Irradiation effects on insulating materials for magnets For IFE and/or MFE

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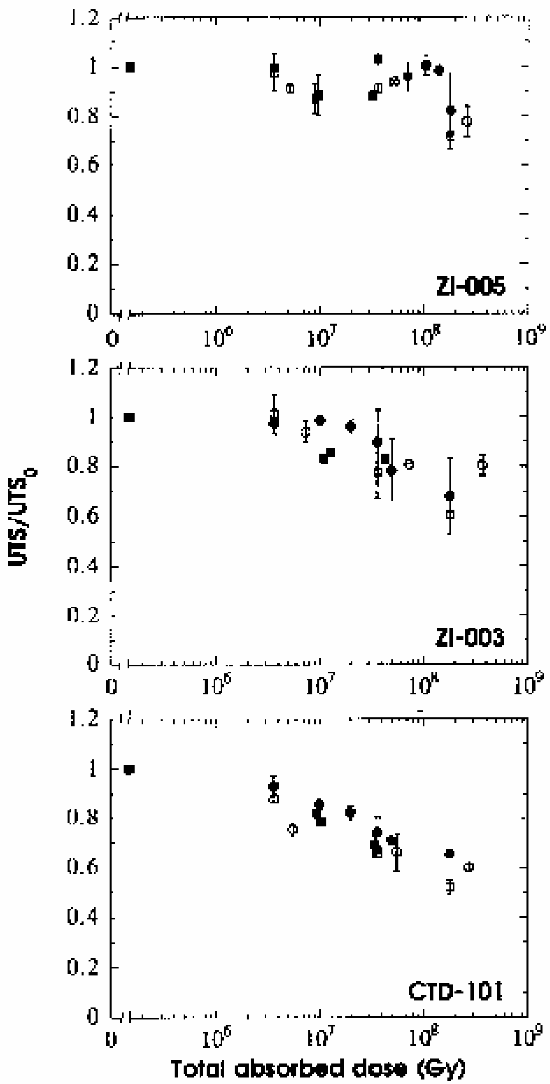
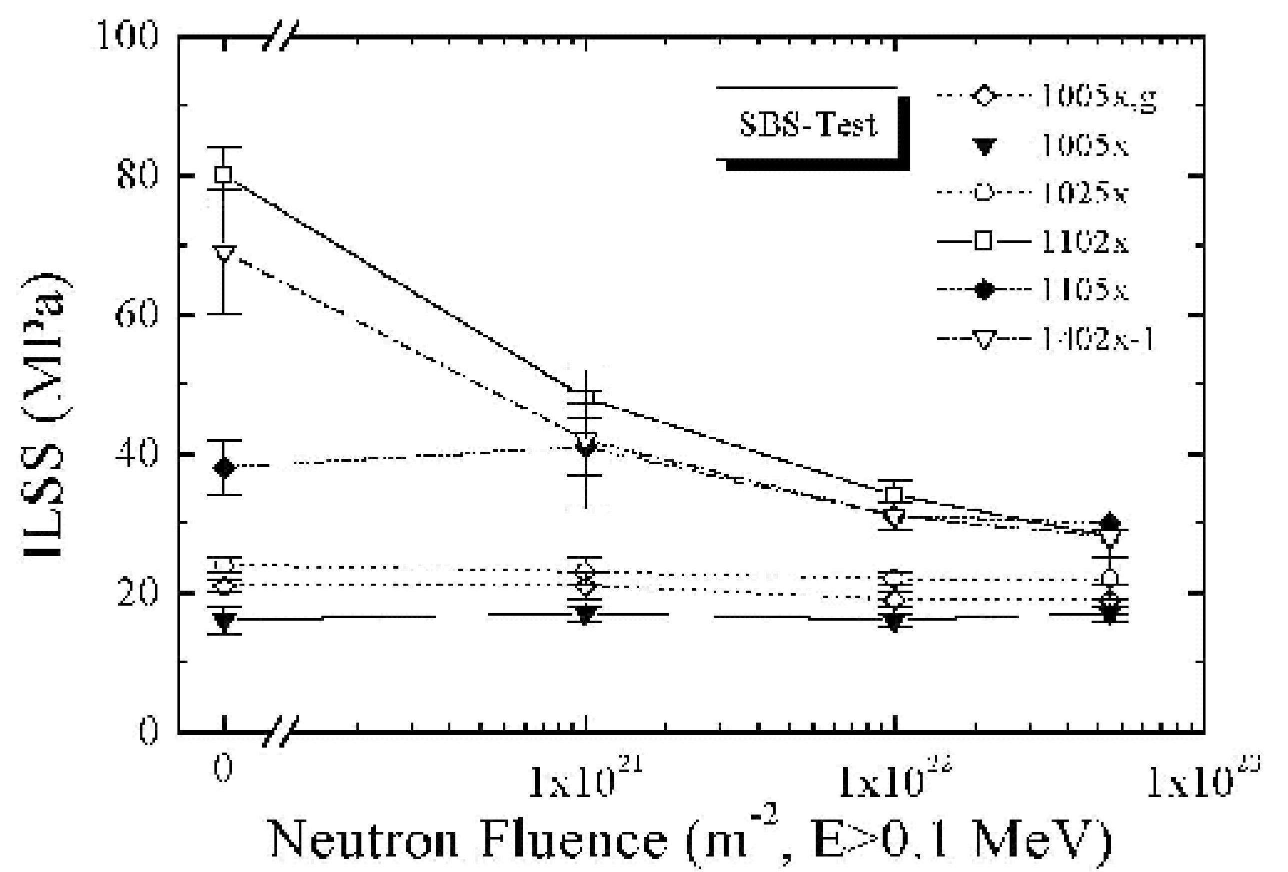


Figure 4 Normalized ultimate tensile strength of ZI-005, ZI-003 and CTD 101 as a function of total absorbed dose following room temperature irradiation with different reactor spectra (○, TRIGA, Vienna; ●, 2 MeV electrons; □, ^{60}Co-gamma rays; ■, IPNS, Argonne) and fracture at 77 K. UTS$_0$ is the ultimate tensile strength prior to irradiation

Type of irradiation

- Tests for irradiation of organics with e-beams, γ's, neutrons indicate that damage is due to power absorption per unit mass (rads, Grays)
  - Independent ot source of radiation.
  - Dependent on radiation dose rate!

Radiation damaged of organics and inorganics (ceramic/ceramic hybrid) CTD-AOU/Austria



CTD-403	Organic
CTD-406	Organic
CTD-410	Organic
CTD-1005x,g	Ceramic
CTD-1005x	Ceramic
CTD-1025x	Ceramic
CTD-1102x	Ceramic/Organic
CTD-1105x	Ceramic/Organic
CTD-1402x-1	Ceramic/Organic
CTD-1402x-2	Ceramic/Organic

FIGURE 5. Interlaminar shear strength (ILSS) of ceramic and ceramic/organic composites as a function of neutron fluence measured at 77 K with the short-beam-shear test.

Radiation damage of organics

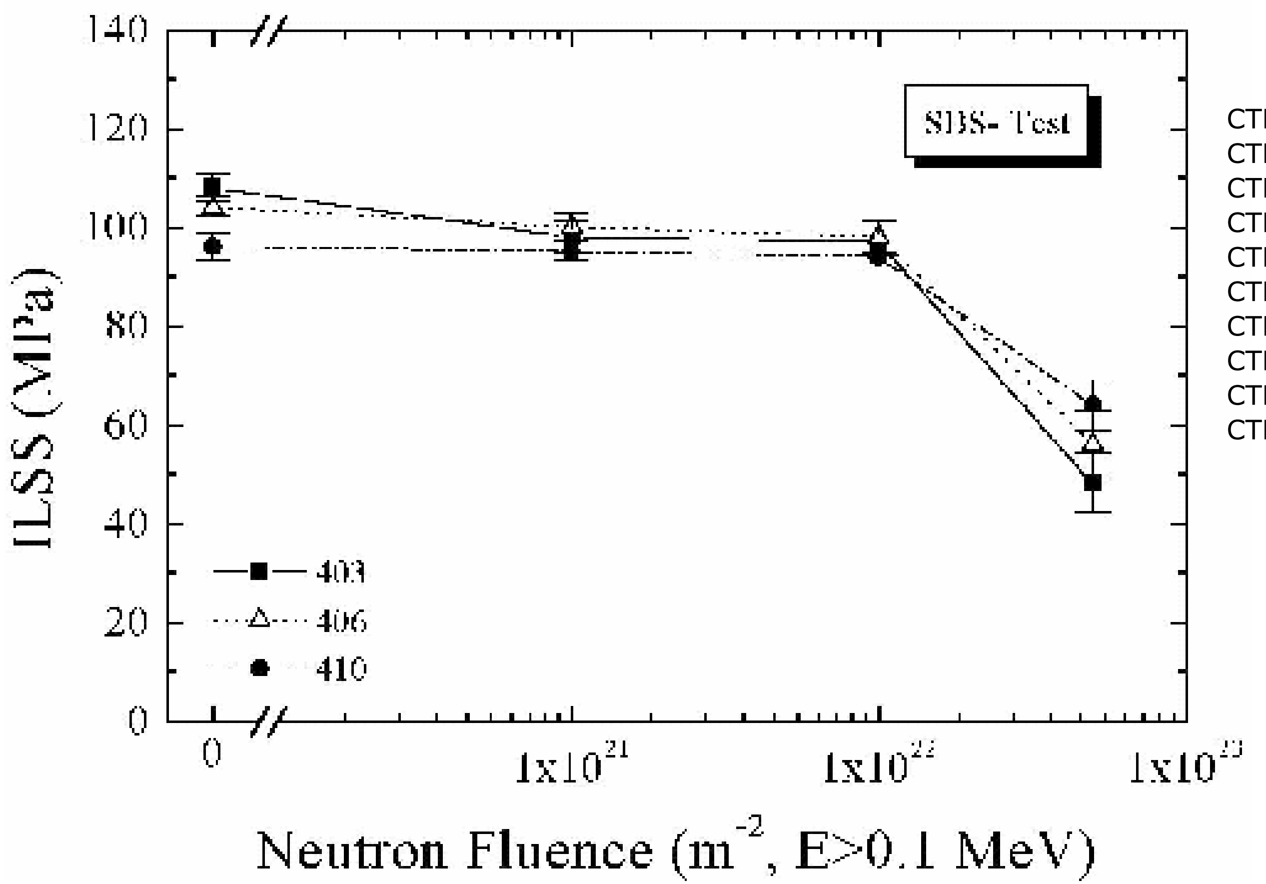


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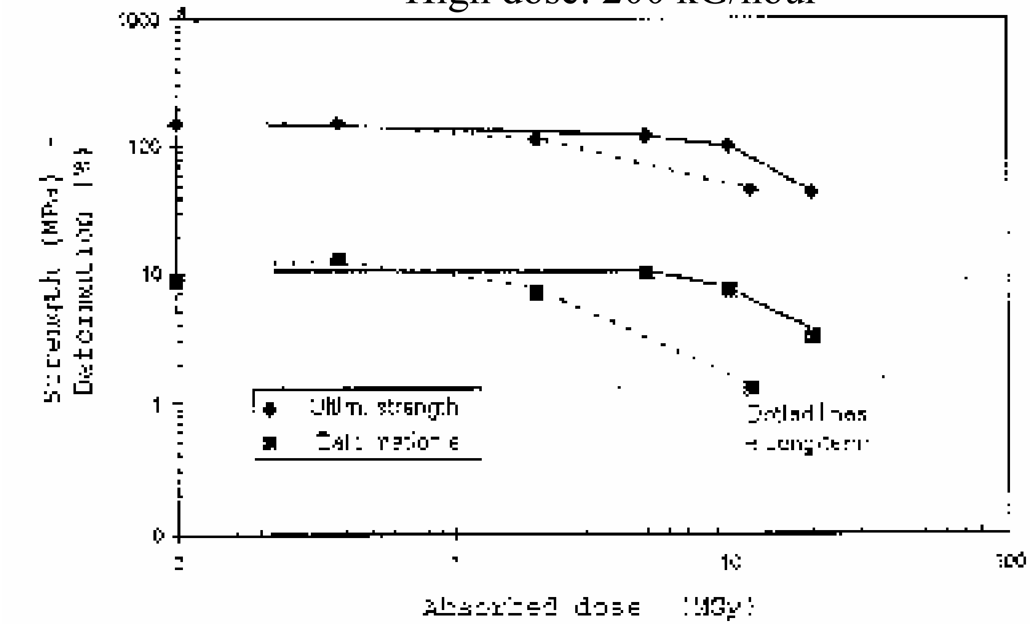
FIGURE 4. Interlaminar shear strength (ILSS) of organic composites as a function of neutron fluence measured at 77 K with the short-beam-shear test.

Dose rate effects

Low dose: 0.5kGr/hour
High dose: 200 kG/hour

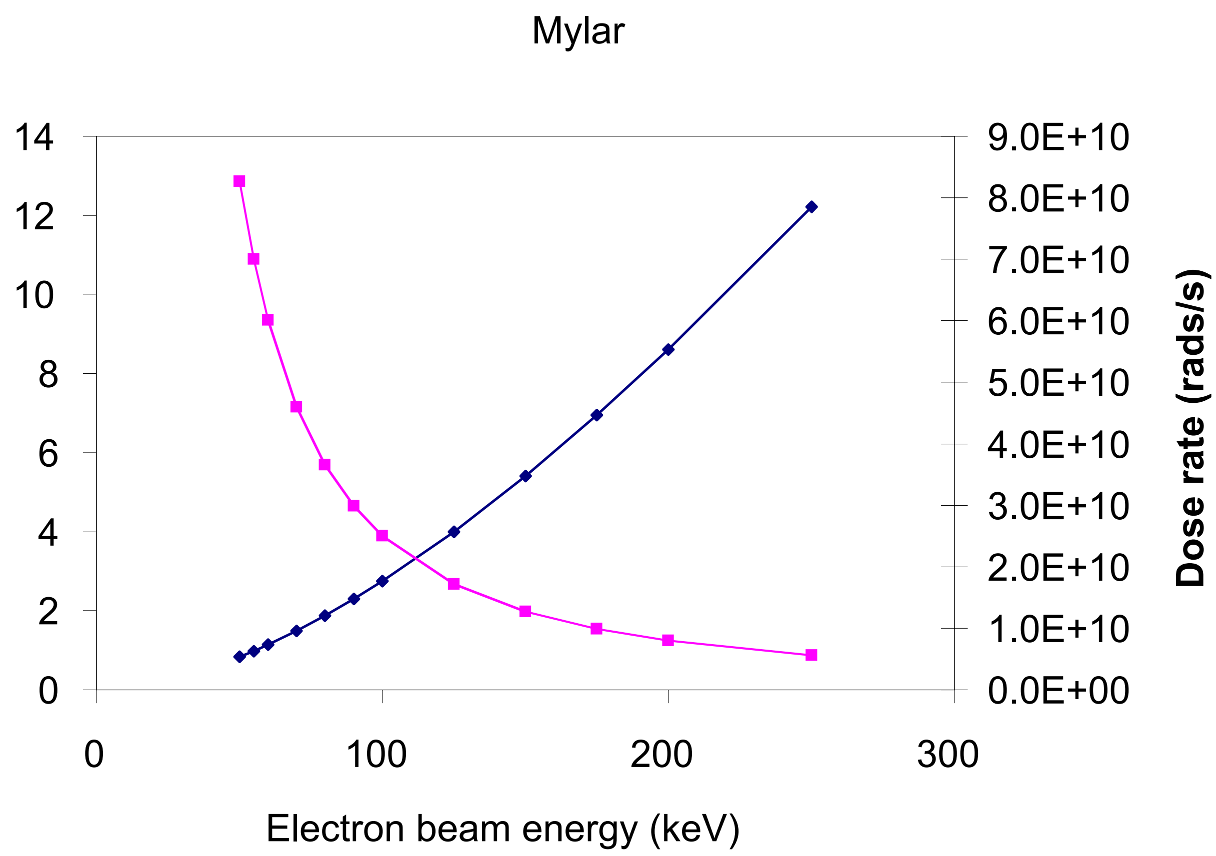


Irradiation degradation in epoxy R 423

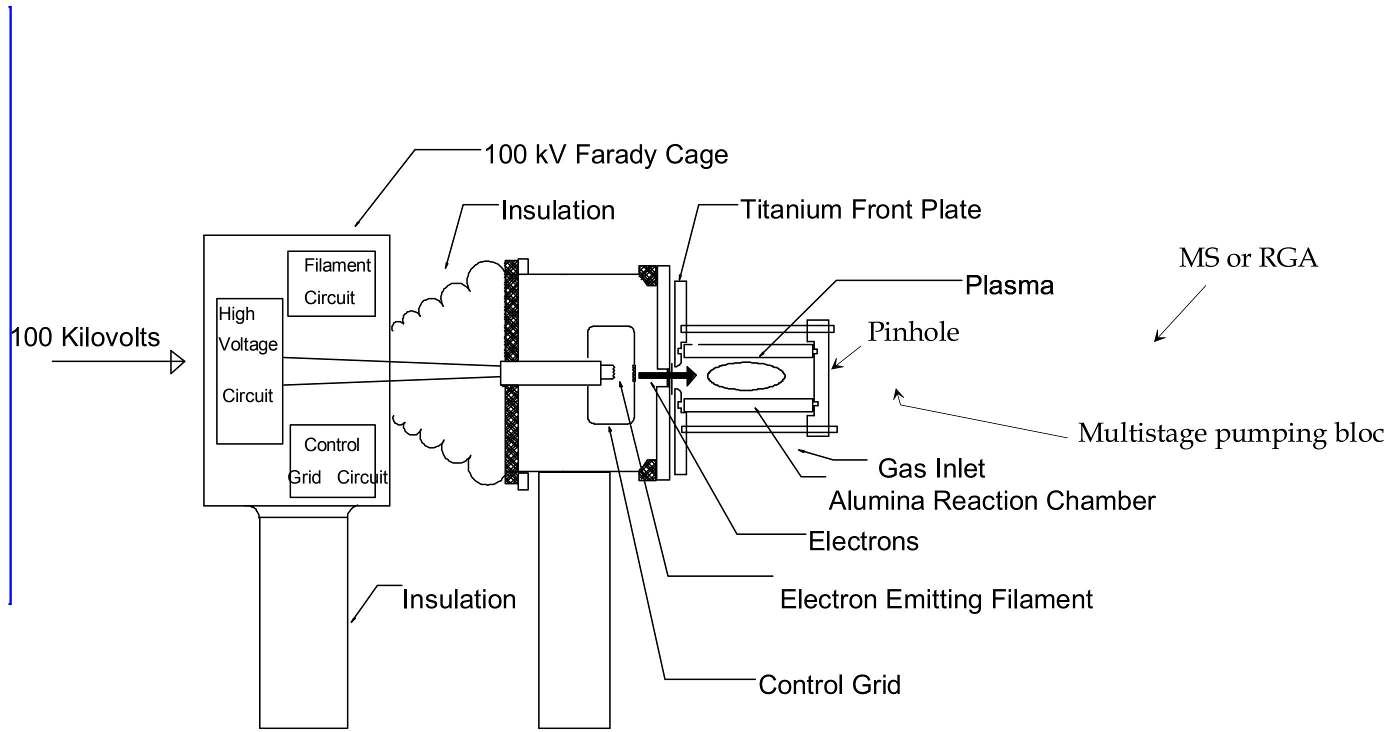
- Aging:
  - The effect of dose rate in radiation damage:
  - Damage underestimated by high dose rate needed for accelerated testing
  - More visible in high filled resins, less in fiber reinforced ones

Electron beam irradiation

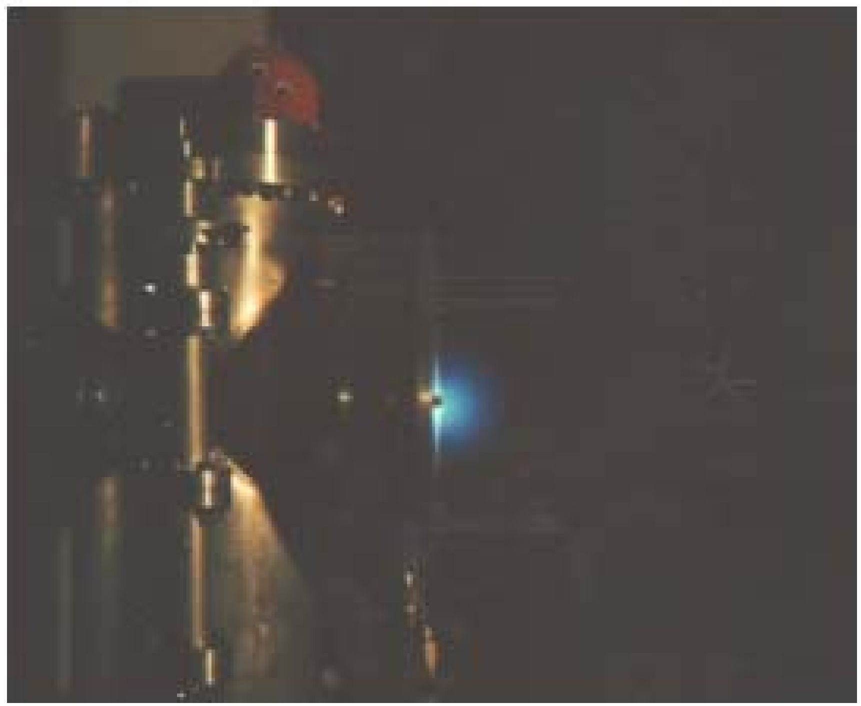
40 W/cm^2 electron beam (mylar)



Electron beam unit at MIT

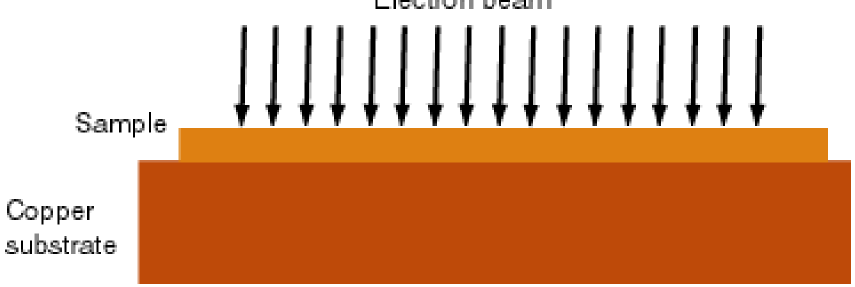


Picture of e-beam unit
Electron beam in air



Cooling of sample

- Sample cooling:
  - Cooled on opposite of side of irradiation by metal



Thermal conducitivy of copper	W/mK	400
Heat capacity	J/g K	8
	J/kg K	8000
Density	kg/m^3	8900
Thickness	m	0.01
Average Delta T/s	K / s	0.00561798
Time constant	s	17.8
Rad dose rate	Mrad/s	1.00E+08
Required dose	Mrad	1.00E+10
Irradiation time	s	100
Delta T	K	0.56179775

Cooling of sample

- Thermal conductivity of the sample limits the maximum dose rate

Thermal conductivity	W/m K	0.05	0.1	0.2
Thickness	m	0.001	0.001	0.001
Surface power density	W/m^2	4000	4000	4000
Delta T	K	80	40	20

Irradiation program

- Negotiation with both Eltron and CTD
  - Issues with confidentiality, non-analysis
  - Managed to develop a program with CTD, and obtained samples:
    - CTD-7021-7X/S-2 glass
    - CTD-7031-HR3/S-2 glass
    - CTD-422/S-2 glass
    - CTD-423/S-2 glass
    - CTD-101K/S-2 glass
    - CTD-403/2 /S-2 glass
    - Average sample size: 4 x 4 in^2
- Main remaining issue is mechanical testing program.

Gas evolution

- Gas evolution can be monitored to determine insulator degradation

Radiation Sensitivity and Gas Evolution Rates of Current Resin Systems

Material	% Reduction in Shear Strength after Exposure to Fast Neutron Dose of 23 MGy (2.3 x 10^9 rad)	Gas Evolution rate after exposure to ~ 2 MGy ($cm^3 g^{-1} MGy^{-1}$)
CTD-101K (DGEBA epoxy)	>50	1.24
DGEBF Epoxy for ITER CS-Coils	Not tested	1.03
CTD-112P (TGDM epoxy)	0	0.4
Epoxy Novolac	Not tested	0.26
CTD-220P (Bismaleimide)	0	0.32