# Alcator C-Mod
# Mini-Proposal

**MP No.** 554

**Subject:** MSE Calibrations – torus temperature effects and background issues

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**Group:** Diagnostics

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**Approved by:** **Date Approved:**

## 1. Purpose of Experiments

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

The purposes of this experiment are

(1) to verify that the shot-to-shot drift in the MSE diagnostic can be reduced by maintaining the torus temperature constant,
(2) to test the effect of the first lens heating on the MSE diagnostic within a shot,
(3) to calibrate several inner MSE channels using plasma sweeping technique; and
(4) to explore the various issues on the MSE background noises.

## 2. Background

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

**(1) Temperature variation in the torus and MSE invessel canister:** Recent invessel experiments show that the polarization angle measured by the MSE diagnostic is affected by stress-induced birefringence on the invessel lenses caused by the heating and cooling of the invessel optical canister, the angle change being as much as 30° with the canister temperature change of 40°C [1]. The beam-into-gas calibration done on 1080318 reconfirms this thermal stress-induced birefringence effect by showing the MSE data drifts over a run day during which the canister temperatures vary by about 30°C [2].

The variation of the temperatures at the MSE optics is correlated with the torus temperature variation. In general, the surface of the MSE canister is hot (up to $100^{o}$ C) at the start of a run day due to the overnight ECDC and then rapidly cools down in first few shots by the circulation of the liquid nitrogen. The cooling becomes rather slow as the run goes on since the cooling competes with the heat accumulation due to the plasma radiations. This complicated temperature variation can affect the polarization measurement on a shot-to-shot basis in a rather unpredictable manner.

**(2) Thermal-stress induced birefringence on the plasma facing lens during a shot:** Thermal calculations performed by David Gwinn indicate that the surface temperature of the plasma facing lens easily exceeds 100°C during a shot with high-power RF heating, with a reasonable assumption of the radiation [3]. The resultant thermal stress in the lens is rather high but (presumably) azimuthally symmetric, and because the incident light has uniform intensity at the plasma-facing lens, the integrated birefringence effect may be small. A proposed in-situ, post-shot calibration system for the MSE diagnostic would compensate for changes in the lens birefringence that occur on a time scale > 10 seconds, but it could not compensate for fast changes that occur during a shot. So it is important to assess whether heating of the plasma-facing lens during a shot can significantly affect the measured polarization angles.

**(3) Absolute calibration using plasma sweeping:** The 1080318 gas calibration suggests that some channels that are immune to the shot-to-shot variability due to the thermal-stress induced birefringence [2]. Another study shows general gas calibrations are useless unless the secondary neutral effect is corrected by either having a ‘zero’ torus pressure which is practically impossible or somehow extrapolating the measured pitch angles to the ‘zero’ pressure [4]. The latter is also practically difficult to do because one extrapolation procedure calibrates only one pitch angle, requiring a number of shots to calibrate a range of pitch angles. In addition, at lower pressure, the uncertainty in the measured pitch angle can significantly increase. A different technique to calibrate the MSE is using a plasma that is ‘swept’ during a shot. In general, the pitch angle calculated by EFIT near the plasma boundary is highly reliable since it doesn’t use any assumed internal profiles to obtain the boundary values. By sweeping the plasma, several inner channels can experience the plasma edge. This was attempted in the last campaign (1070629) and the feasibility was demonstrated, but the result was not actually used to calibrate the MSE diagnostic because of the shot-to-shot drift problem [5]. Now that the shot-to-shot invariable channels are identified, the method should give the absolute calibrations for these channels. In addition, the sawtooth inversion radius is also swept in this kind of shot, implying that not only the transient edge channel but also one inner channel can be calibrated at the same time by properly converting $q = 1$ at this location into the pitch angle using EFIT. It is also possible to calibrate one MSE channel twice within a shot: at the moment when the channel is at the plasma edge and at the moment when the channel is at the sawtooth inversion radius. A range of pitch angles can be calibrated by using different base plasma currents and toroidal fields shot by shot.

**(4) Background issues:** Compared to other tokamaks, the C-Mod MSE diagnostic sees a relatively large amount of ‘background’ polarized light (i.e. polarized light even in the absence of a diagnostic beam) which increases the measurement error. A database study from 1070516 and the observation on the LH-driven H-modes from 1070523 show a strong correlation of the background polarization with the H-alpha signals [6]. This motivated the installation of the edge (high-pass) filters in addition to the existing bandpass filters to eliminate any possible wings from thermal H-alpha radiation.

Unfortunately, however, the observation of the MSE background from 1071211 which is done with the edge filters installed still implies a strong correlation with the H alpha [7]. The tentative conclusion made from this observation is that the background source is not the H alpha radiation itself but something that is correlated with the H alpha signal. The possible background sources are

(a) Impurity line radiation from charge exchanges with neutrals,
(b) D2 molecular line radiation; or
(c) H alpha itself (assuming the edge filter is not properly working).

In addition, two different mechanisms in terms of the background source locations can be considered:

(b) local, i.e., the sources are located within the MSE viewing sightlines; or
(c) global, i.e., the sources are outside the MSE viewing sightlines but are reflected onto the RF antennas which are effectively the MSE viewing dumps.

We want to improve our understanding of the source of our noise, with the long-term goal of reducing it or improving our capability to measure it and compensate for it.

## 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.

**(1) Temperature variation in the torus and MSE invessel canister:** The data from the 1080318 gas calibration (where 4 identical gas shots were taken with different time intervals between them) were obtained with the torus, and thus the invessel MSE canister, temperature rather rapidly changing over the course of the day. We will repeat this experiment, but this time maintaining the constant torus temperature. ***No ECDC will be done overnight to avoid high temperature at the beginning and the circulation of the liquid nitrogen will be on well before the run, for example, from the previous night, to avoid the rapid drop after the run***. The data will be compared with those from the 1080318 gas calibration. These gas shots may have shorter pulse lengths, for example, 1 sec., to increase the rep rate. After the several gas shots, several benign low-density Ohmic plasmas will be taken to see the reproducibility under the constant-temperature-torus condition.

**(2) Thermal-stress induced birefringence on the plasma facing lens during a shot:** The plasma facing lens will be intentionally heated by the ICRF with high power. The ICRF timing will be adjusted such that there are reasonably long flattop periods (>200 ms) before and after the ICRF. The pitch angle data from these two flattops will be compared to see if there is any ‘within-shot’ drift due to the lens heating.

**(3) Absolute calibration using plasma sweeping:** The reference shot is available where the plasma current was also ramped down as the plasma size was decreased in order to maintain a reasonable q at the boundary. As mentioned in Section 2, the sawtooth inversion radius is swept so two inner channels can be calibrated at the same time and each channel will be calibrated using two different methods within a shot. The calibration using the EFIT edge pitch angle is direct but the calibration using the sawtooth inversion radius will require multiple runs of EFIT to obtain the pitch angle that matches the sawtooth inversion radii from EFIT and from ECE data. A few different toroidal fields and base plasma currents will be tried to get a range of pitch angles. It should be noted, however, that developing ramped shots with new conditions may take quite a bit of development time and that it may not feasible from both a time perspective and technical limitations.

**(4) Background issues:** Three approaches will be attempted to perturb the background. The focus is to identify the source of the background and its mechanism (local or global):

(a) 'Discrete' gas puffing: D2 and He gas will be puffed in two different shots and the level of the MSE background will be compared. If the He-puff plasma has lower MSE background than the D2-puff plasma, this might suggest that the source of the background isD2 molecular line radiation. If there is no noticeable difference in the background levels from these two shots, the impurity radiations from charge exchanges may play a larger role.

(b) 'Cryo' gas puffing: The purpose here is to perturb the neutral densities only, maintaining the plasma density constant. After taking a shot which has a programmed density, a second shot will be taken with the cryo pump on and with the same programmed density. Then the density feedback will result in the change in the neutral densities.

(c) Intentional MARFE shots: This is for examining the mechanism of how the background sources are coming into the MSE sightlines. If we do not see a noticeable difference in the background level from the shots with/without MARFE, the background source may be local, not from the reflection from the RF antennas of a light source outside the sightline. If we do see any difference, the reflection may play a role.

(d) Spectrum measurements in D and He plasmas with H modes: Alex Graf's GPI spectrometer (4 channels) is available to be connected to various fibers coming out of the torus. These include the MSE and BES fibers. Having these channels connected to the BES fibers would be ideal to measure the spectra close to the MSE lines of sight since BES and MSE share the views. In addition, the UT McPherson spectrometer can be connected to the MSE fiber bundle which is currently not in use due to its broken photo detector. H-modes in D and He plasmas will be used to perturb the density and the conditions in the edge.

Preferably, the spectrum measurements should be available all day except in the beam-into-gas shots on which the BES diagnostic will piggyback. The order of priority is (d)-

(a)-(c)-(b). Part (b) will be analogous to a pair of shots (18 and 21) from Brian LaBombard's run (1071206) [8]

# 4. Resources

## 4.1 Machine and Plasma Parameters

Give values or range for:

| | |
|---|---|
| Toroidal Field: | 4 ~ 6 T |
| Plasma Current: | 0.2 ~ 1.0 MA |
| Working Gas Species: | D2 |
| Density: | NeL = 0.2 ~ 1.1e20 m-2 |
| Boronization: | NO |

Equilibrium configuration: various (will be specified in Sec 5)

## 4.2 Auxiliary Systems

| | |
|---|---|
| ICRF Power, pulse length, phasing: | YES, > 3MW, ~ 1 sec, any phasing |
| LHCD Power, pulse length, phasing: | NO |
| Pellet Injection (species): | NO |
| Impurity blow-off injection: | NO |
| Diagnostic Neutral Beam: | YES |
| Special gas puffing: | D2, He |
| Cryopump: | YES |
| Non-axisymmetric Coils (Connections, Current); | NO |
| Other: | NO |

## 4.3 Diagnostics

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

MSE in normal operation conditions (including invessel thermocouples via PLC)
DNB
ECE and SXR to document the location of the q = 1 surface
Thomson scattering to measure the plasma density in the plasma sweeping tests (TCI is not appropriate since the path length of the line integration changes a lot
GPI connected with 4 BES fiber bundles and tuned for individual pass band
UT McPherson connected with MSE ch8 fiber bundle and tuned for its pass band

# 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.

One run day
NO overnight ECDC
Magnet cooling well before the run (for example, from the previous night)

## 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.

(1) Temperature variation in the torus and MSE invessel canister

(a) Beam-into-gas shots: 5 ~ 8 shots between 9 ~ 11AM

- Reference: 1080318029
- DNB starts at 0.2 sec for 1.5 sec with on/off = 80/20 msec
- MSE HV: 1870V for all
- Two zero-field shots for the BES piggyback during this part
- After this part, move the BES fibers to the GPI spectrometer
- Also connect MSE ch8 fiber bundle to the McPherson spectrometer

(b) Beam-into-plasma shots: 4 shots

- Reference: 1080320013 with Bt = 5.4T
- DNB starts at 0.2 sec for 1.5 sec with on/off = 80/20 msec
- MSE HV: 1700V for all

(2) Thermal-stress induced birefringence on the plasma facing lens during a shot

- Reference: 1080411027 with the following modifications
    - Nel = constant 0.8e20 m2
    - Ip and Bt flattop = 0.2 ~ 1.6 sec
    - RF pulse = 0.5 ~ 1.3 sec (but the power is the same; ~ 6MW)
- May require some transient shots to reach the target RF power
- ~ 4 shots including the transient shots
- DNB starts at 0.215 sec for 1.4 sec with on/off = 70/30 msec
- MSE HV: 1700V for all

(3) Absolute calibration using plasma sweeping

- Reference: 1071221002
- 2 shots with Bt = 5.4T (Set Ip range such that $q_{cyl} > 3$)
- If the situation permits, 2 shots with Bt = 4T (Set Ip range such that $q_{cyl} > 3$)
- If the situation permits, 2 shots with Bt = 6T (Set Ip range such that $q_{cyl} > 3$)
- DNB starts at 0.3 sec for 1.7 sec with on/off = 70/30 msec
- MSE HV: 1700V for all
- MSE filter setting follows the Bt values
- Make sure ECE is available

(4) Background issues (the order of priority: (d)-(a)-(c)-(b))

(a) 'Discrete' gas puffing

- Reference: 1071206022 with the following modifications
    - Nel = constant 0.8e20 m2
    - Bt flattop extended to 1.7 sec
- 2 shots with D2 puffing starting at 0.5 sec for 0.5 sec
- 2 shots with He puffing starting at 0.5 sec for 0.5 sec
- DNB starts at 0.2 sec for 1.7 sec with on/off = 60/20 msec
- MSE HV: 1700V for all

(b) 'Cryo' gas puffing

- Reference: 1071206022 with the following modifications
    - Nel = constant 0.8e20 m2
    - Bt flattop extended to 1.7 sec
- 2 shots (cryopump off)
- 2 shots (cryopump on) with the same Nel as the first two shots.
- DNB starts at 0.2 sec for 1.7 sec with on/off = 60/20 msec
- MSE HV: 1700V for all

(c) Intentional MARFE shots

- Reference: TBD
- 3 shots
- DNB starts at 0.2 sec for 1.7 sec with on/off = 60/20 msec

(d) Spectrum measurements in D and He plasmas with H modes

- Reference 1: 1080404014 including ICRF conditions
- Reference 2: 1080404015 including ICRF conditions
- Backup references for He plasmas with H modes: 1080325012, 14, 17

- 2 shots (Reference 1 & 2) with D plasma
- 2 shots (Reference 1 & 2) with He plasma
- Make sure GPI and McPherson spectrometers are in operation
- DNB starts at 0.2 sec for 1.7 sec with on/off = 60/20 msec
- MSE HV: 1600/1700/1600/1700 V

- This test has the highest priority in Part (4) but is planned at the end of the run to avoid any additional engineering procedures to go back to D plasmas.

## 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 topics (1) and (2) will address the usefulness of the MSE diagnostic if properly insulated from the ambient temperature variations. The topic (3) can provide absolute calibration data for the MSE channels that do not suffer from the shot-to-shot drift and therefore, the constraints to EFIT. The last topic will help to identify and eliminate the MSE background noises and eventually to make the MSE a reliable routine diagnostic in various H-mode and/or high-density plasma experiments.

## 7. References

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

[1] J Ko et al. “Effect of secondary beam neutrals on MSE: Experiment”, 49th APS/DPP Meeting, Orlando, FL, November 2007

[2] J Ko et al. “1080318 MSE beam-into-gas calibration (MP 491)”, MIT PSFC Weekly C-Mod Meeting, March 2008

[3] D Gwinn, *private communication*

[4] S Scott et al. “Effect of secondary beam neutrals on MSE: Theory”, 49th APS/DPP Meeting, Orlando, FL, November 2007

[5] S Scott et al. “Summary of MP491: plasma sweeps”, MIT PSFC Weekly C-Mod Meeting, July 2007

[6] S Scott et al. “Summary of MP491: MSE calibrations”, MIT PSFC Weekly C-Mod Meeting, June 2007

[7] S Scott et al. “Evaluation of MSE Steep-edge filters”, MIT PSFC Weekly DNB Meeting, Dec 2007

[8] B LaBombard, “Run Summary for 1071206 MP#475 “Cryopump Startup” – H/D control experiments”, MIT PSFC Weekly C-Mod Meeting, Dec 2007