FES Joule Milestone 2008

Annual Target: Conduct experiments on major fusion facilities leading toward the predictive capability for burning plasmas and configuration optimization. In FY08, FES will evaluate the generation of plasma rotation and momentum transport, and assess the impact of plasma rotation on stability and confinement. Alcator C-Mod will investigate rotation without external momentum input, NSTX will examine very high rotation speeds, and DIII-D will vary rotation speeds with neutral beams. *The results achieved at the major facilities will provide important new data for estimating the magnitude of and assessing the impact of rotation on ITER plasmas.*

Quarter 1 Milestone
Develop a research plan and prepare the three facilities as necessary to accomplish the required experiments.

Completion of 1st Quarter Milestone

The three facilities have made the necessary preparations to accomplish the required experiments. Each is on schedule in their respective start-up and conditioning phase.

Each of the three facilities has completed their respective research forum for accepting experimental proposals for FY2008 and all are presently in the final stages of establishing the detailed experimental run plans. In response to the FES FY2008 Joule Milestone each facility has selected a large number of experiments that directly apply. Over 20% of the run allocation at each facility is directed toward responding to the goals of the milestone. Two of the three have established a Rotation Task Force and the third has a senior manager overseeing the progress of the rotation experiments in different areas. As stated in the Annual Target, the impact of rotation cuts across many areas of science important for ITER, and consequently, cross-disciplinary rotation focused experimental teams have formed at each facility.

The Excel spreadsheet at the end of this document lists the planned experiments. As new results emerge there may be some modification to the list. A given line item may represent a multiple day experiment, or in some cases the experiment will be done in the background of others, i.e. as a "piggyback". These planned rotation experiments are categorized in topic by a focus upon the ultimate goal cited above of assessing the magnitude and impact for ITER. For the magnitude, the rotation itself, we subdivide the topics into sources, transport, and momentum sinks. This rotation is intrinsic rotation by definition because of the lack of external momentum input. One goal is to have an empirical scaling for intrinsic rotation from present devices to ITER. An equally important, yet more complex goal is to develop a physical understanding of the cause of intrinsic rotation.

Neutral beam (NB) driven rotation is also in the source category because this is a tool used to study momentum transport. First, there are experiments to verify the NB momentum deposition and related effect of NB driven plasma current. For momentum transport two facilities will conduct experiments with modulated NB torque. An important issue is to understand the efficacy of a possible pinch of momentum that takes boundary momentum and transports it toward the magnetic axis.

The momentum sinks in this list are those internal to the plasma due to external magnetic perturbations. These are subdivided into two categories, nonresonant and resonant perturbations. The more benign nonresonant perturbations may actually be the source of a nonzero toroidal rotation according to the so-called neoclassical toroidal viscosity (NTV) theory. Verifying NTV theory is presently a high ITER priority. The resonant perturbations are to be avoided but to some extent are always present due to minor construction misalignments. It is important to understand the threshold for impact in ITER.

One important aspect is the phenomenon of rotation shielding of external magnetic perturbations and this is listed as a topic itself. The rotation has a mitigating effect upon the unwanted effects of error fields by shielding these fields from the interior of the plasma. We need to know how much rotation is necessary for practical shielding in ITER.

There can also be a sink, or source at the boundary of the plasma, which we place into the special topic of the boundary condition. Without knowing the boundary condition on rotation, theory cannot predict a rotation profile for ITER.

We have included a topic specifically to address the main ion rotation. In almost all cases measurements are made of trace impurity ion rotation. It is very important to be able to know how to predict the rotation of the bulk plasma from such measurements. These experiments are planned with this goal in mind.

Then there are topics covering the effect of rotation upon stability and confinement. In stability there are experiments both on the Resistive Wall Mode instability, and Neoclassical Tearing Mode instability. Reactor relevant plasmas with high stored energy are potentially subject these modes, which degrade confinement. Rotation tends to provide stability. It is important to understand the significance of any rotation stabilization at projected ITER values.

Lastly there are specific experiments on rotation topics that could prove very important for ITER, the effect of rotation upon the power threshold for the L->H transition, and the possibility of achieving QH-mode, an operating mode with no ELMs, at low rotation. For emphasis we also re-cite the overall intrinsic rotation database development for ITER impact because all projections require a scaling for the intrinsic rotation to ITER conditions.

Topic	Facility C: C-Mod D: DIII-D N: NSTX	Reference Number	Experiment description	Related Experiments
IA Sources: Intrinsic	C	1	Intrinsic rotation database continuation	5,6
	C	2	Intrinsic rotation profile evolution	5,13,14
	C	3	Rotation in LHCD plasmas, (and possibly MCEH plasmas)	6
	C	4	Rotation inversion vs ne, Ip - in limiter/divertor plasmas	
	D	5	Intrinsic rotation at high normalized pressure using balanced NBI	1,2
	D	6	Expand DIII-D intrinsic rotation database, especially shape effects, SO	1,3
	D	7	Measure edge turbulent momentum transport (relates to boundary con	8
	N	8	Mean and oscillating turbulent flows using Doppler reflectometry	7
IB Sources: Driven	D	9	Measure off-axis NBCD and validate NBCD physics	
	D	10	Affect of Alfven Eigenmodes on NBCD and fast ion profile†	
II Momentum Transpor	N	11	Perturbative modulation of core rotation using beam blips; diffusion an	14,2
	N	12	Non-core perturbative modulation of rotation using n=1 magnetic brak	19,20
	C	13	Momentum transport, locked/unlocked	2,20,22
	C	2	Intrinsic rotation profile evolution	11,14
	D	14	NBI modulated transport at low rotation with balanced NBI (piggyback	2
IIIA Sinks:	N	15	Comparison of NTV among tokamaks	18
non-resonant Δb	N	16	Island-induced NTV	
	D	17	Test Two vs. One row ELM-suppression coils for ITER, n=3	
	D	18	Test NTV offset rotation, and collisionality effect, with applied n=3	15,21
IIIB Sinks:	C	19	Intrinsic rotation with n=1 braking	12
resonant Δb	D	20	Resonant n=1 braking and error field thresholds	12,13
IV Δb Penetration	D	21	RMP screening or amplification dependence upon rotation	18
	C	22	Rotation in H-modes and locked modes	13
V Boundary Condition	C	23	Er well spatial structure and parameter scaling	
	D	7	Measure edge turbulent momentum transport	8
	D	5-7	included in these experiments	
VI Main ion rotation/	C	24	Edge ion rotation in helium plasmas (related to boundar condition)	25
Neoclassical theory	D	25	Main ion rotation studies (helium)	24,26
	N	26	Poloidal rotation studies; relation to neoclassical theory	25
VIIA Rotation and	D	27	Measure RWM damping by plasma rotation	29
Stability - RWM	D	28	Demonstrate RWM feedback stabilization at low rotation	
	N	29	RWM stabilization and damping	27
	N	30	Active RWM feedback stabilization optimization	
VIIB Rotation and	N	31	Rotation dependence of 2/1 NTM thresholds	33
Stability - NTM	N	32	Studies of the 3/2 NTM; rotation and rampdown	34
	D	33	Effect of rotation on NTM beta limits	31
	D	34	NTM 3/2 mode stability at low rotation	32
VIII Impact of Rotation	N	35	Dependence of energy and impurity transport upon rotation (n=3 modification)	
on Confinement	D	36	Changes in confinement with rotation	
	C	37	Rotation during sawteeth	33
IX Other Rotation Effec	D	38	Dependence of the L->H power threshold upon rotation	
that impact ITER	D	39	QH mode at low small plasma rotation	
	N	40	Dependence of the L->H power threshold upon rotation through n=3 braking	
	C	1	Intrinsic rotation database continuation	

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Joule Milestone: *"In FY08, FES will evaluate the generation of plasma rotation and momentum transport, and assess the impact of plasma rotation on stability and confinement. Alcator C-Mod will investigate rotation without external momentum input, NSTX will examine very high rotation speeds, and DIII-D will vary rotation speeds with neutral beams. The results achieved at the major facilities will provide important new data for estimating the magnitude of and assessing the impact of rotation on ITER plasmas"*

Q1 Joule Target: "*Develop a research plan and prepare the three facilities as necessary to accomplish the required experiments*."

Report of completion of Q1 target: A plan for the 2008 NSTX research campaign to study plasma rotation, momentum transport and their impact on plasma stability and confinement was developed at the FY2008 NSTX Research Forum held November 27-29, 2007. Approximately 20% of the experimental run time will address the milestone, and the experiments will be run within the Transport & Turbulence and the Macroscopic Stability Topical Science Groups. The following experiments were discussed in the Research Forum and are under detailed consideration: Perturbative transport experiments will utilize applied non-resonant n=3 fields and beam blips to study momentum transport near the edge and core of the plasma respectively. Steady n=3 braking will be used to study the effect of rotation on energy and impurity transport. Toroidal momentum pinch effects inferred from these experiments will be compared to recent scalings derived from gyrokinetic simulations, and poloidal rotation measurements will be compared to predictions from neoclassical theory. Stability experiments will include variation of rotation using n=2 and 3 braking fields to assess the impact of rotation on RWM and NTM stability and to better understand flow damping, with emphasis on determining how the torque applied by the n=2 and 3 braking fields relates to predictions from Neoclassical Toroidal Viscosity (NTV) theory.