FUSION ENGINEERING DESIGN CENTER

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C.A.Flanagan
Fusion Engineering Design Center

FEDC TRADE STUDIES

Upgraded Capability Exists To Examine Cost/Performance Sensitivities For All Tokamak Options

Presented At
Ignition Studies Mission 2 Meeting
At
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CONTRIBUTORS

T.G. Brown
J.R. Haines
W.R. Hamilton
S.S. Kalsi
R.L. Reid
E.C. Selcow
D.J. Strickler
N.A. Uckan

D.B. Montgomery
J. Sheffield

FY-85 MISSION II
FEDC PROGRAM PLAN

Objective

Identify the Features and Characteristics of an Attractive Reactor Relevant Device. Establish a Design Concept Incorporating the Most Desirable Features

Areas of Study

- ***Systems Analysis/Sensitivity Studies***
- ***Design Integration***
- ***Critical Issues***
- ***International Collaboration***

OVERALL FY85 GOALS

- ***Develop Cost/Performance Sensitivity to a Wide Spectrum of Goals,Assumptions, Specifications, and Approaches***
  - ***Trade-off Studies; Upgraded TSC***
  - ***Point Designs***
- ***Identify Concept Improvement Ideas***
- ***Provide Basis for Focus in FY86***

TFCX GUIDELINES

- ***Fixed Physics***
- ***Fixed Engineering***
- ***Fixed Cost Algorithms***
- ***Fixed Configuration***

SENSITIVITY STUDIES

- ***Vary Physics***
- ***Vary Engineering***
- ***Fixed Cost Algorithms***
- ***Fixed Configuration***

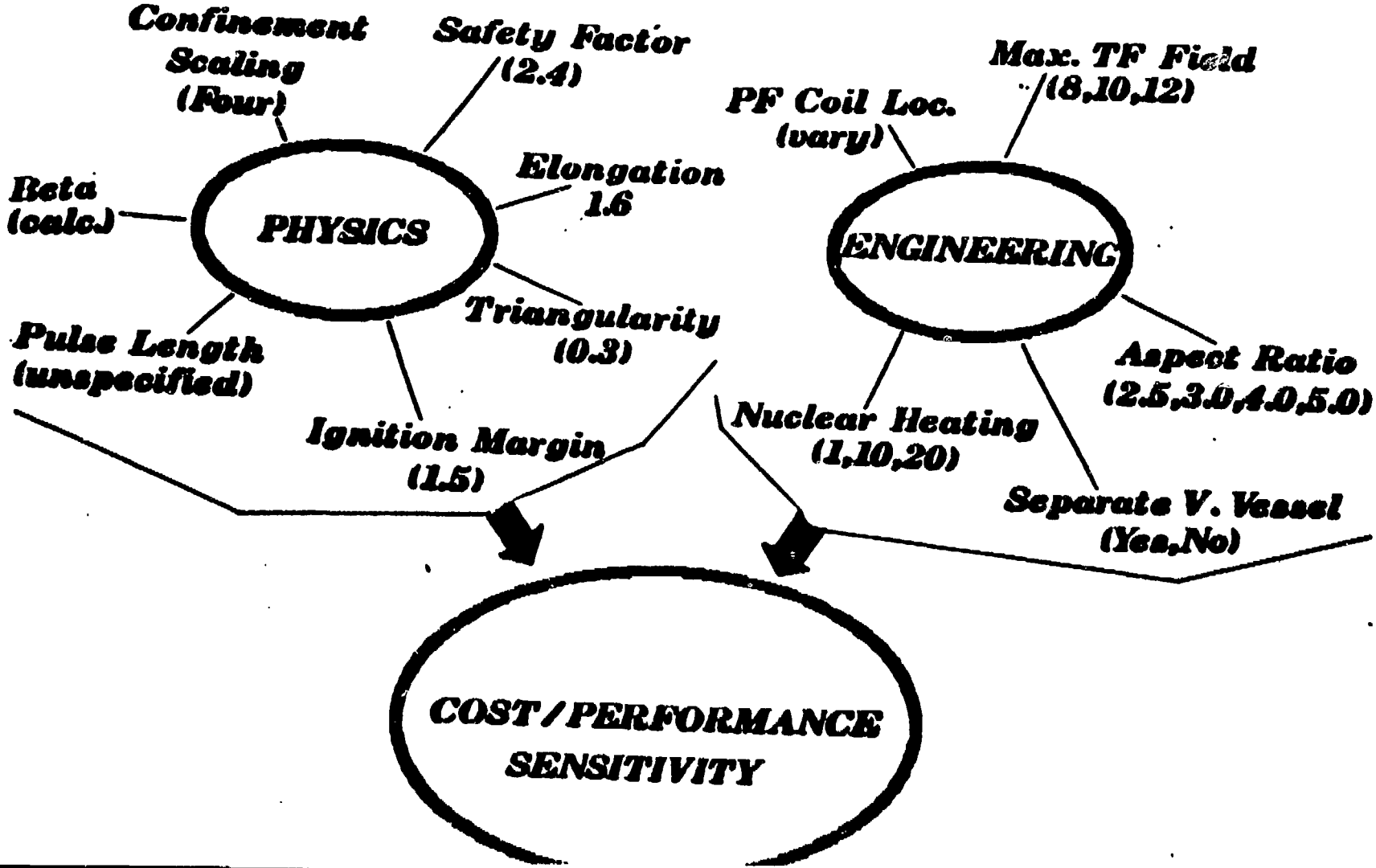
PHYSICS

TFCX	*Trades*
Mirnov Scaling	*Many Scalings*
Triangularity	*Can Vary*
Elongation	*Can Vary*
IGN Margin	*Can Vary*
Safety Factor	*Can Vary*
Pulse Length	*Can Vary*
Beta	*Options*

ENGINEERING

TFCX	*Trades*
Maximum Field	*Vary*
Aspect Ratio	*Vary*
Nuclear Heating	*Vary*
Sep. Vacuum Ves.	*Two Options*

VARIATIONS ARE MANY



The Capability To Generate Output Is Enormous

For One Scaling

3 Fields
4 Aspect Ratios
3 Nuclear Heat Rates
2 Vac. Vessel Options
72 Cases

For Four Scalings

288 Cases

In Future:
Multiple Scalings,Ignition Margin, Elongation, Triangularity, Safety Factor, Etc., Etc., Etc.

⬇⬇

SATURATION


Stop Already !
Here's the next run, Chuck

GETTING READY

•Systems Code Modifications•

- ***Physics Module***
- ***Summary Routine***
- ***Plot Routine***
- ***MHD Eq. Code Addition***
- ***Configuration Geometry Code***
- ***COSMOS Executive Routine***

PHYSICS MODEL

- *Major Assumptions*
  - *Ions and Elect. Temps. are equal*
  - *Profiles:Temp=Parabolic; Dens.=Flat*
  - *Parabolic Press. profile =⇒*
    - *Concentrate Flux Surfaces*

- *IONS*

$$\chi_i = (1/C_i)\,\chi_i^{\text{Neo-classical}}$$

where: C_i *= 2-4, and*

$$\chi_i^{\text{Neo-classical}} = 1.3\cdot 10^{-21}\left(\frac{R_0}{a}\right)^{3/2} q^2 \frac{n_i}{T_i^{3/2}}\left(\frac{2}{1+h^2}\right)$$

CONFINEMENT SCALING

Scaling	Global Conf. Time
0 Alcator	5e-21 n·a**2
1 Old Schmidt	
2 New Schmidt	0.39 a·Ip
3 TFCX Phys.	
	Xe
4 Neoclass.	
5 Neo-Alcator	4.688 ā/(nR2q)
6 Mirnov-H	0.961 ā/Ip
7 Goldston-H	$(1039/C_q)(nTa^{2.14}/I^{1}A^{0.5})$
8 Asdex-H	3.75 ā/AI
9 Perkins-H	$(611/C_q)(a^{1.15}B^{0.85}T^{0.5}/I^{0.95}A^{0.75})$
10 K-Golsdston-H	$(2679/C_q)(a^{0.93}n^{0.78}T^{0.38}/R^{0.87}B^{-0.15}I^{0.85})$
11 Pfeiffer-Waltz	$5.95(a^{1.04}n^{0.9}R^{1.63}zeff^{0.23})$

CONFINEMENT SCALING

There are four combinations:
Neo-Alcator Combined With:
12 Mirnov
13 Goldston
14 Perkins
15 Kaye-Goldston

C_e Ranges From 2-4 For H-Mode

BETA OPTIONS IN TSC

- ***Tryon Limit Scaling***
- ***TFCX Scaling***
- ***User Input Value Used***

Tokamak Systems Code, Version 4

- ***Beta input or limiting value calculated***
- ***Input ignition margin or calculate***
- ***Additional transport scaling***
  Ion & Electron losses calculated
- ***Scalings include:***
  Neoclassical (I&E)
  Neoalcator (NC I)
  Mirnov (NC I)
  Goldston (NC I)
- ***Beta Calculation is per Tryon Limit***
  Beta= C (I/aB); here C=0.035
- ***Ignition Margin is Ratio of Power/Losses***
  IGM=(P(alpha)+P(ohmic))/(P(loss)+P(rad))

Summary Data

Design Specs

Key Parameters

Costs

Radial Build

m2g7 summary data

System code input file: m2g1
System code output file: m2go7

Run date: 01/18/86

MAJOR DESIGN SPECS		MAJOR PARAMETERS		DIRECT CAPITAL COST ($)		RADIAL BLD	THK(m)	RAD(m)
ignition scaling	3.00	major radius (m)	4.16	facilities	163.67	device cl	0.000	0.000
ignition margin	1.50	minor radius (m)	1.39	pf	111.11	bore	0.767	0.767
safety factor	2.40	plasma curnt (ma)	10.10	tf	129.59	oh sol	0.450	1.217
temp (kev)	10.00	field on axis (t)	4.34	magnet str	7.63	gap	0.030	1.247
elongation	1.60	tf cal bmax (t)	9.99	shield	37.66	bcyl cyl	0.196	1.443
triangularty	0.00	tf stored energy (gj)	7.77	first wall/liniter	35.90	tf coil	0.413	1.856
z eff	1.50	energy conf time (s)	6.46	vacuum systems	132.63	gap - trapiz	0.036	1.892
TF Bmax	10.00	ele density (el9/m3)	10.75	rf	81.96	vac vessel	0.000	1.892
TF heat rate (mW/cc)	1.00	beta (%)	4.94	cryo plant	1.66	gap	0.030	1.922
TF cond cd (a/cm2)	3500.00	internal flux (ws)	31.66	heat transport	6.39	inbd shield	0.669	2.591
aspect ratio	3.00	start-up v-s reqd	97.40	tritium system	27.00	gap	0.060	2.651
vv shld thk (m)	0.00	burn time (s)	365.00	reactor ele equip	24.34	first wall	0.060	2.701
		icrh power (mw)	15.72	plant ele equip	8.27	scrape off	0.070	2.771
		pl edge neu load (mw/m2)	0.07	I & C	62.67	plasma rad	1.386	4.156
		fusion power (mw)	329.82	remote maintenance	33.62			
		oh v-s supplied (ws)	21.23					
		ef v-s supplied (ws)	25.85	Total BCC	864.50			

m2g8 summary data

System code input file: m2g1
System code output file: m2go8

Run date: 01/18/86

MAJOR DESIGN SPECS		MAJOR PARAMETERS		DIRECT CAPITAL COST ($)		RADIAL BLD	THK(m)	RAD(m)
ignition scaling	3.00	major radius (m)	3.75	facilities	166.25	device cl	0.000	0.000
ignition margin	1.50	minor radius (m)	1.50	pf	140.40	bore	0.325	0.325
safety factor	2.40	plasma curnt (ma)	11.70	tf	100.36	oh sol	0.450	0.775
temp (kev)	10.00	field on axis (t)	3.63	magnet str	6.83	gap	0.030	0.805
elongation	1.60	tf cal bmax (t)	10.01	shield	33.82	bcyl cyl	0.133	0.938
triangularty	0.00	tf stored energy (gj)	6.42	first wall/liniter	34.49	tf coil	0.432	1.371
z eff	1.50	energy conf time (s)	6.89	vacuum systems	123.31	gap - trapiz	0.027	1.398
TF Bmax	10.00	ele density (el9/m3)	8.62	rf	74.46	vac vessel	0.000	1.398
TF heat rate (mW/cc)	1.00	beta (%)	5.93	cryo plant	1.51	gap	0.030	1.428
TF cond cd (a/cm2)	3500.00	internal flux (ws)	33.29	heat transport	5.44	inbd shield	0.641	2.068
aspect ratio	2.50	start-up v-s reqd	92.31	tritium system	27.31	gap	0.060	2.128
vv shld thk (m)	0.00	burn time (s)	365.00	reactor ele equip	30.36	first wall	0.050	2.178
		icrh power (mw)	12.26	plant ele equip	8.28	scrape off	0.070	2.248
		pl edge neu load (mw/m2)	0.59	I & C	62.79	plasma rad	1.499	3.747
		fusion power (mw)	218.59	remote maintenance	34.05			
		oh v-s supplied (ws)	7.00					
		ef v-s supplied (ws)	20.01	Total BCC	867.62			

m2g7 summary data

System code input file: m2g1
System code output file: m2go7

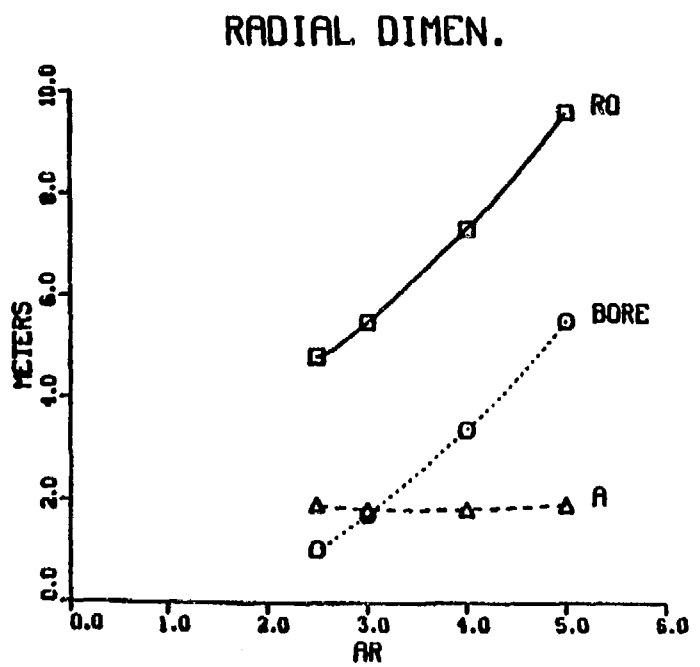
Run date: 01/18/85

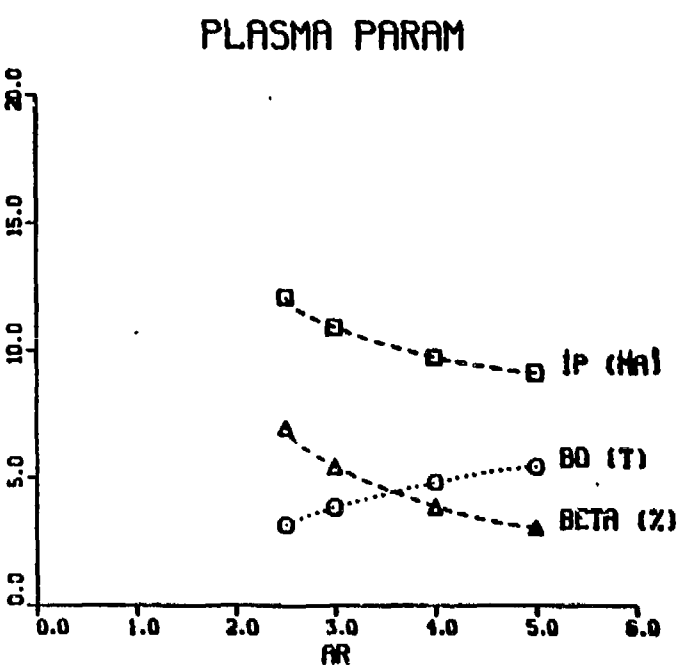
MAJOR DESIGN SPECS	
ignition scaling	3.00
ignition margin	1.50
safety factor	2.40
temp (kev)	10.00
elongation	1.60
triangularty	0.00
z eff	1.50
TF Bmax	10.00
TF heat rate (mW/cc)	1.00
TF cond cd (a/cm2)	3500.00
aspect ratio	3.00
uv shld thk (m)	0.00

MAJOR PARAMETERS	
major radius (m)	4.16
minor radius (m)	1.39
plasma curnt (ma)	10.10
field on axis (t)	4.34
tf coi bmax (t)	9.99
tf stored energy (gj)	7.77
energy conf time (s)	6.46
ele density (el9/m3)	10.76
beta (%)	4.94
internal flux (ws)	31.66
start-up v-s reqd	97.40
burn time (s)	366.00
icrh power (mw)	15.72
pl edge neu load (mw/m2)	0.07
fusion power (mw)	329.02
oh v-s supplied (ws)	21.23
ef v-s supplied (ws)	25.86

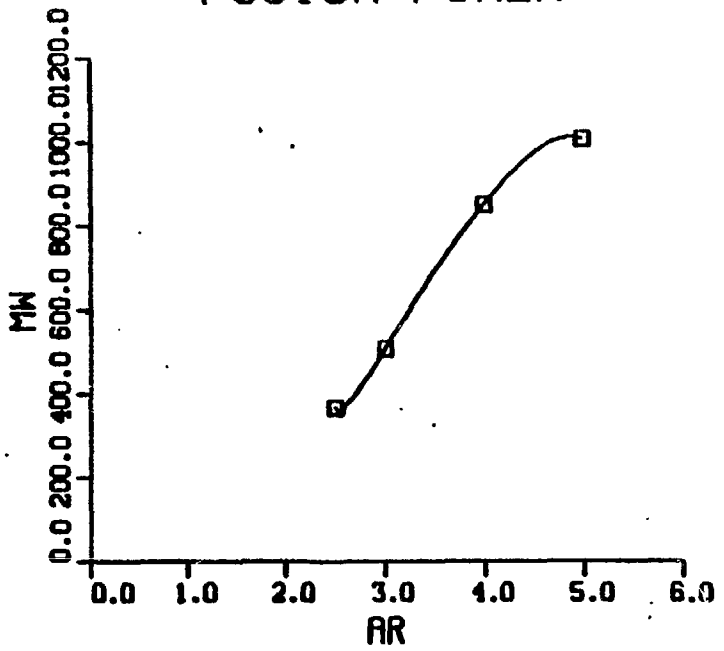
DIRECT CAPITAL COST ($)	
facilities	163.67
pf	111.11
tf	129.69
magnet str	7.53
shield	37.56
first wall/limiter	35.90
vacuum systems	132.63
rf	81.96
cryo plant	1.66
heat transport	6.39
tritium system	27.00
reactor ele equip	24.34
plant ele equip	8.27
I & C	62.67
remote maintenance	33.62
Total DCC	964.00

RADIAL BLD	THK(m)	RAD(m)
device cl	0.000	0.000
bore	0.767	0.767
oh sol	0.450	1.217
gap	0.030	1.247
bcyl cyl	0.196	1.443
tf coil	0.413	1.856
gap - trapiz	0.036	1.892
vac vessel	0.000	1.892
gap	0.030	1.922
inbd shield	0.669	2.591
gap	0.060	2.651
first wall	0.050	2.701
scrape off	0.070	2.771
plasma rad	1.385	4.156

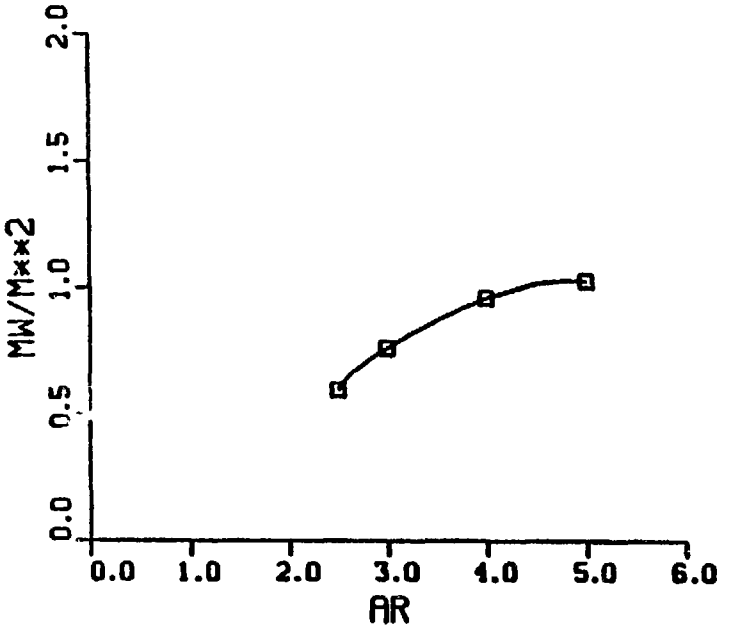




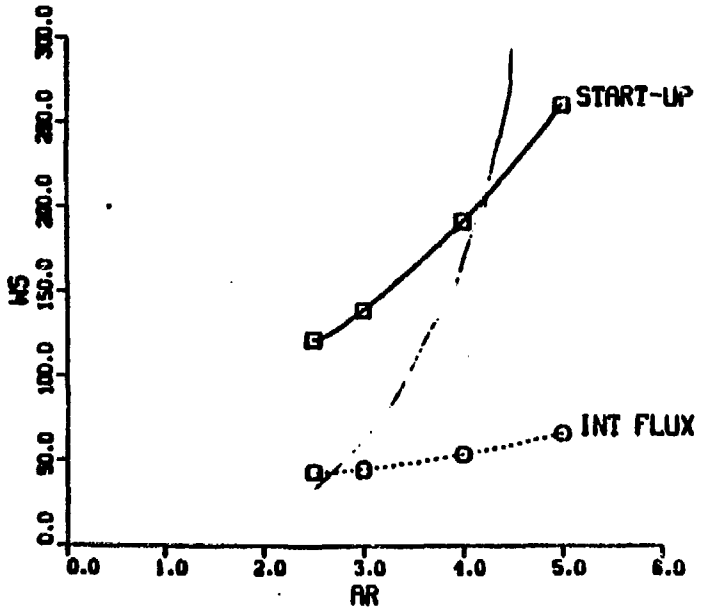
FUSION POWER



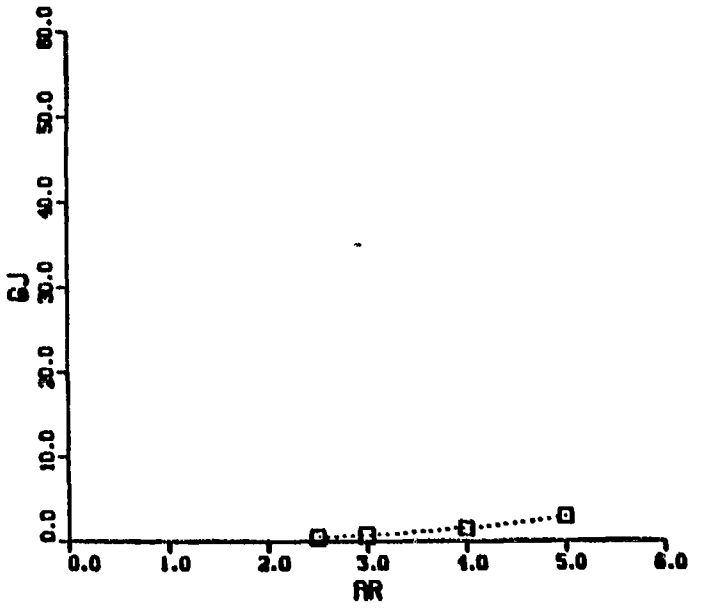
WALL LOAD



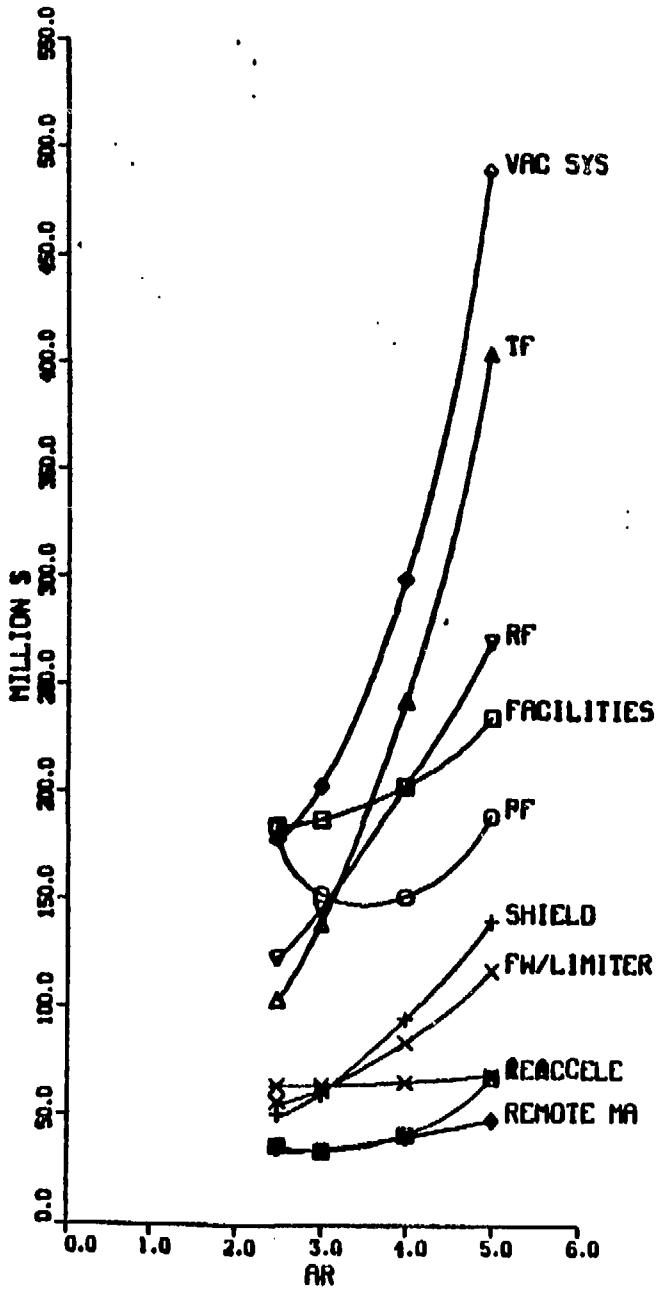
V-S DATA



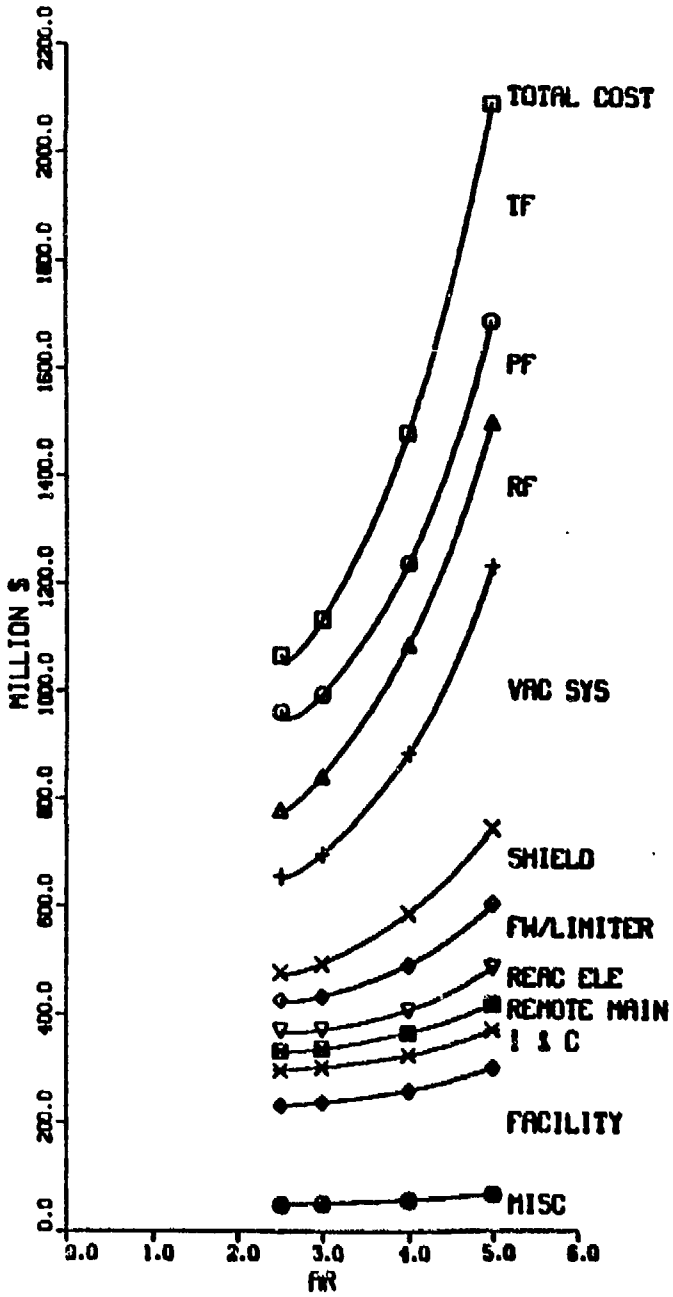
TF STORED ENERGY



COMP CAPITAL COST



CAPITAL COST SUMMARY



PF Module For TSC

•With Simplified MHD Eq. Code•

PURPOSE

This module calculates PF Coil Currents
Using a simplified version of MHD Eq. Code

PROCEDURE

- *Define PF Coil Locations*
  Based on Configuration Reqmnts.
- *Calculate Coil Currents with MHD Code*
  (Simplified Version in TSC)
- *Determine PF Coil System*
  (Size, poweer supply requirements, etc)
- *Calculate Cost of Coils and Power Supplies*

APPLICATION

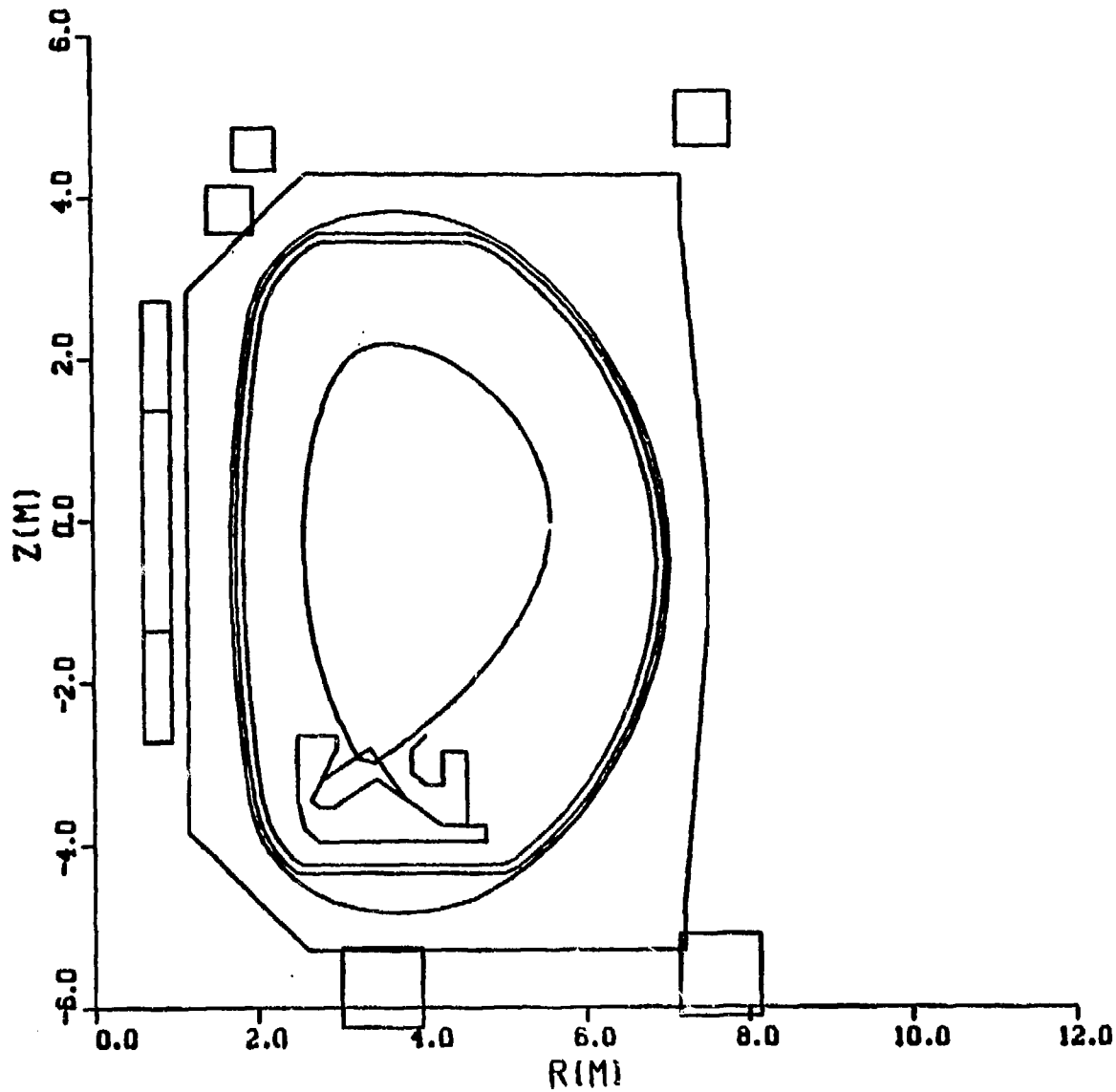
- *Routine must be called every time PF Coil*
  Location is changed

STATUS

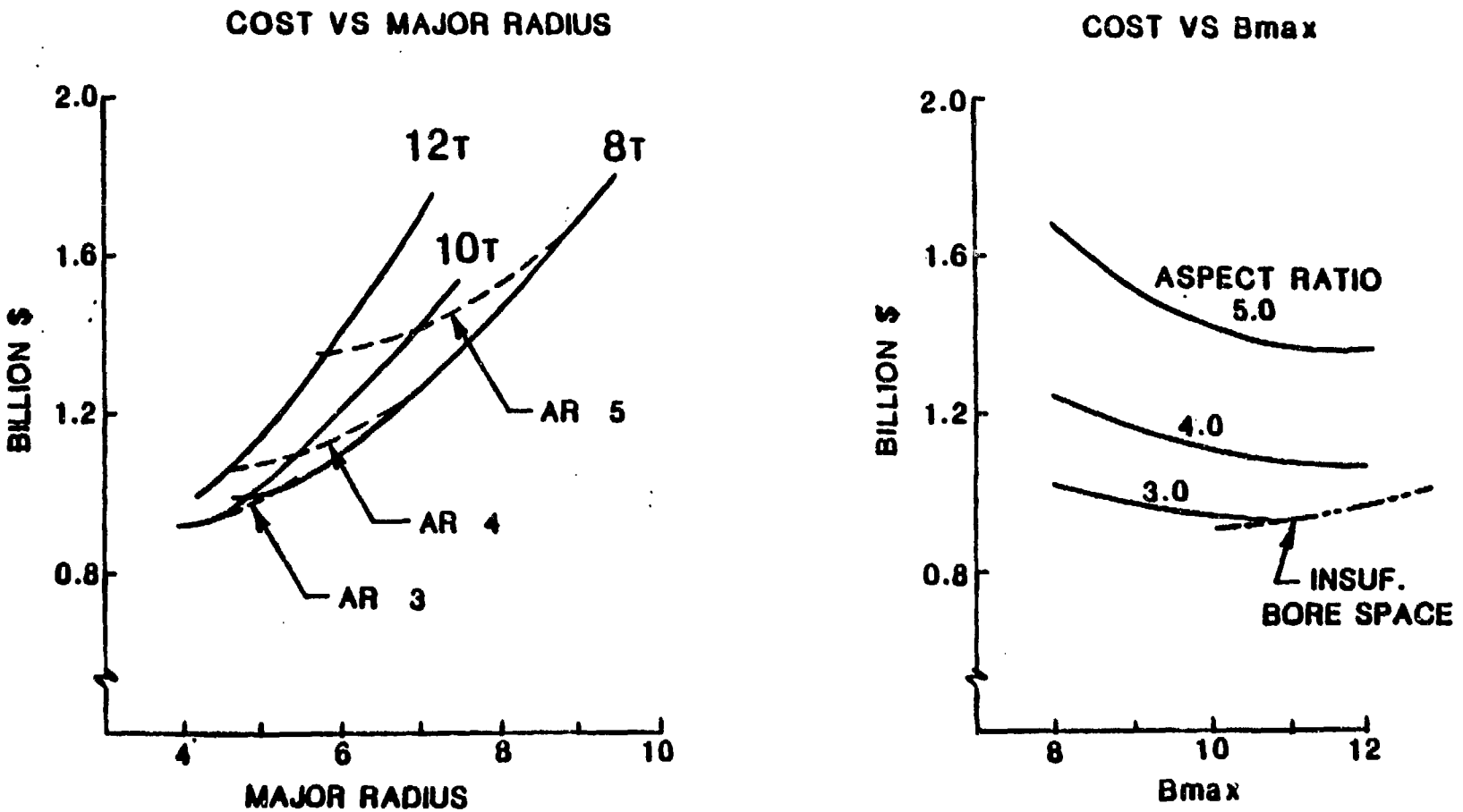
•In De-bug Stage

Configuration Geometry Code

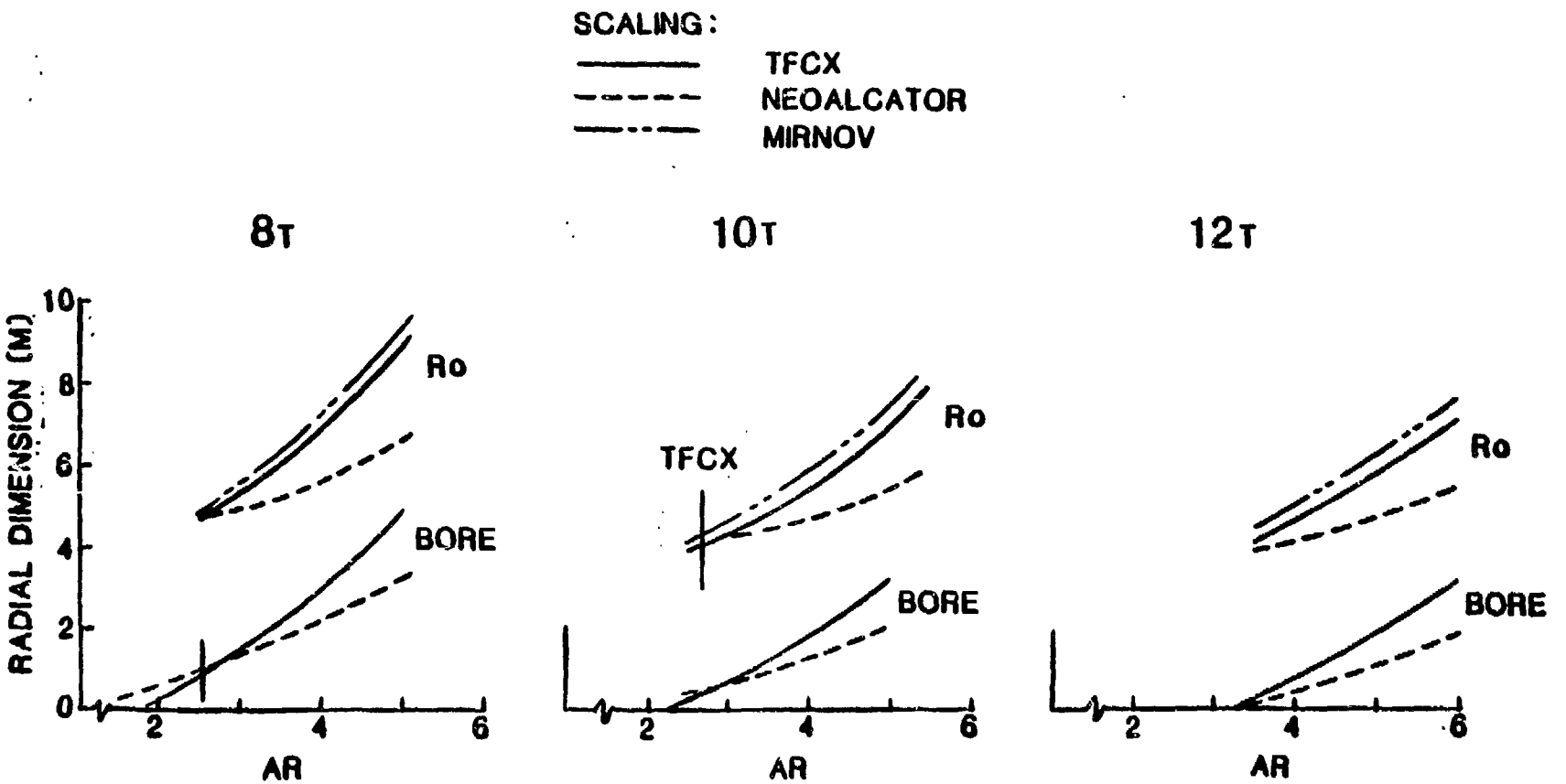
TFCX-NSC RO=4.084 - 10/16/84



CAPITOL COST VARIATION WITH TF PEAK FIELD AND MACHINE MAJOR RADIUS



MAJOR RADIUS AND MACHINE BORE
CHANGES DUE TO SCALING AND ASPECT RATIO

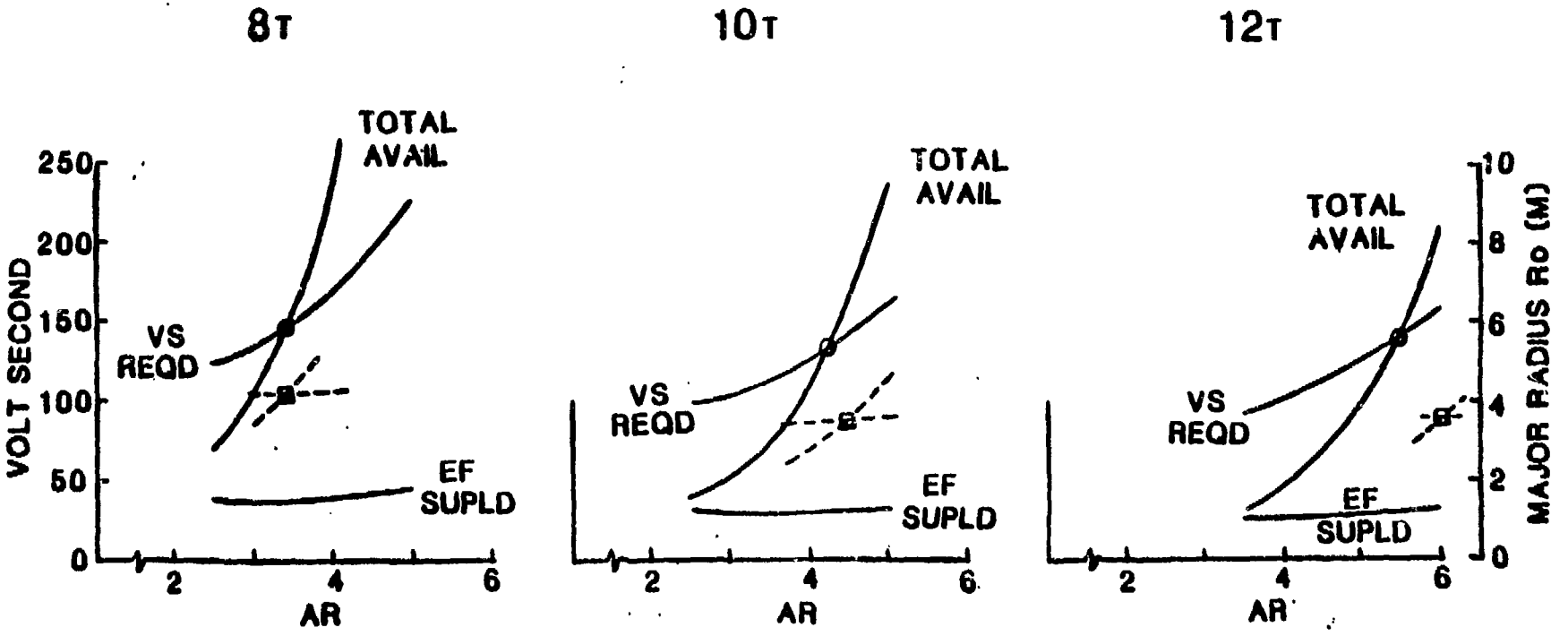


VOLT SECOND PERFORMANCE BASED ON ASPECT RATIO AND IGNITION SCALING

SCALING:

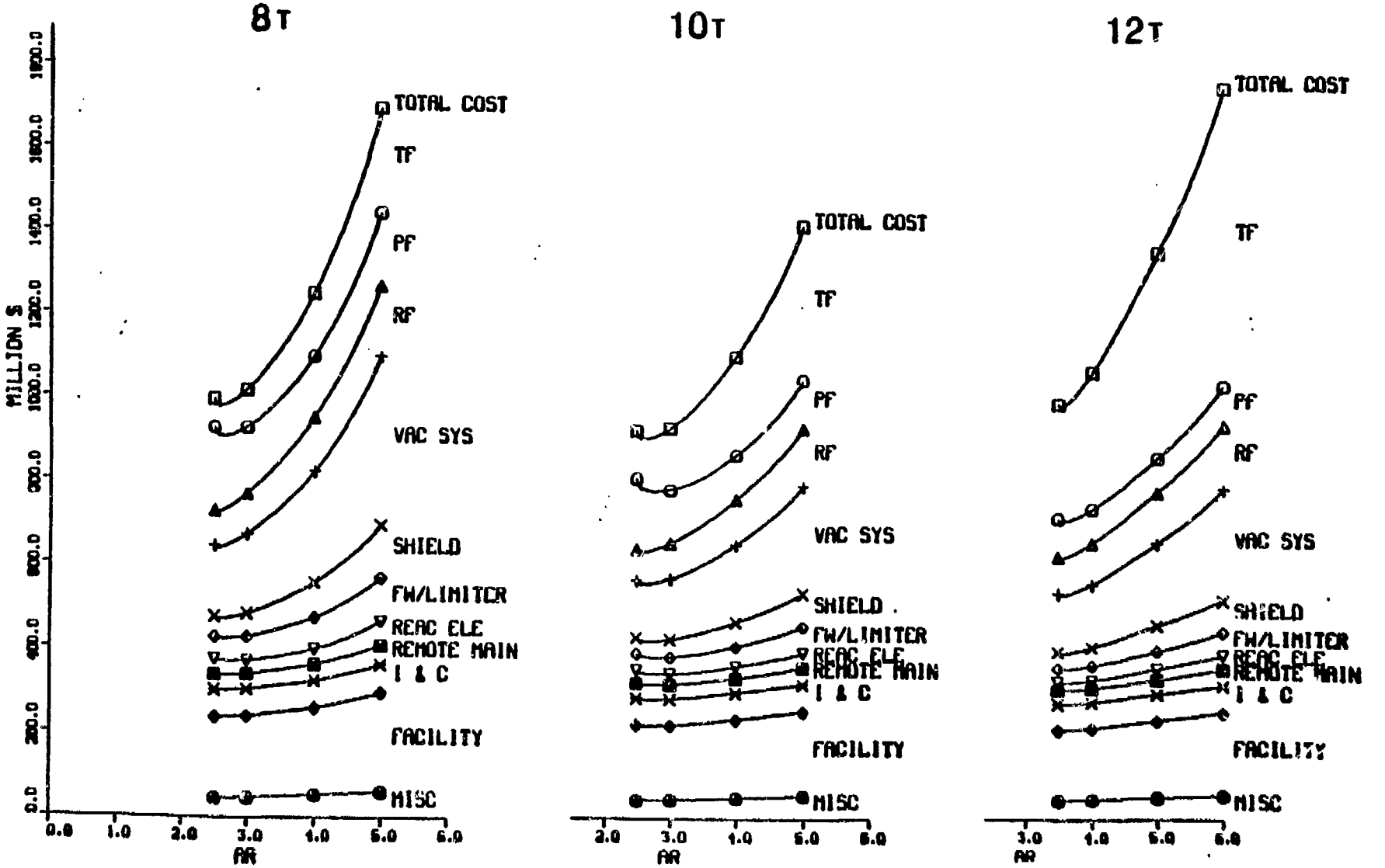
——— TFCX

- - - - - NEOALCATOR



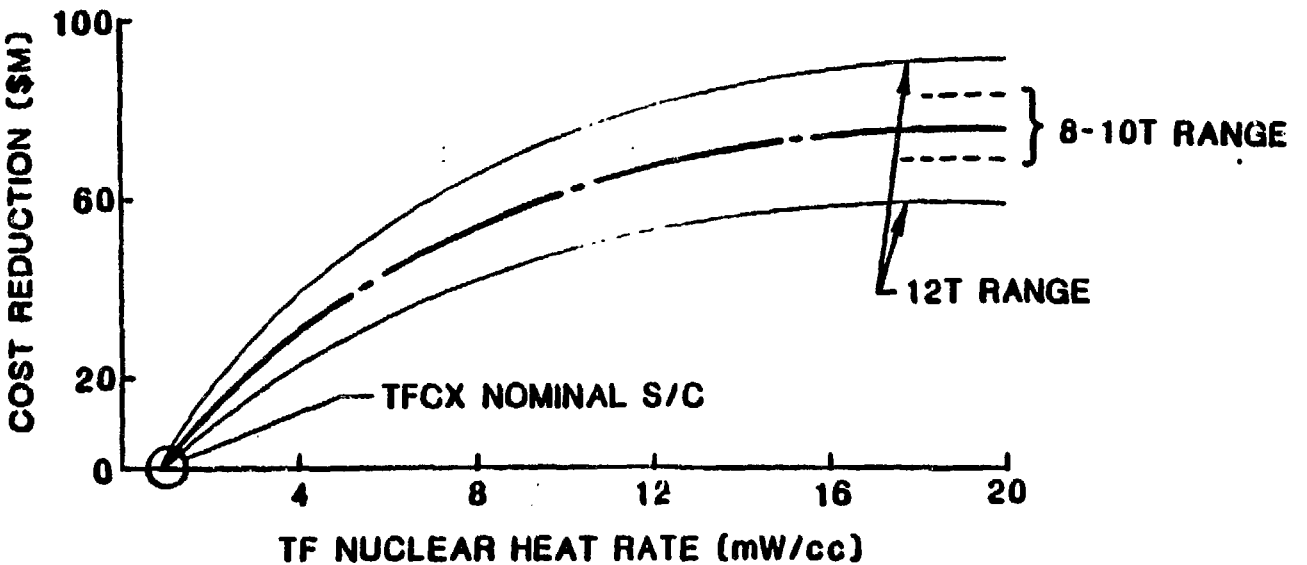
CAPITOL COST ACCUMULATION

(TFCX SCALING, 1mW/cc, INT. VV)



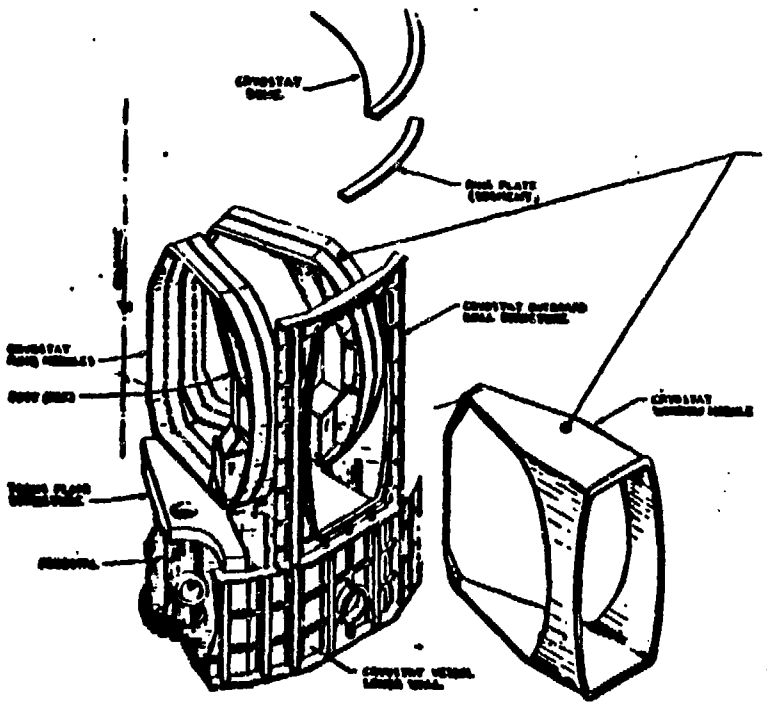
TOTAL COST REDUCTION DUE TO INCREASE IN TF HEAT RATE

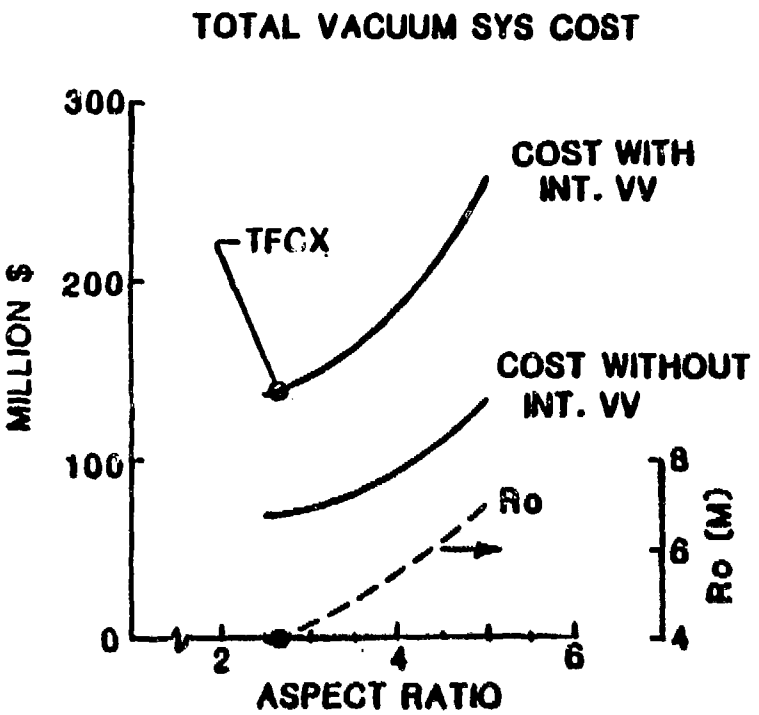
FOR: AR 5.0 - 2.5
Bmax 12T - 8T



VACUUM SYSTEM COST WITH AND WITHOUT INTERNAL VACUUM VESSEL

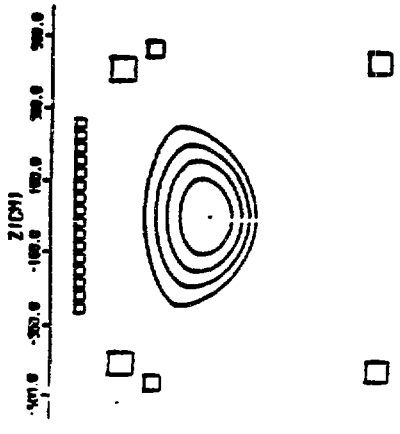
(TFCX SCALING, 10T)





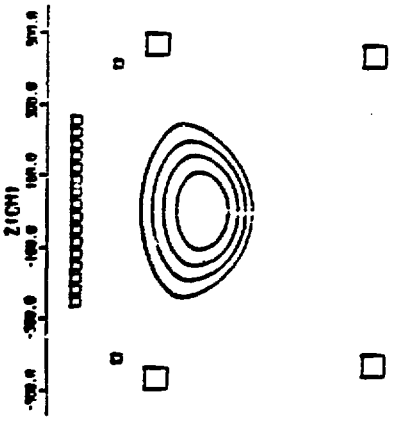
PF POSITION & TRIANGULARITY COST IMPACT

TFCX DEFINED PF LOCATION



0.3 TRIANG

919 TCC (M$)
149 PF
27 ELE
38 MA
1100 MAM



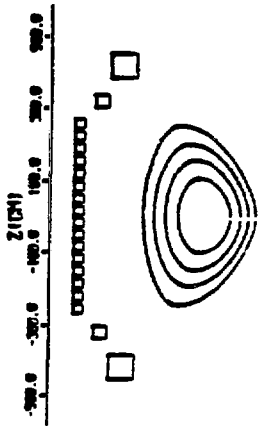
0.2 TRIANG

915 TCC
145 PF
28 ELE

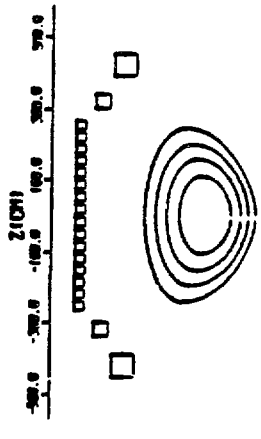
0.1 TRIANG

NOTE: PF B_{MAX} WILL CHANGE, IMPACTING MACHINE SIZE AND COST.

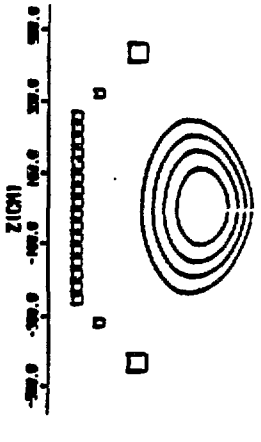
UNCONSTRAINED PF LOCATION



829 TCC
90 PF
19 ELE
32 MA
604 MAM



820 TCC
83 PF
18 ELE
28 MA
544 MAM



802 TCC
68 PF
16 ELE
18 MA
460 MAM

TFCX PERFORMANCE UNDER ALTERNATE SCALING ASSUMPTIONS

IGNITION SCALING	TFCX	NEO-ALCATOR	MIRNOV
IGNITION MARGIN	1.50	1.44	1.33
SAFETY FACTOR	2.40	2.40	2.40
TF B_{MAX} (T)	10.0	10.0	10.0
TF HEAT RATE (mW/cc)	1.0	1.0	1.0
ASPECT RATIO	2.69	2.69	2.69
VV ALLOCATION (m)	0.16	0.16	0.16
VV SHIELD THICKNESS (m)	0.05	0.05	0.05
MAJOR RADIUS (m)	4.09	4.09	4.09
PLASMA CURRENT (MA)	11.21	10.17	10.17
FIELD ON AXIS (T)	3.72	3.72	3.72
ENERGY CONFINEMENT TIME (s)	6.65	3.31	3.06
BETA (%)	5.51	6.28	6.28
FUSION POWER (MW)	264	307	307
TOTAL DCC (M$)	919	932	936

CONCLUSIONS

- ***Significant Capability Developed to do Trade Studies; They Should Continue***
- ***There are Many Knobs to Vary; Care Must be Taken to Assure Self-consistency***
- ***More Effort is Needed to Perform Remaining Trades and Fully Understand Implications***
- ***The Major Cost Variations Observed to Date are with Aspect Ratio and PF Coil Location.***