Radiation Issues in Capture Solenoid

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General Radiation Limits for Several Materials

NbTi: ~ 10^{19} n/cm^2 E>.1 MeV
Nb_3Sn: A little bit better

Note: 10^{19} n/cm^2 = 10^8 Gy = 10^{10} Rad

Organics: 10^6 to 10^8 Gy

Ceramics: > 10^9 Gy

Copper: > 10^{10} Gy

Radiation damage is not well defined. Some properties are more sensitive than others.

Example:
Dielectric strength of G10 less sensitive than mechanical properties such as yield strength.

Basis of discussion is N. Mokhov's 10/19/99 report (www-ap.fnal.gov/mokhov/mumu/target99)

Issues raised:

- Superconductor damage
- Insulator damage
- Shielding materials damage

UNSHIELDED

Component	Hg/Cu	Hg/W	C/Cu
SC coil (kW)	7.84	3.25	8.66
Power to SC winding (kW/m^3) (ITER limit is 5)	56	23	23

Taking the case of C/Cu:

Component	Energy deposition
Copper	96 mJ/g = 4.5×10^{10} Gy/yr
Water	60 mJ/g = 900 Gy/sec
SC coil	0.038 mJ/g = 2×10^{7} Gy/yr

(Assuming 100% operation)

1 MW

Meaning?

Assume 50% duty cycle per yr:

Insulation: 10^7 Gy = 1-2 years

Nb_3Sn: 10^7 Gy = 10 years at low field

Cu: $2.8 X 10^{10}$ Gy = 20 years, but resistance increases a few % per year and thermal conductivity decreases

Water: 900 Gy/sec = erosion of copper and lowering of voltage holding capacity

~~What we need:~~

Other organic "problems":

Superinsulation - $6X10^6$ Gy

Solution: aluminized Kapton - good to at least 10^8 Gy

G10 - ~ $2X10^7$ Gy

Solution: Spaulrad-S (S-glass) - at least $4X10^9$ Gy

Damage correlation with specific spectrum

Insulation good for 10^8 Gy (both dielectric strength and compressive/shear strength)

High field Nb_3Sn sensitivity

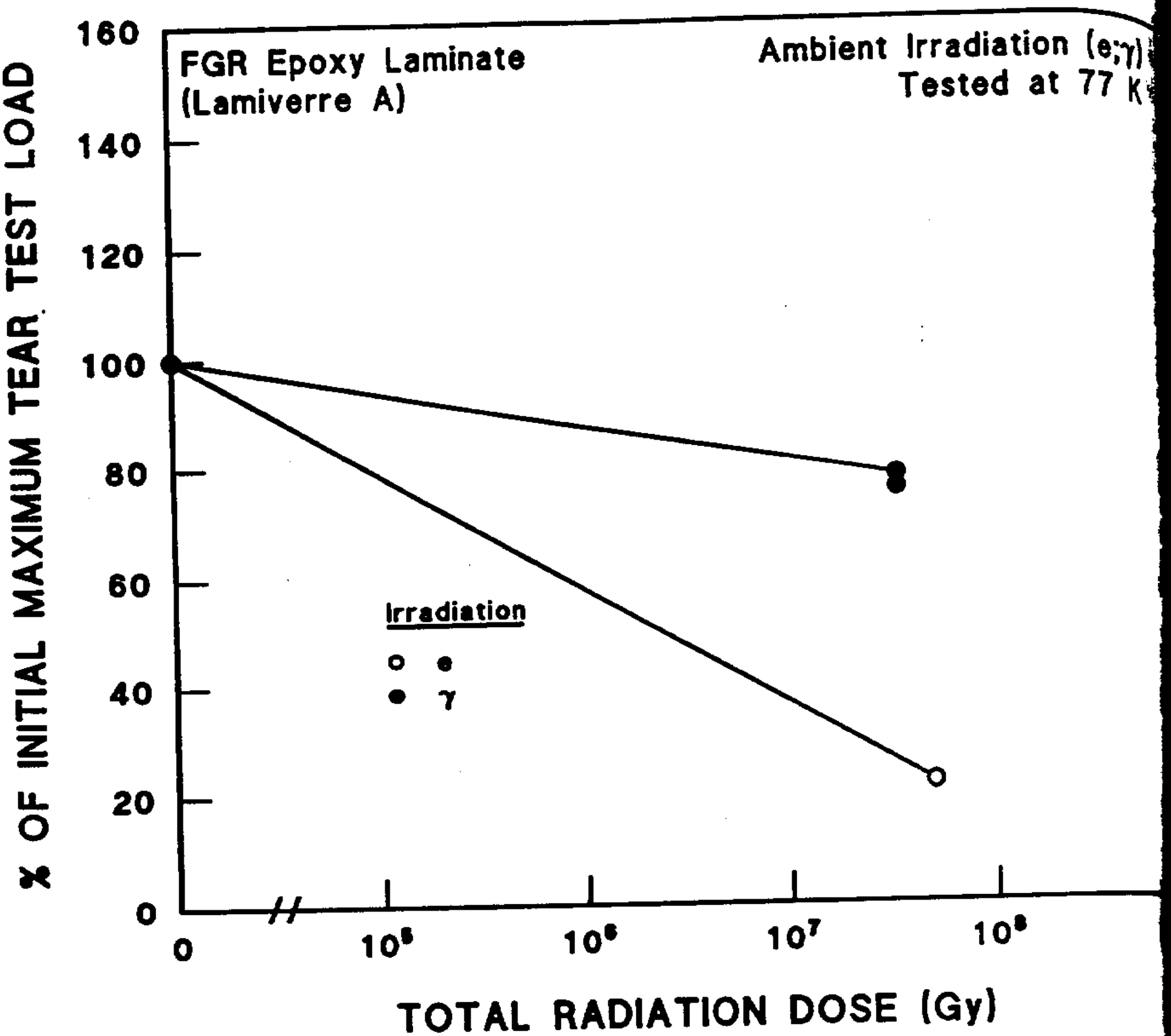
Temperature effects

Testing and specifications

Note on ITER:

Nb_3Sn field at coil is about 13 T

Tgt solenoid is 20 T
(What fraction of max epoxy strength is used?)



"0" Load, N		Weave	Finish	Glass	Supplier
○	108.0	Plain	Silane	62–65 mass %	---
●	108.0	Plain	Silane	62–65 mass %	---

Figure A.3-14. Maximum tear test load at 77 K of FGR epoxy laminate (Lamiverr after ambient gamma or electron irradiation. Supplementary Table A.2-10. Dat Nishiura et al. [1988a].

Table 1.5. Linear Energy Transfer and Mean Spur Separation for Different Radiations*. (Data from Van de Voorde [1970] and citations therein).

Radiation	-dE/dx, eV/nm	Spur Separation, nm
0.01 MeV electrons	2.3	26
0.1 MeV electrons	0.4	140
1 MeV electrons	0.2	300
^{60}Co γ rays	0.2	300
1 MeV protons	28	2.1
10 MeV protons	4.7	13
1 MeV α particles	264	0.23
10 MeV α particles	56	1.1

* Mean energy per spur taken as 60 eV

protons, which corresponds with the intense local damage produced by the (B,n) → (Li,α) reaction and by knocked-on protons from neutron collisions.)

Despite the equivalence, in theory, of gamma and electron irradiation, considerable differences have been observed experimentally. However, if the irradiation is carried out in ambient air, different dose rates can cause a difference between the damage observed at a given dose for electron and gamma irradiation. The dose rate factor was used by Egusa [1991a] to explain the different results shown in Figure A.3-16 for neat resin specimens irradiated by either ^{60}Co-gamma rays at 0.017 MGy/h or 2-MeV electrons at 11.5 MGy/h. Considerably more degradation was exhibited by the specimens irradiated with gamma rays. Since the bulky solid specimens were irradiated in air, regions near the surface could experience more oxidative degradation during the gamma ray irradiation because there was much more time for the oxygen to diffuse in. However, when glass-reinforced composites of the same TGDM resin system were irradiated with both gamma rays and electrons under the same conditions as the neat resins, no difference between the two types of irradiation was observed (Figure A.3-17). Egusa proposed that the well-known sensitivity of neat resin specimens to surface flaws (see also §1.4 below) and the relative

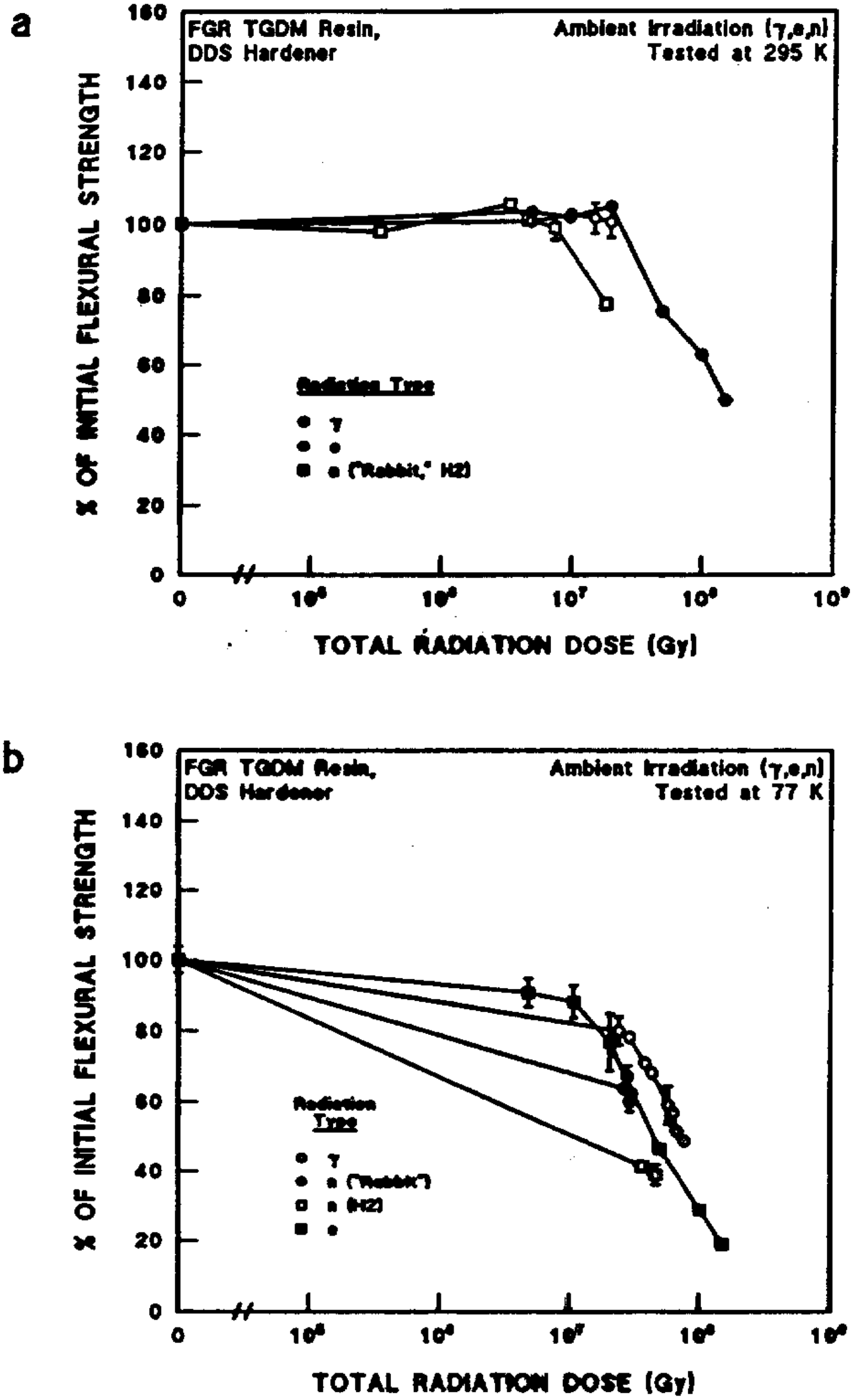
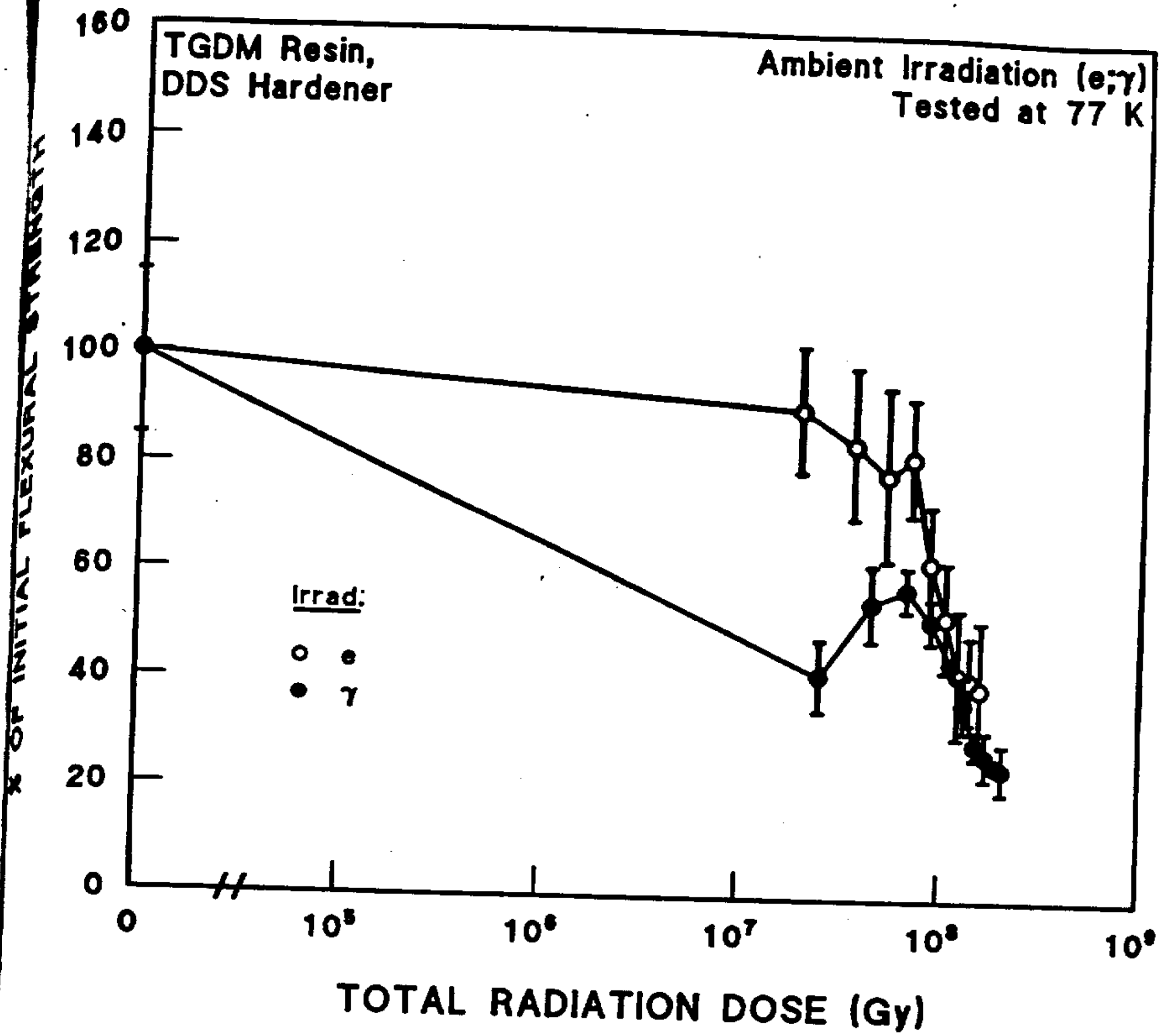


Figure 1.20. Irradiation data comparing the effects of neutron, electron, and gamma irradiation on a fiber-glass reinforced TGDM (tetraglycidyl diaminodiphenyl methane) epoxy matrix cured with DDS (diaminodiphenyl sulphone). (a) Flexural tests at 295 K. Data from Egusa et al. [1984a,b]. (b) Flexural tests at 77 K. Data from Egusa et al. [1985a; 1987b]. The H2 irradiation thimble exposed specimens to a heavier dose of thermal neutrons than the "Rabbit" thimble. (Supplementary Table B.1-1.)



	"0" Strength, MPa	Supplier
○	241.3 ± 6.2	Sumitomo Bakelite Co., Ltd.
●	241.3 ± 6.2	Sumitomo Bakelite Co., Ltd.

Figure A.3-17. Flexural strength at 77 K of neat TGDM resin with DDS hardener after ambient gamma or electron irradiation. Supplementary Table A.3-4. Data from Egusa [1991a].

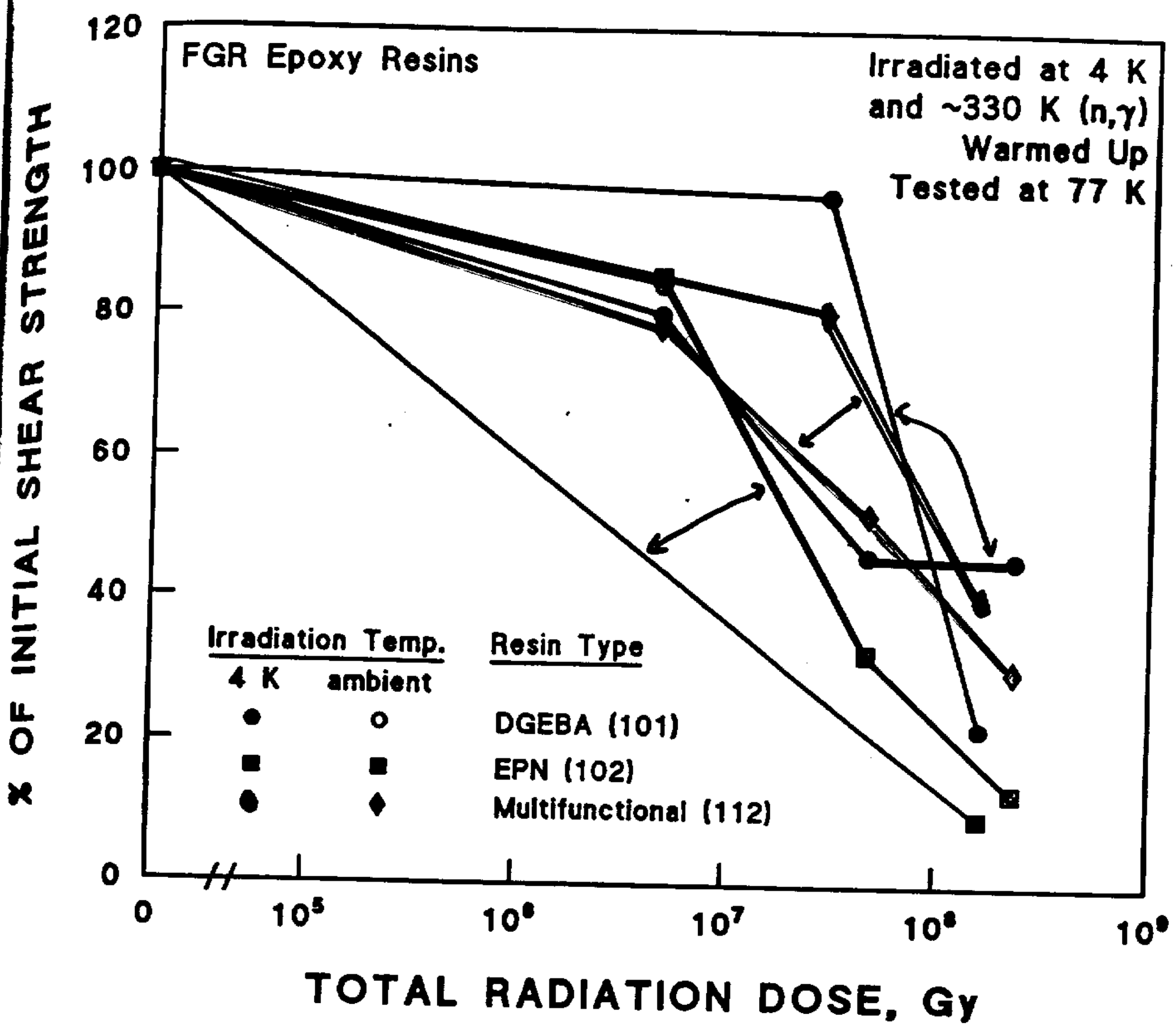
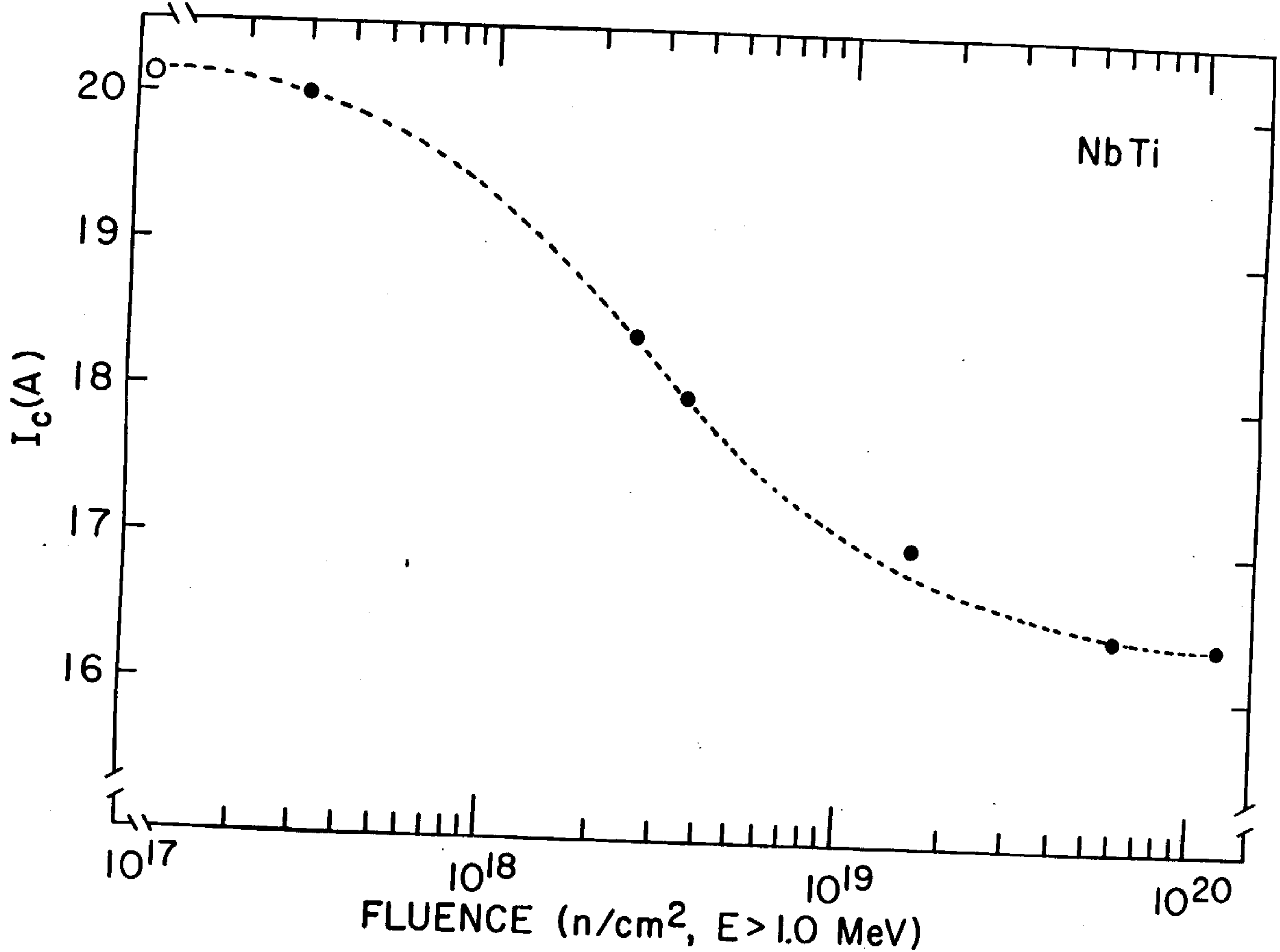
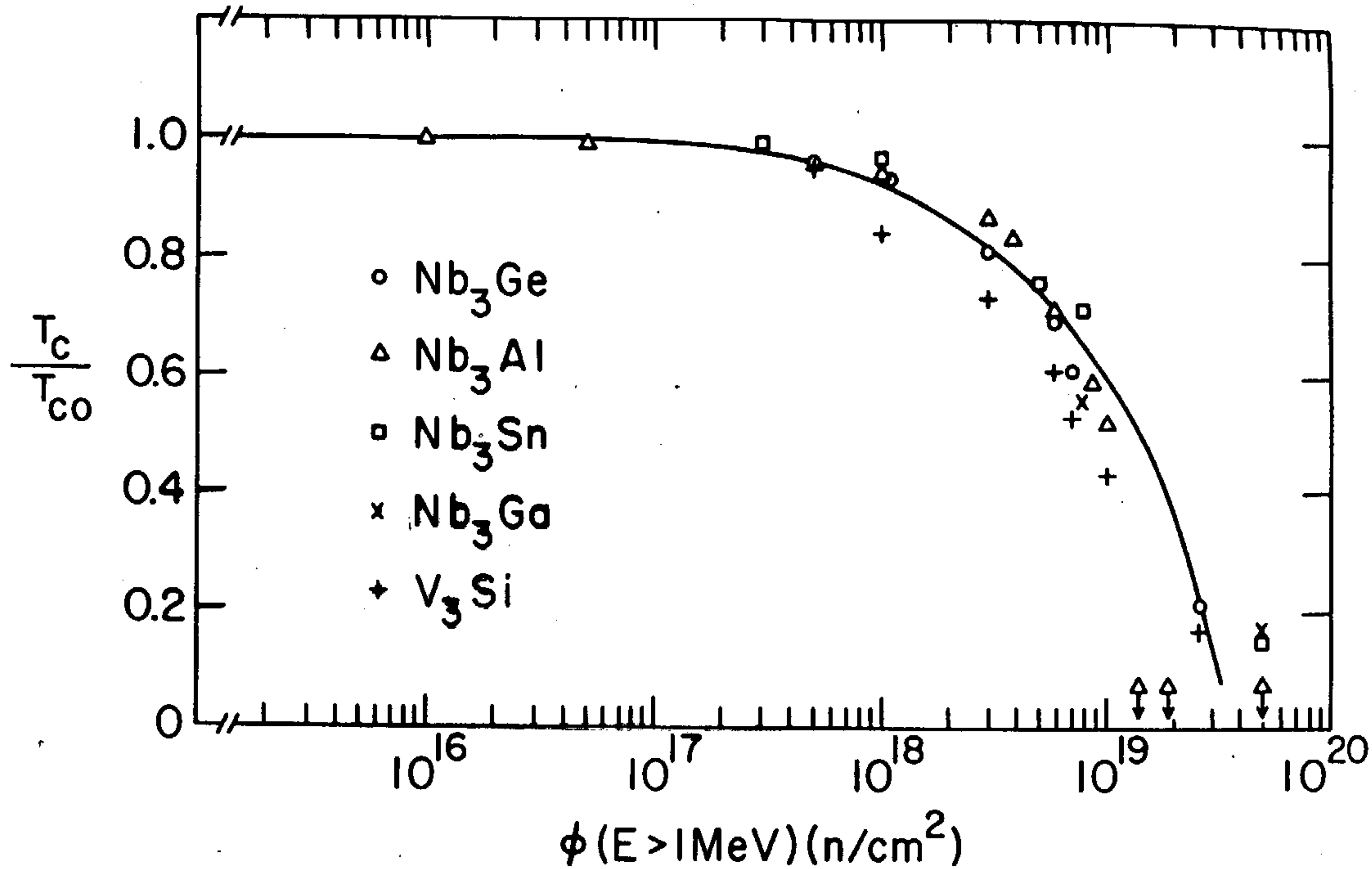


Figure 1.25. A comparison of the shear strengths of three types of reinforced epoxy resins that were reactor-irradiated at both 4 K and at ambient temperature. See text for differences in the fast neutron spectrum in the two reactors. Data from Munshi [1991]. (Supplementary Tables A.3-3 and A.8-4.)



NbTi
$I_c(A)$
20
19
18
17
16
10^{17}
10^{18}
10^{19}
10^{20}
FLUENCE (n/cm^2, E > 1.0 MeV)



T_c / T_{co}
1.0
0.8
0.6
0.4
0.2
0
○ Nb_3Ge
△ Nb_3Al
□ Nb_3Sn
× Nb_3Ga
+ V_3Si
10^{16}
10^{17}
10^{18}
10^{19}
10^{20}
ϕ (E > 1MeV) (n/cm^2)

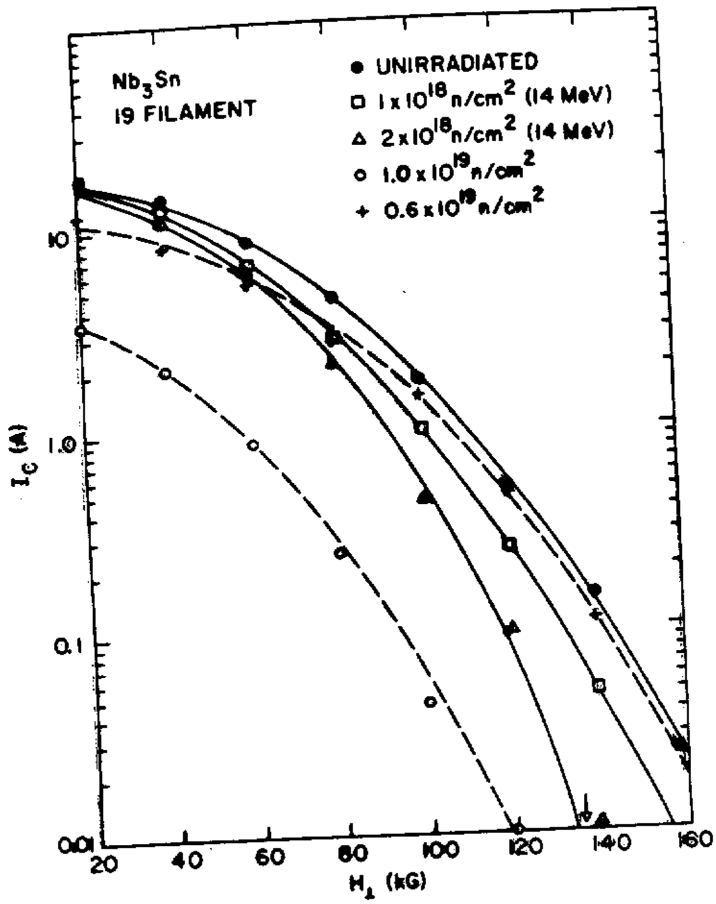


Fig. 16. The critical current is plotted versus applied field for two fluences of 14-MeV-neutron irradiations performed at room temperature. Also plotted for comparison are the results for two comparable fluences of fission-reactor neutrons. (After Snead et al. 1976.)

this analysis (admitting that the peak, or I_{max}, had not been reached for the fluences of either irradiation), a conclusion that possibly two mechanisms were at work, presumbaly pinning at cascades and increasing H_{c2} due to increasing ρ_N. The lack of recovery in the high-energy-neutron case in annealing to room temperature, whereas the Brown et al. results did show recovery, argues that possibly the cascade effects are more important in the high-energy case than for the fission-reactor neutron case.

Insert
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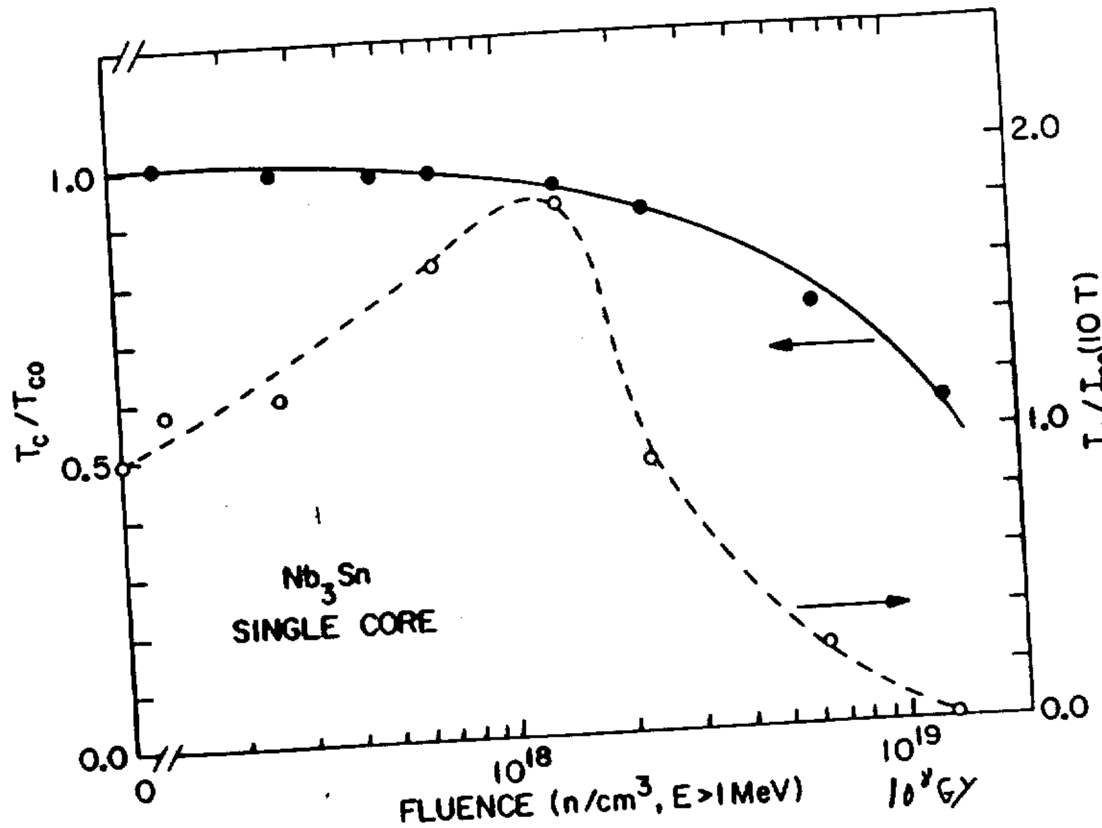
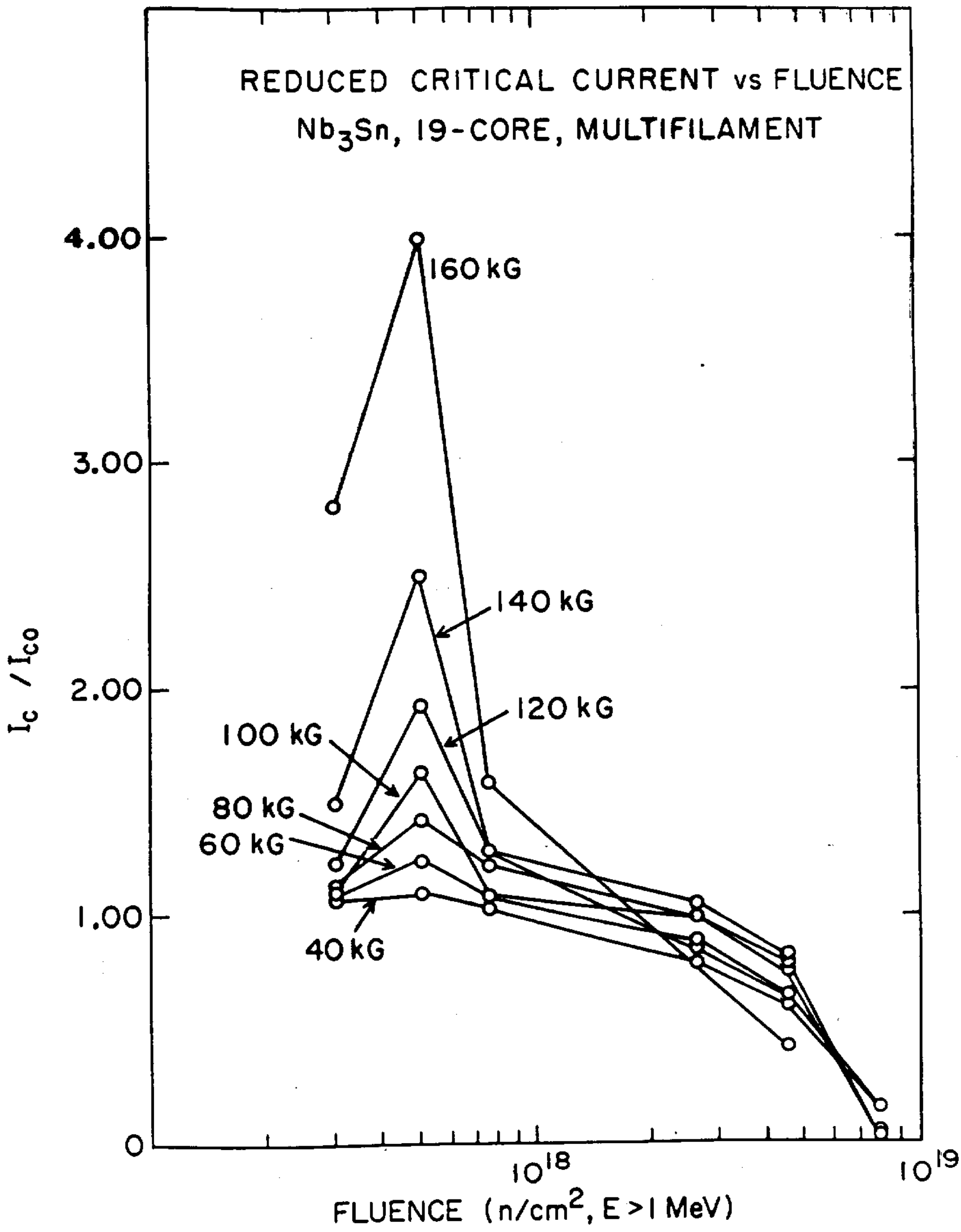


1.0
0.5
0.0
2.0
1.0
0.0
T_c/T_{co}
I_c/I_{co}(10 T)
Nb_3Sn
SINGLE CORE
0
10^{18}
10^{19}
FLUENCE (n/cm^3, E>1 MeV)


REDUCED CRITICAL CURRENT vs FLUENCE
Nb3Sn, 19-CORE, MULTIFILAMENT
160 kG
140 kG
120 kG
100 kG
80 kG
60 kG
40 kG
4.00
3.00
2.00
1.00
0
Ic / Ico
10^18
10^19
FLUENCE (n/cm^2, E > 1 MeV)