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ACTIVE REALTIME CONTROL ISSUES AND ROLE OF A FUSION DEVELOPMENT FACILITY

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GENERAL ATOMICS

ACTIVE REALTIME CONTROL DEVELOPMENT AND DEMONSTRATION ISSUE

DEMO and a commercial fusion reactor require high reliability control performance in many areas in order to operate steady state for sustained durations of many months close to various stability limits. Fusion power plant characteristics requiring control solutions beyond those supplied by ITER include:

1. Routine operation in advanced tokamak regimes, in close proximity to stability limits
2. Multi-month operation with much higher reliability and availability than ITER
3. Requirements for breeding, fuel cycle, economically attractive power generation
4. Provable performance in all aspects of control including off-normal response.

TECHNICAL REQUIREMENTS FOR RESOLUTION

Areas of control required for operation of DEMO and a commercial power plant are shown in Table I, with color coding indicating the level of solution expected as the output of present-day devices and research efforts, as well as ITER (black = no solution, yellow = limited solution, orange = partial solution, red = complete solution needed for DEMO). A column is also provided for FDF (in which white denotes limited advances beyond ITER). Key areas of contribution for FDF include:

1. Sustained-duration control for operating point and power plant performance
2. Control performance and reliability demonstration, quantification
3. Integrated control with full blanket, fuel cycle operation
4. High reliability stability control in AT regimes.

ROLE OF FDF AS A RESEARCH THRUST FOR RESOLVING CONTROL ISSUES

Design and operation of FDF will produce solutions for many identified gaps following ITER, including the key elements of fully sustained operational control, blanket operation and full breeding cycle regulation, and high performance AT control with DEMO level reliability and performance. Examples of FDF characteristics satisfying control research requirements include:

1. ARIES-AT point design (representing a model for DEMO), has similar control-relevant physics characteristics to FDF: $\kappa \sim 2.2$, $\delta \sim 0.7$–0.9), $\beta_N \sim 5.0$, high bootstrap fraction $f_{BS} \sim 0.9$ imply operation within 10%–20% of ideal stability limits in both devices;
2. Fully noninductive, high bootstrap fraction operation for periods up to 2 weeks in FDF demonstrate sustained operational control above the no-wall beta limit, in close proximity to controllability boundaries needed for DEMO;
3. Neutron fluence of ~2 MW/m^2 qualify control diagnostics and solutions in the neutronic environment of DEMO's first several years of operation.

The FDF project will work with associated research thrusts involving accurate control-level model development from detailed MHD and transport codes, development of sustained-operation heating and current drive technologies, and control design research to produce many of the key algorithmic and architectural solutions required. The facility will provide a critical platform for implementation and demonstration of these solutions.

Table I. Control topical gaps from ITER to DEMO, and the role of FDF.

Control Topical Area	Issue (needed for reactor)	Present Day Output of	ITER Output of	FDF Output of
Fraction of Solution: None				
Limited				
Partial				
Complete				
Operating regime	Bulk quantities (I_p, β,…)	Partial	Complete	
	Shape/position	Partial	Complete	
	Divertor config	Partial	Complete	
	Profile control (J, P, n, rotation, …)	Partial	Partial	Complete
	Noninductive	Partial	Partial	Complete
	Stationary/long pulse issues	Limited	Partial	Complete
	Self-heated	None	Partial	Complete
Plant startup/shutdown		Limited	Limited	Partial
Kinetics (particles, heat)	Fueling	Limited	Partial	Complete
	Divertor operation (advanced config.)	Limited	Partial	Complete
	Burn state, P_{fus}	Limited	Partial	Complete
Fusion plant	Blanket operation	Limited	Partial	Complete
	Power regulation	Limited	Partial	Partial
	Remote maintenance	Limited	Complete	
	Sustained duration	None	Limited	Complete
Stability	Axisymmetric	Partial	Complete	
	ELM	Partial	Complete	
	RWM	Partial	Partial	Complete
	NTM	Partial	Partial	Complete
	Energetic particle modes	Limited	Partial	Complete
	Thermal instability	None	Partial	Complete
	Integrated system stability control (noninductive, self-heated, sustained duration…)	Limited	Limited	Complete
Off-normal control/response	Integrated system for avoidance of off-normal events, response to predicted or detected	Limited	Partial	Complete
	Realtime predictors	Partial	Partial	Complete
	Actuators/solutions for mitigating damage	Partial	Partial	Complete

Table I. Control topical gaps from ITER to DEMO, and the role of FDF (Continued)

		Present Day	**ITER**	**FDF**
Control Topical Area	**Issue (needed for reactor)**	Output of	Output of	Output of
Fraction of Solution: None				
Limited				
Partial				
Complete				
Enabling/supporting elements	Computational hw			
	Actuator performance			
	Superconductors			
	Diagnostic capability			
Reliability/certification	Methods/results to enable certification of risk/reliability; all subsystems…			
	Nuclear plant control licensing requirements			
Modeling/design	Computational tools: control level models, simulations			
	Fully integrated comprehensive plasma/plant simulation			
Algorithms/approaches	Control algorithm solutions			
	Plant operation algorithm solutions (supervisory, off-normal response…)			
Experimental demonstrations	Fundamental need for demonstrations			