Experimental Research Operations: Status and Plans

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presented for the

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Topics

- Changes in device capabilities *(upgrades by Engineering Division)*
- Diagnostic status
- Diagnostic upgrades and development FY'01-03
- Plasma control
- Boundary physics and wall interactions
- *HHFW status & plans will be described in talk by J.R. Wilson*

Analysis Complete for Increasing Current to 1.5MA

- Recent experiments demonstrated benefits of higher I_p for NB heating
  - Confinement improvement
  - Avoidance of NTMs (lower β_P)
- We have capability for higher I_p for short pulses
  - Resistive and inductive flux consumption sufficiently small, *if we*
  - Apply some auxiliary heating (NB, HHFW) during I_p rampup
- Engineering calculated acceptable stresses for I_p = 1.5MA
  - Disruption dI_p/dt and halo current peaking lower than design basis
  - Will limit $I_p \times I_{TF}$ product to original 71×10^9 A^2 *i.e.* $B_T(0.85m)$ = 0.4 T
  - q_{edge} similar to 1.07MA @ 0.3T already achieved
- Completed scale-factor changes to magnetic diagnostics (Dec-00)

Bipolar Supplies for PF1a Coils

- PF1a upper/lower coils used for
  - control of triangularity δ
  - providing PF null in absorber region during CHI
  - Original 15kA unipolar supplies connected to increase δ, *but*
  - Low inductance of PF1a coils also led to large current ripple, reducing their usefulness
- Duration of CHI plasmas and achievement of conditions for flux closure have been limited by arcs in absorber region
  - bipolar PF1a can help maintain field null in absorber
- Now installing, to be ready in February,
  - two +15/-5 kA supplies *and*
  - external inductors for factor 10 ripple reduction

NB Upgrades

- NB group implementing pulse-width modulation of sources to provide
  - "blips" for fast-ion doping
  - "notches" for background measurement
  - "fractional" sources for power scans
- Analysis complete for operating NB sources at higher voltage (100kV)
  - Possibility for increasing NB power to >6MW if warranted

High-Temperature Bakeout

- Current bakeout capability after major vacuum vents:
  - Center column and inboard tiles to ~300°C
  - Outer vacuum vessel to 100°C
  - PFCs on outboard side to ~150°C
- Plasma performance has shown slow secular improvement after each vacuum vent
  - Higher temperature bakeout should accelerate improvement
- Now implementing a pressurized helium system
  - 350°C on PFCs, 150°C on outer vacuum vessel
- *Plan for availability in July*

Planned Diagnostics Can Address Research Goals

- FESAC/IPPA 5-year objective for ST:
  - Assess high-beta stability, confinement, self-consistent high-bootstrap operation, ... divertor heat flux
- NRC FuSAC Recommendation:
  - Advance understanding of key science issues in concerted efforts
    - Identify and implement diagnostic tools required to compare with theory ...
- **Stability**: profiles of j, p_{tot}, p_{fast}; mode identification (real-time for control)
- **Confinement**: profiles of n_e, n_{imp}, Z_{eff}, T_e, T_i, P_{rad}, v_ϕ, E_r, fluctuations, with resolution for internal & edge transport barriers
- **Divertor**: heat fluxes and profiles, local P_{rad}, particle sources & fluxes, erosion/redeposition
- **Advanced control**: magnetics, real-time equilibrium (incl. CHI), fueling, current drive, local heating

Diagnostic Coverage is Significantly Improving

* Diagnostics in operation 12/00
• *Diagnostics in commissioning phase 12/00*

Confinement Studies

* Magnetics for equilibrium reconstruction
* Diamagnetic flux measurement
* Thomson scattering (10 ch., 30Hz)
* 2 mm interferometer (single chord)
* VB detector (single chord)
* Midplane tangential bolometer array
* X-ray crystal spectrometer
* X-ray pulse height analyzer
* Edge reflectometer: n_e profile *[UCLA]*
• *CHERS: T_i and v_ϕ (17 ch.)*
• *Electron Bernstein wave radiometer*
• *Neutral particle analyzer (central chord)*
• *FIReTIP interf'r/polarimeter (2 ch.) [UCD]*

MHD/Fluctuations

* High-n and high-frequency Mirnov arrays
* Soft x-ray arrays (3) *[JHU]*
* Edge reflectometer *[UCLA]*
* Visible edge fluctuation imaging *[LANL]*
* Fast ion loss probe (non-resolving)

Plasma Monitoring

* Fast visible camera *[LANL]*
* VIPS-1: Visible survey spectrometer with reticon array
* Fission chamber neutron measurement
* Fast neutron measurement
* 1-D CCD camera H_α monitor
* Visible filterscopes *[ORNL]*
* Scrape-off layer reflectometer *[ORNL]*
* Wall coupon analysis *[SNL]*
* GRITS: VUV spectrometer *[JHU]*
• *IR camera*
• *VIPS-2: Visible survey spectrometer with CCD detector*
• *SPRED: UV spectrometer with CCD detector*

Diagnostic Upgrades in FY'01

- Locked mode coils (6) *installed, ready for commissioning*
- B_{pol} measurements ⇒ *more robust coils on center stack*
- Thomson scattering (30Hz, 10 ch.) ⇒ *60Hz (May), 20 ch. (Sep)*
- EBW radiometer ⇒ *2nd channel*
- IR survey (currently prototyping) ⇒ *additional cameras and views*
- Fast ion losses ⇒ *probe with E, pitch angle resolution*
- CHERS ⇒ *~75 ch. in conjunction with MSE collection optics*
- Neutral particle analyzer ⇒ *horizontal, vertical scan*
- FIReTIP ⇒ *install additional channels [UCD]*
- Edge reflectometer ⇒ *radial correlation measurement [UCLA] (May)*
- *MSE (CIF) polarimeter 2 ch. [Nova]*
- *Fast scanning edge probe [UCSD]*
- *Natural diamond neutral particle analyzer*
- *Prototype divertor bolometer*
- *Tangential x-ray camera (equilibrium constraint, slow) [with U. Wisc.]*
- *Resolve diagnostic grounding issues (with Engineering Division)*

Diagnostic Development FY'01

- X-ray imaging diagnostics
  - Fast (MHz) tangential x-ray camera *[PSI]*
  - Assessing upgrades for poloidal views *[JHU]*
    - increase detector density
    - additional/alternate views
    - filtered array
- Divertor imaging with fast visible camera *[Hiroshima U.]*
- Conceptual study for divertor bolometry initiated at Research Forum
    - Absolutely calibrated 2D or high resolution, fast 1D or 2D system
- Laser Induced Fluorescence MSE polarimeter *[Nova]*
  - *discussed in talk by F. Levinton*

Diagnostic Upgrades - FY'02 Base Funding

- Thomson scattering ⇒ *90Hz, 30 ch.*
- FIReTIP ⇒ *7 channels [UCD]*
- MSE (CIF) polarimeter ⇒ *10 ch. [Nova]*
- Poloidal x-ray arrays ⇒ *upgrade spatial resolution, views*
- Mirnov coils ⇒ *additional locations and DA upgrade*
- VB measurement ⇒ *array (supplement MPTS detectors)*
- *Design of "Poloidal CHERS" for v_{pol} profile*
- *"Dynamo" (CHI) probe for reciprocating drive*
- *Divertor bolometer system*
- *Fast tangential x-ray camera*
- *Design of interface(s) for new fluctuation diagnostics*
  - *Discussions at Research Forum and Turbulence Diagnostics Workshop*

Diagnostic Upgrades - FY'02 Incremental Funding

- IR cameras ⇒ *high speed camera with image transport*
- *Poloidal CHERS installation*
- *"Laser blowoff" impurity doping for transport studies*
- *Divertor Thomson scattering system, Stage I*
- *Imaging x-ray crystal spectrometer [$T_e(R)$, $T_i(R)$]*
- *MSE (LIF) polarimeter, preliminary [Nova]*

♦ Fueling system upgrade (FY'02 Incremental Funding)

- *Compact cryogenic pellet injector, inside launch [ORNL]*

Diagnostic Upgrades - FY'03 Base Funding

- Thomson scattering ⇒ *35 ch.*
- Fixed divertor Langmuir probes ⇒ *new locations and instrumentation*
- *Poloidal CHERS installation (if not funded in FY'02 Incremental)*
- *Fluctuation diagnostic(s)*
- *Scanning divertor Langmuir probe*
- *MSE (LIF) polarimeter [Nova]*
- *Divertor imaging with fast visible camera [Hiroshima U.]*

♦ Support of new diagnostics will be a significant challenge in FY'03

Diagnostic Upgrades - FY'03 Incremental Funding

- Thomson scattering $\Rightarrow$ *40 ch.*
- Divertor Thomson scattering system $\Rightarrow$ *Stage II (if previously funded)*
- *Edge neutral-He spectroscopy*
  - *temperatures, densities and flow in edge and scrape off*
- *Absolute Lyman-α XUV diode array for divertor region*

Status of Real-Time Control System

- New 4-processor computer installed and being tested with
  - Same inputs as present system
  - Existing control software
  - Initially operate in parallel and then phase into use during next run
- DA hardware received and tested except fast interface module
  - Vendor had problems meeting spec. but expects to deliver soon
- Implement feedback control of additional gaps (~ κ,δ) in summer '01
- Integrate gas control with equilibrium control in FY'02
  - Gas puffing currently preprogrammed separately, without feedback
  - Procure additional data link for gas system when modules tested
  - Reliable real-time density diagnostic also needed for feedback

Plans for Real-Time Control System

- Development underway for rtEFIT implementation in FY'02 *(with GA)*
  - Real-time analysis of plasma equilibrium based on full range of data
  - Eventually provide capability for controlling profiles through feedback control of gas puffing, NBI, HHFW (power and phase) (FY'03)
- CHI presents challenges for control *(with UW)*
  - New conditions for and constraints on equilibrium during CHI
    - Simplest case may be addition of CHI to inductive plasma
  - Research and development required for algorithms to control
    - CHI startup
    - Transition to inductive sustainment
  - Provide both equilibrium control and suppress absorber arcs
    - additional magnetic measurements in absorber region
    - investigate need for additional control coils and supplies

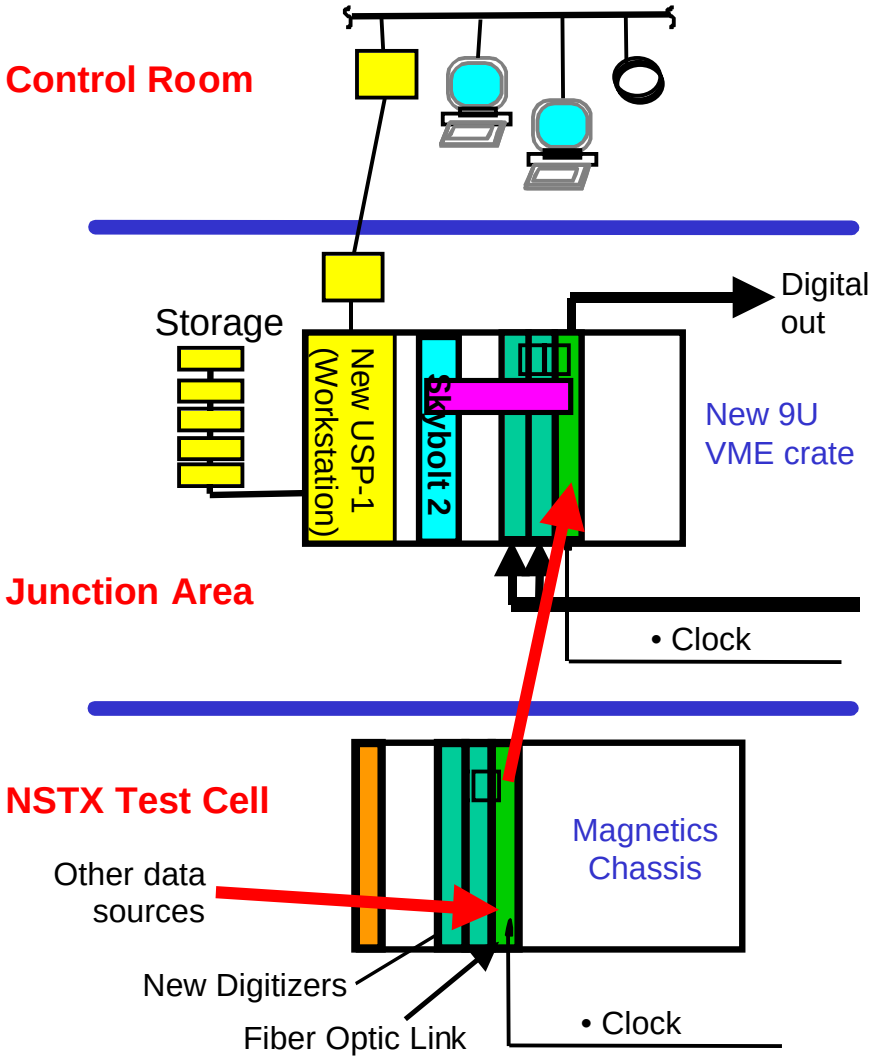
Boundary Physics Plans in FY'01

- Investigate re-boronization of eroded surfaces in normal discharges
  - TEXTOR: Trimethyl boron fueling improved plasma performance
  - PISCES: High deposition rates with carborane in similar plasma
  - Measure boron deposition/erosion - Quartz Crystal Probe
- Install low-velocity injector for boron & lithium pellets (CDX-U design)
  - Edge and core transport measurements
  - Wall conditioning studies
- Conceptual study for Divertor Bolometry
  - Initial discussion at Research Forum '01
    - Absolutely calibrated, broad-band 2D system
    - High spatial-resolution, fast 1D or 2D system
- Conceptual study for Edge Cryopump (with ORNL)

Summary

- We expect further significant operational improvements for CY'01
  - Enhanced machine capabilities: 1.5MA, bipolar PF1a
  - Improved control system: κ, δ
  - Improved wall conditioning: 350°C bakeout, advanced boronization
  - New and improved diagnostics:
    - upgraded MPTS, CHERS, MSE, multi-chord interferometry, LM coils, scanning NPA, comprehensive spectroscopy, edge measurements
  - Routine operation of HHFW system with advanced capability
    - real-time phase control
- CHI control is significant challenge
  - Limited resources to develop multi-purpose control system
- Support for diagnostics and tools to satisfy research goals is a problem

Control System Upgrade Hardware



- High Speed low-latency digital data acquisition FPDP + Fiberchannel
- "Skybolt 2" computer (4 G4 processors at 333MHz ⇒ 10GFlop)
- Expandable up to 64 processors in one chassis
- Up to 768 channels of data
- 50MB/s sustained data rate