An In-Situ Accelerator-Based PFC Diagnostic for Alcator C-Mod

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PSI science is severely hindered by the lack of comprehensive in-situ diagnostics

- There is an enormous differential between measurement capabilities of plasma and PFC-surface properties.

- The ideal PFC surface diagnostic would provide measurements:
  - in-situ without vacuum break
  - on a shot-to-shot frequency for time resolution
  - of large areas of PFC surfaces (poloidally and toroidally resolved)
  - of elemental/isotope discrimination to depths of ~10 microns

- Existing in-situ PSI surface diagnostics (QMB, colorimetry) are limited in deployment and unable to meet all requirements.

- Ion beam analysis (IBA) is the “gold standard” but it is ex-situ and intrinsically yields “archaeological” information.
Basic principles of in-situ IBA for a tokamak satisfy ideal diagnostic requirements

   - In-situ w/ no vacuum breaks? ✓

2. Tokamak's magnetic fields steer beam to PFC surfaces of interest.
   - Shot-to-shot frequency? ✓

   - Large section of PFC surfaces? ✓

4. Induced neutrons and gammas are detected, yielding material information
   - elemental/isotope detection? ✓

Courtesy of D. Whyte
Developing “neo-classical” IBA requires beam dynamics and particle transport simulations

- Unlike the “ideal” conditions of traditional IBA, computer simulation tools are necessary to address the challenges presented by the complex geometry and activated environment of Alcator C-Mod.

- A beam dynamics simulation (in IDL) has been developed for:
  - RFQ beam dynamics and magnetic steering
  - PFC surface coverage capabilities
  - optimization of operational “parameter space”

- A Monte-Carlo particle-in-matter transport simulation (in Geant4) functions as a complete “synthetic diagnostic” to:
  - simulate the start-to-finish diagnostic technique
  - guide detector placement within C-Mod superstructure
  - determine detector requirements and design
  - data interpretation
Simulation used to determine optimal RFQ injection angle and position for Alcator C-Mod

- ISSUE: Diagnostic pulse time is limited by C-Mod magnetic coil heating.
- GOAL: Optimize RFQ injection position and angle to minimize B-field.
Simulation of a realistic neutron detector spectrum from deuterium retention profile

- D+ enter PFC material and lose kinetic energy
- D+ react with retained deuterium via $^2$H(d,n)$^3$He reaction
- Neutron birth energy is proportional to D+ reaction energy at depth of reaction
- Neutron energy spectrum can be deconvolved to obtain deuterium fuel profile
Simulation of a realistic neutron detector spectrum from deuterium retention profile

- The deuterium profile above produces the neutron spectrum at right, which is convolved with geometry and detector effects.
Towards ITER: RFQ diagnostics could perform global tritium inventory of first wall

- *ITER has no planned global tritium diagnostic tool.*

- Preliminary scoping studies show the feasibility of using a 10 MeV D+ RFQ accelerator to monitor *global* tritium retention in first wall materials when toroidal field is brought down.
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Towards ITER: Preliminary studies demonstrate feasibility of tritium measurements

- 10 Mev D+ beam induces DT neutrons when reacting with retained tritium.
  - D+ beam produces DT neutron fluxes of ~10^7 cm^-2s^-1
  - 10 MeV D+ have large penetration depths in PFC materials. Tritium measurements can be made ~300 microns in CFC, ~100 microns in W

- However; significant background fluxes are present from activated radio-isotopes in first wall and shield, even after 2 weeks of dwell-time.†
  - neutrons ~10^5 cm^-2s^-1, gammas~10^{11} - 10^{12} cm^-2s^-1
  - Ratio of signal to background neutrons: ~10^2  good!
  - Ratio of signal to background gammas: ~10^{-4} - 10^{-5}  bad!

- Neutron spectroscopy with liquid organic scintillators and digitized pulse processing techniques will be combined with detector shielding to vastly improve the signal to background ratio.

Conclusion

- In-situ Ion Beam Analysis in the tokamak is the leading candidate to provide time- and depth-resolved measurements for a wide variety of PSI phenomena.

- Robust simulation tools are facilitating the development of the prototype IBA diagnostic on Alcator C-Mod.

- An extension of in-situ Ion Beam Analysis to the ITER tokamak could function as a much-needed global tritium diagnostic.