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CONF-870188--1

DE87 011657

AGENDA

Introduction	Murray Rosenthal
Review of ORNL support	Mike Saltmarsh
Physics	John Sheffield
FEDC	Tom Shannon
Technology	Lee Berry

General discussion of ORNL role in support of TIBER, FY1988 FTP's

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ORNL SUPPORT FOR THE LLNL ETR EFFORT

Lawrence Livermore national Laboratory

January 27, 1987

by
Murray Rosenthal
Associate Director for Advanced Energy Systems
Oak Ridge National Laboratory

* ORNL IS STRONGLY INTERESTED IN SUPPORTING THE LLNL ENGINEERING TEST REACTOR EFFORT

* ORNL HAS A UNIQUE COMBINATION OF CAPABILITIES

* WE WOULD LIKE A BROAD AND SUBSTANTIAL ROLE IN THE ETR

PROPOSALS FOR ORNL SUPPORT OF LLNL ETR EFFORT

M.J.SALTMARSH

Presented at LLNL, 27th January 1987

THE ELEMENTS OF A SUCCESSFUL US ETR EFFORT ARE

INNOVATION

CREDIBILITY

BROAD COMMUNITY SUPPORT

INNOVATION	TIBER II IS AN EXCELLENT STARTING POINT COMPARED TO PREVIOUS DESIGN STUDIES
CREDIBILITY	TIBER II IS AT THE EDGE OF THE LIKELY ETR PARAMETER SPACE. THE CONSEQUENCES OF INCONSISTENCIES BETWEEN PHYSICS/ENGINEERING /TECHNOLOGY CONSTRAINTS ARE MORE SEVERE AND REQUIRE FURTHER STUDY
COMMUNITY SUPPORT	REQUIRES WIDER COMMUNITY INVOLVEMENT AND DISTRIBUTION OF RESOURCES

- ORNL WOULD PROPOSE AN INTEGRATED EFFORT INVOLVING

  PHYSICS

  CONCEPTS

  TECHNOLOGY R&D

  DESIGN

- WITHIN THE US PROGRAM ORNL HAS

  A SUBSTANTIAL THEORETICAL GROUP WITH AN EXCELLENT RECORD OF INVENTIVENESS AND WELL-COUPLED TO EXPERIMENT

  UNIQUE SYTEMS INTEGRATION AND DESIGN CAPABILITIES AND EXPERIENCE AT FEDC

  50% OF THE TOTAL D&T PROGRAM, INCLUDING MAJOR TEST FACILITIES

  A HISTORY OF SIGNIFICANT INNOVATION IN ALL THESE AREAS

  GOOD WORKING CONTACTS AT OTHER INSTITUTIONS DUE TO MORE COLLABORATIVE VENTURES (NATIONAL AND INTERNATIONAL) THAN ANY OTHER LAB.

FOR THE NEAR TERM

0 THE PRIMARY ISSUE IS TO DEVELOP DATA AND PROCEDURE TO SELECT THE ETR DESIGN POINT TAKING INTO ACCOUNT THE MULTIPLE INTERACTIONS BETWEEN CONSTRAINTS

0 PHYSICS	IDENTIFY COUPLED PHYSICS CONSTRAINTS 0-D CODE - 1 1/2 D WHIST - SYSTEMS CODE DEFINITION OF PHYSICS WORK PACKAGES
0 FEDC	BROADEN ROLE OF DESIGN CENTER OVERALL DESIGN STUDIES EXAMINE TRADE-OFFS IDENTIFY HIGH LEVERAGE AREAS
0 TECHNOLOGY	SCOPE OUT POSSIBLE R&D PROGRAMS IN CRITICAL AREAS (E.G. PELLETS, MATERIALS, MAGNETICS) EXAMINE TECHNOLOGY OPTIONS (USE OF FERRITICS, RF HEATING, RF ACCELERATED BEAMS, S/C MAGNET DESIGN OPTIONS, ETC.)

PHYSICS CONSTRAINTS ARE A MAJOR CONCERN IN THE DESIGN OF FUTURE LARGE TOKAMAKS

- MHD
- BETA (TROYON)
- CURRENT DRIVE
- DENSITY (MURAKAMI-GREENWALD)
- FUELING
- TRANSPORT
- MICROINSTABILITIES
- ALPHA EFFECTS
- L → H MODE
- IMPURITIES
- DIVERTOR
- HEATING

PROPOSED PARTICIPANTS IN ORNL PHYSICS STUDIES

ORNL COORDINATOR AND REPRESENTATIVE ON ETOC Mike Saltmarsh.

CONTACT ETOC to IPSG Uckan.

PROPOSED CONTRIBUTORS

WHIST

0-D Analyses <------>	1.5-D Analyses <------>	Systems Analyses
Uckan,Dory	Houlberg	Poloidal Coils
Sheffield	Attenberger	Divertor Magnetics
	Tolliver	Peng
		Strickler
		Galambos

POSSIBLE CONSULTANTS

Theoretical Studies: Dory

MHD: Carreras, Charlton ------
Holmes

Neo-classical: Hirshman ------

Anomalous: Lee, Diamond*----

Impur: Hirshman, Sigmar*----
Stacey*

RF: Current Drive (RAYS) -----
Batchelor, Hogan,
Uckan, Weitzner*

Fueling: Houlberg, Gouge -----

Edge: Howe, Rome ----------

Alphas: Spong, Sigmar* ------
Miley*

*Some potential participants from other laboratories.

FEDC ROLE

SUPPORT FOR LLNL WOULD BEST BE ACHIEVED THROUGH

A BROADER COMPLEMENTARY EFFORT

- 0 SCOPING OUT OF DESIGN SPACE INTERMEDIATE BETWEEN TIBER II AND NET ETC.
- 0 EXAMINATION OF TRADE-OFFS

AS WELL AS

- 0 EXISTING RESPONSIBILITY FOR SPECIFIC WBS ELEMENTS

FOR TECHNOLOGY, PROPOSED ETR TASKS INCLUDE:

- Contributing to reference
- Developing and evaluating options
- Identifying issues, planning R&D
- Conducting critical R&D

ETR RELATED WORK WILL BE A SIGNIFICANT

FRACTION OF THE ORNL PROGRAM

CO-ORDINATION OF FTP/A SUBMISSIONS IS NEEDED

WE NEED ADVANCE UNDERSTANDING OF THE TECHNOLOGY
AND FEDC ROLES IN ORDER TO PLAN OUR IN-HOUSE
PROGRAMS

PROPOSAL FOR ORNL PHYSICS SUPPORT FOR TIBER

Lawrence Livermore National Laboratory

January 27, 1987

by
John Sheffield
Associate Director for Confinement
Fusion Energy Division
Oak Ridge National Laboratory

PHYSICS CONSTRAINTS ARE A MAJOR CONCERN IN THE DESIGN OF FUTURE LARGE TOKAMAKS

- MHD
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- L → H MODE
- IMPURITIES
- DIVERTOR
- HEATING

AT ORNL WE PROPOSE TO DO A PRELIMINARY STUDY OF ALL AREAS IN FY 1987 WITH THE FOLLOWING GOALS

- IDENTIFY MISMATCHES IN REQUIREMENTS FOR AREAS

- WORK WITH TIBER TEAM TO IDENTIFY A GROUP TO TACKLE EACH AREA

- ULTIMATELY CREATE MODULES FOR USE IN HOULBERG'S WHIST CODE AND OTHER CODES TO ALLOW INTERACTIVE STUDIES

- IMPROVE UCKAN'S 0-D CODE TO ALLOW QUICK SCANS TO FILTER CASES FOR WHIST

- UPDATE PHYSICS PACKAGE IN THE ETR SYSTEMS CODE

- PREPARE WORK PACKAGES FOR FY 1988

* THROUGH NATIONAL IPSG ACTIVITY REVIEW
  STATE OF KNOWLEDGE IN EACH CRITICAL AREA
  IDENTIFY WHAT WORK IS PROPOSED IN WORLD PROGRAM

- WORK WITH TIBER TEAM TO ESTABLISH ADDITIONAL WORK REQUIRED IN FY 88 AND BEYOND IN THEORY EXPERIMENT AND MODELLING

FOR EACH AREA THERE IS AN OPTIMUM OPERATING CONDITION

FOR EXAMPLE BETA = 3.5 I/aB % (I(MA), a(m), B(T))

THERE IS A CRUCIAL QUESTION TO BE ANSWERED

"WHAT ARE THE OPTIMUM OPERATING CONDITIONS SUBJECT TO ALL LIMITATIONS TAKEN SIMULTANEOUSLY?"

THE DIFFICULTY IS THAT FOR SOME OF THE AREAS THERE ARE CONFLICTING REQUIREMENTS

SOME IMPORTANT FACTORS ARE

- BETA LIMIT/MHD —> determine Pressure and Current Profiles
  - *Equilibrium —> constrains Poloidal Coil System, Shell?
  - *Stability —> limits choices of b/a and R/a, Shell?
    —> Disruptions, Sawteeth

- CURRENT DRIVE —> Access, Efficiency, Profile Control, Bootstrap Current

- DENSITY —> not an issue with Greenwald Scaling

- FUELING —> obtaining Desired Density Profile
  Inward Pinch?

- TRANSPORT —> ?
  Profile Consistency

- MICROINSTAB'S —> e.g., avoid Eta-i Modes

- ALPHA EFFECTS —> Profiles, Fishbones, Ballooning

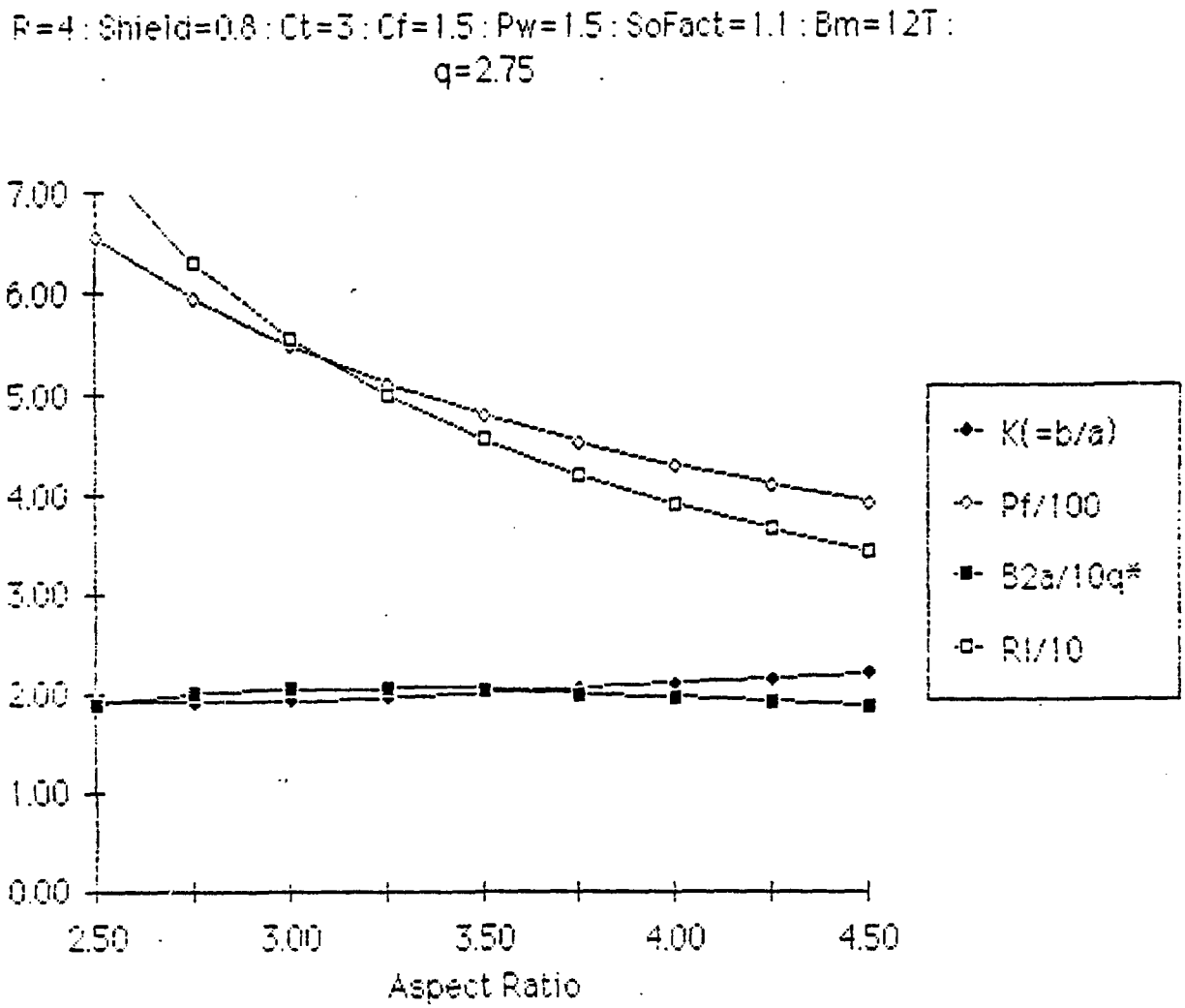
- L —> H MODE —> High Edge Temperature, Control, Divertor

- IMPURITIES —> Transport, E-fields?

- DIVERTOR —> Low Edge Temperature? Control

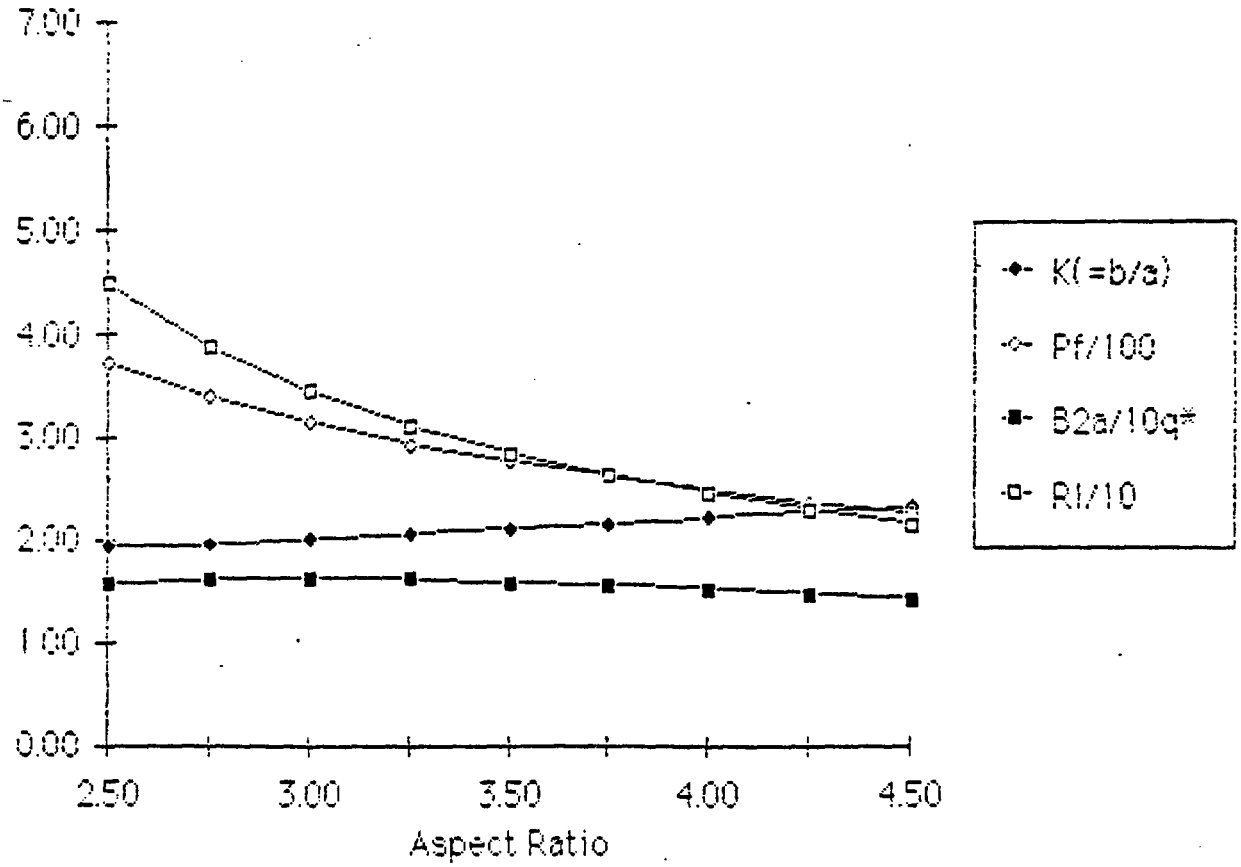
- ICH —> Coupling, L—>H

ETR designs vs R/a



Overlay: At constant, major radius, neutron wall loading 1.5 MW/m^2, Troyon factor 3, shield thickness 0.6m, scrape-off layer 0.05a, safety factor 2.75, and coil field 12T, the required ellipticity varies little with R/a. However, at the larger aspect ratios a conducting shell will be required for stability. The poloidal coil system will become more demanding as R/a is increased. A better understanding is required of these effects in order to adequately optimize the ETR.

R=3 : Shield=0.6 : Ct=3 : Cf=1.5 : Pw=1.5 : SoFact=1.05 : Bm=12T : q=2.75



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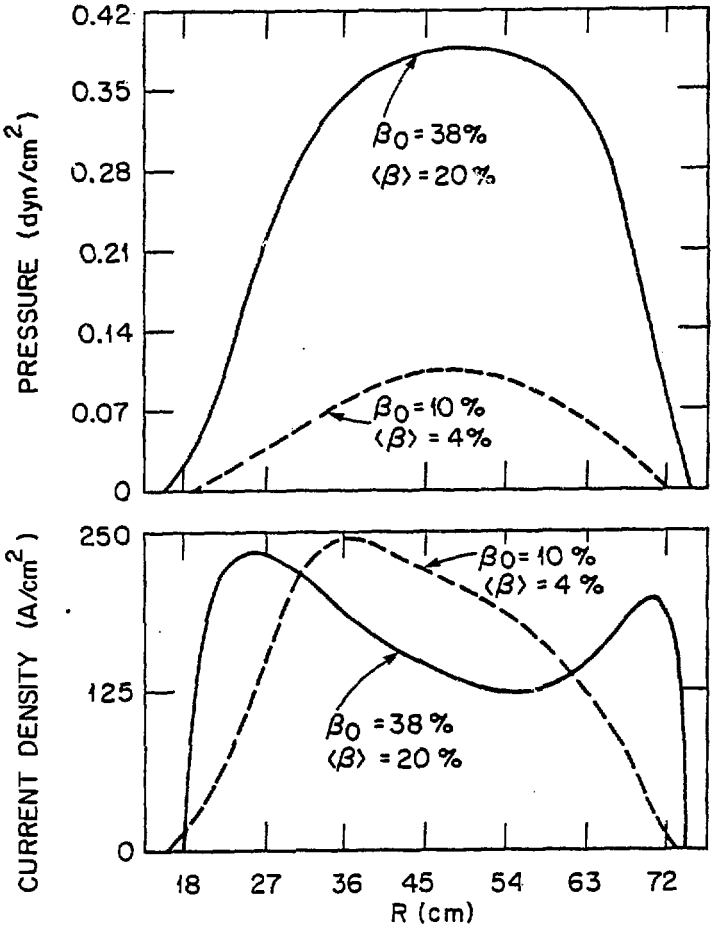
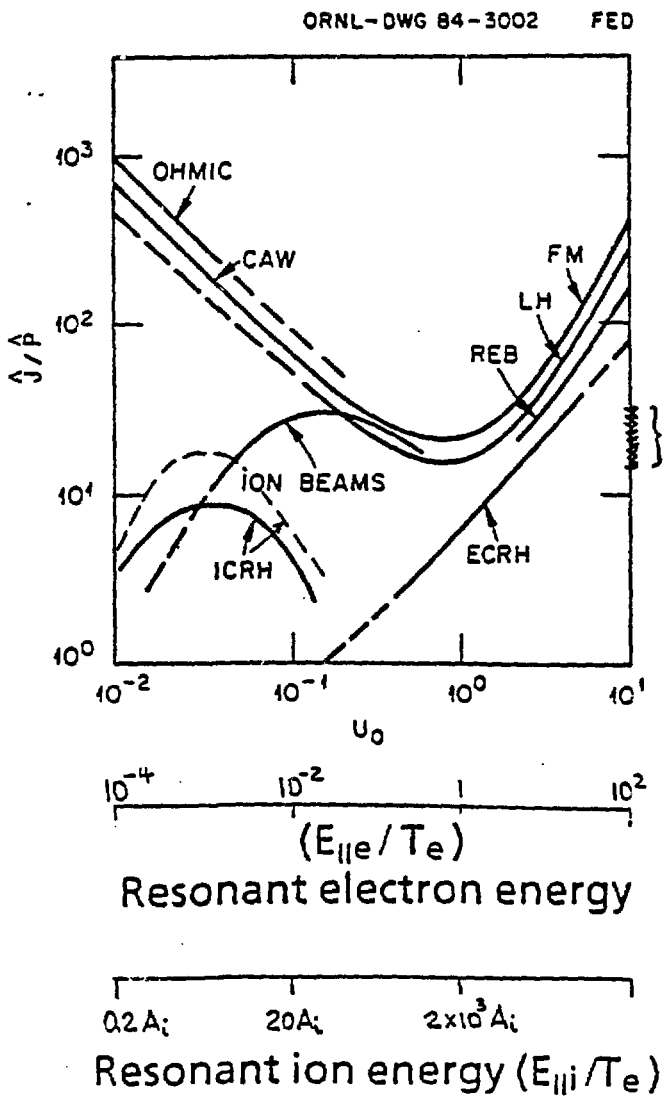
ORNL-DWG 87-2039 FED

STABLE PRESSURE AND CURRENT PROFILES (STX)



COMPENDIUM OF NORMALIZED CURRENT DRIVE EFFICIENCY ($\hat{J}/\hat{P}$)

- There are several good prospects for steady state current drive with $\hat{J}/\hat{P} \sim 15\text{-}30$



Except for Lower Hybrid Current Drive only very limited information exists on non-inductive current drive.

$\hat{J}/\hat{P} \sim 15\text{-}30$

Waves:

$$U_0 = \frac{V_\parallel}{V_e} = \frac{\omega}{k_\parallel V_e} \quad \text{(Landau damping)}$$

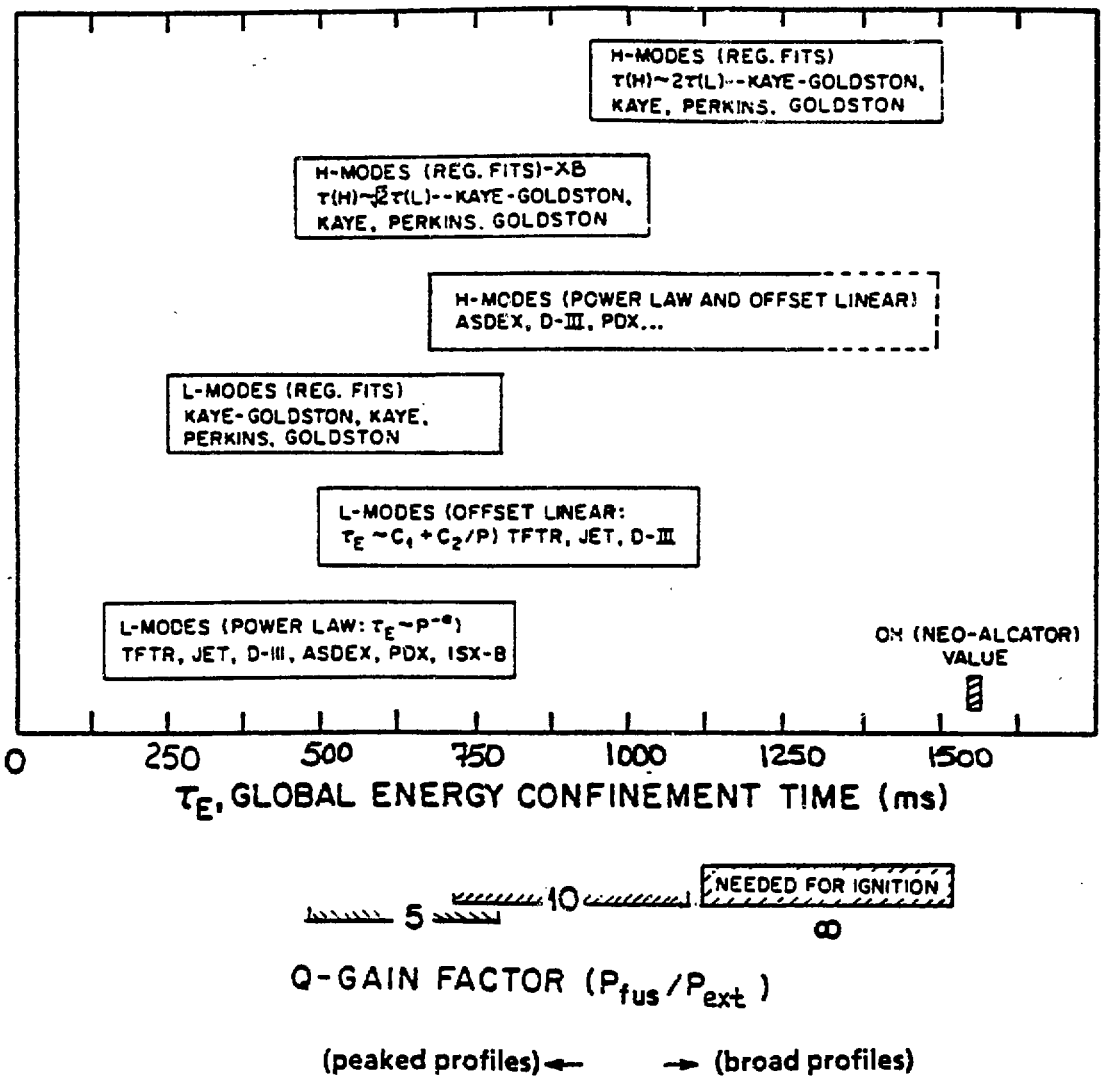
$$= \frac{\omega - \ell\Omega}{k_\parallel V_e} \quad \text{(Cyclotron damping)}$$

Beam:

$$U_0 = \frac{V_{beam}}{V_e}$$

CONFINEMENT PROJECTIONS FOR A REFERENCE ETR

TIBER-II -- 10 (MA)



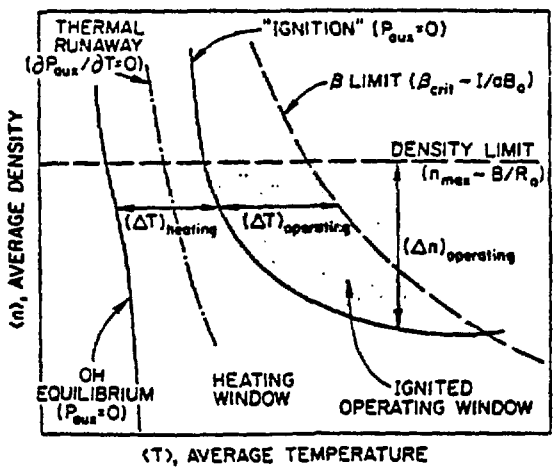
PLASMA PARAMETER OPERATING SPACE IS CONSTRAINED BY:

CIT:
- Confinement (ion & electron transport, impurities)
- MHD effects (β limit, q_ψ, etc.)
- Density limit (Murakami limit)

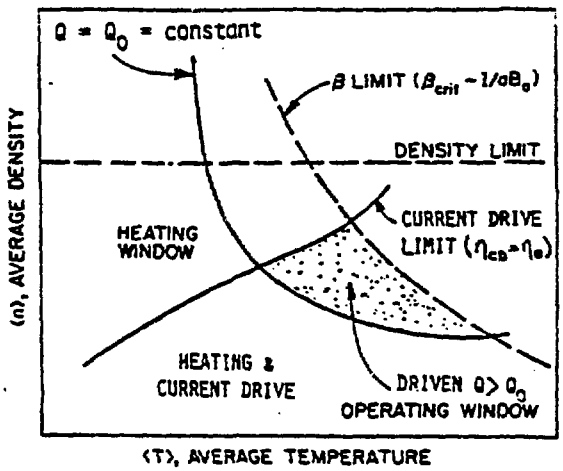
ETR:
- Confinement (ion & electron transport, impurities)
- MHD effects (β limit, q_ψ, etc.)
- Density limit (Murakami limit)
- current drive requirements

CURRENT DRIVE

INDUCTIVE



NONINDUCTIVE



The prime operating conditions, and start up scenario for the CIT differ from those for the non-inductive TIBER scenario.

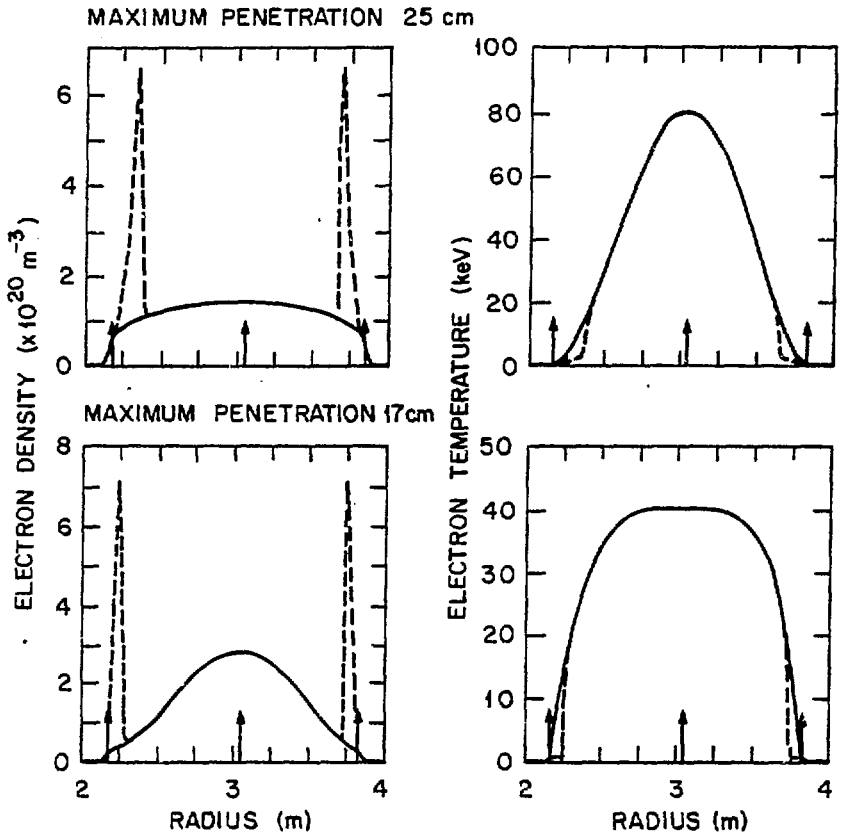
ORNL-DWG 86-2040 FED

PELLET INJECTION INTO TIBER-WHIST CODE

$\langle T \rangle = 27$ keV $\langle n_e \rangle = 1.1 \times 10^{20}\ m^{-3}$

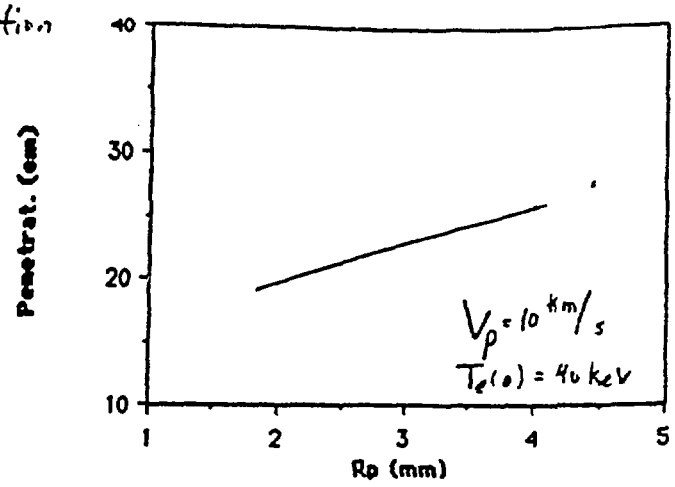
$V_p = 10\ km \cdot s^{-1}$ $P_\alpha = 54$ MW

——INITIAL - - - FINAL



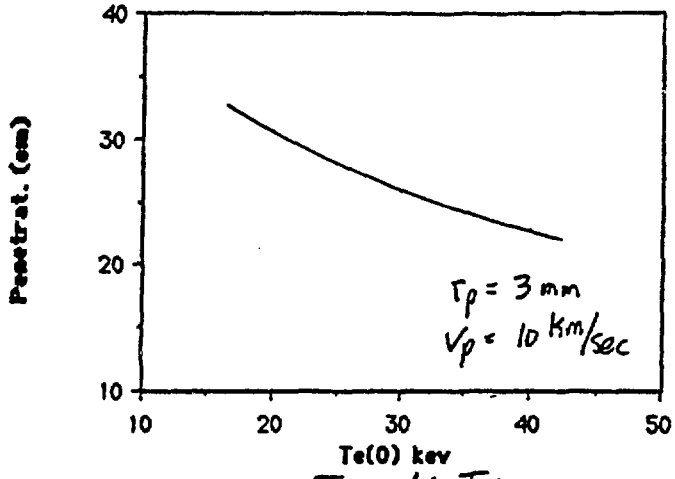
(EVEN WITH $V_p = 50\ km \cdot s^{-1}$, MAXIMUM PENETRATION IS ONLY 30 cm)

EIK
Pellet Penetration



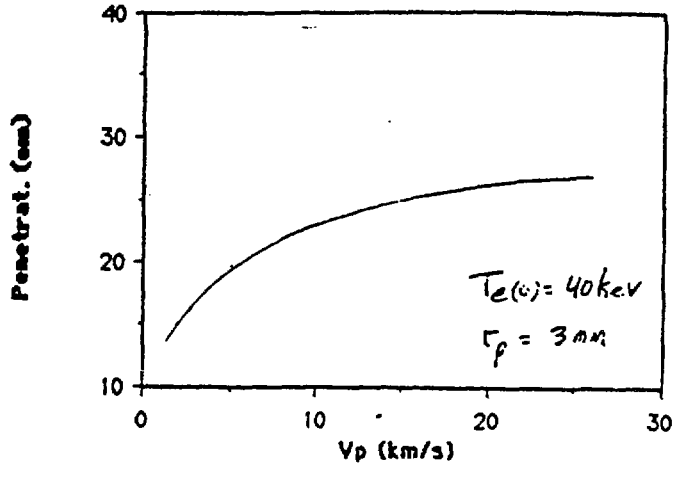
ETR-Tiber II
Ro= 3m
a= .834m
<Ne>= 1.1e14 cm-3

Palpha= 541W



$\langle T_e \rangle = 1/3\ T_e(0)$

Te profile: $(1-(r/a)^2)^2$
Ne profile: $(1-(r/a)^2)$



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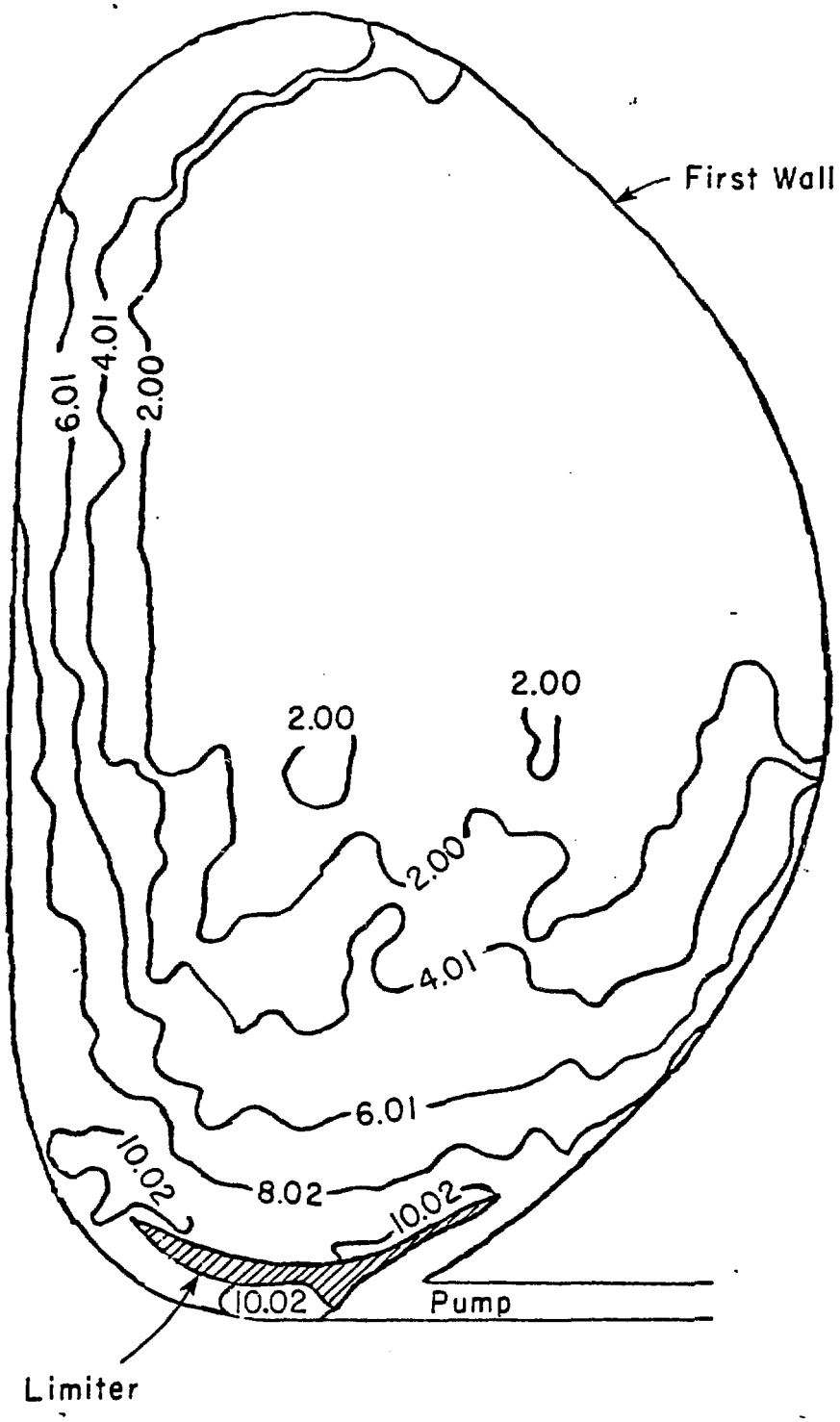
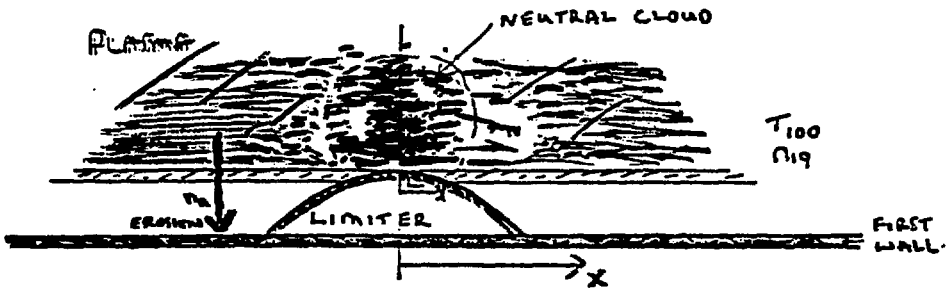


A cloud of neutrals emanates from each point of contact of the plasma with the wall. The question of compatibility of H-mode operation with acceptable wall/ target erosion rates should be studied.

PLASMA EROSION OF THE FIRST WALL

LIMITER CASE



FIRST WALL DEPTH ERODED IN 4 YEARS

$$\Delta W \simeq \frac{3 \times 10^{-5}\, P_t\, S}{A_L\, \gamma e\, T_{100}} \exp\left(-\frac{(X-L)n_{19}}{0.2\sqrt{T_{100}}}\right) (m)$$

CONSIDER OUTER BELT LIMITER. $A_L = 2 \times 9 \times 1\ m^2$, $X-L = 0.5$ m

$P_t = 3.5 \times 10^{-8}$W. SPUTTERING COEFF $S = 10^{-2}$

$$\Delta W \simeq \frac{0.5}{T_{100}} \exp\left(-\frac{2.5\, n_{19}}{\sqrt{T_{100}}}\right)$$

- $T_{100} = 1,\ n_{19} = 2,\quad \Delta W = \underline{3\ mm}$
- $T_{100} = \underline{0.5},\ n_{19} = \underline{2},\quad \Delta W = \underline{0.8\ mm}$ (50eV, $2\times10^{19}\ m^{-3}$)
- $T_{100} = 2.0,\ n_{19} = 1,\quad \Delta W = \underline{43\ mm}$

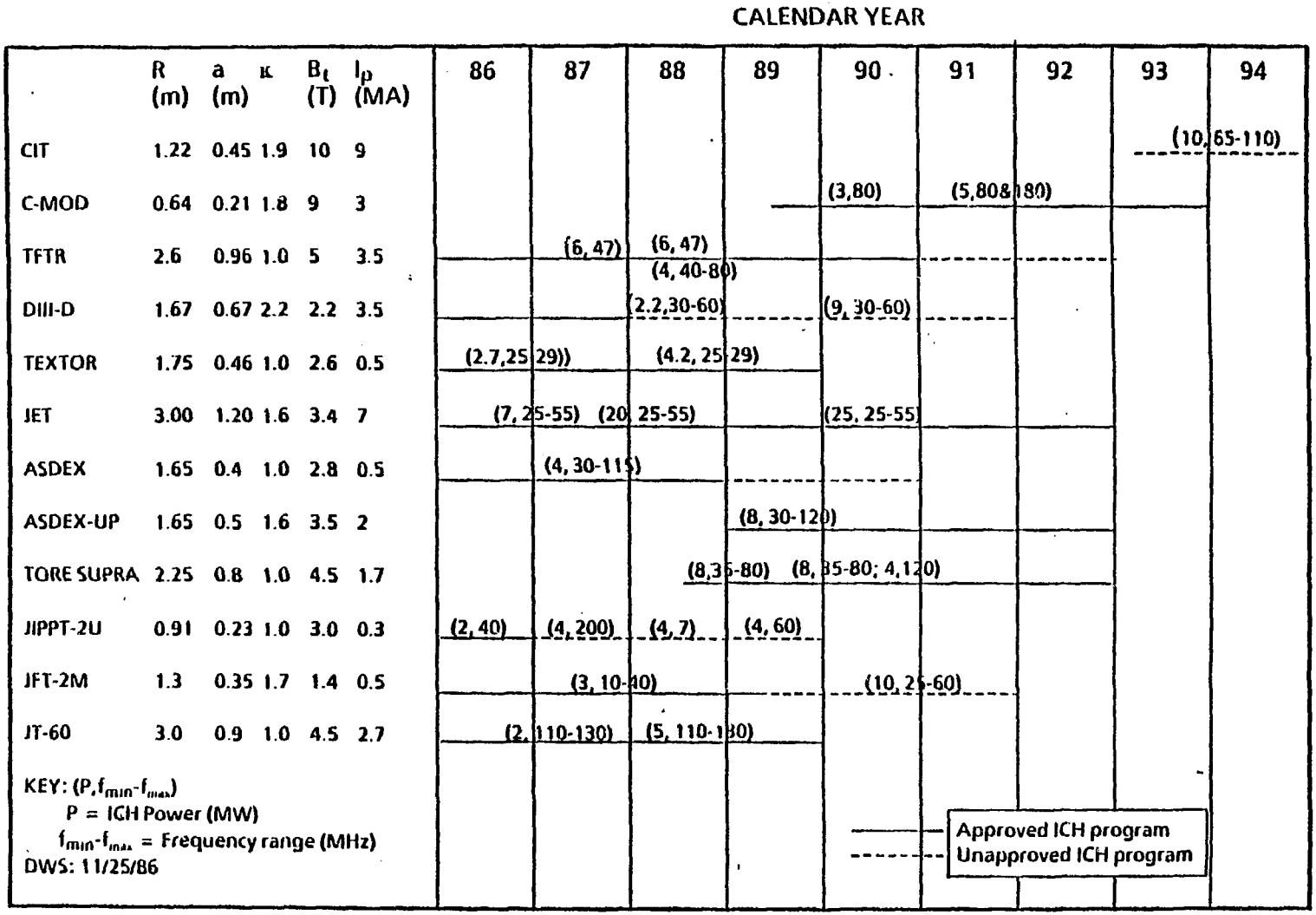


Fig. 3. Major tokamak ICH experiments.

The IPSG performs an important role; in assessing the status and needs of a particular area - eg ICH ; and in determining what programs exist to resolve outstanding issues.

PROPOSED PARTICIPANTS IN ORNL PHYSICS STUDIES

ORNL COORDINATOR AND REPRESENTATIVE ON ETOC Mike Saltmarsh.

CONTACT ETOC to IPSG Uckan.

PROPOSED CONTRIBUTORS

WHIST

0-D Analyses <------>	1.5-D Analyses <------>	Systems Analyses
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	Tolliver	Peng
		Strickler
		Galambos

POSSIBLE CONSULTANTS

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Holmes

Neo-classical: Hirshman ------

Anomalous: Lee, Diamond*----

Impur: Hirshman, Sigmar*----
Stacey*

RF: Current Drive (RAYS) -----
Batchelor, Hogan,
Uckan, Weitzner*

Fueling: Houlberg, Gouge -----

Edge: Howe, Rome ----------

Alphas: Spong, Sigmar* ------
Miley*

*Some potential participants from other laboratories.

T. E. SHANNON, MANAGER
FUSION ENGINEERING DESIGN CENTER

FEDC/ORNL ROLE IN ETR DESIGN

PRESENTED TO LLNL
JANUARY 27, 1987

WE BELIEVE THAT THE FEDC SHOULD PLAY A STRONGER ROLE IN THE ETR CONCEPTUAL DESIGN

* AS A MAJOR LEADER/PARTICIPANT IN VIRTUALLY ALL NEXT-STEP DESIGN STUDIES FOR THE PAST 10 YEARS, THE FEDC IS THE MOST EXPERIENCED ADVANCED FUSION DESIGN ORGANIZATION IN THE WORLD.

* ORNL, MAJOR INDUSTRIAL ORGANIZATIONS, MANY OUTSTANDING INDIVIDUALS AND THE FUSION PROGRAM IN GENERAL HAVE MADE A LARGE INVESTMENT IN BUILDING THE PRESENT CAPABILITY.

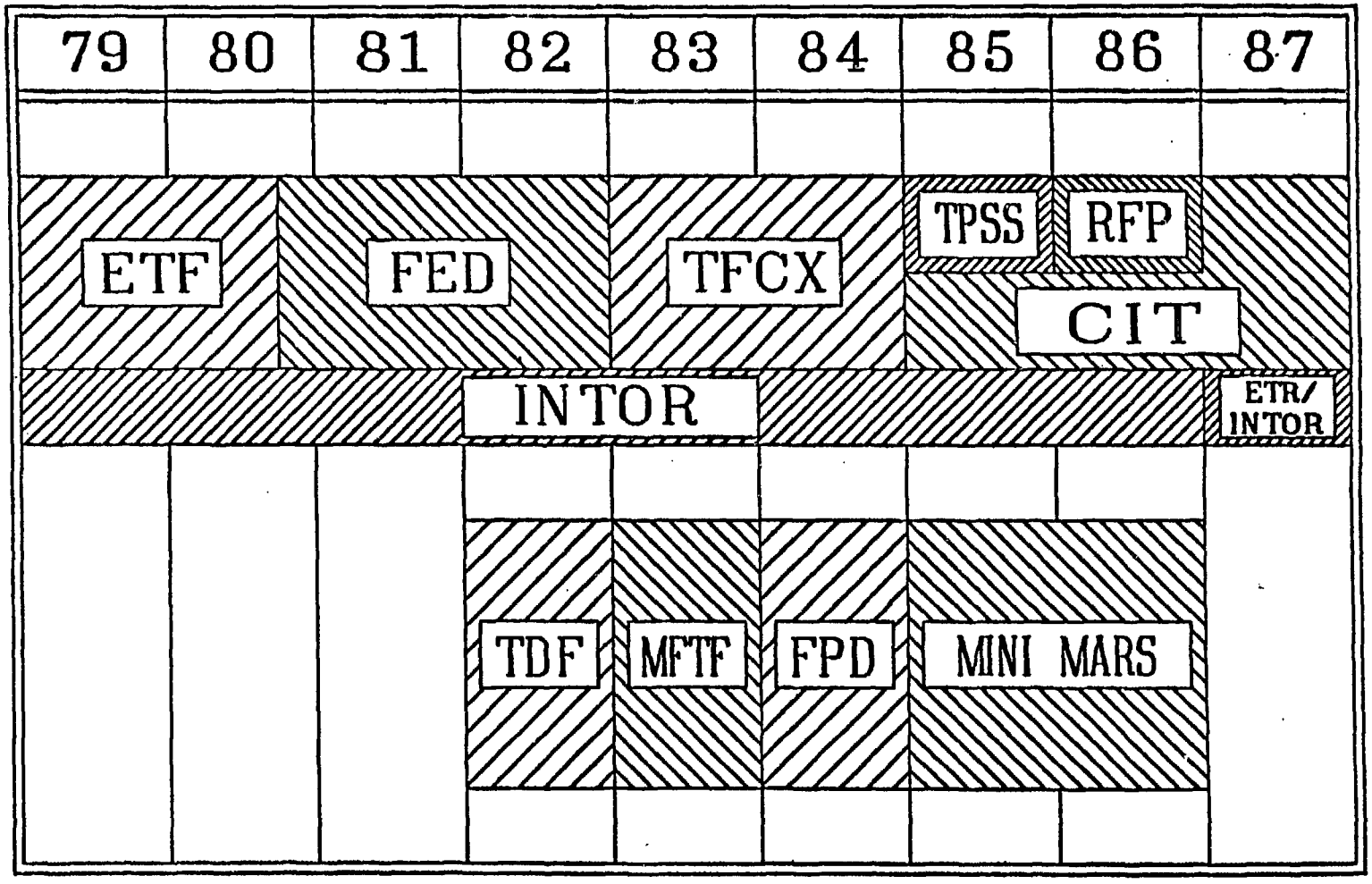
* THE ON-SITE TEAM HAS ALL FUNCTIONAL AND SYSTEM CAPABILITIES TO VERY QUICKLY DEVELOP INTEGRATED DESIGN CONCEPTS.

* THE CIT PROGRAM PROVIDES A BROAD BASE OF ONGOING EXPERIENCE.

* WE PROPOSE EXPANDING OUR PRESENT TIBER DESIGN RESPONSIBILITY TO INCLUDE AN OVERALL DESIGN STUDY.

* A CLOSE RELATIONSHIP WITH ORNL PROVIDES THE NECESSARY LINK BETWEEN ENGINEERING DESIGN, PHYSICS AND TECHNOLOGY.

FEDC ACTIVITIES 1979-1987



FEDC PERSONNEL STATUS

TECHNICAL STAFF	
ORNL	
FUSION ENERGY DIVISION	2
ENGINEERING	5
COMPUTER SCIENCE	2
INDUSTRY	
GRUMMAN	6
TRW	2
MDAC	2
JOB SHOP (DESIGN)	2
BITS & BYTES (COMPUTER SUPPORT), WESTINGHOUSE, BECHTEL, TVA	4
OTHER	
JAERI VISITOR, GRADUATE STUDENT	2
SUPPORT STAFF	
ADMINISTRATION	1
SECRETARIES	3
TOTAL STAFF	31

FEDC PERSONNEL STATUS

FUNCTIONAL AREAS

MECHANICAL ENGINEERING CONFIGURATION DESIGN, THERMAL/HYDRAULICS, FW/DIVERTOR, MAINTENANCE EQUIPMENT, STRUCTURAL ANALYSIS, DESIGN INTEGRATION	7
ELECTRICAL ENGINEERING HEATING SYSTEMS, MAGNETS, FUELING, I&C/DIAGNOSTICS, POWER SYSTEMS	6
NUCLEAR ENGINEERING NEUTRONICS ANALYSIS	2
PLASMA ENGINEERING MHD/MAGNETICS, PLASMA PERFORMANCE, IMPURITY/PARTICLE CONTROL	3
SYSTEMS ENGINEERING SYSTEMS ANALYSIS, SYSTEMS CODE DEVELOPMENT, RELIABILITY/AVAILABILITY ANALYSIS, COSTING	5
DESIGN, DRAFTING, CAD	4

ORNL/FEDC CONTRIBUTIONS TO THE CIT PROGRAM

SPRING/SUMMER 85

* ORGANIZED ENGINEERING AND PHYSICS FEASIBILITY STUDIES LEADING TO THE ENDORSEMENT OF A COMPACT DEVICE AT THE INTERNATIONAL WORKSHOP.

FALL/WINTER 85-86

* ORGANIZED SYSTEMS STUDIES TO EVALUATE/OPTIMIZE AND COST MAJOR CONCEPTS
* ADOPTED IGNITOR APPROACH AND DEVELOPED THE IGNIFED CONCEPT
* DEVELOPED STRONG TECHNICAL TIE WITH COPPI AND ITALIAN TEAM
* FEATURES OF THE IGNIFED CONCEPT

  -SIMPLIFIED PRELOAD CONCEPT
  -SIMPLIFIED PF SYSTEM
  -CLEAN STRUCTURAL DESIGN AND ASSEMBLY
  -LOWEST COST OPTION

ORNL/CIT CONTRIBUTIONS (CONT)

SPRING 86/PRESENT

* MAJOR SYSTEM RESPONSIBILITY AS PART OF NATIONAL TEAM UNDER PPPL

  - PHYSICS PERFORMANCE ANALYSIS
  - DESIGN INTEGRATION
  - CONFIGURATION DEVELOPMENT
  - NUCLEAR ANALYSIS
  - PF MAGNETICS
  - ELASTIC/PLASTIC ANALYSIS-TF MAGNETS
  - COST ESTIMATE
  - WBS MANAGEMENT, SIX SYSTEMS

ORNL WILL PLAY A CONTINUING ROLE IN THE CAPITAL PROJECT

* ITOC AND IPSG (SHEFFIELD, UCKAN)

* ENGINEERING AND R&D MANAGEMENT (BERRY, SHANNON)

* DESIGN, FABRICATION, INSTALLATION AND R&D ($60-70 M)

  -RF
  -REMOTE MAINTENANCE
  -SHIELDING
  -TOKAMAK STRUCTURE
  -VACUUM PUMPING
  -FUELING

FY87 FELC TIBER RESPONSIBILITY

ENGINEERING SUPPORT ($250 K + CFFTP = 3 MY)

1. DESIGN INTEGRATION
   - CONFIGURATION OPTION
   - ELECTRICAL SYSTEMS
   - FACILITIES

2. SYSTEMS ENGINEERING
   - AVAILABILITY ANALYSIS
   - COSTING

3. SYSTEM DESIGN
   - VACUUM VESSEL
   - DIVERTOR
   - PELLET INJECTOR
   - MAINTENANCE EQUIPMENT
   - REACTOR BUILDING AND PLANT
   - HOT CELL

FY87 FEDC TIBER RESPONSIBILITY (CONT)

SYSTEMS ANALYSIS/CODE DEVELOPMENT ($200 K = 1.5 MY)

1. CODE DEVELOPMENT
   - MANAGE NATIONAL EFFORT
   - PROVIDE SIX MODULES
   - INTEGRATE TOTAL CODE

2. SYSTEMS ANALYSIS
   - ANALYZE ETR DESIGN SPACE
   - PERFORM SENSITIVITY AND OPTIMIZATION ANALYSIS

WE PROPOSE TO DO AN ANALYSIS OF THE DESIGNS WHICH LIE BETWEEN NET AND TIBER AS A COMPLIMENTARY PART OF THE US ETR PROGRAM

* PAST EFFORTS HAVE DEMONSTRATED FEDC ABILITY TO SUBSTANTIALLY INFLUENCE LARGE TEAM EFFORTS.

  -CIT BASELINE DESIGN (MIT, PPPL, COPPI)
  -INTOR (USSR, JAPAN, EC)
  -TFCX (PPPL, MIT)

* INVOLVEMENT IN OVERALL SYSTEM DESIGN IN PARALLEL WITH LLNL WILL STIMULATE NEW IDEAS AND MOTIVATE KEY STAFF MEMBERS.

* FEDC WILL SUPPORT THE LLNL DESIGN IN THE AREAS PREVIOUSLY AGREED UPON.

DESIGN PHILOSOPHY FOR FEDC ETR

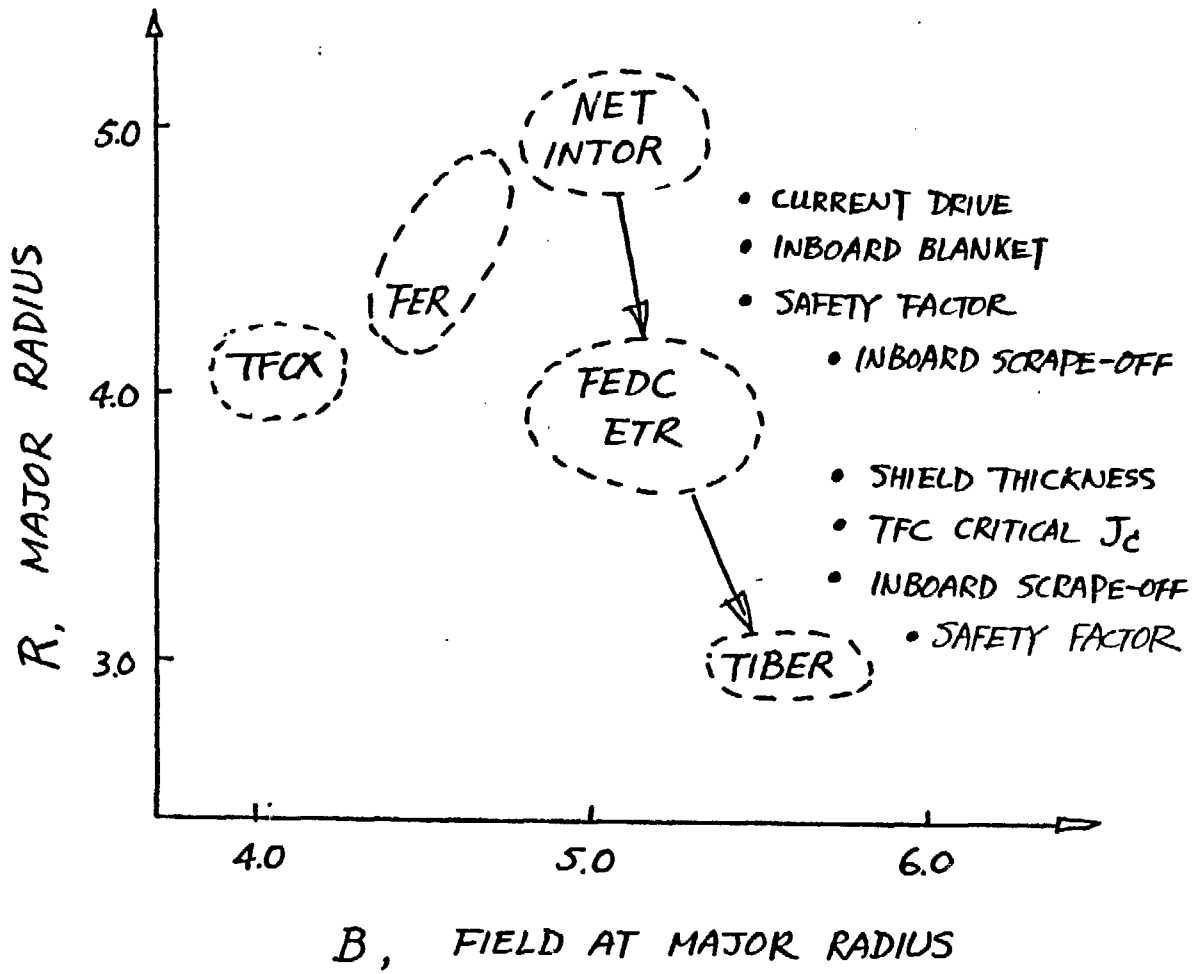
1. USE PHYSICS AND ENGINEERING SPECIFICATIONS WHICH ARE COMPATIBLE WITH THE ANTICIPATED DATA BASE IN 1992.

2. BUILD ON CIT EXPERIENCE

   -DOUBLE NULL/SINGLE COLLECTOR DIVERTOR
   -HIGH ELONGATION
   -ICRH - FOLDED WAVE GUIDE
   -OPTIMIZATION OF PARAMETERS

PRELIMINARY WORK INDICATES THAT THIS MACHINE WILL LIE BETWEEN TIBER AND NET AS SHOWN IN THE FOLLOWING FIGURE.

ETR DESIGN SPACE IN R AND B



WE BELIEVE THAT THE FEDC SHOULD PLAY A STRONGER ROLE IN THE ETR CONCEPTUAL DESIGN

* AS A MAJOR LEADER/PARTICIPANT IN VIRTUALLY ALL NEXT-STEP DESIGN STUDIES FOR THE PAST 10 YEARS, THE FEDC IS THE MOST EXPERIENCED ADVANCED FUSION DESIGN ORGANIZATION IN THE WORLD.

* ORNL, MAJOR INDUSTRIAL ORGANIZATIONS, MANY OUTSTANDING INDIVIDUALS AND THE FUSION PROGRAM IN GENERAL HAVE MADE A LARGE INVESTMENT IN BUILDING THE PRESENT CAPABILITY.

* THE ON-SITE TEAM HAS ALL FUNCTIONAL AND SYSTEM CAPABILITIES TO VERY QUICKLY DEVELOP INTEGRATED DESIGN CONCEPTS.

* THE CIT PROGRAM PROVIDES A BROAD BASE OF ONGOING EXPERIENCE.

* WE PROPOSE EXPANDING OUR PRESENT TIBER DESIGN RESPONSIBILITY TO INCLUDE AN OVERALL DESIGN STUDY.

* A CLOSE RELATIONSHIP WITH ORNL PROVIDES THE NECESSARY LINK BETWEEN ENGINEERING DESIGN, PHYSICS AND TECHNOLOGY.

PROPOSED
ORNL DEVELOPMENT AND TECHNOLOGY
ENGINEERING TEST REACTOR ROLES

Lee A. Berry
Associate Division Director
for Development and Technology
Fusion Energy Division

January 27, 1987
Lawrence Livermore National Laboratory

OBSERVATIONS:

- ORNL D&T Program is comprehensive and has about 50% of national effort
- CIT and then ETR are likely to become focus of D&T programs
- D&T; experiment; theory are well integrated – e.g., pellets and rf
- ORNL program is broadly connected into international–national programs

ORNL IS BROADLY INVOLVED IN FUSION TECHNOLOGY

- RF Heating
- Pellet Fueling
- Magnet Development
- Environmental Assessment
- Radiation Transport
- Design Studies
- Alloy Development
- Plasma Materials Interaction

ORNL PARTICIPATES IN MANY MAJOR INTERNATIONAL COLLABORATIONS

Fusion Area \ Country	E.C.	Japan	USSR	France	FRG	Spain	Switzerland
Tokamaks	JET			Tore Supra	ASDEX		
Stellarators		Heliotron E	U-3,2M L-2M		W-VII A	TJ II	
Superconducting Magnets	LCT	LCT					LCT
Pellet Fueling	JET			Tore Supra			
RF Heating	JET	Heliotron E		Tore Supra	TEXTOR ASDEX		
Plasma/Material Interaction		Heliotron E		Tore Supra	TEXTOR ASDEX		
Materials Development	"Oak Ridge Matrix"	HFIR/ORR					
Theory	JET	Nagoya U. Kyoto U.	U-3		Garching	JEN	
Design Studies	INTOR	FER INTOR	INTOR				

TORE SUPRA CHARACTERISTICS

$R = 2.25$ M

$a = 0.7 - 0.8$ M

$B = 4.5$ T

$I_p = 1.7 - 2.5$ MA

τ_{PULSE} 30 s → CONTINUOUS (LIMITED ONLY BY VOLT SECONDS)

P_{BEAM} 6-7 MW TO PLASMA AT 100 kV

P_{ICH} 6 MW TO PLASMA AT 35 - 80 MHz OR 120 MHz

P_{LH} 8 MW AT 3.7 GHz

TARGET DATE FOR OPERATION OF EARLY 1988

TORE SUPRA COLLABORATION OBJECTIVES

Study plasma characteristics in a long pulse (30 s) device approaching steady state conditions

1. Utilize pellet fueling combined with edge pumping to produce quasi-steady state, well confined, auxiliary heated discharges for long pulses

2. Test the use of an ergodic limiter to connect the high T_e, low n edge apparently required for good confinement to the low T_e, high n surface plasma required to reduce limiter erosion

3. Investigate long pulse high power ICRF heating of a high temperature plasma utilizing compact antenna

TORE SUPRA TASKS AND PARTICIPANTS

- Pump limiter program (task coordination) including physics analysis and diagnostics – ORNL
- Pump limiter development and construction – SNL
- Ergodic limiter analysis – GA
- Pellet injector development and construction – ORNL
- ICRF launcher development and construction – ORNL

STEADY-STATE ATF OBJECTIVES

- Maintenance of a high beta plasma for times long compared to resistive diffusion time scales

  - Profile evolution and control
  - Current relaxation and control

- Impurity and particle control at high edge power levels for times long compared to that for wall temperatures and plasma-materials interactions to come into equilibrium

  - Inhibition of impurity accumulation
  - Minimization of wall erosion

- Steady-state technology development

  - Pellet fueling
  - Pump limiters and divertors
  - ICRF heating at high wall power density
  - Neutral beam heating
  - High heat flux materials

THE JET PELLET FUELING COLLABORATION

- Is a multi-year program to investigate physics of pellet fueling in long pulse, high density reactor grade plasma.

- Will coincide with and contribute to JET program to reach Q = 1 conditions.

- Features ORNL state-of-the-art repeating pneumatic injectors (3) operating with multiple 2.7 mm, 4 mm, and 6 mm hydrogen and deuterium pellets.

- Has 20% of JET machine time devoted to program over two full operational periods.

PROPOSED ETR TASKS INCLUDE:

- Contributing to reference
- Developing and evaluating options
- Identifying issues, planning R&D
- Conducting critical R&D

SPECIFIC TASK AREAS INCLUDE:

1. Fueling
2. Heating/Current Drive
3. Plasma Facing Materials
4. Special Purpose and Structural Materials
5. Environmental Assessment
6. Remote Maintenance
7. Magnets

PELLET PENETRATION NEEDS ARE UNCERTAIN

Kaufman	~1 km/s –	sufficient scrapeoff penetration,
TIBER	~50 km/s –	r/a ~.3-.5 desirable, but development for even 5-10 km/s is difficult.

Thus, fueling experiments and critical analysis on TFTR, JET, and Tore Supra are essential for determining future needs.

PELLET EXPERIMENTS HAVE BEEN AND WILL CONTINUE TO BE AN EXCITING AND VITAL PART OF THE FUSION PROGRAM

ORMAK – First pellet experiments

ISX-B – First fueling

Alcator C – Improved OH confinement

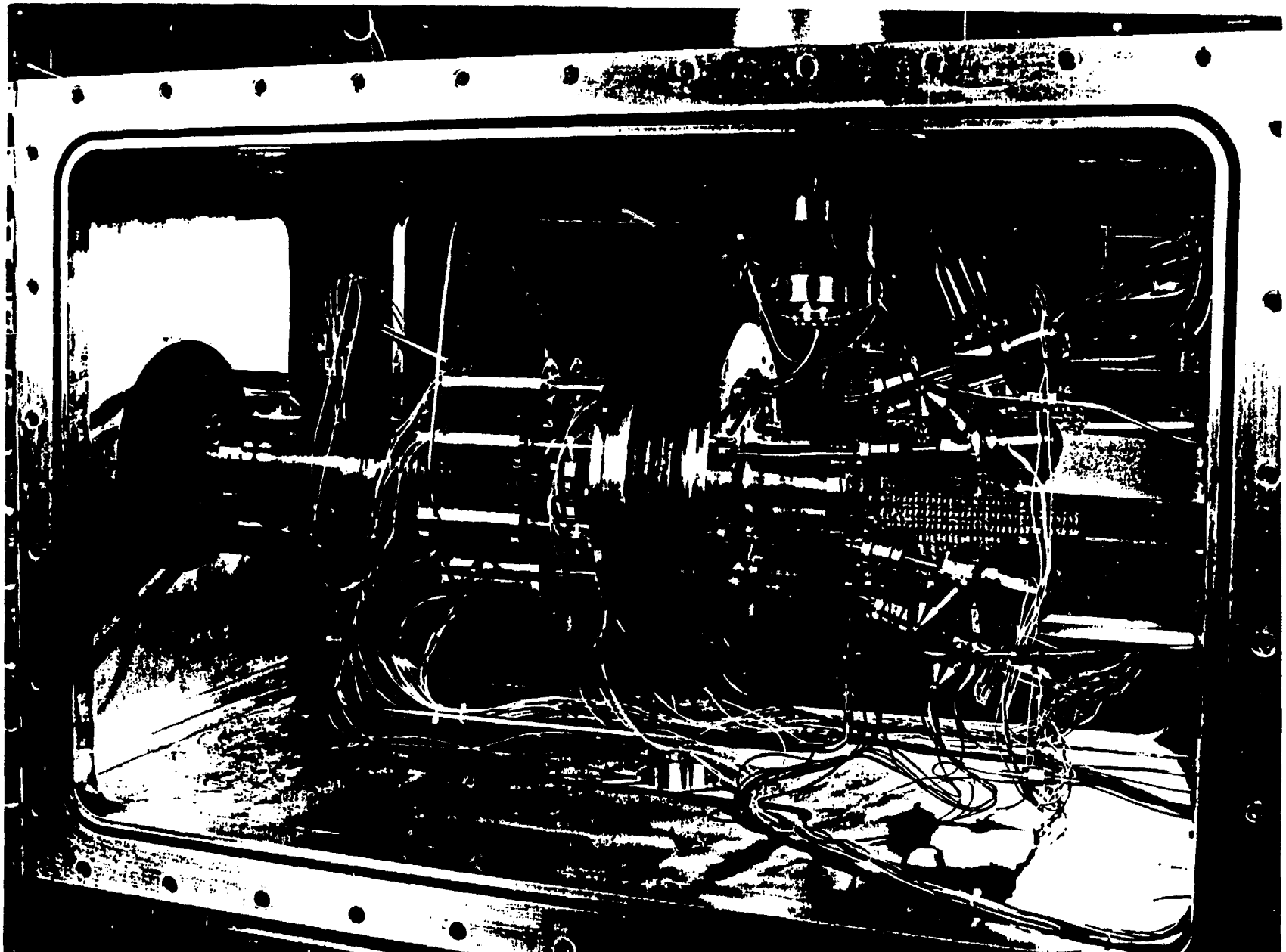
D-III – Improved confinement with beams

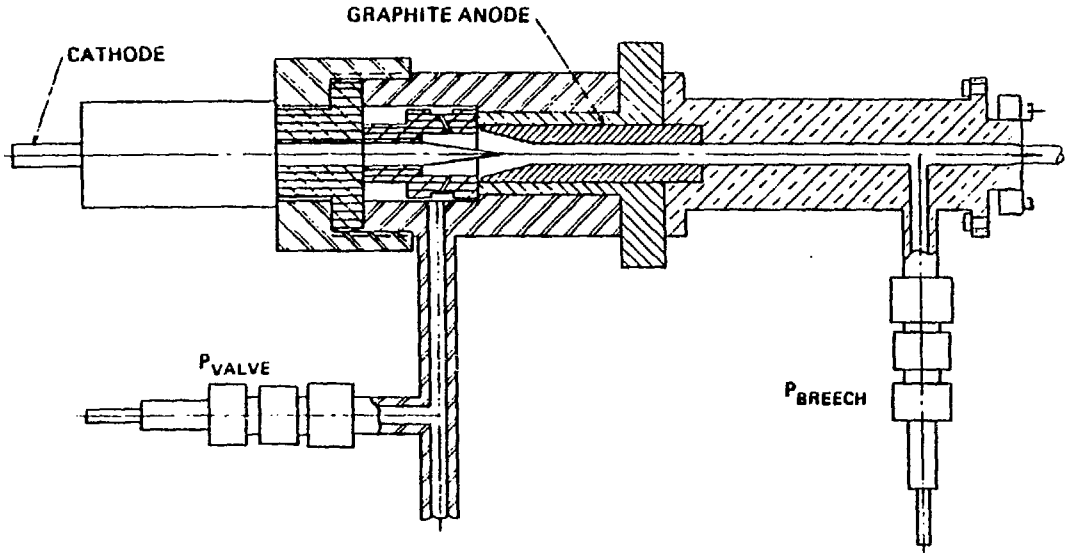
TFTR – Profile self consistency, achieved reactor densities

TFTR – Confinement optimization, tritium

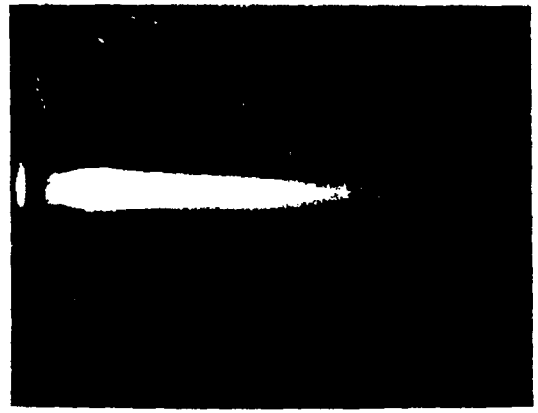
JET – Plasma size and RF-NB comparison

Tore Supra – Quasi-steady state fueling and exhaust

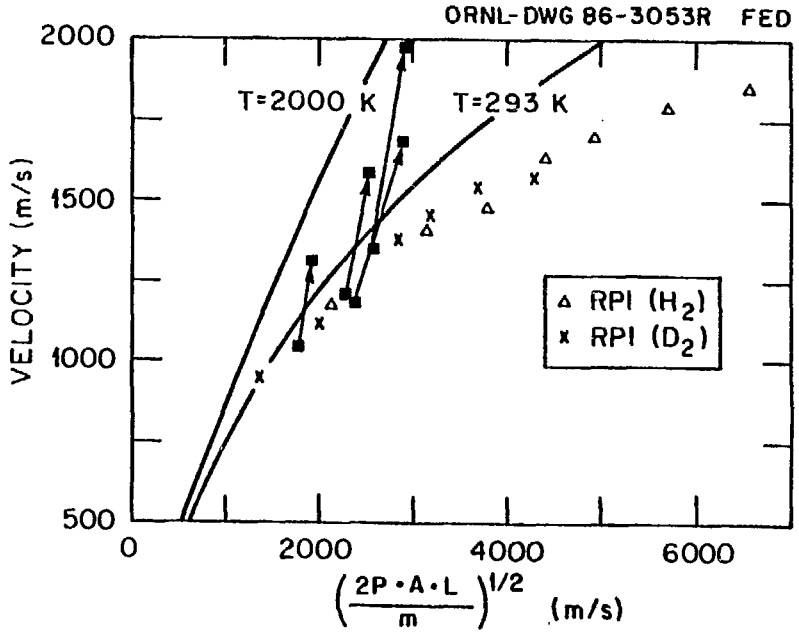




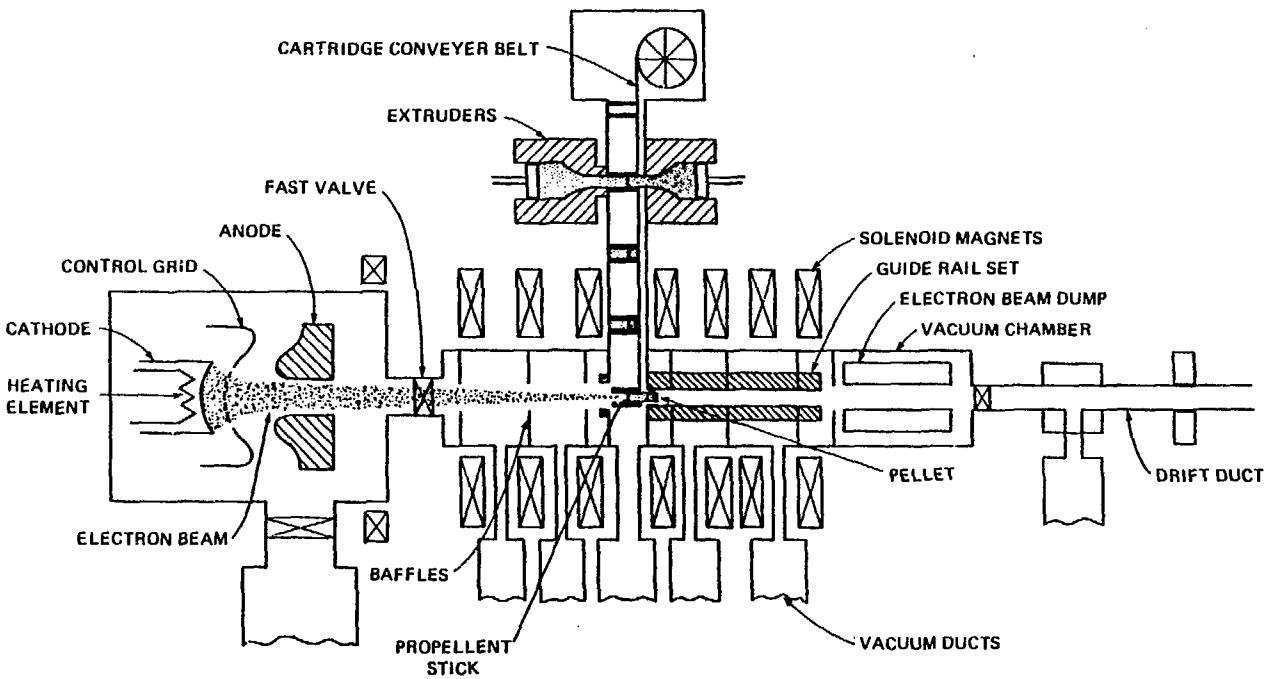
PLASMA GENERATOR



PLASMA JET


ORNL-DWG 86-3053R FED
2000
1500
1000
500
VELOCITY (m/s)
T=2000 K
T=293 K
RPI (H2)
RPI (D2)
0
2000
4000
6000
(2P • A • L / m)^1/2 (m/s)

ORNL-DWG 86-2660 FED



LASER PLASMA JET PROPOSAL (LOGAN) UNDER EVALUATION

- High aspect ratio disk targets are preferred to pellets.
- Both laser and acceleration efficiencies should be in the range of 10-20%.
- Mechanical layout needs to be developed – neutron and gamma heating of feed material may be a problem.

PROPOSED FUELING TASKS

- Assess results of JET, TFTR, Tore Supra fueling programs and incorporate into physics models

- Expand development program to proceed on

  - tritium pellet injection,
  - 3-4 km/s arc boosted pneumatic system, and
  - ~10 km/s E-beam rocket system

  on a timely basis

- Continue advanced concepts evaluations

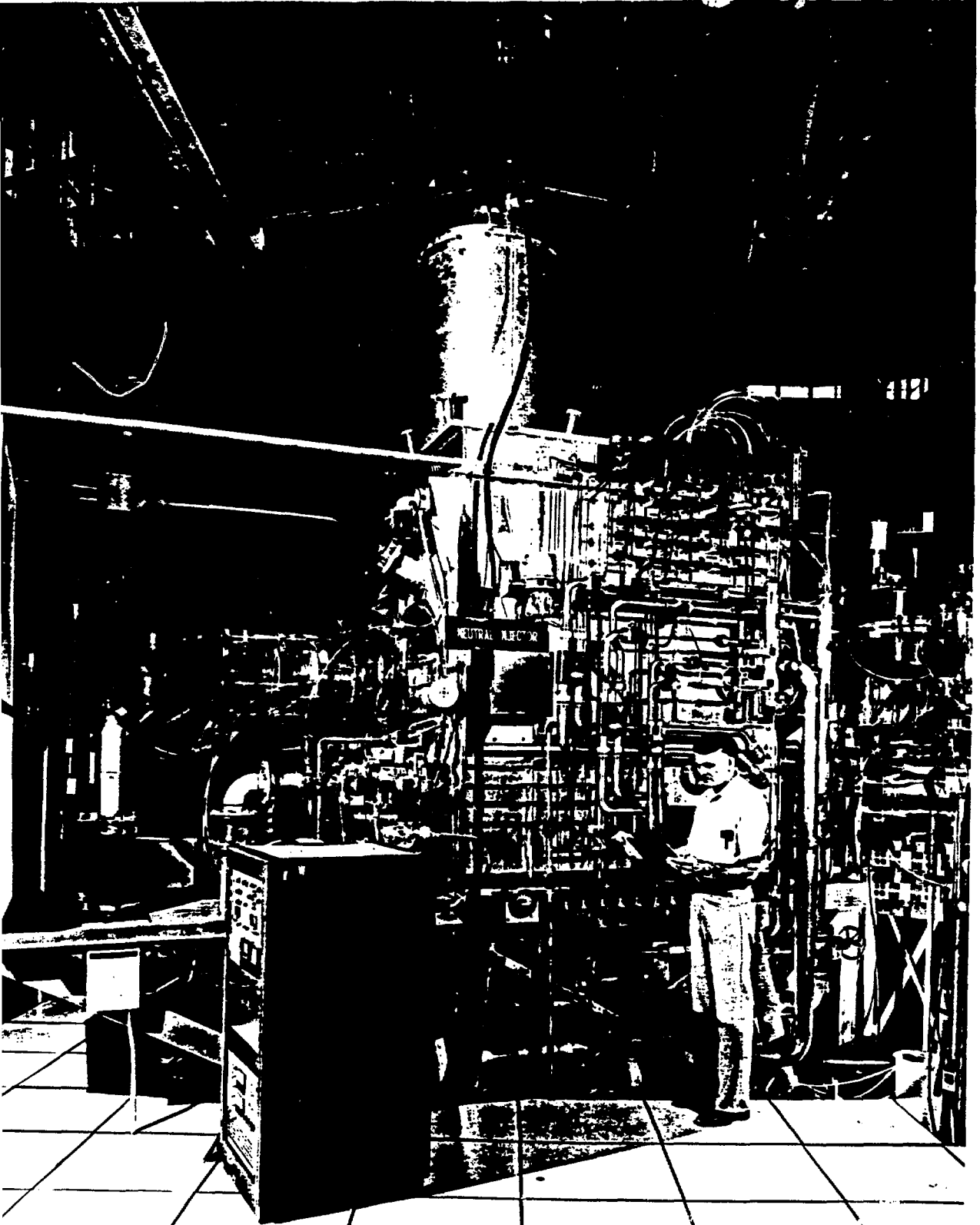
OPTIMIZING THE HEATING/CURRENT DRIVE SELECTIONS AND DEVELOPING AN R&D STRATEGY IS A CRITICAL TASK.

- Amount of inductive current drive pushes overall machine size
- Data base for non-inductive current drive is weak
- Physics/technology/cost trade-offs are complex

A BROAD ROLE IN HEATING/CURRENT DRIVE IS PROPOSED

- Evaluate long-pulse heating physics and technology (JET, Tore Supra, JT-60, ATF)
- Provide input to design and/or design key subsystems
- Identify issues, plan and carry out R&D

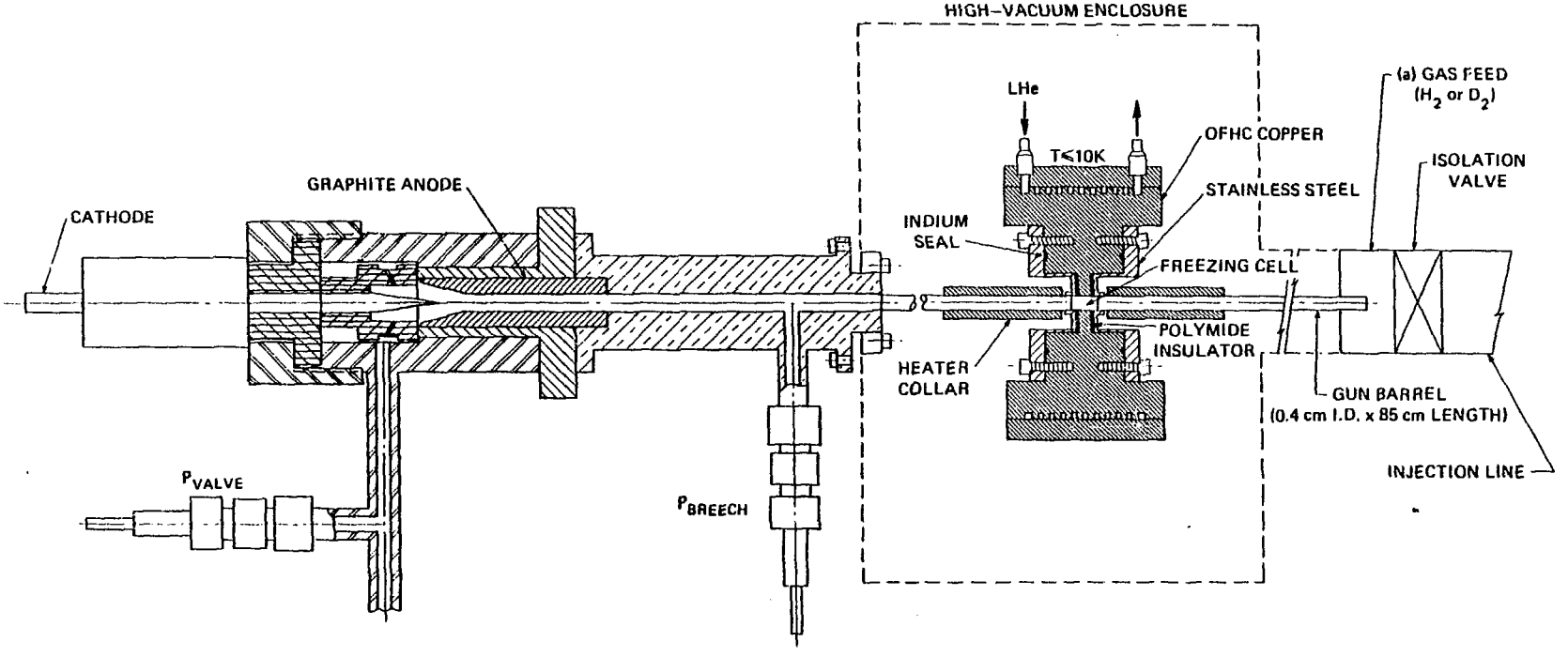
Efforts within FEDC, theory, and technology groups will be integrated.

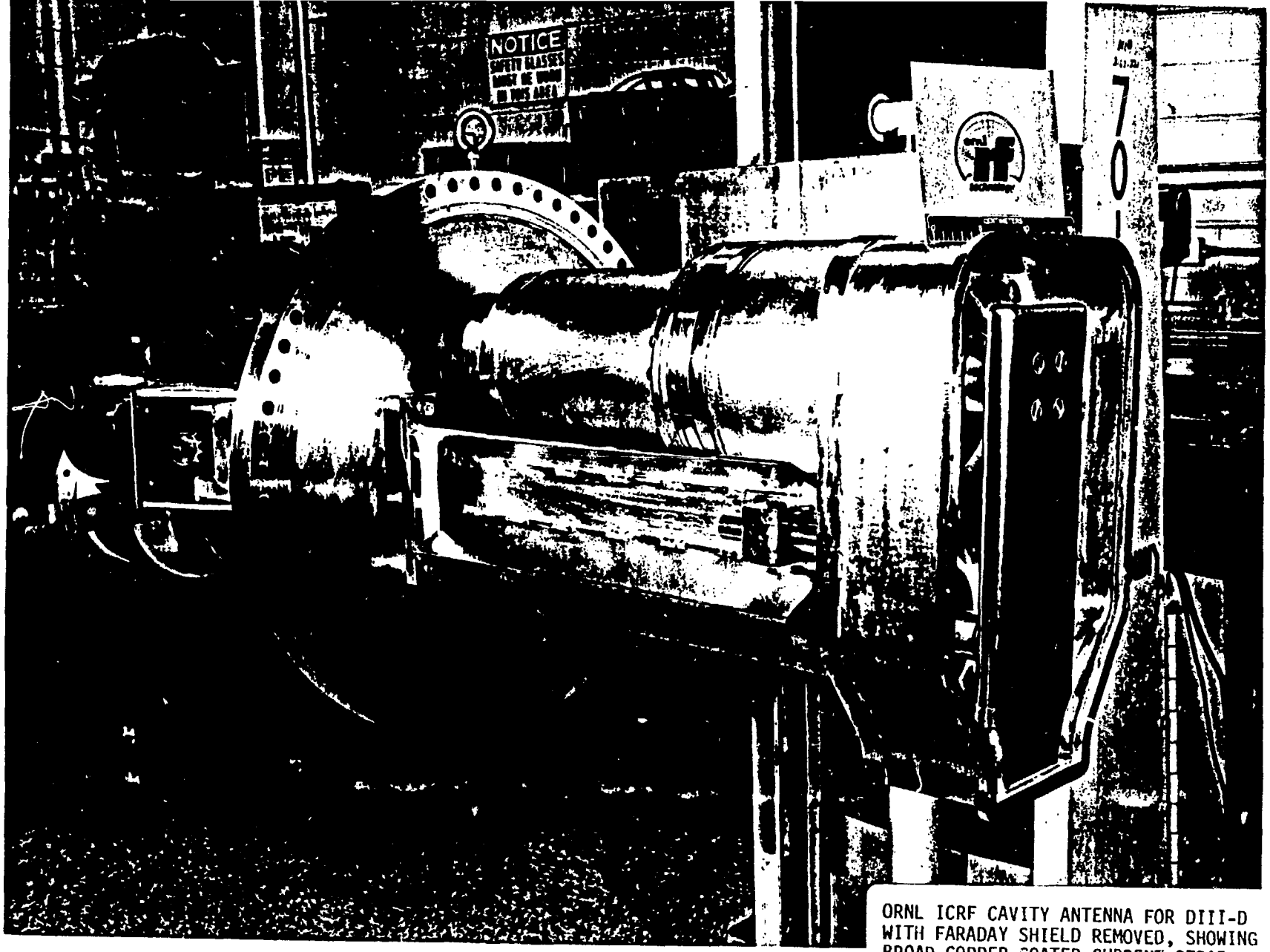


ISX-B NEUTRAL BEAM

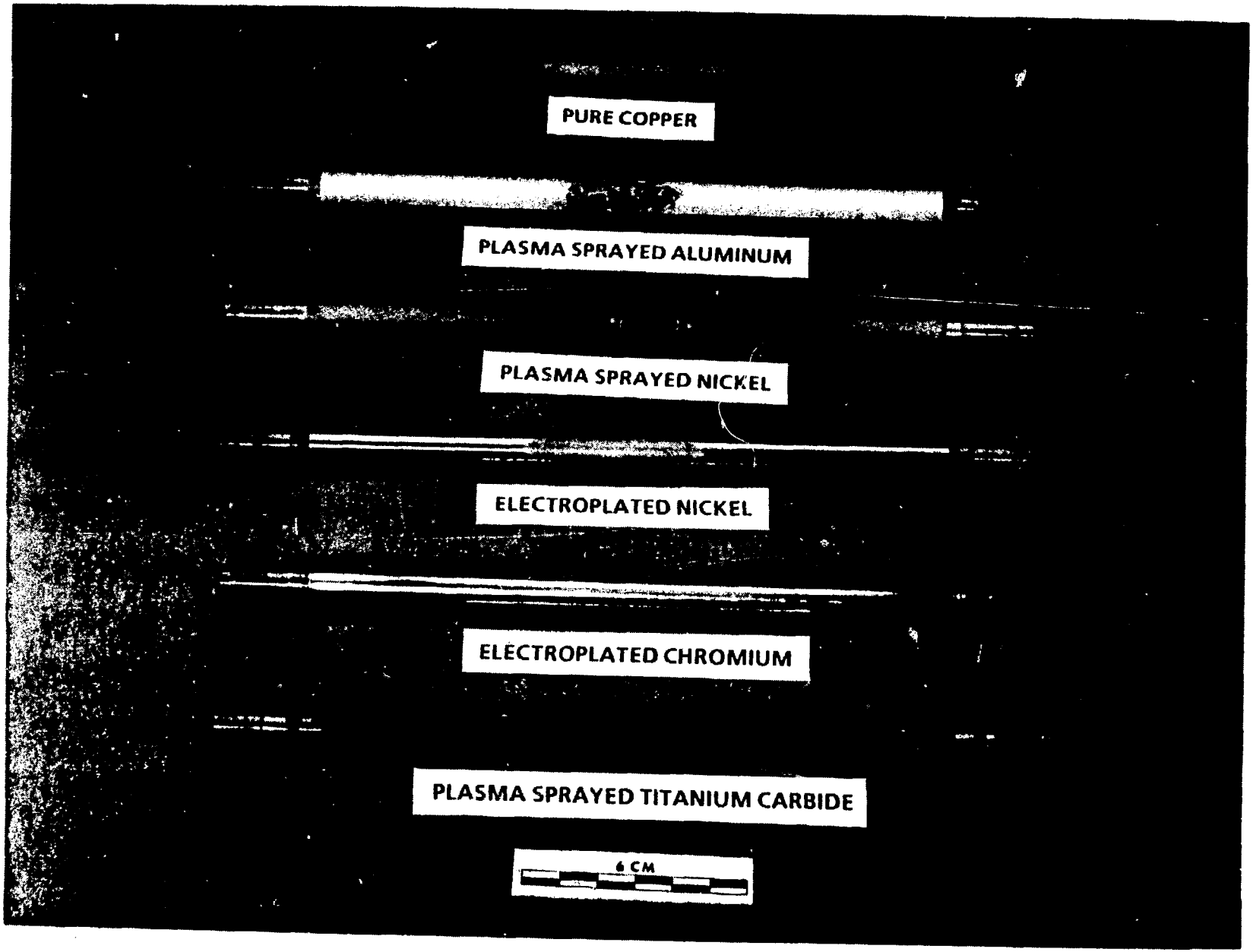
ornl

ORNL-DWG 86-2501 FED



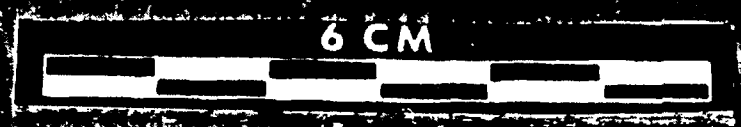


ORNL ICRF CAVITY ANTENNA FOR DIII-D WITH FARADAY SHIELD REMOVED, SHOWING BROAD COPPER-COATED CURRENT STRAP

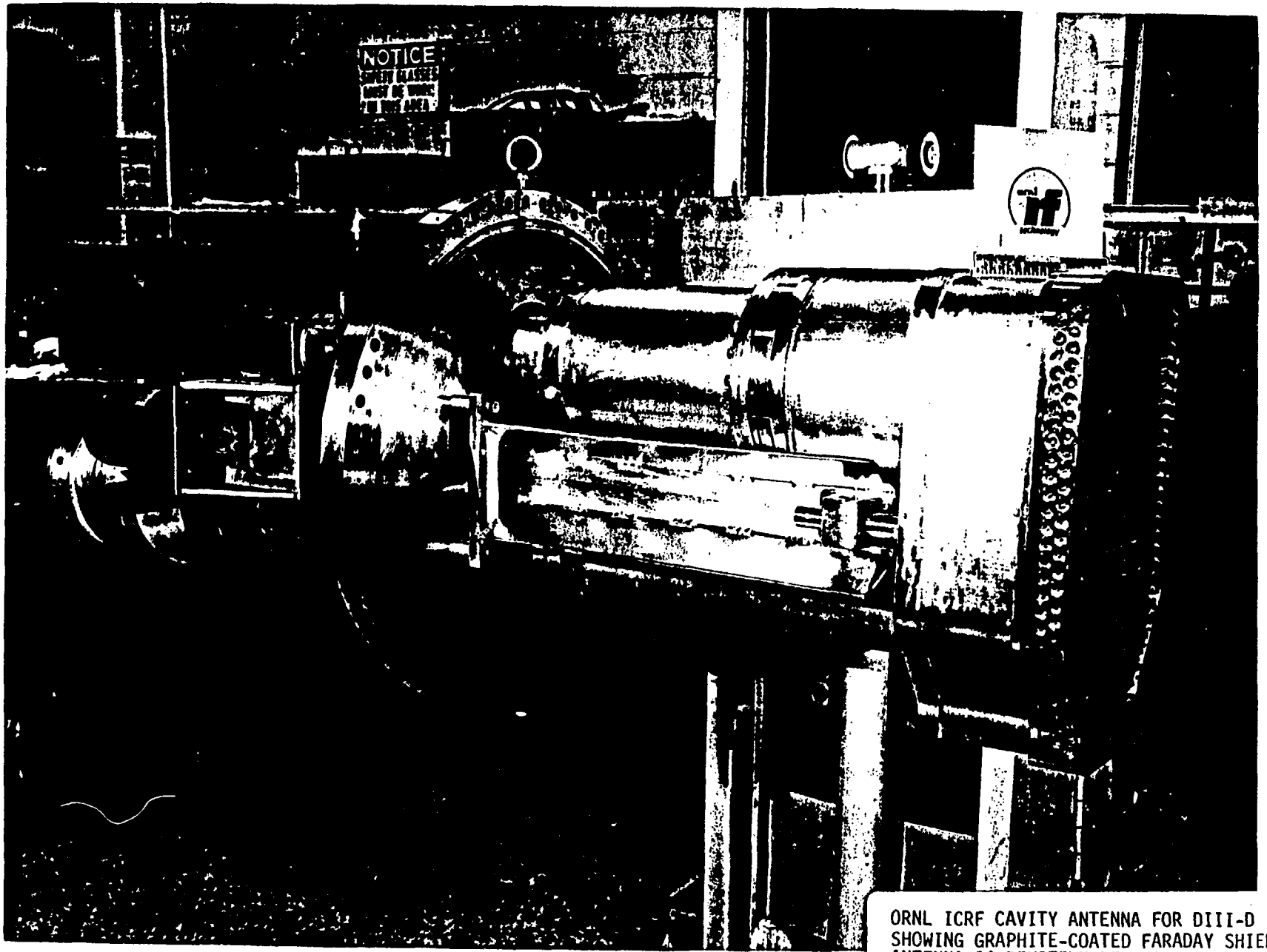

PURE COPPER
PLASMA SPRAYED ALUMINUM
PLASMA SPRAYED NICKEL
ELECTROPLATED NICKEL
ELECTROPLATED CHROMIUM
PLASMA SPRAYED TITANIUM CARBIDE
6 CM

BRAZED GRAPHITE IS MATERIAL OF CHOICE

GRAPHITE BRAZED TO COPPER TUBE

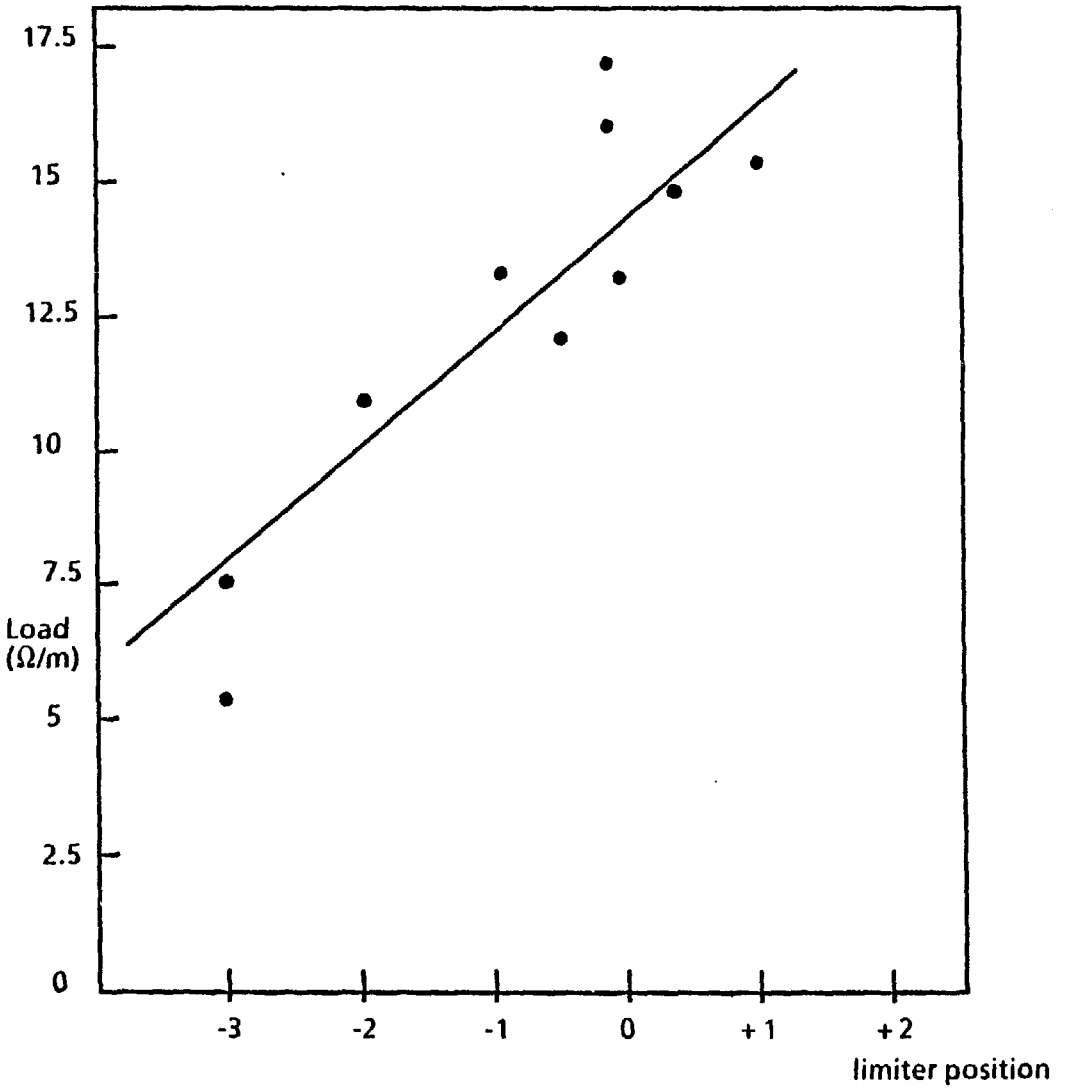


(2,000 SHOT 1-25; 4 kW/cm^2 peak)



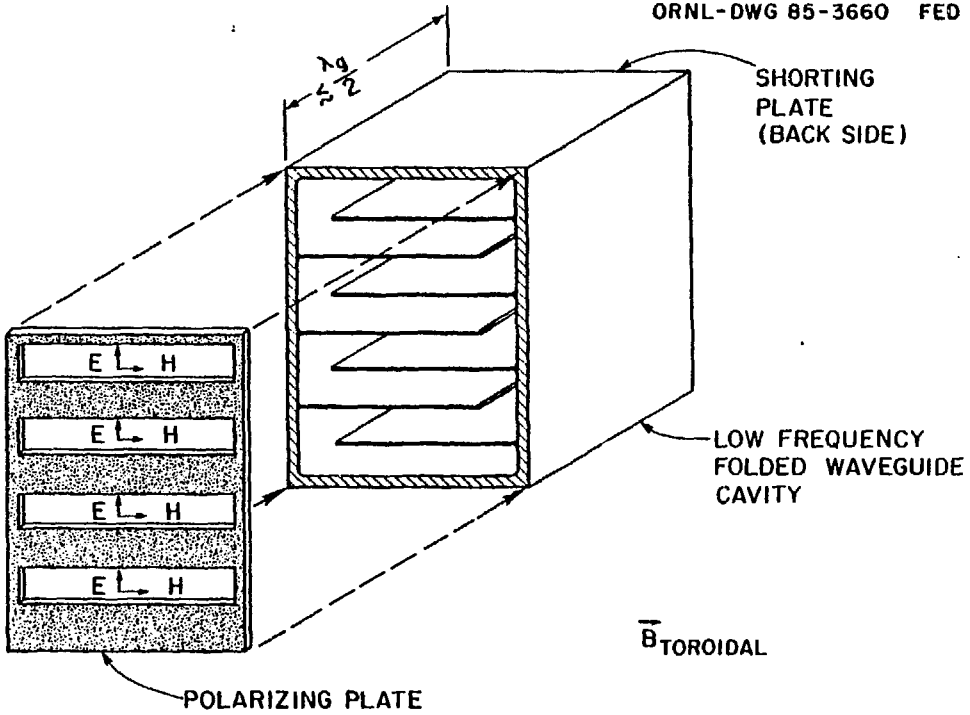
ORNL ICRF CAVITY ANTENNA FOR DIII-D SHOWING GRAPHITE-COATED FARADAY SHIELD. ANTENNA IS REMOTELY REMOVABLE ±5 cm SLIDING ON RAILS SHOWN ON THE SIDE.

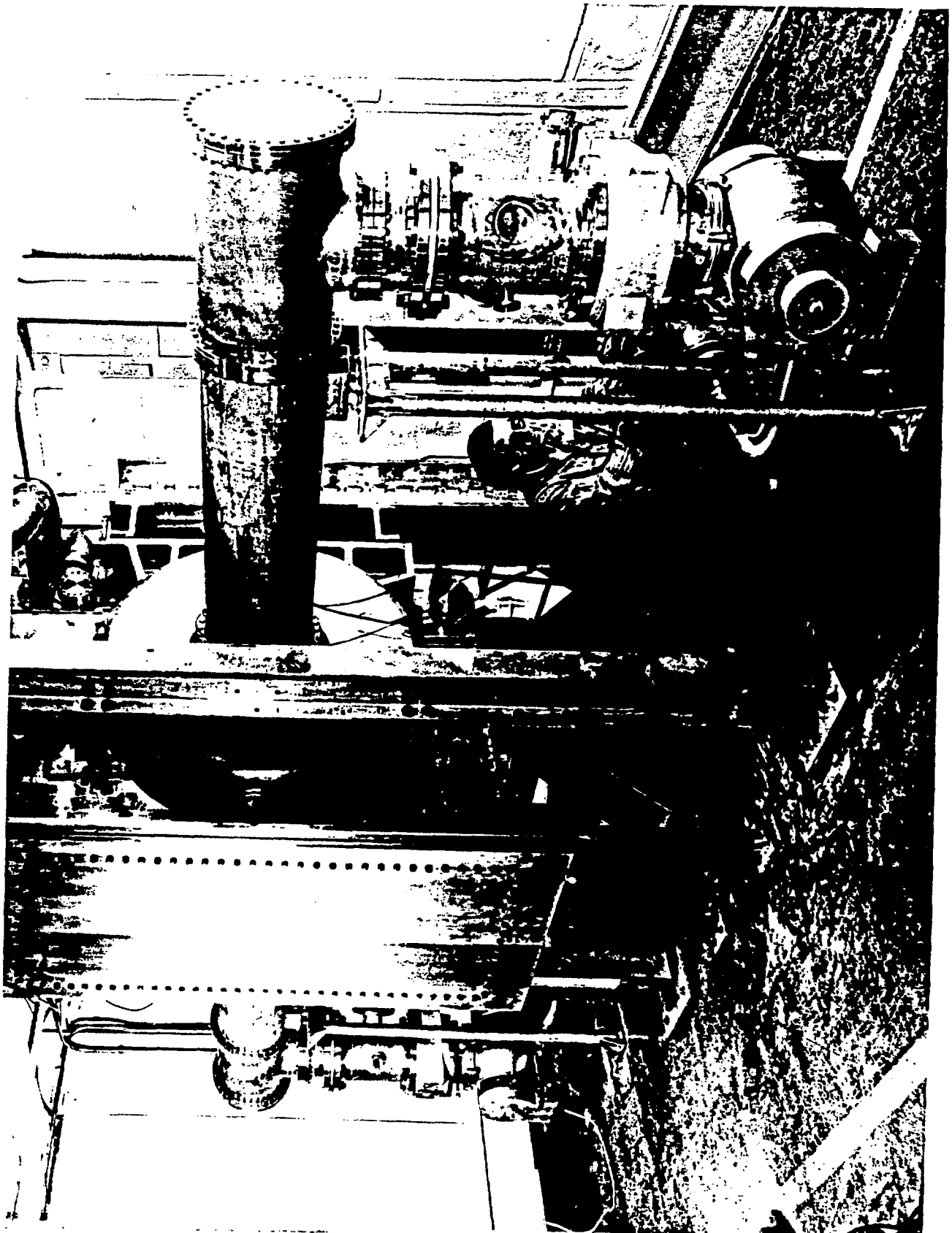
MEASURED LOADING ON DIII-D IS SIGNIFICANTLY GREATER THAN 5 Ω/m



Loading vs Antenna Position on DIII-D at 55 MHz

ORNL-DWG 85-3660 FED





PROPOSED HEATING/CURRENT DRIVE TASKS

Neutral Beams

- Develop concept for ~2 MeV neutral beam system based on SDI technology
- Evaluate physics, technology, and cost trade-offs

Lower Hybrid

- Continue and expand collaboration with Tore Supra
- Initiate component development in support of confinement systems as needed

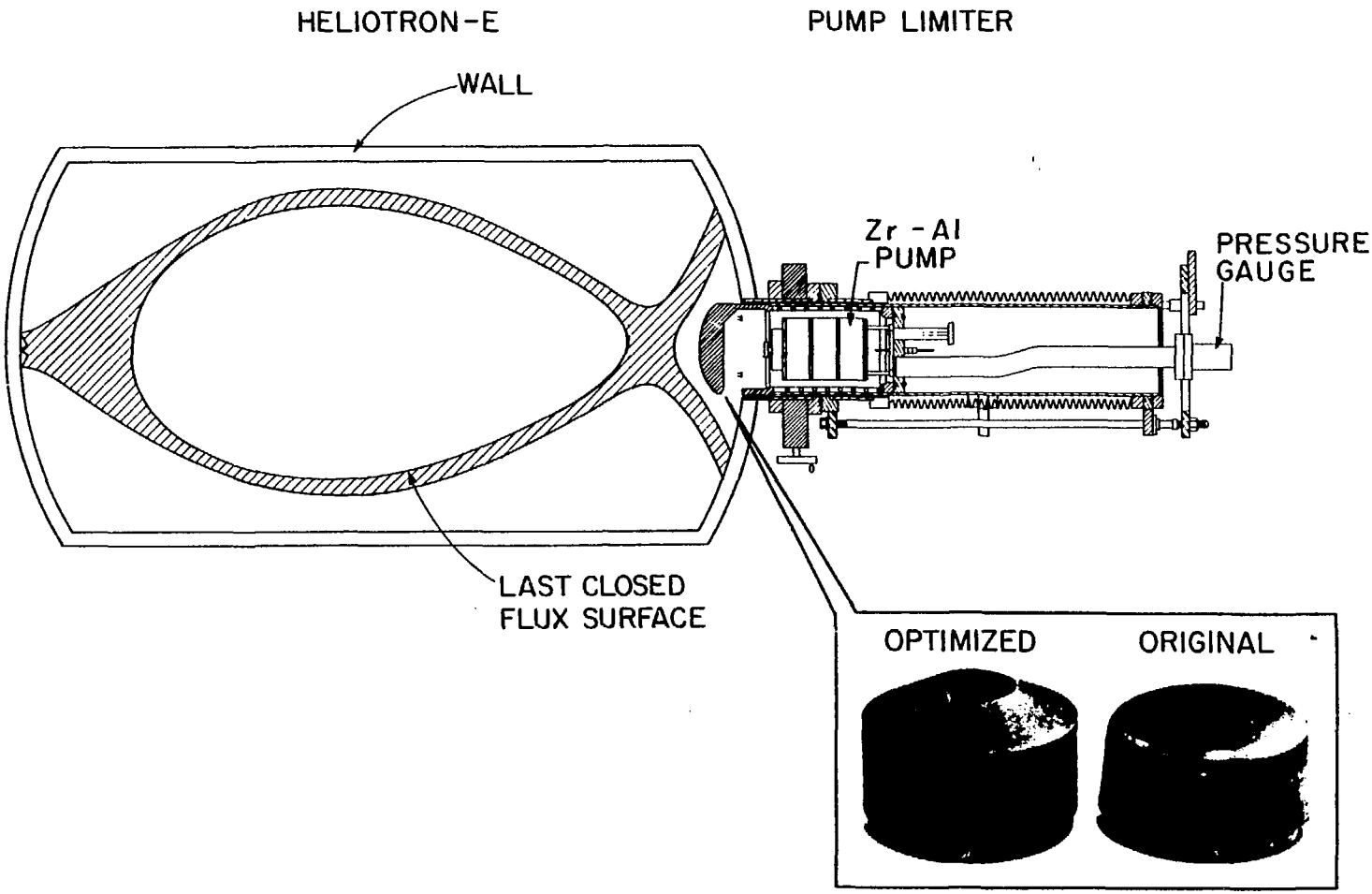
ICH

- Develop ICH option (still has best data base)
- While not the front runner, explore ICH current drive (combinations with NBI may be more attractive)

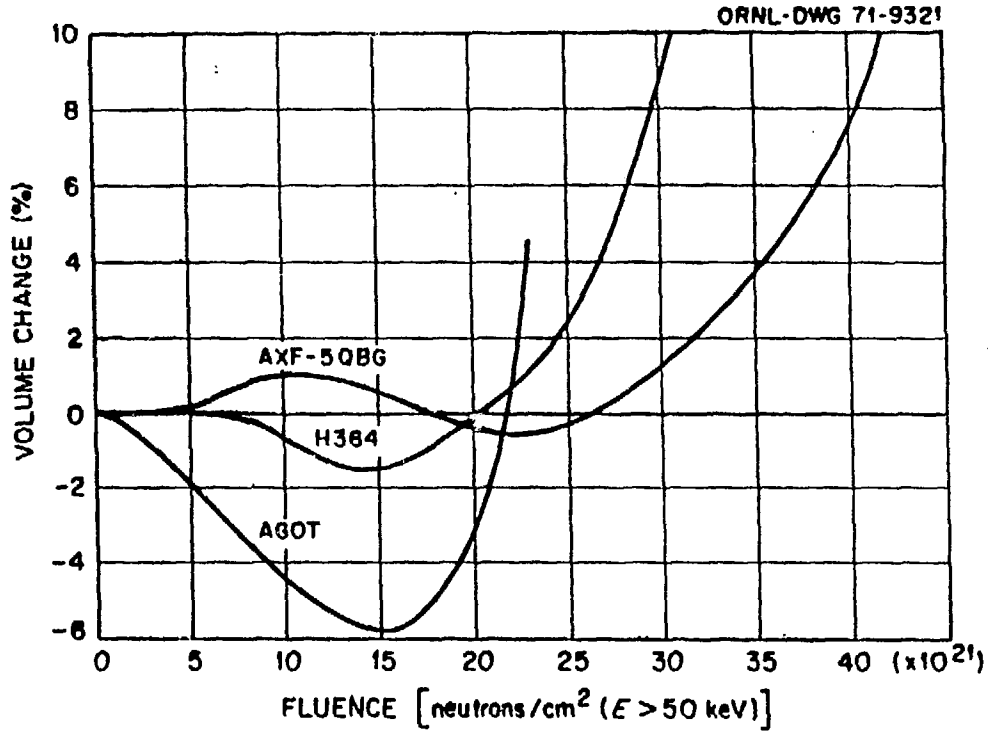
COMBINED MATERIALS, ENGINEERING, AND PLASMA PHYSICS CONSTRAINTS MAKE DESIGN OF THE HEAT AND PARTICLE HANDLING COMPONENTS VERY DEMANDING

- High steady state and peak heat fluxes
- Physics requirements for H-mode and plasma exhaust
- Meager understanding
- Need for reliability and reasonable life time

ORNL-DWG 86-2140A FED



Radiation Damage will Limit Graphite to ~1 MWY/m2



A Comparison of Several Grades of Graphite Irradiated at 715°C.

PROPOSED PMI TASKS

- Incorporate Tore Supra, TEXTOR, and ATF results into plasma exhaust models
- Provide first wall materials data and assessments
- Plan and carry out key R&D

Even at 3 MWY/m^2, materials response to neutrons will be significant; and materials input to design is important and development likely needed.

- Materials choices will require compromises.
- Special purpose materials may be a sleeper.
- The possibility of a low activation structure deserves consideration, but will require significant development.

FERRITIC STEELS

- Have good resistance to thermal stress; and low activation development is well underway;

but

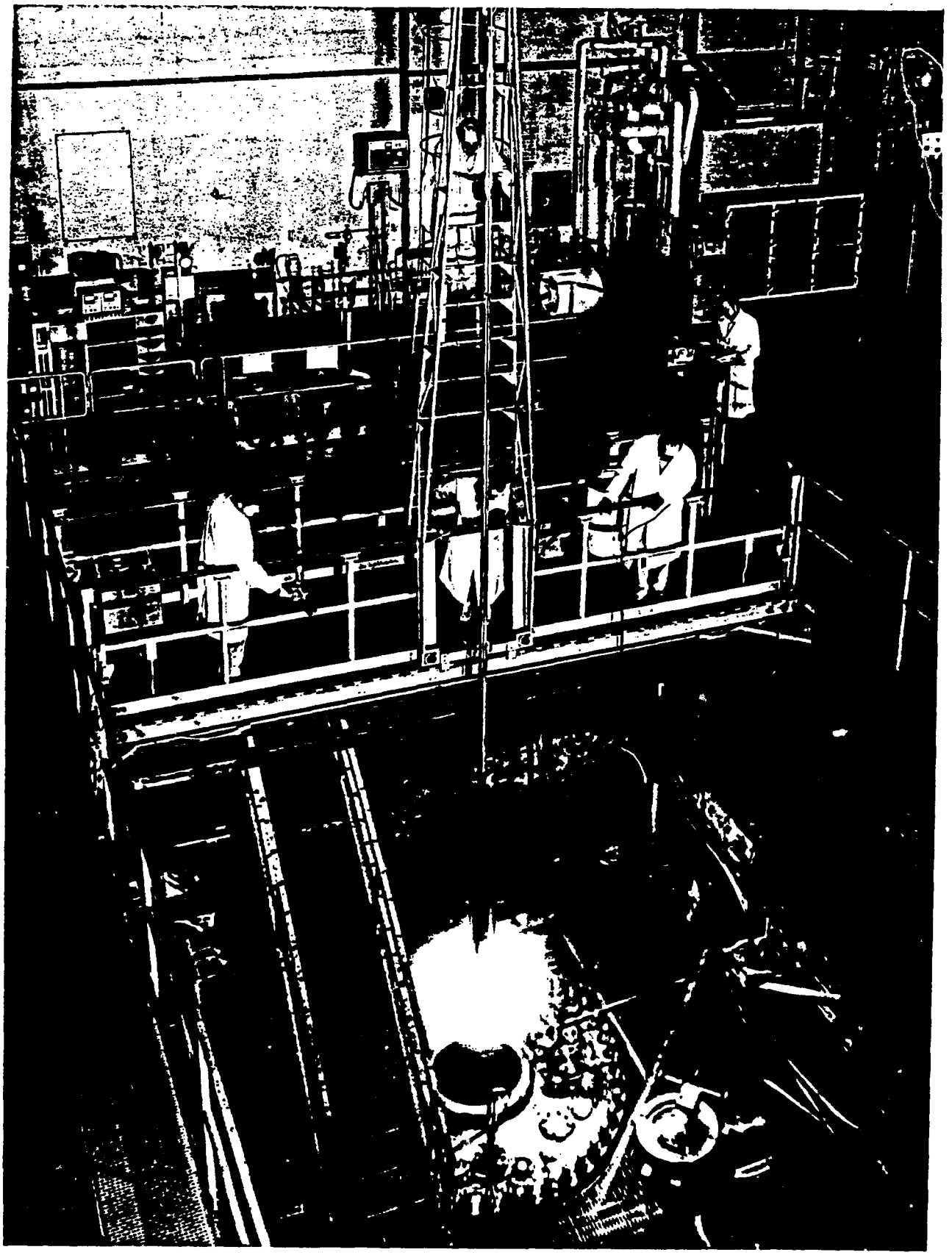
- DBT shift may be a problem for low temperatures; and post weld heat treatment will be difficult for large, complicated structures.

AUSTENITIC STEELS

- Have the best data base – close to sufficient for detailed design and a well established fabrication technology,

but

- Have low resistance to thermal stress, and low activation formulations are further away.



PROPOSED MATERIALS TASKS

- Provide data for both special purpose and structural materials
- Identify, plan R&D
- Initiate tasks, including irradiations where needed

DOE/ER-0170

BACKGROUND INFORMATION AND TECHNICAL BASIS FOR ASSESSMENT OF ENVIRONMENTAL IMPLICATIONS OF MAGNETIC FUSION ENERGY

August 1983

Prepared by:
J.B. Cannon
Oak Ridge National Laboratory
Under Contract No: OR ENG 26

Prepared for:
U.S. Department of Energy
Office of Energy Research
Office of Fusion Energy
Division of Development and Technology
Washington, D.C. 20545

PROPOSED ENVIRONMENTAL ASSESSMENT TASK

- Prepare technical background document as design is fixed, perhaps early 1989

OVERALL MAINTENANCE STRATEGY AND DETAILED IMPLEMENTATION ARE VITAL ELEMENTS FOR A SUCCESSFUL ETR.

- Experience on ETR will be judged as indicative of the future.
- Desire to push physics and technology conflict with reliability.
- All subsystem designs must be permeated by maintenance considerations from the beginning.

PROPOSED REMOTE MAINTENANCE TASKS

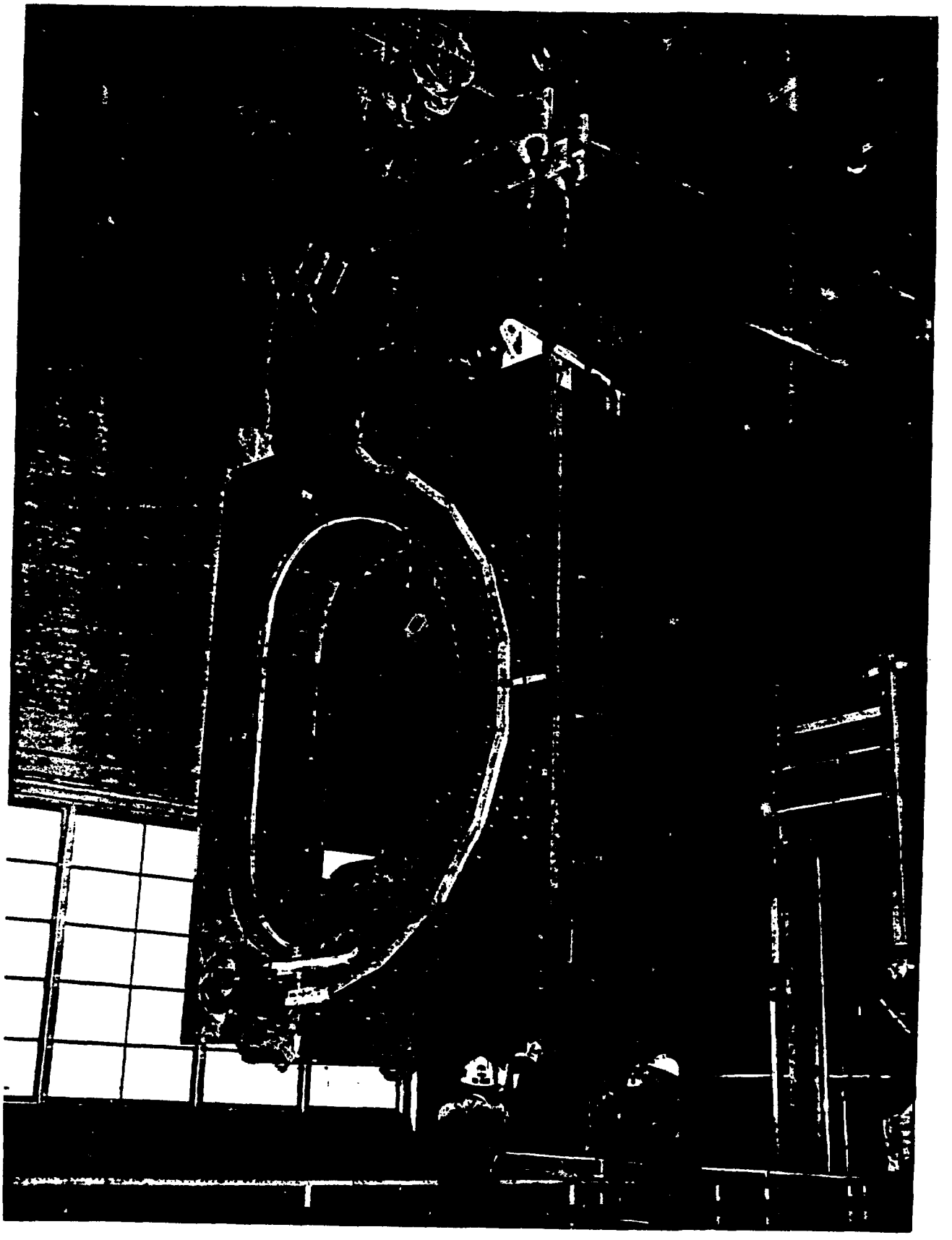
- Review, contribute to design effort
- Incorporate CIT experience into ETR
- Identify, plan R&D

ETR REQUIREMENTS ARE SUBSTANTIALLY MORE DEMANDING THAN LCP

- Higher performance is needed at lower cost.
- Thermal margin for stabilization is small at high current density and high field
- Nuclear heating levels of 10 to 50 mW/cm^3 over an appreciable volume of the winding pack create significant stability and cryogenic problems.
- Very high disruption energies (>200 mJ/cm^3) require a high degree of stability.
- Larger forces due to both higher fields and larger size require a reliable interface between winding pack and structure.

INTIMATE EXPERIENCE WITH A WIDE RANGE OF COIL AND CONDUCTOR CONCEPTS PROVIDES A UNIQUELY BROAD PERSPECTIVE

- Five coils use NbTi conductor, one uses Nb_3Sn.
- Three coils use pool-boiling cooling (4.2 K, 1 ATM) and three use supercritical helium (3.9 K, 15 ATM).
- Five coils are pancake wound, one is layer wound.
- Five coils use lumped austenitic stainless steel structure, one used distributed aluminum plates
- Some structures are bolted, some welded, some both.
- Two force flow coils are potted, one is wound into grooves.



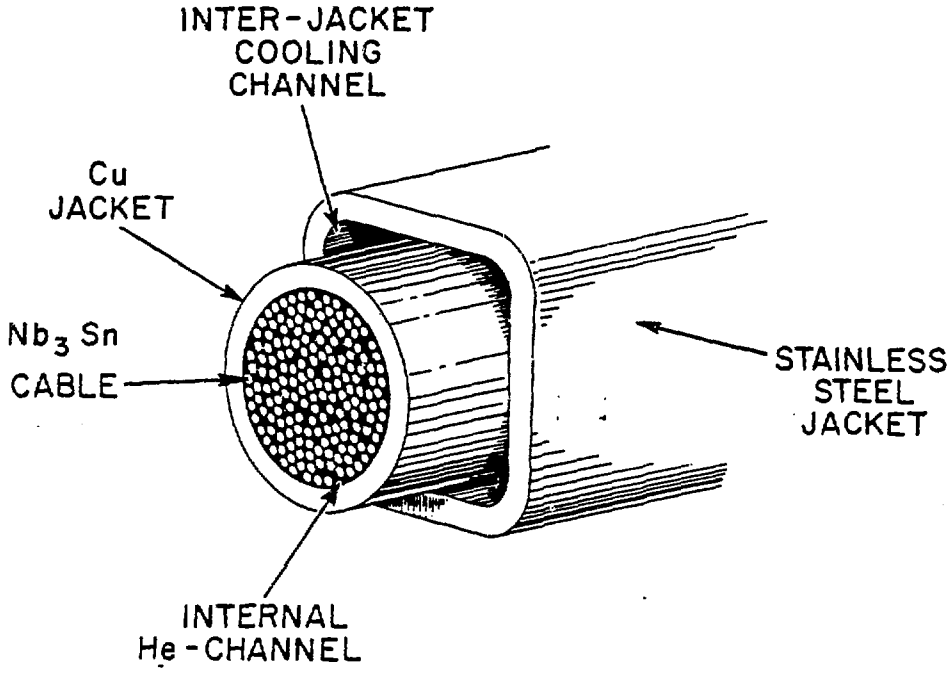
NEW, IMPROVED FORCE-FLOW DESIGNS HAVE BEEN CONCEIVED WHICH ARE APPROPRIATE FOR ETR REQUIREMENTS

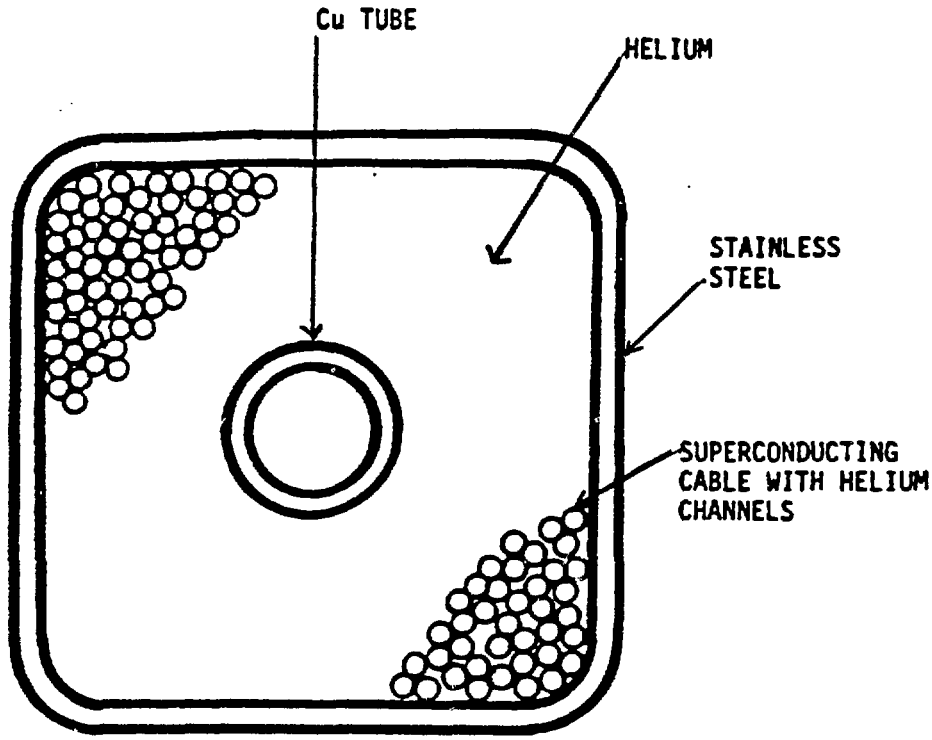
- Cable-and-tube-in-conduit conductor (combination of WH and CH designs)
- External-tube cable-in-conduit conductor

- Both conductor concepts provide ample copper for protection (to reduce quench pressure and ease the need for fast dump) and large hydraulic diameter (to reduce quench pressure and the need for many short hydraulic paths)

- Both concepts can be wound in pancakes and potted, providing triple containment of helium

ORNL-DWG 85-3390 FED




Cu TUBE
HELIUM
STAINLESS
STEEL
SUPERCONDUCTING
CABLE WITH HELIUM
CHANNELS

PROPOSED MAGNET TASKS

- Support reference concept
- Develop alternative magnet and conductor concepts
- Initiate conductor development and testing
- Plan for intermediate scale testing in early 1990s using production quantities of conductor on IFSMTF (LCTF)

IN SUMMARY:

- The tasks of ETR design and development are challenging and central to the advancement of fusion.

- ORNL has unique capabilities for contributing to this undertaking.

- A broad and substantial role for Oak Ridge
  - would be a key element in the ORNL program.
  - will lead to a stronger U.S. effort.
  - result in a more desirable ETR.