Adequacy of TF Insulator Life

J.H. Schultz, P. Titus

MIT Plasma Science and Fusion Center

P. Heitzenroeder

Princeton Plasma Physics Laboratory

Required Insulation Strength

	Insulator Dose (Rad)	Compressive stress (MPa)	Von Mises (MPa)	Required Compressive Strength (MPa)
Plasma side 10T operation 2.14m FIRE*	1.31e10	283		
CS side 10T operation 2.0m FIRE*	2.01e8	472	580	**870**
Plasma side 10T operation 2.0m FIRE	1.31e10	240	300	450
CS side 10T operation 2.0m FIRE	2.01e8	360	469	704
Plasma side 12T operation 2.0m FIRE	1.41e10	346	440	660
CS side 12T operation 2.0m FIRE	2.01e8	520	689	**1033**

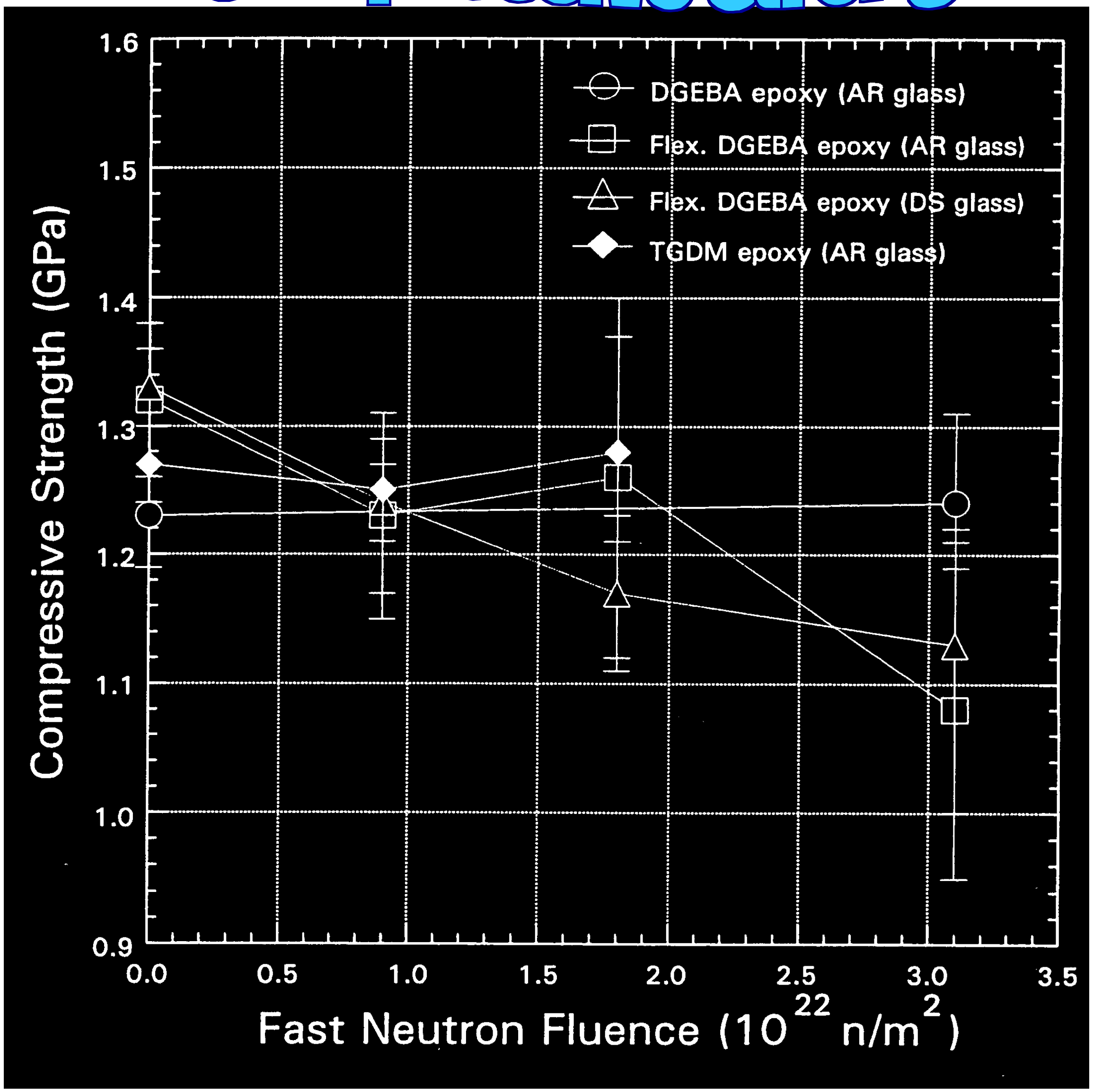
Required σ_y down from 1033 MPa to 870 MPa

Compatible with all “serious” composite candidates

Material	$T_{irradiation}$	T_{test}	Irradiation Level (10^{22} n/m^2)	$\sigma_{compression, avg}$ (GPa)
Shell 826, 6781, S-glass	4	4	3.1	1.24
CTD-101K AR, 6781, S-glass	4	4	3.1	1.08
CTD-101K DS, 6781, S-glass	4	4	3.1	1.13
CTD-101K AR, 6781, S-glass	4	4	1.8	1.26
CTD-112P, 6781, S-glass	4	4	1.8	1.2
CTD-101K DS, 6781, S-glass	4	4	1.8	1.17
CTD-112P AR, 6781, S-glass	4	4	0.9	1.24
CTD-101K DS, 6781, S-glass	4	4	0.9	1.24
CTD-101K AR, 6781, S-glass	4	4	0.9	1.23
CTD-101K AR, 6781, S2-glass	Control	4	0	1.32
CTD-101K DS, 6781, S2-glass	Control	4	0	1.33
Shell 826 AR, 6781, S2-glass	Control	4	0	1.23
CTD-112P AR, 6781, S2 glass	Control	4	0	1.27
CTD-112P, 6781 S2 glass	?	4	1.8	1.28
CTD-112P Kapton, 6781 S2 glass	?	4	1.8	1.27
CTD-112P Mica, 6781 S2 glass	?	4	1.8	1.24
CTD-112P/Mica/Kapton 6781 S2 glass	?	4	1.8	1.22
CTD-112P DS, 6781 S2 glass	?	4	1.8	1.15
AFR-700, 6781 S2 glass	?	4	1.8	1.23
AFR-700/Kapton, 6781 S2 glass	?	4	1.8	0.98
CTD-220P, 6781 S2 glass	?	4	1.8	1.23
CTD-112P/Mica, 6781 S2 glass	4	4	1.8	1.23
CTD-112P/Katpon, 6781 S2 glass	Control	4	0	1.24
CTD-112P/IMI Mica, 6781, S2 glass	Control	4	0	1.21
CTD-112P/Kapton/IMI Mica, 6781 S2 glass	Control	4	0	1.12
AFR-700, 6781, S2 glass	Control	4	0	1.22
CTD-112P DS	Control	4	0	1.3
CTD-220P, 6781, S2 glass	Control	4	0	1.2
CTD-112P/Midwest Mica, 6781, S2 glass	Control	4	0	1.25
AFR-700/Kapton HA, 6781, S2 glass	Control	4	0	1.01

σz, All candidate insulation systems = 1.1 Gpa +/- 0.1

Compressive Strength vs. Radiation

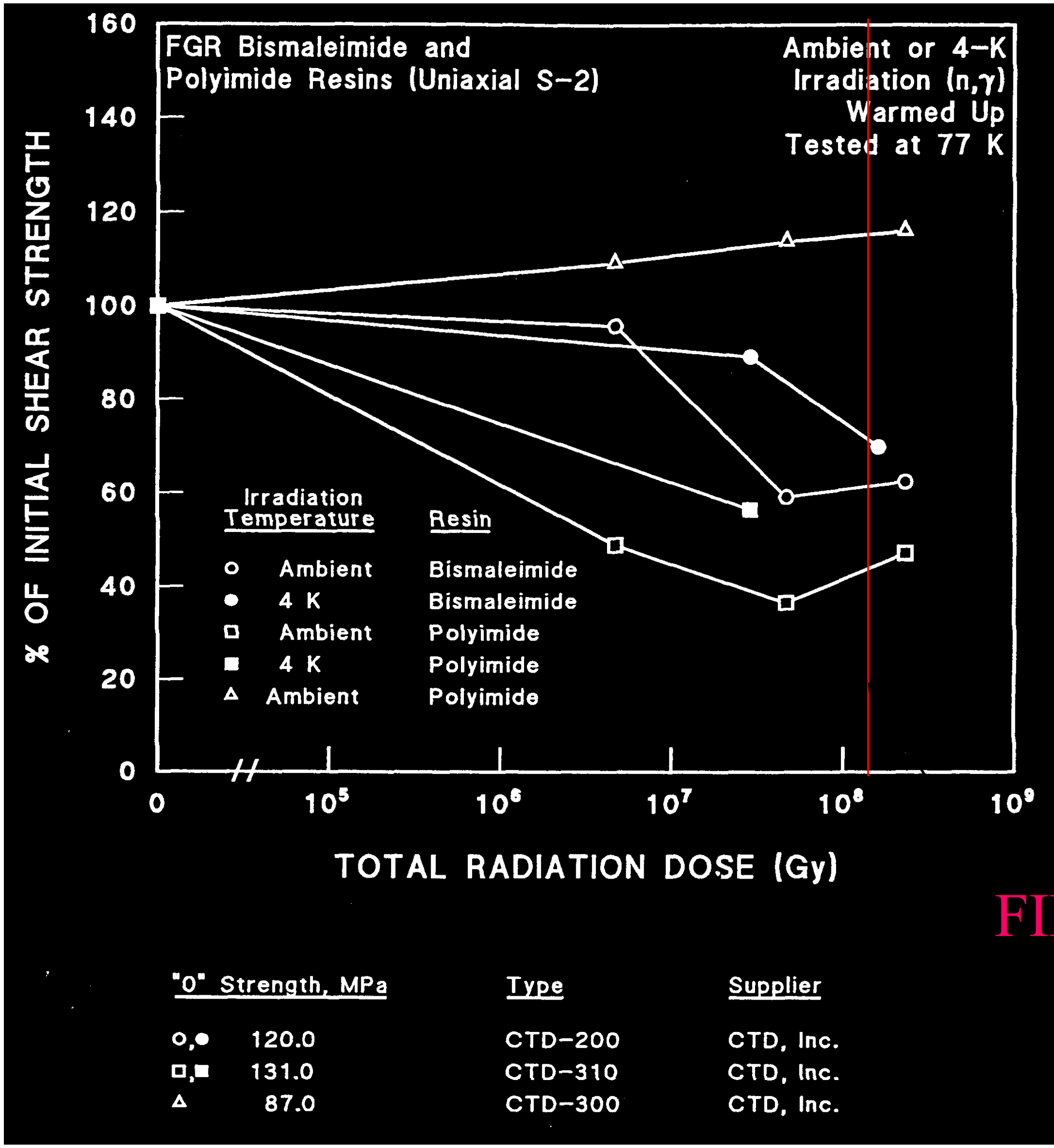


Epoxy compressive radiation resistance much better than shear strength resistance

Not as good as polyimides

Not good enough

Shear Strength Radiation-Resistance



FIRE

Munshi, tests of polyimides and bismaleimides at 77 K

Peak FIRE fluence:

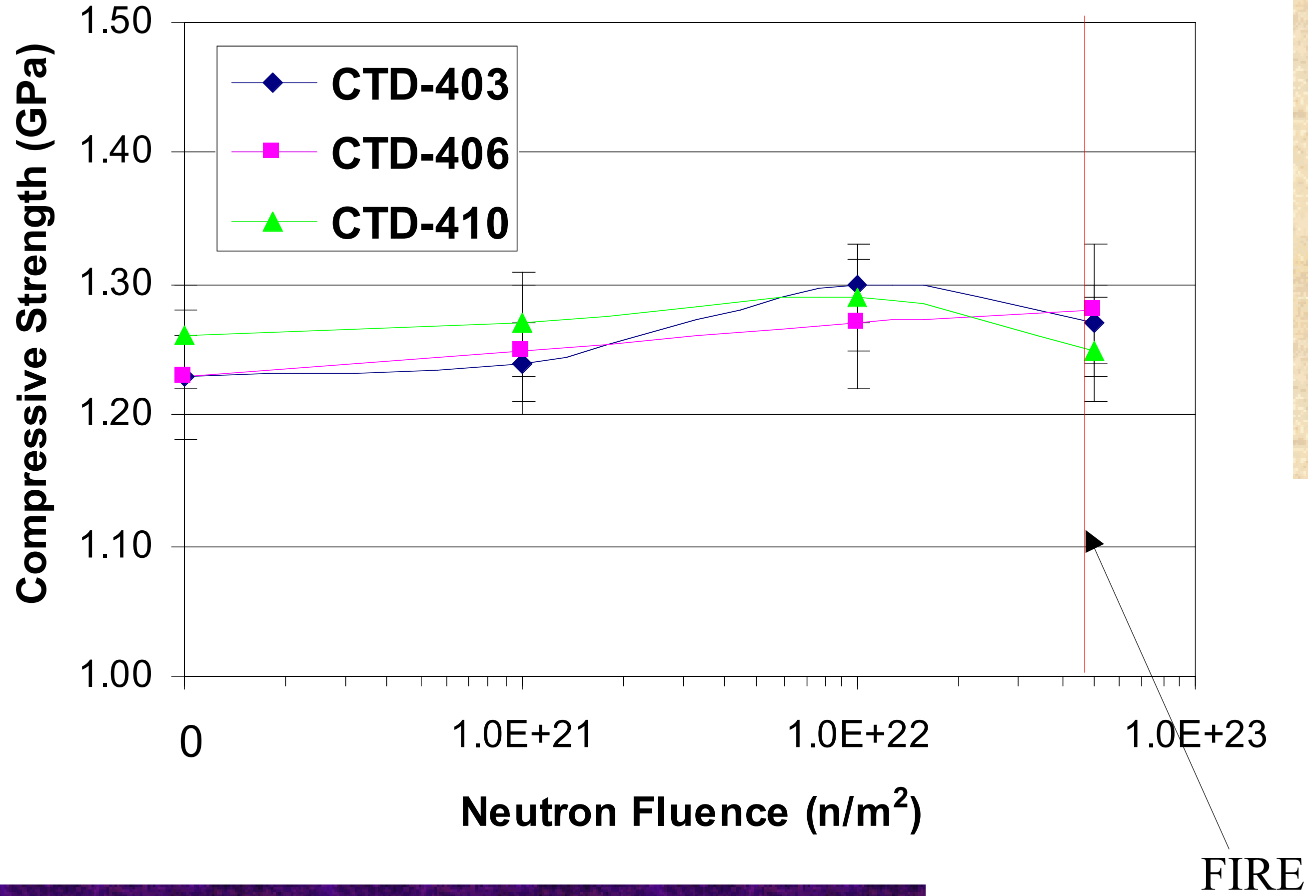
9.8×10^{22} n/m^2

1.3×10^{8} Gy

Modest shear degradation

Few data points

Irradiation Test Results - Compression



New cyanate ester and CE/polyimide hybrids from CTD have compression strength with margin out to 2 x 10^{10} Rad

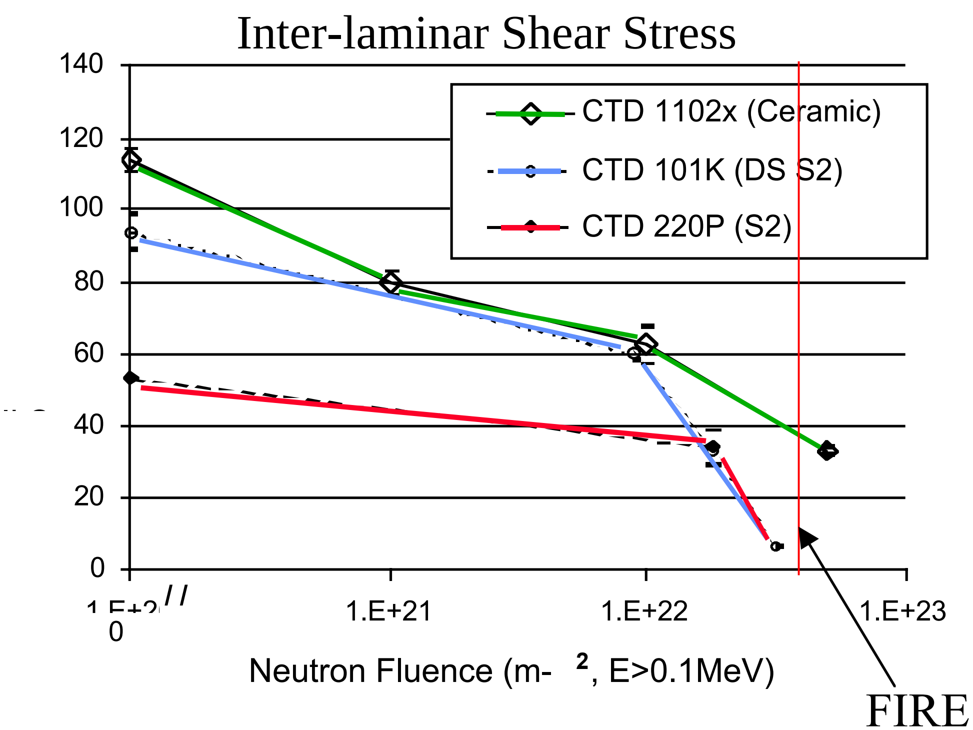
(Limited by TRIGA reactor time)

Most hopeful data to date for FIRE extended operating life

Preliminary Radiation Results for Cyanate Ester Hybrids

Ceramic Insulations

Tape developed by CTD, used in Fermilab dipoles
- sheet being developed as part of SBIR, along with organics



All ceramic insulator reported by CTD at ICEC – unpublished

No degradation at ~10^{10} rad (5 x 10^{22} n/m^2)

Shear strength only 15 MPa

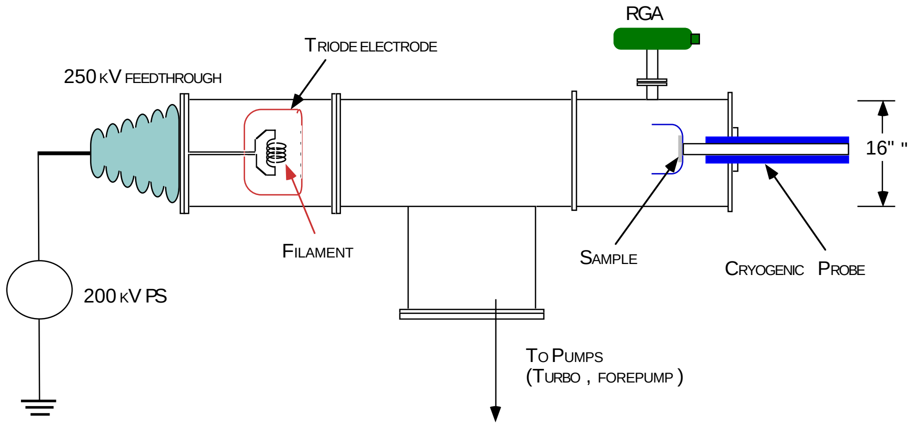
Great promise for ceramics – Not there yet

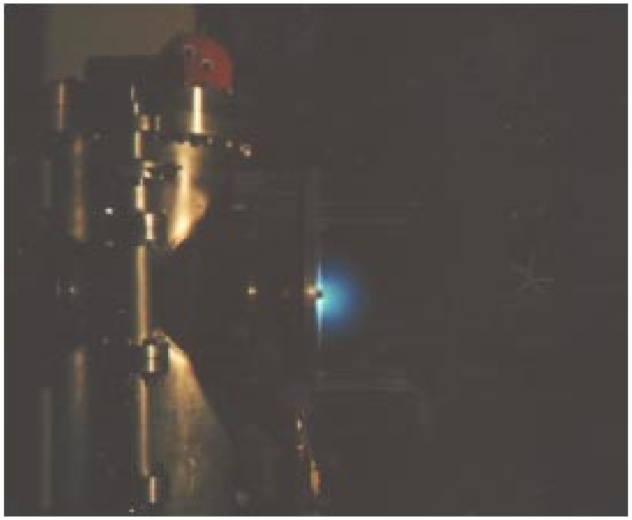
Hybrid encouraging, but inadequate rad resistance

Reactor Irradiation Rates

Irradiation Source	Location	Irradiation temperature	Fast neutron flux density (> 0.1 MeV)	γ-dose rate	Hours/1.3 x 10^{10} Rad
		(K)	m^{-2}/s	(Gy/h)	(hr)
2 MeV electron accelerator	JAERI, Takasaki, Japan	Ambient		3.6×10^{6}	36
Pure 60Co γ-radiation	JAERI, Takasaki, Japan	Ambient		1.35×10^{4}	9630
TRIGA Mark II reactor	Vienna, Austria	Ambient	7.6×10^{16}	1×10^{5}	1300
Intense Pulsed Neutron Source	Argonne IL, USA	Ambient	1.6×10^{15}	2×10^{4}	6500
FRM, Munich	Garching, GY	5 (Closed)	2.9×10^{17}	2.8×10^{6}	46.4
IVV-2M Zarachny	Ekaterinburg, Russia	80	1.6×10^{18}	1.8×10^{7}	7.2

Irradiation testing of insulators at M.I.T. (Bromberg)





- **Irradiation damage to organics mainly due to radiochemistry, driven mainly by electrons**
- **Radiation facility consisting of:**
    - **E-beam unit (200 kV, 4 mA)**
    - **Capable of large dose rates up to Grad/s (5.6 hr/2 x 10^{10} Rad)**
    - **Large sample capability (5cm x 5 cm)**
    - **Capable of cryogenic testing**

Gas evolution rates of epoxy resins

Resin/Hardener	MNA (anhydride)	MTHPA (anhydride)	DDM (aromatic amine)	DETD (aromatic amine)
	(cm^3/g-MGy)	(cm^3/g-MGy)	(cm^3/g-MGy)	(cm^3/g-MGy)
DGEBA	1.35	1.38	0.32	0.57
	1.23	1.27		0.58
DGEBF		1.08		0.58
		1.03		
TGPAP		1.19		
		1.1		
TGDM	1.4		0.38	
	0.77			

ρ~ 1.2 g/cc

Φ~0.22 MGy

R~O(1) (cm^3/g-MGy)

Vgas,lifetime ~106 cc/cc

Vgas, 1 shot

~0.01 cc/cc

(Maybe lower for cyanate ester)

Conclusions

1) Existing and new materials hopeful for 130 MGy and Beyond

   - many composites with σ_z > 1000 MPa

   - polyimides, cyanate esters without degradation to 100 MGy

   - active SBIR program, active NSO R&D doable

   - possible improvements in organic, inorganic insulation systems

2) Inadequate data base for 100 MGy, let alone >> 100 MGy

   - few points at 100 Mgy

3) Electron beam screening should be considered

4) Worrisome synergy: stress/radiation/powdering/carbonization/gas evolution/photoconductivity, and electric field