Thin Faraday foil collectors as a lost ion diagnostic

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Overview of poster

• Concept

• Accelerator based proof-of-Principle

• Existing devices
  – K-\(\alpha\)-1 on JET (1995)
  – NSTX (1998)

• Proposed devices
  – ITER (?)
Faraday foil concept

Schematic of lost $\alpha$ detector consisting of four 2.5 $\mu$m foils of Ni separated by three 2.5 $\mu$m sheets of mica electrical insulator (the range of a 3.5 MeV $\alpha$ particle in Ni is about 7 $\mu$m)

Ref. F.E. Cecil, Proc EPS Conf (Montpelier) 1994
Range and straggling for protons and alphas in Ni (TRIM2000)
Predicted Detector Response
(TRIM2000)

\[ E_\alpha = 3.5 \text{ MeV}; \theta_{\text{max}} = 30^\circ \]

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**Proof of principle**

Accelerator based measurements with $\alpha$ beam; Sandia Nat’l Labs 1998. 6.0 $\mu$m Al foils with 2.5 $\mu$m CH$_2$ insulator

**JET K-α-1**

Interior of JET showing lost alpha detector mounting on left side near limiter and slightly below torus midplane.

Photograph of fast lost ion probe on NSTX. The three small holes are the apertures for the three Faraday collectors.

Ref D.S. Darrow et al Rev Sci Instrum 72 (2001) 784
NSTX "Beam-Blip" Shot 105704

neutral beam power

neutron source strength

161 cm

163 cm

166 cm

time (sec)

Ref WW Heidbrink et al, Nucl Fus 43 (2003) 883
Photograph of graphite housing of single foil detector on vessel wall with upward facing aperture

**D III D Shot 113177**

**Neutron source strength**

- Neutrons/sec
- 0, 1e+14, 2e+14, 3e+14
- Arbitrary units

**D-alpha brightness**

- Active foil - Blind foil
- Time (msec)

**Active foil - Blind foil**

- Volts
- 0, 2, 4, 6, 8

- Time (msec): 0, 500, 1000, 1500
**JET (K-α-2)**

- Fifteen detectors each with four foils at three radial locations for each of five poloidal locations

Poloidal locations

• Model of distribution of lost alphas from 42982 d-t plasma

Ref Sean Conroy, private communication 2002
Expected signal level

$Z = +94.5$ mm at center of 8x17 array of 3mm x 3mm holes at

$\theta_{\text{rad}} = 52.2^\circ$ (outward) and $\theta_{\text{tor}} = 20^\circ$ CCW

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**Graph**

- Signal Current (nA) vs. Major Radius (mm)
- JPF42756 (2 MA, 2T)
- JPF42983 (4.5 MA, 3.5T)
- JPF42976 (4.5 MA, 3.5T)

- Front, Middle, Back markers
Comparison of K-α-1 and K-α-2

Efficiency ($\alpha$/source neutron)

Toroidal field (T)
Efficiency of $K-\alpha-2$ vs Plasma Profile and Plasma Current

$\log_{10}(\text{Efficiency(alphas/source neutron)})$
Comparison of efficiency for 3.5 MeV alphas and 15 MeV protons

Efficiency of a 3 mm x 3 mm Aperture vs Major Radius; Poloidal Limiter at 3752 mm for Z = 393 mm

- 15 MeV Proton for Shot 42982
- 3.5 MeV Alpha particle for Shot 42982
K-α-2

Problems

• Environmental (dust, Beryllium, x-rays)
• Heat load
• Neutron/gamma
• Electrical noise

Solutions

• Tilt aperatures
• Aperture array
• Thin foils eliminate background
• Subtract control foil from signal foil
Efficiency for JET Shot 42976 at 53.0 sec for 3mm x 3mm aperture at R=3800 mm versus orientation angles.
**HEAT LOAD**

Ni foil with array of 3mm x 3 mm aperture and .037 W/mm² of 3.5 MeV alphas with intermediate points anchored at wall temp
Neutron/gamma

Measured and calculated signal for 4.5 T, 3.5 MA pulse with $10^{19}$ total n/sec

- $n/\gamma$ background $\sim 10^{13}/\text{cm}^2/\text{sec}$
- Expected $I_\alpha \sim 100 \text{ nA/cm}^2$
- Predicted $I_n \sim 0.1 \text{ nA/cm}^2$
- Predicted $I_\gamma \sim 0.01 \text{ nA/cm}^2$
- Measured current from Ni foil in fission reactor core with $10^{13} \text{ n/}\gamma /\text{cm}^2/\text{sec} \sim 0.08 \text{ nA/cm}^2$
- Conclusion $(I_n + I_\gamma) \ll I_\alpha$

**ELECTRICAL NOISE**

By subtracting current from control foil from current in signal foil, background electrical noise measured to be $\sim 0.5$ nA for 50 Hz low pass filter.

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**Detail of JET Pulse 42976**

- **Foil 1(V)**
  - rms noise $\sim 0.2$ V $\Rightarrow$ 4 nA

- **Foil 2(V)**
  - rms noise $\sim 0.2$ V $\Rightarrow$ 4 nA

- **Foil 1 - Foil 2(V)**
  - rms noise $\sim 0.03$ V $\Rightarrow$ 0.6 nA
ITER Source Profile; Shot 3000; time= 190 sec

ITER

ITER Machine Profile

Ref George Vayakis (ITER), private communication (2003)
ITER

Midplane detection efficiency

Efficiency (alphas/source neutron for 1 cm² upward foil)

Major radius (mm)