NSTX Weekly Report (Apr.17, 2009)

FY 2009 NSTX plasma operations
Planned: Base - 11 run weeks, ARRA - 5 run weeks (pending funding approval)
Completed: Base - 3.57 run weeks, ARRA - 0 run weeks

Jong-Kyu Park successfully defended his Princeton University Ph.D. thesis entitled "Ideal Perturbed Equilibria in Tokamaks". During his thesis work, Jong-Kyu developed the Ideal Perturbed Equilibrium Code (IPEC) based on the DCON and VACUUM codes to compute 3D perturbed equilibria in tokamaks. Given 3D vacuum fields from external coils, IPEC computes the ideal plasma response to those fields. IPEC helped to explain several error field correction paradoxes in NSTX and DIII-D, and is now being applied to better understand the locked-mode threshold for present tokamaks and for ITER. Jong-Kyu also developed a generalized/extended theory of neoclassical-toroidal-viscosity (NTV) which when coupled with IPEC compared favorably to NSTX and DIII-D data and improved the understanding and predictability of toroidal flow damping in tokamaks. IPEC is also being applied to the understanding of ELM suppression by resonant magnetic perturbations in tokamaks and STs with application to ITER ELM control. Jong-Kyu's thesis advisors were Jon Menard and Allen Boozer. (J. Menard)

The General Atomics NSTX research participation update was submitted (see the attached below) which describes the research accomplishments and remaining plans by the GA NSTX collaboration group for "the Resonant Magnetic Perturbation Edge Localized Mode Control Coil Modeling" (T. E. Evans), "H-Mode Edge Pedestal Stability" (T. Osborne), "Plasma Control" (D.A. Humphreys), and "Neo-classical Tearing Modes and the Effect of Non-Axisymmetric Fields" (R.J. La Haye) (R.J. La Haye, General Atomics).

Run Coordination (R. Raman , University of Washington, Deputy: E. Fredrickson)

April 9-15 was a very productive week. Lithium evaporation was used to support all XPs this week. Excellent progress was made on all six XPs that were run this week.

On April 9, XP-827(09), "LITER Characterization and ELM Mitigation -H. Kugel" was completed. Starting on April 8, a total of 49 LITER deposition sequences were applied for 10 or 8 minutes each, at selected rates from 16 to 50 mg/minute, yielding a total deposition on the lower divertor plasma facing components (PFCs) of about 21g. Data were obtained for high elongation and low elongation discharges. As the net lithium deposition increased, the high elongation discharges, relative to the pre-lithium reference discharges, became increasingly ELM-free, and finally, became ELM-free. In addition, the discharge pulse length, with lithium wall conditions and RWM applied, increased to about 1.2 sec, and the OV/CIII impurity ratios decreased below those following boronization, and approached the 2008 levels. A high elongation, H-mode, discharge was obtained with 1 MW NBI (1.8 MW total) with Tau-E of about 100ms. HeGDC was reduced from 10 minutes, to 6.5 minutes, to 4 minutes, and then 0 minutes, thereby allowing the duty cycle to be increased significantly. Finally, for two different conditions, low elongation discharges were obtained that closely reproduced the same 2008 ELM-free discharges.

On the morning of April 10, the H-mode portion of XP-903 "Error field threshold studies in high-beta plasmas – J-K. Park (S. Gerhardt)" was successfully completed. n=1 fields were

applied to the plasma with varying polarities, application times, and ramp rates, and the values of the plasma density and normalized beta at the time of mode-locking was documented. These scans were repeated for three target discharges designed to provide a scan over normalized beta. Previous measurements in low-beta ohmic plasmas showed that the error field required for mode-penetration scaled with the density. Initial results from XP-903 show that at high beta, this scaling fails, with error-field penetration occurring at significantly lower applied field than expected from the previous scaling. It is likely that amplification of the error field by the high-beta plasma is playing an important role.

On the afternoon of April 10th, XP-937 "Impact of improved confinement with lithium on scenario development – D.A. Gates" was run for approximately 2 hours. The goal of the XP was to investigate whether the recently observed confinement improvements could be extended to higher field and current. During this XP, a record stored energy of 450kJ was achieved using 6MW of heating power in a strongly shaped plasma (kappa = 2.4, delta ~ 0.6) with a plasma current of 1.3MA and toroidal field of 0.5kGauss. The previous record of 430 kJ was set at 1.4MA with 7.3MW of heating power. Planned future experiments will investigate higher currents and powers and also the dependence on magnetic X-point balance.

On the morning of April 13, XP-917 “FIDA Validation – W. Heidbrink” was conducted to validate measurements by the fast-ion D-alpha (FIDA) diagnostic. Calculations indicate that there should be marked differences in the blue and red-shifted FIDA spectra caused by two special features of the ST: large poloidal field and large fast-ion gyroradius. To avoid fast-ion instabilities that might alter the FIDA spectra, the experiment used modulated neutral-beam injection at reduced voltage (65 kV). Good FIDA and NPA data were collected during scans of the toroidal field and of the plasma current.

On the afternoon of April 13 and the morning of April 14, XP909 “Dependence of L-H power threshold on X-point radius – R. Maingi” was run. The L-H power threshold was measured as a function of triangularity at comparable elongation, Ip and Bt. It was found that the lowest triangularity ~ 0.4 had the lowest P_LH ~ 1.1 MW, which increased by ~ 100% at the intermediate (0.55) and highest triangularity (0.7). These results will be compared with XGC-0 code predictions of the ion X-point loss and resulting Er profile.

On the afternoon of April 14, XP902 “Search For the n=3 Error Field Source in NSTX and Implementation of Improved n=3 EF Correction – S. Gerhardt” was run for three hours. A scan over the n=3 applied field at Ip=1100 kA and BT=0.55 T was completed, as was a partial scan at Ip=750kA and Bt=0.45T. These scans will be completed in the coming week.

On April 15, the first portion of XP916 “Study of TAE and TAE-induced fast ion transport in L-mode, center-stack limited deuterium plasmas – M. Podesta” was run. A good baseline scenario with center-stack limited, L-mode plasma was achieved. Then, n=3 braking was introduced. An optimal value for the SPAs' current of 1kA was identified for the TF=5.5kG, Ip=900kA case, leading to a period of ~50ms with essentially no plasma rotation. TAE modes and TAE avalanches were reproduced by adjusting the NB timing/voltage. Similar conditions were reproduced for TF=4.5kG and Ip=750kA. The remaining density scan portion of the XP will be completed on a later date.

Engineering Operations (A. von Halle, C. Neumeyer)

NSTX continued plasma operations to this week, utilizing lithium evaporation via the two LITER probes, neutral beam injection including beam modulation, and the machine's error field

coils in experiments requiring TF field to 5.5kG. In addition to improving energy confinement and providing reliable access to sustainable H- modes, the use of lithium evaporation has greatly reduced the amount of glow discharge cleaning needed between discharges, thereby increasing the machine's rep rate. The two LITER probes were taken out of service this weekend to be refilled, and will be ready for operation early next week. The NSTX Test cell will be in restricted access this coming week during plasma operations. Extended run days (to 7PM) are planned for Tuesday and Thursday this week.

Research Operations (M. Bell)

Boundary Physics Operations (H. Kugel)

• Liquid Lithium Divertor (LLD)
- A teleconference was held with SNL and PPPL to discuss LLD progress and planning. (M.Viola)
- The molybdenum coating vendor received the following LLD brazed copper samples: a 2" x 8" flat sample from PPPL, a 8" x 10" curved sample from PPPL, and flat 4" x 4" sample from SNL. The samples are schedule to be flame sprayed with molybdenum mid next week in three runs, and then shipped to PPPL for testing.
- Preparations for testing the samples at PPPL are in progress.
- Pictures of the Control Rack assembly at SNL were received. It is on schedule for shipping 5/05/09.
- By agreement with SNL, the Control rack programming at SNL will stop at this point, and be resumed at PPPL after the Control Rack arrival so that it can be tested with the actual hardware.

• Lithium Evaporator - LITER 2009
- Preparation of lithium material and procedure requirements for reloading LITERs this weekend was completed. (J. Winston, J. Timberlake)

• Lithium Dropper (D. Mansfield)
- Unit-2 is loaded with lithium powder and has achieved a satisfactory vacuum base pressure in preparation for calibrations prior to installation during the next maintenance period. (D. K. Mansfield)

• Edge Sample Probe
- Samples exposed during XP-911 were received at Purdue University (J.P. Allain) and are being analyzed. (C. H. Skinner)

The General Atomics NSTX Research Participation Update (R. La Haye)

RMP ELM Control Coil Modeling (T. E. Evans)

Work done consisted of: 1) developing a new FORTRAN 95 version of the TRIP3D field line integration code needed for modeling field line loss fractions associated with various NSTX

RMP coil options and 2) calculating spectral features for a set of Front Surface Primary Passive Plate RMP coils (FSPPP Coils) being considered as an option for the NSTX RMP coils.

A new, modularized, version of the TRIP3D (TRIP3D95) field line integration code was developed to facilitate rapid calculations of field line loss fractions. We are in the process of parallelizing this version of the code and adapting it to run on a Graphical Processing Unit (GPU). Standardized tests of the TRIP3D95 code, when compared to the original FORTRAN 77 version of the code (TRIP3D77), have resulted in a factor of 3 reduction in the execution time when run on an 8 processor Linux workstation. Preliminary tests of a parallelized GPU version of the subroutines that involve the most cpu intensive part of the code (the Biot-Savart field calculations) indicated an increase in the speed of the code by a factor of 20 to 50 depending on the number of field lines integrated. Based on these results a simplified version of the TRIP3D95 code was converted to run on an nVidia GeForce GTX 280 (1024 Mb) GPU. Initial tests of this version using double precision accuracy resulted in a reduction of the computational time by a factor of 3.5 when integrating 1000 field lines and a factor of 11.4 when integrating 16000 field lines. It was also found that, single precision GPU calculations are approximately a factor of 4 faster than double precision GPU calculations. A Dell XPS 630 tower workstation, with a dual core Intel E8400 CPU (3.0 GHz, 6 Mb, 1333 FSB), was ordered in February along with an nVidia GeForce GTX 280 GPU card that will be installed when the machine arrives.

Additional work is currently underway on implementing a fast prototyping algorithm in TRIP3D95 that will be used to model and compare various coil designs. An optimized GPU version of the TRIP3D95 code will be developed for detailed field line loss studies. The parallelized version of the code is critical for field line loss studies associated with coil design prototyping because a single high-resolution simulation takes approximately 120 cpu hours when run on our 8 processor Linux workstation. Our goal is to reduce this run time to less than 5 hours with the optimized GPU version of the code.

A set of 6 NSTX equilibrium files was generated covering a range of elongation, triangularities and safety factor profiles. These files were used for modeling studies of a two-row Front Surface Primary Passive Plate RMP coil set (the FSPPP coil set) with 12 loops per row. The dimensions of these coils were optimized to fit in front of the existing primary passive stabilization plates on NSTX. Preliminary TRIP3D77-SURFMN runs were completed for odd and even parity configurations using a low q_{95} (= 5.5) discharge (123662, t = 380 ms) with k = 1.9 and dRsep = -0.6 cm. It was found that the best n = 3 coil configuration for this discharge is odd parity. With 1 kAt of current in the upper and lower row of coils, the Chirikov parameter exceeds unity between y_N = 0.87 and 1.0 in this case. Figures showing the Chirikov parameter profiles, total surface normal RMP field just inside the separatrix and a contour plot of the n=3 polodial Fourier spectrum were sent to several members of the NSTX group who are collaborating on the coil design and discussed during conference calls held on February 3rd and 26th. Comparisons of odd and even n=3 RMPs were also done for a discharge (125006, t = 343 ms) which has a higher q_{95} (= 13.0) and k = 2.6 with dRsep = -0.8 cm. In this case, the Chirikov parameter exceeds unity between y_N = 0.672 and 1.0 with odd parity and exceeds unity between y_N = 0.689 and 1.0 with even parity although the Chirkov profile in the even parity case indicated a significantly higher level of stochasticity across the entire edge region than in the odd parity case. These results need to be confirmed with detailed field line loss fraction calculations using TRIP3D95-GPU once the code is running, verified and benchmarked against TRIP3D77. Other modeling activities during this period included preliminary n=3 shape/elongation/triangularity optimizations studies and

some initial modeling of several n=6 FSPPP coil cases using NSTX equilibria that provided the best match to the n = 3 perturbations.

During 2009 and 2010 we will continue the development, optimization, validation and benchmarking of the TRIP3D95-GPU version of the code and initiate field line loss fraction calculations of the most promising configurations found with the TRIP3D77 code. We will continue using the TRIP3D77 code for optimization studies of the FSPPP coils as a function of squareness, beta normal and dRsep. In addition, we will compare the FSPPP coils to other internal and external coil options using optimized equilibria from the TRIP3D77 modeling studies discussed above.

H-Mode Edge Pedestal Stability (T. Osborne)

Pedestal Analysis Software

Several enhancements and updates were made this year to the H-mode pedestal analysis software which was installed at NSTX in 2007. The ability to combine ELM synchronized data from several similar discharges was added to the profile reconstruction and EFIT equilibrium fitting. This improved the resolution of pedestal pressure and current density profiles needed for edge stability analysis. Rotational energy terms in the equilibrium force balance, which are important in NSTX, were added to the equilibrium reconstruction. A major upgrade to the software was driven by the switch to 64 bit LINUX operating systems on the NSTX data analysis computers. The main array analysis package was found to be unusable at 64 bit requiring conversion of most of the higher level software to use a more modern array analysis package.

Analysis Results

A number of NSTX discharges were analyzed for edge stability using the pedestal analysis toolkit. In particular the results of the Lithium wall coating experiments were analyzed. With Lithium coating ELM free periods of up to about 0.3 sec appear accompanied by improved energy confinement. The ELM free periods are terminated by a global MHD event with the characteristic of a resistive wall mode rather than an ELM. The toolkit was used to produce equilibrium for edge stability analysis of pre-Lithium ELMing discharges and ELM free post – Lithium discharges. This analysis indicates improved edge stability in the post-Lithium discharges as a result of broadening of the pedestal density profiles. A Physical Review Letter was submitted covering the pre to post-Lithium stability comparison. ELITE stability analysis of ELMing cases indicates that the edge peeling-ballooning mode growth rates are typically significantly below the usual threshold value of ½ the ion diamagnetic frequency. The ½ ω_{*I} threshold shows good consistency with results from higher aspect ratio tokamaks such as DIII-D.

Plans for 2009 and 2010

We will expand the range of edge stability analysis of NSTX discharges. We have proposed an experiment for operating NSTX at reduced triangularity, which should strongly reduce the edge stability, and look for changes in the pedestal and ELM structures. We would also like to add the ability to use density profiles from the reflectometer diagnostic in the profile reconstruction.

Plasma Control (D.A. Humphreys)

The broad goal of the NSTX plasma control task is to implement a multivariable model-based controller on NSTX. To support this goal, the task includes developing improved understanding

of fundamental NSTX control capabilities, as well as developing appropriate models for the planned controller design. Previous work studying NSTX identified potential areas for which the linear GA TokSys control models routinely used for tokamak control design may not describe the NSTX system accurately. In particular, the need for models of plasma control effects of nonrigid plasma responses, nonaxisymmetric conducting structure, and complex power supply dynamics was identified. As a result, NSTX plasma control task work over the last year has included:

- Development of a new nonrigid model of the linearized plasma response to enable investigation of the role of nonrigidity in NSTX axisymmetric mode control;

- Study of fundamental NSTX controllability issues in terms of standard axisymmetric stability performance metrics, including maximum controllable displacement (Fig. 1);

- Adaptation of GA TokSys nonaxisymmetric structure modeling tools to enable application to the NSTX configuration;

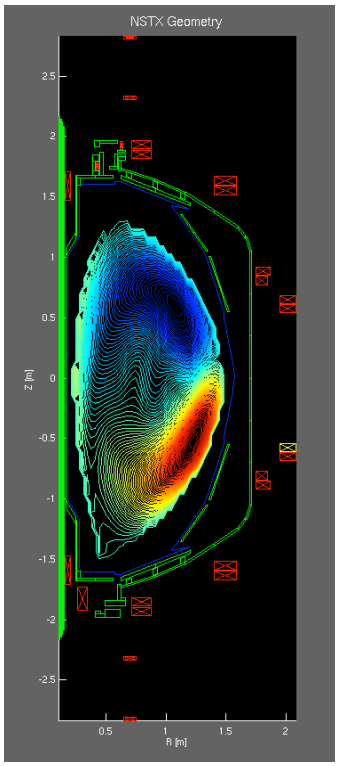

Fig. 1 An example of calculated nonrigid plasma response in NSTX caused by current change in a coil (marked in yellow). The contour plot shows how current density is shifted in the plasma with red meaning increase and decrease in current density)

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Planned Work in the Coming Year

NSTX plasma control modeling and design work planned for next year includes:

- Comparison of nonrigid plasma responses to NSTX vertical displacement event equilibrium data to study the degree of nonrigidity in the evolving unstable mode;

- Further study of controllability boundaries, in concert with improved power supply models and nonrigid plasma response;

- Initial design of controllers and study of robustness characteristics in the event of plasma response variation consistent with the difference between rigid/nonrigid models and nonaxisymmetric/axisymmetric-equivalent conducting structure models.

NTMs and the Effect of Non-Axisymmetric Fields (R.J. La Haye)

An XP (914) was written and discussed in the MHD stability group but not yet been given a final review, "NSTX and DIII-D Aspect Ratio Comparison of NTM Physics". It is planned to destabilize an m/n=2/1 neoclassical tearing mode in each discharge during the rise in beta and switch phases to beta ramp down.
While information on the beta for destabilization is useful (to be coordinated with XP-915 R. J. Buttery et al), the key points here are the conditions for the saturated NTM (before power and thus beta ramp down) and the marginal point at which self-stabilization occurs. The effect of rotation on the saturated condition will be obtained by varying the rotation with n=3 magnetic braking.
Previously in NSTX (2008) mode locking occurred before stabilization. This will be avoided in part by starting with both better n=1 and n=3 error field correction. The saturated island width in the low aspect ratio NSTX can be compared to data in the large aspect ratio DIII-D; this allows evaluation of delta' and DR (curvature) terms. The marginal island width comparison will help check the physics of the small-island stabilizing effects, important both for destabilization, and for stabilization by radio frequency current drive. Matching experiments in q95~7 shapes similar to NSTX have been completed in DIII-D in February in which there are now 3 cases of m/n=2/1 and 2 cases of m/n=3/1 saturated modes with beta ramp downs to marginality.