1. Purpose of Experiments

The purpose of this experiment is to determine the effect of a change in safety factor on confinement in Enhanced Dα (EDA) H-modes [1-3], to better understand their stability, and to better diagnose the conditions under which they occur. The idea of the experiment is to dynamically ramp the plasma safety factor during the EDA H-mode to attempt to determine the causes of its stability as well as the limits of its operation. By ramping the plasma current or toroidal field, the q profile can be changed to determine how the location of particular rational q values (e.g., q=4) affects the EDA stability. This mode of operation may be a good compromise for ITER operation and needs to be thoroughly investigated.

2. Background

High frequency fluctuations have been observed during EDA H-mode both on the edge reflectometer signals and on magnetic pick-up coils. The stability of these modes may depend on changes in the edge q [4] and on changes in the location of the edge pedestal gradients with respect to the rational q surface [5]. By modifying the location of the steep gradient with respect to the rational q surface, it may be possible to change the stability of the EDA H-mode. There are also indications that energy confinement improves with lower safety factor. So, by dynamically changing q during a steady-state EDA H-mode, even a small change in confinement with q should be observable during the q ramp.

3. Approach

Describe the methodology to be employed; explain the rationale for the choice of parameters, etc. Describe the analysis techniques to be employed in interpreting the data, if applicable. If the approach is standard or otherwise self-evident, this section may be absorbed into the Experimental Plan.
Start with a well conditioned boronized machine. The ICRF must be running well with high power up to at least 2 MW, preferably more. To ramp q dynamically during a single discharge, the ICRF should be run for up to $\sim 0.8$ sec long pulses so that $I_p$ or $B_T$ can be ramped slowly. By running these longer pulses, the evolution of the EDA H-mode and the energy confinement can be followed when gradually changing q. Plasma current ramps allow q to change without changing the RF resonance and without changing the position of the edge ECE $T_e$ measurements. Toroidal field ramps change q without changing confinement substantially. So, a comparison of these two ways of changing q should provide useful information both on edge stability and on confinement.

To better understand the EDA H-mode, many diagnostics will need to be coordinated to obtain fast fluctuation measurements, edge temperature and density measurements, and plasma rotation measurements. Magnetic pick-up coils need to be set up with fast sampling during the EDA H-mode phase and coordinated with fast edge reflectometry signals. The ECE polychromator is needed to measure edge $T_e$. The edge soft x ray array is also needed to follow the position and steepness of the edge pedestal. The CHROMEX spectrometer should be set to look at the Balmer series to determine how much recombination may be playing a role in the EDA H-mode. The Maryland visible spectrometer should be used to look for poloidal and toroidal flows in the edge. Particle confinement should also be measured with trace impurity injection for several shots. Some repeated shots may be necessary to change wavelengths and to obtain Fast Scanning Probe measurements with notches programmed into the RF pulse during the H-mode. By having a dedicated run for this experiment it will be possible to coordinate these diagnostics to obtain the required data.

4. Resources

4.1 Machine and Plasma Parameters

Give values or range for:

- **Toroidal Field**: 4.5 to 6.2 T
- **Plasma Current**: 0.8 - 1.2 MA
- **Working gas species**: $D_2$
- **Density**: 1.2 - 1.4 x $10^{20}$ m$^{-2}$ L-mode target
- **Equilibrium configuration** (if possible, refer to database equilibria): Lower single null diverted, e.g., 960209014, 960214027
- **Pulse length, typical current & density waveforms, etc.** Refer to database or sketch desired waveforms: Extend pulse to begin rampdown at 1.2 s. See enclosed ramp waveforms.

4.2 Auxiliary Systems

- **RF Power, pulse length, phasing**: 2 - 3 MW for up to 0.8 sec
Pellet Injection (species): none
Impurity blow-off injection: Sc
Special gas puffing: standard valves
Other: This run requires a very clean machine that has been recently boronized.

4.3 Diagnostics
List required diagnostics, and any special setup or configuration, e.g. non-standard digitization rate.

Fast magnetic pick-up coils (500 kHz - 1 MHz sampling)
Edge reflectomter (500 kHz - 1 MHz sampling)
U of Maryland visible spectrometer
McPherson VUV spectrometer
CHROMEX spectrometer setup to view Balmer series
HIREX
Fast D$_\alpha$ array (C-Top)
Fast Scanning Probe
Divertor Langmuir probes
Interferometer
ECE polychromator and Michelson
Core and Divertor Thomson Scattering if available
Edge soft x ray array

4.4 Neutron Budget
Estimate the neutron dose rate at the site boundary. Give basis for estimate. (Once some experience has been gained a standard formula will be provided for estimating dose rates.)

$10^{15}$/day

5. Experimental Plan

5.1 Run sequence plan
Specify total number of runs required, and any special requirements, such as consecutive days, no Monday runs, extended run period (10 hours maximum), etc.

Given a well running clean tokamak shortly after a boronization, one run (25-30 shots) should be sufficient to perform this experiment.
5.2 Shot sequence plan

For each run day, give detailed specification for proposed shot sequence: number of shots at each condition, specific parameters and auxiliary systems requirements, etc. Include contingency plans, if appropriate.

EDA H-modes should be obtained under standard conditions ($B_T = 5.3$ T, $I_p = 1$ MA, $n_{\text{lo4}} = 1.2 \times 10^{20}$ m$^{-2}$, $P_{\text{RF}} \geq 2.5$ MW) ($\sim 5$ shots). If EDA is not obtained, try $n_{\text{lo4}} = 1.4 \times 10^{20}$ m$^{-2}$. Once EDA H-modes are obtained, ramp the plasma current up from 0.8 to 1.2 MA over 0.6 sec during the EDA H-mode (cf. 960905003). To achieve EDA H-mode early in the discharge, the density will have to be raised quickly to reach $n_{\text{lo4}} \sim 1.2 \times 10^{20}$ m$^{-2}$ by 0.4 sec (e.g., 960209014). The RF should turn on 0.2 sec prior to the start of the ramp to allow the plasma to get into a fully developed EDA H-mode before the ramp starts. So, the RF should run at $\sim 2.5$ MW from $t=0.4$ sec to $t=1.2$ sec and $I_p$ should ramp from 0.6 sec until 1.2 sec. Then, run the opposite discharge ramping $I_p$ down from 1.2 to 0.8 MA during the EDA H-mode. The $q_\psi(a)$ should vary from about 2.8 to 4.3 (4 shots).

Then, returning to 1 MA, the TF will be ramped starting at 0.6 sec from 6.2 T to about 4.5 T during the EDA H-mode. The plasma current should be flat at 1 MA from about 0.45 sec to 1.2 sec. Next, breakdown as usual around 5.3 T, then ramp the TF down from $t=0$ to 4.5 T around 0.4 sec and maintain until 0.6 sec, then ramp the TF up to 6.2 T at 1.2 sec during the EDA H-mode (4 shots). Here, $q_\psi(a)$ should vary from about 2.9 to 4. If the results indicate that more variation in $q$ is desirable, it should be possible to ramp both $I_p$ and $B_T$ simultaneously in opposite directions starting from the downward $B_T$ ramp from 6.2 T to 4.5 T and including an upward $I_p$ ramp over the same 0.6 sec interval from 0.8 - 1.2 MA. This would give a change in $q_\psi(a)$ from about 5 to 2.4. If time permits, this could be done in two steps, one at high $q$ and the other at low $q$. The first could start at 6.2 T and 0.8 MA, then ramp $I_p$ down to 0.7 or even 0.6 MA during the EDA H-mode. Low $q$ could then be attempted by running at 1.2 MA and 5.3 T, then ramping down the TF to 4.5 T just before the end of the $I_p$ flattop during EDA H-mode. It is expected that some shots will have to be repeated to change wavelengths of spectrometers and to notch the ICRF power for Fast Scanning Probe insertion.

6. Anticipated Results

Discuss possible experimental outcomes and implications. Indicate if the program may be expected to lead to publications, milestone completions, improved operating techniques, etc. Indicate if the experiments are intended to contribute to a joint research effort, or an external database.

The EDA H-mode confinement and stability dependence on safety factor will be determined by this experiment. Changes in the stability of the EDA H-mode and associated fluctuations should shed light on the underlying causes of these modes. The information learned in this experiment will be useful for future publications and the next EPS meeting.

7. References

Include references both to external and internal literature or communications which bear on this proposal. See Section 2.