1. Purpose of Experiments
Include immediate goal of the experiments, scientific importance and/or programatic relevance. Refer to any relevant program milestones.

The purpose of this piggy-back experiment is to determine whether c-MOD suffers anomalous loss of energetic perpendicular fast ions.

2. Background
Discuss Physics basis of the proposed research, Prior results at Alcator or elsewhere, and any related work being carried out separately.

The efficiency of minority RF heating in recent c-MOD operation is quite low – about 45%. One possible explanation for this poor performance is anomalous loss of the fast ions, i.e. the RF power is successfully delivered to a fast-ion population, but the fast ions are lost radially before they can couple power to the thermal plasma. We have not modeled the effect of error fields on fast ion confinement, but qualitatively one might expect error fields and/or locked modes to cause radial transport of energetic, fast ions.

The fast-ion population created by DNB injection will have the same orbits as 70 keV hydrogen ions, which is typical of the fast-ion tail temperature (prior to redistribution at sawteeth). The fast DNB deuterons will probably have a radial distribution that is less centrally weighted than the RF minority tail.

The expected volumetric neutron emission is $R = n_b n_d \sigma_{dd} v_b$ where $n_b$ is the local beam ion population given by the local fast-ion birth rate $\dot{n}_b$ multiplied by the slowing down time $\tau_{slow}$

$$\tau_{slow} = \frac{6\pi^{3/2} \epsilon_0^2 M_b T_e^{3/2}}{\sqrt{2} n_e Z_b^2 e^4 m_e^{1/2} \log \Lambda} = 0.013 T_e^{3/2} / n_e^{20} \text{ (seconds)} \quad (1)$$
where $T_{e,kev}$ is the electron temperature in keV and $n_{e20}$ is the electron density divided by $10^{20}$ m$^{-3}$. Integrating over the plasma volume gives

$$R = \left( I_b^{full} / e \right) \tau_{slow} n_d \sigma_{dd} v_b$$

(2)

where $I_b^{full}$ is the full-energy beam current (amps). At $E_b = 50$ keV, $\sigma_{dd} = 5 \times 10^{-31}$ m$^{-2}$ and $v_b = 2.2 \times 10^6$ m/s. For a 4-amp DNB with a full-energy current component of 50%, the final expression for the expected neutron emission is:

$$R = 1.8 \times 10^{13} T_e^{3/2} \frac{n_d}{n_e}$$

(3)

For a plasma having a single impurity with charge state $Z$, $n_d/n_e = (Z - Z_{eff})/(Z - 1)$. For example, $n_d/n_e = 0.75$ for a boron impurity in a plasma with $Z_{eff} = 2$, yielding

$$R = 1.3 \times 10^{13} T_e^{3/2}.$$  

(4)

A good RF heated plasma was 1010703003 which had $P_{RF} = 3.5$ MW, $W_{tot} = 165$ kJ, $R = 5 \times 10^{13}$ neutrons/sec, and $T_e = 3$ keV – for comparison, we expect the DNB to yield $6.8 \times 10^{13}$ neutrons/sec in this plasma. So the DNB should be able to generate a neutron emission that exceeds the thermal neutron production over most of C-MOD’s operational parameter space, including high-power RF operation.

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

We propose to operate the diagnostic neutral beam (DNB) in deuterium rather than the customary hydrogen to create a population of perpendicular 50 keV deuterons that will fuse with the thermal deuterium as they slow down. To identify possible anomalous fast ion losses, the measured d-d neutron emission rate will be compared with calculations by TRANSP which assumes classical beam ion thermalization. The decay rate following beam turn-off will also be compared against TRANSP predictions.

Ultimately, we will perform these measurements in a variety of plasmas including ohmic plus RF-heated L-modes and H-modes. This particular mini-proposal is mostly a shake-down exercise to identify any unforeseen problems. We propose to inject the DNB in deuterium on a run day where significant RF power is expected (> 3 MW) and for which the beam-based diagnostics are not needed.

4. Resources
4.1 Machine and Plasma Parameters

Give values or range for:

Toroidal Field: 5.4 T (on-axis H minority ICRF)

Plasma Current:

Working gas species: D (or T)

Density: \( n_e l \leq 1.2 \times 10^{20} \text{ m}^{-3} \)

Equilibrium configuration (if possible, refer to database equilibria): Intended as a piggy-back run

Pulse length, typical current & density waveforms, etc. Refer to database or sketch desired waveforms:

4.2 Auxiliary Systems

RF Power, pulse length, phasing: \( P_{RF} > 3 \text{ MW} \)

Pellet Injection (species):

Impurity blow-off injection:

Diagnostic Neutral Beam: deuterium beam, 50 kV

Special gas puffing:

Other:

4.3 Diagnostics

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

- Customary diagnostics that are needed for kinetic analysis: Thompson scattering, ECE, interferometer, etc.
- Neutron emission diagnostics
- We will need measurements of the DNB current fractions at the full, half, and third energies.

5. Experimental Plan

Both sections must be filled in.

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.

In principle, this is a piggy-back experiment which will have little effect on the plasma with the exception of the neutron emission for a single 50-ms pulse during the shot. However, all beam-based diagnostics (MSE, BES, CXRS) will be affected, mostly for the worse because the Doppler shift is reduced and the beam penetration is reduced. So the DNB should not inject deuterium for any experiments that require these diagnostics to be operational.

Edge BES measurements might actually benefit from the deuterium operation, since there would be more beam-plasma interaction at the edge owing to the reduced beam velocity. In addition, neutral beams typically operate at higher current in deuterium than in hydrogen.
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.

On a given run day for which the DNB is operated in deuterium, we would plan to inject on all shots unless specifically requested otherwise.

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 expected neutron emission that is calculated by TRANSPL involves the measured profiles of $T_e$, $n_e$, and $Z_{eff}$ plus the beam parameters (energy, current, full-energy current fraction). Qualitatively, the neutron emission scales at $T_e^{3/2}$. The local neutron emission has negligible density dependence because the linear dependence on the target deuterium density cancels the inverse dependence on the slowing down time. But globally the neutron emission will decrease rather strongly with increasing density, thereby depositing the beam ions in colder regions of the plasma. In principle all of these effects are properly accounted for in TRANSPL.

But my experience from TFTR is that we argued for years over discrepancies of order 15% between the calculated and expected neutron emission. My educated guess would be that we would be able to identify an anomalous loss of fast ions by comparing measured/calculated neutron emission during deuterium DNB injection only if it were in excess of 25%, although this threshold might be reduced with some work.

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

8. Safety Issue: Conditioning the DNB in Deuterium

We will need an administrative plan to ensure that the DNB does not fire in deuterium when staff are present in the cell.

A quote from Larry Grisham at PPPL: “We did not allow anyone on the floor when we were operating the PLT ion sources with deuterium. Those had more current (maybe 30 or 40 amps), but they were at lower voltage (mostly 35 - 38 kV than you are talking about), so the total neutron flux from those was probably less than what you would get from 4 amps at 50 kV. Once during the development phase, the Oak Ridgers ran a PLT source on D at the sort of parameters I just mentioned on a Saturday without checking it out with the safety people (I was there). They were told on Monday not to do that again.”