Response to Question 4b) from FESAC Panel Feedback to the ST Community

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4) How would the ST program address and resolve the following questions?

   a. Integrated scenarios with steady-state high heat flux and low collisionality: In case of using large NBI power, how does large rotation affect transport and stability, including momentum transport? In case of using large RF power, how should transport and stability be affected without driven rotation? What additional focus will be needed to deal with the more over-dense plasmas for the present and the ST goal? What are the scientific bases for these to extrapolate to the ST goal? [co-author: Masa Ono, Dave Gates]

In case of using large NBI power, how does large rotation affect transport and stability, including momentum transport?

There is a great deal of evidence to suggest that strong plasma rotation driven by angular momentum injection coming from tangential neutral beam injection can improve plasma confinement. (A note: In a recent NSTX experiment on plasma confinement vs plasma rotation, a relatively weak dependence on the plasma confinement with rotation was observed so the situation may not be as simple.) In numerous experiments including MAST, correlations have been drawn between the ExB shearing rate and improved ion confinement, which has been associated with the suppression of ion-temperature gradient mode turbulence. In addition, there is a large body of evidence that indicates that the large scale MHD modes which are observed to be responsible for the ultimate limit to plasma pressure in axisymmetric toroidal devices are stabilized in plasmas which are rotating in the presence of a close fitting conducting boundary.

An important factor in determining the level of plasma rotation that can be achieved for a given level of momentum injection is the magnitude and spectrum of the non-axisymmetric field that is either applied intentionally or exists independently due to imperfections in the construction of the magnetic field coils. Depending on the spectrum of the non-axisymmetric fields, plasma global stability can also be affected.

The ability to modify the rotation profile using the application of neutral beam power as a source of momentum and non-axisymmetric error fields as a sink, coupled with the observed dependence of confinement on the ExB shearing rate raises an intriguing possibility. In particular, one can imagine controlling the pressure profile in a toroidal plasma by tailoring the rotation profile using available tools.

In case of using large RF power, how should transport and stability be affected without driven rotation?

If the bootstrap current and neutral beam driven current are insufficient to provide 100% non-inductive current in the spherical torus additional current drive techniques will be required. RF current drive techniques currently envisioned for the ST include Electron Bernstein Waves and HHFW. EBW has not yet been tried in the ST at power levels sufficient to determine its utility. There is a sizable database for HHFW on NSTX. The HHFW heating has shown strong core electron heating where over 5 keV electron temperature was obtained with HHFW in NSTX. The rotation rates of plasmas heated with RF alone have been measured to be ~1/10 that of plasmas with NBI. (There is some evidence that edge rotation is clamped by the application of HHFW during NB injection possibly due to a change in the edge potential.) The observed HHFW global heating efficiency is significantly less than that of NBI. The reason for the lower heating efficiency maybe two folds. With reduced rotation and reduced ExB shearing, the ion energy transport is worse for HHFW compared to NBI. Also, being dominantly an electron heater, the heating efficiency maybe dominated by the electron transport which is generally much worse compare to that of ions. (With reversed shear, electron confinement is greatly improved inside q_{min} and the core efficiency is increased dramatically.) As a result of the reduced confinement, there is insufficient power on NSTX to reach the ideal MHD beta-limit with RF power alone. The experimental data for reduced MHD beta-limits due to insufficient rotation is therefore lacking.

What additional focus will be needed to deal with the more over-dense plasmas for the present and the ST goal? What are the scientific bases for these to extrapolate to the ST goal?

It should be noted that for a given plasma beta value, the over-dense plasma condition ($\propto n_e/B_T$^2) goes down with the increased magnetic field since n_e typically only goes up linearly with B_T. So for example, compared to NSTX which is running at $B_T \sim 0.5$ T, the future ST devices such as ST-CTF or ARIES-ST running at $B_T \sim 2$ T has about a factor 4 less over-dense condition as NSTX. The primary issue that the ST faces due to having plasmas that are overdense is the challenge of providing RF current drive, so as to be able to tailor the current profile for optimal stability in the presence of large bootstrap current. HHFW has been shown to be able to provide localized on-axis current drive with moderate efficiency. In NSTX, the HHFW performance thus far has been increasing strongly with the magnetic field (say compared to 0.35T to 0.55T). HHFW performance is expected to further improve as the magnetic field is increased (or over-dense condition is reduced) as we move toward future ST devices. In so far as on-axis current drive proves necessary if future ST designs, this tool may be able to provide for this need. However, many designs of future STs require off-axis current drive. EBW has been predicted to be able to provide efficient off-axis current drive. However, the database on using EBW in an ST is extremely limited. If current profile control is indeed required for future STs, it is important that EBW research be performed to confirm the utility of this RF technique for off-axis current drive.