LONG PULSE ITER SCENARIOS AND CONTROL ON KSTAR

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People

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Project is Broken Down into Two Tasks

- Task 1: develop, enhance, and assess ITER Q=10 scenarios
- Task 2: enable their robust control in long-pulse operation

Key element: assess the performance and controllability of these scenarios before and after the installation of the new KSTAR tungsten divertor

Motivation – Towards ITER and Reactor-Relevant Systems

- Studies on present devices have been largely confined to discharge durations comparable to or less than a resistive relaxation time
- The ITER standard inductive (“ITER Baseline Scenario (IBS)” or “Baseline Inductive”) and the lower disruption-risk backup alternative inductive (“Hybrid” or “Advanced Inductive”) scenarios require demonstration and qualification in long-pulse operation (i.e., for many resistive relaxation times) under a control architecture based on reactor-relevant actuators and diagnostics.
- Many of the fundamental control solutions needed to robustly produce these scenarios with low to zero disruptivity, which are so far being developed mostly in short-pulse devices, require extension and demonstration in long-pulse devices
- Both ITER and KSTAR use similarly-distant, super-conducting shaping coils, and share the high-field-side shaping coils for inductive Ip control and Ohmic heating

KSTAR and the ITER Baseline Scenario

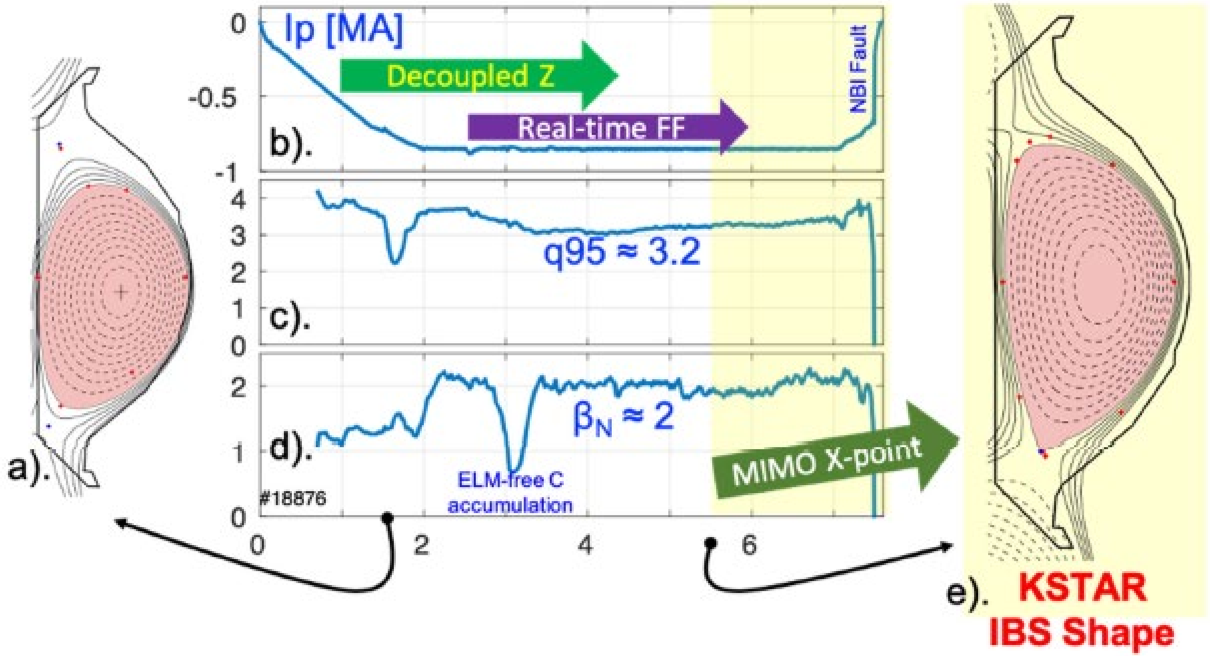


TABLE 4.1-1. DIMENSIONLESS PLASMA PARAMETERS OF ITER IBS AND HYBRID SCENARIOS COMPARED WITH KSTAR'S IBS			
	ITER Baseline Scen. (IBS)	ITER Adv. Ind. Scen. (ITER Hybrid)	KSTAR IBS
A (Aspect Ratio)	3.1		3.72
κ (Elong.)	1.85		1.75-1.85
δ_U (Upper Tri.)	0.48		0.45-0.64
q_{95} (Safety factor)	3	4	3.2-3.6
$I_N = I_p/aB_t$	1.13	1.06	0.9-1.0
β_N (norm. pressure)	1.8	2-2.5	1.8-2.0
l_i (internal ind.)	0.8	0.9	0.86-0.94
Source	[IO 2018 ITER]		[Hahn 2021 NF], [Eidietis 2017 APS]

Shape development supporting the ITER Baseline Scenario in KSTAR [Eidietis 2017 APS], including:

a) the equilibrium at the end of ramp-up in L-mode

b) the plasma current

c) safety factor

d) normalized plasma beta, and

e) final ITER-like shaped equilibrium sustained for over 1.5 s

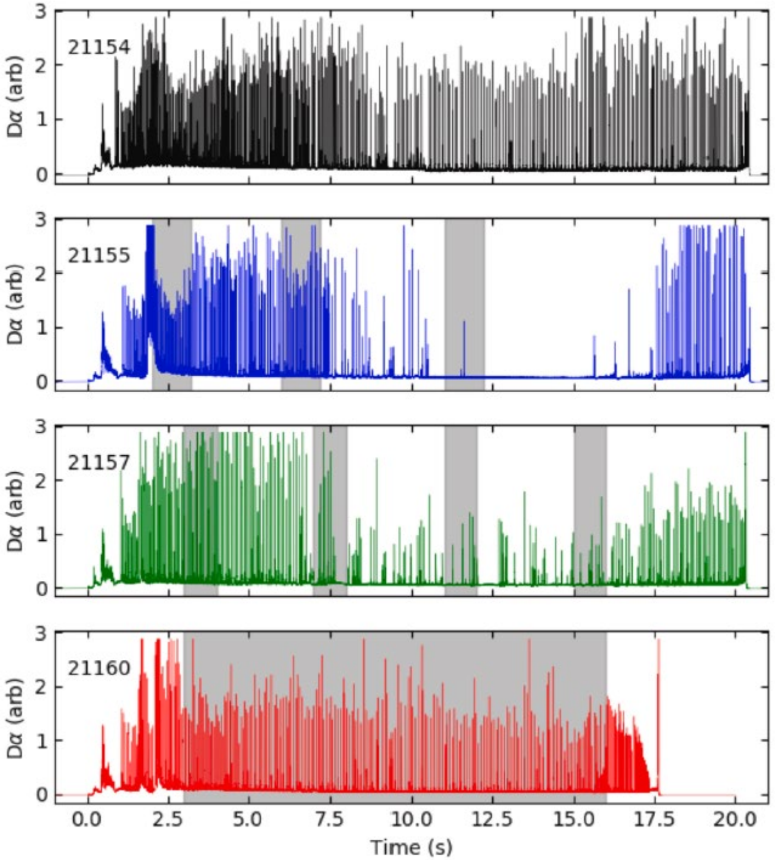
Task 1 – Scenario Development & Assessment

- In addition to IBS and Hybrid "flat-top" studies, develop and assess control solutions for current ramp-up and ramp-down
  - Time-dependent simulations, reduced models, and optimization tools (TRANSP, COTSIM, FASTRAN, GSevolve) will be used to design the plasma evolution and to inform scans of plasma parameters and identify optimum operating points
- Extend prior KSTAR high-performance Hybrid scenario work [Y.-S. Na 2020 NF] to the ITER shape and closer match ITER Q=10 Hybrid scenario specifications
  - **Gyro-kinetic simulations will likewise be applied for enhanced nonlinear simulation of the tearing mode island evolution**
- Compare tungsten/carbon divertor core magnetic flux-pumping mechanism which enables the creation of this scenario (and compare with DIII-D)
  - IPS-FASTRAN simulations with tearing mode predictor will be applied to explore these scenarios to enhance understanding and optimize
  - Simulation results would be compared to the ECE imaging system
  - **Gyro-kinetic simulations will likewise be applied flux pumping**
- **The Impurity Powder Dropper will provide a novel and additional tool for control of wall recycling characteristics and plasma edge conditions, enabling new insights and regulation possibilities for performance optimization**

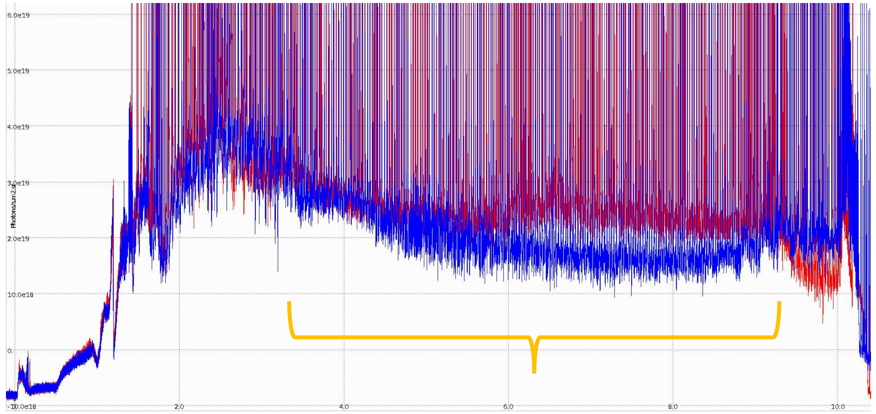
red = PPPL tasks

IPD

- IPD installed on KSTAR in 2018 and initial B and BN experiments
- 2019 – 2022 BN experiments only
- Demonstrated ELM mitigation and wall conditioning effects



Dα for ELMy H-mode, strong BN bursts, moderate BN bursts, and low steady BN injection

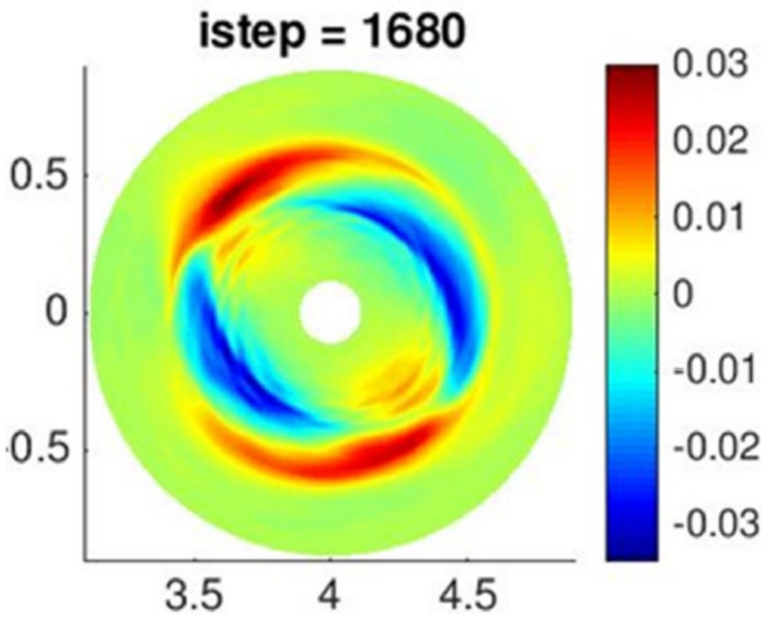


10 s discharge with weak BN injection and with strong BN injection shows reduced wall refueling effect

GTS

The gyrokinetic analyses by GTS will cover:

- key scenario points for detailed analysis of stability maintenance techniques for the IBS
- for the Hybrid scenario, GTS simulations will explore various physics effects that may regulate the core current density profile
  - help develop physics bases needed for controlling the safety factor close to or above unity that is required for a sawtooth-free operation
  - Including, but not limited to, the magnetic flux-pumping effect
- quantification of the effects of tearing modes on transport and confinement in the development of Hybrid scenarios



Electron density perturbations of 2/1 tearing mode simulated by GTS

Task 2 – Scenario Control

- equilibrium control for long-pulse operation (superconducting coils) in reactor environment (noisy or no magnetic diagnostics) to robustly achieve ITER shapes in all phases of the discharge (ramp-up, flat-top, and ramp-down)
- density control by simultaneous gas puffing and pellet injection emulating ITER's actuator dynamics and timescales
- current profile control for the robust realization and sustainment of desired plasma profiles
- gain G control for Q=10 operation
- W accumulation control in preparation for the installation of the tungsten divertor

The capability of using the IPD in feedback loop will be developed to potentially used it as an additional actuator for density control, internal energy control, and profile control