1. Purpose of Experiments

Include immediate goal of the experiments, scientific importance and/or programatic relevance.
Refer to any relevant program milestones or ITER R&D commitments.

1. To investigate impurity fuelling efficiency by injecting gaseous impurities at a known rate into the divertor and measuring the impurity concentration in the core plasma. Conditions will be varied to see how the fuelling efficiency depends on plasma density and temperature in the SOL and on the impurity puffing position. Results will be compared with impurity transport codes.

2. To study impurity sputtering of Mo in the divertor. By varying the density, $T_e$ in the divertor may be varied. With a constant impurity influx the threshold temperature for Mo sputtering can be determined. This is of intrinsic interest, since it tells us the maximum value of $T_e$ we can tolerate. If we repeat the experiment with a number of injected gases with different Mo sputtering thresholds it should also give a fairly direct estimate of the divertor sheath potential.

Since both these experiments require similar conditions they can be carried out in parallel.

2. Background

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

1. Impurities produced at the divertor have in principle a high probability of being ionised and swept back to the divertor plate. Other factors may however over-ride this simple picture. Reverse flow in the SOL, as observed in 2-D fluid calculations, is one possibility and the ion temperature gradient force acting away from the plate is another. Since these factors are difficult to quantify theoretically, experimental measurements are valuable.

A straightforward way of obtaining a global picture of impurity transport is to introduce impurities at a known rate at the divertor target and to measure their concentration
in the confined plasma as a function of time. Gas injection is a convenient way of measuring fuelling efficiency directly since the impurity influx can be kept constant as plasma conditions are changed. This contrasts with intrinsic impurities where the influx changes with plasma conditions and the absolute value of the influx is difficult to measure accurately.

Ar is a particularly attractive impurity species to use on C-Mod because we can make profile measurements with HIREX. Preliminary experiments have already been carried out. These were successful and although only a few shots are available, the measurements indicated that ~ 0.5 % of the injected Ar atoms appeared in the core plasma. This is very much lower than the figure obtained by the DIII-D team injecting neon [2]. It is thus important to try Ne to see whether the difference between C-Mod and DIII-D is due to the different ionisation rates of Ne and Ar or due to the geometry or other differences in the two machines.

We also want to see whether the position of injection affects the fuelling efficiency or the time behaviour of the impurities. The gas injection system has been significantly improved since the last campaign and it will be possible to inject a factor 10 less impurity flux, allowing the experiments to be truly trace experiments, whereas the earlier experiments slightly increased both $Z_{eff}$ and $P_R$

While easy to use, Ar and Ne have the disadvantage that they are recycling gases. This means that they have a higher probability of escaping from the divertor as neutrals than do nonrecycling impurities like carbon or moly. It is therefore proposed that we should compare the results from Ne and Ar with nonrecycling species such as C, (injecting methane) and $N_2$

2. Preliminary experiments have already been carried out, observing the MoI flux in the divertor as a function of target $T_e$ for both argon and deuterium. No MoI was observed up to a $T_e$ of 25 eV in deuterium whereas a threshold was observed at about 8 eV in Argon [3]. These results are consistent with the sputter thresholds of 90 eV for $D^+$ on Mo and 30 eV for $Ar^+$ on Mo. If we do the experiments with a range of impurity gases with different sputter thresholds we will be able to get an estimate of the charge state of the predominant impurity ion and an estimate of the normalised sheath potential. These measurements fit in very well with the experiment 1 described above.

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

See experimental plan

4. Resources

4.1 Machine and Plasma Parameters

Give values or range for :
Toroidal Field: 5T

Plasma Current: Not critical; in the range 0.5 to 1.0 MA. It is probably desirable to repeat some of the measurements with 2 significantly different currents, in order to alter the edge $T_e$ independant of density. However this is not part of the present proposal.

Working gas species: $H_2$ or $D_2$.

Density: $\bar{n} = 3 \times 10^{19} \text{ m}^{-3}$

Equilibrium configuration (if possible, refer to database equilibria):

Standard single-null lower x-point with outer strike point on the vertical outer divertor tiles, eg shot 931014022. Equilibrium to remain constant for as long as possible during the discharge, ≥ 1s.

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

Pulse length to be ≥ 1 s if possible, plasma current constant and plasma density constant throughout each discharge. Density increased in steps in successive discharges.

4.2 Auxiliary Systems

RF Power, pulse length, phasing: None

Pellet Injection (species): None for initial tests

Impurity blow-off injection: None

Special gas puffing: Impurity (He, Ne, $N_2$, $CH_4$, and Ar) gas puffing through the divertor gas puffing system at constant rates

Other: None

4.3 Diagnostics

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

Interferometer; ECE; $2\pi$ Bolometer and array; Divertor Bolometer arrays; Fast scanning probe; Flush mounted divertor probe array; Visible bremsstrahlung; OMA spectrometer viewing divertor, 20nm bandwidth, 0.1nm resolution, set on NeI, CII, N and ArI as appropriate; Visible spectrometer viewing neutral impurities from inside wall; MacPherson spectrometer viewing Ne, C, N, and Ar lines as appropriate; Molybdenum monitor; CCD camera; All reticon arrays with $H_\alpha$ filter and C II and NeI filters in selected shots; Ratiomatic pressure gages; Divertor pressure gages;

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.)

Not applicable
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.

Two runs are requested. With constant plasma current and density the impurity gas will be puffed from the divertor capillary system. The density will be raised in successive discharges with a given impurity to produce a scan in SOL $n_e$ and $T_e$. During each shot the time evolution of the impurity will be followed on HIREX where possible (Ar), on the MacPherson and on the OMA visible spectrometer. The reticon arrays will be able to view CII, CIII, NeI and other lines, where appropriate.

During the same shots molybdenum sputtering in the divertor will also be followed. For a given impurity it is expected that as $T_e$ increases (ie as $n_e$ decreases) a threshold energy will be reached for sputtering. This threshold will be different for each impurity species.

In the case of Ar, because it is probably the best diagnosed impurity, we will vary the gas puffing position at fixed density. Puffing will be varied from the private flux region to the inner and outer SOL, up to the horizontal midplane on the inside wall and to the upper divertor.

Following the Ar experiments a density scan will be carried out with each of the other impurity species in turn. Measurements of the impurity distribution, central concentration and Mo sputtering will be made as a function of time at each density in successive shots.

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.

Constant density and current conditions will be set up in a single-null diverted discharge as specified above. The main chamber gas puffing system will be used to maintain the density constant during the discharge. In each shot an argon flow rate will be maintained constant at $2 \times 10^{18}$ atoms s$^{-1}$ for a period of typically 100 to 200 ms. The optimum conditions will be determined by experiment. The plasma density will be raised in successive shots to cover the maximum density range available. (15 shots)

At constant density and constant Ar injection pulse the position of the impurity injection will be varied from the private flux zone to the inner and outer divertor SOL, the inner wall at midplane and the upper divertor. A similar impurity flow rate will be used at each position and the time response and absolute impurity density in the confined plasma will be compared. (10 shots)

A density scan will then be carried out with each of the other impurity gases in turn, using a fixed gas puffing position and a fixed puffing rate. A few set-up shots will be required for each gas to determine the optimum impurity puffing rate and injection time in order to find values at which the impurity can be diagnosed without causing any global disturbance to the plasma. (10 shots each for Ne, $N_2$, and $CH_4$; total 30 shots)
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 fuelling efficiency determined for each of the gases as a function of SOL density (and $T_e$). This will provide a good database to test 2-D codes, both fluid and Monte Carlo.

The Mo influx threshold measurements will give us empirical information on what are tolerable impurity levels and edge $T_e$’s to work at. These results are particularly important to an assessment of the level of impurity radiation which can be attained to dissipate the power in the divertor and reduce the heat load on the targets. In addition, by comparing the sputter threshold for different impurities and making estimates of the impurity charge state it should be possible to determine the sheath potential normalised to $T_e$.

A successful set of experimental data should enable us to write one, possibly 2, good Nuclear Fusion papers.

7. References

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

[2] DIII-D impurity experiments