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

The purpose of this experiment is to complete the implementation of the divertor heat flux feedback system and demonstrate its use in high input power EDA H-modes. It will also explore if/when such a system affects the H-mode confinement and what sensors and actuators could be used to restore confinement.

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

It can almost go without saying that control of the plasma conditions at the first wall while maintaining core confinement is one of the great challenges to development of an economically viable magnetic fusion reactor. To-date there has never been a system that directly controlled one of the most important quantities: first wall heat flux.

MP784 (run 1150729) has demonstrated the viability of using the real-time heat flux calculation from a divertor surface thermocouple as the input and the duty cycle of an impurity seeding valve as the output to a real-time controller of divertor heat flux. Shot 30 demonstrated control with an unstable oscillations, Fig. 1. Although, the run was not long enough optimize signal conditioning and controller gains. As such, the first portion of this MP will be to tune-up the controller.

The ultimate goal of this series of heat flux feedback MPs is to explore the viability of a system to mitigate the divertor heat flux while maintaining good core confinement. Many past experiments with feedforward seeding of radiative impurities have found that there is
a fine line between mitigation of divertor heat flux and negatively affecting core confinement. For instance, experiments in the FY15 campaign (MP770) have shown that, with the RF power available at the time, there was no window in EDA H-modes with neon seeding where the divertor heat flux could be mitigated without affecting core confinement (there was a window with nitrogen). Through the implementation of a feedback system it is hoped that this line is easier to walk. The second half of this MP will focus on exercising the heat flux control system in high input power EDA H-modes.

![Graph showing the relationship between time and various parameters such as surface temperature, heat flux, duty cycle, and core nitrogen VI.](image)

**Figure 1** First shot where the feedback of impurity seeding duty cycle on divertor heat flux was used, albeit a very unstable feedback due to having only proportional gain. Note that negative duty cycle demand corresponds to zero duty cycle on the valve.

3. **Resources**

4.1 **Machine and Plasma Parameters**

- Toroidal Field: 5.4T
- Plasma Current: 0.8MA
- Working Gas Species: D₂
- Density: \( n_{04} \approx 0.85 \times 10^{20} \text{ m}^{-2} \) (L-mode target)
- Boronization Requested: yes, immediately preceding run
- Equilibrium configuration: 1150625 (see PO summary from this run)

4.2 **Auxiliary Systems**

ICRF Power, pulse length, phasing: D&E full power and pulse, hope for J
LHCD Power, pulse length, phasing: yes, full power and pulse
Impurity blow-off injection: yes, tungsten slide
Diagnostic Neutral Beam: not allowed
Special gas puffing: N$_2$ divertor piezo valves, 15psi in H-bottom
Cryopump: yes
Non-axisymmetric Coils: standard configuration
Other: feedback inputs/outputs connected to DPCS

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

Absolutely necessary:
- divertor STCs with real-time output to DPCS
- divertor bolometers with real-time output to DPCS
- edge ECE with real-time output to DPCS
- divertor piezo valve controlled by DPCS
- core and boundary spectroscopy (XEUS, LoWEUS, CHROMEX), optimized for nitrogen and viewing the lower divertor (e.g., 1150625)
- divertor Langmuir probes

Should probably have:
- Thomson scattering
- IR camera
- X-point imaging with D-gamma filter for recombination
- fast magnetics
- reflectometer
- PCI
- Lyman alpha
- AXUV

Nice to have:
- divertor MLP system
- x-point polychromator
- GPI
- CXRS
- reciprocating probes
- HIREX

4. 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 normal run day requested for this MP.
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. Optimize feedback control and boronization recovery:
1. Reload shot from 1150625 and start boronization recovery. Adjust strikepoint to be at the bottom of tile 2. Add in divertor heat flux feedback from 1150729, adjust to STC near strike point.
2. Add signal conditioning to heat flux feedback and tune gains to achieve stable feedback to 5MW/m$^2$ with prompt response.
3. Switch to other STCs, assess if a common set of gains is sufficient.
4. Establish EDA H-mode with maximum $P_{net}$ achievable from ICRF.
   10 shots total for this section

B. Exercise feedback system, basic goals are to:
1. Demonstrate programmable control of divertor heat flux during H-mode at levels of 10, 5, and 2.5MW/m$^2$.
   6 shots
2. Assess heat flux feedback system response to drop-outs and step-ups in RF power. After H-mode is established and while seeding feedback is on, step down RF (~1MW), wait 0.3s, and step RF power back up.
   2 shots
3. Assess heat flux feedback system response to L-H and H-L transitions. This should come for free if we program the controller across the transitions.
   0 shots (piggyback)
4. Assess heat flux feedback system response to impurity injections. This will likely come for free.
   0 shots (piggyback)

C. Explore plasma performance and feedback control limitations at reduced set point levels. Throughout this portion of the experiment, an eye will be kept on many sensors (e.g., edge ECE, divertor bolometers and diodes) for options on feedback inputs that signal the onset of or the occurrence of core confinement degradation.
1. Step through sensors progressively further away from the strike point—presumably pushing deeper into detachment—and assess affects on core confinement.
   6 shots

If time allows, add additional RF into conditions of reduced core confinement. Assess the ability of RF to repair confinement or perhaps play tug-of-war with seeding:
2. Ramp ICRF to find power level at which confinement recovers, if possible. This will require starting with less ICRF power than the maximum used in section B. Then try to feedforward such a power to maintain core confinement.
   3 shots
3. Ramp LH to find power level at which confinement recovers, if possible. Then try to feedforward such a power to maintain core confinement.
   3 shots

About 30 shots total for this run.
5. **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, an ITER request, or an external database.

This experiment should result in the implementation of a divertor heat flux controller in the C-Mod digital plasma control system that could be used as a standard part of operation. This will be the first of its kind of such a controller. This experiment will exercise the controller in a variety of transient scenarios to assess its performance. It will also explore if there are any sensors or actuators available for core confinement if the heat flux controller does affect it.

This experiment will result in a post-deadline invited talk submission for APS DPP 2015, an abstract submission to PSI 2016, the publications associated with both conferences, and a submission to RSI.

6. **References**

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