Diagnostic experience with DT fusion neutrons on TFTR

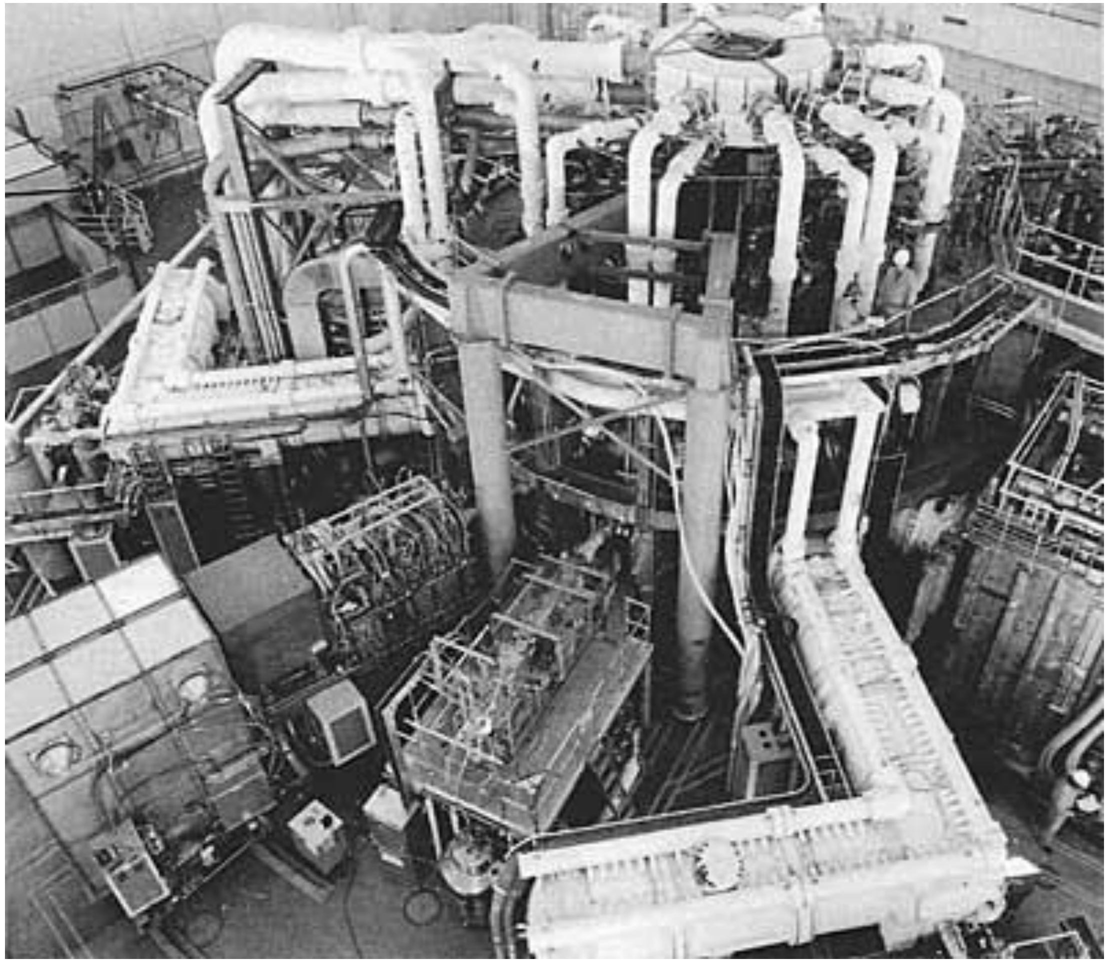
Kenneth M. Young

Long-time ago, Head of TFTR Diagnostics

with information supplied by many scientists who worked on TFTR

Jim Strachan led the Fusion Products team

TFTR shut down over 25 years ago.

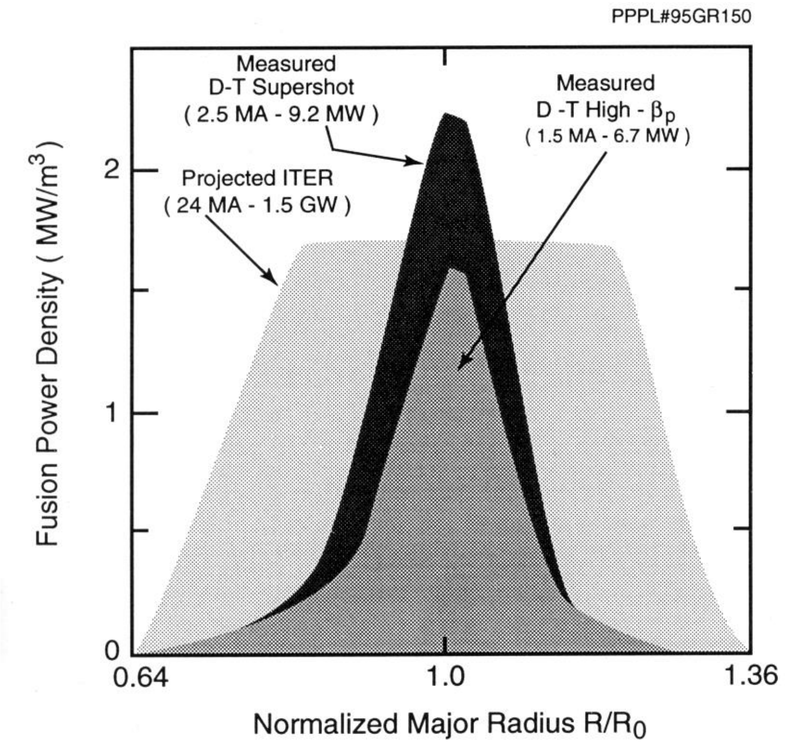


Fusion Community does not fullyunderstand the impact of fusion neutrons

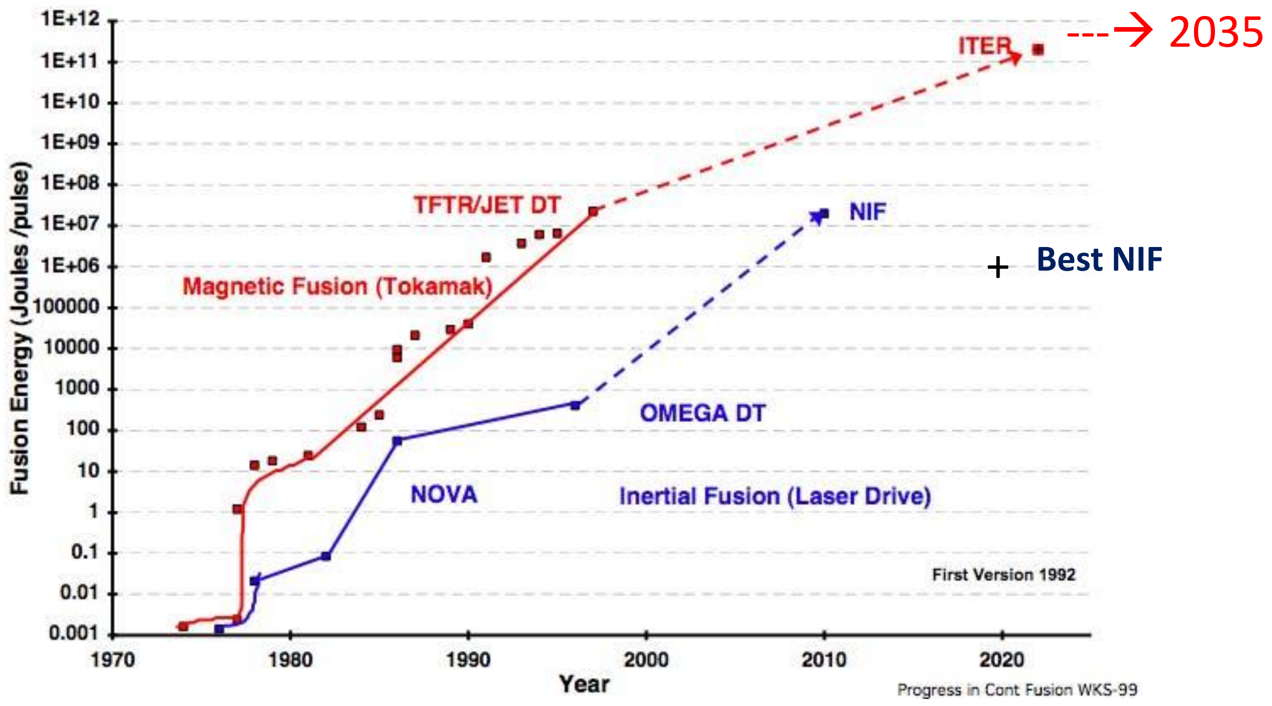
- Extremely short times being promised to achieve a fusion reactor,
- Proposals to install fiber-optic based bolometers and magnetic loops close to plasma,
- Poor funding, particularly in U.S.A., for studying materials close to the plasma,
- Lack of interest in neutron measurements on current devices,
- Engineering challenges forced by narrow gaps and tight tolerances for large scale devices,
- Lack of development needed for measurement and other anciliary equipment for fusion devices

Old fogey talking about neutron impacts here

TFTR relevance to ITER



Spatial profiles of the fusion power density of 2 TFTR plasmas compared to that projected for ITER (1995 numbers)



Progress of tokamaks in obtaining fusion energy from DD and DT reactions for OH, NBI, and RF-heated plasmas. (Meade, 2010)

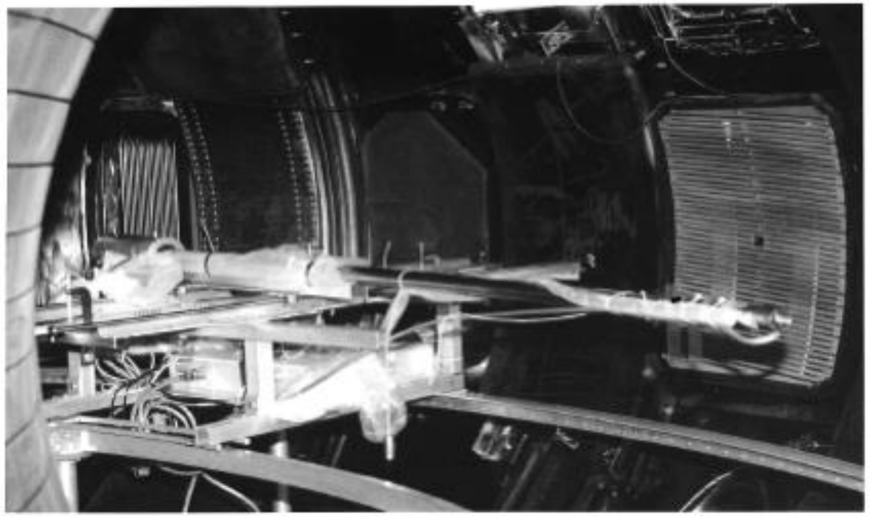
Introduction to neutron calibration for ITER
(2013 Neutron calibration meeting)

- Calibration of individual detectors to check at DA:
  - Detectors meet specification,
  - Connectivity and electronics function meet specification,
    - Desirable but probably not practical;
      - Functioning of detectors at relevant temperatures and magnetic fields at relevant orientation.
- Pre-in-vessel calibration checks at ITER:
  - Detectors fully operational with relevant grounding scheme and power supplies:
- In-vessel calibration of neutron measurement instruments:
  - Detector plus surrounding material make up an instrument:
    - Some instruments need calibration by in-vessel source:
      - e.g.(some or all) flux systems, all camera channels, one activation system,
    - Other instruments by cross-calibration through specially targeted plasma shots:
      - e.g. low-sensitivity flux systems, activation systems.

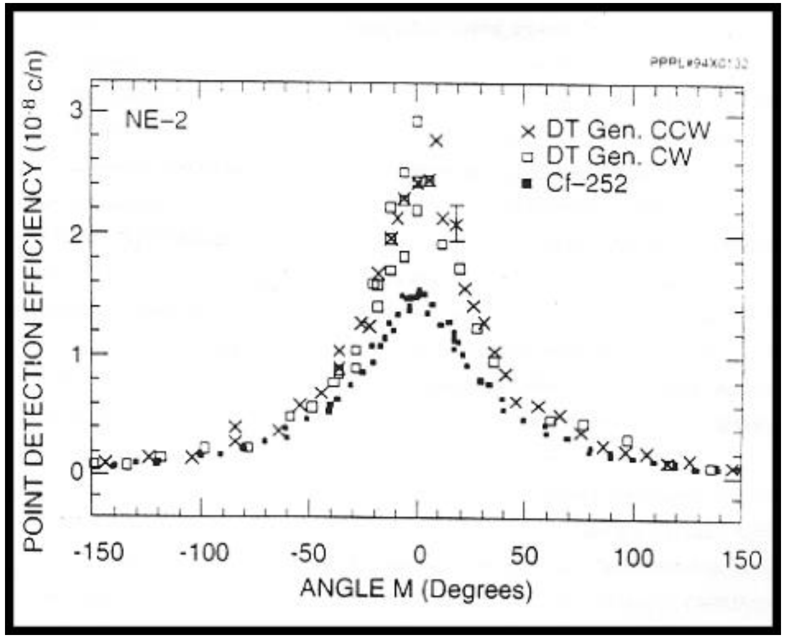
Neutron diagnostics for DT on TFTR

Neutron Diagnostic	Purpose	Number of Papers
Flux Monitors (Epithermal System)	Calibrated flux	4
Activation system	Fluence in shot	8
Camera (10-12 Channel Collimator)	Neutron source profile	9
He^3 Ionization Chamber	Ion temperature (DD only)	1
He^4 Proportional Counters	Triton burn-up (DD)	1
Silicon diodes	Discrimination of 14 MeV neutrons	4
Scintillating fibers	14 MeV neutrons within large DD background	2
ZnS scuntillators	Fast changes, fluctuations	1
Cotetra Spectrometer	Japanese development	1
Natural diamond detectors	Demonstration of function, DT spectra	3
Bubble chamber	>14 MeV a- generated neutrons (failed)	1
He^3 Gas cell	Tritium-breeding assessment	1
	In-vessel Calibration	**10**

TFTR: Neutron calibration



14MeV “bore-hole” neutron generator on track in vacuum vessel

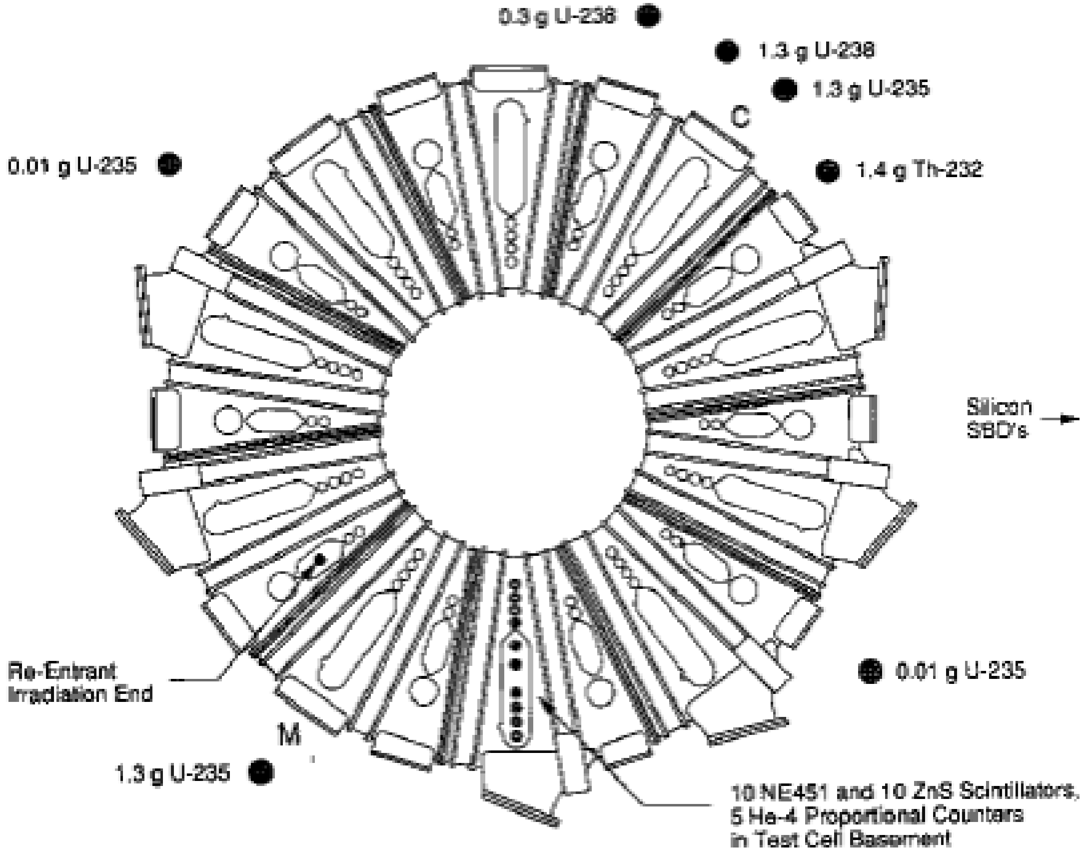


Toroidal steps of 20 cm to 75 cm

Flux monitor fission chamber

- **Multiple detector types and locations; operated in counting, Campbell. and current modes; uses included total yield, spatial source, n_D/n_T ratio, fluctuations.**
- **Detailed calibration by well characterized sources inside vacuum vessel: ^{252}Cf and D-T generator (~1 x10^8 n/s)**
- **Accuracy determined for source strength ±12%.**
- **Low neutron count rates allow noise to matter (e.g. micro-arcing in fission chambers).**
- **Code calculations indicated 3 - 4% change for presence of coil coolant.**

Calibration of the main neutron diagnostics

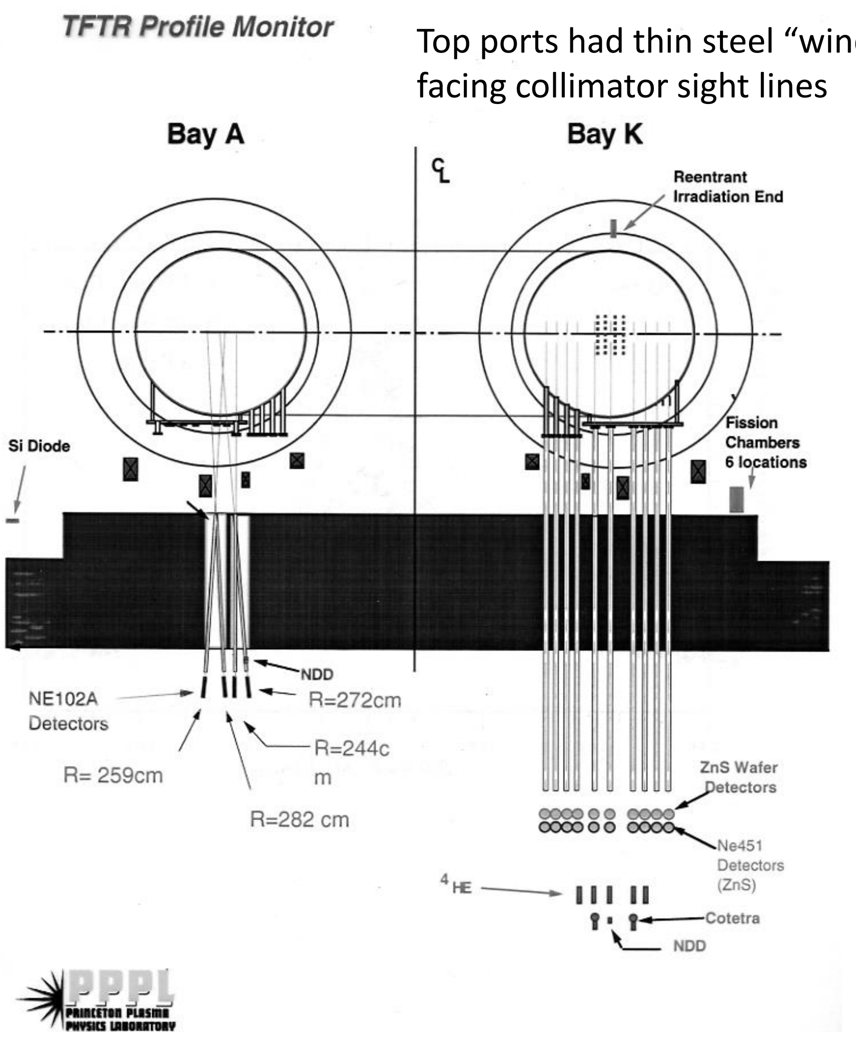


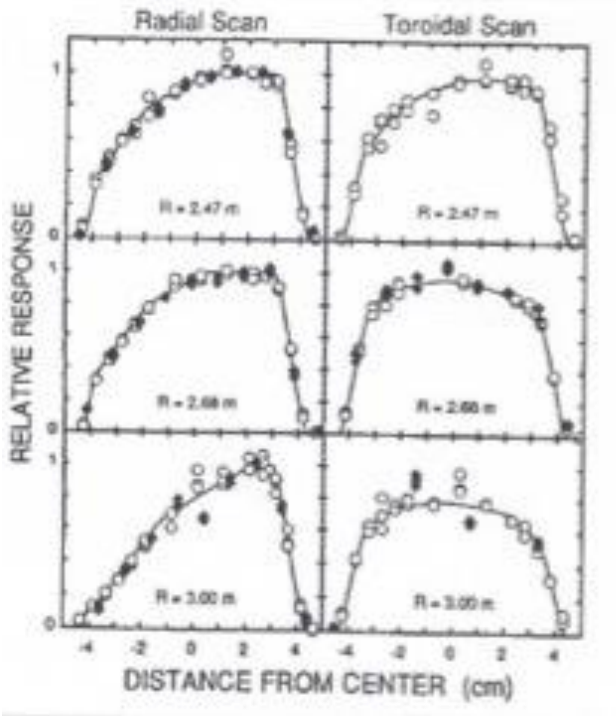
- **The *in situ* calibration concentrated on three detector systems, two 1.3 g ^{235}U fission chambers, the 10 channel neutron collimator, and a reentrant irradiation end for activation analysis.**
- **Calibration took several days.**
- **The less-sensitive fission chambers were cross-calibrated using moderate-emission DT plasma shots.**

Roquemore, Strachan

TFTR: Calibration of the neutron “camera”

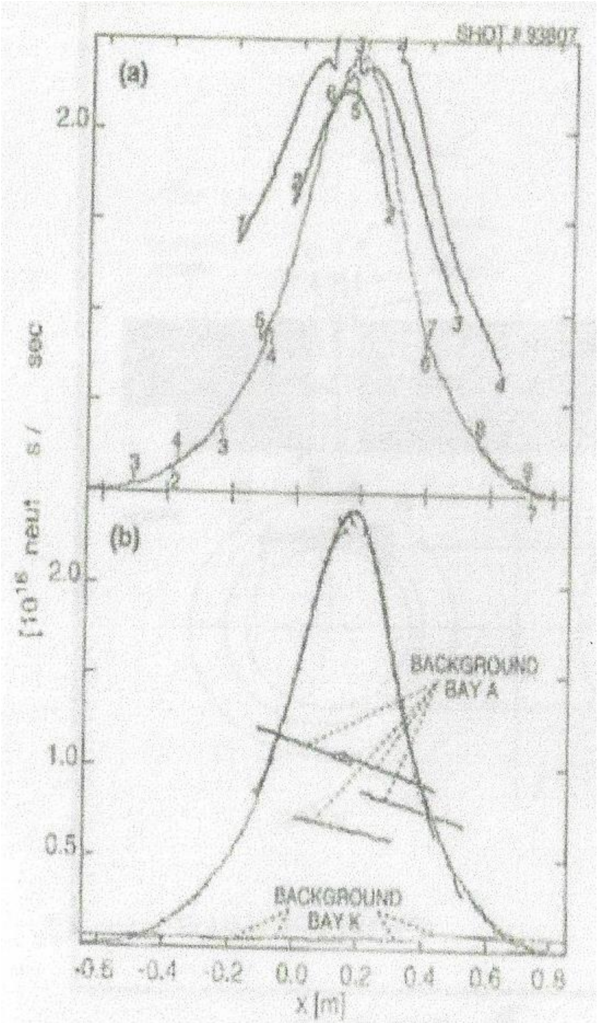
Top ports had thin steel “windows” facing collimator sight lines





- In-vessel calibration carried out for vertical sightline collimator.
- Each collimator channel was scanned in the toroidal and radial direction using both the DT generator and Cf source.
- <2% scattered neutrons due to viewing “dump” and shielded window.
- As-built had channel asymmetries.
- ~14% calibration accuracy.
- With small plasmas, inward or outward could get scattering info.

TFTR: Jog-shot neutron cross-calibration



v. Goeler, RSI, 1997.

- Bay-K collimator set viewed the plasma through thin (2-3 mm) steel and toward thin “dumps” on top.
- Bay-A collimator viewed plasma through standard vessel cover plate thickness and had similar cover plate on top.

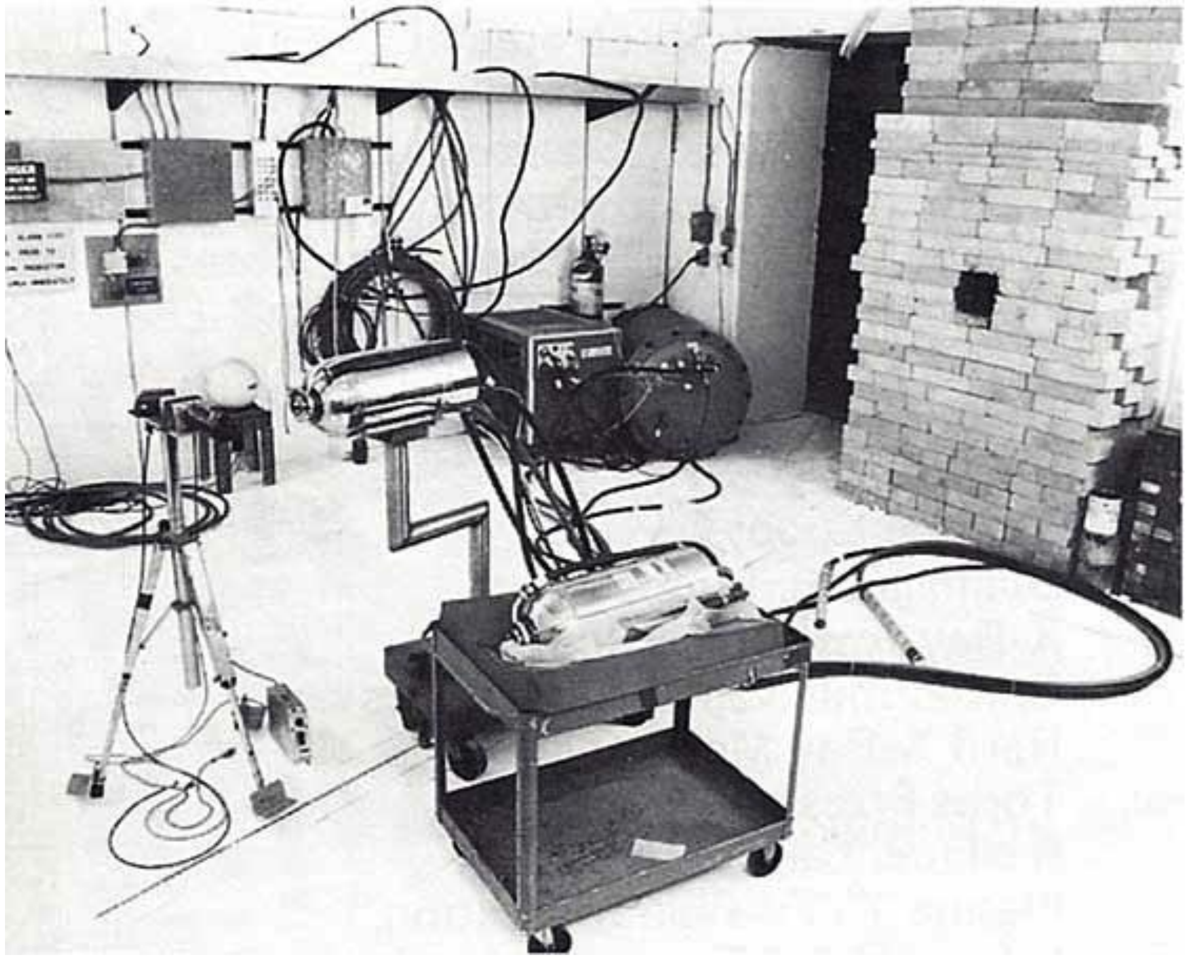
- TFTR fortunate in having a vertical neutron “camera” not looking at core of device.
- Small DT plasma could be moved ~ 0.35m in 70ms across face of collimator pipes.

- Scattering in vessel steel contributed about 35% of signals at bay-A.
- No coil material in either sightline

- Fusion power numbers based on 4 independent calibration techniques.

See end of talk for list of references on calibrations.

TFTR: Neutron test facility



Facility previously used in neutral beam development.

Guesstimate of actual size ~12 m x ~10m x ~5m high.

Picture shows two neutron generator heads.

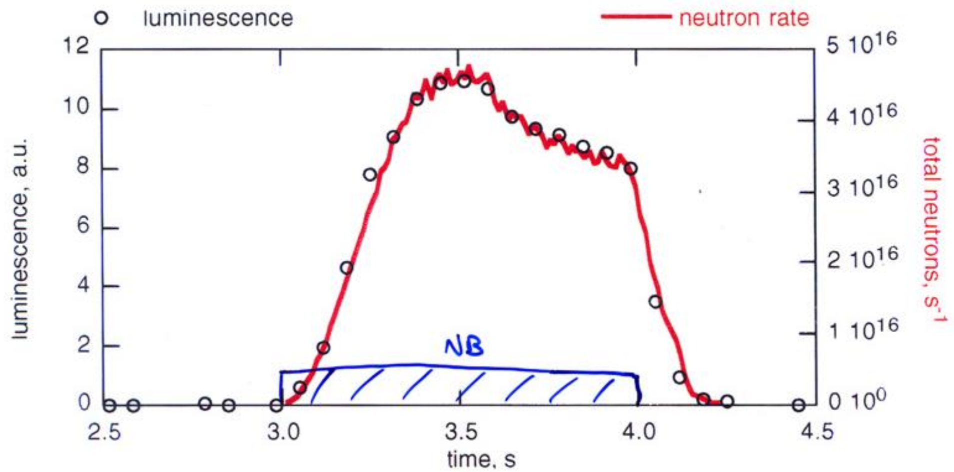
Used to characterize calibration sources.

Facility needed to check impact of neutrons on other diagnostic detectors and store sources.

Studies of radiation effects on optical fibers on TFTR

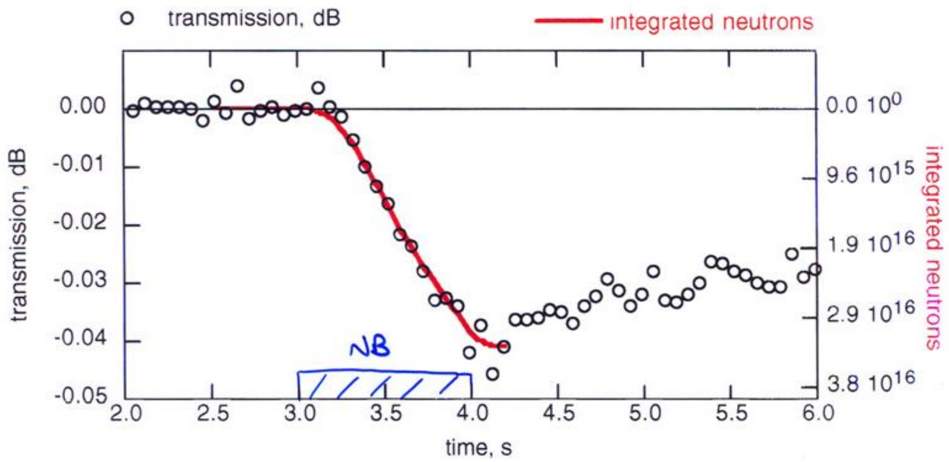
- Two effects of the mixed neutron and γ radiation in fibers:

Luminescence



- Radio luminescence, which increases the background signal with wide spectral range.

Transmission Loss



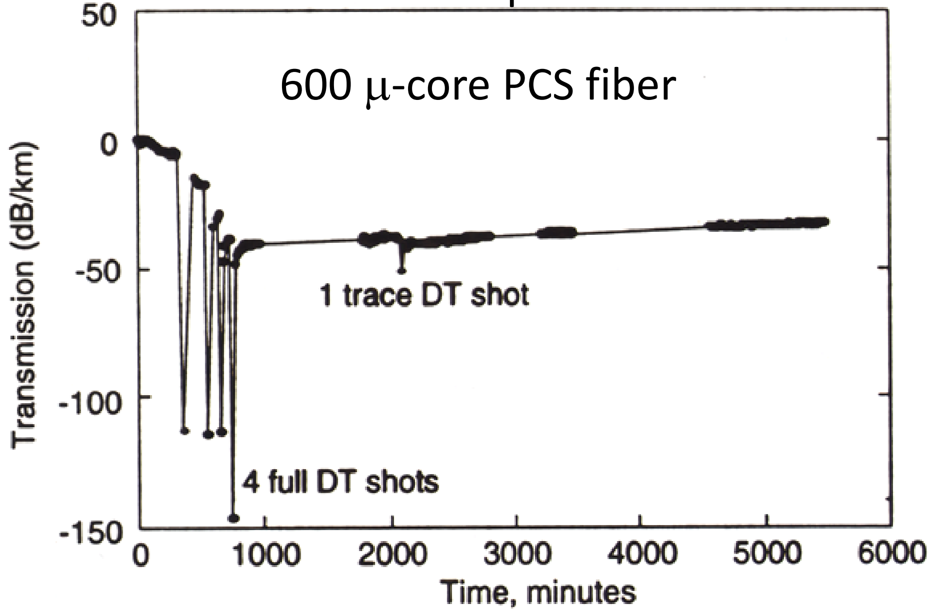
- Transmission loss, both transient and permanent.

Radiation dose rate for fiber in ITER interspace < 10^{-2} that of closest TFTR fiber; long-term loss of transmission is most significant issue.

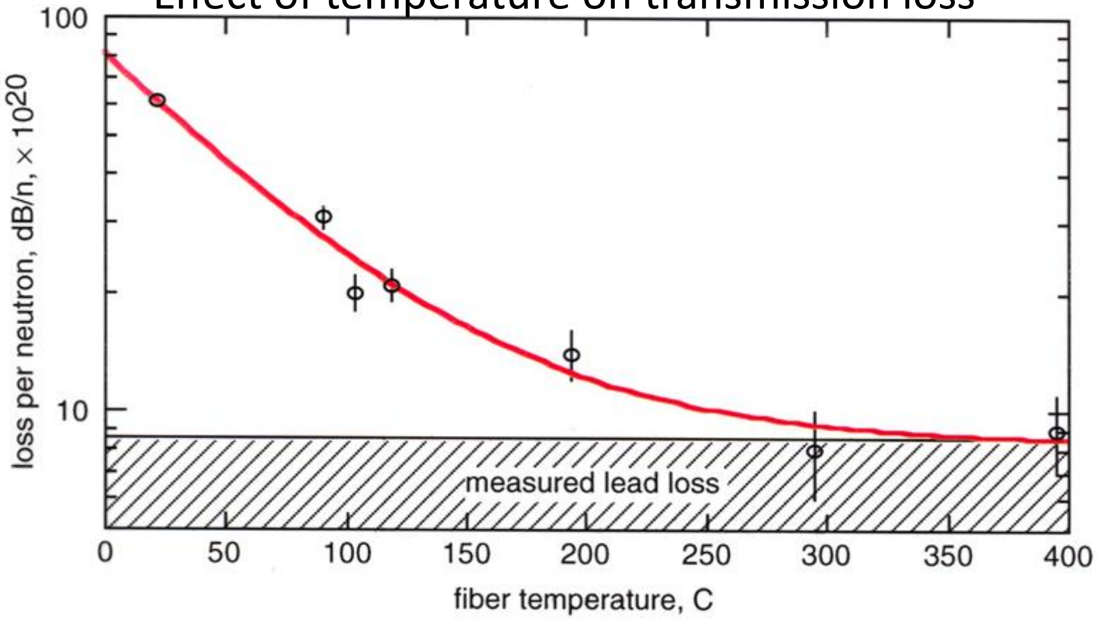
A. Ramsey

Transmission loss; Recovery

Room temperature



Effect of temperature on transmission loss

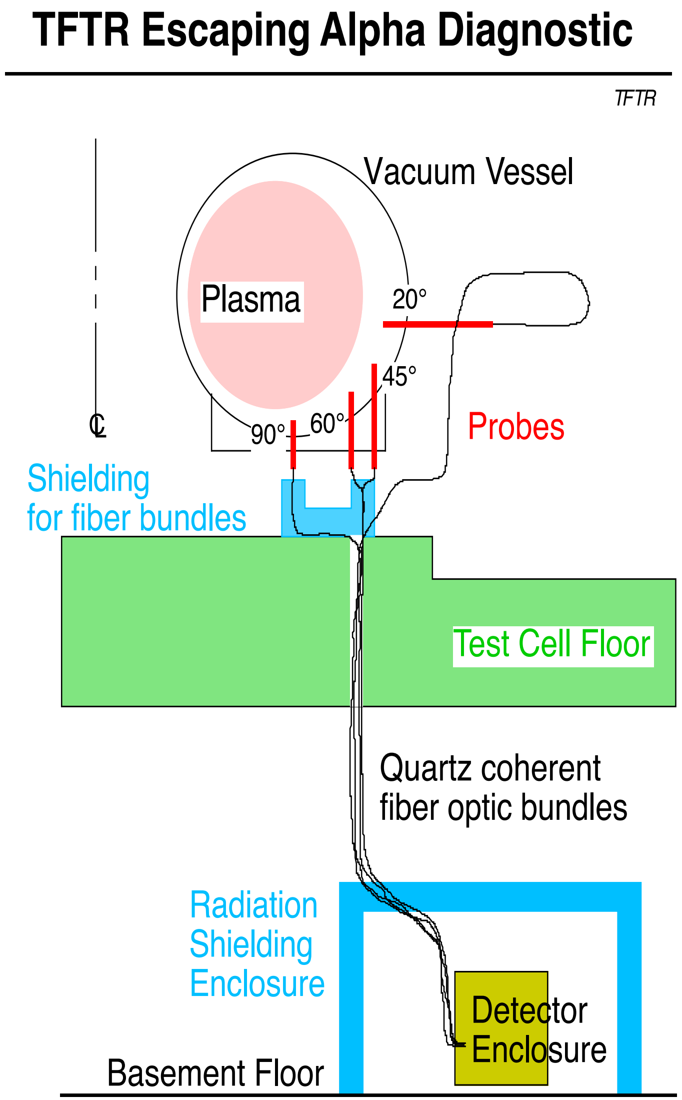


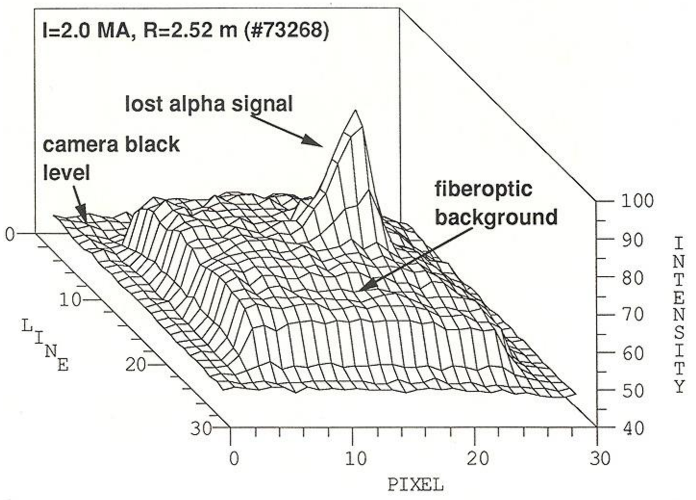
Substantial self-annealing on time scale of minutes.
After 4 days recovery is still continuing

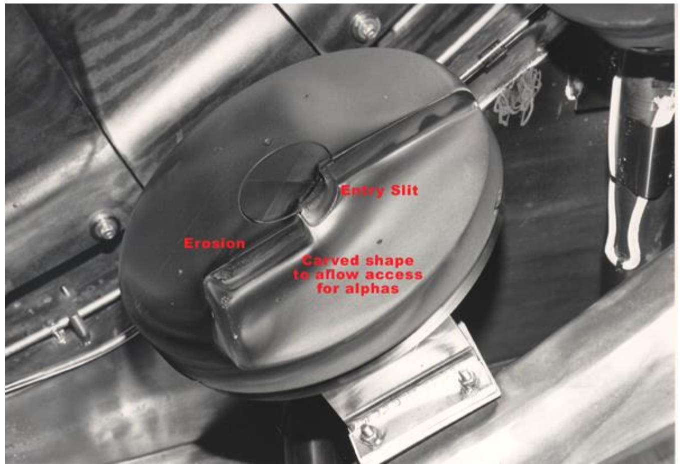
Impact on transmission loss of heating fibers is very strong.

Impact on luminescence is very small up to 400°C

Impact of luminescence (and absorption) on measurement in escaping-α diagnostic







Post=operation detail of one detector

Zweben

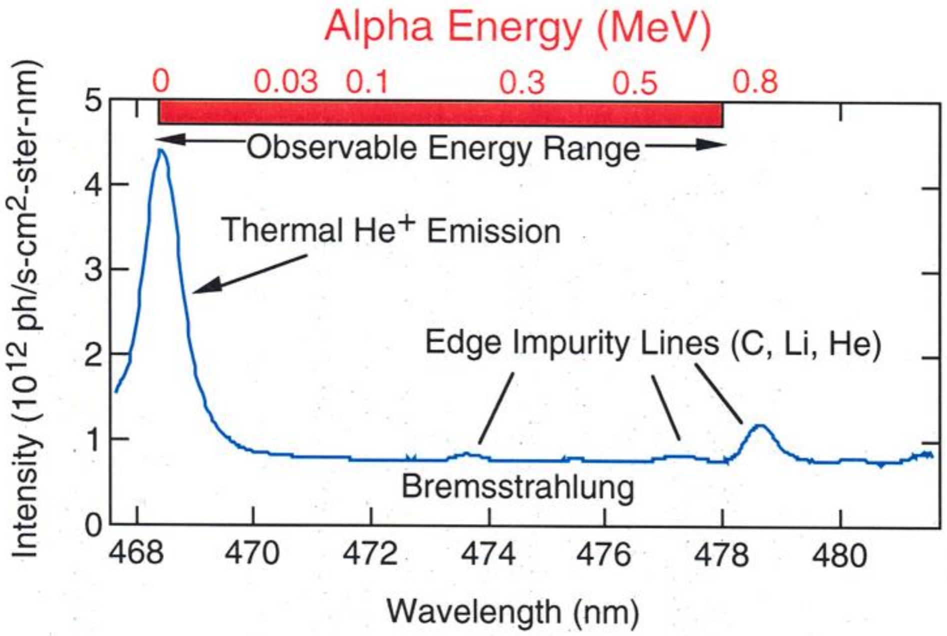
- "Plateau" on signal due to luminescence in the fiber optics.
- Shielded (open-end) fiberoptic outside vacuum vessel.
- TFTR shot at 5MW (~5x10^{-2} MW/m^{2}) at firstwall.
- Dose at front end of fiber ~ 30Gy/s.

(ITER interspace level ~ 0.03Gy/s (beyond optical relay in port plug))

KMY-Varenna 2007

Darrow, Zweben

α–CHERS for measurement of thermalizing alphas

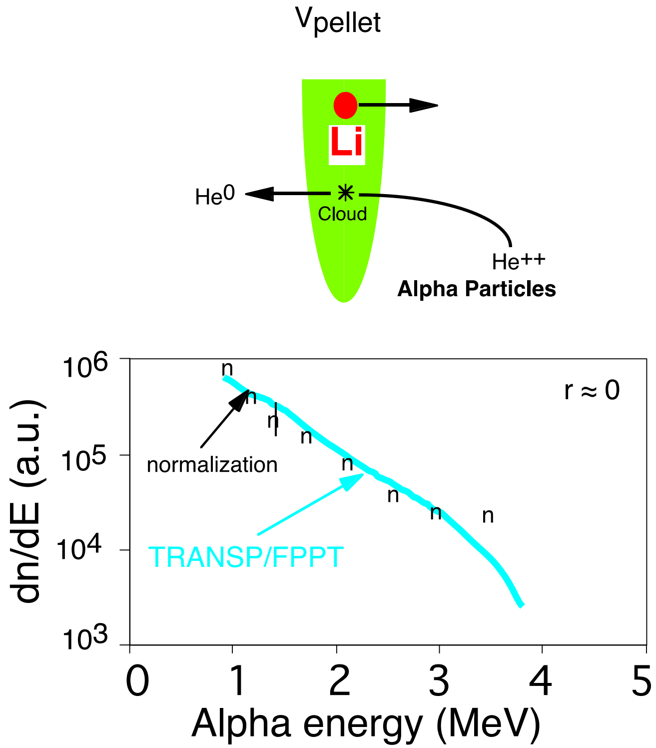


McKee, Stratton, Fonck

- Aim to measure alpha-particles with $E_\alpha \leq 0.7$ MeV ($E_{beam} \sim 100$ keV)
- Spectrum is dominated by the thermal component from near the plasma edge
- High-energy tail is ~ 1% of bremsstrahlung at 0.3 MeV
- In high-power D-T (5 - 10 MW output), fiberoptic noise ~5 - 10% of bremsstrahlung (should not be a problem for ITER, observing heating beam and behind a mirror relay in port plug)

Therefore quoted measurements were taken after T-beams turned off

PCX for Measurement of α-particle Energy and Spatial Distribution

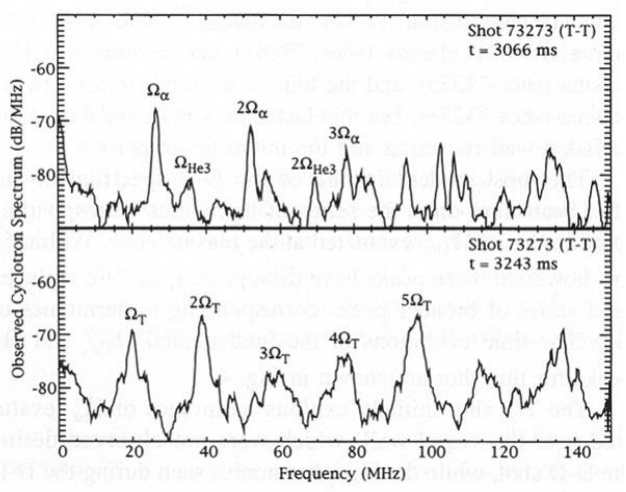


- **Li-pellet fired across plasma; neutralized He-atoms measured by high energy neutral particle analyzer.**
- **Spatial location obtained from pellet flight time**
- **Confined alphas showed classical slowing down spectrum**

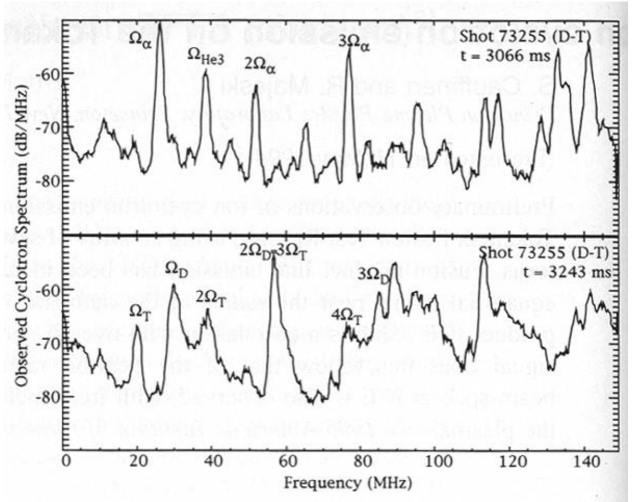
Fisher, Medley, Petrov

Pellet could not penetrate to core of plasma because of ablation during neutral beams. Therefore data taken <u>after beams shut down.</u>

Ion Cyclotron Emission



T-beam into D-plasma



T and D-beam injection

Early

< 200 ms later

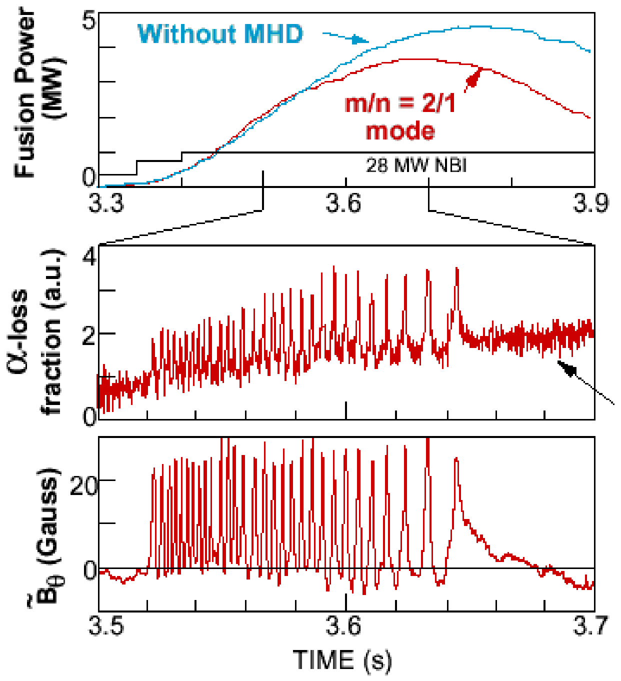
Cauffmann, Majeski

- **Emission spectra observed at harmonics of the ion cyclotron frequency for the magnetic field strength in the scrape-off layer on the low field side.**
- **Harmonics of fusion-product particles only observed for short time after beam turn-on. Harmonics at later times are from beam particles.**
- **Emission predominantly from "barely-trapped" particles.**
- **Requires either very narrow α-distribution (early) or high edge density (late) to make alphas superalfvénic.**
- **Theory explains spectra of low harmonics and continuum (Gorelenkov)**

Does not appear to offer a clear diagnostic for confined or escaping alphas.
The required antenna is very simple.

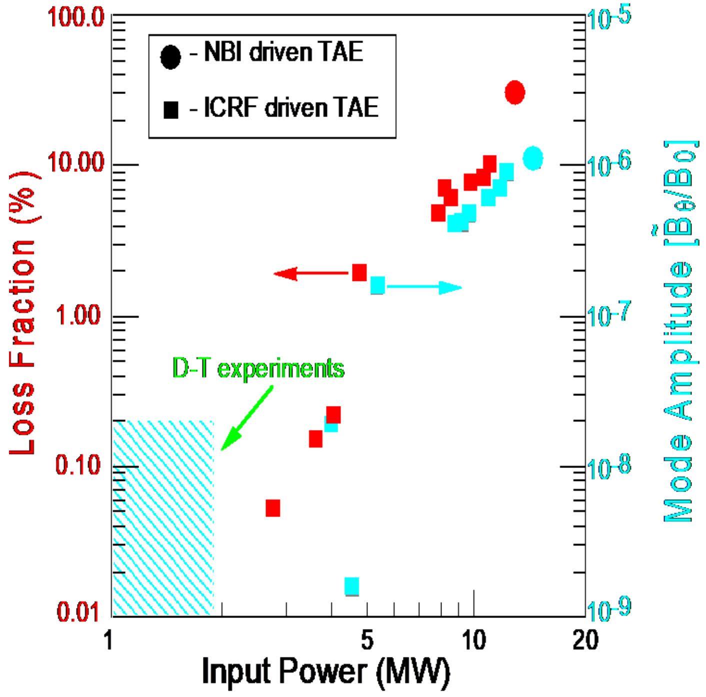
Instabilities and fast ion losses

Alpha-particle Loss by NTM



- Strong toroidal anisotropic loss apparent as NTM mode was rotating.
- Enhanced loss also observed due to:
  - disruptions
  - kinetic ballooning modes, sawteeth

Fast Ion Loss by TAE



- In normal shear D-T discharges, TAE was stable.
- Alpha-driven TAE observed in discharges with weak central shear after the beams were off.

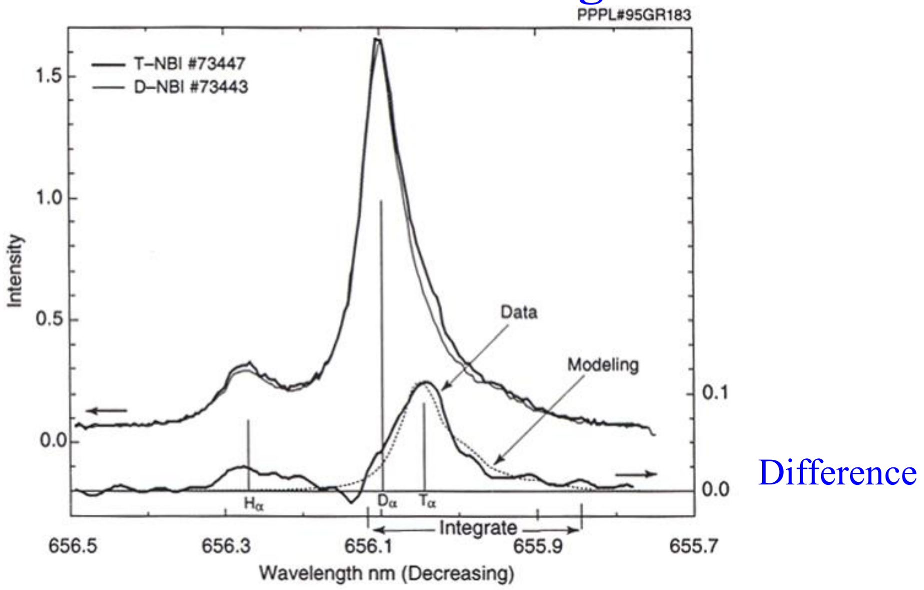
Multiple AE modes can be expected across ITER, leading to α-particle loss.

TFTR tried several α-diagnostic techniques with less success

Alpha diagnostic	Difficulty	Reference
ICE	Signal interpretation	Cauffmann, NF 1995
Alpha collector foils	Integrated; ex-vessel analysis	Hermann, RSI 1995
Diamond detectors	Signal to noise	Krasilnikov, RSI 1999
H_0 light emission	Needed impurity pellet	Sasao, FE&D 1997
Collective scattering (done at JET)	Needed higher power source	Machuzak, RSI 1997
Alpha nuclear reactions	Low signal-to-noise	Cecil, NIM 1998
Faraday Cup	Small signals	Cecil, RSI 1997
Alpha knock-on neutrons	Not steep enough discrimination	Fisher, RSI 1997
First-wall heating	Large backgrounds	Ikeda, NF 1996
Foil neutralization	Fragile foils	Gerdin, Fusion Tech 1985

Measurement of tritium in the plasma

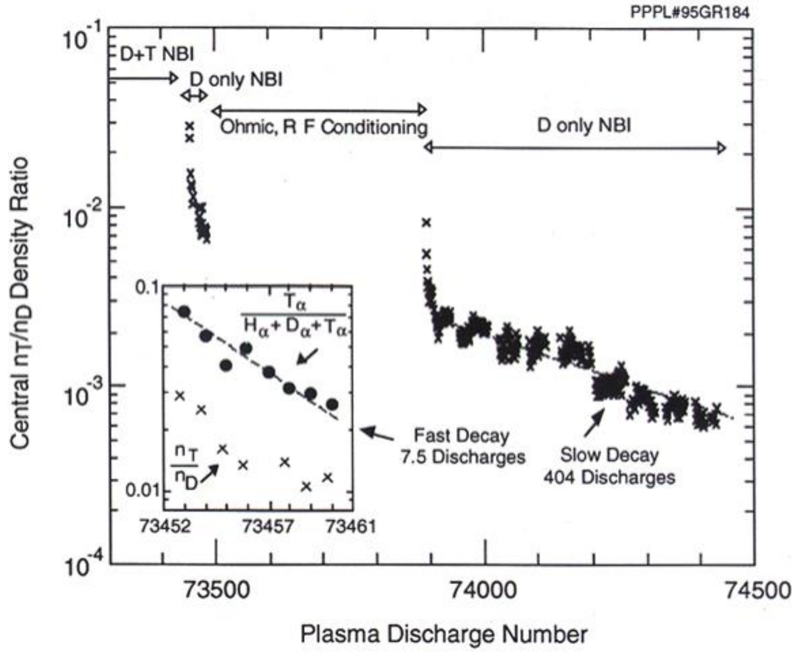
From beam fuelling



- **Fabry-Perot measurement comparing T_α from T-beam-fuelled plasma with D_α from a D comparison plasma.**
- **$T_\alpha/(H_\alpha+D_\alpha+T_\alpha) = 5\% \pm 2\%$**

Could be used on ITER with good spectroscopic modeling.

Decay during Post-Tritium Operation



Skinner, Kruger

- **Tritium (from limiter) persists for many discharges after use.**
- **D-T to D neutron ratio and F-P spectroscopy observation tools.**

Very difficult to remove tritium from the first wall!

Summary and additional comments

- Experience on TFTR in the 1990s very relevant for ITER,
- Pioneered α-diagnostics, effect of radiation on fibers for fusion,
- Many more neutron diagnostics used but not described here (I can provide references),
- In DT, some loss of photodiodes, noise in monitor cameras, x-ray imaging out (full recovery for DD) due to neutrons/gammas,
- In-vessel neutron calibration vital for the neutron measurement instruments: TFTR showed need for very many locations for neutron source because of local materials,
- MCNP not used for calibration task. Used very successfully in calculations for shielding design for diagnostic detectors with small mesh size and detailed materials and geometry. Shielding of diagnostics needed because of reduction in planned tokamak shielding.
- New TRANSP studies comparing measured neutrons and predictions hint at need to include trace amounts of high-Z impurities.

Thanks to all the people who helped make TFTR such a successful device.

9 Papers on Calibration of Neutron Diagnostics on TFTR

For DD:

1. E.B. Nieschmidt et al., Rev Sci. Instrum, **56**, 1084 (1985).
2. H.W. Hendel et al., Rev Sci. Instrum, **59**, 1682 (1988).
3. E.B. Nieschmidt et al., Rev Sci. Instrum, **59**, 1715 (1988).

For DT:

4. C.W. Barnes et al., Rev Sci. Instrum, **61**, 3151 (1990).
5. D.L. Jassby et al., Rev Sci. Instrum, **66**, 891 (1995).
6. L.C. Johnson et al., Rev Sci. Instrum, **66**, 894 (1995).
7. J.D. Strachan et al., Rev Sci. Instrum, **66**, 1247 (1995).
8. D.L.Jassby et al., Rev Sci. Instrum, **68**, 540 (1997).
9. S. von Goeler et al., Rev Sci. Instrum, **68**, 5482 (1997).

Report on International Meeting on Neutron Calibration:

10. J.D Strachan et al., Rev Sci. Instrum, **61**, 3501 (1990).