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WHIST CODE CALCULATIONS OF IGNITION MARGIN IN AN IGNITION TOKAMAK*

4/3 [illegible]

PRESENTED AT THE

IGNITION DESIGN POINT WORKSHOP
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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,

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

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

  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

$$\left.\begin{array}{l} \beta_{crit} = 3 \times 10^{-2} \dfrac{I\ (MA)}{a(m)\ B_0(T)} \\ \\ \text{and} \quad n_{20} \lesssim n_{crit} = 1.7 \dfrac{B_0}{q\ R_0} \end{array}\right\} \begin{array}{l}\text{VOLUME}\\ \text{AVERAGE}\\ \text{VALUES}\end{array}$$

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

  $\chi_i = C \times \chi_i$ (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

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

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

$n_{e20}\, T_{e10} \simeq 1.15\, \beta B_0^2$ 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

$$\chi_e = f_{ex}\,\chi^{OH}_{\text{Neo Alcator}} = f_{ex}\,\frac{2.7a}{n_{e20}\,R_0^2\,q}\left(\frac{2\kappa^2}{1+\kappa^2}\right) \quad m^2\,s^{-1}$$

$$\chi_i = f_{ix}\;\chi_{iCH} = f_{ix}\left[2.06\times10^{-2}\,K_2^*\;\frac{n_{e20}\,Z_{eff}{}^{-3/2}}{T_{i10}{}^{1/2}}\;\frac{q^2}{B_0{}^2}\;\frac{2}{(1+\kappa^2)}\right] m^2\,s^{-1}$$

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

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

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

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

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

$f_{ex} = 1$

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

$f_{ex} = 1$, $T_{i10} = 1$

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

$f_{ex} = 1$, $T_{i10} = 1$

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

$f_{ex} = 2$, $T_{i10} = 1$

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

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

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

WHIST CODE CALCULATIONS

- CASES WERE RUN WITH:

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

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

  NO THERMAL ALPHAS

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

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

- THE RESULTS ARE SLIGHTLY MORE FAVORABLE THAN THE GLOBAL MODEL BUT THE SAME TREND SHOWS THAT

  - GOING FROM $f_{ix} = 1 \rightarrow 2$ SUBSTANTIALLY REDUCES M.
  - GOING FROM $f_{ex} = 1 \rightarrow 2$ ELIMINATES IGNITION.

- A RECENT TFTR/JET WORKSHOP SUGGESTED USING $f_{ix} = 3$!

- REMOVAL OF THE HIGHER LOSSES FOR $q < 1$ DOES NOT CHANGE P_α MUCH AT THE β-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 $\chi_i \quad \frac{P_{\alpha i}}{P_{\alpha e}} \chi_e$.

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 χ_e AND χ_i CRITERIA SHOULD BE GIVEN.