Issues Regarding Divertor, Scrape-Off layer, and Fueling

Working Group V
National Spherical Torus Experiment Research Forum
February 5-7, 1997, PPPL

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The discussions in WG5 concentrated on two major topics: (1) the NSTX divertor configuration, aimed at providing input to the NSTX design team, and (2) the NSTX plasma boundary physics and fueling program, including a base program and individual program proposals.

1. Summary of the discussion on the NSTX divertor configuration

The NSTX divertor configuration is still evolving and the working group discussed possible options for implementing a pumped divertor configuration. The main boundary conditions for designing a pumped divertor for NSTX are the available space in the vacuum vessel and the plasma equilibria that need to be accommodated. Neil Pomphrey discussed the range of equilibria and modifications of the stabilizer plates which should be possible without severely affecting the desired range of plasma operations.

After some discussion by the group, it was clear that it would be desirable at this stage to leave the maximum configurational flexibility for the first phase of NSTX operation and install a pumped divertor, which can be optimized for a small range of configurations only, after adequate operational experience. The working group came to the following consensus:

- Based on existing experimental experience, especially on DIII-D, divertor pumping is highly desirable for plasma and neutrals control (e. g. for non-inductive current drive or high-density operation).
- However, a pumped divertor configuration will impose restrictions on the configurational flexibility of NSTX and it would be premature to install it for day-1 operation, before having explored the most likely and successful configurations.
- Therefore, it is recommended to start with the most flexible divertor configuration which retains the full configurational flexibility to allow full exploration of the NSTX capability.
- After sufficient operational experience, it will become clearer which configuration is optimal for plasma performance and should be adapted for divertor pumping.
- The working group recommends a design study (group of 3-4) to explore different options for a pumped divertor. Among other, to be determined objectives, the study should include:
    - an evaluation of the expected pumping and power handling performance by plasma-edge and neutrals modeling,

- an assessment of the possible impact of configuration modifications on other operational aspects (e. g. stability), and
- an engineering assessment of the modifications to the in-vessel components.

- In order to avoid major changes to the in-vessel components later, some features of a future pumped divertor may have to be implemented into the design as soon as possible.
- Therefore, it is recommended to proceed with the design study immediately.

2. NSTX Plasma Boundary Physics and Fueling Program

In the discussion of the NSTX boundary and fueling program it was pointed out that the NSTX edge program should not simply repeat the major issues addressed by divertor programs on present machines, but emphasize specific aspects of spherical tori (ST), in particular, transport in the plasma boundary. This was generally agreed upon, however, it was also pointed out that the fundamental characterization of the edge plasma is a needed prerequisite before progressing to the more specific ST issues. Furthermore, there are operational requirements on the plasma boundary program such as, for example, measurement and control of the power fluxes to the plasma-facing components (PFCs).

In order to cover the needed elements of a base program in addition to the individual program proposals, the program discussions were organized in two major categories: A) base program and B) individual program proposals. Of course, the ideal match would be if the individual proposals covered the needed program elements of the base program. The following is a strawman listing of the major elements that should be included in the base program.

A. Base Program

- **Basic Divertor and SOL Characterization**
  - temperature and density profiles; midplane and divertor
  - measurements of power flux profiles in the divertor
  - characterization of neutral fluxes (H-alpha)
  - studies of basic edge transport mechanisms in NSTX

- **Specific Spherical Torus Aspects**

- investigations of mirror effects and trapped particles in the SOL
- effects of connection lengths on temperature gradients along field lines
- development of expanded boundary operation of IW-limited plasmas
- plasma edge instabilities and transport mechanisms in ST configurations

- **<u>Particle Control</u>**
  - development of fueling scenarios for improved plasma performance
  - application of divertor pumping for plasma and neutrals control
  - studies of plasma-surface interactions in support of confinement improvement
  - development and application of wall conditioning for optimized plasma performance
  - studies of impurity generation and transport mechanisms
  - evaluation of neutrals and impurity effects on confinement

- **<u>Power Handling</u>**
  - characterization of power fluxes in different divertor configurations
  - evaluation of power deposition in IW-limited configurations
  - studies of power flux limitations for high-recycling divertor operation
  - exploration of power flux reduction with radiative divertor

B. Individual Research Proposals

<u>Divertor and Boundary Plasma Characterization and Physics Studies</u>

The following proposals were discussed during the working group session:

1. Rajesh Maingi and P. Mioduszewski, ORNL

<u>Baseline Plasma Boundary and Divertor Characterization</u>

The objective of this proposal is the baseline plasma characterization in double-null divertor (DND) and inner-wall limited (IWL) configurations. The goals of the program are to ensure that damage to the divertor tiles is prevented and to avoid a limitation on the pulse length from divertor tile temperatures in excess of 1500 K. In the event that the heat flux limits pulse length, we propose to develop techniques to reduce the peak heat flux to acceptable levels (e.g. gas injection, “puff and pump”). Due to the smaller major radius in spherical tokamaks, the deposition area for power flow to the wall can be quite small compared with conventional tokamaks. 0-D and 1-D SOL transport models predict a peak heat flux between 7-15 MW/m^2 at 6MW input power; the highest heat flux will limit the pulse length. This baseline characterization is needed to prevent damage to the tiles in the cases of high input power. Diagnostics needed include IRTV's (inner wall and divertor target), target Langmuir probes, a midplane reciprocating Langmuir probe, bolometry with 2-D reconstruction capability, and a measure of dW/dt for power balance. Impurity density profiles will be necessary to evaluate heat flux reduction techniques, if needed.

2. M. Finkenthal, Johns-Hopkins

We propose to address topics related to the following three areas of research identified by the WG5:

1. Investigation of specific ST aspects

• Particle transport 5-10 cm inside the separatrix and in the SOL, using a radial array of multilayer mirror (MLM) based cameras for CVI (34 A) and C V (40 A) line emission. The spatial resolution will be 1 cm or better at the outer edge, and 1-2 cm at the inboard side. The time resolution will be 0.1 ms.

• MHD activity at the edge using a fast (XUV filter based) 2-D camera with frequencies in the 10 kHz - 100 kHz range.

2. Basic SOL and Divertor characterization

• Space and time resolved T_e measurements based on XUV $Ly\alpha/Ly\beta$ emission of intrinsic carbon.

3. Particle control

• local impurity density distribution and radiative losses from all charge states of carbon. The resonance lines of CV/CVI will be measured with MLMs, and the resonance CII, CIII and CIV will be measured with a miniature Rowland mount spectrometer.

3. F. C. Jobes and N. L. Bretz, PPPL

Edge Density Imaging on NSTX

An edge density diagnostic, the Imaging Second Harmonic Interferometer (ISHI) is being developed for C-MOD, and it could be adapted (mostly copied) for NSTX divertor and/or SOL. For C-MOD, the design goal is to make 50 spatially contiguous measurements over the outer 50 mm of the plasma with a resolution and separation of ~1mm, a 10 kHz repetition rate, and a line density resolution of <7 10^{17} e/m^2. (The separation and resolution on NSTX would be ~1.5 mm.) If the array of sight lines is in a horizontal plane, the data can be inverted by an Abel inversion about the centerline of the device. This diagnostic is a special type of optical two color interferometer (1064 & 532 nm), in which any motional or vibrational effects are exactly null. The device for C-MOD is being developed by a small business under an SBIR: phase 3 of the SBIR, if it's awarded, will be to build and deliver the device.

4. S.J. Zweben, PPPL

Studies of Edge Turbulent Transport

The edge turbulence of NSTX will be an important factor in determining the core plasma confinement through the L-H transition, and the plasma-wall interaction through the scrape-off layer width. The unique parameters of NSTX will also allow a unique test of the existing theories of edge turbulence, e.g. the nature of turbulence suppression by shear flow at the L-H transition, and the effect of high beta on magnetic turbulence near the edge. Experiments on NSTX should aim to develop a fundamental understanding of the physics of the edge turbulence, and to use this knowledge to invent reactor-relevant techniques to actively control the L-H transition threshold and the scrape-off layer thickness. These techniques could include: RF generation of Reynolds' stress near in the edge plasma, edge biasing to create radial currents, and control of the beam ion or RF minority tail ion loss processes. The relevant diagnostics for edge turbulence include Langmuir probes and fast 2-D imaging of visible emission from edge species.

5. H. Kugel, PPPL

NSTX Divertor and Edge Diagnostics

NSTX Divertor and Edge Diagnostics are required to facilitate safe operation and allow the through characterization of divertor and edge physics.

The proximity of the inner edge to the vessel center column, the effective locations of the strike-points and x-points in the divertor regions, and outer edge interactions with passive plates, RF antennas, and edge probe place severe requirements on edge diagnostics to facilitate safe operation. This will require real-time monitoring of power deposition, edge, strike-point and x-point locations, and all edge interactions with vessel hardware.

These requirements and associated issues involving the unique aspects of the NSTX divertor and edge physics also require suitable diagnostics to allow a through characterization of the divertor and edge physics. Physics characterization involves documenting and understanding power handling, particle influx and entrainment, neutral and particle density, and other divertor and edge plasma processes.

Table 1 shows recommended basic NSTX Divertor Diagnostics for facilitating safe operations and allowing the characterization of divertor and edge physics. These diagnostics are either relatively inexpensive and/or are available for NSTX. Other important diagnostics for addressing these issues are listed at the bottom of Table 1.

Table 1. <u>NSTX Divertor Diagnostics to Facilitate Safe Operations and Allow Characterization of Divertor and Edge Physics</u>

- Recommended Basic NSTX Divertor Diagnostics
    - *<u>Facilitate Operations</u>*
        - Monitor Power Deposition
            - Fast Thermocouple Array
            - IR Camera Viewing
        - Strike-Point and X-Point Positioning
            - Floating Probe Array
            - Local Flux Loops
            - TV Camera Viewing
    - *<u>Physics Characterization</u>*
        - Power Handling
            - Thermocouple Array
            - IR and TV Camera Views
            - Foil Bolometers
            - Water Calorimetry for long pulse
        - Particle Influx and Entrainment
            - H-Alpha / CII Detectors
            - Divertor Region Spectroscopy
            - Filtered Camera Imaging
            - Fabry Perot (flow and species)
            - Gas Injection Manifolds
            - Laser Ablation Impurity Injection
            - B and Li Coating Deposition

- Deposition Thickness Monitor
- Neutral and Particle Density
  - Fast Neutral Pressure Gauges
  - μ-Interferometry
- Divertor Edge Plasma Parameters
  - Edge Probe Arrays

• Other Important Diagnostics

Edge TVTS, Reflectometry, Fast Framing Camera, 2-D Bolometry, X-point Poloidal Rotation

6. R. Maingi and P. Mioduszewski, ORNL

Boundary Plasma and Divertor Transport Studies with Emphasis on ST Aspects

This program has two parts: (A) Comparison of edge and scrape-off layer (SOL) transport with models, and (B) Impact of neutrals and impurities on transport and transport barrier formation.

A. Compare predictions from different transport models with measured SOL widths for heat flux, particle flux, n_e, and T_e in the divertor plasma and n_e/T_e upstream, as done by COMPASS and START. Determine if high mirror ratio enhances edge transport and increases SOL width, decreasing peak heat flux. Also determine if the small SOL connection length inherent in ST's makes it difficult to maintain a high temperature gradient from the X-point (high T_e needed for good confinement) to the divertor (low T_e needed for low heat flux).

B. Determine the impact of neutral and impurity density on main and edge plasma transport and transport barrier formation. If the transport barrier height/width scales inversely with the neutral/impurity scale length which may increase in ST's, then it might be difficult to maintain a hot edge and the accompanying good confinement.

2. Relevance to ST's

A. Power and particle transport in the edge of ST's may be governed by different processes than the classical diffusive type transport in conventional tokamaks. Finding ways to increase the power flux widths and decrease the peak heat flux may be necessary to allow operation in a high beta regime. A comparison with different transport models (i.e. Bohm, Gyro-Bohm, Ideal Ballooning, etc.) would help identify the transport mechanisms and identify techniques to generate broad SOL's

B. Because of the relatively compact design, neutral and impurity penetration into the main plasma may be more efficient than conventional tokamaks; this may limit the height of a transport barrier to be lower than conventional tokamaks. Different theories indicate that the transport barrier height/width scales with different quantities (e.g. ion gyro-radius, neutral/impurity scale length, width of second stability region in the edge, and physical spacing between rational surfaces). The latter 3 terms are all inherently changed from conventional tokamaks in such a way to reduce the pedestal width. On the other hand, dT_e/dr is expected to be higher (due to higher p'), which may offset the geometry effects.

3. Measurements needed

A. High resolution edge/SOL n_e and T_e and profiles near the outer midplane, probably from a reciprocating Langmuir probe; divertor and inner wall IRTV's; Langmuir probes in divertor target; 2-D bolometry and dW/dt for power balance.

B. Fluctuation diagnostics; main chamber n_e and T_e profiles across the plasma column; Langmuir probes on the divertor target; D_α monitors; fast time response neutral pressure gauges in main chamber; impurity density measurement; measurement of neutral density near X-point (LIF?).

7. C. Skinner, PPPL

<u>Turbulence Measurements by Laser Induced Fluorescence</u>

This proposal addresses transport in the plasma boundary. In particular, it describes ion turbulence transport measurements which can be used to challenge or validate existing models on edge transport. Laser induced fluorescence measurements are proposd using a Nd-YAG-pumped Ti Sapphire laser with frequency conversion from 4684 A to 2271 A. The fluorescent light emitted at 90 degrees will reveal turbulent structures in the plasma.

An auxiliary option for this proposal is a modification to H-alpha density and velocity measurements.

Other proposals in the area of diagnostics and edge physics, which were submitted to the working group, but not discussed at the meeting, are:

8. C. E. Bush, ORNL

Bolometry in Support of Divertor, Plasma-Surface Interactions, and General Plasma Physics Experiments

Total radiated power and radiated power tomography will be important on NSTX from day-1. At present, a total radiated power monitor is not included in the day-1 diagnostics package. Several of these, distributed around the torus with good time resolution, should be included. Initial machine startup may be hampered by radiation-dominated (Frad=100%) plasmas. The operator and task force leader needs to know this so as to be able to choose the proper clean-up methods. However, care must be taken when designing the monitor due to the very narrow center column. The single bolometer should be collimated toroidally (un-collimated poloidally) so that it does not see the emission from the plasma on the other side of the center post. The same care must be taken in the design of the bolometer arrays. NSTX has a number of plasma-facing components which may be subjected to intense plasma-wall interaction. These would lead to poloidal asymmetries in the emissivity. Most likely there will be a highly emissive region near the inboard graphite wall similar to what was observed at the inner bumper limiter of TFTR. Also, since NSTX is a very different device, we want to be able to study MARFEs or similar features which may be first time observations of new phenomena.

9. G. R. Hanson, J. B. Wilgen, C. E. Bush, and T. S. Bigelow, ORNL

Reflectometry for Edge and Core Electron Density Profile Measurements on NSTX

Microwave reflectometry has been proven to be a reliable density profile diagnostic on TFTR and PBX-M (ORNL) and on DIII-D (UCLA), and is expected to play a significant role in ITER density profile measurements. On NSTX, reflectometry has the potential to provide both edge density profile measurements for the rf and divertor physics programs, and core density profiles for the general physics program. In addition, reflectometry profile measurements have the potential of being a valuable tool for feedback control. However, NSTX represents a unique situation for reflectometry because of the low magnetic field and its high shear. Because of the low magnetic field, the x-mode cutoff surface is not as spatially differentiated from the o-mode cutoff surface as in typical Tokamaks. The high shear makes the launching of a pure o- or x-mode wave impossible; however due to the low magnetic field, this might not be so important. Additionally, the time variations in magnetic field profile and the radial movement of the plasma during a discharge represent potential problems that need to be addressed. Due to these unique conditions, detailed modeling is required to resolve the questions raised above and identify the optimum reflectometry technique and mode of propagation.

The first step in a reflectometry program for NSTX is to perform detailed modeling and conceptual design work to determine the optimum system and what its capabilities would be. This is likely to be a $25k effort. The second step would be the detailed design of the actual reflectometer system, including the launcher, waveguide and electronics systems, for both core and edge profile measurements. This is likely to cost between $25k and $50k. Additionally, the final design and fabrication of in vacuum hardware should be started at the earliest possible time. Actual hardware and installation costs depend on the number of separate systems (i.e., extent of frequency range that must be covered) required for both edge and core measurements, and the extent to which existing hardware may be utilized.

10. Y. Hirooka, S. Luckhardt UCSD, M. Ulrickson SNL

<u>Edge Physics and Boundary Control on NSTX</u>

The ST plasma boundary and SOL has unique properties that arise at low aspect ratio, these affect divertor operation, edge transport barrier formation and properties. Plasma materials interaction (PMI) including wall conditioning and center post erosion, heat loading and RF coupling will require boundary plasma measurements and controls. We propose to deploy two scanning (reciprocating) SOL/edge plasma probes for ST boundary physics measurements and wall conditioning experiments for impurity and edge control. The probes will be located in the divertor region and in the midplane region of NSTX. They will provide spatially resolved measurements of SOL/edge density, electron temperature, potential, electric fields and flows as well as local turbulence and particle transport characterization. The UCSD group has extensive experience with this diagnostic including experiments and associated modeling on DIII-D, TEXTOR, PBX-M, and PISCES. The second part of our proposal addresses the need for wall conditioning and preparation including boron and/or lithium coating/ conditioning of the NSTX wall. We propose to deploy a wall conditioning boron/lithium source in the NSTX boundary. In the following we summarize the needs for and capabilities of these probes.

Summary of Edge/SOL physics issues addressed by the proposed scanning probe diagnostics and boron/lithium conditioning experiments.

1. The ST/NSTX has unique SOL/edge characteristics and transport barrier formation properties.
2. Very little is currently known about the PSI/PMI behavior in the ST center post/divertor.
3. High wall loadings are expected because the ST has small center post and generally a minimized surface to volume ratio (for a given major radius).
4. The wide variation in magnetic curvature in the edge and the large divertor flux expansion ratio will affect the SOL and edge characteristics including turbulence and flows.
5. Poloidal transport and flow asymmetries may be large.
6. ST may have enhanced poloidal flow shear, transport barrier formation compared to tokamaks.
7. Edge and SOL plasma characterization needed to optimize RF antenna coupling.

Summary of proposed UCSD/SNL/PPPL boundary diagnostic and conditioning experiments:

SOL/TRANSPORT BARRIER CHARACTERIZATION

- MIDPLANE SCANNING PROBE ($n_i(x)$, $T_e(x)$, $\phi(x)$, $\delta n(x)$, $\delta f(x)$, $E_r(x)$, $E_r'(x)$,$\Gamma_p(x)$,Mach(x))
- DIVERTOR AREA SCANNING PROBE (compare with midplane, divertor/SOL modeling)
- SCANNING OPTICAL PROBE (Out-year upgrade to scanning probe diagnostic set. Edge spatial and temporal resolution of impurity density profiles)

CENTER POST and WALL CONDITIONING

- Solid target boronization (STB) and develop solid target “Lithium-ization” (STLi).
- Erosion/deposition coupon array (center post, divertor, and outer shell).
- Flush mounted probe array for PMI/SOL characterization.
- Appropriate spectroscopy and IR camera for surface temperature of center post/divertor.
- Particle fuel and recycling diagnostics(H-alpha monitors, Neutral gas (ASDEX) gauge, RGA)
- Modeling with DEGAS-FMS code (A. Grossman, UCSD).
- Out years upgrades: DiMES - like probe and surface analysis station (in situ Auger and XPS), biasing for edge flow control.

BACKGROUND:

Summary of UCSD/SNL background in edge/SOL physics

_ The UCSD and SNL collaboration has extensive expertise in scanning probe diagnostic techniques TEXTOR, PBX-M, PISCES A&B, and at DIII-D.

_ UCSD/PPPL collaboration has extensive experience in relevant PSI/PMI: solid target boronization (STB) i.e. in PBX-M, lithium conditioning deposition probe experiment (TFTR-96,97), erosion & redeposition processes.

_ Center post armor performance is critical to the success of the ST. Optimum solution has minimum thickness armor providing more space for the TF/OH core. We recommend that erosion rates and heat fluxes on the center post be monitored during NSTX operation, moreover modeling of the plasma boundary interaction is needed. UCSD has unique modeling tool the DEGAS-FMS-CAD code permits exact wall and divertor CAD boundaries to be specified.

_ Electrical biasing was the subject of a major collaboration between the UCSD group and PPPL on the PBX-M tokamak. Biasing may be of value in NSTX for SOL, edge transport, and edge flow control. The presence in NSTX of the electrically isolated center post and the outer shell will facilitate edge biasing. We recommend continued evaluation of this topic for the ST.

SCOPE OF WORK:

1. Install and operate midplane and divertor scanning probes for edge plasma, transport barrier, and divertor flow. Interact with boundary modeling efforts.

2. Implement wall conditioning and erosion control techniques (e.g. STB, STLi) to improve wall and plasma performance.

3. Monitor plasma wall interaction including centerpost by means of heat and particle load diagnostics, material coupons, and possibly DiMES-like probes.

RESOURCES:

UCSD: One post-doctoral scientist and one graduate student on site, visiting by Dr.s Y. Hirooka, S. Luckhardt, UCSD designed compact scanning probes, UCSD designed solid target probes (B and Li), probe electronics, and analysis packages, and other hardware. The UCSD PISCES A&B facility availability for development of lithium coating system.

Particle Control and Plasma-Surface Interactions

11. G. Schmidt, PPPL and S. Milora, ORNL

Fueling Scenarios for NSTX

NSTX plasma offers a new plasma regime which should be approached with an array of fueling techniques. Fueling by all the standard techniques should be available to exploit this new regime fully. Techniques which are suitable are Gas puffing, NBI fueling and Pellet injection. Because NSTX is a relatively large low field device, this configuration could also serve to explore the physics of core particle deposition using compact torus injection.

Of these techniques, pellet fueling was considered in detail. NSTX plasmas are well matched to existing pellet technology. Several aspects of NSTX plasmas are particularly well suited to pellet fueling.

Moderate electron temperatures allow both deep and shallow pellet fueling to be achieved thereby permitting density profile control and peaking to be obtained. Beam target plasmas can be obtained with high fueling efficiency. Deep fueling allows access to a high core confinement regime demonstrated on standard tokamaks in plasma heated by NBI + RF and by RF alone. If this regime is obtainable in NSTX high β could be obtained early in NSTX operation.

In addition the potential for suppression of core turbulence shown by Rewoldt et al [PoP 1996] means that NSTX plasmas might easily transition to other advanced core confinement regimes for which particle sources within the barrier region are essential for efficient fueling. The pellet source function would be one such source. In this regard, the existence of a magnetic well in the ST configuration and, more importantly, its low aspect ratio will allow NSTX to fully exploit a recent phenomena demonstrated on Asdex-U that results in deeper pellet penetration and improved retention of deposited fuel.

The ST configuration based on the START result [IAEA - Montreal 1996] appears well suited to high density operation. Pellet fueling has extended density limits in standard tokamaks and would be well suited for similar experiments in NSTX. Interaction of pellets with Internal Reconnection Events (IRE) observed at the density limit in START could be an important aspect of these experiments.

Finally, given the potential for improved core confinement at low aspect ratio, use of pellets as one of several perturbation techniques should be available to study particle transport in this new regime.

12. C. Skinner, H. Kugel, D. Mansfield, PPPL and J. Hogan, ORNL

Surface Modifications in NSTX

Much of the improvement in plasma performance in the last decade has come from better control of plasma surface interactions - for example: boronization at C-mod, supershots on TFTR. Low neutral densities near the main plasma are important for good energy confinement. Lithium conditioning has proved to be a powerful tool to control edge temperatures and densities. 'Pumping' by conditioned walls may help prevent leakage of neutrals from the divertor back to the main plasma.

We propose to 're-aim' the ~$0.5m lithium laser deposition system 'DOLLOP' to interface with NSTX. This device is currently being tested on TFTR and is already in place on the future NSTX site. The access port on NSTX needs to be specified and machine interface designed.

13. H. Kugel, PPPL

NSTX Wall Conditioning with Boronization

Boronization has had a profound impact on the plasma performance at C-Mod and is used to suppress oxygen and hydrogenic impurities after vacuum openings on TFTR. The NSTX high duty cycle (>100 discharges per day) which will result in the rapid erosion of deposited films. It is desirable for efficient operations to minimize frequent and inconvenient interruptions in operations for redeposition and baking. The Boronization options for NSTX involve Chemical Vapor Deposition (CVD) of boron during maintenance periods, and real-time boronization during plasma operations.

CVD of boron has been performed on various devices using several different boron compounds. Diborane [B_2D_6] , although explosive, pyrophoric, highly toxic, and requiring of special procedures such as weekend application with a Fire Truck present, is the simplest of the practical boranes, and minimizes issues of D and H co-deposition. Diborane is available at the NSTX Site. Trimethylborane [$B(CH_3)_3$] is less pyrophoric and less toxic. Carboranes [$C_2B_{10}H_{12}$,.. $C_8B_{10}H_{14}$,..] are safer, but also involve the issues of co-deposited C, H, and complex radicals. Decaborane [$B_{10}H_{14}$] is being used successfully on JT-60, and off-line experiments were performed for its use on PBX-M. The deuterated form may become available commercially.

Boronization during plasma operations has been performed using boranes as fuel gases with the attendant issues of the unwanted co-deposition of C, H, and complex radial compounds. PBX-M has performed real-time boronization 31 times using Solid Target Boronization probes containing boron powder loaded in graphite-felt matrix. Real-time solid target boronization was found to be very effective for accelerating conditioning to new regimes and for achieving and maintaining high performance plasma conditions.

14. C. Skinner, H. Kugel, PPPL and J. Brooks, ANL

Plasma-Surface Interactions in NSTX

Plasma surface interactions are a critical issue in fusion power development. The condition of the surface of plasma facing components (PFC's) profoundly influences the plasma performance. However, researchers are highly uncertain as to the details of the surface. A promising initiative is the DiMES probe at DIII-D, where a retractable PFC is used for studies of erosion, redeposition. The results are used to benchmark codes used to predict erosion, plasma contamination, and tritium co-deposition for ITER. Small, accessible devices like NSTX can be used to study key PSI-related phenomena such as sheath structure, sputtering, and near-surface impurity transport/redeposition. Specific issues arising from ST magnetic field topology are hard to predict in advance (the effect on TFTR supershots was not predicted in advance), however ST reactors will challenge the limits of materials as much or more than large devices.

We propose to install a retractable PFC in the passive plate or other location, to provide an empirical link between improvements in plasma performance and the surface condition of PFC's. The data will aid the scientific understanding of the influence of PFC's and indicate routes for further improvement in plasma performance. Other desirable diagnostics are: quartz crystal oscillators to monitor deposition on PFCs, fast thermocouples to monitor the incident power, Langmuir probes. Gas balance diagnostics are important too - monitor of gas input, RGA, mass spectrometers on exhaust, sampling for off-line analysis, pressure measurements.

Other proposals in the area of particle control and PSI which were not discussed at the meeting, but also submitted to the working group, are:

15. M. Ulrickson, SNL

Scrape-off layer characterization for NSTX

The scrape-off layer in a spherical torus may be very different from that in a conventional tokamak because of the unique magnetic topology in an ST. There is a great deal to be learned from understanding the physics of the edge plasma in an ST. Sandia has collaborated with ORNL and UCSD on a variety of tokamaks (e.g., DIII-D, TEXTOR, Tore Supra) We are proposing a collaborative effort among Sandia, Oak Ridge, and UCSD. The scrape-off layer (SOL) would be measured using an array of surface mount probes. These probes are solid state devices capable of determining the flux and energy of particles striking the walls (atoms and ions). Such probes have been used on many past and existing toroidal confinement devices. No development is needed for application to NSTX. New developments in microprocessors are making it possible to perform processing of data from probes before that data is sent to external recording instruments. These smart probes reduce the data reduction time and increase productivity. We will attempt to incorporate such technology in probes for NSTX. The data from the probes would be used by ORNL to develop models of the scrape-off layer. Our existing collaboration with UCSD on DIII-D will be used to enhance the effort by applying lessons learned from the application of probes to a tokamak.

Sandia also has extensive capabilities in the area of surface analysis and characterization. Most of the equipment was purchased by other programs and is offered to the fusion effort at no extra charge. The capabilities include external ion beam analysis (including Rutherford backscattering, proton induced x-ray analysis, and nuclear reaction analysis for deuterium content). Metal contamination on graphite surfaces can be measured using beta backscattering (also carbon coatings on metals). Secondary ion mass spectroscopy, Raman scattering, Low energy electron diffraction, and Auger electron spectroscopy are available to determine the chemical state of materials on surfaces. All of these capabilities have been used on samples from various tokamaks to study surface conditioning and measure erosion and trapping of hydrogen isotopes on surfaces. These techniques can be used in conjunction with an erosion probe similar to the DiMES probe on DIII-D.

We designed the moveable Langmuir probes on DIII-D in collaboration with UCSD. These probes have proved very valuable for understanding the scrape-off layer because they can scan the edge region while the plasma is fixed. This permits cross correlation with edge Thomson scattering with constant conditions with respect to interactions with the walls and possible divertor pumps. Moveable probes coupled with fixed Langmuir probes can be provided relatively inexpensively based on the designs for DIII-D. We propose to extend the UCSD collaboration to include NSTX. The data would be shared with ORNL to add to the modeling effort.

Innovative Concepts

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Innovative Power Removal Techniques for NSTX

If STs are ever to develop into compact fusion power plants, new methods will have to be devised to remove the plasma heat from a relatively small area. One innovative idea involves a moving belt limiter [1], in which a flexible carbon belt passes across the divertor strike regions and carries the heat out to a cooled roller. Such a belt could solve several problems at once: increase the heat flux capability of the divertor target plates, avoid the erosion problem by continuously depositing fresh carbon on the belt, reduce retention of Tritium inside the vessel, and provide freshly coated surface for improved plasma wall interactions. Development of a prototype movable belt limiter on NSTX could test this idea for later use on a higher-powered ST or most other magnetically confined fusion devices. Other innovative ideas could be tested on NSTX, such a local magnetic divertor to control the scrape-off layer flow into a divertor baffle, or liquid metal surface coatings.

[1] Snead and Vesey, Fusion Technology 24, p. 83, 1993