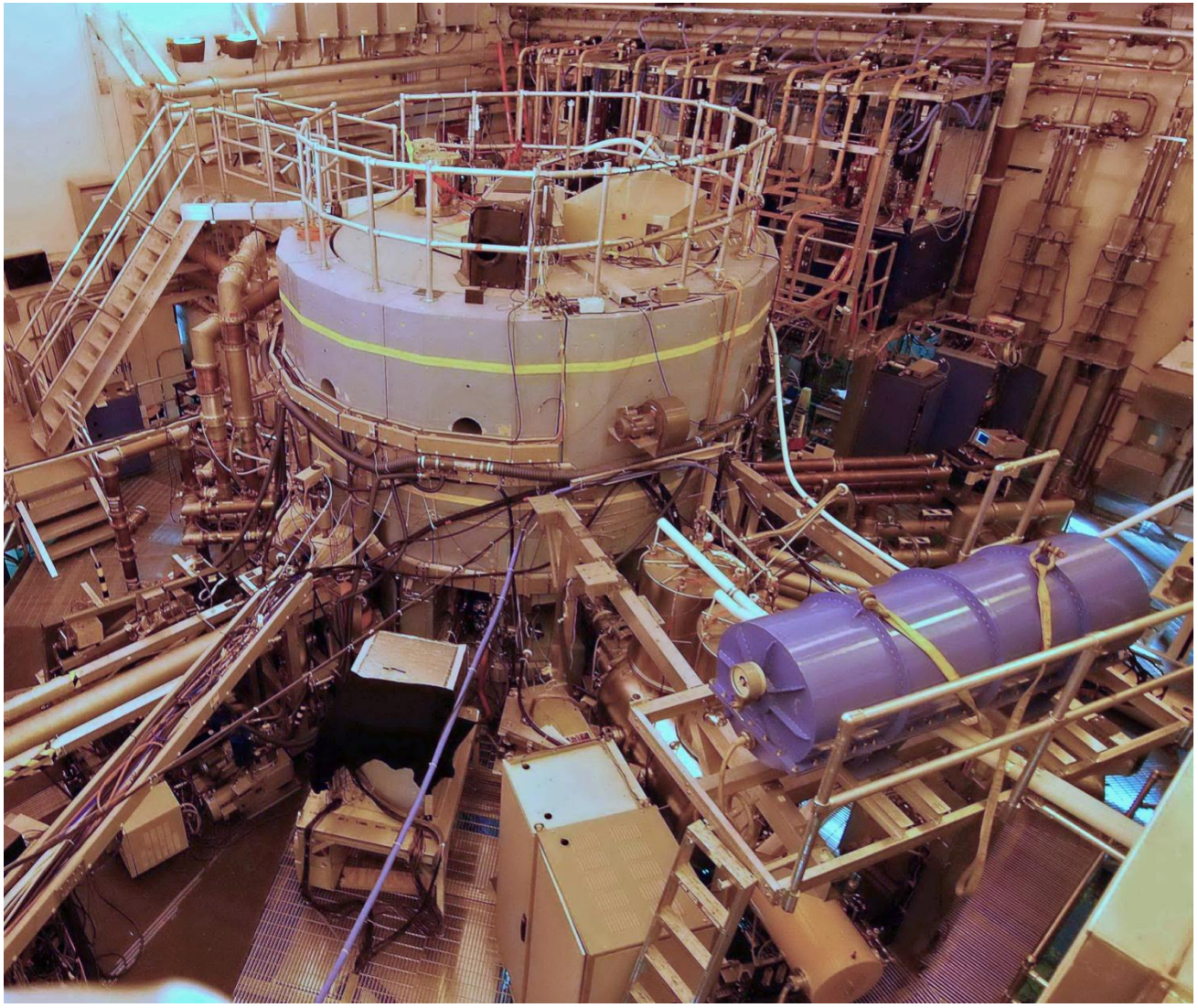
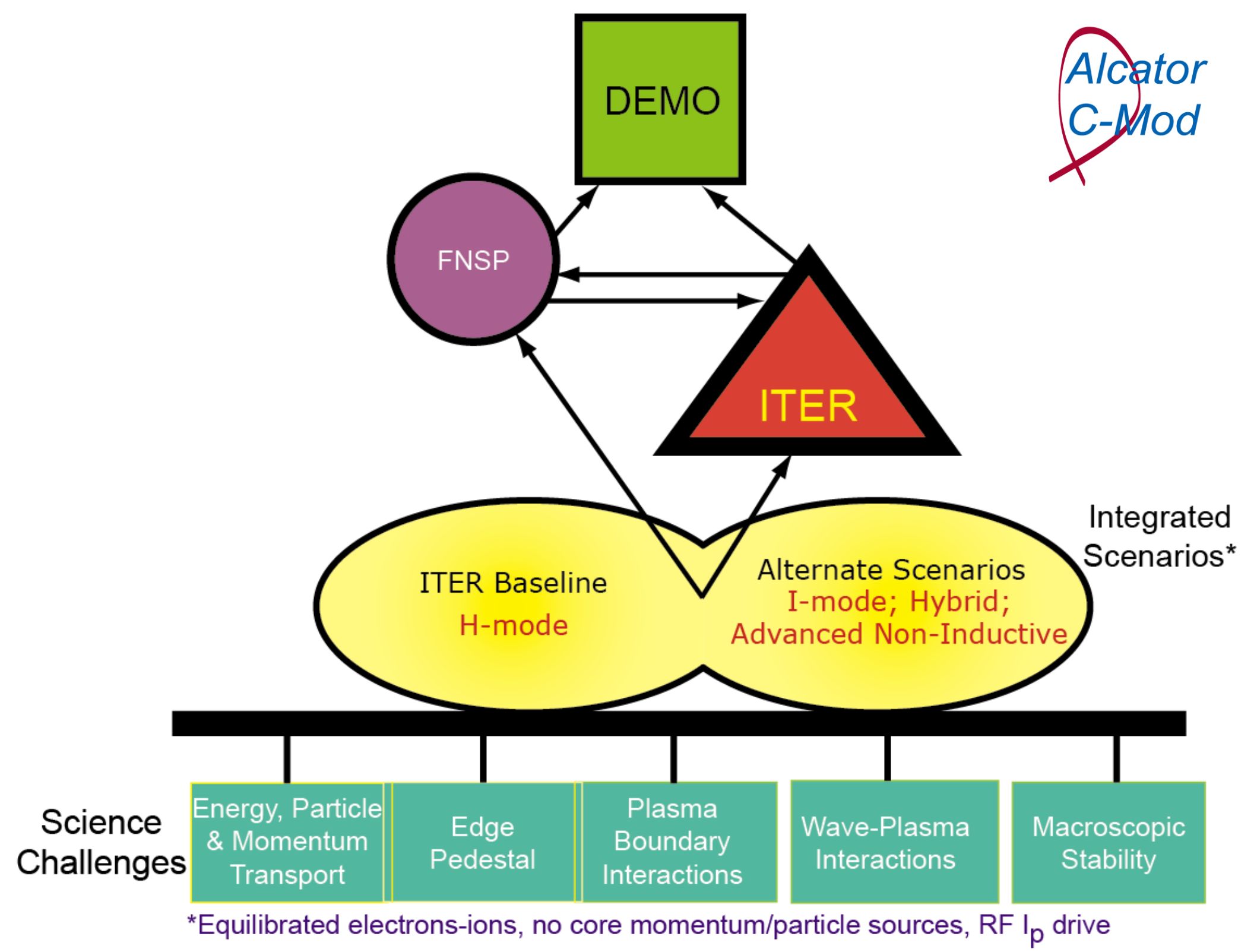
Alcator C-Mod
Highlights, Plans and Collaboration Opportunities



NSTX Forum
March 15, 2011

E. S. Marmar
for the Alcator Group

Compact high-performance divertor tokamak research to establish the plasma physics and engineering necessary for a burning plasma tokamak experiment and for attractive fusion reactors.


Alcator
C-Mod
DEMO
FNSP
ITER
Integrated
Scenarios*
ITER Baseline
H-mode
Alternate Scenarios
I-mode; Hybrid;
Advanced Non-Inductive
Science
Challenges
Energy, Particle
& Momentum
Transport
Edge
Pedestal
Plasma
Boundary
Interactions
Wave-Plasma
Interactions
Macroscopic
Stability
*Equilibrated electrons-ions, no core momentum/particle sources, RF I_p drive

C-Mod research program focuses on areas of unique capability, ITER relevance

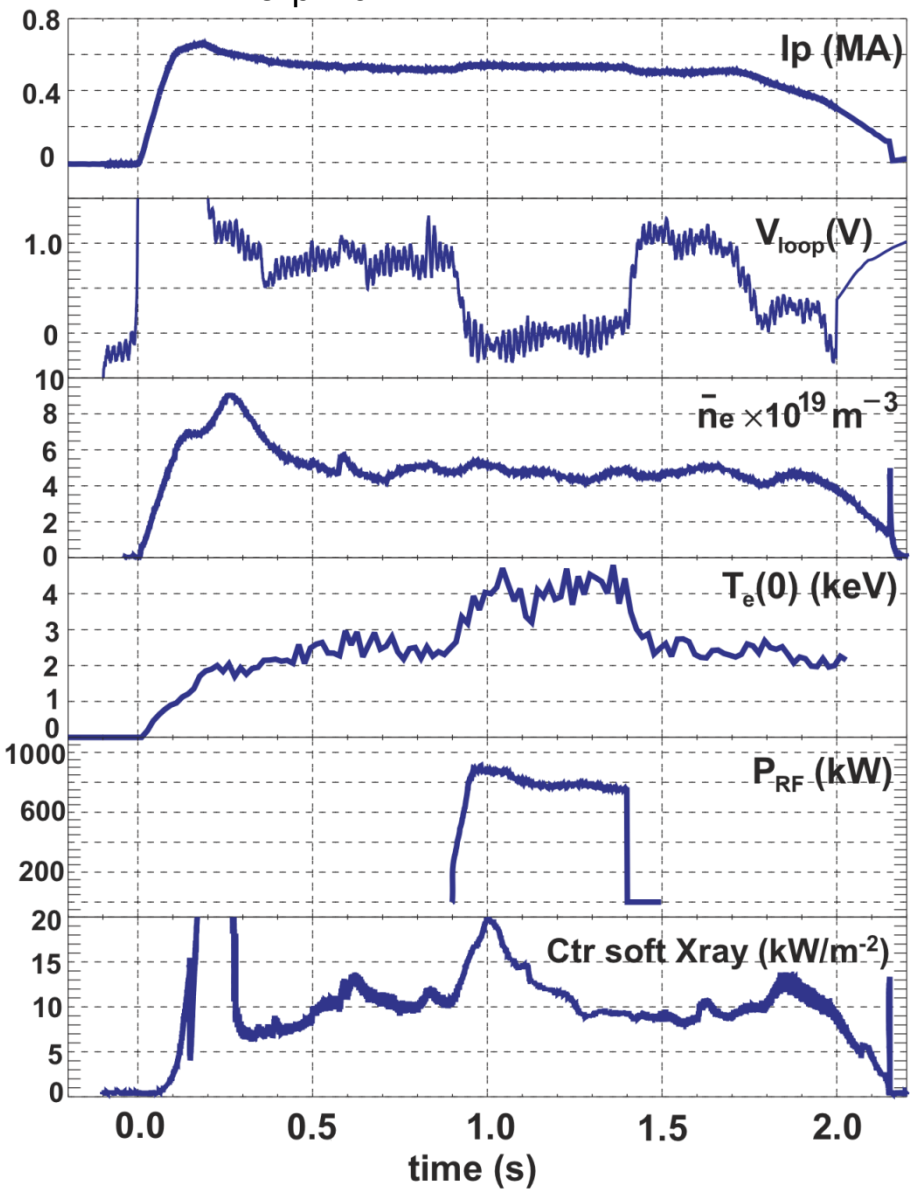
- **Broad science campaign, with particular emphasis on ITER needs and requests.**
- **Experiments exploit key C-Mod features,** eg.
  - Solid metal walls; Mo, W: D retention and recovery
  - High divertor heat fluxes: Power handling, impurity generation.
  - High density and neutral opacity: Pedestals and n_e control.
  - ICRF and LHCD at ITER B_T, density: H&CD physics
  - Transport studies in electron dominated regimes: ITER and reactor relevant
  - High pressure (<P> up to 1.8 atm): Disruption mitigation
- **Tokamak Facility and Auxiliary Systems are operating at full performance, with high reliability**
  - Completed 21 research weeks in FY2010
  - So far, completed 12.2 (of 15 planned) research weeks in FY2011

Recent Research Highlights

- Many new and interesting results from recent research operations
  - Lower Hybrid Current Drive
  - Intrinsic and driven flows, momentum transport
  - I-mode
  - Neon and nitrogen seeded plasmas (all regimes)
  - H-mode pedestal physics (FY11 joint research milestone)
  - Disruption mitigation
  - ITER discharge development
  - Impurity/particle transport
  - Edge/SOL turbulence
  - Gyro-kinetic modeling of core turbulence measurements
  - SOL transport, divertor heat flux (FY10 joint research milestone)

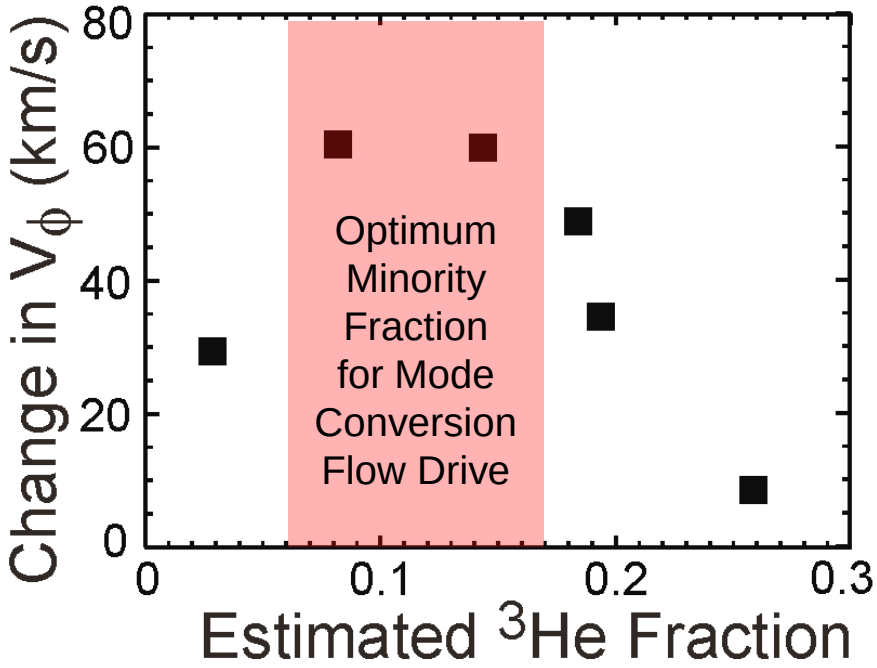
>0.5 MA sustained with 0 V_{loop} for $2\tau_{c.r.}$

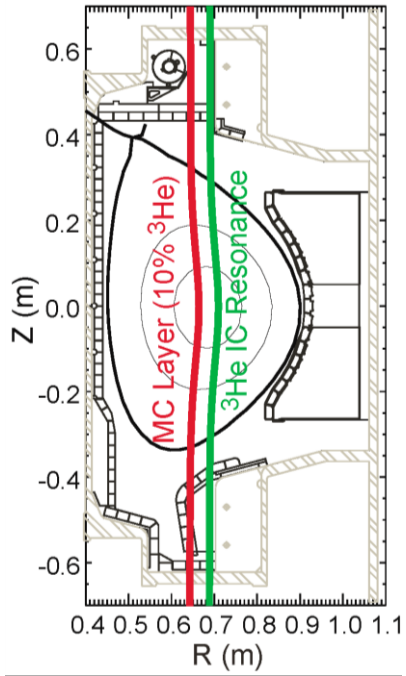
$\eta \equiv n_e I_p R_0 / P_{LH} \sim 2 \times 10^{19}$ A/(Wm^2)



Recent Research Highlights

- Many new and interesting results from recent research operations
  - Lower Hybrid Current Drive
  - Intrinsic and driven flows, momentum transport
  - I-mode
  - Neon and nitrogen seeded plasmas (all regimes)
  - H-mode pedestal physics (FY11 joint research milestone)
  - Disruption mitigation
  - B-coated Mo tile operation
  - ITER discharge development
  - Impurity/particle transport
  - Edge/SOL turbulence
  - Gyro-kinetic modeling of core turbulence measurements
  - SOL transport, divertor heat flux (FY10 joint research milestone)





Collaborators are key participants in all aspects of the program

Alcator C-Mod

Domestic

Princeton Plasma Physics Lab
U. Texas FRC
UC-Davis
UC-Los Angeles
UC-San Diego
CompX
Dartmouth U.
General Atomics
LLNL
Lodestar
LANL
U. Maryland
MIT-PSFC Theory
NYU
ORNL
PPPL Theory
Purdue U.
SNLA
U. Texas IFS

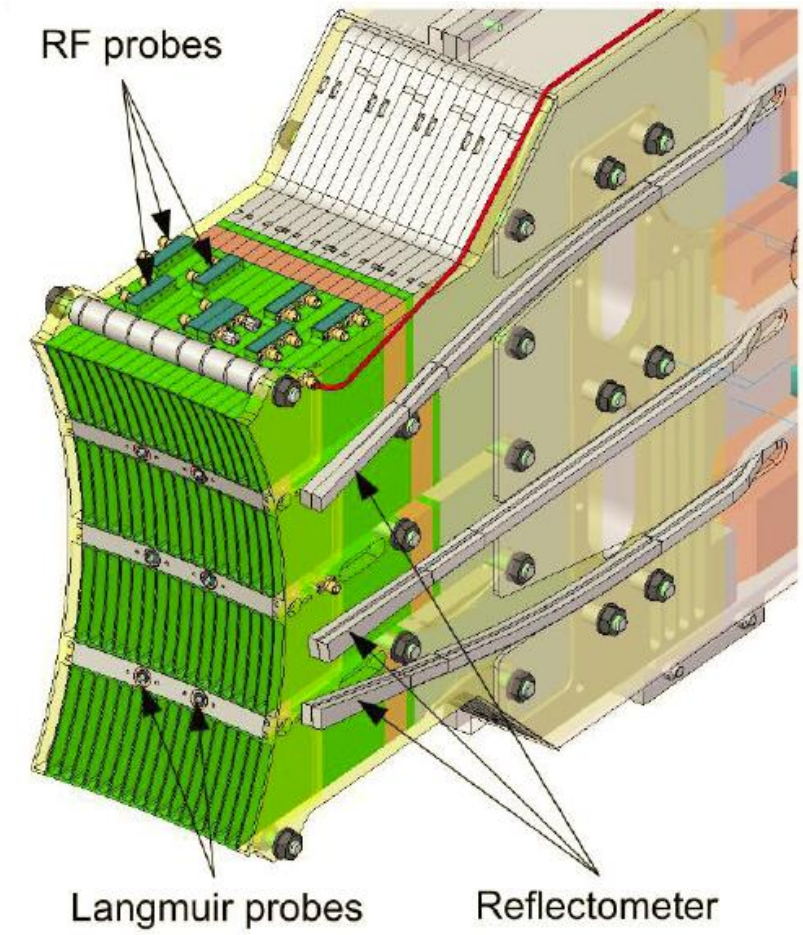
International

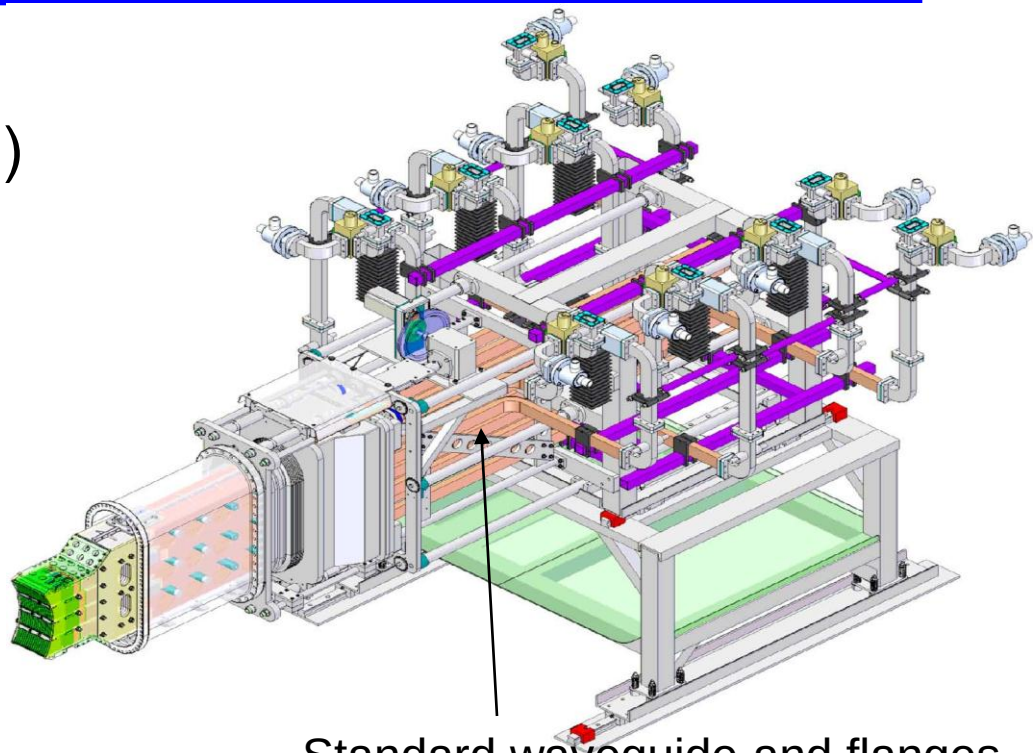
ASIPP/EAST Hefei
C.E.A. Cadarache
C.R.P.P. Lausanne
Culham Centre for Fusion Energy
ENEA/Frascati
FOM Nieuwegein, Netherlands
IGI Padua
IPP Garching
IPP Greifswald
ITER Organization Cadarache
JET/EFDA
JT60-U, JAEA
KFA Jülich
KFKI-RMKI Budapest
KSTAR Korea
LHD/NIFS
Oxford U.
Politecnico di Torino
Royal Institute of Technology Stockholm
U. Tokyo
U. Toronto
U. Tromso Norway

Coordination: FFCC, USBPO, TTF, ITPA, IEA

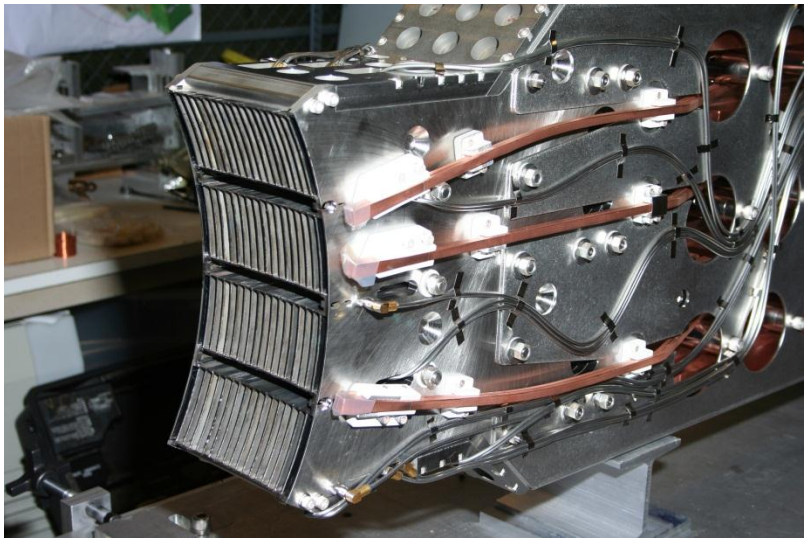
Facility Plans and Major Enhancements

- Lower Hybrid upgrades
  - 7 new klystrons @ 0.25 MW (’10)
  - Additional launcher and 4’th MW (’13)





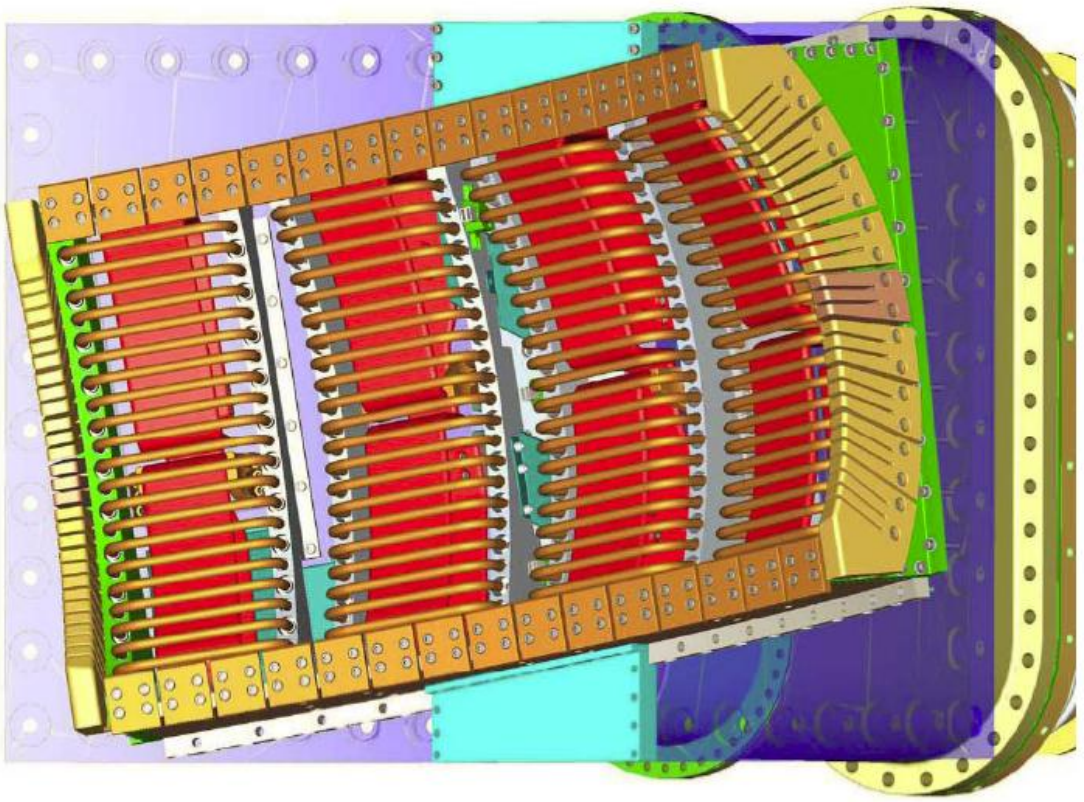
Standard waveguide and flanges



16x4 wave guide array

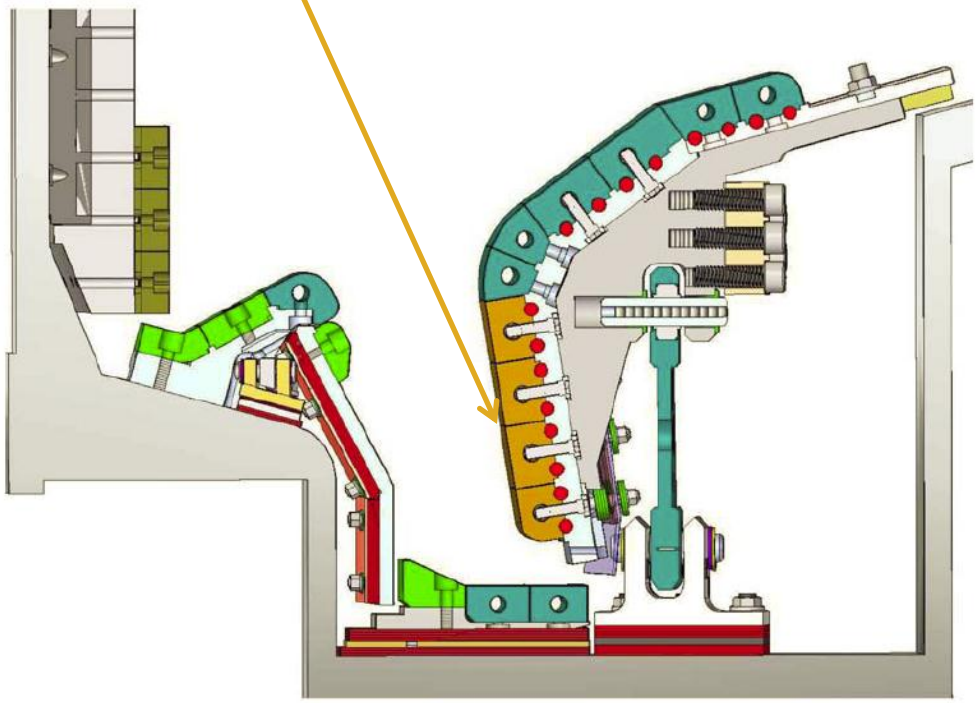
Facility Plans and Major Enhancements

- ICRF upgrades
  - New 4-strap antenna (’11)
    - Rotated/aligned with B
      - Reduce RF induced $E_{||}$ sheath, high-Z impurity sources
  - Fast-Ferrite Tuners for all 4 transmitters (real time adaptive tuning) (’11-’12)
  - Power supply + fast opening switch upgrade (with DTI SBIR) (’11)



Facility Plans and Major Enhancements (cont'd)

- Outer divertor upgrade – DEMO-like divertor ('13) (joint with PPPL)
  - Continuous vertical plate (higher power/energy handling, reduced EM loads)
  - Tungsten lamella plate tiles in high heat-flux region
  - High temperature (~ 600 ^{0}C)
    - Long pulse operations
    - Hydrogen isotope retention studies



Major Diagnostic Enhancements/Upgrades 2011-2013

Alcator C-Mod

- QCM (*shoelace*) Antenna (’11)
- In-Situ Accelerator* [first wall analysis] (’11)
- ICRF SOL Reflectometer (with ORNL) (’11)
- High Resolution X-ray Crystal upgrades (’11)
- Fast Ion loss diagnostics (’11-’12)
- PCI upgrades to detect LH waves* (’11-’12)
- Polarimetry (with UCLA) [j(r), n_e(r), magnetic fluctuations] (’11-’12)
- Ion Temperature Probes (’12)
- Correlation ECE (’12)
- New Gas Puff Imaging views (with PPPL) (’12)
- Lyman-α poloidal array (LH power loss) (’12)
- SOL Thomson Scattering (’12-’13)
- Two Color Interferometer upgrades (’12-’13)
- Doppler Reflectometry (’13)
- Core Soft X-Ray Diode Imaging upgrade (’13)
- High Resolution X-Ray Spectroscopy upgrade (’13)
- Lyman-α upgrade (CX power loss) (’13)

*Primarily funded through OFES Diagnostic Initiatives

Research priorities: Core Transport

Alcator C-Mod

- Development of fluctuation measurements and further upgrades in core profile measurements – development of corresponding synthetic diagnostics.
- JRT 2012: Detailed comparisons with theory and modeling, especially simultaneous comparisons of energy (ion and electron) and particle (and impurity) channels.
- Exploration of origin and impact of self-generated rotation
- Exploitation of RF tools to control transport through modification of current or rotation profiles

Research priorities: Pedestal

- Compare pedestal structure and transport with available models, code predictions
- Identify stability boundaries for growth rates for MHD modes across various pedestal regimes
- Relation of particle, thermal transport to fluctuations, ExB shear suppression in H-modes and I-mode
- Explore pedestal and ELM modification by external means, including RF tools and driven magnetic perturbations
- Study trigger conditions for H-mode transitions, relating edge profile characteristics to power thresholds and assessing the effects of hidden variables

Research priorities: Boundary

Alcator C-Mod

- Employ techniques to modify/probe edge turbulence, both to enhance tokamak operation and to uncover turbulence dynamics (spectral coupling, particle, energy and momentum fluxes) - link to transport and modeling
- Develop/optimize impurity seeding tools for mitigation of divertor heat flux and improvement of core plasma performance (H_{98}, Z_{eff}) with all-metal PFCs
- Further explore relationship of divertor heat flux profiles to 'upstream' conditions near the LCFS (pedestal, T_i, coherent modes) and plasma confinement; link to modeling
- Explore physics of fuel retention and plasma-surface interactions via direct in-situ measurements
- Explore impurity effects and SOL transport physics associated with RF and off-normal events (e.g. new Mo source rate measurements, missing tile experiments, ionization source measurements)

Research priorities: ICRF

- Wave propagation and absorption:
  - Characterize ICRF flow/current drive actuator.
  - Physics and simulation validation in both H and 3He minority and mode conversion regimes.
- Antenna compatibility –RF power in the SOL
  - Evaluation of rotated antenna and impurity production associated with RF antenna operation.
  - Assess SOL density profile and fluctuations impact on antenna loading.
  - Characterize ICRF sheaths, modification of SOL, and transport with RF power.

Research priorities: Lower Hybrid RF

- Validate working model of reduced current drive efficiency at high density by elaborating SOL-RF interactions, and determining CD efficiency in regimes with near-single-pass absorption.
- Investigate transport in flat/reversed shear plasmas with q(0) >1 and near-zero loop voltage, assessing the effect of shear on transport and turbulence in regimes with Internal Transport Barriers and significant bootstrap fraction.
- Upgrade available LH source power to 4 MW for the FY13 campaignby fabricating a second launcher and completing the fourth klystroncart.
- Develop, through experiment and simulation, steady-state scenarios achievable in AlcatorC-Mod with high (≥50%) bootstrap fraction.

Research priorities: Macrostability

- Study the effect of two toroidally-displaced gas jets on disruption mitigation, particularly focusing on the toroidal asymmetry of radiated power using the expanded set of AXUV detectors
- For disruption runaways, try to discriminate between limiter configuration and low elongation in terms of the prevalence of RE's in the current quench.
- Using our newly added fast particle diagnostics (FILD, FICXS), in addition to the CNPA array, continue our studies of the effects of Alfven modes on the confinement/loss of fast particles, and any degradation of heating efficiency.
- Test ITER CBN grounding scheme

Research priorities: ITER Baseline Scenarios

- Optimization of seeding for ITER-like discharges (including development of feedback)
- Full discharge sequence demonstrations (half and full field)
- H-mode access and characteristics during current ramps
- Evaluation of transient control requirements
- LHCD assisted ramp-up experiments

Research priorities: Alternate Scenarios

- Optimizing performance and expanding operational space of I-modes, in both favorable and unfavorable configurations.
- Optimizing off-axis LHCD in hot plasmas (likely I-modes), comparing with models of LHCD and edge. (aim to get high single pass absorption).
- Assessing effects of LHCD in H-modes, both current profile modification (and its effects on confinement) and direct effects on particle and energy transport.
- Integrated modeling, incorporating LHCD w density limit model, and based on above experiments, to optimize advanced scenarios enabled by additional LH power, aiming at increased bootstrap and non-inductive current fraction.

Research Operation Plans

- We are completing the current phase of FY11 operations in the next 2 weeks (to ~13.5 weeks)
- Maintenance period through August, including installation of new rotated ICRF antenna
  - FY11 target (on guidance budgets) is 15 weeks
- FY2012 guidance (Administration budget) is 17 research weeks
  - Currently planning to run through winter 2011/2012
- Welcome collaboration across all experimental topical areas and diagnostics, as well as modeling support