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

These experiments seek to investigate the mechanisms impacting high-Z impurity transport near the magnetic axis (r/a < 0.3) of Alcator C-Mod plasmas, looking at the importance of neoclassical and turbulent transport, highlighting effects driven by changes in the minority heating. C-Mod’s robust ICRF capabilities allows the impurity transport to be studied in a wide range of plasmas where external particle or momentum sources are absent, enabling a unique contribution to world-wide research in support of ITER to study high-Z impurity transport. This experiment focuses on H-mode and L-mode plasmas where the minority concentration and minority species are scanned using D(H) and D(3He) heating schemes. This will modify the minority-impurity friction as well as change the electron and ion heating balance via the changes in the mean energy and mass of the minority heated species. Experiments will attempt to examine if such changes impact the flux-surface averaged impurity transport and if majority or minority interactions dominate.

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

MP 753 and MP 728 give significant background on the current state of and motivations for world-wide investigations of high-Z impurity transport. One additional new area of investigation that will be tested with these experiments is the ability for minority ions heated by ICRF to screen heavy impurities from the core. On-axis, localized heating leads to large temperature gradients in the minority population, R/LTm, increasing the effective neoclassical temperature screening (outward impurity flux). In regions of peak power density, minority-impurity collisionality is small due to high minority temperatures, but moving away from the resonance layer, R/LTm remains above R/LTi as v_{iZ} approaches v_{mZ}, leading localized impact on impurity transport. This has been
estimated to quantitatively impact neoclassical radial impurity flux in JET plasmas [Casson – 2015], and suggested from initial results from MP 753, shown in the Figure to the right. Here, the minority fraction and RF power were scanned in a small sample of EDA H-modes. At nominally fixed $T_e$, and thus similar impurity radiation efficiency, the gradient in the soft x-ray emissivity, and thus impurity density, following tungsten laser ablation showed a strong response that scaled with $P_{RF}/n_{min}$. Insufficient data were collected to fully understand the phenomenon, and existing shots have gaps in HIREXSR data collection that prevent more thorough analysis of the impact on the ion temperature profile. At this point it is unclear if changes in the minority fraction led to a direct minority-impurity friction interaction or acted indirectly through standard main-ion temperature screening as the ion and electron heating fraction. Coupled with this are changes to the poloidal variation in the impurity density as variations in rotation and poloidal electric field forces are modified. New experiments look to investigate variations in minority concentration and species further as it has been demonstrated to have a much more substantial effect than scans in RF power [Loarte 2015].

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.

Prior research (MP 753) focused on low current, $I_p \leq 0.6$ MA, low collisionality plasmas to access mid-radius density peaking. Results indicated that density peaking at $r/a \sim 0.5$ did not impact high-Z transport, qualitatively explained by peaking being driven by turbulent driven convection that avoided neoclassical transport associated with the density gradients from playing a significant role. Complications with limiter heating from these experiments (1140723) resulted in RF powers limited to < 3 MW. Thus these experiments move away from the low-$I_p$ plasmas, both to improve RF heating flexibility and to increase the sawtooth period to aid in near-axis inter-sawtooth transport analysis.

To modify the minority distribution function and its interaction with the plasma, it is proposed that minority concentration and minority species be modified. One approach would compare $D(H)$ and $D(3He)$ heating in the same H-mode target plasma, but this requires modification of J-ANT to operate at 50 MHz to place the $^{3}\text{He}$ minority resonance
on-axis at ~5.4 T. This also reduces the upper limit in ICRF heating power to < 3 MW for each heating configuration. An alternative approach is proposed, where the experiment will compare impurity transport as the minority concentration is scanned in EDA H-modes at 5.4 T, using D(H) heating and L or I-mode plasmas using D(3He) heating at 7.2 T. While this will result in dissimilar target conditions, complicating analysis, it would allow the full RF power capabilities to be used for each heating scheme, expanding the range of $P_{RF}/n_{min}$.

Main-chamber H (or 3He) puffing will be used, with scans targeted to push minority from low or ambient levels, ~5% for H, to under 15%. Higher levels move heating from minority to mode-conversion which is also suggested to play a role in impurity transport, but is the subject of other proposed experiments (MP 650).

At 5.4 T, a resonance layer scan will be done by modifying $B_t$ to move the resonance layer to the HFS/LFS of the magnetic axis. This has the effect of modifying the poloidal asymmetry as well as moving the effects of the minority-impurity friction, helping to elucidate their possible impact on cross-field transport. A scan from 4.8-6.0 T will be done, to move the ICRF resonance layer through the $q=1$ surface which was shown to impact the impurity transport in JET [Graves – 2015].

4. Resources

4.1 Machine and Plasma Parameters

- Toroidal Field: 5.4, 7.2 T (Rev B.)
- Plasma Current: 0.8 MA for 5.4 T, 1.1 MA for 7.2 T
- Working Gas Species: D$_2$
- Density: lowest steadily achievable: $n_{04} > 1.0e10^{20}$ m$^{-2}$
- Boronization Requested (if yes, specify whether overnight or between-shot, how recently needed, and any special conditions.): overnight boronization
- Equilibrium configuration (if possible, refer to database equilibria): LSN with small SSEP to enhance pumping: use 1140723015 (630 kA) and increase Ip to 800 kA.

4.2 Auxiliary Systems

- ICRF Power, pulse length, phasing: < 5 MW
- LHCD Power, pulse length, phasing: none
- Pellet Injection (species): none
- Impurity blow-off injection: yes, tungsten
- Diagnostic Neutral Beam: not required
- Special gas puffing: Ar for HIREXSR, H, 3He for minority control at 5.4, 7.2 T, respectively
- Cryopump: yes
- Non-axisymmetric Coils (Connections, Current): locked mode prevention
- Other:
4.3 Diagnostics
List required diagnostics, and any special setup or configuration, e.g. non-standard digitization rate.

**REQUIRED**
all \( T_e \) and \( n_e \) profile diagnostics (core/edge TS, TCI, GPC)

**optimize diagnostic for core profile coverage**

- HIREXSR for impurity emissivity (Ar, Mo), core \( T_i \) and rotation
- VUV/SXR impurity spectroscopy (XEUS and LoWEUS)
- core XTOMO
- AXUV diodes
- H/D spectrometer
- PCI modified to monitor the mode-conversion layer position, thus core minority fraction

**DESIRED**
- \( Z_{\text{eff}} \) diagnostics
- F-Port HIREX viewing tungsten
- core and edge fluctuation diagnostics (TCI, CECE)
- neutron rate

**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.

1.0 run day at 5.4 T is requested for [A-D]
piggyback or ~1/3 of a day at 7.2 T for [E]

At 5.4 T, 36 plasmas scheduled: 8 conditioning, 2 diagnostic, 26 physics. From the 26 physics plasmas, 20 successful conditions are desired. Options for scope reduction if delays, problems encountered would be to reduce to x3 minority concentration points in [C] and perform resonance layer scan for only x1 minority concentration level in [D].

At 7.2 T, 12 physics plasmas scheduled, with 9 successful conditions desired.

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.

[A] (8 shots) ICRF conditioning at ~800 kA, LBO testing
- use 1140723015 and raise \( I_p \) to 0.8 MA
- demonstrate steady EDA H-mode, outgas PFCs to help achieve low density
- condition ICRF up to 4.0-5.0 MW, establish max power available and pulse duration (est. 0.7 < t < 1.5) that avoids excessive limiter heating
- demonstrate tungsten LBO level and timing to allow for physics studies minimizing impact on H-mode conditions
- establish minimum RF power level that allows quasi-stationary EDA w/ W LBO
[B] (2 shots) Diagnostic calibration plasmas
  - HIREXSR locked mode calibration (2 shots)

[C] (16 shots) ICRF power and H-minority concentration scan. At 3 RF power steps, and 4 minority levels, fire W LBO at $t \sim 1.0$ seconds. ICRF power levels, established from bounds in [A], estimated at 2.4, 3.2 and 4.0 MW as ‘L’, ‘M’ and ‘H’ power levels. H-puffing from B-SIDE at 8 psi (based on 1140723 levels).
  - No H-puffing, ICRF: L, M, H
  - H puff for 150 ms at ~30% (prior to ICRF turn-on), ICRF: L, M, H
  - H puff for 150 ms at ~60% (prior to ICRF turn-on), ICRF: L, M, H
  - H puff for 150 ms at ~100% (prior to ICRF turn-on), ICRF: L, M, H

[D] (10 shots) Choose 2 cases from [C] and conduct a minority resonance layer scan at fixed RF power and H-puffing.
  - H-puffing level 1, BT = 4.8, 5.1, 5.7, 6.0 T.
  - H-puffing level 2, BT = 4.8, 5.1, 5.7, 6.0 T.

[E] (12 shots) ICRF power and $^3$He minority concentration scan. This assumes that ICRF conditioning, HIREXSR calibration has been completed. Either run in piggyback, with tungsten LBO into minority concentration scan (i.e. a MCFD experiment) or use dedicated run-time on an extended run-day that focused on high-field I-mode research.
  - $^3$He puffing level 1 (low), ICRF: L, M, H
  - $^3$He puffing level 2 (med), ICRF: L, M, H
  - $^3$He puffing level 2 (high), ICRF: L, M, H

5. Anticipated Results
Discus 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, an ITER request, or an external database.

Based on prior experiments, H-mode plasmas are expected to exhibit variations in inter sawtooth impurity peaking. By comparing the kinetic profiles of the background plasmas with varying RF heating and minority concentration levels, we seek to investigate what direct and indirect role the ICRF-heated species is playing to impact impurity transport.

Analysis can contribute in four stages
  1) Qualitative – If on-axis peaking of Ar/Mo/W is observed, can ICRH (distribution or location) mitigate the effect and at what power level?
  2) Quantitative – are changes in impurity density scale length observed and with neoclassical drives (process initial kinetic profiles)?
  3) Simulation – as motivated by the data, compare measurements to transport models using neoclassical (NEO, NEOART) and gyrokinetic codes (GKW, GYRO). Use TRANSP to model the changes in the minority distribution.

Analysis of HIREXSR data for Ti, rotation and (Ar, Mo) impurity densities will be done by MLR, while initial analysis for Te and ne will be completed by JWH and AH.
Analysis of SXR, AXUV and spectroscopy data for tungsten density will be done by MLR with assistance from MC, JER.

Neoclassical and gyrokinetic simulation work will be pursued by MC, NH, FC and others as resources and interests are available. Simulations using NEO and/or NEOART will not require computational resources beyond those available at C-Mod.

Results from these experiments will be presented at various national and international meetings. Due to a connection to high-profile research within the EUROfusion programme, it is expected that C-Mod work would be communicated within internal discussions at JET and ASDEX-U. Work also will contribute to open research on high-Z impurity transport under the ITPA Transport and confinement group.

6. References
Include references both to external and internal literature or communications which bear on this proposal. See Section 2.
See references in MP728 as well

