Diagnostics for Burning Plasma Physics Studies: A Status Report.

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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.

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.**

Examples of Target Plasma Measurement Capability proposed for ITER-FEAT

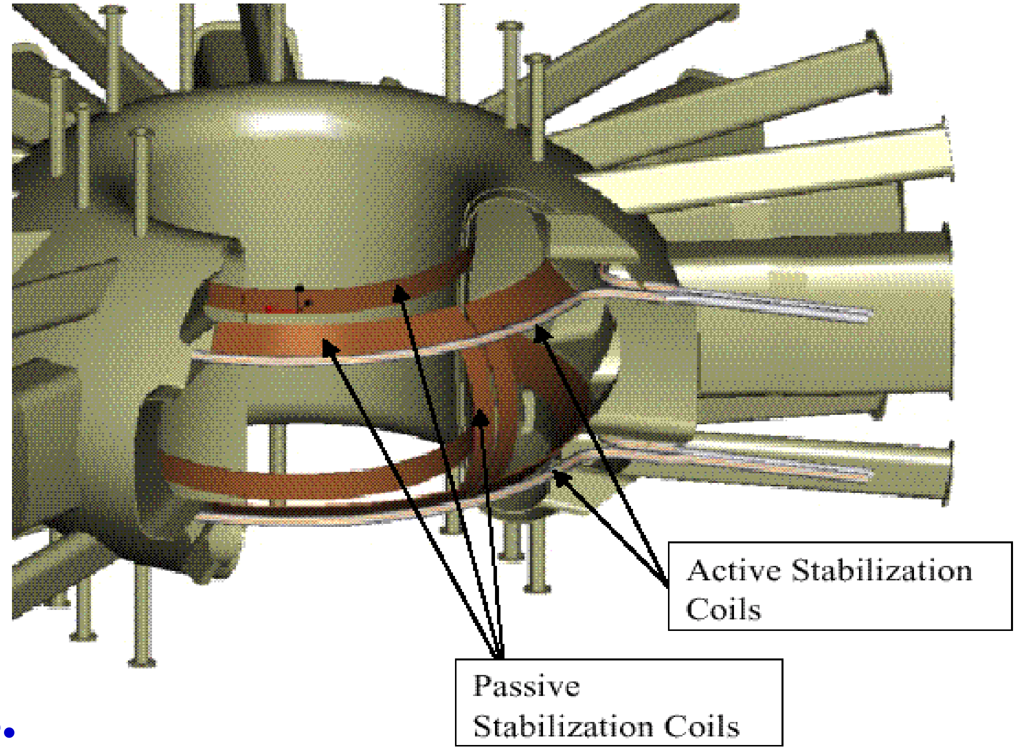
PARAMETER	PARAMETER RANGE	SPATIAL RESOLUTION	TIME RESOLUTION	ACCURACY
Plasma current	0.1 – 17.5 MA	Not applicable	1 ms	1% (I_p>1 MA)
Total neutron flux	$1x10^{14}$ - $1x10^{21}$ n s^{-1}	Integral	1 ms	10%
Neutron & α-particle source	$1x10^{14}$-$4x10^{18}$ $ns^{-1}m^{-3}$	a/10	1 ms	10%
Divertor surface 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%

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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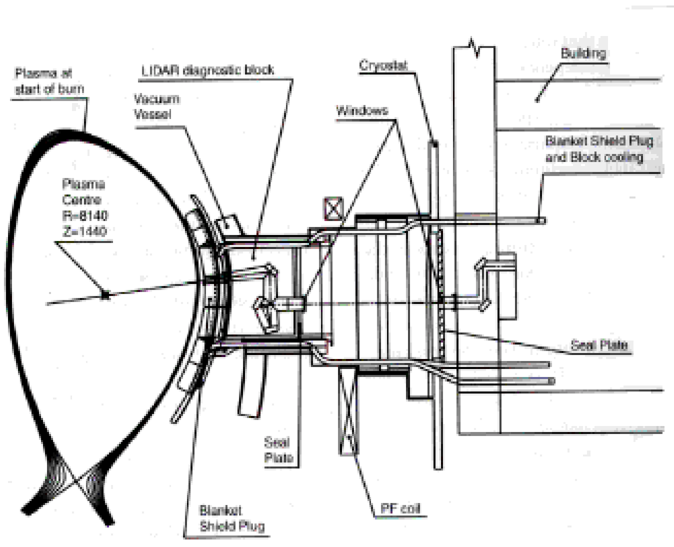
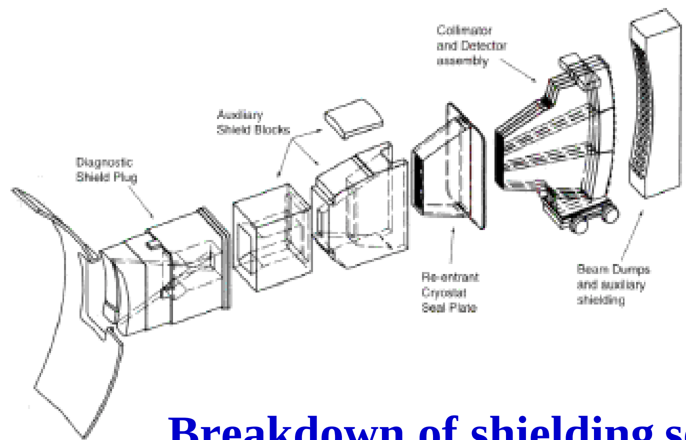
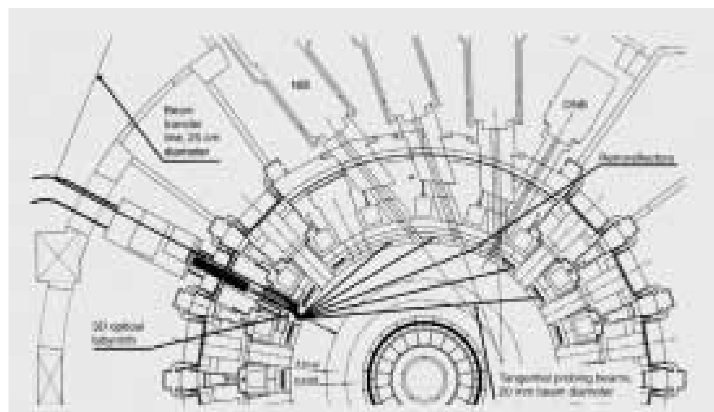
Access Configurations for Diagnostics



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

Radiation Effects on Diagnostic Components

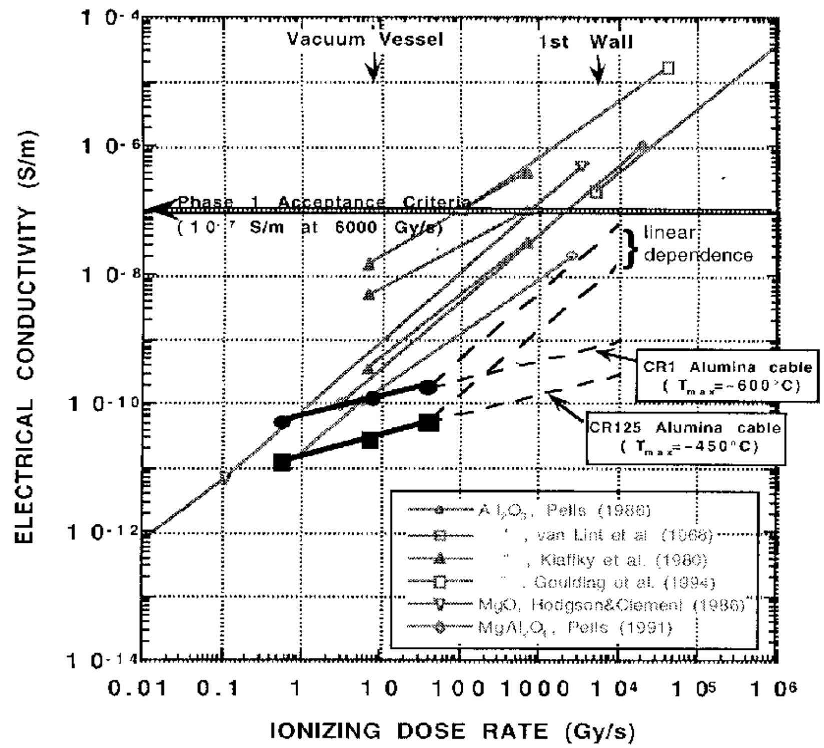
Diagnostic Component	Worst Radiation Problem
Ceramics (and Detectors)	Electrical (RIC, RIED, RIEMF, TSC)
Fiberoptics (and Windows)	Absorption, Luminescence, Numerical aperture
Mirrors	Mechanical + Neutrals in Surface Modification

- **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

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.

COMPARISON OF THE MEASURED RADIATION INDUCED CONDUCTIVITY IN MONOLITHIC CERAMICS vs. MI CABLES



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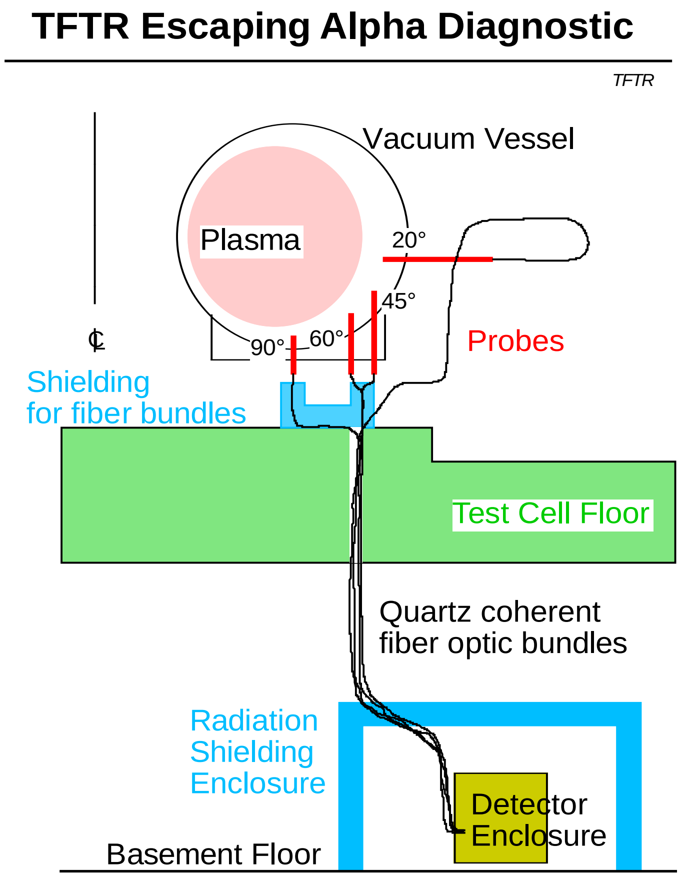
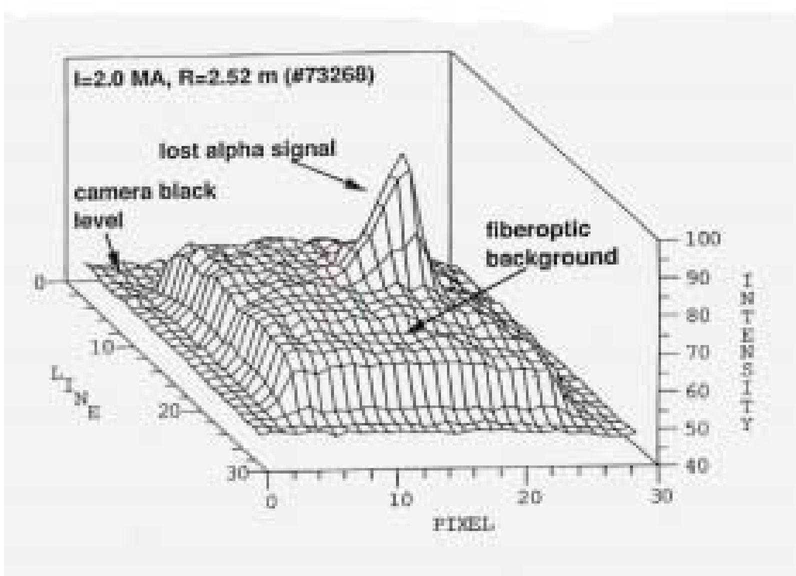
Luminescence (and Absorption) Impact on Measurement in an α-diagnostic

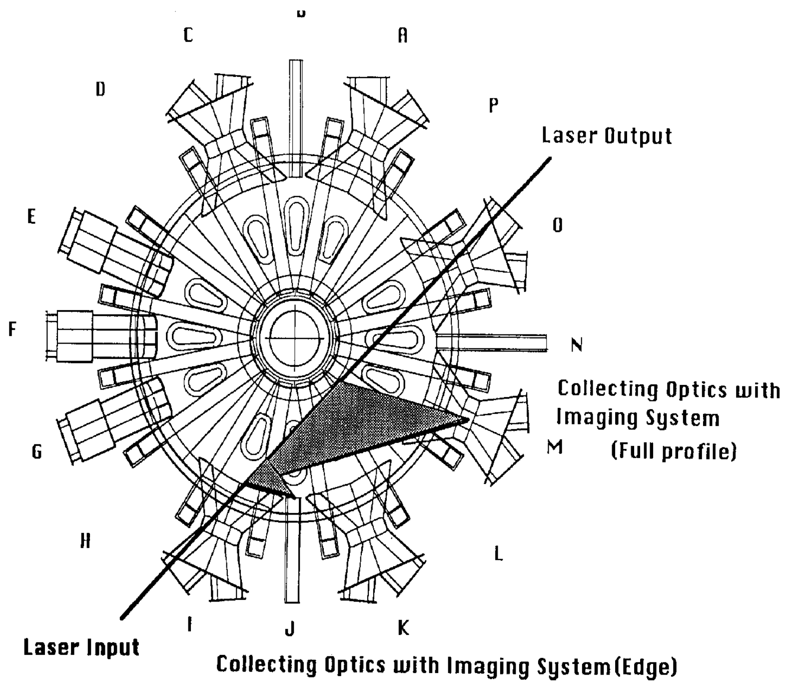




Lost-α diagnostic on TFTR with fiberoptic outside vacuum vessel.
TFTR shot at 5MW ($5x10^{-2}$ MW/m^2 at first wall.
Dose at front end of fiber ~ 30 Gy/s

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

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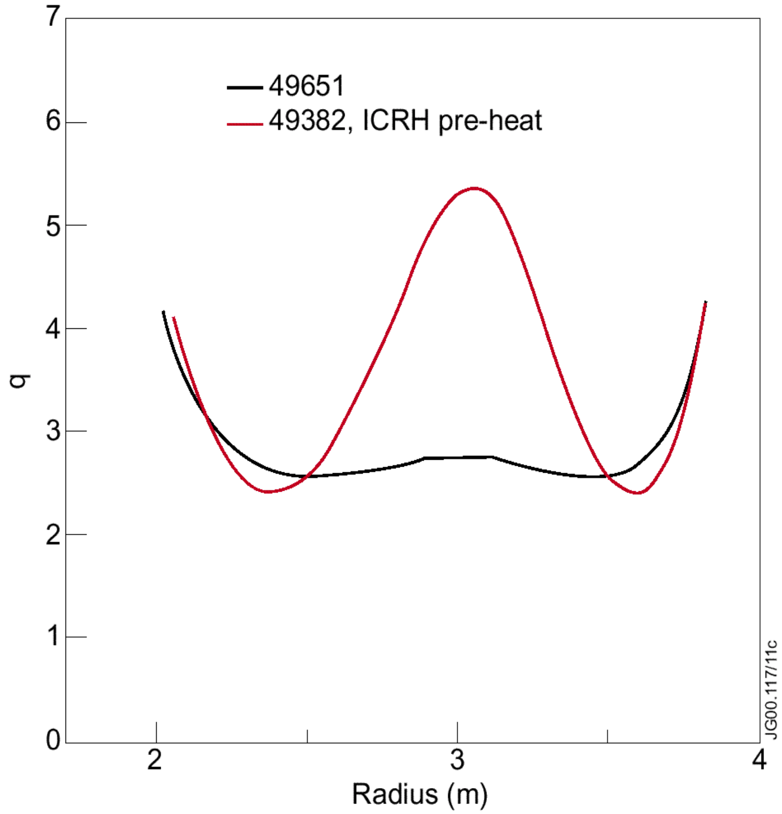
Good Profile Diagnostics often use a Neutral Beam

- $T_i(r)$, $v_f(r)$, $v_q(r)$, $q(r)$, $n_{HE\text{-}ash}(r)$, $(E_r(r))$,
- 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.

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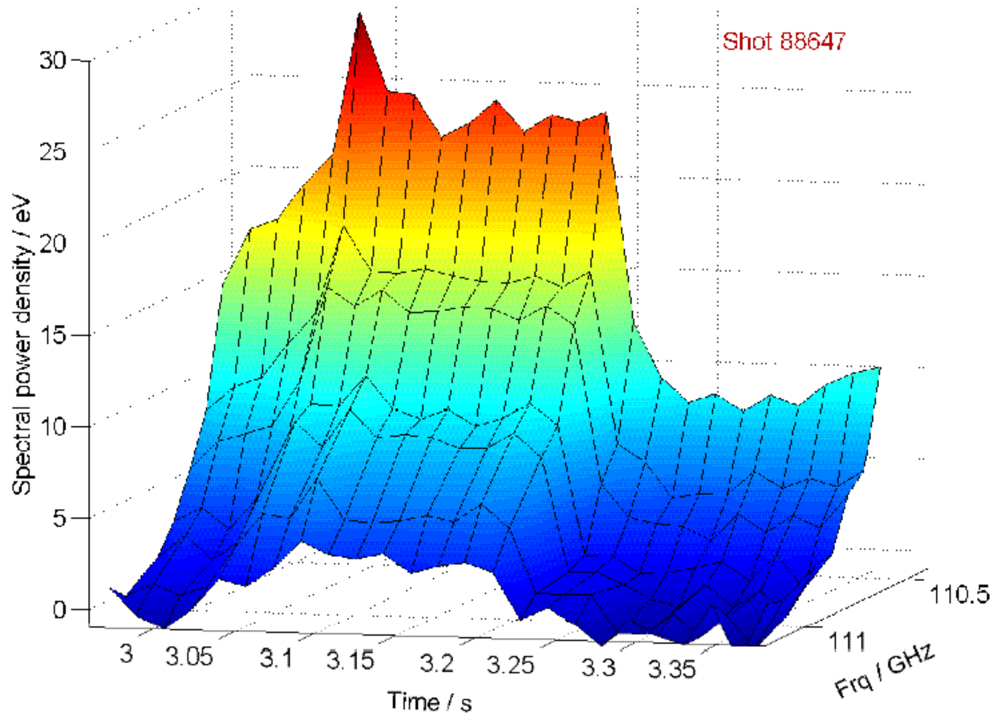
Diagnostics for Alpha-Particle Physics

- 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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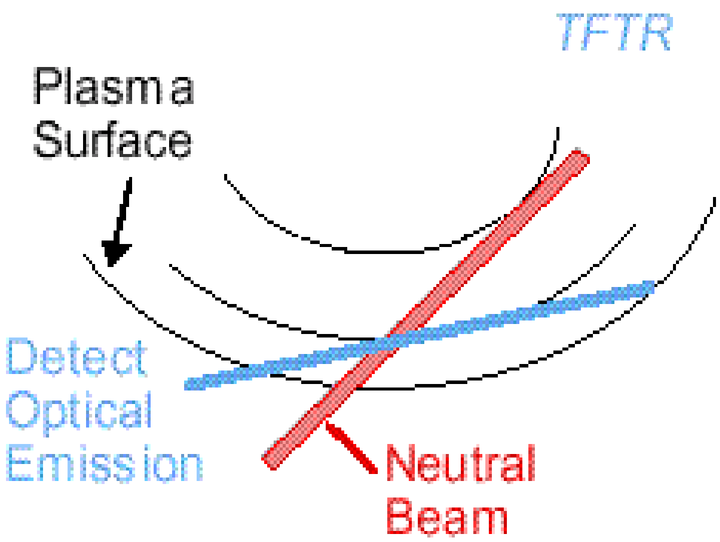
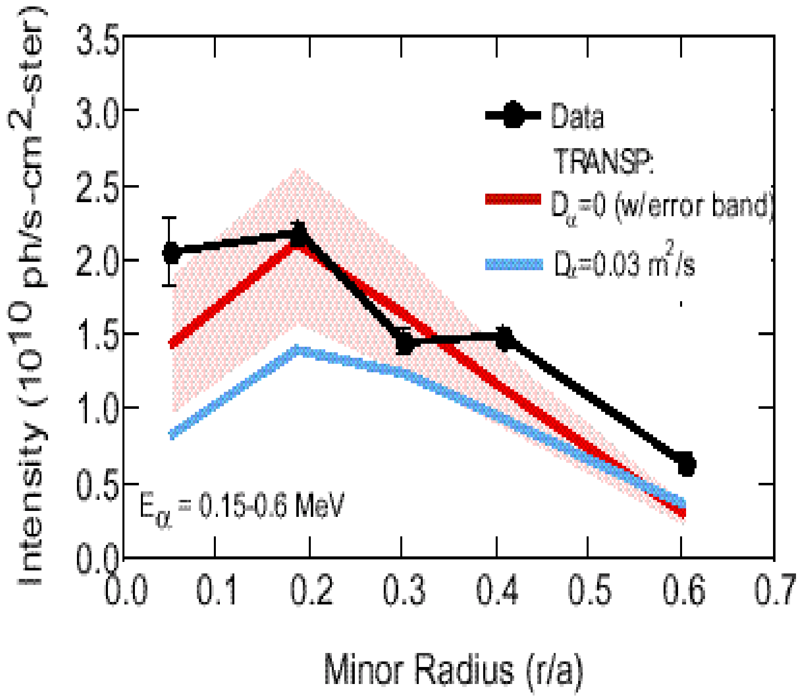
Alpha-Chers can Provide Absolute Measurement of some Confined Alphas



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

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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