ATF EXPERIMENTAL PLANS

CONF-871179--2-Vugraphs

DE88 004177

Masanori Murakami

The ATF Group

Presented at

U.S.-Japan Stellarator/Heliotron Workshop

Oak Ridge, Tennessee

November 10, 1987

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

87-140

THE ATF EXPERIMENTAL PROGRAM

- The Program is directed at better understanding and improvement of toroidal confinement through studies of:

  - β limit; 2nd stability region
  - Low ν^* transport; role of E-field
  - Effects of magnetic configurations (externally controlled) on β and transport
  - Issues critical to steady state operation (energy and particle handling, ICRF)

OUTLINES

1. First-year Experimental Plans :
   - Capabilities Available and Upgrades
   - General Confinement Studies
2. Goals and Issues of Individual Physics Studies :
   - Confuguration Studies
   - High Beta / MHD Stability Studies
   - Transport / Role of Electric Field Studies
   - Edge and Particle Control Studies
   - RF Heating Studies

OTHER ATF PRESENTATIONS IN THIS WORKSHOP

Monday Morning

Status of ATF Project – G. H. Neilson

Tuesday Morning

ATF Diagnostics – R. C. Isler

Tuesday Afternoon

Transport Scaling in the Collisionless–Detrapping Regime – E. C. Crume

Transport Analysis for ATF – H. C. Howe

Wednesday Morning

Benchmarks of NBI Codes for Stellarators – R. H. Fowler

ECH Commissioning and Plans for ATF – T. L. White

ECH and ICH Startup Analysis – M. D. Carter

Wednesday Afternoon

ICH Program for ATF – F. W. Baity

ICRF Wave Propagation – D. B. Batchelor

Thursday Morning

Compact Torsatron Studies – B. A. Carreras

Configuration Studies for ATF – J. H. Harris

Thursday Afternoon

Currents in ATF – B. A. Carreras

Friday Morning

PMI Program and Wall Conditioning for ATF – P. K. Mioduszewski

Hard X-ray Suppression on ATF – D. A. Rasmussen

Status of Heavy Ion Beam Probe for ATF – A. Carnevali (RPI)

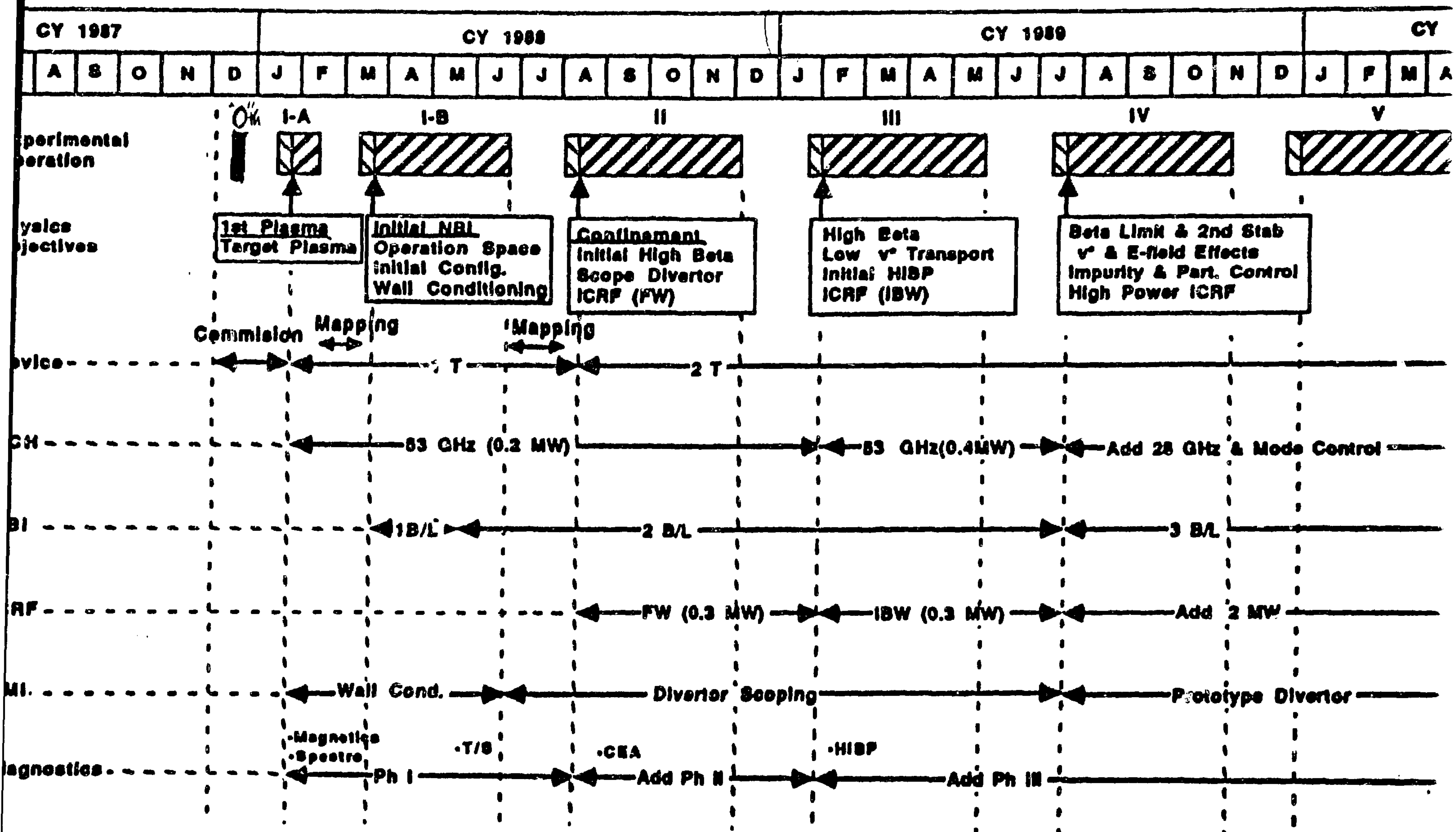
The first-year program emphasizes implementation of basic hardware and physics capabilities in preparation for physics program

Phase I-A	First Experimental Plasmas
Phase I-B	Initial NBI
Phase II	NB Confinement

Expected Capabilities at the End of the Phase I-A : Commissioning and First Plasma Operation (Dec 87 - Jan 88)

- Magnetic field (HF to B_0=1 T; Inner and Trim VF).
- Runaway suppression systems (interceptor probe, Ar dump) in operation and hard X-ray survey completed
- ECH target plasma with P_{ECH} = 0.2 MW, 2^{nd} harm. at 53 GHz
- Wall conditioning (GDC and ECR-DC)
- Phase I diagnostic and limited analysis capabilities (magnetics, 2mm, PHA , etc.)
- First NBI (if possible)
- Magnetic surface verified with e-beam technique after Phase I-A (and later after Phase I-B)

ATF EXPERIMENTAL PROGRAM (Rev: 8-Oct-1987)



Basic Hardware Capabilities in the First Year and Their Upgrades

- Magnetic Field :
  - HF - $B_0=1 \rightarrow 2T$ (Ph II)
  - VF - Inner and Trim VF, Mid VF (Ph. II)
- ECH :
  - 53GHz - P_{ECH} =0.2MW → 0.4Mw (Ph. III)
    Open waveguide launch
    → mode controlled launch (Ph. IV)
  - 28GHz - P_{ECH} ~ 0.2Mw (Ph. IV)
- NBI :
  - # 1 (CO), # 2 (CN) } P_{NB}=2MW at 40keV
  - # 3 P_{NB}=3MW (Ph. IV)
- ICRF :
  - FW antenna (Ph. II), IBW antenna (Ph. III) } P_{ICRF} = 0.3 → 2 MW (Ph. IV)
- Wall Conditioning :

  GDC, ECR-DC, Baking at 150°C, RF-assist.-DC, Ti or Cr Getter
- Diagnostics :

  Phase I (global), Phase II (profile)

  Phase III (HIBP)

[R. Isler's Talk]

General Confinement Studies in Phase I-B and II

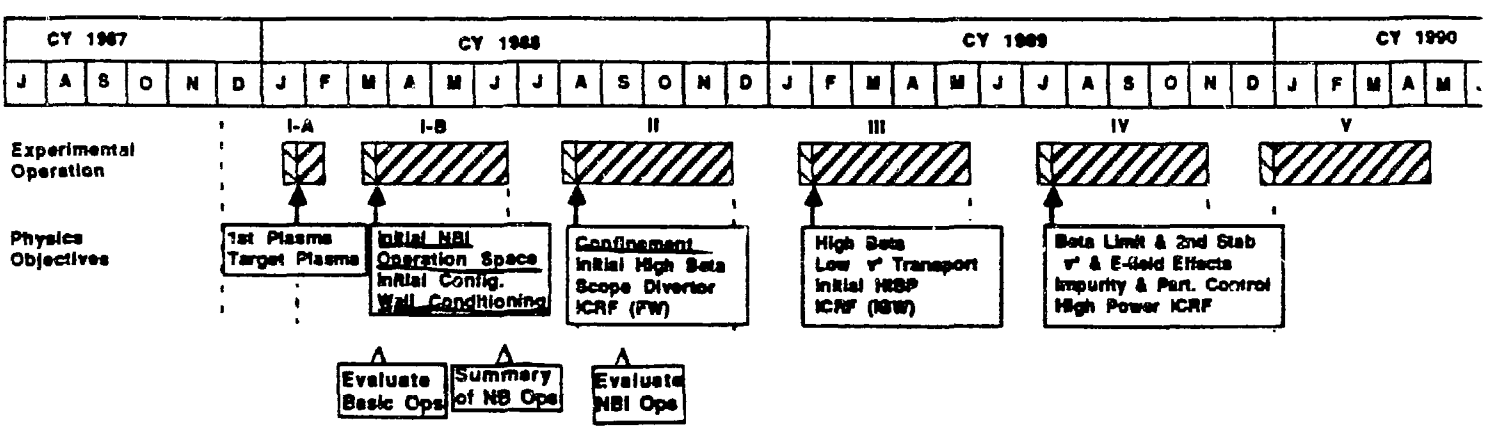
1. Establish Basic Mode of Operation
   - "Baseline" Conditions:

     NBI (CO+CN), B_0=0.95T with I_p=0,

     Clean, Reproducible
   - Bringing up new diagnostics

2. Survey Operating Space for <u>General</u> Purposes
   - Test "knobs":
     - Beam Power and Beam Directivity
     - Density (gas puffing)
     - Configuration (ΔQ_1, ΔQ_2)
   - Look for:
     - Operating limits [$(\bar{n}_e)_{max}$, β_{max}]
     - τ_E^* and scaling
     - Current
     - Profile changes [e.g., $\bar{n}_e(R)$ from FIR]
     - Any gross change in impurity and edge behavior, etc.

3. Systemetic (Single) Parameter Scans with Detailed Documentation



87-154

Confinement Scaling

- PROCTR Analysis with He-E NB data
  - Finite-β equilibria (VMEC)
  - Beam calc. benchmarked with MC

  } No substantial changes in global τ_E

  - $\tau_E^{HE} = 11 \cdot P^{-0.66} n^{0.45} B^{0.51}$ [ms; Mw, $10^{20}m^{-3}$, T]

- A τ_E scaling used in the Next Large Device Design Studies in Japan:

$$\tau_E^{emp1} = 170 \cdot P^{-0.58} n^{0.69} B^{0.84} a^{2.0} R^{0.75}$$

fits reasonably well with data from Heliotron-E and other devices.

- These scalings show that τE values expected in ATF with 2MW injection at B=0.95 T are of the order of 20 - 30 ms, corresponding to $\langle\beta\rangle$ values of the order of 2 - 3 %:

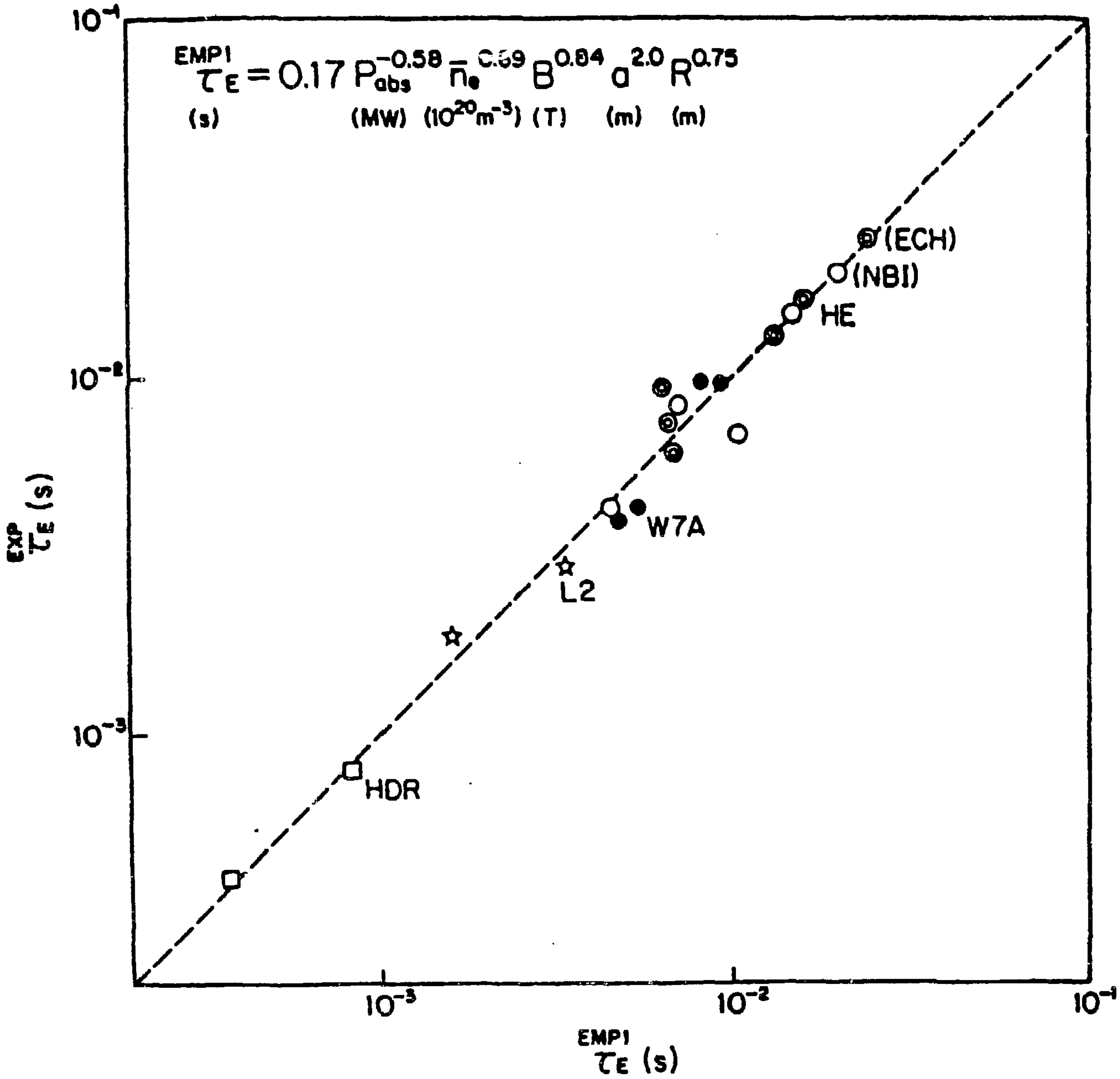


図３－１－２　ヘリカルシステムのスケーリング

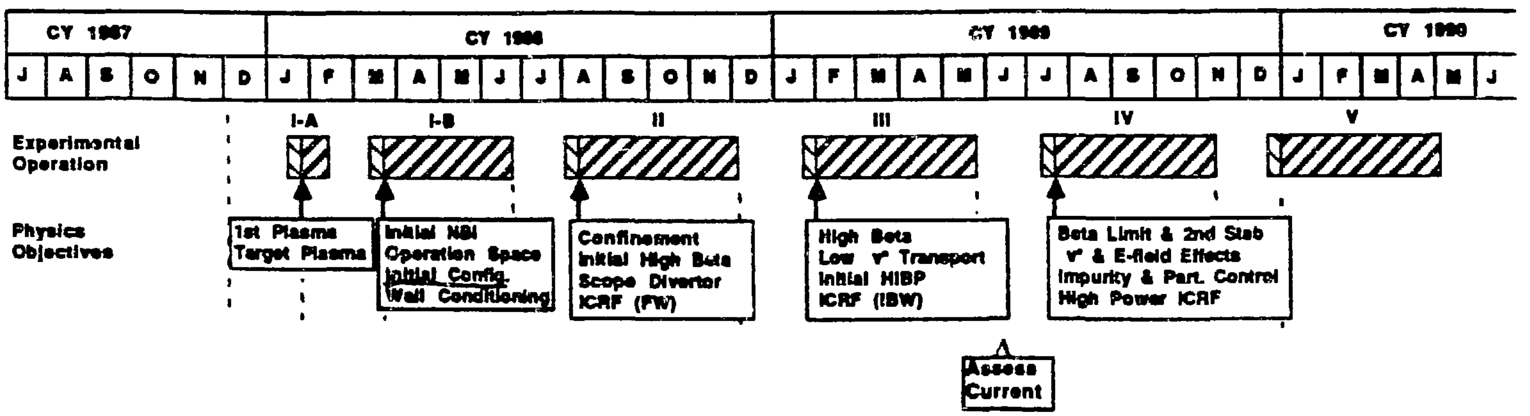
Individual "Physics" Studies Branch out from the Initial General Confinement Studies.

- Configuration Studies
- High Beta / MHD Stability Studies
- Transport / Role of E-Field Studies
- Edge and Particle Control Studies
- RF Studies

MAGNETIC CONGIGURATION CONTROL STUDIES

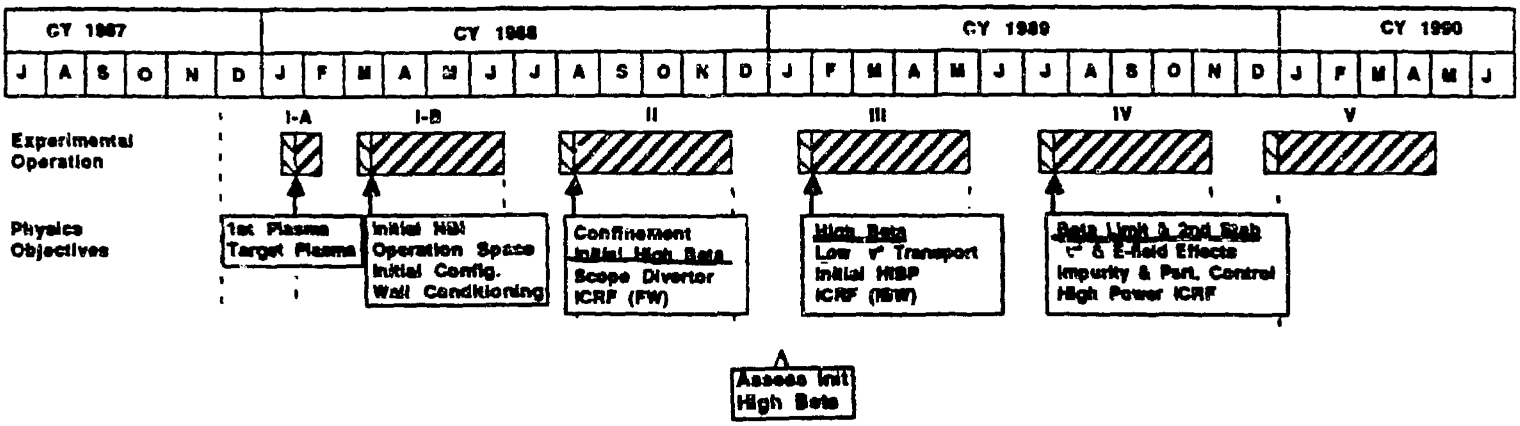
- Ability of varying the magnetic configuration provides a powerful experimental tool that will enable us to:

  - Vary MHD stability properties (e.g., second stability operation)
  - Control net currents
  - Control the geometry (e.g., for plasma wall-interaction)

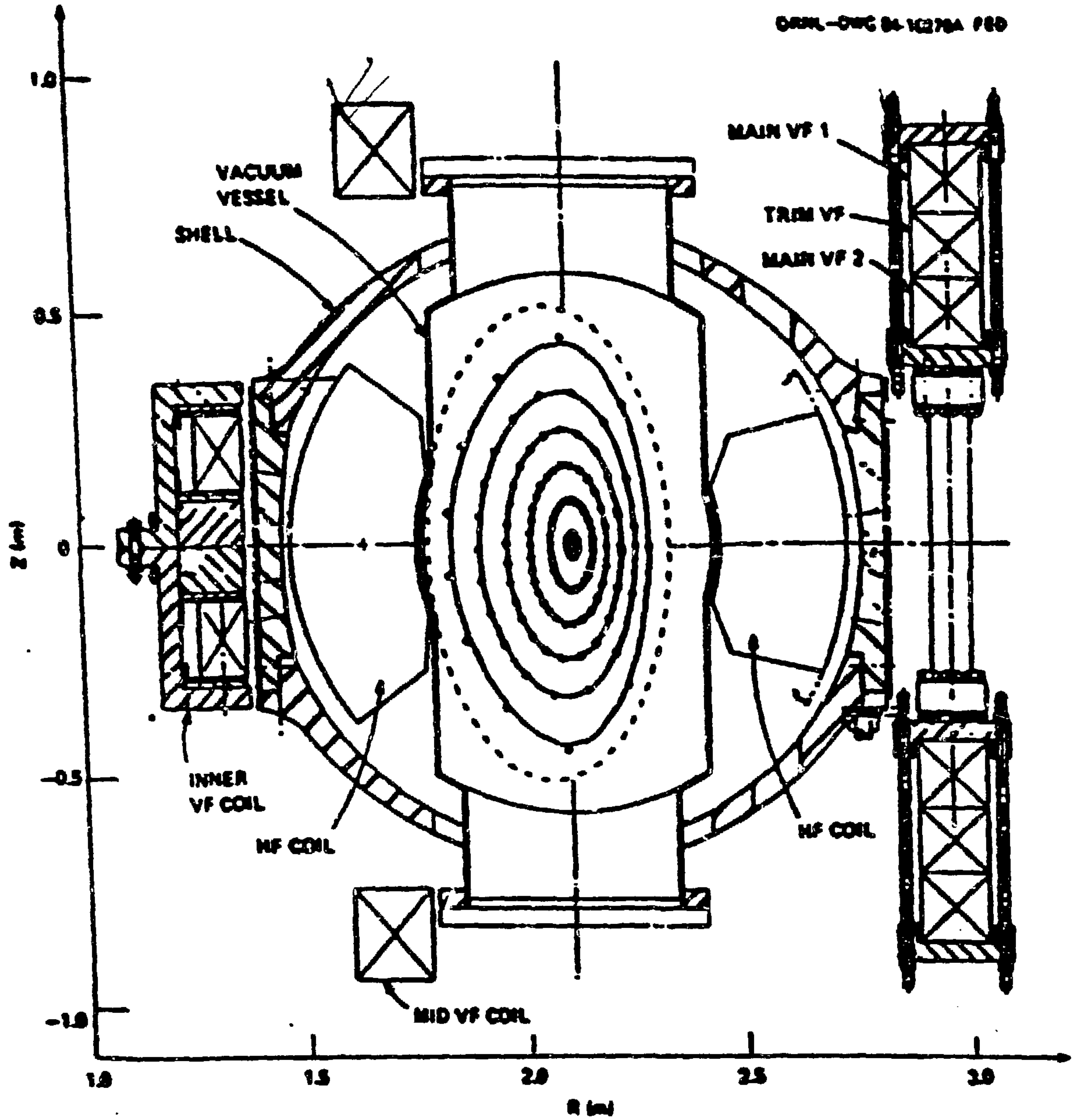


High Beta / MHD Stability Studies

- Objectives are to study MHD stability and β limits, with emphasis on :
  - Maximum $\langle\beta\rangle$ values
  - Second Stability region (i.e., "β self-stabilization")
  - Configuration effects (t_0, V', I_p)
  - Flux conserving effects
- τ_E scalings based on He-E NBI data analysis predict $\langle\beta\rangle$ values of 2 - 3 %. Achievement of $\langle\beta\rangle$ higher than these values may require :
  - Low field operation (28GHz gyrotron → B_0=0.5T in FY89)
  - More heating power, requiring
    - -- Third beamlines (1.0-1.5Mw) late FY89-FY90
    - -- BBC transmitter (2Mw) for ICRF in FY90.



Control of Magnetic Configuration

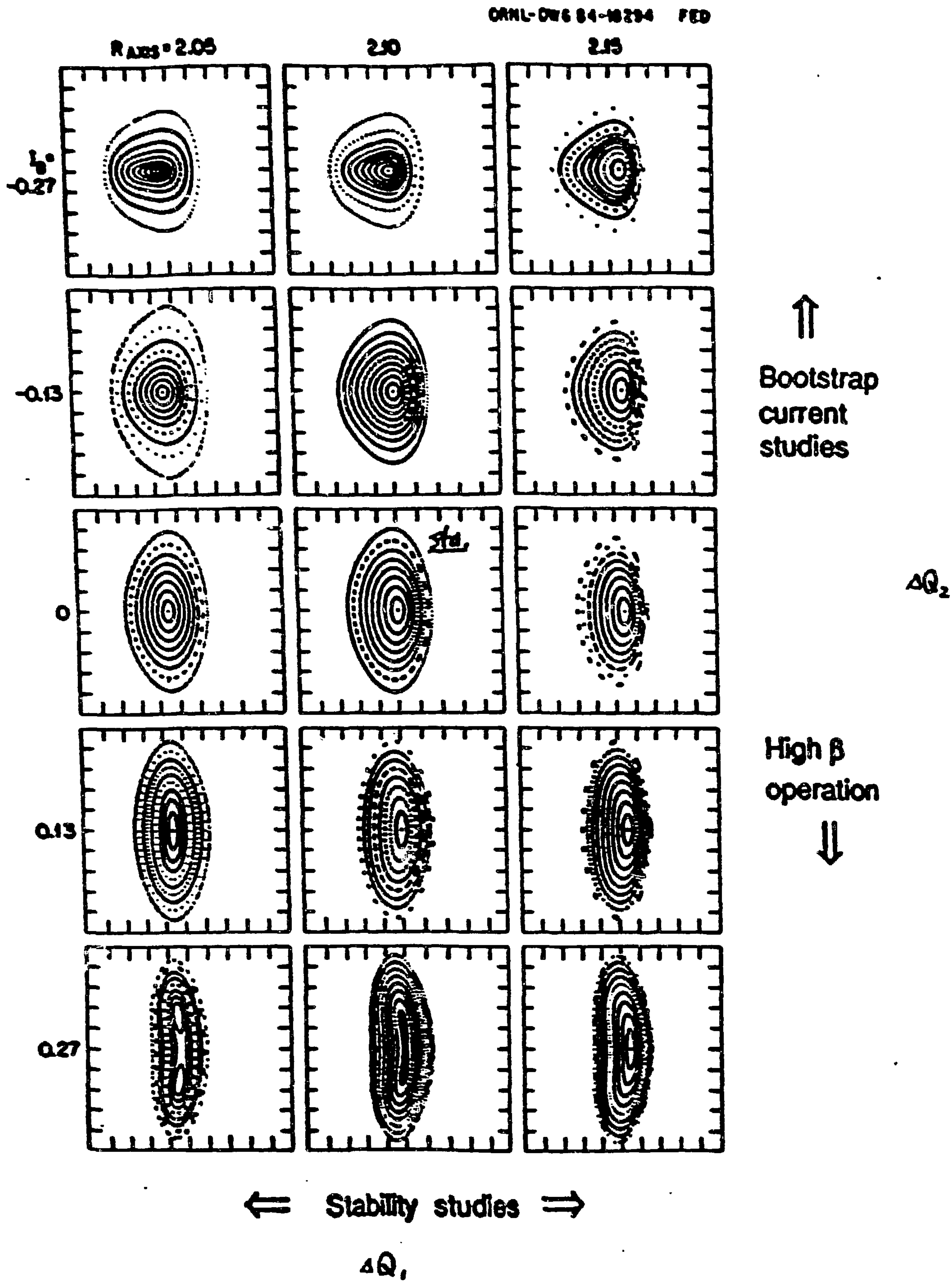


- 3 independent VF coils provide 3 control "knobs":

multipole fields
- Q_0(pol.flux) → I_p
- Q_1(dipole) → horiz. shift → well / hill
- Q_2(quadrupole) → elongation → $\iota(0)$,

harmonic contents in B_{HF}

ATF VF COIL SYSTEM OPERATIONAL RANGE



CURRENTLESS OPERATION

- Possible causes of net toroidal current
  - "Flux conserving" current

    $I_{fc} \sim 4 \cdot \beta_0(\%)$ [kA]

  - Beam-driven current

    $I_{bd} \sim -4 \cdot \bar{n}_e(10^{20} m^{-3})^{-1.5} \cdot (P_{CO}(MW) - P_{CN}(MW))$

  - Bootstrap current

    $I_b \sim 52 \cdot G_b \cdot \beta_0(\%) \cdot B_T(T) \cdot f(\nu^*)$

    $\sim 5\beta_0(\%) \cdot f(\nu^*)$ [kA] [G_b=0.1 for high β]

  - External source (VF)

    $I_{ext} \sim \pm 200 \cdot (\Delta I_{VF} / I_{VF})$ [kA]

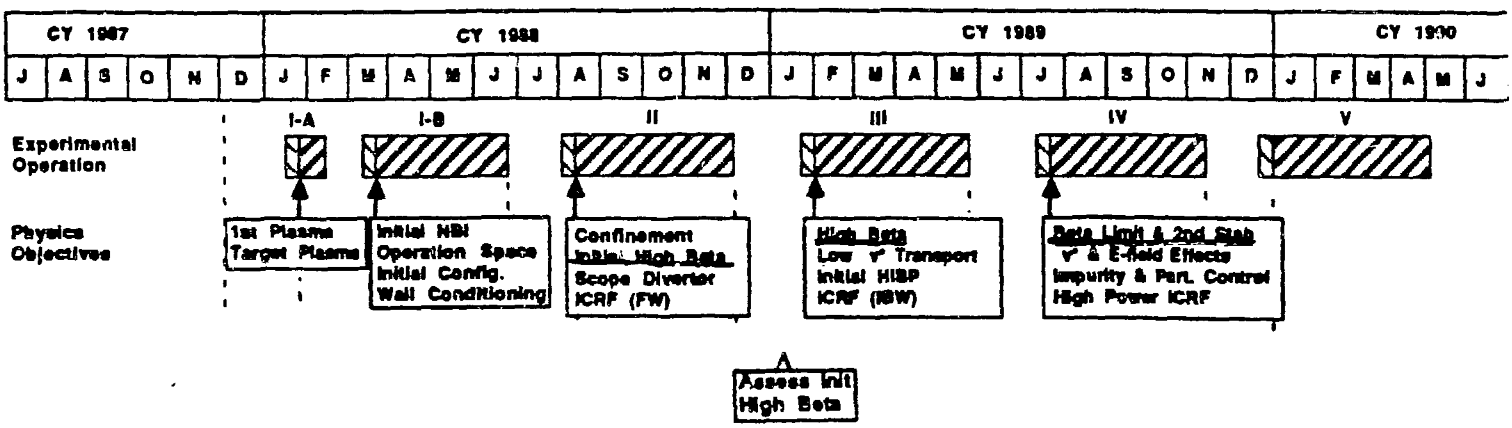
- The ATF VF coil system has been designed to handle
  - large change in $\iota(r)$ with ΔQ_2
  - residual net current by Q_0

- The bootstrap current can be maximized
  - G_b = 0.5 by adjusting the VF quadrupole components
  - I_b as high as ~ 90 kA

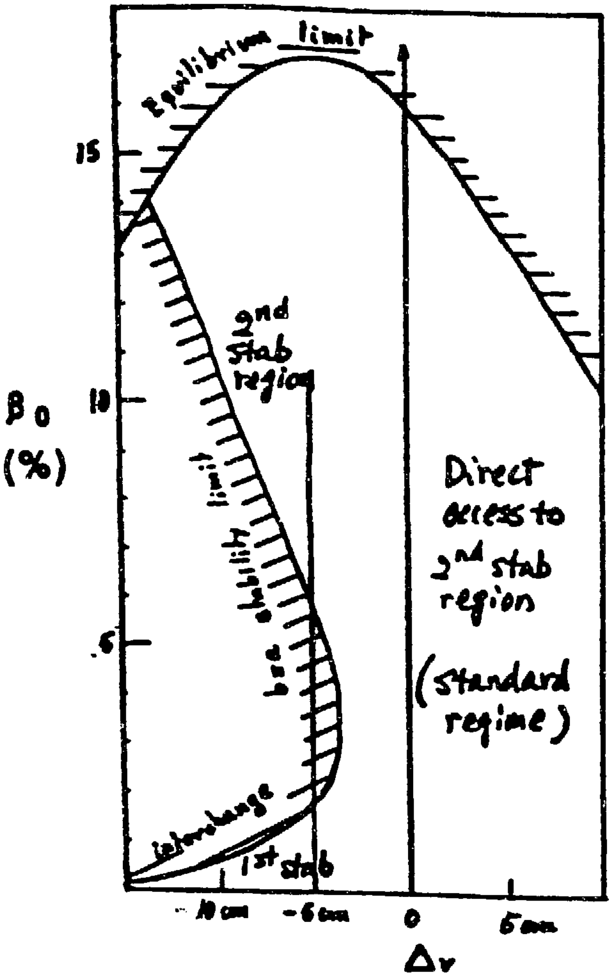
[B.Carreras' talk]

High Beta / MHD Stability Studies

- Objectives are to study MHD stability and β limits, with emphasis on :
  - Maximum $\langle\beta\rangle$ values
  - Second Stability region (i.e., "β self-stabilization")
  - Configuration effects (ι_0, V', I_p)
  - Flux conserving effects
- τ_E scalings based on He-E NBI data analysis predict $\langle\beta\rangle$ values of 2 - 3 %. Achievement of $\langle\beta\rangle$ higher than these values may require :
  - Low field operation (28GHz gyrotron → B_0=0.5T in FY89)
  - More heating power, requiring
    - -- Third beamlines (1.0-1.5Mw) late FY89-FY90
    - -- BBC transmitter (2Mw) for ICRF in FY90.



STABILITY BOUNDARIES (2nd stability region) CAN BE TESTED AT RELATIVELY LOW BETA BY SHIFTING THE MAGNETIC AXIS



- $p \propto \psi^2$
- Equilibrium limit → $\Delta \approx \frac{a}{2}$

[B. Carreras]

- Global modes (m, n ≈ 1 - 3) can be studied:
  - variation of configuration (shift (V"), shaping (κ), I_p)
  - diagnostics:

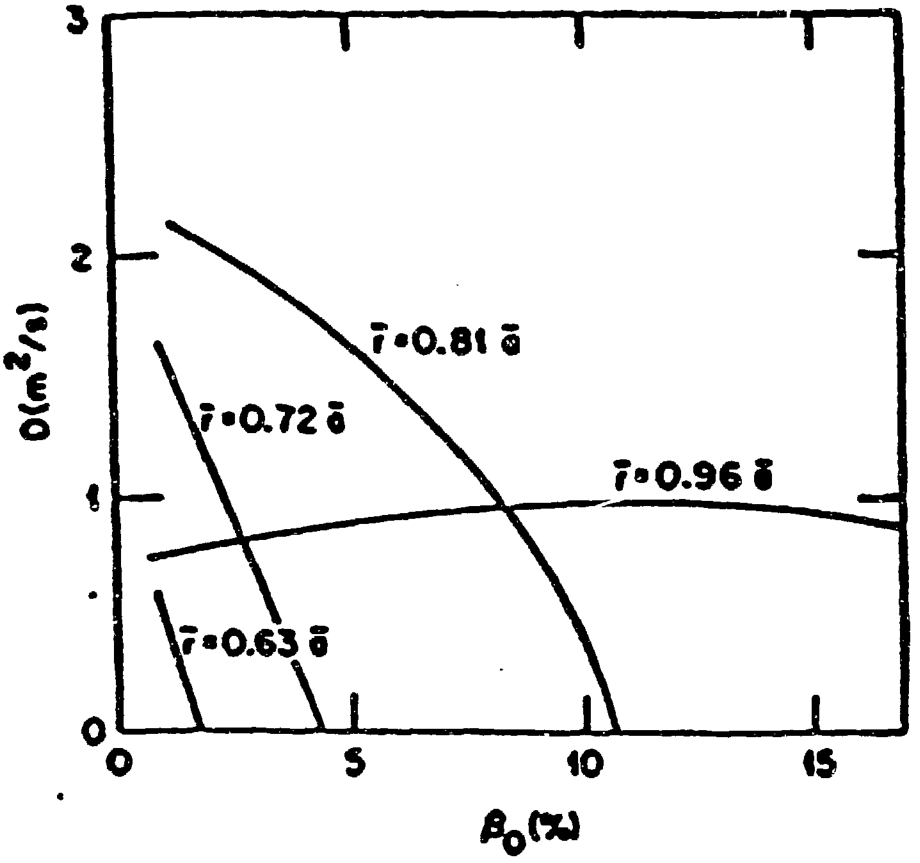
    magnetic loop array (external $\tilde{B}$)

    FIR interferometer (chordal $\tilde{n}$)

    soft x-ray array (internal $\tilde{n}\tilde{T}$)

[R. Isler]

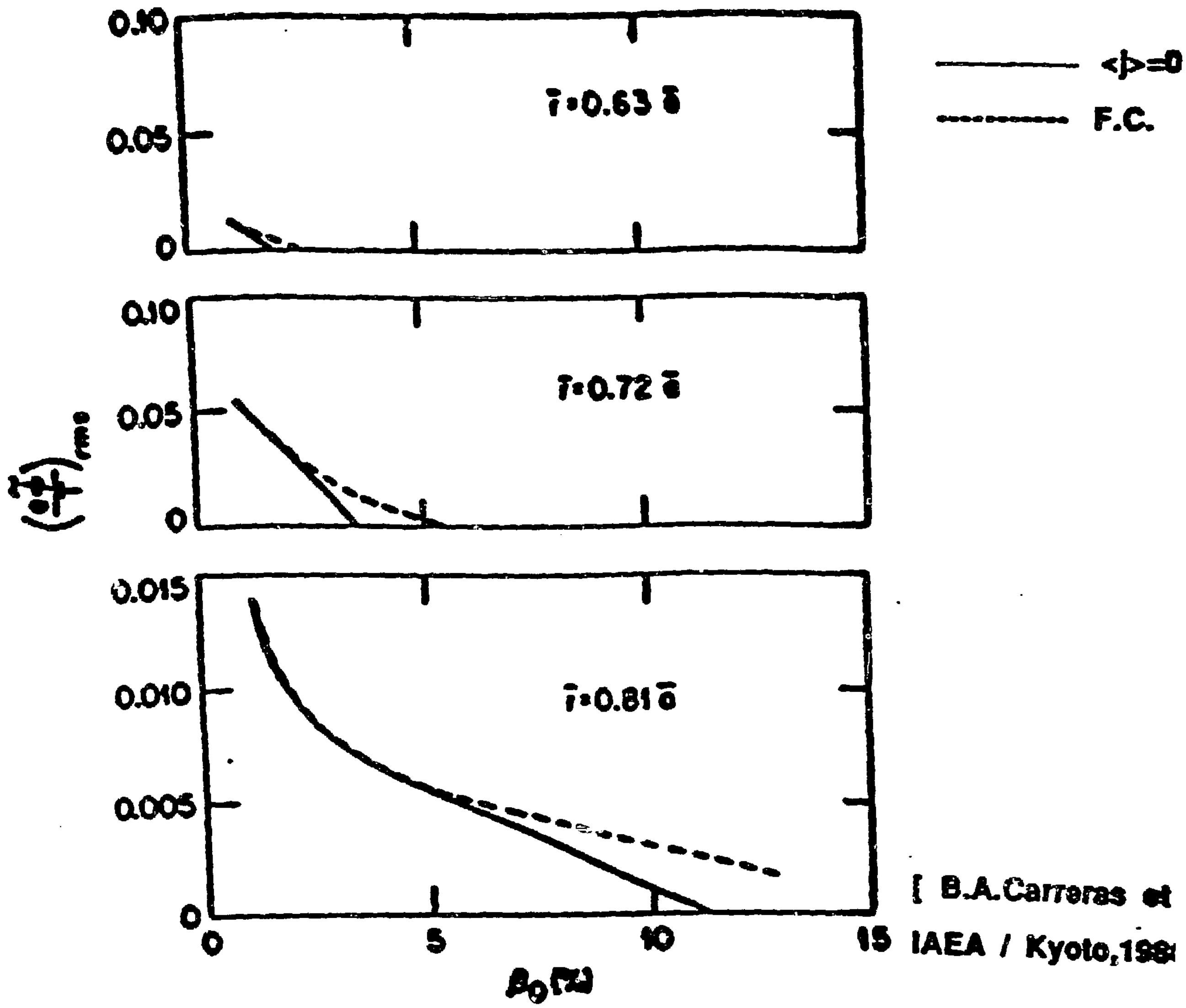
ANOMALOUS DIFFUSIVITY DUE TO SATURATED ∇ p - DRIVEN FLUCTUATIONS



[B.A.Carreras et al
IAEA / Kyoto,1980

- Similar behavior predicted for electron heat conductivity
- The β self-stabilization improves confinement with increasing β in ATF.
- Turbulent spectra can be correlated with confinement.

THE BETA SELF-STABILIZATION IS PREDICTED TO REDUCE TURBULENT FLUCTUATIONS



[B.A.Carreras et ... IAEA / Kyoto, 198...

- The nonlinear model for resistive ∇p - driven instabilities (higher m,n) predicts flucuation levels.

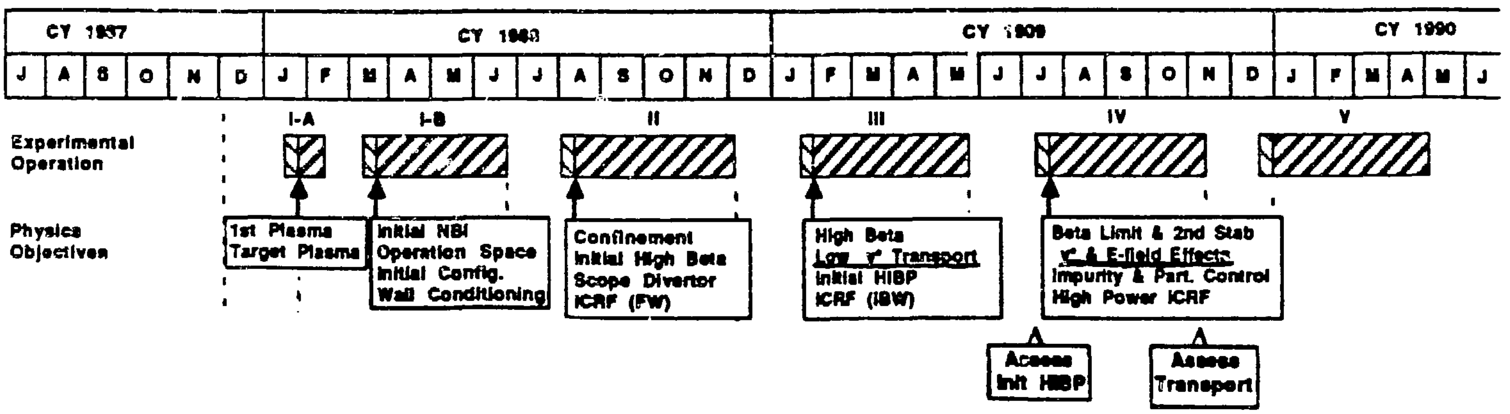
- Variations of the turbulent fluctuations can be observed by:
  - Microwave reflectometry (with CIEMAT, Madrid)
  - Heavy ion beam probe (with RPI)
  - FIR Scattering
  - Edge Langmuir Probes

Transport / Role of E-field Studies

- Objectives are to study stellarator transport with emphasis on :
  - Transport in low collisionality regime
  - Fast ion ripple losses
  - Role of electric field

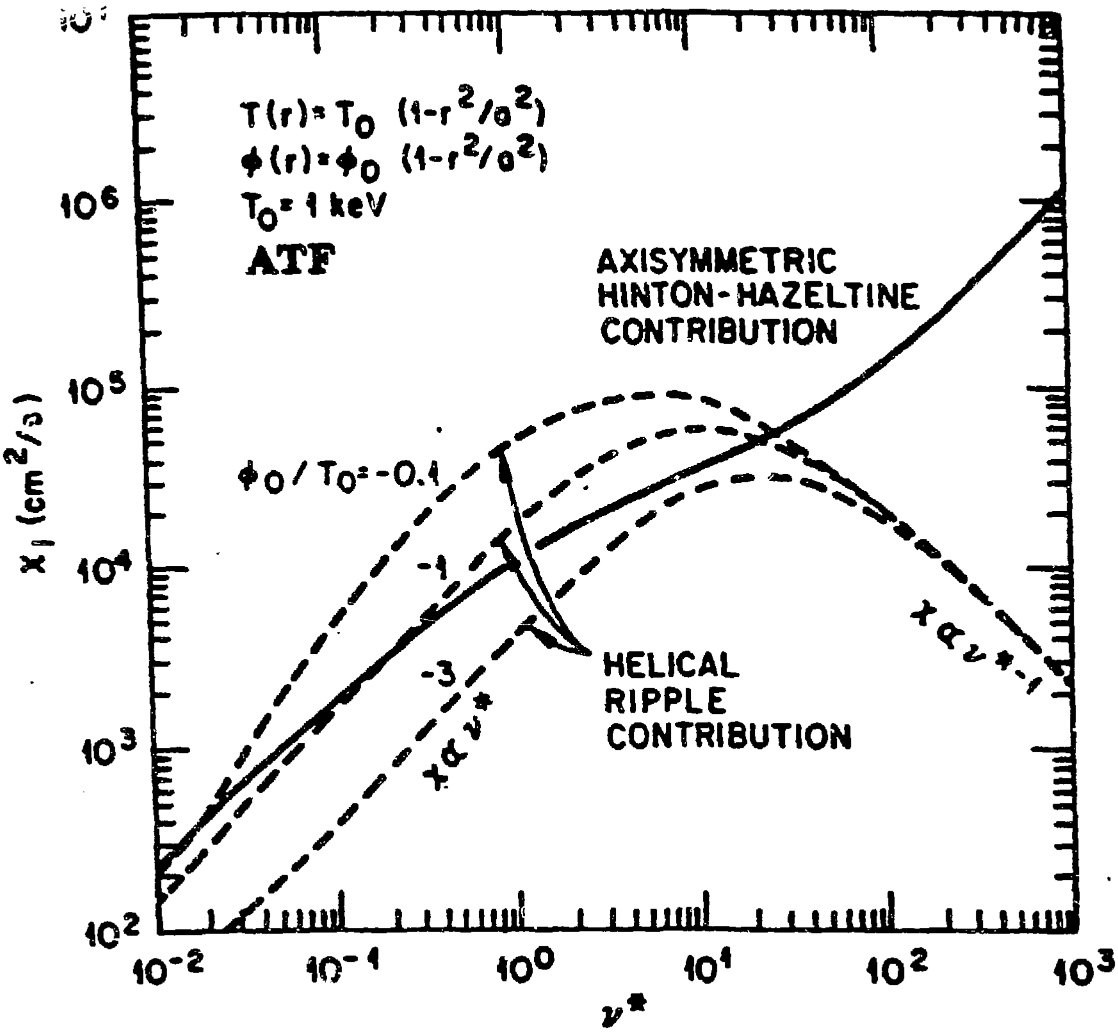
- Early information will come from :
  - τ_E scaling with B_0, $\overline{n}_e$, P_{NB}, etc.
  - PROCTR analysis → neoclasical anomaly
  - T_i, v_ϕ, v_θ measurements from spectroscopy
  - T_i and fast ion measurements from NPA

- Comprehensive studies require :
  - High temperature at low $\overline{n}_e$ (B_0=2T, higher power, particle control)
  - Profile diagnostics
  - HIBP



NEOCLASSICAL THEORY PREDICTS THAT RADIAL ELECTRIC FIELDS OF EITHER POLARITY REDUCE HELICAL RIPPLE LOSS, THEREBY IMPROVE CONFINEMENT

ORNL-DWG 84-2563 FED

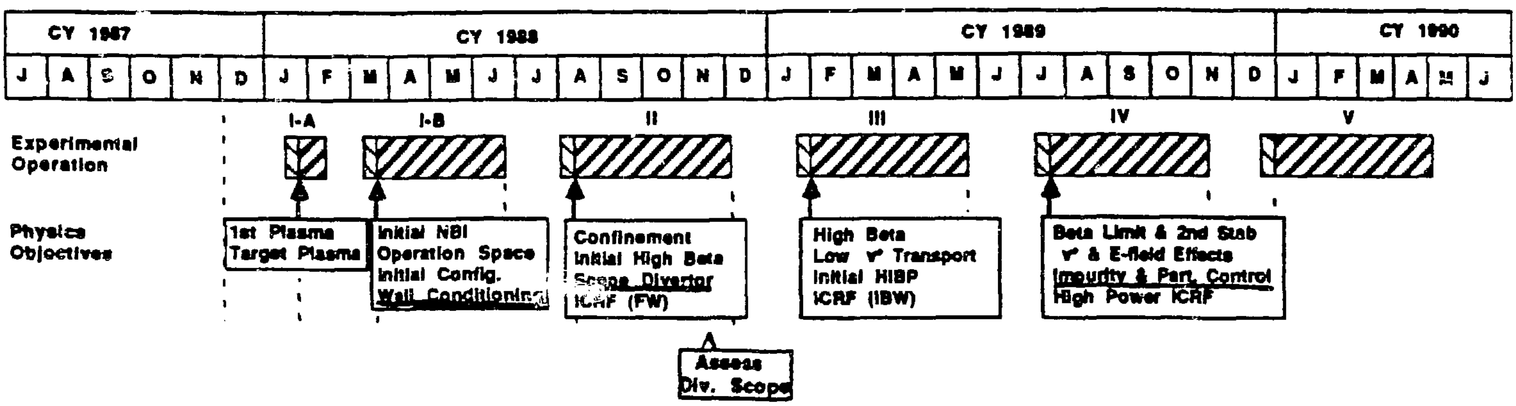


- Electric potential measured with HIBP (*with RPI*)
- Control of potential with:
  - Momentum inputs from opposing tangential beams (as in ISX-B)
  - Overlapping ECH and NBI (?) (as in H-E and W7A)

Edge and Particle Control Studies

- Investigate optimal procedures for reducing impurity sources and removing impurities
  - Additional wall conditioning : RF-assisted glow, Cr or Ti getter

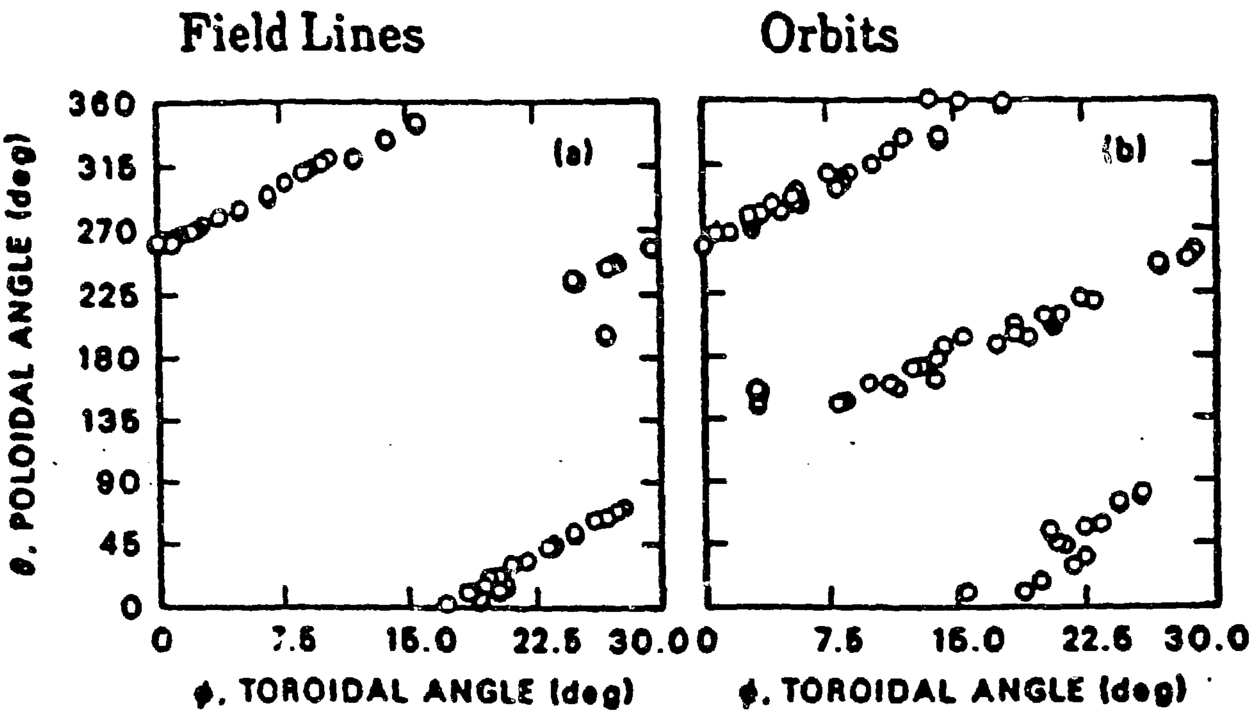
- Investigate particle and energy flows in the plasma edge region to provide a database for the design of divertors and cooled panels.
  - Divertor scoping studies with a graphite target to determine edge parameters and connection lengths of divertor "stripes"
  - Prototype divertor and cooled panel modules
  - Pellet injector



PARTICLE AND IMPURITY CONTROL

- Divertor action should occur in ATF

- Experimental observations of helical stripe patterns in stellarators are consistent with modeling



RF Heating Studies

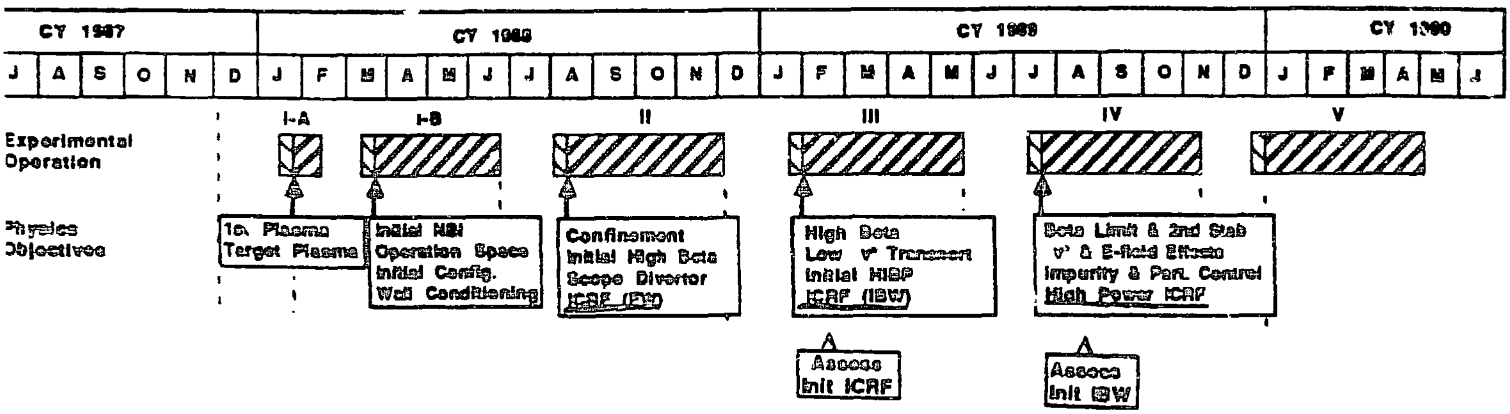
- Objectives are to develop long pulse (to steady state?) high-power heating

- Initial low-power (<0.3MW) experiments will determine optimum approach by comparing :

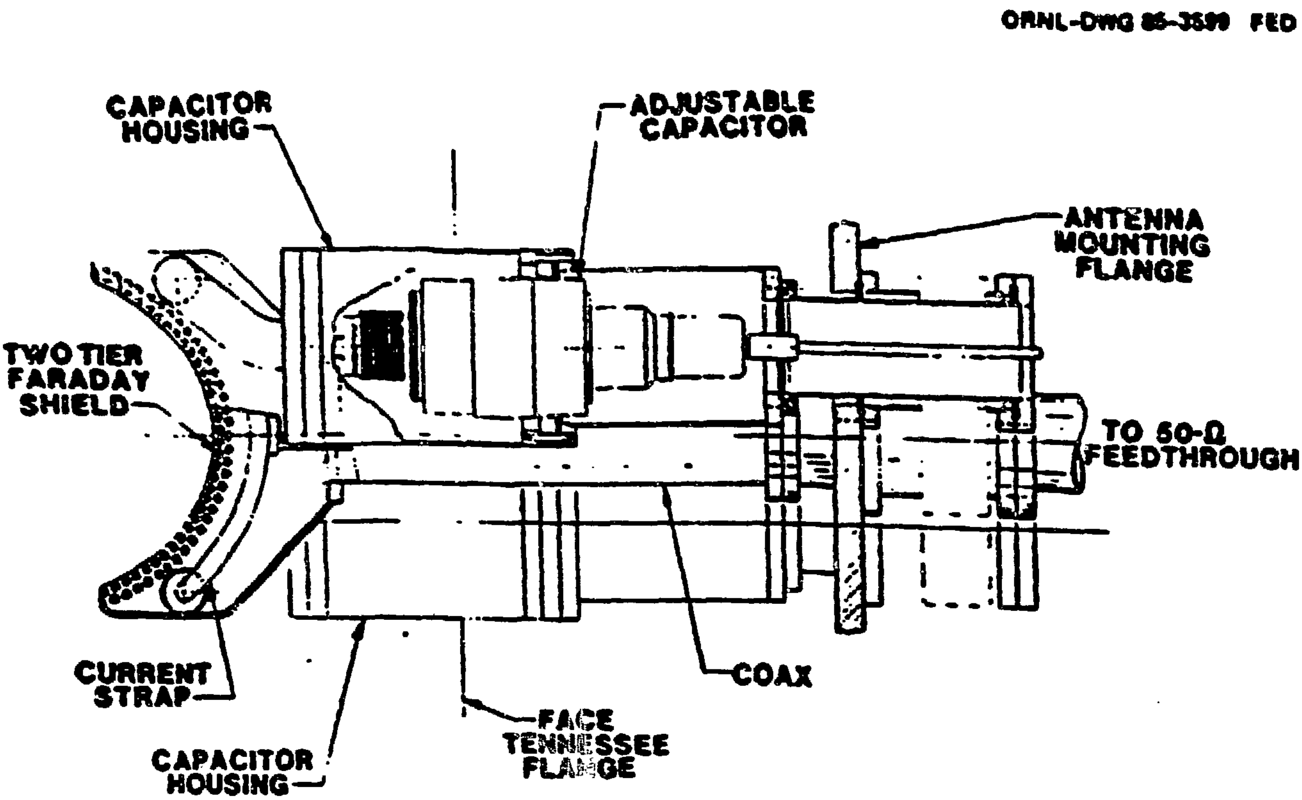
  - Fast wave (minority, 2nd harm.) launcher
  - Ion Bernstein wave (3/2, 2nd, 3rd, 4th harm.) launcher

- High power ICRF :

  - BBC transmitters (2MW @ 5-20MHz; upgraded to 30MHz) in FY90



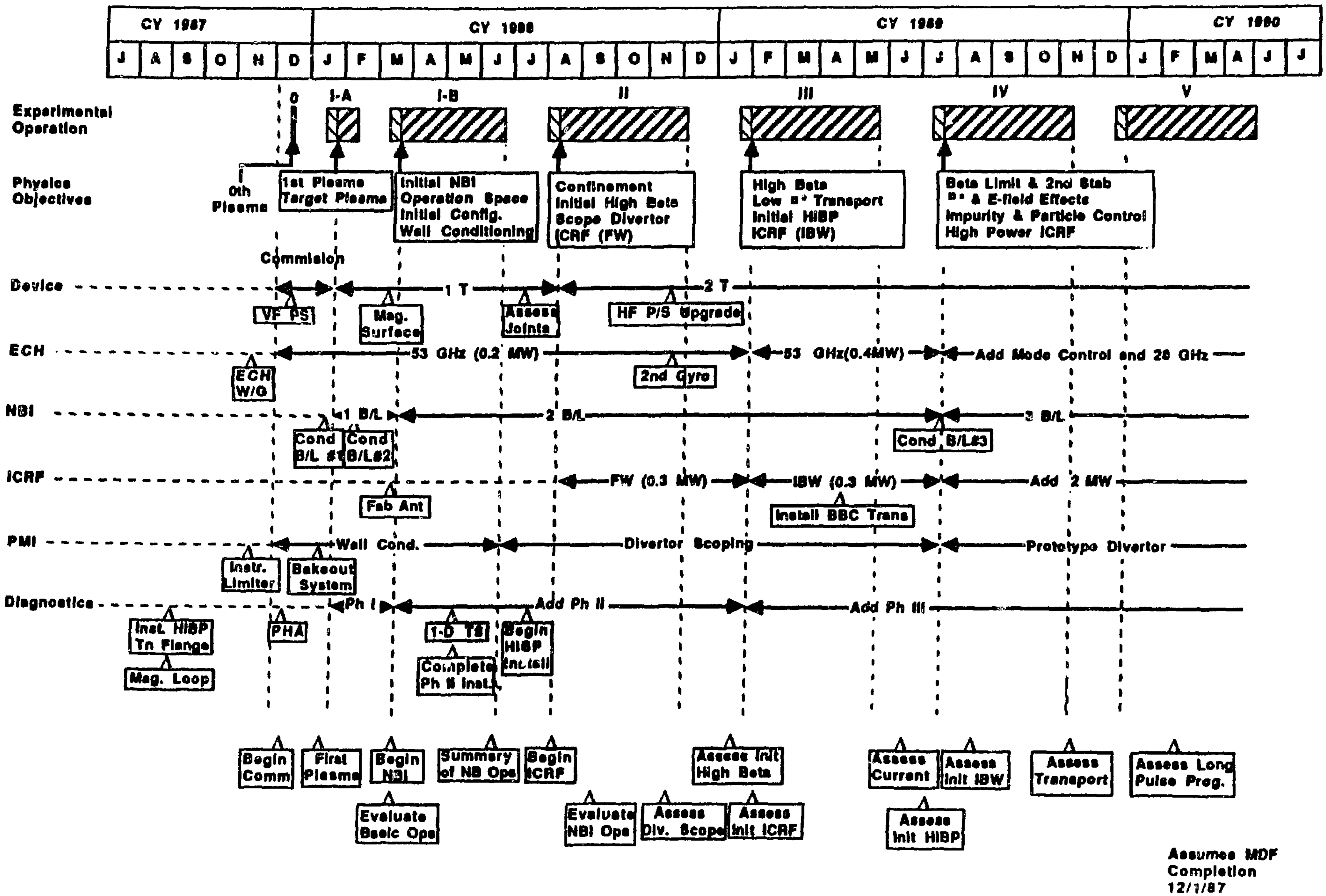
ATF ICRF Antenna



SIDE ELEVATION

- Uses ORNL compact loop design as on D-III-D, Tore Supra, TFTR.
- Tuned by adjustable vacuum capacitors.
- Radially movable over 15 cm range.
- Uses two-tier graphite-coated Faraday shield, and graphite armor on sides of housing.

ATF MILESTONE SCHEDULE (Rev: 18-Nov-1987)



SUMMARY

- The ATF Experimental Program is directed at better understanding and improvement of toroidal confinement through:
  - Configuration Studies
  - High Beta and MHD Stability Studies
  - Transport / Role of E-field Studies
  - Edge and Particle Control Studies
  - RF Heating Studies

- The first-year program will increase hardware and physics capabilities and provide early indications for these studies.

- Collaboration with Heliotron-E and other groups has been very beneficial in formulating the ATF Program.