

CONF-8503123--1

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DE85 009507

WHIST CODE CALCULATIONS OF IGNITION  
MARGIN IN AN IGNITION TOKAMAK\*

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PRESENTED AT THE  
IGNITION DESIGN POINT WORKSHOP  
PRINCETON PLASMA PHYSICS LABORATORY  
MARCH 12, 1985

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BY

JOHN SHEFFIELD  
ASSOCIATE DIRECTOR FOR CONFINEMENT  
FUSION ENERGY DIVISION  
OAK RIDGE NATIONAL LABORATORY

**MASTER**

\* Research sponsored by U.S. Department of Energy, Office of Fusion Energy, under contract DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

A SIMPLE GLOBAL MODEL WAS DEVELOPED TO DETERMINE THE IGNITION MARGIN OF TOKAMAKS INCLUDING ELECTRON AND ION CONDUCTION LOSSES - JOHN SHEFFIELD, ORNL/TM-8924, 1984 AND UPDATED BY NERMIN UCKAN, JANUARY 1985.

- THE MODEL HAS NOW BEEN COMPARED FOR A REFERENCE IGNITION DEVICE,

$$R = 1.5\text{m}, a = 0.5\text{m}, K = 1.6, \delta = 0.2$$

$$B_0 = 9\text{T}, q_{\psi} \approx 3, Z_{\text{eff}} = 1.5$$

AGAINST RESULTS FROM WAYNE HOULBERG'S  
1 1/2 D-WHIST CODE.

- BOTH CALCULATIONS SHOW THAT UNDER THE PHYSICS CONSTRAINTS PRESENTLY IMPOSED ON THE IGNITION TOKAMAK ION CONFINEMENT PLAYS AN IMPORTANT ROLE

$$\beta_{\text{crit}} = 3 \times 10^{-2} \frac{I \text{ (MA)}}{a \text{ (m)} B_0 \text{ (T)}} \left. \vphantom{\beta_{\text{crit}}} \right\} \begin{array}{l} \text{VOLUME} \\ \text{AVERAGE} \\ \text{VALUES} \end{array}$$

and  $n_{20} \leq n_{\text{crit}} = 1.7 \frac{B_0}{q R_0}$

- THEREFORE IT IS IMPORTANT TO ESTABLISH A CRITERION (Cx) FOR ION CONFINEMENT

$$\chi_i = C \times \chi_i \text{ (CHANG-HINTON)}$$

FORMULA FOR IGNITION MARGIN (M)

$$M \left[ \chi_e + \left( \frac{n_i}{n_e} \right) \frac{T_i}{T_e} \chi_i \right] \leq 0.162 F_{\alpha} \left[ 4 f_D (1 - f_D) f_{DT}^2 \right] n_{e20} T_{e10} \left( \frac{T_i}{T_e} \right)^2 a^2 \left( \frac{2\kappa^2}{1+\kappa^2} \right)$$

$F_{\alpha} \simeq 0.8$  fraction of alpha power to support conduction losses

$$f_D = \frac{n_d}{n_{DT}} = 0.5, \quad f_{DT} = \frac{n_{DT}}{n_e} \simeq 0.84$$

$$\frac{n_{\alpha}}{n_e} \sim 0.05, \quad \frac{n_Z}{n_e} \sim 0.007 \quad (Z \sim 8), \quad \frac{n_i}{n_e} \simeq 0.9$$

$$n_{e20} T_{e10} \simeq 1.15 \beta_{B_0}^2 \text{ allowing for alpha pressure}$$

$$M \left[ \chi_e + 0.9 \frac{T_i}{T_e} \chi_i \right] \lesssim 0.105 \beta_{B_0}^2 a^2 \left( \frac{2\kappa^2}{1+\kappa^2} \right)$$

EXAMPLE

$$\chi_e = f_{ex} \chi_{Neo\ Alcator}^{OH} = f_{ex} \frac{2.7a}{n_{e20} R_0^2 a} \left( \frac{2K^2}{1+K^2} \right) m^2 s^{-1}$$

$$\chi_i = f_{ix} \chi_{iCH} = f_{ix} \left[ 2.06 \times 10^{-2} K_2^* \frac{n_{e20} Z_{eff}^{-3/2}}{\tau_{i10}^{1/2}} \frac{a^2}{B_0^2} \frac{2}{(1+K^2)} \right] m^2 s^{-1}$$

$$K_2^* = (0.66 + 1.88 \epsilon^{1/2} - 1.54 \epsilon)(1 + 1.5 \epsilon^2)$$

$$\epsilon = \frac{a}{R_0}$$

For  $Z_{eff} = 1.5$ ,  $K = 1.6$ ,  $F_\infty = 0.8$ ,  $A = 3$ ,  $\epsilon = 0.33$ ,  $\frac{a}{a} = 5$ ,  $T_e = T_i$

$$\frac{a B_0^2}{a} \geq M \left\{ 10.1 f_{ex} + \frac{4.5}{\tau_{i10}^{1/2}} f_{ix} \right\}$$

(1)  $f_{ix} = 0$ ,  $M = 1.5$  need  $\frac{a B_0^2}{a} \geq 15$   
 $f_{ex} = 1$

(2)  $f_{ix} = 1$ ,  $M = 1.5$  need  $\frac{a B_0^2}{a} \geq 22$   
 $f_{ex} = 1$ ,  $\tau_{i10} = 1$

(3)  $f_{ix} = 2$ ,  $M = 1.5$  need  $\frac{a B_0^2}{a} \geq 29$   
 $f_{ex} = 1$ ,  $\tau_{i10} = 1$

(4)  $f_{ix} = 2$ ,  $M = 1.0$  need  $\frac{a B_0^2}{a} \geq 29$   
 $f_{ex} = 2$ ,  $\tau_{i10} = 1$

AT THE MURAKAMI AND  $\beta_{crit}$  LIMIT, FOR  $T_i \simeq T_e$ ,  $\tau_{i10} \simeq 1.1$ ,  $n_{e20} \simeq 3.9$

$$\chi_e \text{ Neo Alcator} \simeq 0.085 m^2 s^{-1}, \chi_{iCH} \simeq 0.032 m^2 s^{-1}$$

$$\left( \frac{r}{a} = 0.5, Z_{eff} = 1.5 \right)$$

## WHIST CODE CALCULATIONS

- CASES WERE RUN WITH:

$$R = 1.5\text{m}, \quad a = 0.5\text{m}, \quad K = 1.6,$$

$$B_0 = 9\text{T}, \quad q_\psi = 3, \quad \text{NO RIPPLE LOSSES,}$$
$$\text{NO THERMAL ALPHAS}$$

$$\text{FAST ALPHA PRESSURE, } Z_{\text{eff}} = 1.5$$

$$\begin{array}{l} \chi_e = f_{\text{ex}} \chi_{\text{Neo Alcator}}^{\text{OH}}, \quad f_{\text{ex}} = 1, 2 \\ \chi_i = f_{\text{ix}} \chi_{\text{Chang-Hinton}}, \quad f_{\text{ix}} = 1, 2 \end{array} \left. \vphantom{\begin{array}{l} \chi_e \\ \chi_i \end{array}} \right\} \begin{array}{l} \text{Higher losses} \\ \text{inside } q = 1 \\ \text{surface.} \end{array}$$

- THE RESULTS ARE SLIGHTLY MORE FAVORABLE THAN THE GLOBAL MODEL BUT THE SAME TREND SHOWS THAT
  - GOING FROM  $f_{\text{ix}} = 1 \rightarrow 2$  SUBSTANTIALLY REDUCES M.
  - GOING FROM  $f_{\text{ex}} = 1 \rightarrow 2$  ELIMINATES IGNITION.
- A RECENT TFTR/JET WORKSHOP SUGGESTED USING  $f_{\text{ix}} = 3$  !
- REMOVAL OF THE HIGHER LOSSES FOR  $q < 1$  DOES NOT CHANGE  $P_\alpha$  MUCH AT THE  $\beta$ -LIMIT.

## WHY IS ION CONFINEMENT IMPORTANT?

1. IGNITION MARGIN IS SENSITIVE TO  $T_i$  and  $\frac{T_i}{T_e} > 1$
2. THE BULK OF THE ALPHA POWER GOES TO THE ELECTRONS, TO ACHIEVE  $\frac{T_i}{T_e} > 1$  REQUIRES THAT  $\chi_i = \frac{P_{\alpha i}}{P_{\alpha e}} \chi_e$ .
3. FOR THE HIGH FIELD IGNITION DEVICES THE MAXIMUM IGNITION MARGIN IS FOR  $n_{20} \sim 4$  and  $T_{i10} \sim 1$  AND  $\frac{\chi_i}{\chi_e} \approx \frac{P_{\alpha i}}{P_{\alpha e}}$ .

## CONCLUSION

BOTH  $\chi_e$  AND  $\chi_i$  CRITERIA SHOULD BE GIVEN.