Chris Yeaw
University of Wisconsin

"Preliminary Investigation of Radiation Effects upon ITER TF Coil Stability"

Preliminary Investigation of the Radiation Effects Upon the Stability of the ITER TF Coils

Chris Yeaw

University of Wisconsin
Fusion Technology Institute
Madison, WI

MagRad

Purpose:

To predict the effects of radiation upon the stability of fusion magnet systems.

Bases:

1) **CICC's predictions for the ITER design**
2) **Recent radiation effects data and expressions**

Radiation Affects:

1) Critical Temperature, T_c

2) Critical Field, B_c

– ρ_N, γ, ε

3) Copper Resistivity, ρ_{Cu}

Note: There is no J_c dependence in I_{lim} given by Dresner. J_c effects are decoupled in this analysis, though for coil optimization they will certainly be important.

Procedure

1) Determine iteratively the T_{Ilim}, B_{Ilim}, and I_{lim}.

2) Repeat 1) at a given fluence, with the inclusion of *all* radiation effects.

3) Use the geometry of the stability curve to find ΔH.

Alternatively: Solve for a given (limiting) ΔH and determine corresponding fluence.

Assumptions

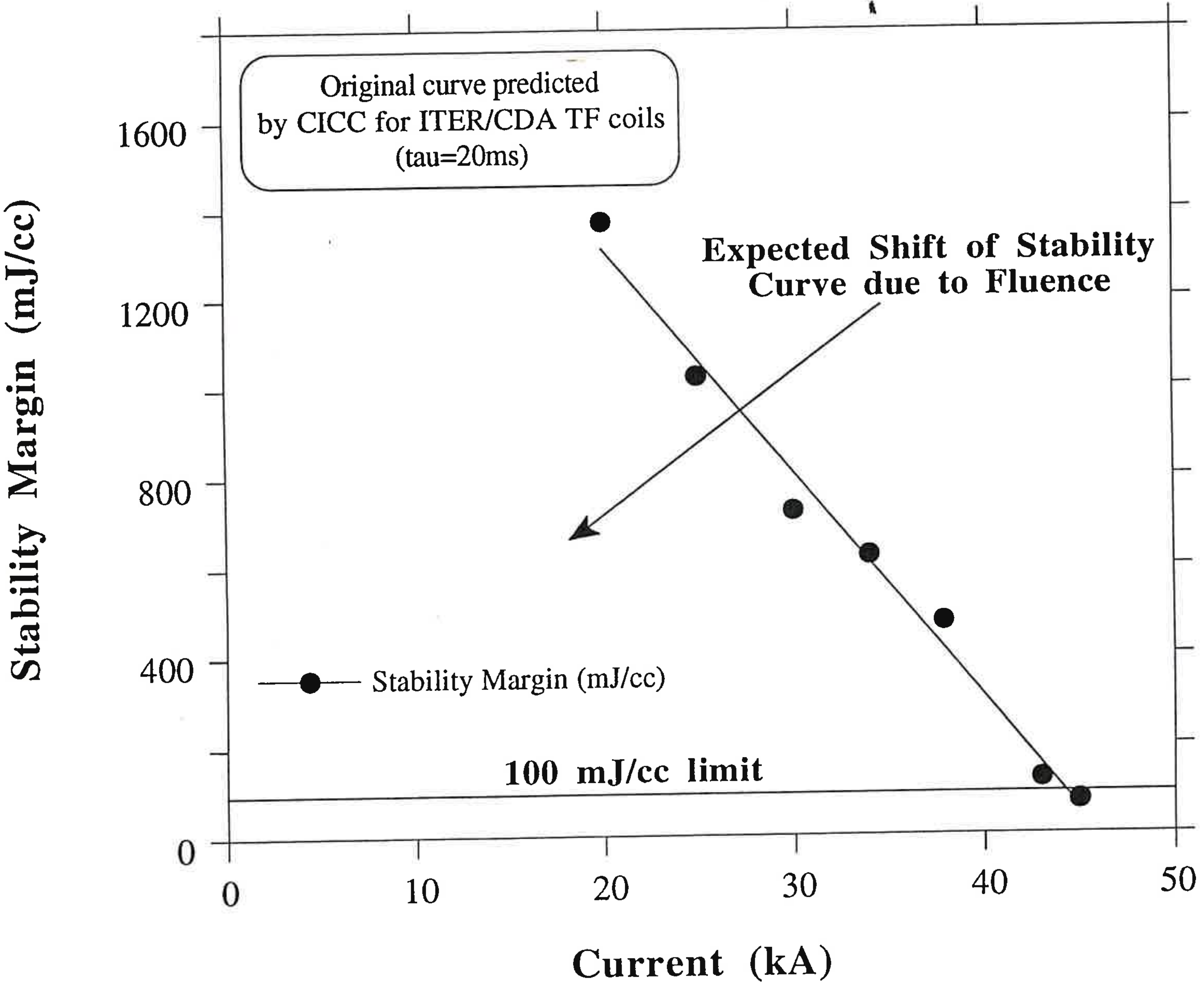
1) **Stability curve retains same slope after irradiation.**

   a) **Suppression of induced convective helium cooling implies a constant slope.**

   b) **According to Bottura's approximate expression (1993) for ΔE, slope would actually decrease.**

2) **Case of τ = 20 ms is worse than τ = 10 ms. Thus worse case is used.**

CICC Stability Margin



Copper Resistivity

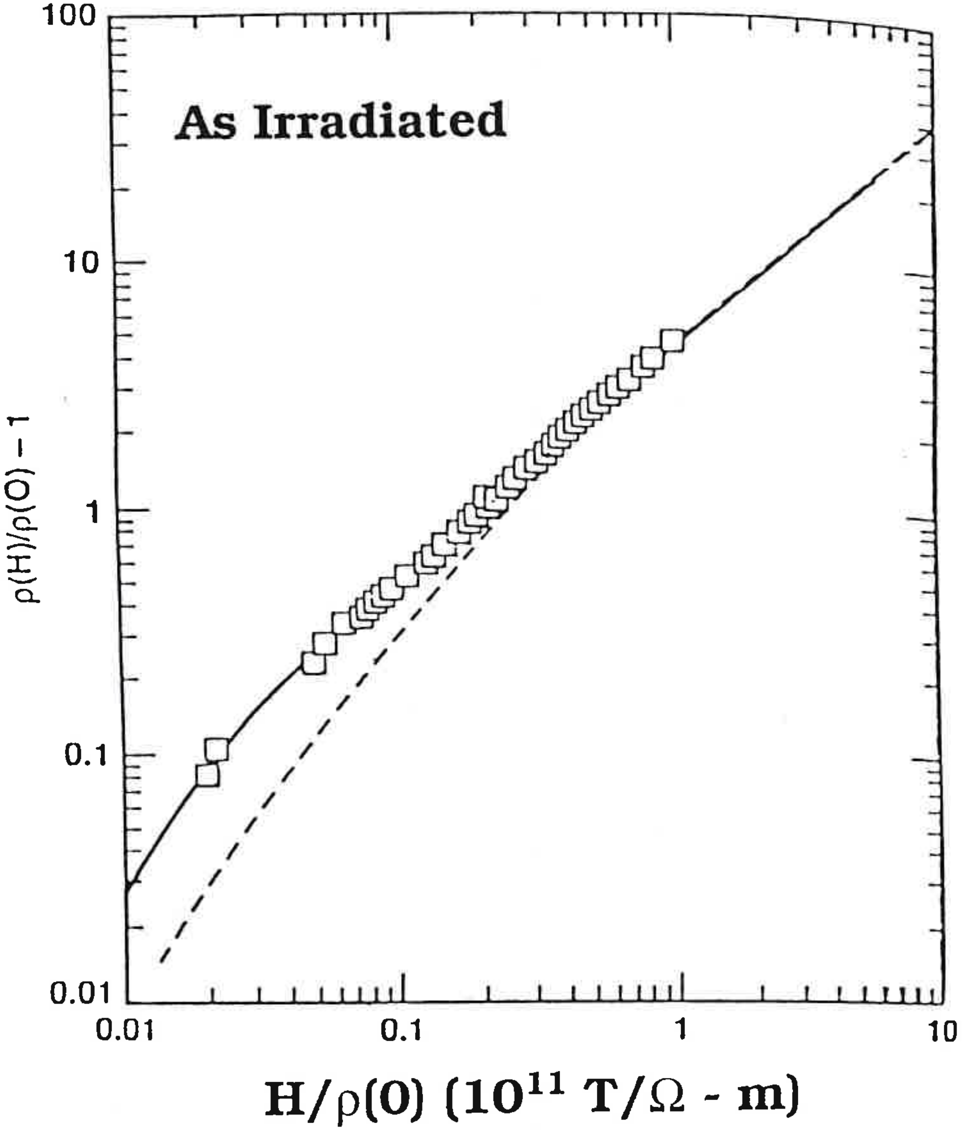
It has been shown (Guinan, et al., 1988) that after irradiation, Cu no longer exhibits a single Kohler plot. Therefore I use this expression:

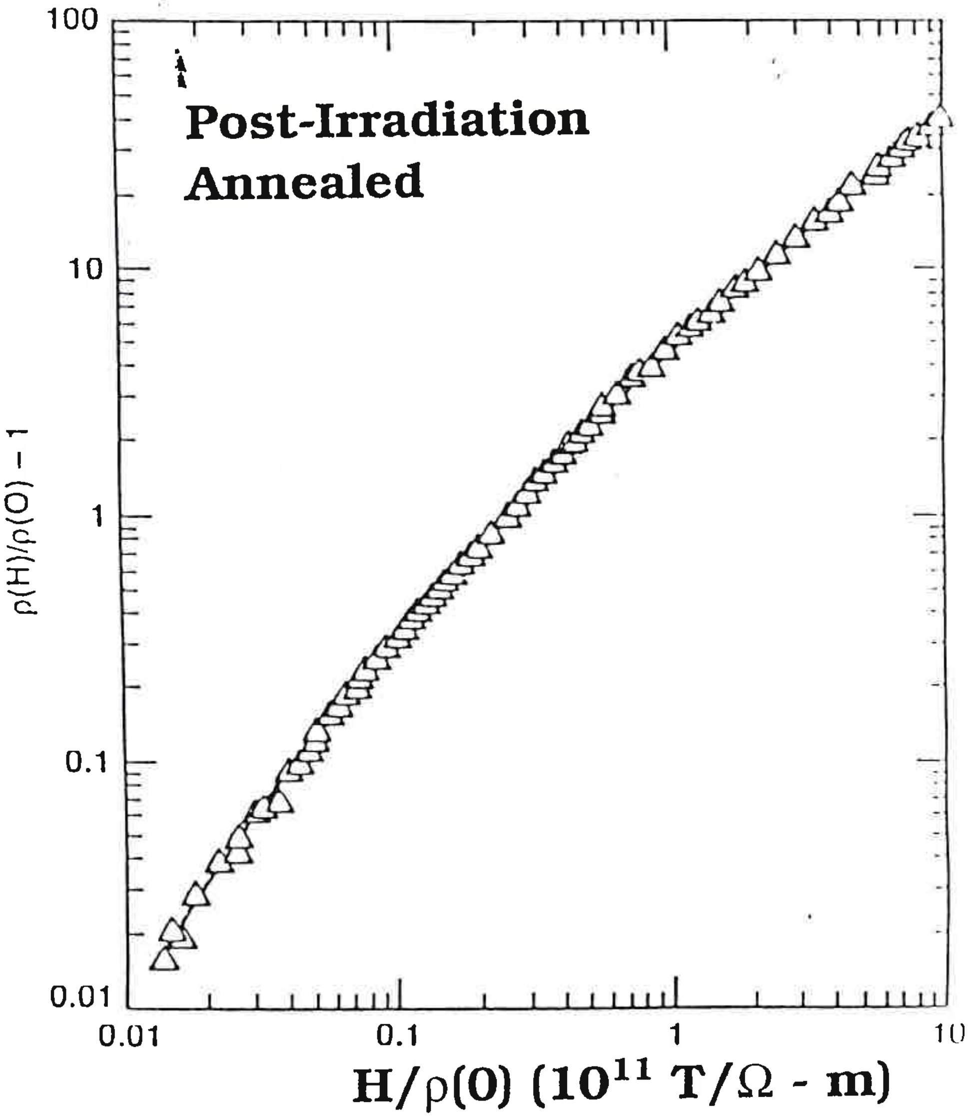
$$\rho(B) = [\rho_0 + 300(1 - e^{-240\mathrm{dpa}})] \cdot \{\tan^{-1}[(.7698 + 0.215\mathrm{fluence})9.683\mathrm{xrad}]/ \\ 9.683\mathrm{xrad} + \tan^{-1}[(.2049 + .0209\mathrm{fluence})153.5\mathrm{xrad}]/153.5\mathrm{xrad} + \\ \tan^{-1}[(.0263 + .00203\mathrm{fluence})15.37\mathrm{xrad}]/15.37\mathrm{xrad}\}^{-1}$$

where $\mathrm{xrad} = \frac{B_{lim}}{[\rho_o + 300(1 - e^{-240\mathrm{dpa}})]}$.

This does not impact stability much (I also calculate ρ_{Cu} two other ways for comparison; they are quite close).

Radiation Effect Upon Kohler Plot of Copper*
(Guinan et al., 1988)





******at RTNS-II fluence of* 1.33×10^{18} *n/cm*^{2}

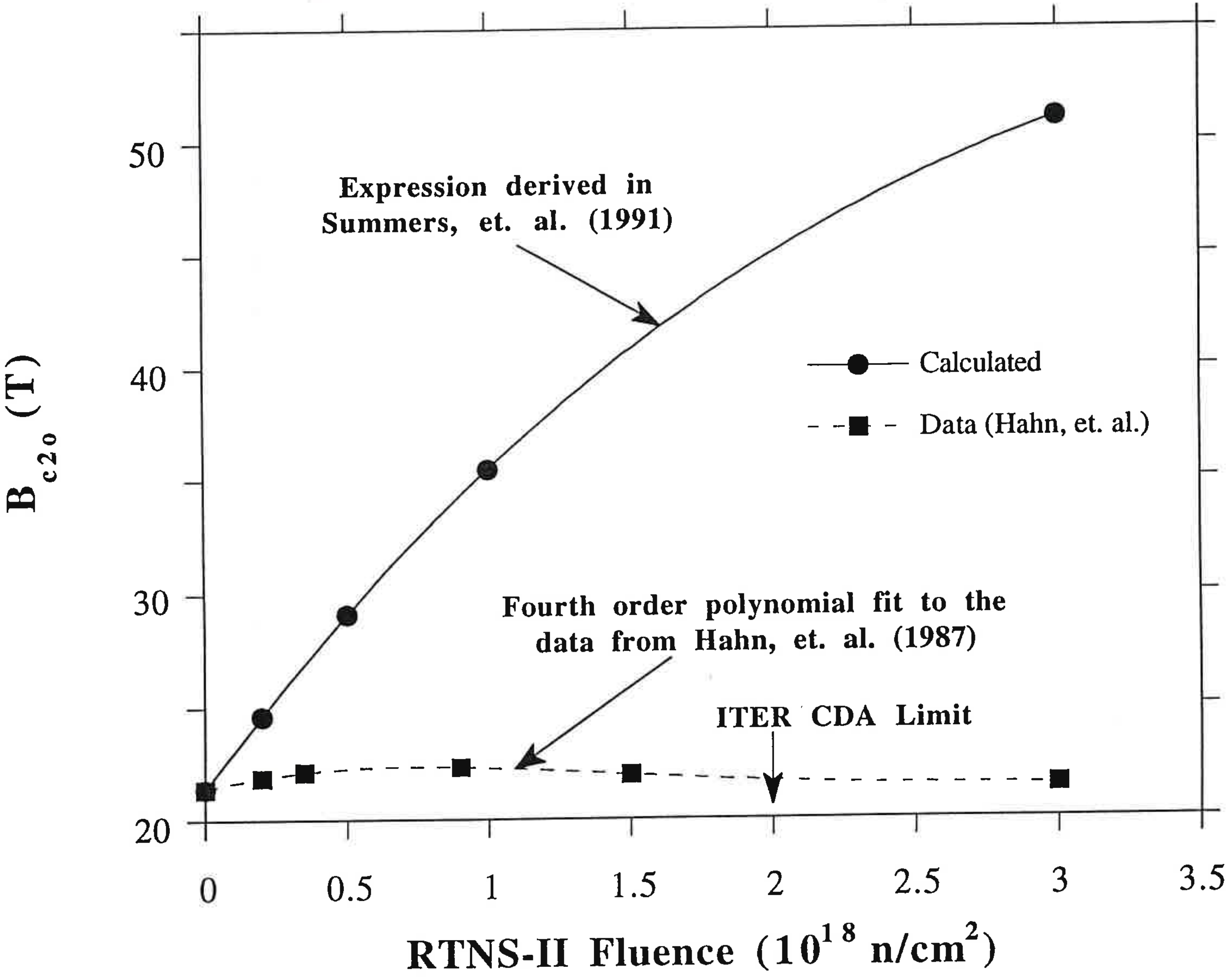
The Upper Critical Field Problem

- In all codes and literature surveyed this is the form that is used,

$$B_{c20m}(E_d) = B_{c20m}(0)\,\frac{\rho_o + 600\,E_d}{\rho_o}\,e^{-\frac{5}{8}E_d} \qquad \text{(Summers et al., 1991)}$$

- However, it *must* be noted that this expression yields a peak upper critical field of about 63 T at an ITER fluence of about $25\text{x}10^{18}$ n/cm^2 ! (even higher $B_{c20m}(E_d)$ for ternaries).

Nb_3Sn B_{c20} v. Fluence



Why Did This Problem Occur?

- The "dirty" limit was used,

$$H_{c2} \propto \gamma \rho_N T_c$$

– we have $\gamma, \rho_N, T_c,$ so what's the problem?

- The problem may be that the dirty limit may not apply to these conductors (especially after irradiation).

In the "dirty limit",

$$H_{c2} = 3.1\text{x}10^{3}\,\gamma\,\rho_{N}\,T_{c} \qquad \text{(Wilson, 1983)}$$

- This gives an H_{C20m} for Nb_3Sn at zero fluence of about 9 T. Thus, even at zero fluence we should be wary of using this formula (as Wilson also says of Nb_3Sn, p.283)

- Moreover, we are not certain how the coherence length and electron mean free path are affected by radiation.

Conclusion: Use the data, not the modelled expression.

One Possible Solution

- Inspection of Hahn's data, however, gives a peak B_{c20} of only about 30 T at an ITER fluence of about 5×10^{18} n/cm^2.

- Therefore, in lieu of the previous expression one may fit the data to,

$$B_{c20m}(E_d) = B_{c20m}(0) + 3.12(\phi t) - 3.19(\phi t)^2 + 1.11(\phi t)^3 - .13(\phi t)^4$$

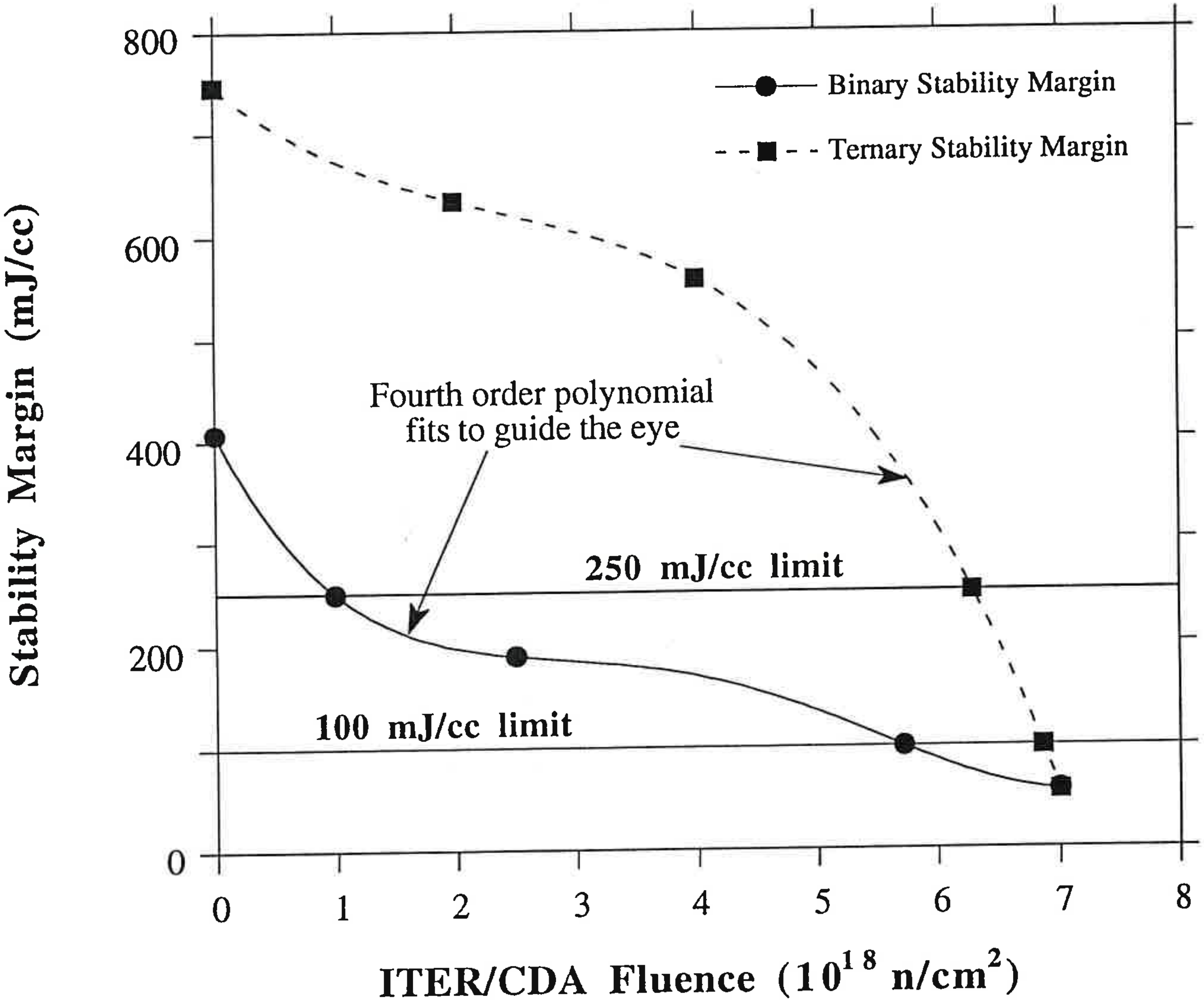
where ϕt is RTNS-II fluence. Valid up to ITER fluence of 1.5×10^{19} n/cm^2.

- One might also use a best fit (which still is not good) to the data of the same form as the Summers, et al. expression, giving,

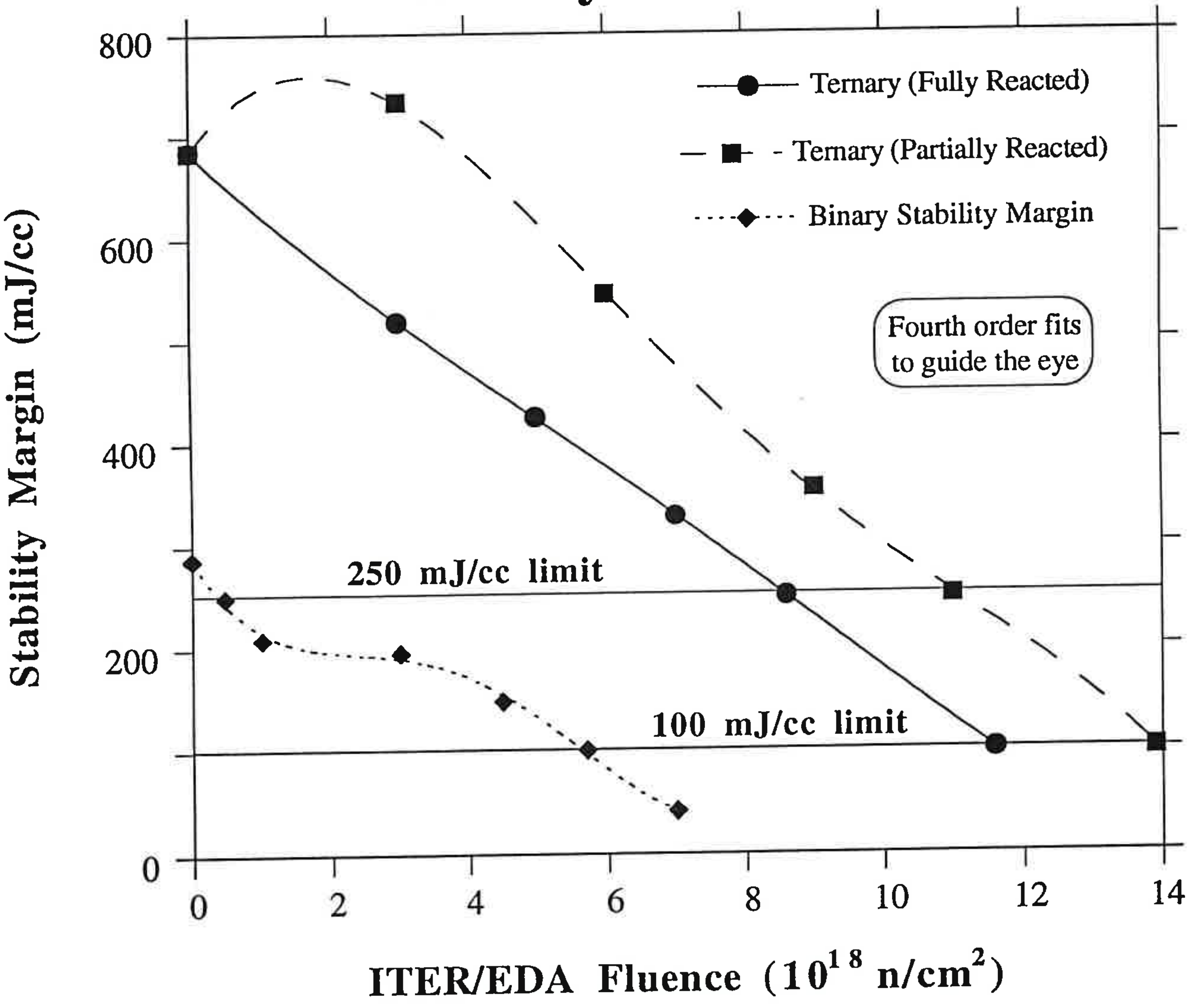
$$B_{c20m}(E_d) = B_{c20m}(0) \frac{\rho_o + 42(\phi t)}{\rho_o} e^{-0.2(\phi t)}$$

where ϕt is defined as above.

ITER/CDA
Stability v. Fluence



ITER/EDA
Stability v. Fluence



Design Conclusions

1) EDA design demonstrates better stability than the CDA design at all ITER fluences for ternary Nb_3Sn, but worse stability for binary Nb_3Sn.

2) Use of binary Nb_3Sn may be precluded in the EDA design, unless used in conjunction with inorganic insulators with a suitable magnet annealing schedule adopted.

3) Ternary Nb_3Sn will most probably allow the full ITER fluence limit to be attained in the coils (given frequent stabilizer anneals) with only minor, if any, design modifications.