Reactor Issues

J. F. Lyon, ORNL

NCXS Physics Meeting

May 13, 1999

FESAC Reactor Questions

- **One of the criteria that we will be judged on is ENERGY VISION -- their scorecard reads**
  - **What is the overall attractiveness of the energy vision for this concept?**
  - **Have the important issues been identified?**
  - **Can the issues be addressed in the context of the broader national and world programs?**
  - **What is the proposed activity to contribute to this effort**
  - **What is the potential for energy applications?**
  - **What is the definition and impact on development pathway: costs, schedule and risks?**
- **In the past year FESAC has questioned compact stellarator usefulness as reactor**
  - **a number of questions at June 1998 FESAC meeting**
  - **supposedly John Sheffield thinks that we know B_{max}/B_0 and aren't saying because it is bad news**
  - **we can't duck this issue this time!**

REACTOR CONSTRAINTS

- **A reactor configuration is characterized by the shape of the LCFS, the aspect ratios $A_p = R_0/\langle a \rangle$ and $A_\Delta = R_0/\Delta$, and B_{max}/B_0.**

  Here B_{max} is the maximum field on the coils, A_Δ is a geometrical quantity for a given coil configuration, and Δ is the minimum *space* between the coil winding surface and the LCFS for a given R_0

- **A minimum *physical* distance D is needed between the LCFS and the center of the coil centers**

  Assume $D \geq 1.6$ m for plasma scapeoff + wall + blanket + shield + thermal insulation + coil case + assembly distance + half the coil radial depth, etc.

- **P(fusion) = $[P_f]$**, usually a fixed goal corresponding to 1 or 2 GW electric.
  $[P_f]$ $\beta^2 \times A_\Delta^3/A_p^2 / (B_{max}/B_0)^4$.

  This follows from $[P_f]$ $\beta^2 \times B_0^4 \times$ Volume $\beta^2 \times [B_{max}^4] \times (B_0/B_{max})^4 \times R_0 a^2$
  $\beta^2 \times R_0^3/A_p^2 / (B_{max}/B_0)^4$ $\beta^2 \times A_\Delta^3/A_p^2 / (B_{max}/B_0)^4$.

- **Average neutron wall loading $[p_w]$ $[P_f] / (A_p/A_\Delta^2)$ ($p_w \leq 5$ MW/m^2)**

  This follows from $[p_w]$ $[P_f]/R_0 a$ $[P_f] \times A_p/R_0^2$ $[P_f] / A_p/A_\Delta^2$.

- **Maximum field on the coils ($B_{max} \leq 16$ T)**

- **Volume-average beta ($\beta \leq 5\%$)**

Lowest *R*/<*a*> Does NOT Necessarily Lead to the Most Compact Reactor

- **For most reactor studies (ARIES, HSR, SPPS) <a> = 1.7-1.8 m**

  lowest A_p
  - **for earlier QA configuration with A_p = 2.1, this would give *R* ≈ 3.7 m, which is silly**
- **The argument is OK for configurations where distance Δ between LCFS and coil center is not a hard constraint**
  - **OK for *truly* axisymmetric systems, *not* for QA or QO systems**
  - **for CS's there is a maximum feasible Δ for a given *R* before the coils become too kinky; define $A_\Delta = R/\Delta$**
- **A certain distance D (≈1.6 m for optimistic ARIES assumptions) ≤ Δ is needed between LCFS and coil center**

  minimum $R = A_\Delta D$

WHAT CONSTITUTES AN ATTRACTIVE COMPACT REACTOR?

- **The smallest aspect ratio? $A_p = R_0 / \langle a \rangle$ -- NO! (but OK for an exp.)**
- **The minimum major radius? $R_0 = A_\Delta \times [D]$ A_Δ -- NO!**
- **The minimum reactor cost? A_Δ^2/A_p $[P_f]/[p_w]$ -- YES, *IF* fixed P_f**

  This follows from Reactor Cost (blanket + shield area) x [thickness]

  $R_0 \times a$ R_0^2/A_p A_Δ^2/A_p

- **So minimum A_Δ^2 / A_p gives the minimum [COE] (cost of electricity) for fixed $[P_f]$, which means maximizing $\beta^2 \times A_\Delta/A_p / (B_{max}/B_0)^4$**
- ***IF* $[P_f]$ can vary, the minimum COE $A_\Delta^2 / A_p / [P_f]$ $1 / [p_w]$, which is the same result**

  $\beta^2 \times (A_\Delta/A_p) / (B_{max}/B_0)^4$ $[p_w]$ $1 / [COE]$

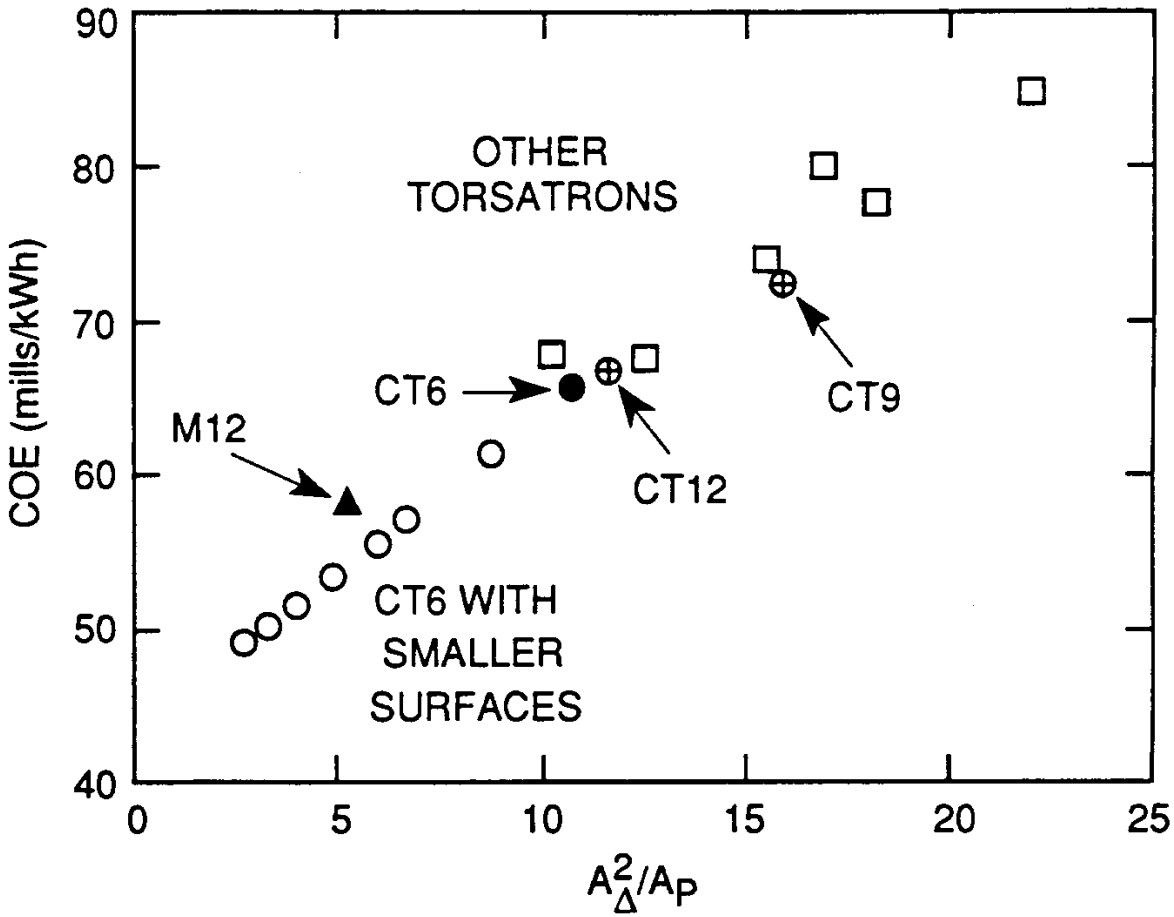
So increasing reactor attractiveness means minimizing

$(A_p/A_\Delta) \times (B_{max}/B_0)^4 / \beta^2$ for COE, not A_p

- **Minimizing A_p/A_Δ and $(B_{max}/B_0)^4$ are as important as maximizing β^2**
- **A_Δ and (B_{max}/B_0) are inversely related because increasing Δ reduces A_Δ and increases (B_{max}/B_0)??**

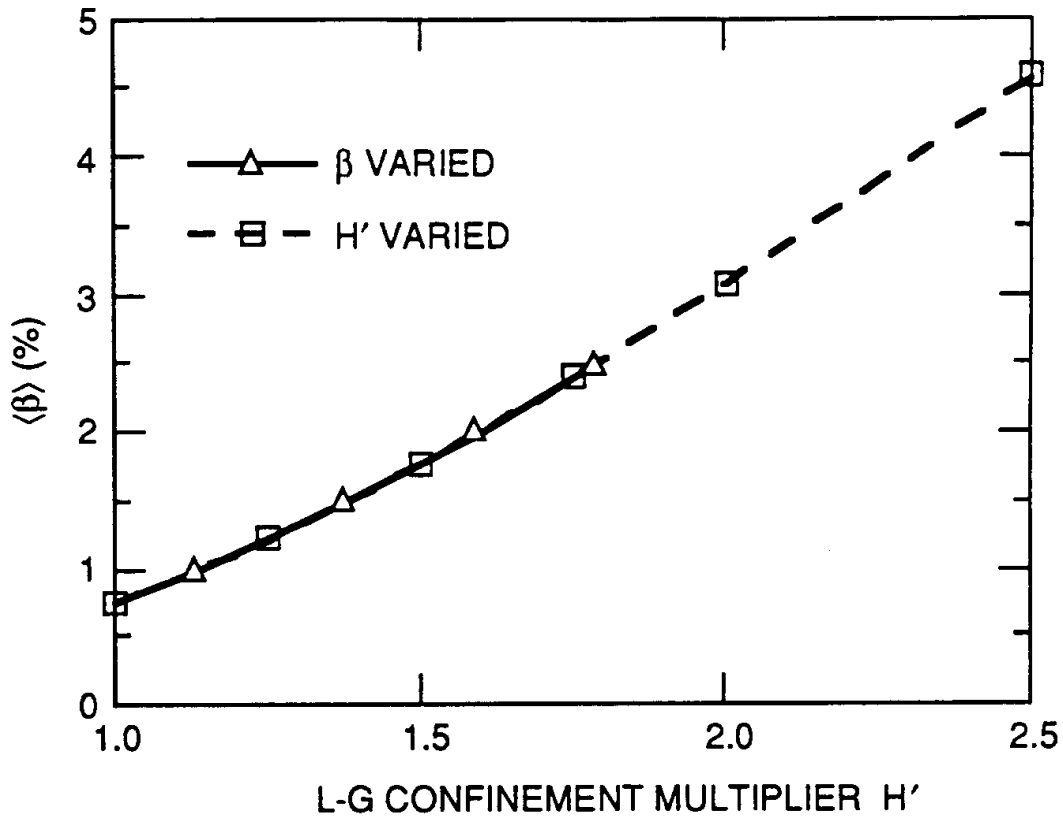
Need to study variation of (B_{max}/B_0) with A_Δ

Cost of Electricity Depends on A_Δ^2/A_p



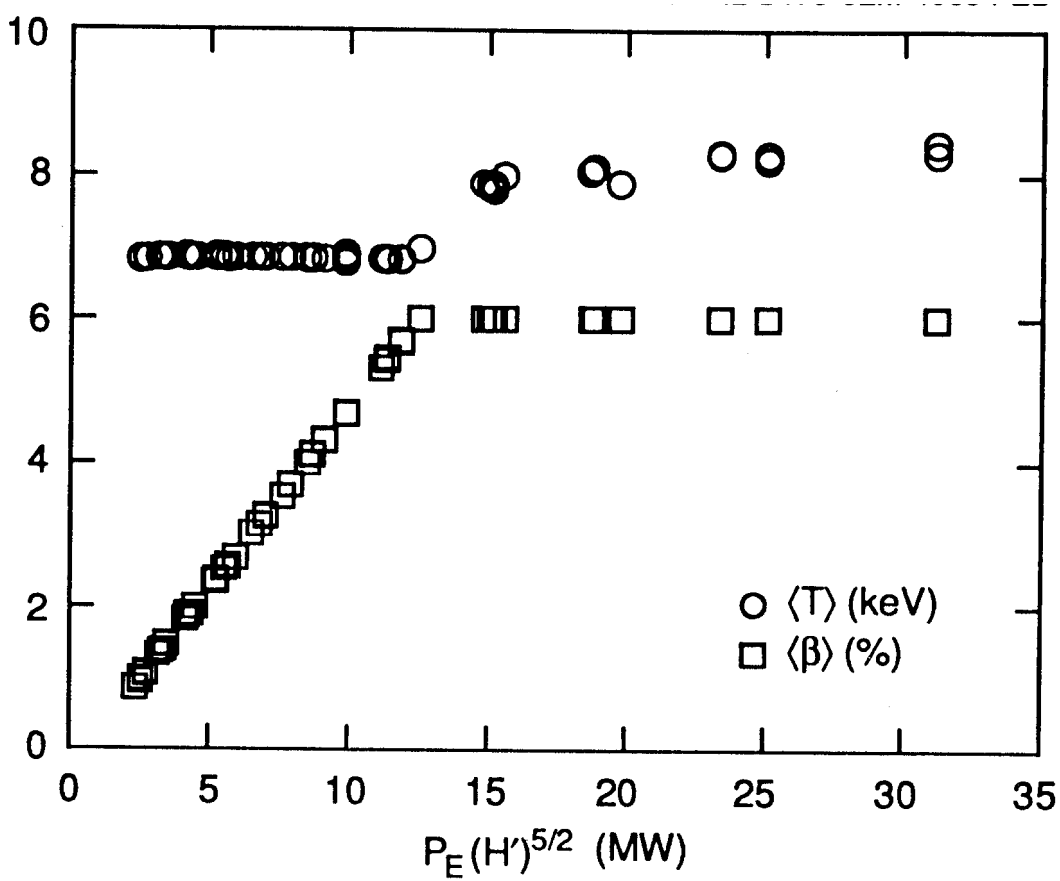
- **Minimized COE for fixed fusion power**

Beta and Confinement Multiplier are Coupled



- **Minimized COE for fixed fusion power**

Beta and Confinement Multiplier are Coupled



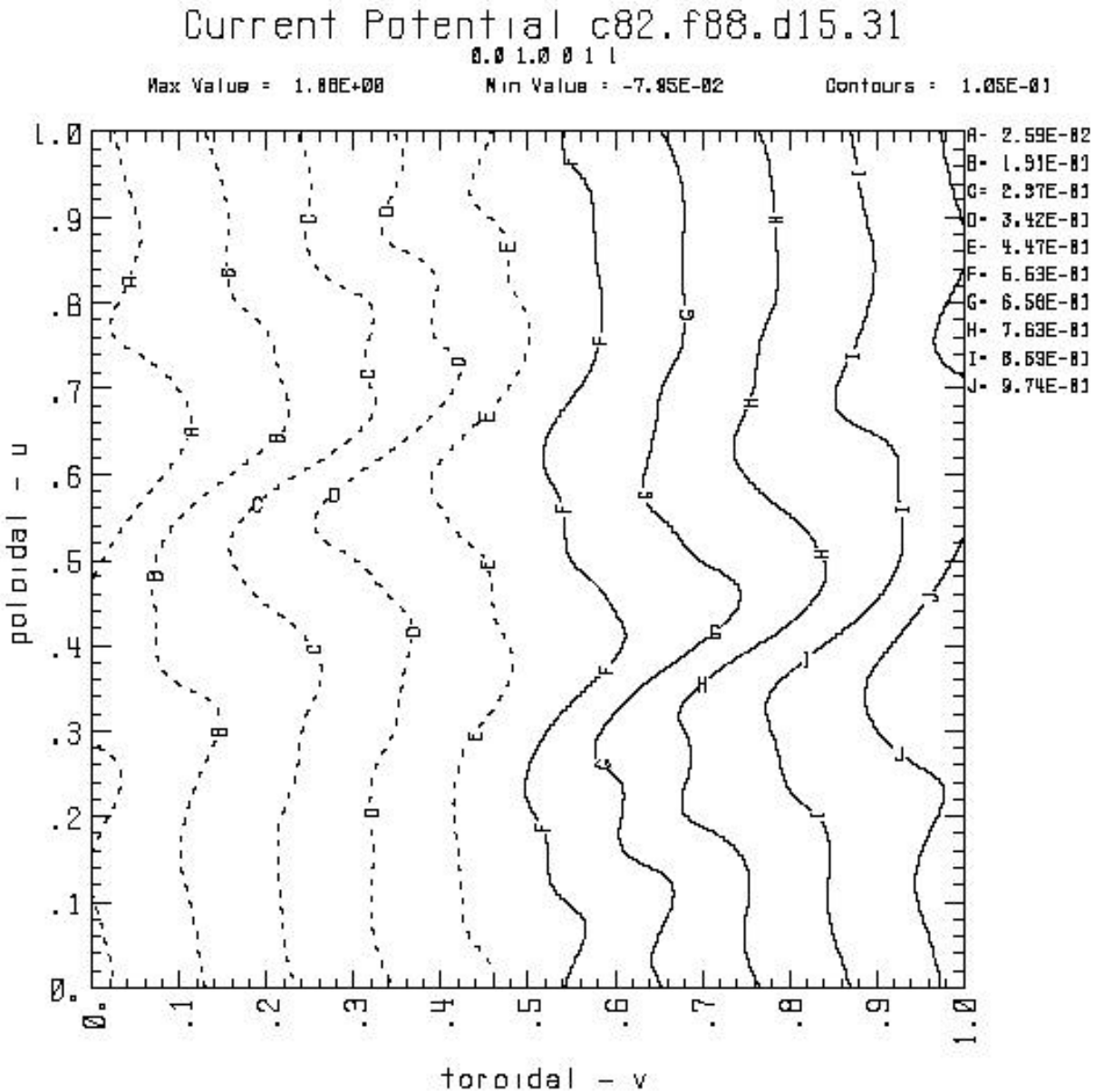
- **Minimized cost of electricity**

Reactor Scoping Studies

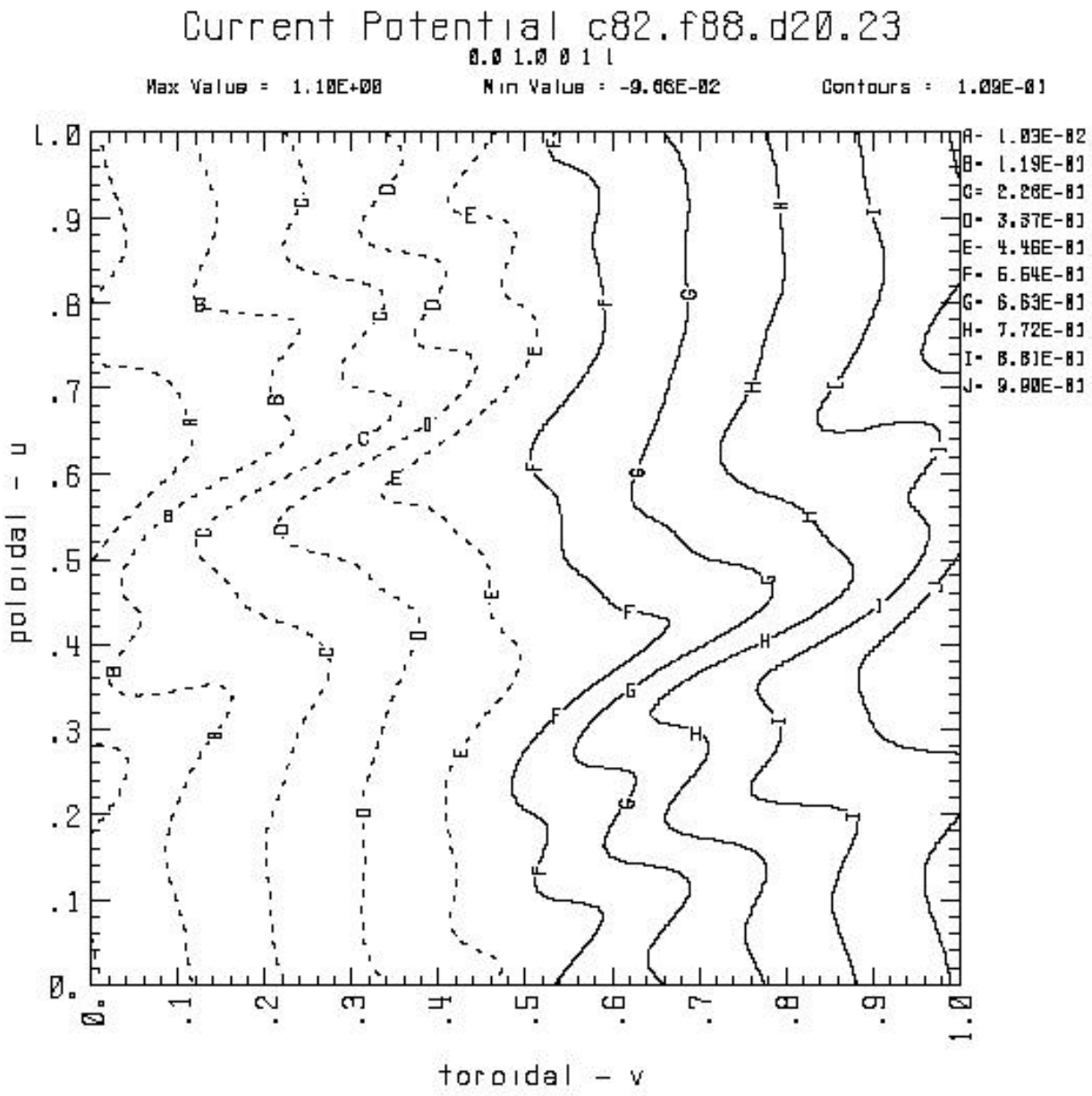
- **Determine B_{max}/B_0 vs Δ for**
  - **QA sheet-current configurations with A_p = 2.1, 3.6, 3.9**
  - **modular-coil QO configurations with A_p = 3.3, 4.8**
  - **modular-coil QA configurations when available**
- **Model variation of B_{max}/B_0 vs Δ for optimization calculations**
- **Simple 0-D spread sheet reactor optimization**
- **Full systems code reactor optimization (OPTOR)**

  (minimize COE: ARIES algorithms, benchmark with ARIES-RS)
  - **simple 0-D transport models**
  - **solve for T_e(r) and T_i(r) for 1-D anomalous $\chi_{e,i}$ and electric-field-dependent $\chi_{e,i}$ with fixed n(r), φ(r): Shaing, Hitchon**
  - **Self-consistent solution for T_e(r),T_i(r), n_e(r), n_i(r), and φ(r) with fixed particle source (pellets or gas)**
  - **study sensitivity to transport models and energetic losses**
- **ARIES group to look at impact of key issues**

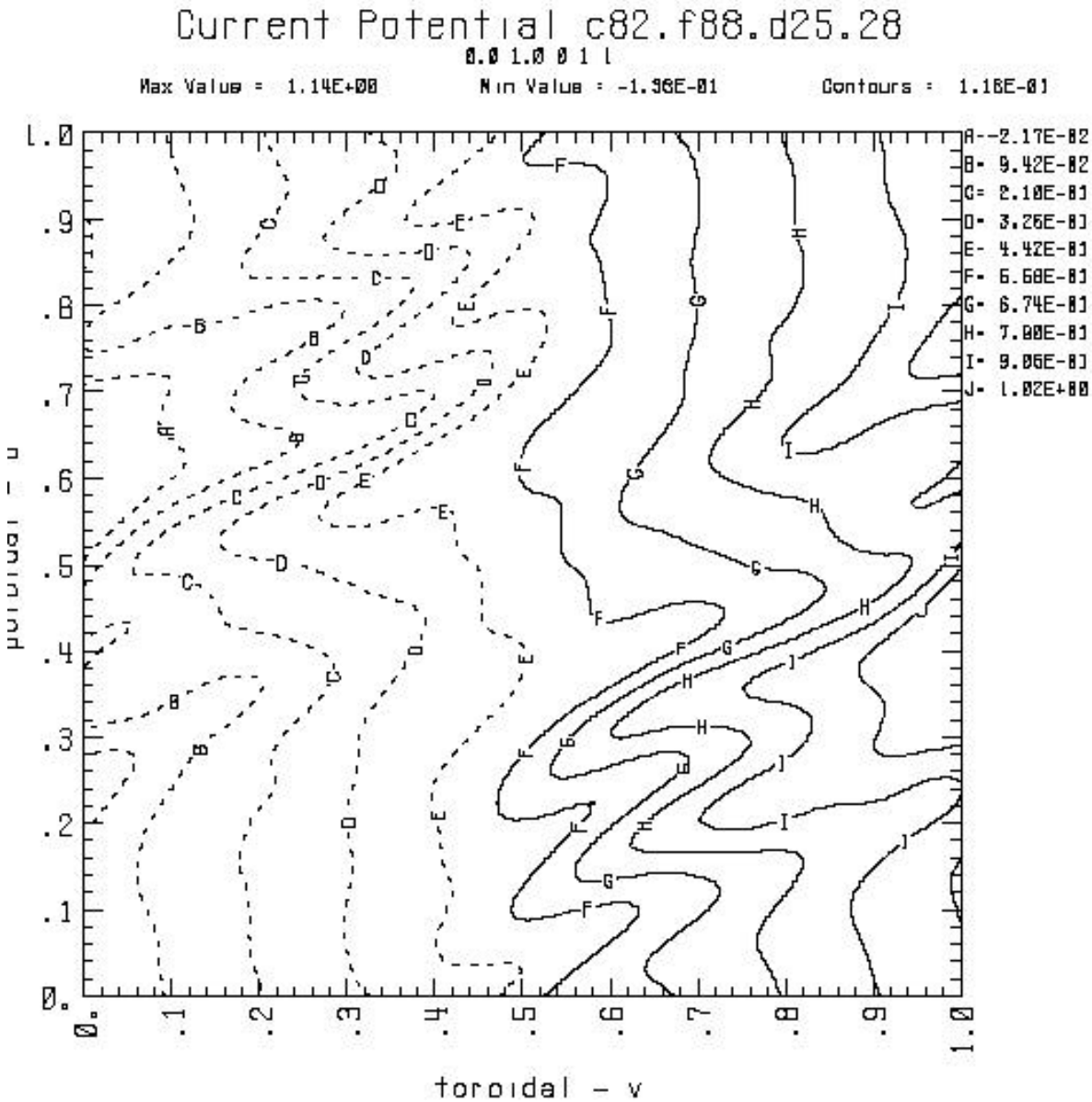
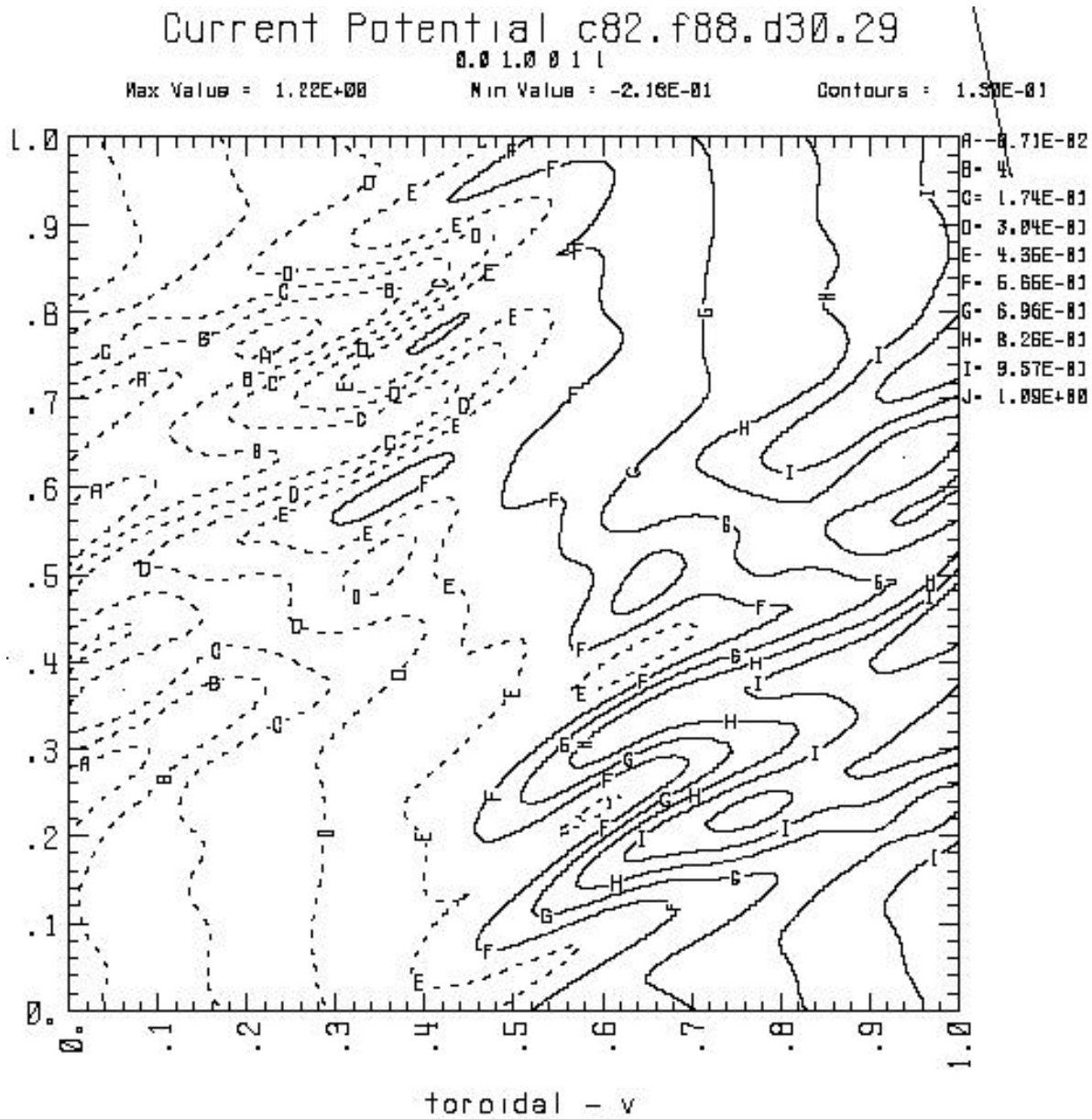
$A_\Delta = 9.67,\ R \geq 15.5$ m



$A_\Delta = 11.6,\ R \geq 11.6$ m



$A_\Delta = 5.8,\ R \geq 9.3$ m



$A_\Delta = 4.83$, $R \geq 7.7$ m