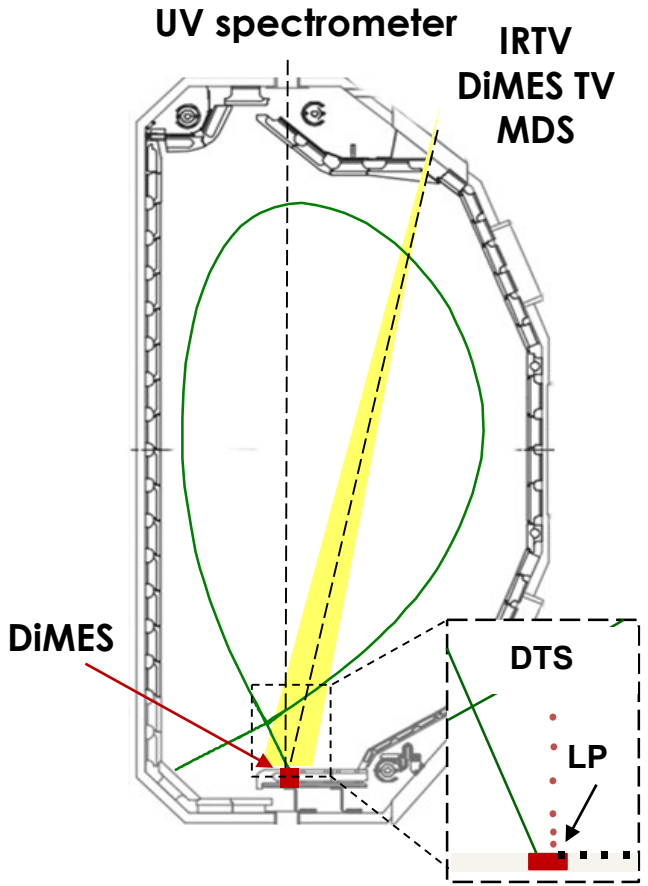
Divertor Material Evaluation System (DiMES): a well-etablished PMI test platform with excellent diagnostics



- Over decades DiMES was used for erosion, deposition and hydrogenic retention studies and tests of plasma-facing materials
- DiMES samples are typically exposed flush with the divertor tiles under well-diagnosed conditions



- DiMES samples are imaged by IR and visible cameras and MDS spectrometer
- Plasma parameters near DiMES are measured by the Langmuir probers (LPs) and Divertor Thomson Scattering (DTS)
- Active temperature control is available with a built-in heater (up to ~ 600 C)
- Local gas injection is available
- Sample size is limited to less than 5 cm in diameter

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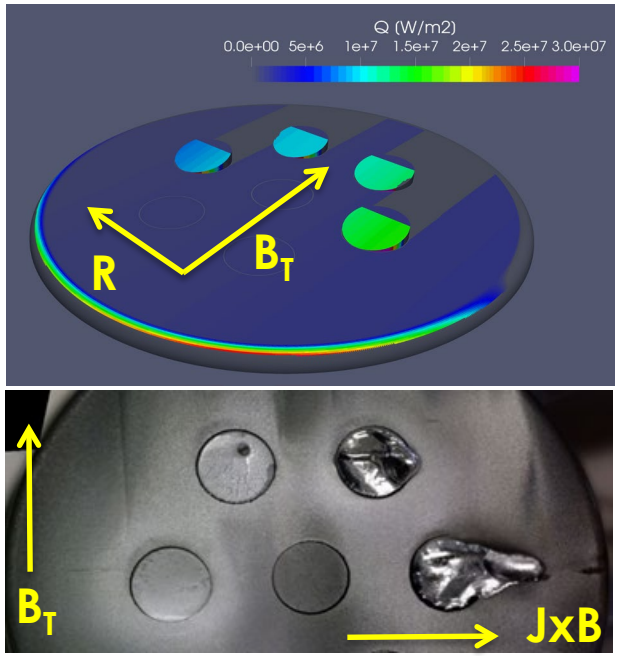
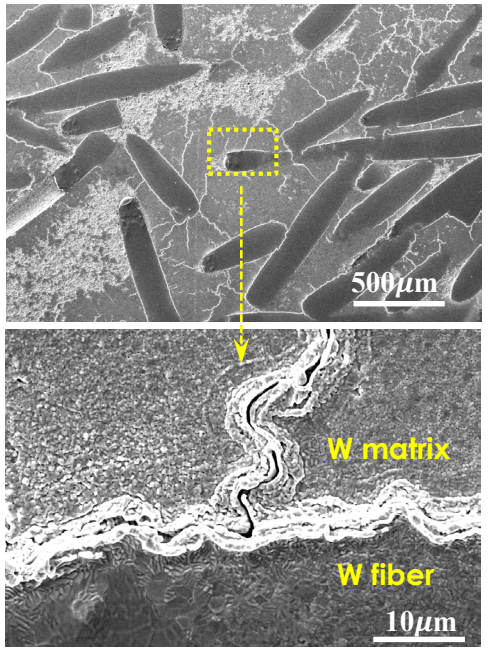
Tests of plasma-facing materials on DiMES: history and limitations

- Prior to 2016 typically only flush samples and trace amounts of high-Z impurities (tens of nm thick films) were allowed on DiMES
- Following the 2016 Metal Rings Campaign (MRC) that demonstrated operation with large amounts of W and Mo in the divertor, macroscopic amounts (> 1 g) of Si, W and advanced ceramics were allowed
- Angled W, Al and Ultra High Temperature Ceramics (UHTC) samples exposed to incident heat fluxes of > 10 MW/m^2 were occasionally allowed

Example 1:
Tests of advanced W materials





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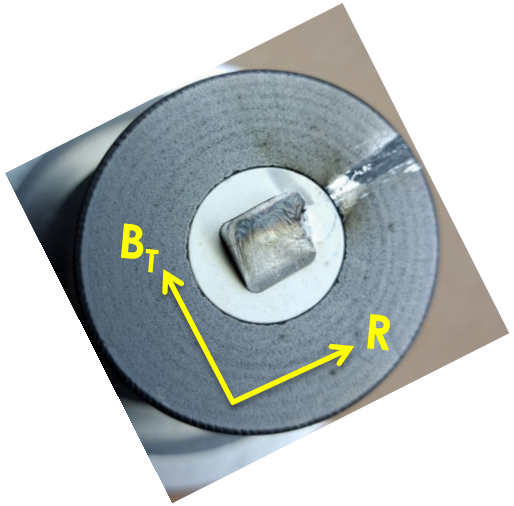
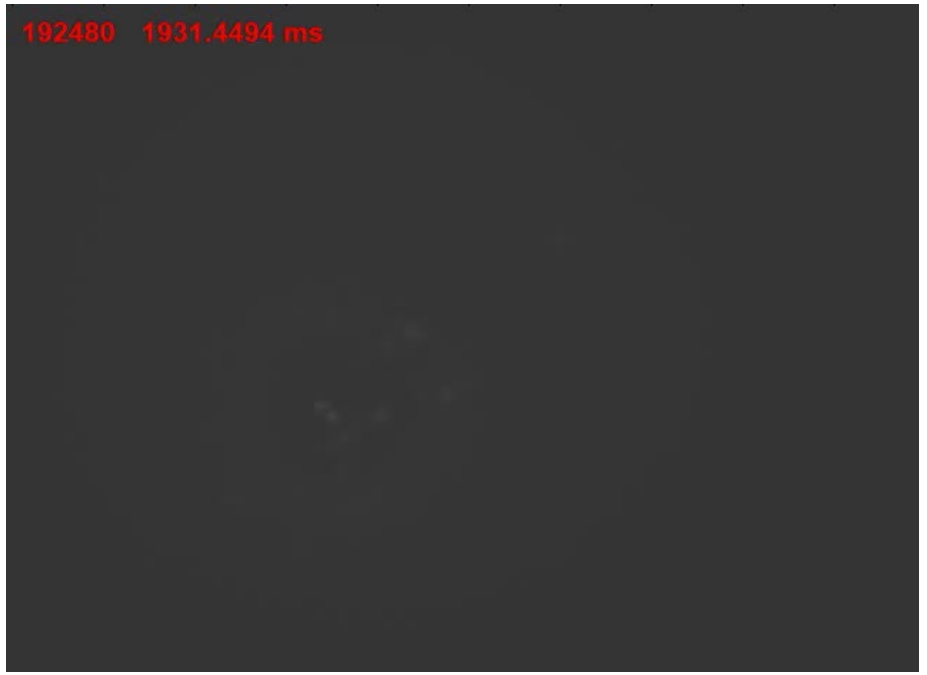
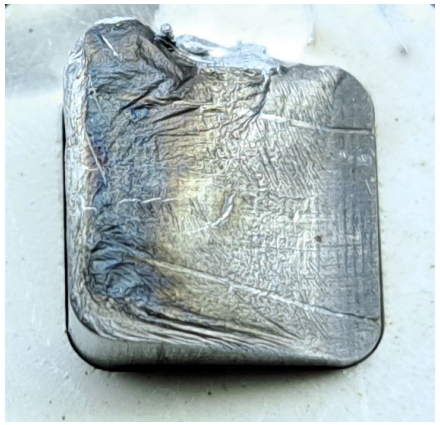
Example 2: Controlled Al Melting







Weight loss 93 mg

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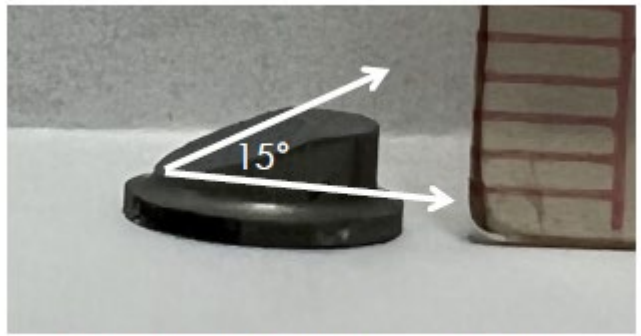
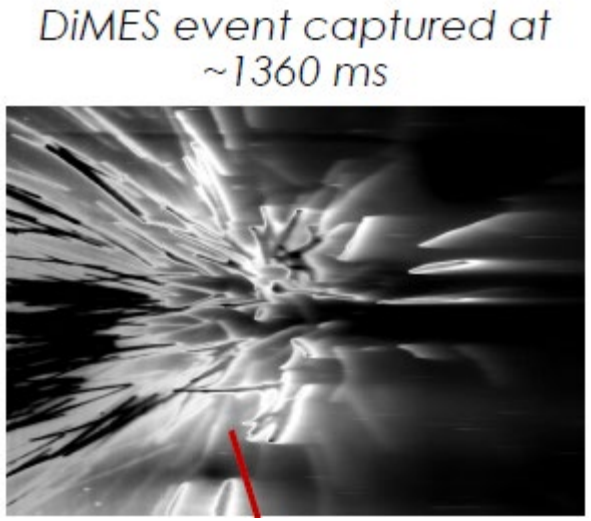
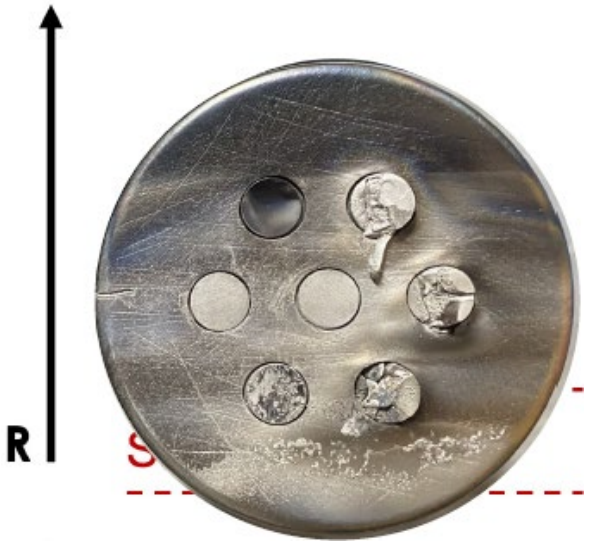
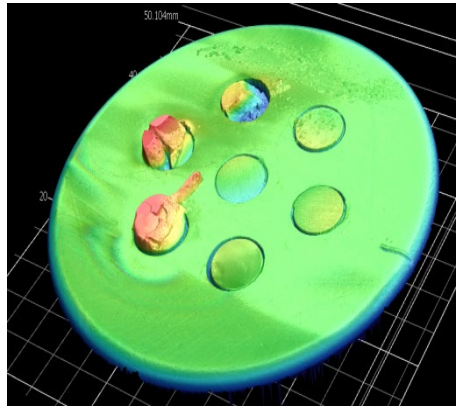
Example 3:
Tests of UHTC ceramics



Angled DiMES sample







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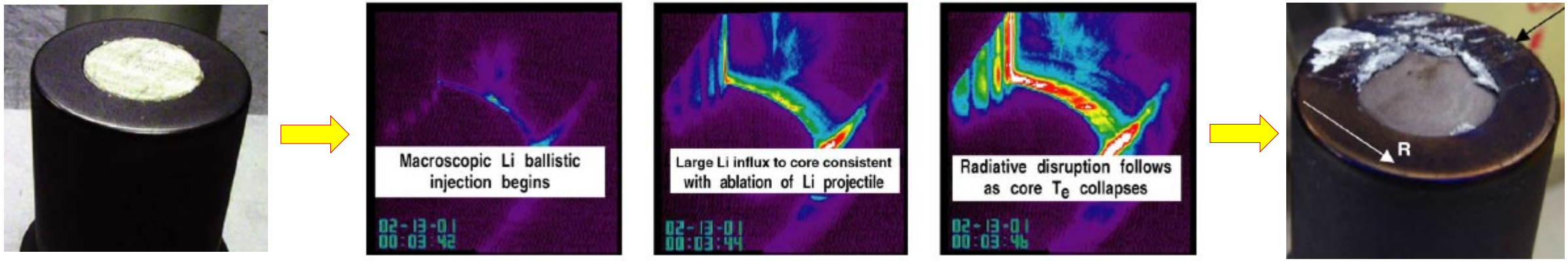
- Tests of solid Li on DiMES have been conducted in 2001 [D.G. Whyte et al. Fus. Eng. Des. 72 (2004) 133]
- Li eventually melted, got ejected and caused a disruption



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Limitations:

- Experiments with chances of machine contamination must be approved by DIII-D Vacuum Committee
- Some materials like Li-Sn-Pb may not be approved

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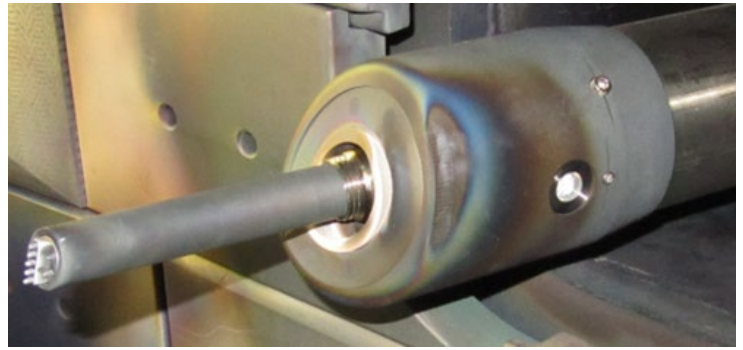
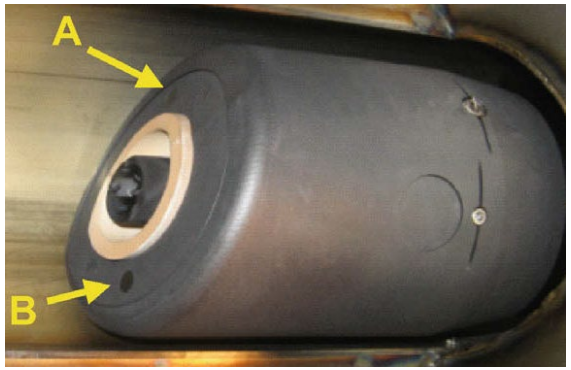
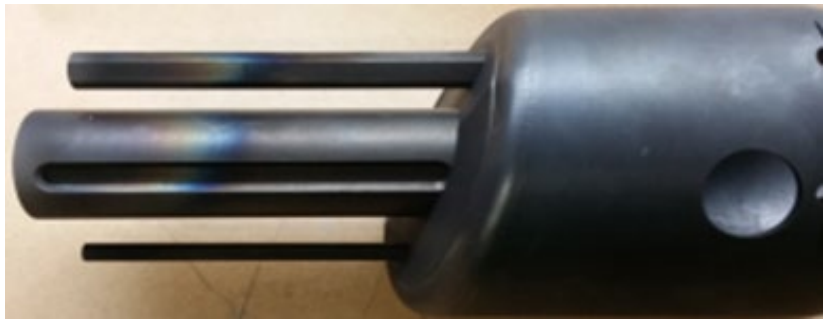
Midplane Material Evaluation Sample (MiMES)

- MiMES was commissioned in 2007 for studies of PMI in the main chamber (installed ~19 cm below the mid-plane)
- MiMES is installed on a movable drive shared with the mid-plane reciprocating probe (RCP) operated by UCSD team
- Can be used to expose up to 4 material button samples ~ 6 mm in diameter
- Erosion rates near the main chamber wall are rather low, long exposures are needed to get measurable results
- Since 2016 MiMES was used primarily to house Collector Probes for material migration studies
- Used heavily during 2016 Metal Rings Campaign and 2022 SAS-VW experiments to study migration of W from W-coated divertors
- Can be used to introduce impurities in a controlled way by changing the distance between the separatrix and the wall







MiMES experiments must be coordinated with UCSD RCP team (PI J. Boedo)

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PMI thrust proposals

- Thrust presentations for PMI
  - Effect of W in the main chamber: Important for ITER, cross-cutting and needs careful scheduling coordinated with entry vents – S. Zamperini
  - Advanced Wall Conditioning Techniques: Will include powder dropping and other techniques like conventional boronization and RF conditioning – F. Effenberg
  - Testing of novel plasma facing materials: Will benefit from creating a thrust by alleviating loads for writing individual MPs for short material exposure experiments; exposures with an elevated risk of vessel contamination can be grouped together close to the entry vent – J. Coburn