Diagnostics for Burning Plasma Physics Studies: A Status Report.

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UFA Workshop on Burning Plasma Science

December 11 - 13
Austin, TX

Aspects of Plasma Diagnostics to achieve Burning Plasma Physics Goals

- The diagnostic set should provide the same quality of data as in best present-day devices.
- High quality, reliable information on many plasma parameters will have to provide control signals.
- New information about the alpha-particles.
- The neutron radiation environment must be considered in design of the diagnostic system.

The Impact of the Neutron (Gamma) Environment

- Special design and materials to be used for in-vessel systems
  - Also prevents the use of many diagnostic components.
- Requirement for thick shielding, penetrated by complex labyrinths
- Constraint on the use of optical components, especially fiberoptics.

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Outline of Talk

- **Specifications of the measurement goals,**
- **Aspects to be considered in design:**
  - **Port configurations,**
  - **Radiation effects,**
  - **Specific issues for different diagnostic techniques.**
- **Alpha-particle measurement.**

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Examples of Target Plasma Measurement Capability proposed for ITER-FEAT

PARAMETER	PARAMETER RANGE	SPATIAL RESOLUTION	TIME RESOLUTION	ACCURACY
Plasma current	0.1 – 17.5 MA	Not applicable	1 ms	1% (I_p>1 MA)
Total neutron flux	$1x10^{14}$ - $1x10^{21}$ n s^{-1}	Integral	1 ms	10%
Neutron & α-particle source	$1x10^{14}$-$4x10^{18}$$ns^{-1}$$m^{-3}$	a/10	1 ms	10%
Divertor surface temperature	200 - 2500°C	-	2 ms	10%
Core electron temp-erature profile	0.5 - 30 keV	a/30	10 ms	10%
Edge electron density profile	(0.05 - 3) x 10^{20} m^{-3}	0.5 cm	10 ms	5%
Radiation profile in main plasma	0.01 - 1 MWm^{-3}	a/15	10 ms	20%
Radiation profile in divertor	≤100 MWm^{-3}	5 cm	10 ms	30%

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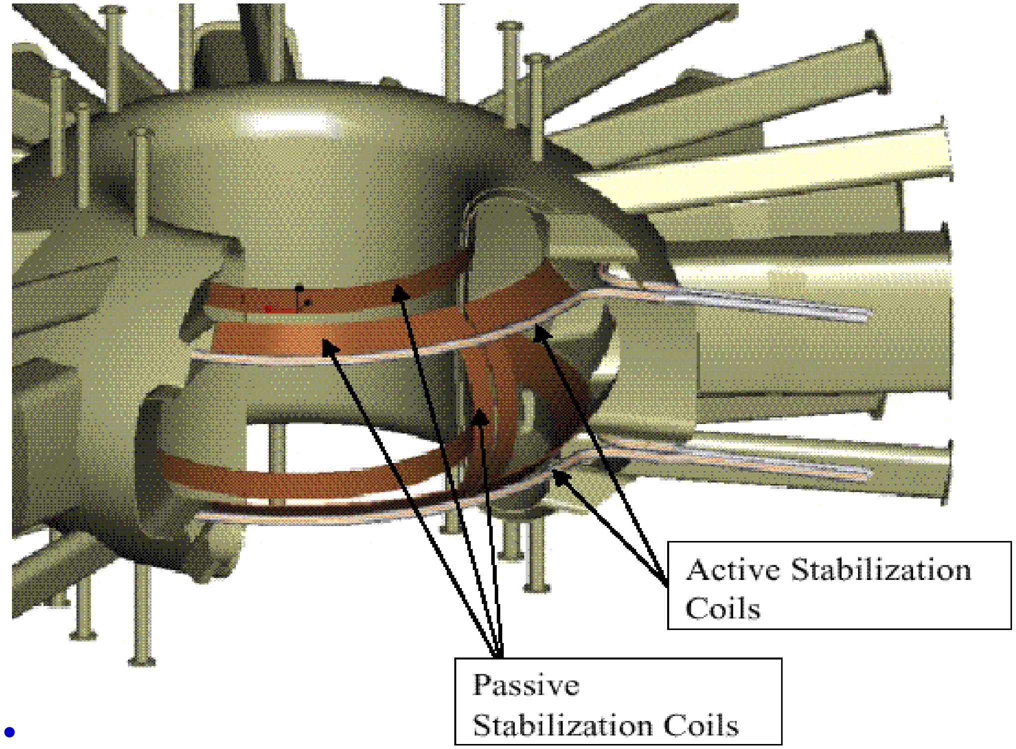
Simplified List of Measurements for Input to Control Systems

- **Fast Plasma Shape and Position Control:**
  - **Magnetic diagnostics, IR camera**
- **Kinetic Profile Control:**
  - **Thomson scattering, Interferometer/Polarimeter, Reflectometer, ECE, CXRS (T_i and He-ash), Neutron Detectors,**
- **Current Profile, Rotation Control:**
  - **Magnetic diagnostics, Thomson scattering, MSE, CXRS**
- **Optimized divertor operation:**
  - **Interferometry, IR camera, Spectroscopy**
- **Fueling control:**
  - **D,T monitoring (edge good enough?)**
- **Disruption prevention (First-wall/ Divertor Protection):**
  - **Magnetic diagnostics (β; MHD), kinetic profile set**

Likely Port Configuration

- Large radial ports with extended necks,
- Very small vertical ports,
- X-point aligned ports to be shared with in-vessel services, and "blocked sightlines", but could be used for divertor sightlines.



FIRE vacuum vessel concept

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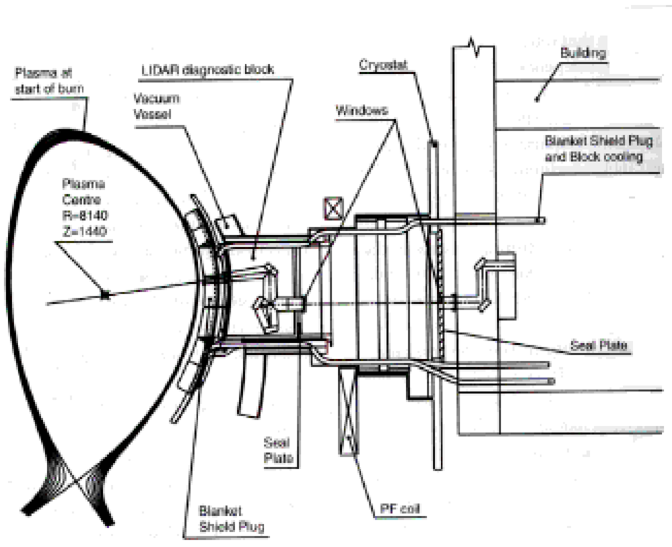
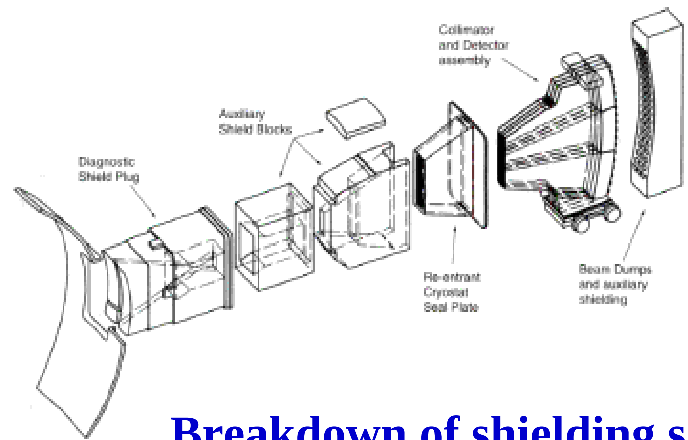
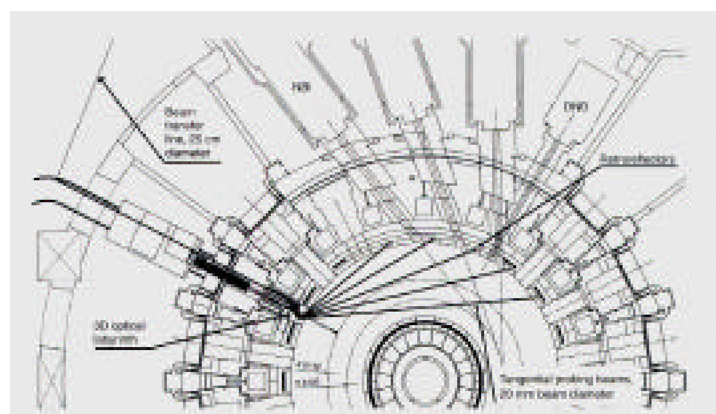
Access Configurations for Diagnostics



ITER port for LIDAR Thomson scattering



Breakdown of shielding sections for ITER neutron camera



Tangential arrangement proposed for interferometer/polarimeter in ITER

Radiation Effects
(Ceramics (1), Optical components (2), Mirrors (3))

	First Wall (Gy/s)	Interspace Structure/ Shielding	Outside Vac. Vess. Port (Gy/s)	Fluence
ITER-FEAT (700 MW, 0.8 MW/m^2)	**4x10^3** **+ neutrals** →	<---------------> →	**5**	**Issue at 1st wall (long-term damage)** **Few x 0.1 dpa**
FIRE (220 MW, 3.6 MW/m^2)	**2x10^4** **+ neutrals** →	<---------------> →	**20**	**Non-issue**
Components	**Magnetics (1) -----** <-------**MI-cable (1)--** **Lost-Alpha** **Retroreflectors (3)** **Thermocouples (1)** **Gauges (1)**	**------>** **Mirrors (3)** **---------------->**	**Windows (2)** **Fiberoptics (2)** **Optical comp-onents ? (2)** **Vacuum-diag.** **Detectors? (1)**	

Numbers are approximate and average

K. M. Young 21 September 2000

Radiation Effects on Diagnostic Components

- **Diagnostic Component — Worst Radiation Problem**

- **Ceramics (and Detectors) — Electrical (RIC, RIED, RIEMF, TSC)**
  - **Studies of RIEMF in progress for MI-cable used in coils**

- **Fiberoptics (and Windows) — Absorption, Luminescence, Numerical aperture**
  - **Developments of new doped fibers in progress for reducing absorption**

- **Mirrors — Mechanical + Neutrals in Surface Modification**
  - **Studies of surface damage impact and of surface preparations in progress**

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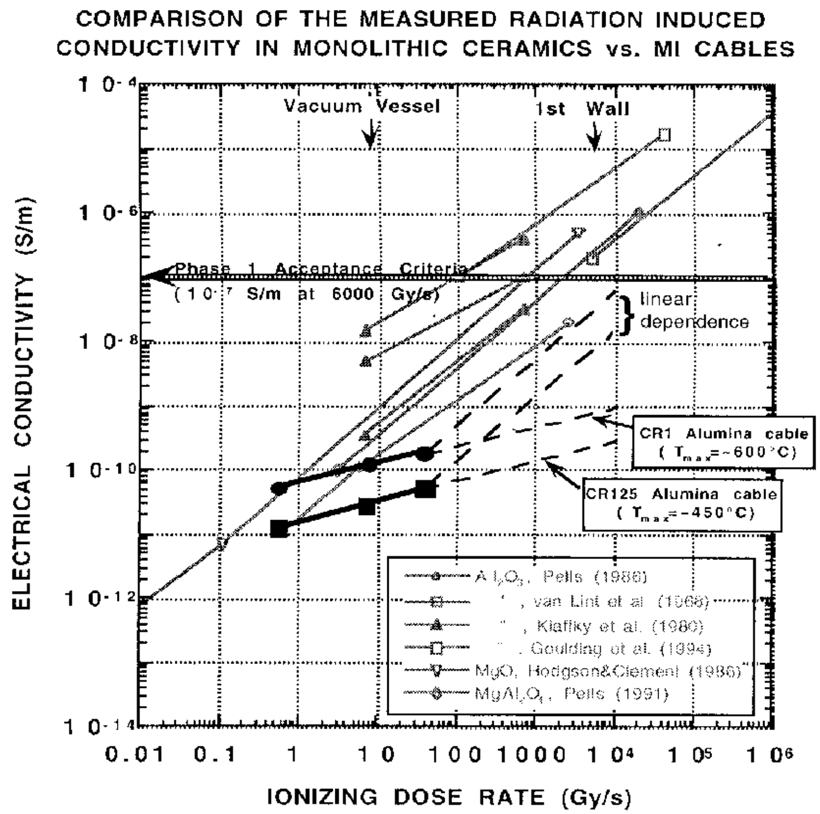
Magnetic Diagnostics: Issues

- Loops, coils, MI-cable must be inside vacuum vessel,
- Maximally unfriendly environment; RIC and RIEMF, temperature, neutral particles,
- Some protection possible with blanket.



Radiation Effects on Optical Systems

- Radiation discolors/blackens optical components,
- Hence must use reflective optics in high-radiation areas.
- Optical fibers suffer from:
  - Prompt luminescence,
  - Prompt absorption,
  - Long - term absorption damage,
  - Effective change in numerical aperture.
- Running fibers hot only affects the long-term absorption.
- Great disparity in radiation effects on nominally identical fibers.

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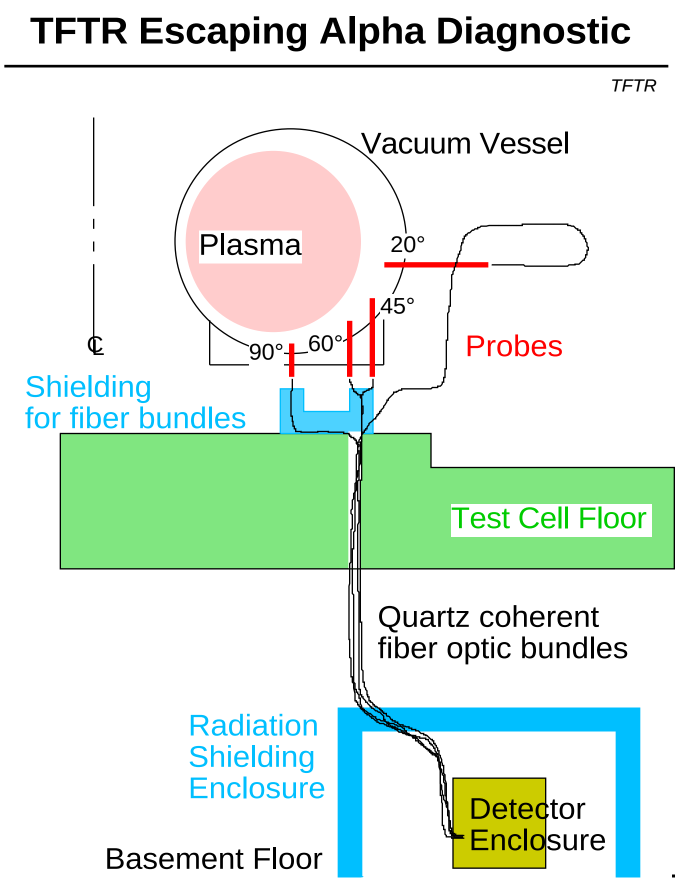
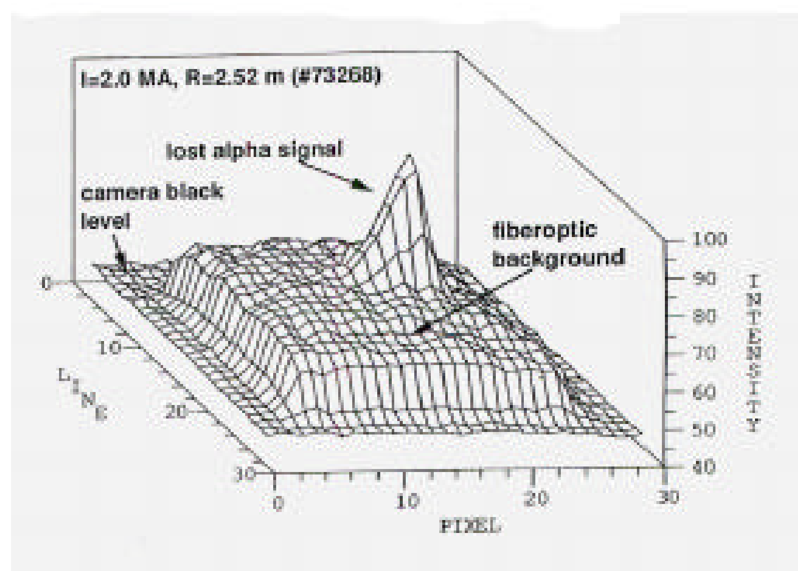
Luminescence (and Absorption) Impact on Measurement in an α-diagnostic

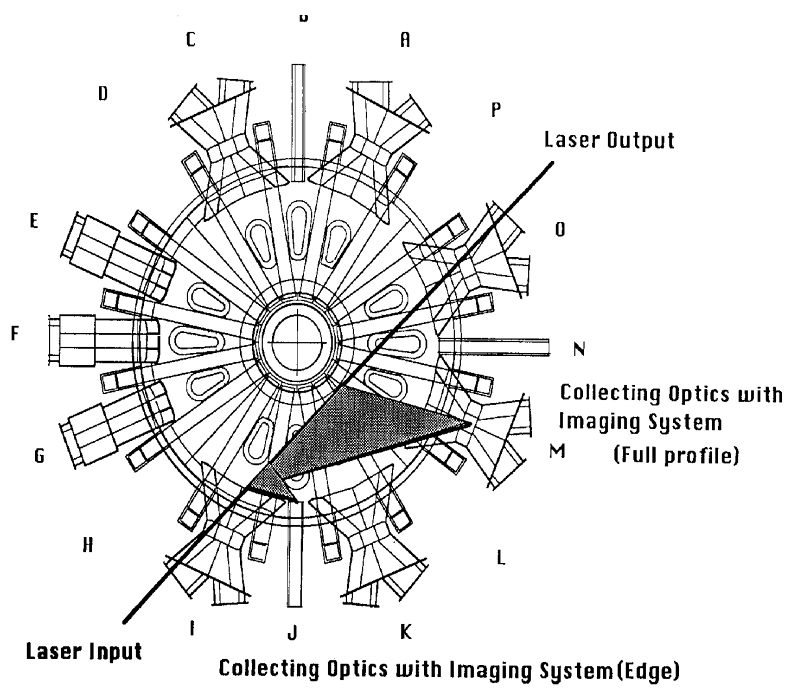




Lost-α diagnostic on TFTR with fiberoptic outside vacuum vessel.
TFTR shot at 5MW ($5x10^{-2}$ MW/m^2 at first wall.
Dose at front end of fiber ~ 30 Gy/s

Issues for Individual Systems

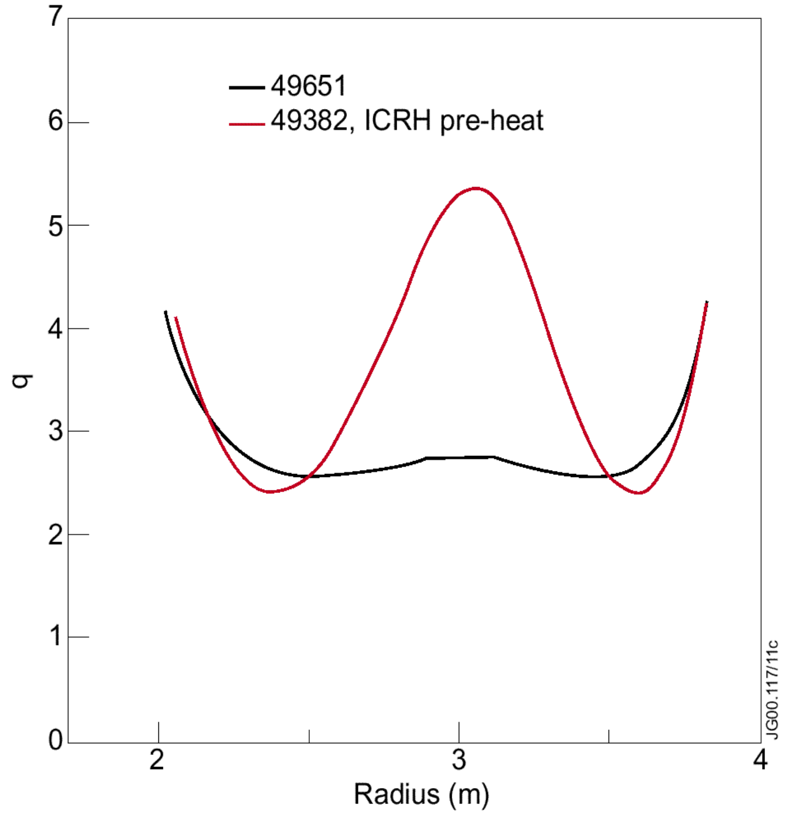
- Size and spatial resolution affects choice of Thomson technique, other methods,
- Magnetic field, density range affect choice of microwave diagnostics,
- X-ray diagnostics particularly susceptible to failure in radiation background,
- Auxiliary heating technique affects diagnostics.



KSTAR Concept for Thomson Scattering

Good Profile Diagnostics often use a Neutral Beam

- $T_i(r)$, $v_f(r)$, $v_q(r)$, $q(r)$, $n_{HE\text{-}ash}(r)$, $(E_r(r))$,
- Good poloidal rotation needs opposing views; not possible,
- Diagnostic beam near-radial; penetration at ~100keV/amu problematic,
- Diode beam, $5x10^9$W for <1ms for CXRS?
- MSE prefers 3 - 400 keV/amu.



MSE q-profiles in the target phase of two JET Optimized Shear discharges. The q-profile for shot 49651 is typical for JET OS plasmas. Shot 49382 had LHCD and ICRF in the pre-heat as well as the beams and it shows a strongly reversed q-profile (Stratton, Hawkes, et al.)

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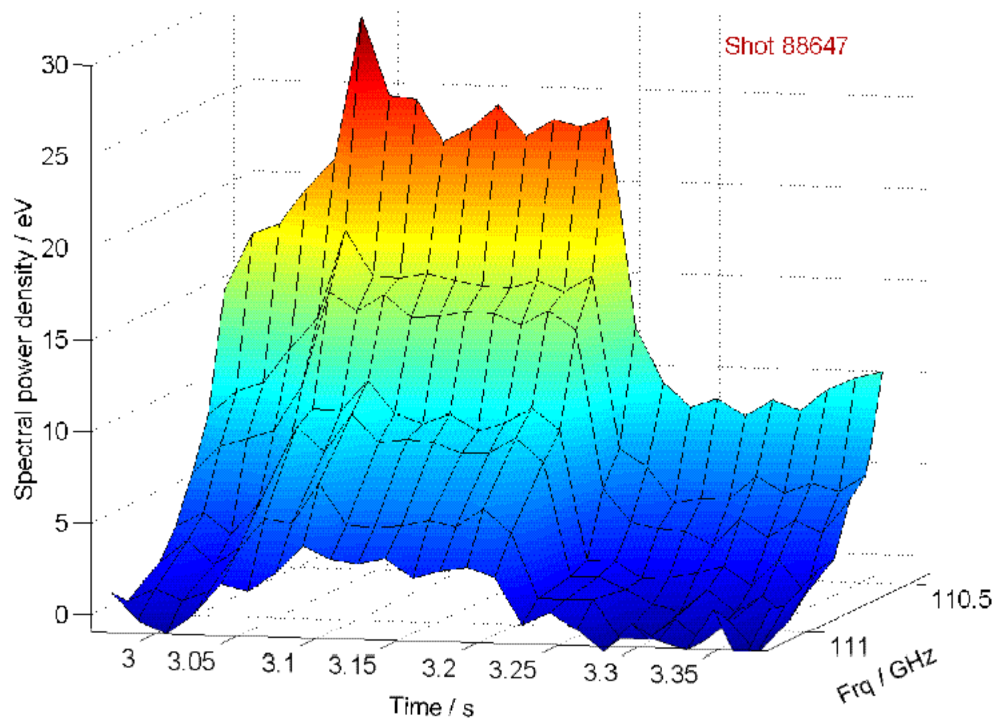
Divertor Diagnostics

- Divertor diagnostics must relate to the physics goals of the device
  - Needs strong modeling interaction,
  - Important for impurity, fueling and ash measurements, tritium accountability,
  - Need validated control schemes.
- Detachment monitoring.
- Survivability of position and shape measurements.

Diagnostics for Alpha-Particle Physics

- Lost fast-ion detectors and IR camera,
- α-CHERS,
- Li-pellet, fast neutral particle analyzer,
- Collective scattering (CO_2?),
- Knock-on neutron,
- New confined-α detector?
- High-frequency Mirnov coils, reflectometry.



Fast-ion spectra from Collective Scattering in TEXTOR (Bindslev, Woskov et al.)

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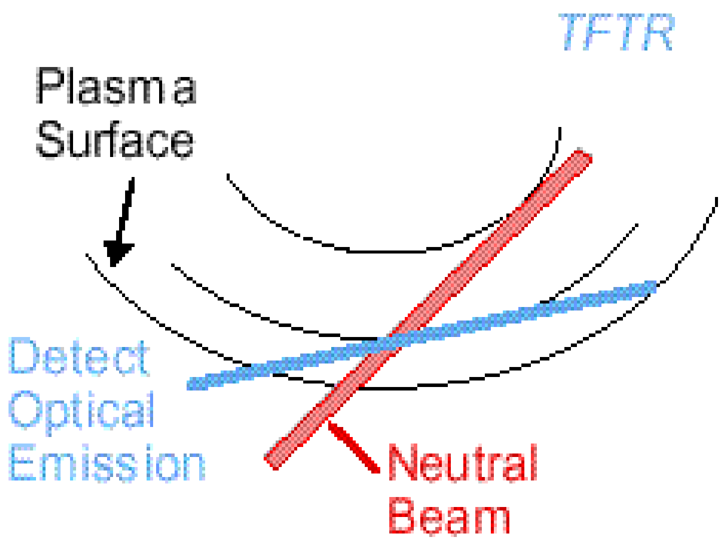
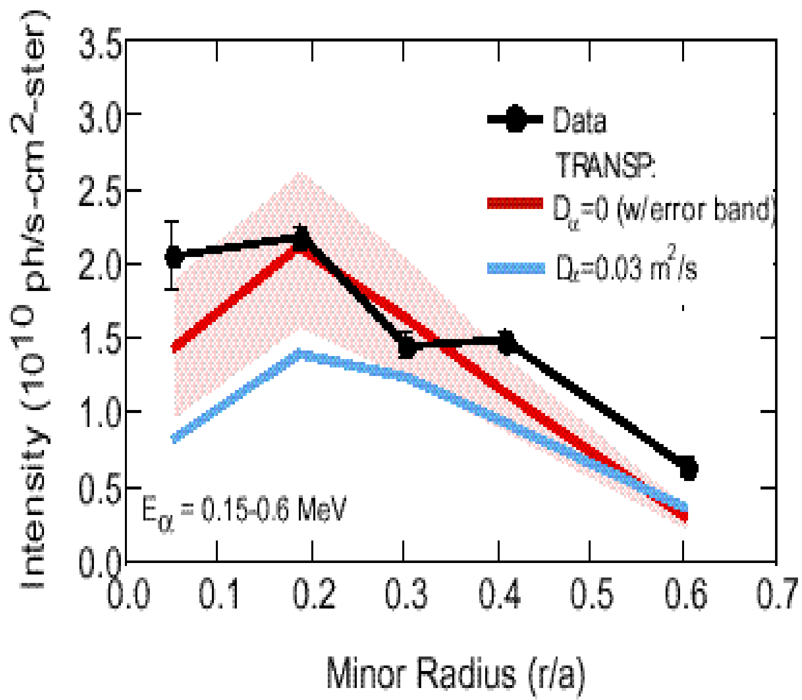
Alpha-Chers can Provide Absolute Measurement of some Confined Alphas



Charge Exchange between fast beam ions and slowing-down Alphas



- $0 \leq D_\alpha \leq 0.03\ m^2/s$

No data taken in TFTR during neutron pulse.

Improved optical design should provide time-resolved measurements of alpha distribution

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R&D Concerns

- What are impacts of high-field, highly shaped, high-$n_{e,}$ high radiation, RF-only on diagnostics selection and development?
  - Radiation "hardness" of diagnostic components?
  - Reliability of magnetic diagnostics?
  - Lifetime of plasma-facing mirrors, other optical elements?
  - ECE overlap?
  - Interferometry refraction/wavelength?
  - Functionality of x-ray systems?
  - CXRS and MSE techniques; capability for diagnostic neutral beam(s)?
  - Inside-launch reflectometry?
  - Confined alpha-particles?

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What do you need?

- Will the new physics need the same high resolutions?
- What input will be needed for control systems?
- What is needed for fluctuation (turbulence) measurement?
- What level of detail is needed about the α-particles?

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