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REPORT ON THE JOINT MEETING OF THE DIVISION OF DEVELOPMENT AND TECHNOLOGY PLASMA/WALL INTERACTION AND HIGH HEAT FLUX MATERIALS AND COMPONENTS TASK GROUPS

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PREFACE

A joint meeting of the Plasma Materials Interaction (PMI) and High Heat Flux (HHF) Task Groups was held on May 21-22, 1985 at the Department of Energy (DOE) Germantown, Maryland. Four working groups were chartered in the following areas:

I. Off-line Facilities: The facilities for PMI and HHF Simulation were listed and critically assessed.

II. U.S. Data Base Requirements for an Ignition Machine: The critical PMI/HHF issues for a Burning Core Experiment (BCX) were prioritized, and materials options for BCX were ranked.

III. International Collaborations: Current and possible future PMI/HHF collaborations with Japan, EC, Canada, etc. were examined.

IV. High Power Density Requirements: PMI/HHF issues for high power density (HPD) systems were contrasted to mainline (i.e. tokamak) concepts.

In addition, a discussion of the Technical Planning Activity (TPA) for the Magnetic Fusion Program Plan (MFPP) was held with representatives of that group.

WORKING GROUP SUMMARIES

I. Off-Line Facilities

II. U. S. Data Base Requirements for an Ignition Machine

III. International Collaborations

IV. High Power Density Requirements

OFF-LINE FACILITIES

M. Abdou, Chairman

I. SUMMARY OF WORKING GROUP ON OFF-LINE FACILITIES

The working group was asked to consider the need for, and availability of, off-line facilities not presently in use by the PMI/HHFC effort. The specific questions suggested for discussion were:

1. Group existing off-line facilities by purpose: research, simulation, prototype development and testing, full-scale testing.

2. Considering all confinement schemes, which technical issues are addressed by the facilities in (1)? Where do gaps exist?

3. Are facilities which are not now used by the fusion program available to fill gaps?

4. If gaps exist, define requirements for new off-line facilities with time schedules. Make statements as to the importance of these needs that may aid prioritization in comparison with other elements of the fusion program. Might any of the facilities presented fill these needs?

5. What are potential opportunities in terms of international collaboration?

A summary of existing or proposed PMI/HHFC off-line test facilities is given in Table 1. These and other off-line facilities that have been used or proposed all perform research aimed at basic property measurement and explanation of phenomena. None appear to provide the combination of complete, reactor-relevant, environmental conditions and test volume needed

for integrated or prototype tests.

The technical issues for PMI/HHFC are listed in Table 2. These are condensed from the detailed descriptions provided as part of the recent Technical Assessment of the Critical Issues and Problem Areas in the Plasma Materials Interaction Field, and in High Heat Flux Materials and Component Development. The ability of the existing and proposed PMI/HHFC off-line test facilities to usefully address these technical issues is summarized in Table 3. Only the most significant applications of each facility are identified in this table. It is important to note that a highly useful facility for an issue does not necessarily resolve the issue.

It is clear that existing off-line facilities do not address or resolve all the technical issues for PMI/HHFC. Proposed off-line facilities could be useful in providing additional information. However, determining the need, requirements and priorities for new off-line test facilities requires assessing the issues and existing facilities (including confinement experiments) in more detail than was possible in this meeting.

TABLE 1. SUMMARY OF EXISTING AND PROPOSED PMI/HHFC OFF-LINE TEST FACILITIES

Name		Location	Status
TPX	Tritium Plasma Experiment	SNLL	Existing/funded for PMI/HHFC work
PISCES	Plasma-Surface Interaction Experiment	UCLA	Existing
CCT	Continuous Current Drive Tokamak	UCLA	Existing
PMTF	Plasma Materials Test Facility E-beam Multiple-beam	SNLA	Existing/funded
RFTF	RF Test Facility	ORNL	Existing
HHFF	High Heat Flux Facility	ORNL	Existing
HPFF	High Particle Flux Facility	ORNL	Existing
HEBF	Hot-Cell Electron Beam Facility	HEDL	Existing/funded
ICTF	Impurity Control Test Facility	ANL	Proposed

TABLE 2: TECHNICAL ISSUES FOR PMI/HHFC

1. Plasma Control
   a. Exhaust efficiency
   b. Heating and fueling
   c. Edge diagnostics
   d. Edge characterization and control

2. Surface Physics
   a. Erosion transport and redeposition
   b. Surface conditioning
   c. Hydrogen reflection and desorption
   d. Tritium permeation and inventory

3. Structural and Material Behavior
   a. Fabrication
   b. Bond or attachment mechanical integrity
   c. Heat transfer across structure
   d. Thermal stresses and fatigue/cracking
   e. Neutron fluence effects
   f. Neutron flux effects on thermal and electrical insulation

4. Active Cooling of Large Areas
   a. Heat transfer limits (including non-water coolants)
   b. Multiple channel flow behavior and stability

5. Disruption and Transient EM Effects
   a. Eddy current forces and response
   b. Melt layer formation and behavior

6. System Integration
   a. Replacement and maintenance
   b. Tritium breeding ratio effects

ISSUE / FACILITY:	TPX	PISCES	CCT	PMTF EB	PMTF MB	RFTF	HHFF	HPFF	ICTF	HEBS
1. Plasma Control										
a. Exhaust eff.		M				M			M	
b. Heating/fueling										
c. Diagnostics		M				M			M	
d. Edge char.control										
2. Surface Physics										
a. Erosion/redep.		H	H			H		M	H	
b. Surface cond.			H							
c. H reflection/desorption	H									
d. H^3 permeation/inv.	H									
3. Structural/Material										
a. Fabrication										
b. Bond mech. integrity				H	H	H	H		H	H
c. Heat transfer				H	H	H	H		H	H
d. Thermal stress/fatigue				H	H	M	H		M	H
e. Fluence effects										(H)
f. Flux effects										
4. Active Cooling										
a. Heat transf. limits				H	H	M	M			
b. Flow stability				M	M					
5. Disruption and EM										
a. Eddy current forces										
b. Melt layer behavior				M						
6. System Integration										
a. Replacement/maint.										
b. Tritium breeding										

H: Highly useful M: Moderately useful

U.S. DATA BASE REQUIREMENTS FOR AN IGNITION MACHINE

K. Wilson, Chairman

II. U. S. DATA BASE REQUIREMENTS FOR AN IGNITION MACHINE

1. INTRODUCTION

PMI/HHF database requirements for the various ignition devices currently under consideration are quite similar. Present designs incorporate limiter surfaces which form the entire inboard first wall area. The limiter surface is constructed of passively cooled graphite tiles attached directly to the vacuum vessel. RF launchers, which may be used to heat the plasma to ignition, will also be subjected to the plasma environment.

As shown in Table 1, peak limiter heat fluxes during normal operation vary from about 5 to 15 MW/m^2 for heating durations of 1 to 5 seconds. Disruption heating conditions, listed in Table 2, are expected to result in energy densities of 3.8 MJ/m^2 during the 1 ms thermal quench followed by an energy deposition of 3.2 MJ/m^2 during the 10 ms current quench.

Key PMI/HHF database needs for these devices include: (1) thermal shock damage characteristics of graphite at the expected disruption heating conditions; (2) tritium retention characteristics of graphite; and (3) graphite temperature limits based on impurity control considerations.

2. PMI/HHF ISSUES

Of the nearly one dozen PMI and HHF issues, three are critical to the successful operation of any ignition device. These are: particle control, impurity control, and high heat flux. The failure to solve either of the first two would result in machine performance below ignition parameters.

DISRUPTION HEATING CONDITIONS

Disruption Phase	Duration ms	Energy Density MJ/m^2
Thermal Quench	1	3.8
Current Quench	10	3.2

PEAK HEAT FLUXES

Device	P_α (MW)	Peak Heat Flux (MW/m^2) Limiter	Peak Heat Flux (MW/m^2) First Wall
ISP	61	6.7	.6
LITE	84	8.6	.7
IGNITOR	55	14.	1.1

The failure of components to handle high heat fluxes, predominantly associated with off-normal operation, e.g., disruptions, could result in the cessation of all machine operations.

The other PMI and HHF issues are: erosion/deposition, wall materials/conditioning, T inventory/recycling, heat removal, activation/remote handling, and bulk and structural properties/auxiliary heating components. Parts of each are related to the three critical issues. For example, wall conditioning is essential to both impurity and particle control. However, the broader requirements of wall conditioning and the other issues causes them to merit recognition as separate entities.

The requirements for each of the above listed topics have been discussed for many years. Sufficiently detailed models of each process exist such that minimum requirements could be well defined. This would involve an interdisciplinary collaboration between plasma modellers, surface scientists, and rf and structural engineers.

2.1 Impurity and Particle Control

All of the proposed ignition devices have large area carbon structures as complete carbon walls. Since none of the devices has a divertor, the impurity control is largely determined by proper wall conditioning on the one hand, and on the plasma scenario on the other hand. The basic wall conditioning consists of discharge cleansing to remove layers of other impurities like adsorbed gases. The database on discharge cleaning of large vessels which consist completely of carbon is not adequate at this time, but in the near future. TEXTOR and JET will gain experience with carbonized walls and graphite limiters. Low-Z material and proper wall conditioning might be sufficient impurity control for short pulse devices

(1-5s). If there are still too many impurities in the plasma, controlling the plasma edge is a possibility to control impurity production. Present scenarios considered are the radiative plasma edge achieved by controlled puffing of radiating gases (neon) as foreseen in JET, as the ergodic divertor to maintain high edge densities and low edge temperatures to reduce sputtering and provide high shielding in the edge, like planned for TORE-SUPRA.

The use of graphite for large area limiters as even the entire first wall, has also some consequences for particle handling. Graphite limiters on the one hand or carbonized walls on the other hand can store large amounts of hydrogen. This creates problems in density control and might be a problem for RF minority heating scenarios. It has been observed that the recycling of hydrogen from carbon limiters can exceed unity, requiring some particle exhaust to control density. Furthermore, pellet injection and possibly neutral beam injection will require some particle removal, so that pump limiters taking high heat loads will be required for the ignition devices.

2.2 Off Normal Operation

Off-normal operation results in a very high heat flux which causes high stresses in materials. The high heat fluxes also produce a large amount of erosion due to melting and/or evaporation. The heat fluxes, stresses, and erosion due to off-normal operation dominate the requirements for material mechanical and thermal properties. These requirements are very stringent and are strong drivers in any design. Off-normal operation is being extensively studied on present machines. TFTR, JET, and JT-60 will provide very useful data to reduce the uncertainty of the requirements. Limits are being defined that can be used for design even

requirements. Limits are being defined that can be used for design even though the mechanisms responsible are not well understood. The compact ignition machines differ in size, power density, and current density from present machines. Hence, there is some concern about using the existing database, but this is not likely to be serious.

2.3 Heat Removal

The issue of heat removal (i.e., passive versus active) in compact ignition machines is dependent on several design and machine operation parameters. These parameters include the total heat flux load, pulse width, tile thickness, tile material, gap conductance, temperature-dependent thermophysical tile properties, and the required period between thermal cycles. Based on the work completed at the Fusion Engineering Design Center, passive cooling is adequate for graphite tile with thicknesses greater than 1.0 cm and subjected to heat flux loads less than 15 MW/m^2 with pulse widths less than 5s. Radiative cooling resulted in the cooldown time being approximately 1200s. However, active cooling will be necessary whenever reactor design or operation require addition restrictions, e.g., thinner tiles, higher heat fluxes, longer pulse widths or shorter cooldown times. In this case, the critical heat flux will be an issue. An additional parametric study, including all the above parameters, is recommended to better define the transition between which active and passive heat removal is required.

3. MATERIALS OPTIONS

3.1 Graphite

Graphite is the leading candidate material for BCX. Its refractory

nature and the lack of a liquid phase makes it an almost ideal material from the point of view of disruption survivability. Low cost, fabricability, and low atomic number are also positive attributes. The loss of thermal conductivity with neutron irradiation damage is not an issue in current BCX designs because of the low pulse length and duty cycle. Conditioning techniques for graphite need to be developed. With typical specific surface areas of $\approx 1\ m^2/g$ for typical nuclear grade graphites, internal porosity can be a major source of oxygen due to water uptake during air exposure.

Chemical erosion has long been known as a major disadvantage, especially in the temperature range of $\approx$ 800K. More recent experiments have demonstrated that above $\approx$ 1200K, graphite is subject to a radiation damage enhanced sublimation process. Erosion yields of unity are observed at 2000K for light ion bombardment. More data are needed on the high temperature erosion of graphite at the particle fluxes expected for BCX.

Hydrogen trapping properties in the near surface region are well documented, but the effects of porosity on low temperature retention has only recently come under investigation. The high temperature lattice diffusivity of hydrogen isotopes in graphite is poorly understood.

The bulk properties database of graphite that relate to heat transfer are adequate. However, more work must be done on the ultimate strength at elevated temperatures, and on thermal shock resistance at power levels expected for BCX disruptions.

3.2 Beryllium

Beryllium is the lowest atomic number material available for plasma interactive components. It has excellent thermal properties, and does not

exhibit elevated erosion characteristics like graphite at elevated temperature. Its main drawbacks are the melt layer formation during disruption and safety considerations (at least during fabrication and initial assembly). Beryllium is not currently under consideration for BCX applications because of the inertially cooled designs. However, a shift to an active heat removal scheme would make beryllium a viable candidate. Data needs for beryllium include more detailed information on disruption response and hydrogen retention release characteristics.

3.3 Novel Approaches

A number of approaches have been taken recently to supplement presently available impurity control techniques. They are: wall carbonization (TEXTOR); in-situ cooling (TiC on Mo in JT-60).....

In addition, new materials are being developed to overcome shortcomings of current technology: carbon composites and graphite doping (e.g., Si-C, GA), Li-alloys (surface segregation, ANL - PISCES), etc. In all of these newer areas, the existing database is very modest and certainly insufficient to make a critical determination of performance versus current state-of-the-art. For example, no data are available on mechanical or thermal conductivity properties of Li-Cu alloys.

4. INTERNATIONAL COLLABORATION

There are several areas where the U. S. program is or will be lacking in research and could therefore benefit from international collaboration if the costs are not higher than if we had performed the task ourselves. These areas include the development and testing of a large area toroidal pumped limiter for TEXTOR (in association with Jülich and Japan),

development of an impurity control system such as ergodic limiters for TORE SUPRA. Furthermore, if there will be no further divertor program in the U.S. we could certainly benefit from participating in the impurity studies performed with the divertor on ASDEX-UG.

In addition to gaps in the U.S. program that can possibly be filled by participation in foreign programs, there are certainly a number of areas where foreign programs complement/supplement the U.S. program. These areas include development and further characterization of first wall candidate materials (Garching and Japan) and coatings (Japan), development and testing of ICRF launchers (JET, JT-60) and lower hybrid couplers (TORE SUPRA, FT, JT-60).

INTERNATIONAL COLLABORATION

W. GAUSTER, CHAIRMAN

III. INTERNATIONAL COLLABORATIONS

1. FOREIGN PROGRAMS

There are several aspects in which the focus of foreign programs differ from our own, and these directly affect PMI/HHF issues.Europe has several long-pulse, high power density machines with emphasis on impurity control issues that are part of approved programs. These include ASDEX-Upgrade and TORE SUPRA, which complement each other in that the first is a divertor machine and the second will rely on limiter operation. Both are scheduled for first plasma in 1987. JET itself also has a program of long-pulse operation and an integrated approach to limiter design and material issues. We can benefit from these programs because they allow tests of PMI/HHF issues in large machines in a time frame that will allow the U.S. program to prepare for programs such as ATF. Finally, TEXTOR is still the only large machine dedicated fully to PMI and related technology issues.

Japan has PMI and HHF programs of broad scope that can usefully complement our own. In some cases, such as ceramics, the Japanese program is more extensive, and collaboration can expand the effective scope of our own activities. Another important feature is the successful integration of industry into the Japanese program. Perhaps related to this is the Japanese lead in process control for coatings and in-situ repair technology.

Additional potential nations include Canada in the area of tritium, although here both we and some European laboratories clearly lead in the research on tritium interaction with materials.

2. PRESENT ACTIVITIES

Many activities are already in place. These include conferences, visits, exchanges, joint studies (INTOR, FINESSE), the U. S. Japan Cooperation Agreement with its program of exchanges, and collaboration on TEXTOR, ASDEX-UG, JET, TORE SUPRA, etc.

New initiatives that are being pursued and should be expanded include the following:

JET	limiter materials
	novel limiter designs
	tritium permeation and inventory
	fueling, exhaust
JT-60	wall materials
	divertor and limiter operation
ASDEX-UG	poloidal divertor experiment with emphasis on plasma edge properties (energy removal, impurity control, helium pumping)
TORE SUPRA	integration of fueling and impurity control elements; steady state heat removal
MATERIALS	coordinated program for U.S., E.C. and Japan

3. INTERNATIONAL STRATEGY FOR CERAMICS

The PMI/HHF "International Strategy" document should be updated to cite specifically the need for work in the area of ceramics. This includes both bulk materials and coatings.

Programs on ceramics for fusion applications are in place in the European Community, Japan, and the U.S. work in Europe includes an ongoing activity at AERE Harwell, and a joint effort involving Germany, France, and

Belgium. Activity in Japan is for the most part sponsored by Monbusho; JAERI may add a ceramics component when their program is reviewed in approximately 1-1/2 years. There is some potential for industrial participation through Monbusho scientists.

The U.S. ceramics program presently includes a collaborative effort on neutron damage with the Japanese. This is based on the bilateral RTNS-II agreement, and involves Monbusho. A more informal collaborative arrangement exists with the Harwell project, and the intent is to work with the program on the European continent once its direction is better established.

The magnitude of the U.S. effort in ceramics is presently quite small, (a 1-manyear/year effort at Los Alamos), and should be enlarged to allow our side to participate meaningfully in the area of PMI/HHF. The new initiative by OFE to begin a small program at ORNL is a start, but that project will be dedicated to a study of transmutation gas effects in ceramics and will not be in a position to direct much effort to other activities.

Some Ceramics/PMI/HHF Interrelationships

- Ceramics for RF Systems
  - windows } transmissivity
  - radomes } transmissivity
  - antenna standoffs

  ] bulk ceramic applications where surface changes are important

- Ceramic Properties before N Damage
  - coatings
    - strength (affected by surface changes)
    - thermal conductivity
    - optimization for thermal stress resistance
  - bulk (e.g., tiles)
    - avoids delamination
    - strength
    - thermal conductivity
    - optimization
    - low activation

- Low-Dose N Damage Effects
  - swelling (e.g., SiC will saturate in approximately two weeks at $T < 1000^{o}C$ in a 2 MW/m^2 machine
  - reduction in thermal conductivity

- Continental Europe's Ceramics Program Plan
  1. insulators for RF systems
  2. ceramics for near-first-wall usage

Needs for high power devices and for an ignition machine are addressed by the other working groups and should then be incorporated into collaboration. They may well fit into the existing structure.

4. SUMMARY

The common thread is that D&T has by and large a PMI/HHF program of broader scope than that of Europe, but perhaps not necessarily broader than the Japanese program. D&T can offer novel materials and design ideas, as well as development and testing capabilities, for the development of plasma interactive components.

The foreign programs provide earlier opportunities than are available in the U.S. for integrated tests of impurity control, fueling and exhaust systems on major fusion devices. In addition, the foreign programs provide complementary resources in anumber of PMI and HHF research and development areas.

An important step has already been taken in focusing the U.S. Japan Workshop for June 1986 in the database requirements for an ignition machine. The addition of E.C. participants to the workshop will allow definition of needed collaboration to take place.

HIGH POWER DENSITY REQUIREMENTS

J. DOWNING, CHAIRMAN

IV. HIGH POWER DENSITY REQUIREMENTS

1. INTRODUCTION

The working group identified the following concepts as having the potential to be High Power Density (HPD)systems:

- Reversed-Field Pinch (RFP)
- OHTE
- Spheromak
- Field-Reversed Configuration (FRC)
- High-β Tokamak

These concepts are characterized by Fusion Power Cores (FPCs) having power densities approaching that of a light water fission reactor ($\sim$19.8 MW_t/m^3). A consequence of the high power density is the potential for high average thermal wall loading. HHF components can be removed for maintenance in the mainline approaches, whereas the HHF components can be a major part of the First Wall (FW) structure in compact systems. A potential advantage associated with HPD systems is the possibility of a few (single?)-piece FPC, which is replaced as a unit instead of depending on remote maintenance of the HHF components. Higher plant availability and reduced costs may be possible.

2. TECHNICAL ISSUES

The ratio of particle flux to neutron current incident on a FW should be similar for both the HPD and "conventional" approaches. The HPD systems achieve both their neutron and erosion lifetime "fluences" in a chronologically shorter lifetime. Most HPD systems require the same area of high heat flux components (for equal power input) as the mainline

approaches. For those concepts which do not utilize magnetic divertors, a larger percentage of the FW area must serve a limiter function. Large peaking factors cannot be tolerated in HPD systems because of the high average power loads. This observation leads to the conclusion that the equilibrium control must be sufficiently good to avoid excessive peaking of the heat flux. The dual role of the FW (limiter and FW) results in higher thermal stresses in the FW structure. In the near-term, consistent with the program plan, pulse lengths will be < 3.0 s. This pulse length is long enough to determine physics issues and short enough that active cooling during the pulse is not required. For the same pulse length, active cooling for the HPD FW will be needed sooner (approximately the same time as active cooling for tokamak limiters) for HPD systems than for tokamaks.

Impurity control schemes are not well developed for HPD systems. Natural magnetic divertors exist for the steady-state spheromak, FRC, and OHTE geometries. This feature offers the possibility of removing part of the heat flux outside the FW structure. The PMI and HHF issues will be the same as the mainline programs where similar fusion outputs produce heat flux problems similar to those which occur in the divertor chamber of a tokamak or the end cell of a mirror machine.

3. HIGH PRIORITY ISSUES

The materials issues for HPD systems are focussed on the selection of the appropriate plasma-side FW material. Associated with the material choice is the development of an appropriately reliable tile retention technique. Most of the current experience is with a rather limited number of graphite types; therefore, an evaluation of alternate graphites

(particularly those with higher thermal shock resistance) is necessary. Further measurements of radiation enhanced sublimation on candidate FW materials in general, and graphites in particular, are needed. Data on the retention of hydrogen isotopes in thick pieces of graphties in the presence of the thermal gradients and the temperature cycling characteristic of FW conditions are needed. If density, impurity, or inventory control prove to be difficult with the bare graphites, the development of in-situ renewable low-Z coatings will be required. Other low-Z materials, such as Cu-Li, should be evaluated.

The application of edge physics modeling that has been developed for the mainline programs should be adapted to the geometries and plasma conditions characteristic of the HPD systems. Accurate edge physics modeling is necessary for the rapid development of impurity control techniques. To benchmark the models, a full spectrum of edge physics measurements should be made for comparison with the extensive work done on the mainline devices.

INTRODUCTION

Strategy for the Development and Technology Reactor Technology Programs in Plasma/Materials Interaction and High Heat Flux Materials and Component Development

Marvin Cohen
Department of Energy
Division of Development and Technology

STRATEGY FOR THE DEVELOPMENT AND TECHNOLOGY REACTOR TECHNOLOGY PROGRAMS IN PLASMA/MATERIALS INTERACTION AND HIGH HEAT FLUX MATERIALS AND COMPONENT DEVELOPMENT

THE PMI/HHFMCD TASK AREAS

ADDRESS 3 OF THE 4 KEY TECHNICAL ISSUES

OUTLINED IN THE MAGNETIC FUSION PROGRAM PLAN

- MAGNETIC CONFINEMENT SYSTEMS
- PROPERTIES OF BURNING PLASMAS
- MATERIALS FOR FUSION SYSTEMS
- NUCLEAR TECHNOLOGY

HOW DID WE GET HERE?

WHERE ARE WE GOING?

If You Don't Know where
You ARE Going,
You ARE Liable to WIND UP
SomeplACE Else!

{Steve Dean,
Circa 1976}

"All men can see these tactics whereby I conquer, but what none can see is the strategy out of which victory is evolved."

Sun Tsu,
Chinese general and strategist (ca. 3000 B.C.)

STRATEGY

strategy gives meaning to tactics and marshalls short-term objectives to the service of broader goals.

Tactics are means to an end, not ends in themselves.

REACTOR TECHNOLOGIES BRANCH

HIGH HEAT FLUX MATERIALS AND COMPONENT DEVELOPMENT

AND PLASMA/MATERIALS AND INTERACTION TASK AREAS

OBJECTIVES

0 TO INSURE THAT OFE TECHNOLOGY PROGRAMS, FACILITIES, AND INTERNATIONAL COLLABORATIVE EFFORTS HAVE THE REQUIRED MATERIALS, COMPONENTS, AND A TIMELY HIGH HEAT FLUX AND PLASMA/MATERIALS INTERACTION DATA BASE WHICH IS ADEQUATE FOR SUCCESSFUL DESIGN AND FABRICATION OF ALL IN-VESSEL COMPONENT NEEDS.

PLASMA/MATERIALS INTERACTION AND HIGH

HEAT FLUX MATERIALS AND COMPONENT DEVELOPMENT

RECOGNIZE THAT WE CANNOT MEET OUR OBJECTIVES ON A LIMITED D&T BUDGET WITH LABORATORY SIMULATION TECHNIQUES ALONE. THE OBJECTIVES DEMAND ENTRE INTO THE BIG CONFINEMENT MACHINES.

STRATEGY

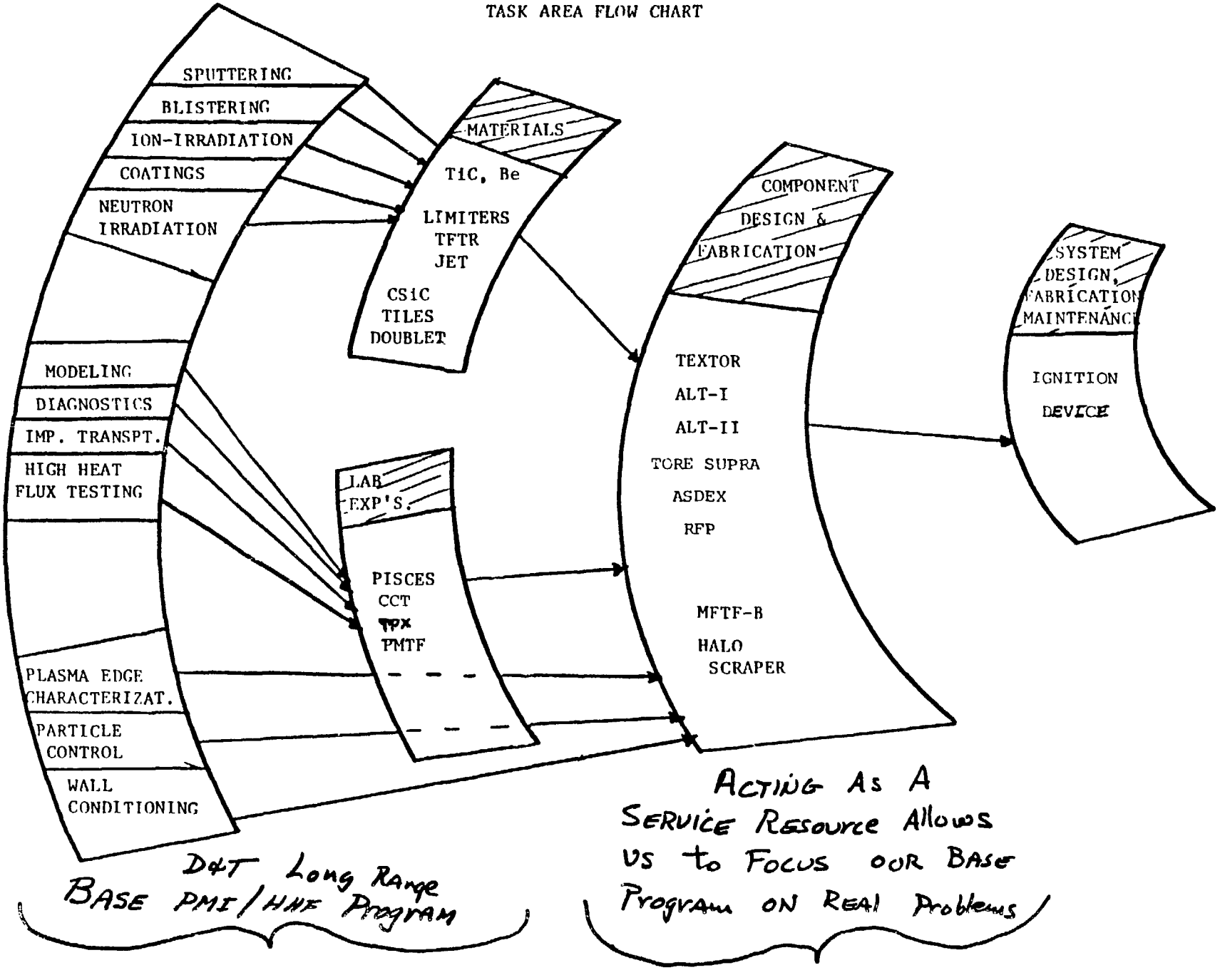
TO DEVELOP AND MAINTAIN A SOUND, FORWARD LOOKING PMI/HHF PROGRAM AND A TECHNICAL COMMUNITY WHICH IS INDISPENSIBLE TO DESIGNERS OF NEAR-TERM EXPERIMENTS, COMPONENTS, AND LONG-TERM DEVICES.

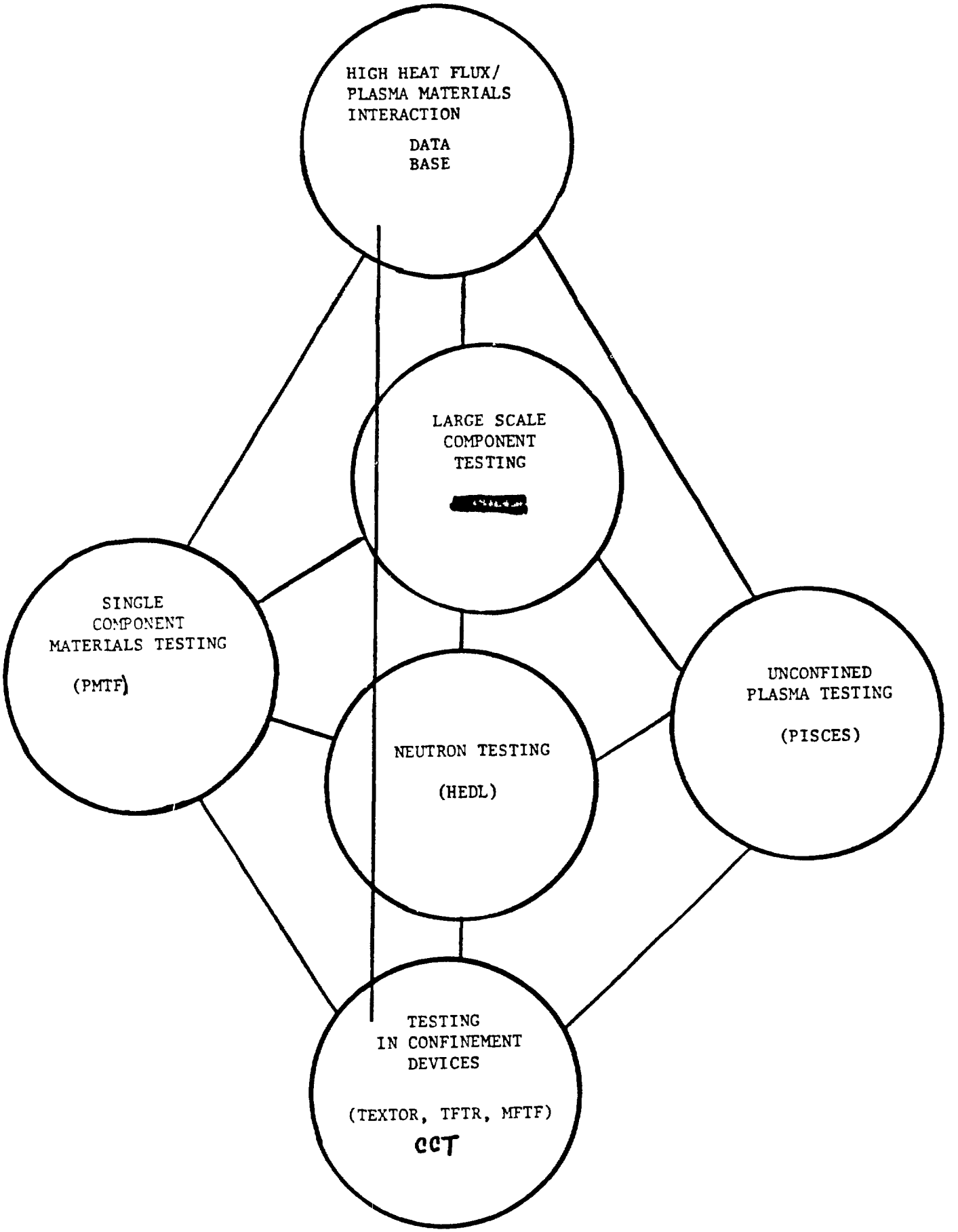
TACTICS

- TO DEVELOP AND UTILIZE HIGH HEAT FLUX DIAGNOSTIC TOOLS AND SIMULATION TECHNIQUES.
- TO DEVELOP PLASMA COMPATIBLE MATERIALS, COATINGS, AND IN-VESSEL COMPONENTS WHICH ARE CAPABLE OF WITHSTANDING THE HIGH HEAT LOAD, PARTICLE, AND NEUTRONIC ENVIRONMENTS EXPECTED IN A FUSION REACTOR.
- TO DEVELOP MATERIALS AND COATINGS FOR IMPURITY, EROSION, AND DISRUPTION CONTROL, SURFACE CONDITIONING AND RECYCLING.
- TO DEVELOP PLASMA/EDGE DIAGNOSTIC TOOLS AND MODELS.
- TO FUNCTION AS A SERVICE ORGANIZATION, UTILIZING THESE TOOLS, MODELS, MATERIALS AND COMPONENTS IN SUPPORT OF PRESENT AND FUTURE OFE PROGRAMS AND FACILITIES AND INTERNATIONAL NEEDS.

PMI/HHFMCD

TASK AREA FLOW CHART




HIGH HEAT FLUX/
PLASMA MATERIALS
INTERACTION
DATA
BASE
LARGE SCALE
COMPONENT
TESTING
[redacted]
SINGLE
COMPONENT
MATERIALS TESTING
(PMTF)
NEUTRON TESTING
(HEDL)
UNCONFINED
PLASMA TESTING
(PISCES)
TESTING
IN CONFINEMENT
DEVICES
(TEXTOR, TFTR, MFTF)
CCT

PROBLEM AREAS

0 ICRF ANTENNA

- "NO ADEQUATE RESPONE FROM D&T PMI/HHF COMMUNITY."
  [PETER MIODUSZEWSKI, WIL GAUSTER]

0 PROGRAM PLAN FOR PMI/HHF

- WE ARE 1 YEAR LATE.
- DRABT PROGRAM PLAN EXISTS, BUT MUST BE REVISED IN LIGHT OF
  - -- MFE PROGRAM PLAN
  - -- NEW EMPHASIS ON HIGH POWER DEVICES
  - -- ORIENT TOWARD IGNITION MACHINE
- HOW SHOULD WE INTERFACE WITH NEW OFE PLANNING ACTIVITY?
  [M. ABDOU. W. GAUSTER, K. WILSON]

PLASMA/MATERIALS INTERACTION (PMI) PROGRAM AND TECHNICAL ASSESSMENT

W. Bauer
Sandia National Laboratories Livermore

REACTOR TECHNOLOGIES BRANCH
PLASMA/MATERIALS INTERACTION TASK AREA

OBJECTIVES

- TO INSURE THAT OFE TECHNOLOGY PROGRAMS, FACILITIES AND INTERNATIONAL COLLABORATIVE EFFORTS HAVE A PMI DATA BASE WHICH IS BOTH TIMELY AND ADEQUATE

- TO DEVELOP MATERIALS AND COATINGS FOR IMPURITY, EROSION AND DISRUPTION CONTROL, SURFACE CONDITIONING AND RECYCLING

- TO HELP IN THE DEVELOPMENT OF PLASMA/WALL DIAGNOSTIC TOOLS AND TO UTILIZE THESE TOOLS IN SUPPORT OF OFE AND INTERNATIONAL NEEDS

REACTOR TECHNOLOGIES BRANCH
PLASMA/MATERIALS INTERACTION TASK GROUP

M. M. COHEN - OFE

W. BAUER (SNL) - CHAIRMAN

K. WILSON (SNL) - SECRETARY

J. BROOKS (ANL)

S. ALLEN (LLNL)

T. TAYLOR (GA)

S. COHEN (PPPL)

R. CONN (UCLA)

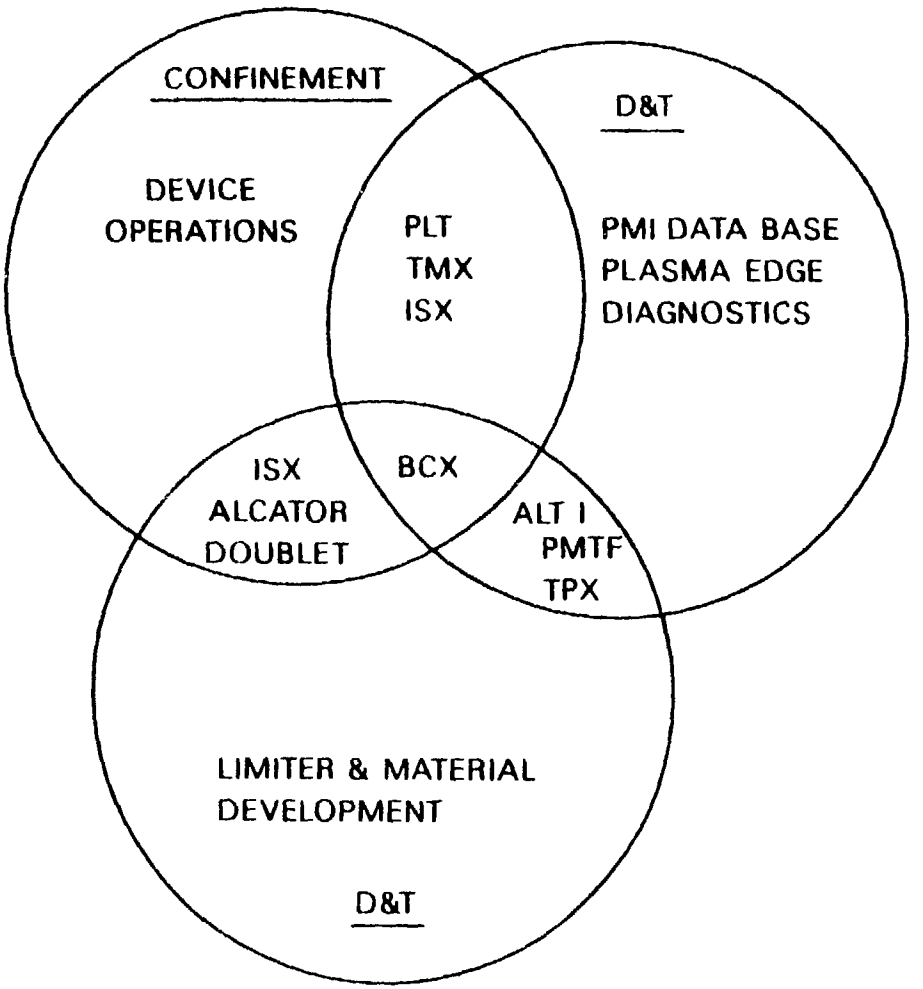
W. GAUSTER (SNL)

P. MIODUSZEWSKI (ORNL)

B. LIPSCHULTZ (MIT)

J. DOWNING (LANL)

PMI PROGRAM INTERACTION



THE D&T FUNDED PMI PROGRAM HAS CONTRIBUTED TO THE OPERATION OF EXISTING DEVICES

EDGE PROBES:	ISX, ISX-B, PLT, PDX, TEXTOR TMX, TMX-U, MACROTOR
GETTERING STUDIES:	ISX-B, TFTR, TMX-U
WALL CONDITIONING:	ISX-B, JET, TEXTOR, MACROTOR
LIMITERS:	ALCATOR, DOUBLET, ISX, ZT-40M
ADVANCED LIMITERS:	TEXTOR (ALT-I)

PMI PROBLEMS IN BCX ARE ADDRESSED WITH TESTS IN EXISTING DEVICES, LABORATORY EXPERIMENTS, AND MODELLING

- TRITIUM EFFECTS, IMPURITY CONTROL, AND WALL CONDITIONING ARE ADDRESSED IN FACILITIES SUCH AS TPX, PISCES, AND PMTF, AS WELL AS IN EXISTING DEVICES

- COMPUTER CODES SUCH AS MARLOW, TRIM, DIFFUSE, ELM, AND REDEP PROVIDE A PREDICTIVE CAPABILITY FOR BCX SCENARIOS

D&T FUNDED PMI FACILITIES PROVIDE CRITICAL DATA FOR THE CONFINEMENT COMMUNITY AND PLASMA EDGE SIMULATION FOR REACTOR APPLICATIONS

- SURFACE ANALYSIS LABORATORIES
  - SNL, ORNL, ANL
- PLASMA EDGE SIMULATION
  - TRITIUM PLASMA EXPERIMENT: TPX (SNLL)
  - PLASMA MATERIAL TEST FACILITY: PMTF (SNLA)
  - PLASMA SURFACE INTERACTION EXPERIMENT: PISCES (UCLA)

TECHNICAL ASSESSMENT - CRITICAL ISSUES
PLASMA MATERIALS INTERACTION TASK GROUP

R. W. CONN/W. BAUER

E. MARMAR	(MIT)	PMI - PLASMA CONFINEMENT
D. HEIFETZ	(PPPL)	PLASMA EDGE PHYSICS MODELLING
K. L. WILSON	(SNL)	SURFACE PHYSICS
W. B. GAUSTER	(SNL)	MATERIALS TECHNOLOGY

PMI TASK GROUP TECHNICAL ASSESSMENT: CRITICAL ISSUES

PMI - PLASMA CONFINEMENT

- IMPURITY CONTROL IN LONG PULSE HEATED DEVICES
- DEVELOPMENT OF PLASMA DIAGNOSTICS

PLASMA EDGE PHYSICS

- COMBINED EDGE PLASMA AND NEUTRAL TRANSPORT MODEL
- IMPURITY TRANSPORT MODEL (TIME DEPENDENT)

SURFACE PHYSICS

- REFLECTION COEFFICIENTS (1 TO 100 eV)
- HYDROGEN TRAPPING, DIFFUSION AND RE-EMISSION
- CHEMICAL EROSION

MATERIALS

- THICK COATING TECHNOLOGY

HIGH HEAT FLUX (HHF) MATERIALS AND COMPONENTS PROGRAM AND TECHNICAL ASSESSMENT

W. Gauster
Sandia National Laboratories
Albuquerque

HIGH HEAT FLUX MATERIALS AND COMPONENTS PROGRAM AND TECHNICAL ASSESSMENT

W. B. GAUSTER

SANDIA NATIONAL LABORATORIES

DOE, GERMANTOWN

MAY 21, 1985

TECHNICAL AREAS AND ASSESSMENT OF ISSUES

A. SOURCE CONDITIONS

1. CHARACTERIZATION OF PLASMA EDGE

A. DATA FROM OPERATING DEVICES

B. THEORETICAL STUDIES

2. CONTROL OF PLASMA EDGE

A. LOW TEMPERATURE, HIGH DENSITY

$\Downarrow$ $\Downarrow$

LOW EROSION CONTROL OF DENSITY

B. IMPURITY CONTROL SCHEMES

DIVERTORS

PUMP LIMITERS

LARGE TOKAMAK MACHINE PARAMETERS

Device	TFTR	JET	JT-60
Country	USA	EC	Japan
First plasma	Dec.1982	June 1983	Apr. 1985
Major radius (m)	2.55	2.96	3.0
Half-width (m)	0.85	1.25	0.95
Ellipticity	1.0	1.0–1.6	1.0
Toroidal field (T)	5.2	3.5	4.5
TF coil conductor	Cu	Cu	Cu
Working gas	H/D-T	H/D-T	H
Plasma current (MA)	2.5 → 3.0	4.8	2.7
Discharge duration (s)	1.0 → 3.0	10 → 20	5–10
NBI power[a] (MW)	27	16	20 → 30
Beam pulse length (s)	0.7 → 2	10	10
NBI energy (keV)	120, D^0	80, H^0 → 160, D^0	100, H^0
RF power[a] (MW)	ICRH 8? LHRH 3?	ICRH 30	LHRH 8 ICRH 3
Fuelling	gas puff pellet inj.	gas puff	gas puff
Impurity control	gettering	wall cond.	magn. limiter wall cond.

[a] Total power into the torus.

LARGE TOKAMAK MACHINE PARAMETERS

Device	T-15	DOUBLET III-D	TORE SUPRA
Country	USSR	USA	France
First plasma	late 1985	Jan. 1986	1987
Major radius (m)	2.4	1.67	2.42
Half-width (m)	0.70	0.67	0.70
Ellipticity	1.0	1.0–2.0	1.0
Toroidal field (T)	3.5 → 4.5	2.2	4.5
TF coil conductor	Nb_3Sn	Cu	NbTi
Working gas	H	H	H/D
Plasma current (MA)	1.4 → 2.0	3.5 → 5	1.7
Discharge duration (s)	5.0	2 → 5	30
NBI power[a] (MW)	5.5 → 8	12 → 14	7
Beam pulse length (s)	1.5	0.7 → 5	30
NBI energy (keV)	80, H^0	80, H^0	100, D
RF power[a] (MW)	ECRH 4 → 6	ECRH 2 ICRH 6?	ICRH 6 LHRH 5
Fuelling	gas puff pellet inj.	gas puff pellet inj.	gas puff
Impurity control	wall cond.	pump limiter stubby divertor	wall cond.

[a] Total power into the torus.

Operating Conditions of Existing Devices

Machine	Component	Peak Heat Flux	Pulse Length
Alcator-C	Limiter	~ 5 kW/cm^2	0.5 s
	First Wall	10 W/cm^2	0.4 s
	Disruption	80-500 kW/cm^2	200-300 s
Doublet-III	Limiter	0.5-2.0 kW/cm^2	0.3-1.0 s
	Divertor Plates	?	
	Disruption	50-75 kW/cm^2	20-100 μs
ISX-B	Limiter	1.0-10.0 kW/cm^2	0.2-0.3 s
PLT	Limiter	2.5-9.0 kW/cm^2	0.15-0.8
PDX	Limiter	0.2-3.0 kW/cm^2	0.3 s
	First Wall	6 W/cm^2	0.3 s
	Divertor Plates	9.75-1.0 kW/cm^2	0.3 s
	Disruption	10 x normal flux	?
TMX	Edge Scraper	~ 0.1 kW/cm^2	0.02 s
	Beam Catcher	?	
	First Wall	?	

Predicted Operating Conditions in Future Devices

Device/Component	Normal Operation Heat Flux (kW/cm^2) Lowest	Typical	Highest	Duration (s)	Off-Normal Heat Flux (kW/cm^2)	Duration
TFTR[24]						
Rail Limiter	2.0	4.5	7.0	0.25-1.0	100	0.002-0.005
Bumper Limiter	0.3	0.65	1.0	1.5	100	0.002-0.005
Beam Armor	0.4	0.6	0.8	1.5	5.6	0.01
First Wall	—	0.03	—	1.5	—	—
MFTF-B[25]						
Beam Dumps	2.0	3.0	4.0	0.5-30	—	—
End Domes	0.03	0.25	0.45	0.5-30	—	—
Halo Scraper	—	0.2	—	0.5-30	—	—
TFCX[20]						
Limiter, Divertor	0.2	0.35	0.5	100	—	—
First Wall						
INTOR[27]						
Limiter, Divertor	0.1	0.3	0.5	100	10	0.02
First Wall	0.01	0.05	0.1	100		
Alcator-DCT[30]						
Limiter	0.2	0.35	0.5	90	20-50	0.001
RFP[31]						
Limiter	0.2	1.8	3.9	0.05-0.25	10	0.003
First Wall	0.05	0.3	0.6			
OHTE[31]						
Limiter		0.6				
First Wall		0.2				
RIGGATRON[31]						
Limiter	2.0	3.5	5.0			
First Wall		0.5				
EBT[31]						
Limiter		0.25				
DEMO[28]						
Limiter, Divertor	0.5	0.75	1.0	Steady-State		
First Wall	0.05	0.075	0.1			
MARS[29]						
Halo Scraper	0.2	0.25	0.3	Steady-State		
Beam Armor	0.19	0.35	0.4			
First Wall	—	—	—			

TABLE I. Candidate Impurity Control Materials

Plasma Side Materials		Heat Sink Materials
Low-Z:	C, Be, B, TiC, SiC, B_4C, BeO	Copper Alloys
Medium-Z:	Stainless Steel, Vanadium	Vanadium Alloys
High-Z:	W, Ta, Nb	Niobium Alloys

TABLE II. Limiter and Divertor Operating Conditions

	Divertor	Limiter
Total power to collector plates	70 MW	84 MW
Particle	53 MW	80 MW
Radiation	17 MW	4 MW
Presheath ion energy	25 eV	150 eV
Sheath potential	60-80 eV	300-800 eV
Peak power	4.7-7 MW/m^2	2.4 MW/m^2

B. SYSTEM INTEGRATION

1. LIFETIME OF COMPONENTS

A. CONTROL EDGE TO MINIMIZE EROSION

B. DEVELOP WAYS TO MINIMIZE OFF-NORMAL CONDITIONS

C. STUDY EROSION/REDEPOSITION

D. DESIGN FOR RAPID REPLACEMENT OF COMPONENTS

2. TRITIUM CONTAMINATION OF COOLANTS

A. PERMEATION DATA

B. TRITIUM BARRIERS

3. INTERACTION OF COOLANTS

A. IDENTIFY COOLANTS OTHER THAN WATER

B. DETERMINE WATER/LIQUID METAL ACCIDENT PROBABILITIES AND SCENARIOS

4. FUEL SELF-SUFFICIENCY

DESIGN IMPURITY CONTROL AND EXHAUST SYSTEMS TO MINIMIZE SPACE (BREEDING BLANKET) AND MAXIMIZE TRITIUM BURN-UP ($\Longrightarrow$ BREEDING RATIO).

C. MATERIALS AND PROCESSES

1. DEVELOPMENT AND SELECTION OF PLASMA SIDE MATERIALS

2. DEVELOPMENT AND SELECTION OF HEAT SINK ALLOYS

3. FABRICATION AND BOND DEVELOPMENT

4. IRRADIATION STUDIES

   10 - 50 DPA

   UP TO $\approx$ 400°C

5. SELECTION AND DEVELOPMENT OF REFRACTORY METALS

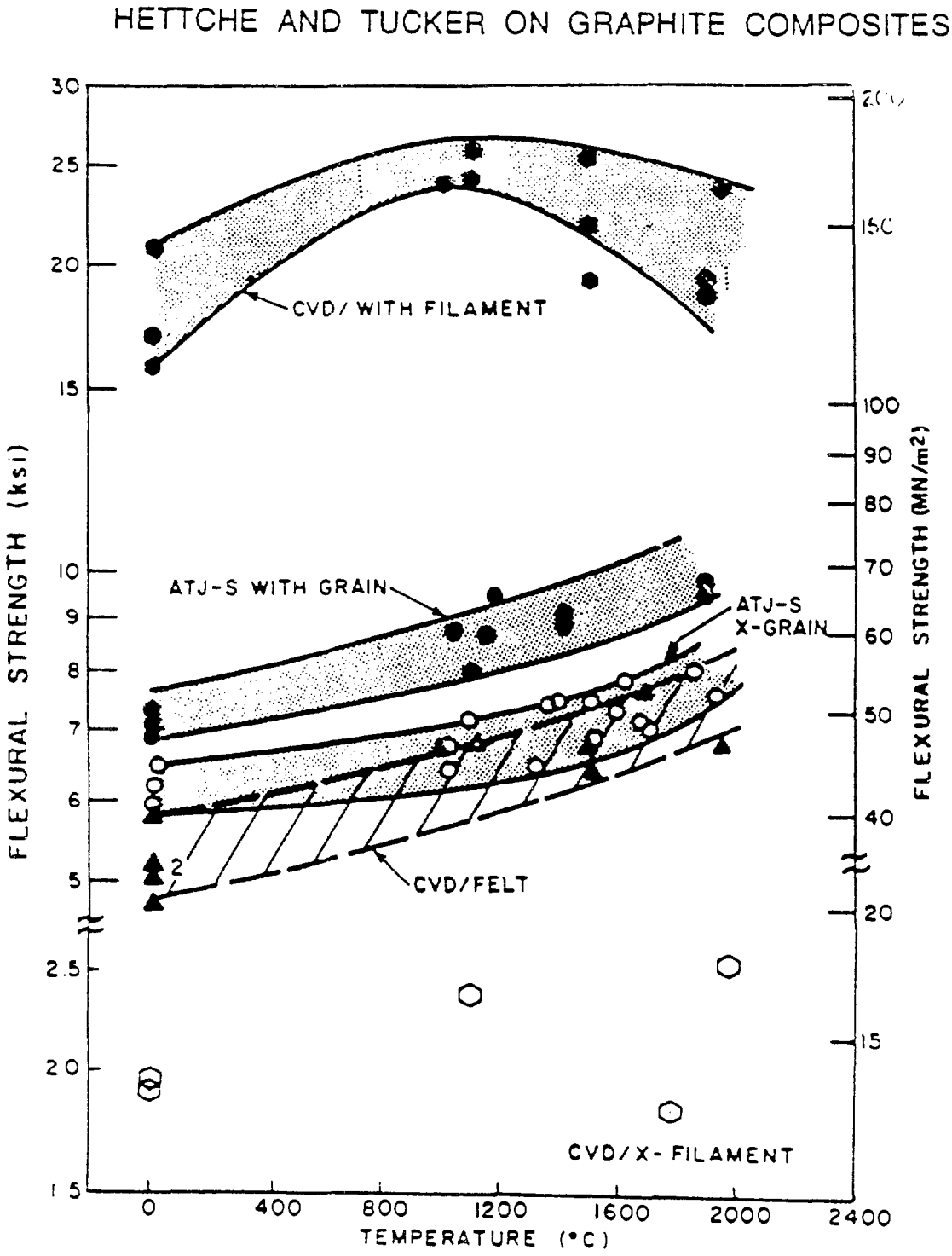


FIG. 5—*Temperature dependence of flexural strength of ATJ-S graphite, and CVD and CVD/filament-wound composites.*

e spacing between adjacent yarns, bundle size, percent of yarn in each rection, yarn packing efficiency and the complexity of the interwoven ttern. A schematic of a plain weave fabric and the five harness satin ave are shown in Figure 2.

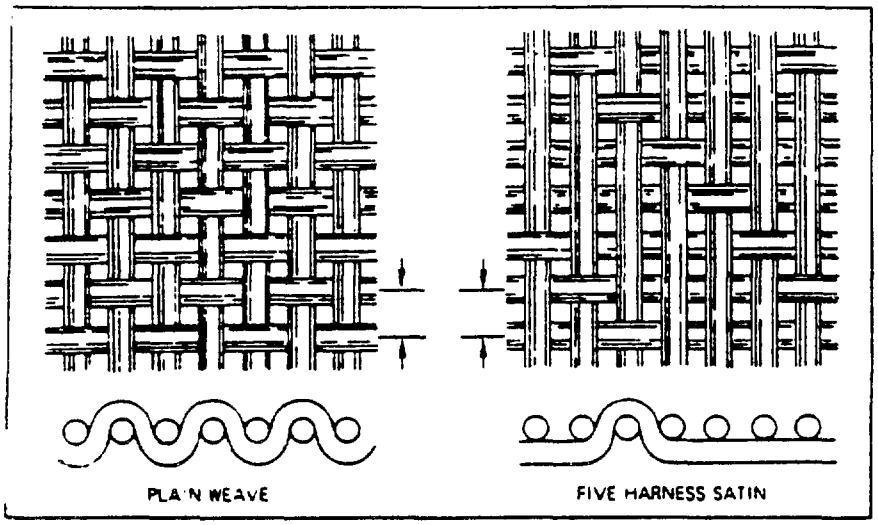


Figure 2 - 2-D Fabric

The satin construction offers the advantage of the floating yarns h contribute more strength to a composite because of the straight hs. This factor results in increased tensile performance over the eave fabric.

The two directional yarn orientation fabric can be further tailored certain applications where a third direction of yarn orientation is re-ed. A typical three-dimensional (3-D) fabric is schematically shown in re 3.

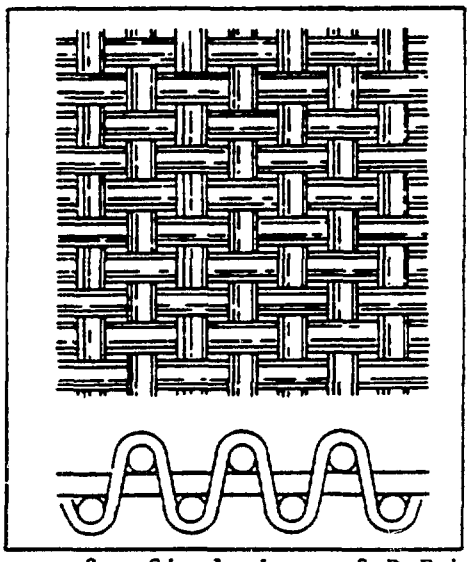


Figure 3 - Single Layer 3-D Fabric

The 3-D fabric offers the benefit of having straight lengths of yarn two normal directions with the third direction interlooping to bind the er directions in position. The yarn bundle size, spacing between ad-ent yarn bundles, yarn packing efficiency, and the percent of yarn in h direction also characterize the 3-D fabric design. As shown in ure 3, the space between adjacent yarns is controlled by the bundle e or diameter of the yarn in the orthogonal direction. This means that smallest center-to-center yarn spacings are obtained by using yarns

Structures with reinforcing yarns oriented in multiple directions may be designed to meet application requirements. A typical 3-D orthogonal structure is shown in Figure 4. The same design parameters apply to this type structure as to the 2-D and 3-D type fabrics. Schematics of various weave configurations are shown in Figure 5 to illustrate the design versatility that 3-D orthogonal structures offer.

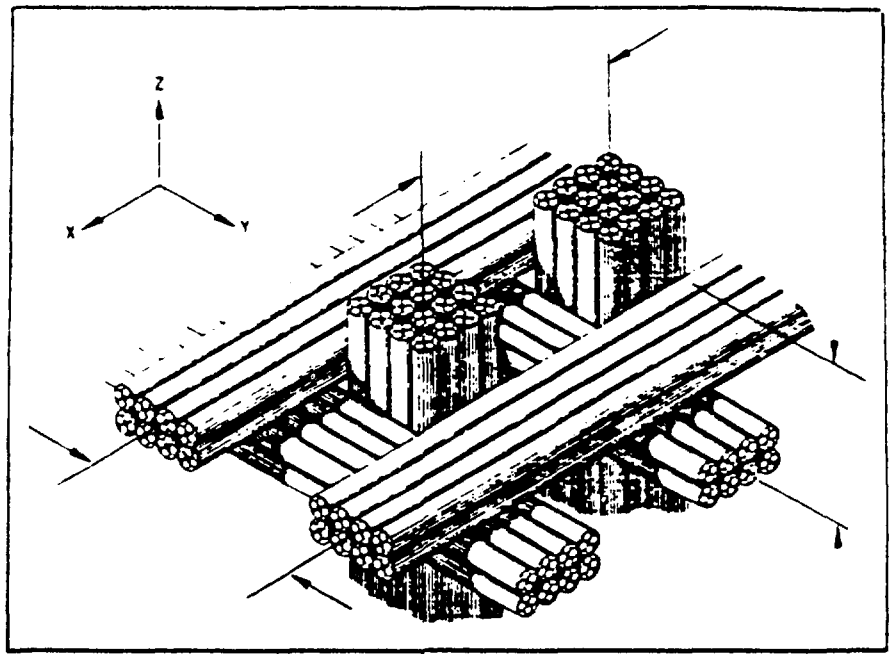


Figure 4 - 3-D Orthogonal Weave

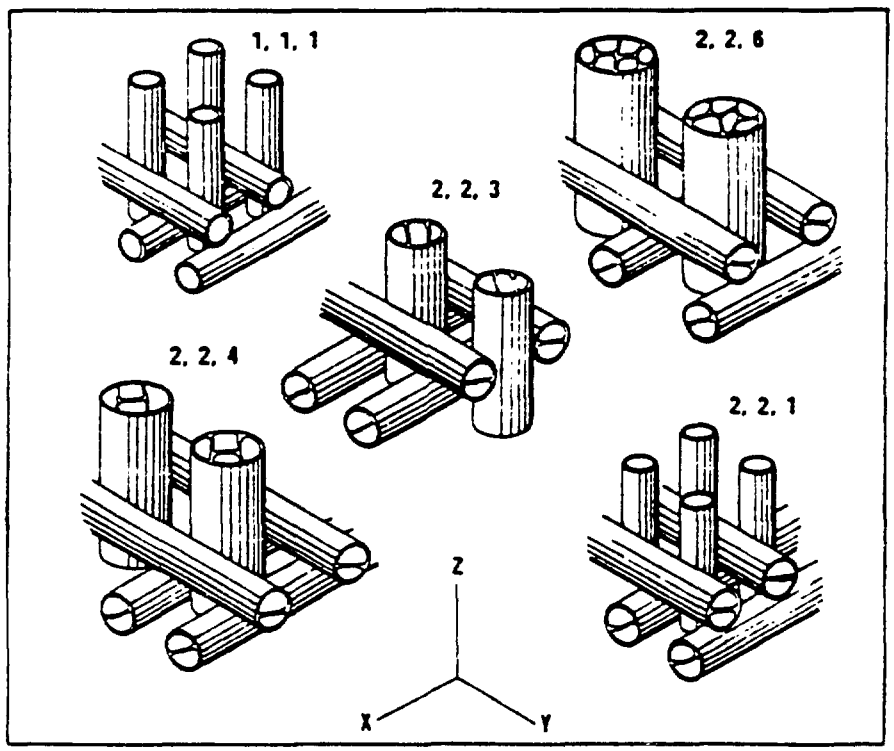
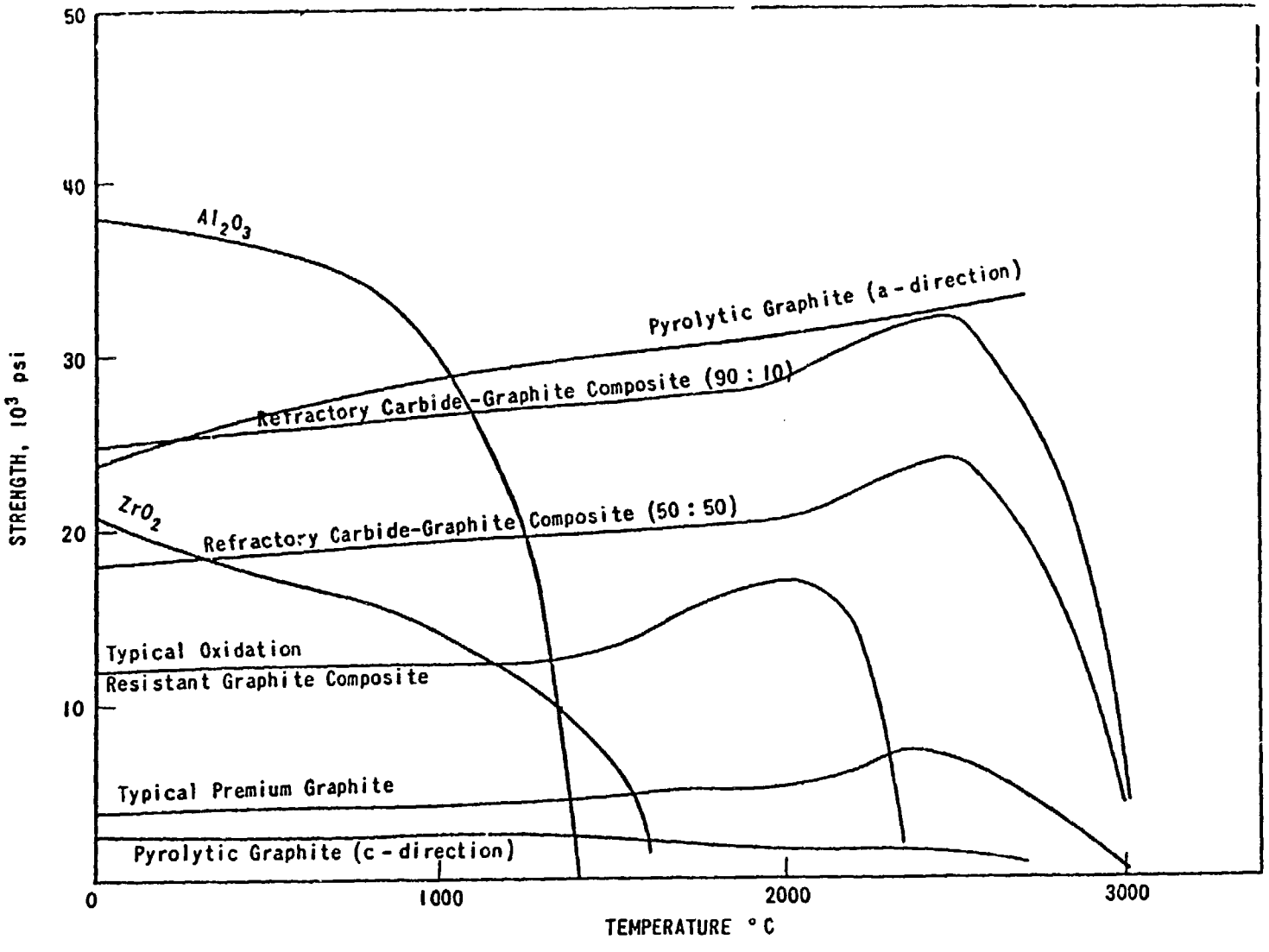


Figure 5 - Typical 3-D Block Constructions

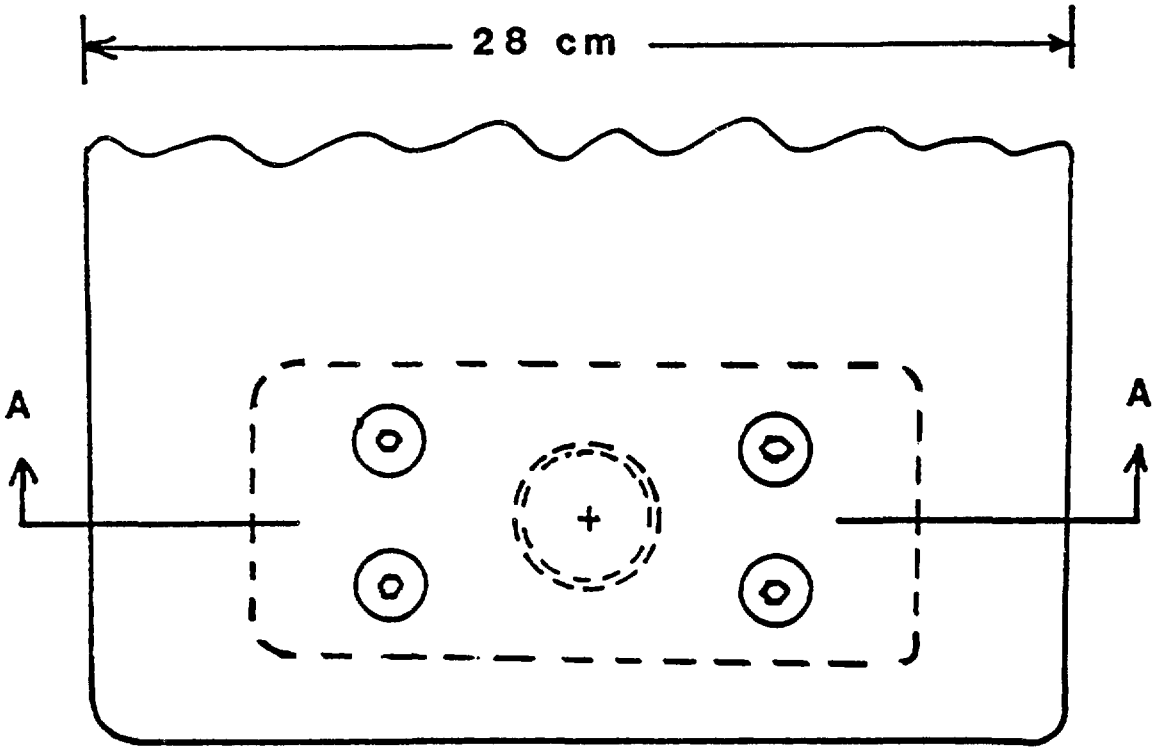
Typical yarn spacings, woven bulk densities, and volume fraction distribution resulting from variations in yarn plies for two selected graphite yarn types are shown in Table II.

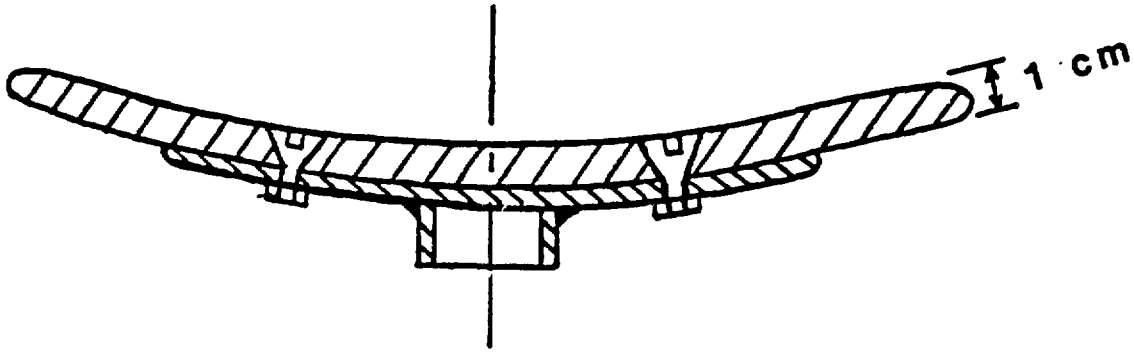
Bulk densities, percent fiber volume fraction, and yarn spacings can be mathematically calculated knowing the linear density of the yarn. The



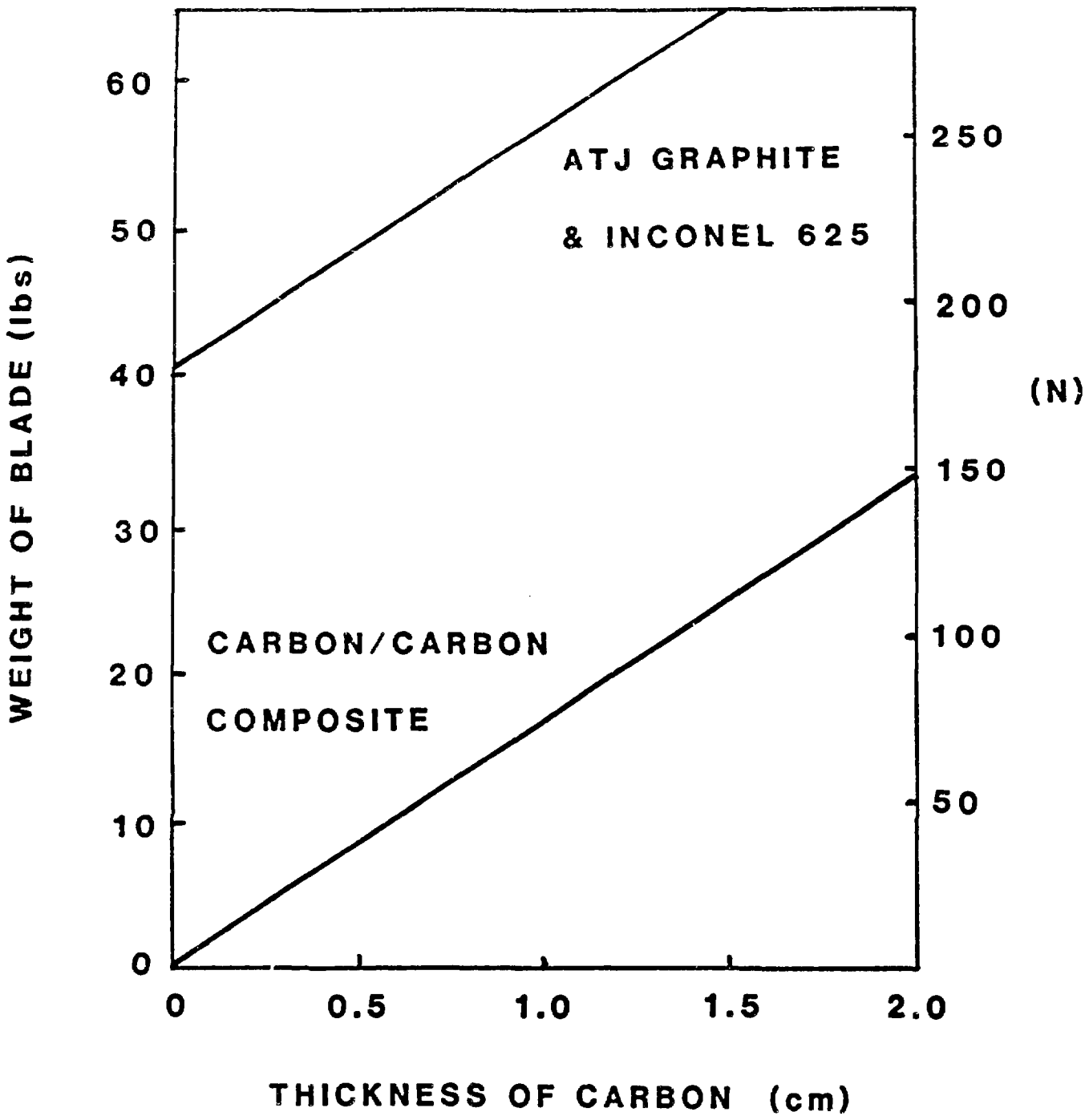
COMPARISON OF FLEXURAL STRENGTHS AT ELEVATED TEMPERATURE

CARBON/CARBON COMPOSITE BLADE

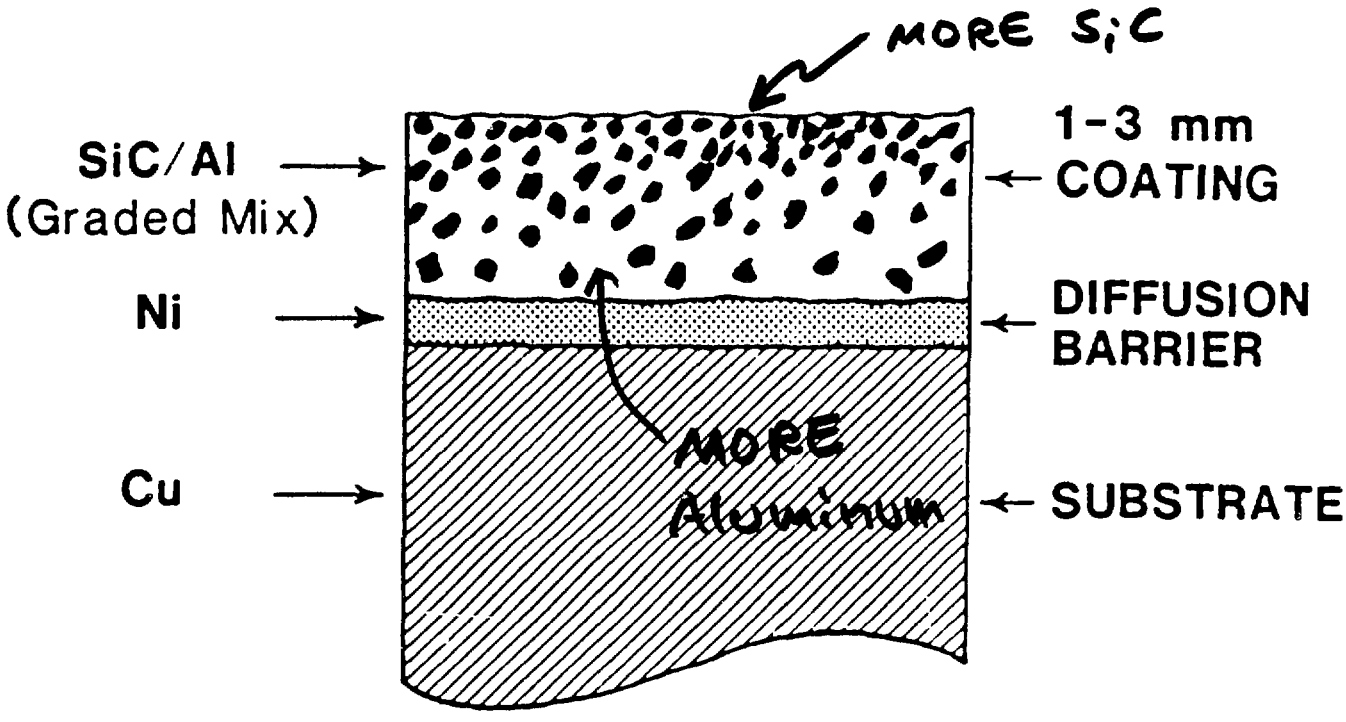




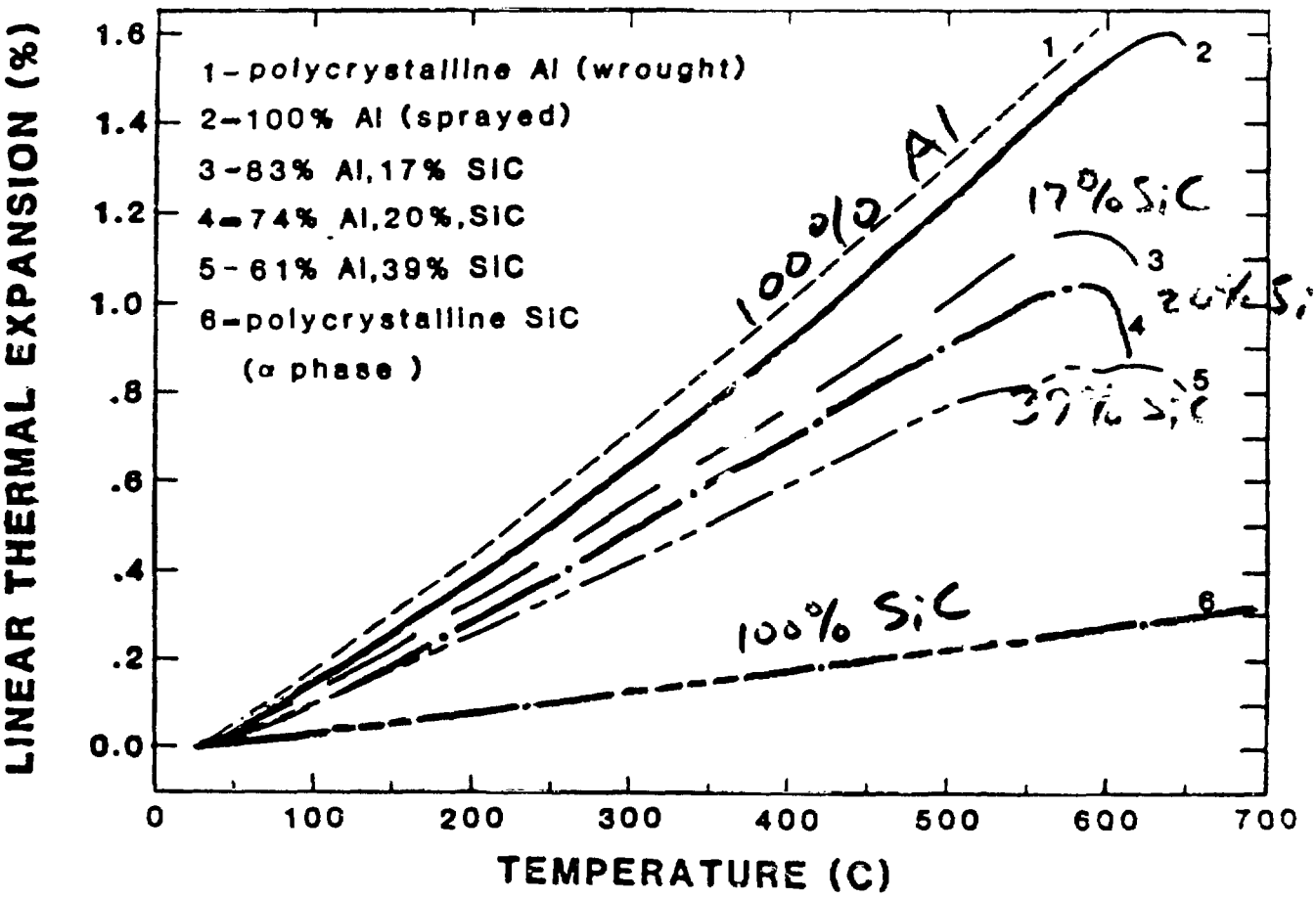
SEC A-A


WEIGHT OF BLADE (lbs)
60
50
40
30
20
10
0
250
200
150
100
50
(N)
ATJ GRAPHITE
& INCONEL 625
CARBON/CARBON
COMPOSITE
0
0.5
1.0
1.5
2.0
THICKNESS OF CARBON (cm)

CERMET COATING



THERMAL EXPANSION



NEUTRON IRRADIATION OF HIGH HEAT FLUX MATERIALS

(HEDL)

COATINGS

Mo, Be, TiC, V, TiB_2, SiC/Al Cermet

Chemical Vapor Deposition

Plasma Spray

Explosive Bond

Brazed Bonds

(No Diffusion Bonds)

SUBSTRATES

Copper, Cu Alloy, Graphite, S.S., Mo, Be, Ni

DOSE LEVELS

FFTF 1-3 dpa

EBR-II 2-9 dpa

≈ 50 Samples

TEMPERATURE

400 - 500 C

D. THERMAL HYDRAULICS

1. CRITICAL HEAT FLUX

EVALUATION OF SFB CRITICAL HEAT FLUX (CHF) BETWEEN 0.1 AND 2.0 kW/cm^2 FOR LARGE (0.1 TO 100. m^2) SURFACE AREAS WITH LARGE (50 TO 600) L/D RATIO COOLING CHANNELS.

2. STABILITY CRITERIA

ESTABLISHING SFB THERMAL-HYDRAULIC STABILITY CRITERIA FOR MULTIPLE, INTERCONNECTED, AND SUBCHANNEL COOLANT CONDUITS.

3. MECHANISMS

INCREASING UNDERSTANDING OF PHYSICAL MECHANISMS LEADING TO SFB CHF; DEVELOPING ENGINEERING THERMAL-HYDRAULIC MODELS TO CHARACTERIZE THE DATA BASE.

FLOW BOILING TEST LOOP - SNLA

- P = 200 KW
- RESISTIVE HEATING

OBJECTIVE:

(1) ACHIEVE LEVELS OF CHF BETWEEN 0.2 kW/cm^2 AND 15 kW/cm^2 FOR FUSION COMPONENT-LIKE CHANNELS

(2) MEASURE TWO-PHASE PRESSURE LOSS IN CHANNEL

(3) DEVELOP DIAGNOSTIC DEVICES WHICH CAN BE USED TO DETECT CHF

(4) EVALUATE AND RECOMMEND EXISTING CHF CORRELATIONS AND DATA FROM EXISTING CHF DATA BASE

(5) MAKE COMPARISONS WITH THE ONE-SIDE HEATED ELECTRON-BEAM EXPERIMENTS

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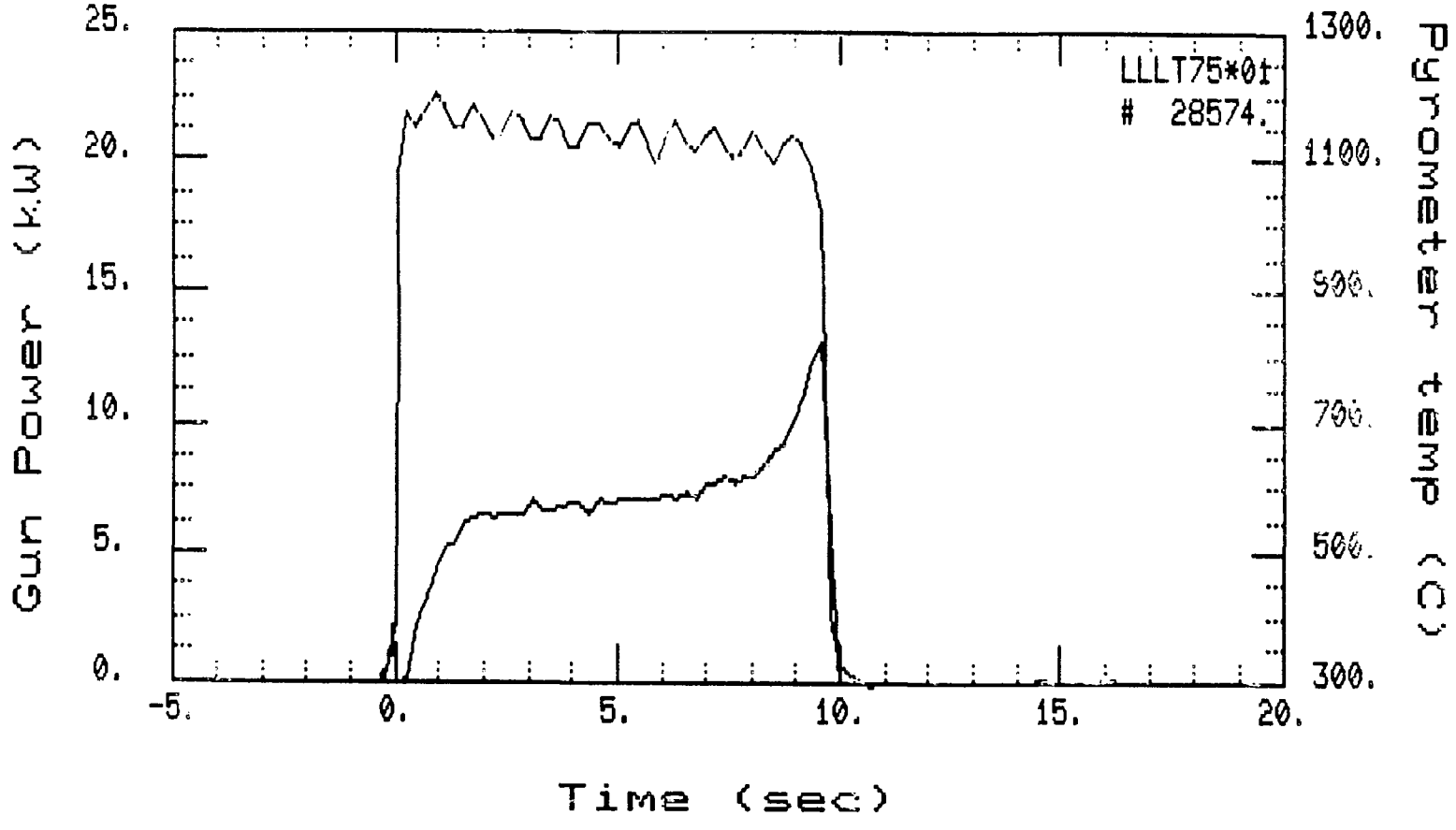
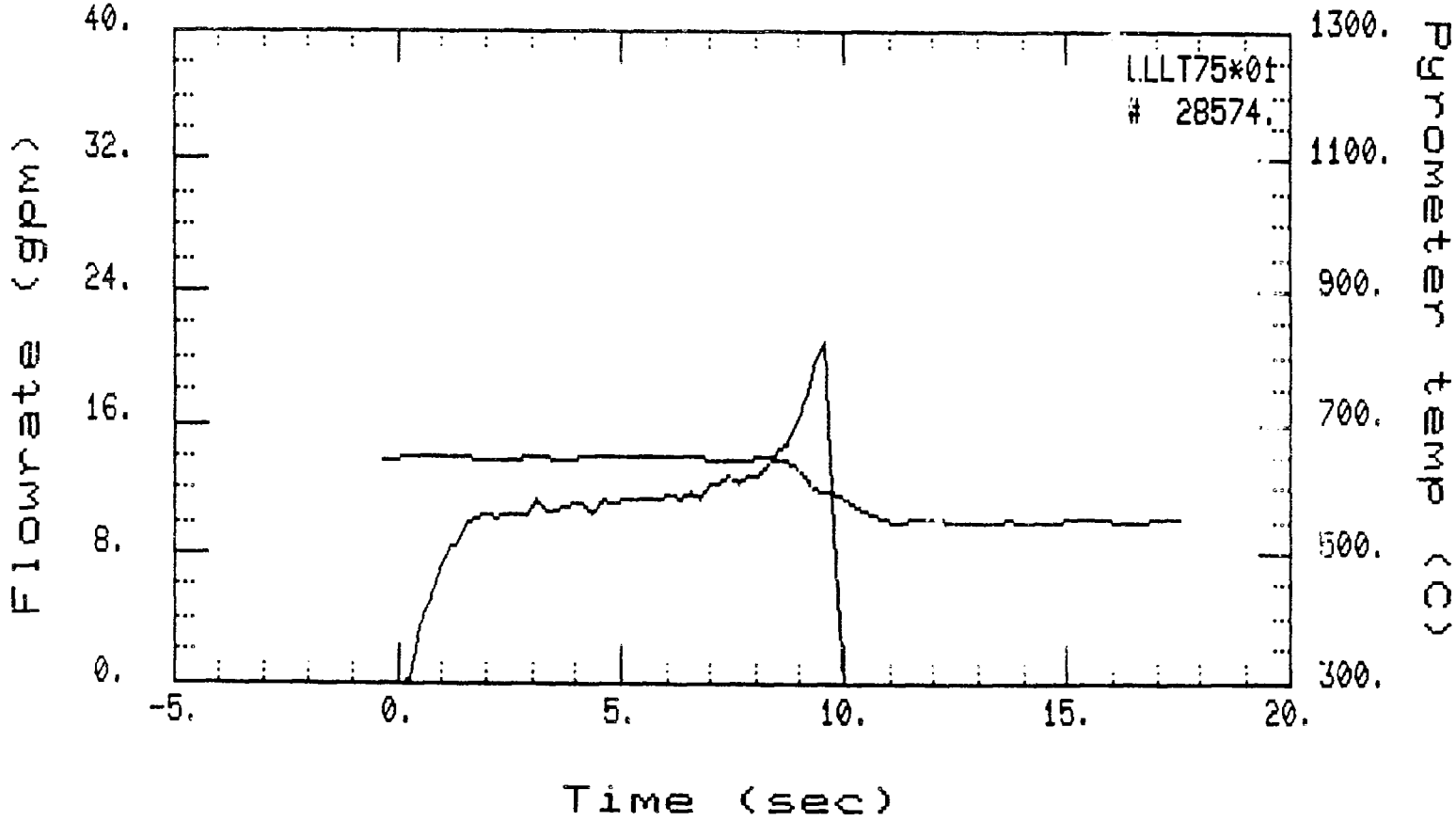
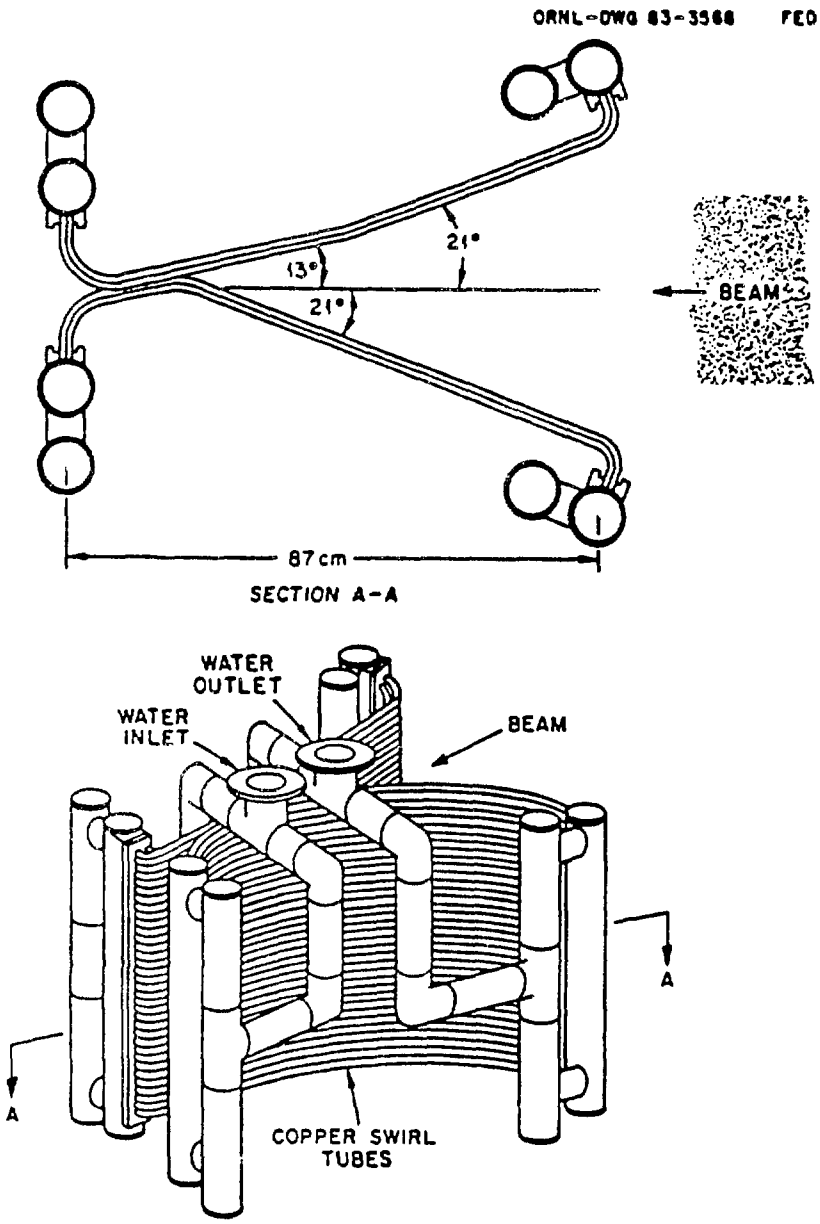

LLLT75*01
28574.
Gun Power (K.W)
Pyrometer temp (C)
Time (sec)
25.
20.
15.
10.
5.
0.
1300.
1100.
900.
700.
500.
300.
-5.
0.
5.
10.
15.
20.


LLLT75*01
28574.
Flowrate (gpm)
40.
32.
24.
16.
8.
0.
Pyrometer temp (C)
1300.
1100.
900.
700.
500.
300.
-5.
0.
5.
10.
15.
20.
Time (sec)



Schematic of the METF swirl tube neutral beam target.

S. L. Milora
S. K. Combs
C. A. Foster

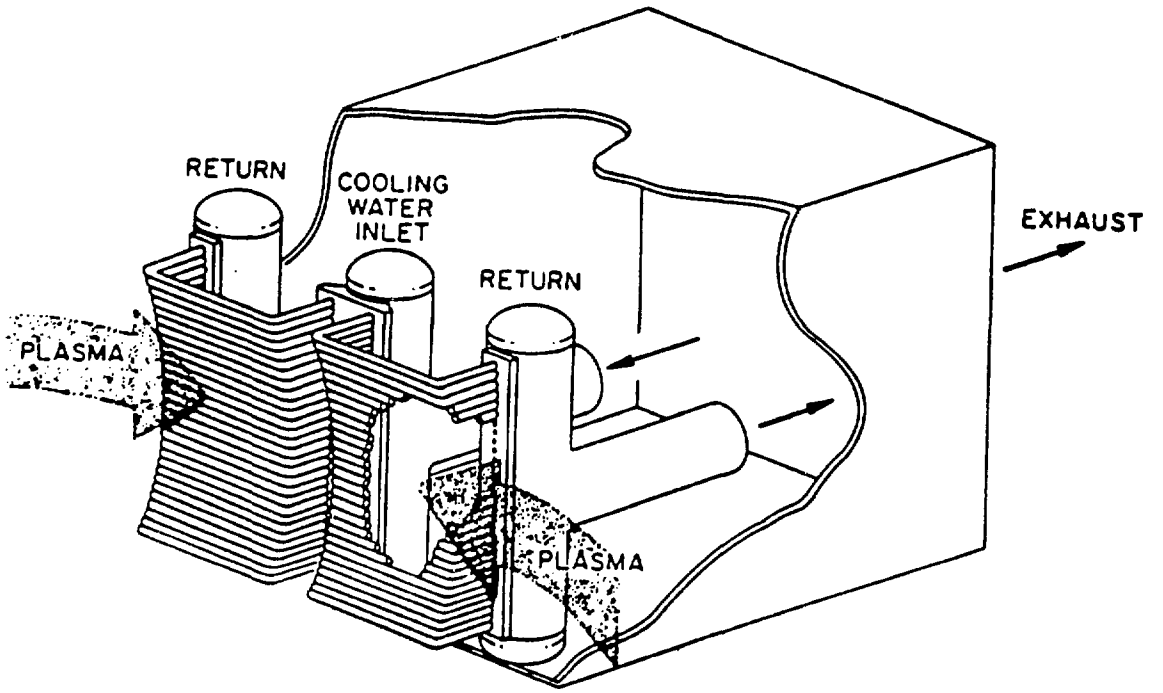
OAK RIDGE NATIONAL LABORATORY

Maximum test parameters for METF swirl tube neutral beam target

Test location: ORNL Medium Energy Test Facility
Power source: ORNL long-pulse ion source
Target: 126 inclined water-cooled copper swirl tubes

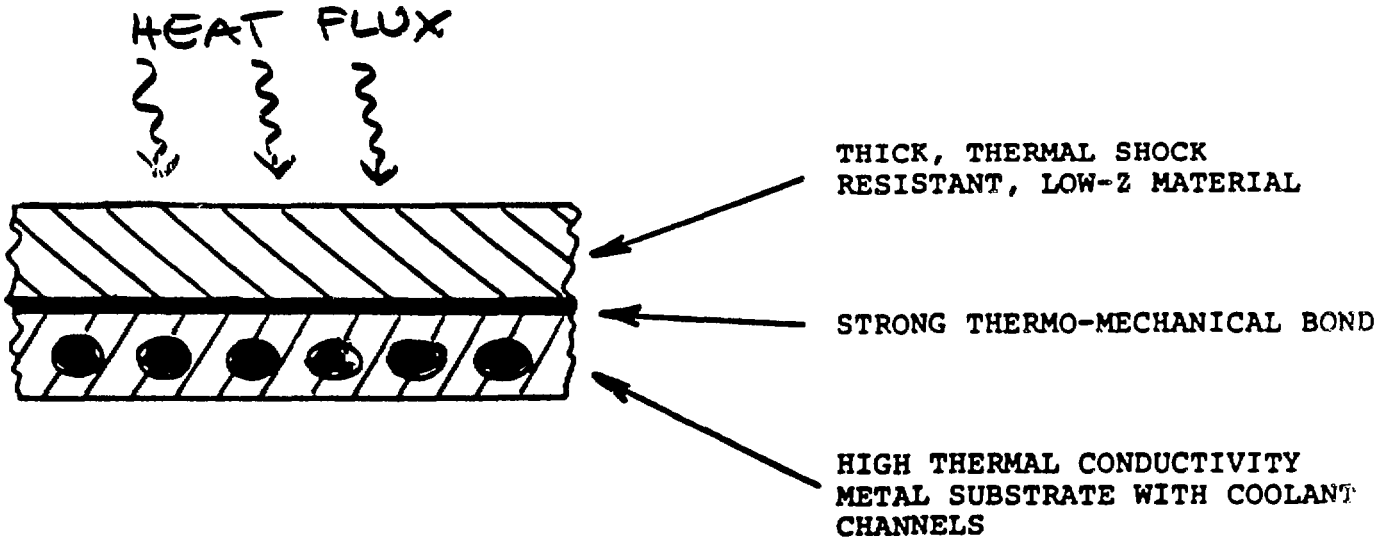
Source voltage, kV	75
Source current, A	40
Pulse length, s	30
Extracted power, MW	3
Extraction surface, cm	13.2 × 43.7
Focal length, cm	950
Power density at 640 cm downstream, kW/cm^2	≈15
Swirl tube outside diameter, cm	0.95
Swirl tube wall thickness, cm	0.16
Angle α between tube arrays and beam axis, deg	13 and 21
Water flow rate, L/s (gpm)	
Total	41.6 (660)
Average per tube	0.33 (5.2)
Water velocity, m/s	11.6
Water pressure, MPa (psia)	
Inlet	1.45 (210)
Outlet	0.31 (45)
Temperature difference ΔT, °C	15.7
Measured power, MW	2.7
Tube surface heat flux, kW/cm^2	≈5.4

ORNL-DWG 84-2649 FED



Design of a pump limiter module based on swirl tube elements. The partial transparency of the grillwork limiter blades allows particles to enter the pump duct.

GENERIC HHF COMPONENT



EXAMPLE: SiC diffusion bonded to Copper alloy substrate with high-velocity sub-cooled water coolant in circular channels.

POTENTIAL FAILURE MODES

* EXCESSIVE SURFACE EROSION
* CRACKING AND LOSS OF LOW-Z MATERIAL
* DEBONDING
* BURNOUT FROM DNB (Departure from Nucleate Boiling)
* STRESS RUPTURE FROM THERMAL CREEP or INTERNAL EROSI(
* EXCESSIVE DEFORMATION

E. THERMOMECHANICAL RESPONSE

1. BOND INTEGRITY

2. MELT LAYERS

3. FATIGUE CRACK GROWTH

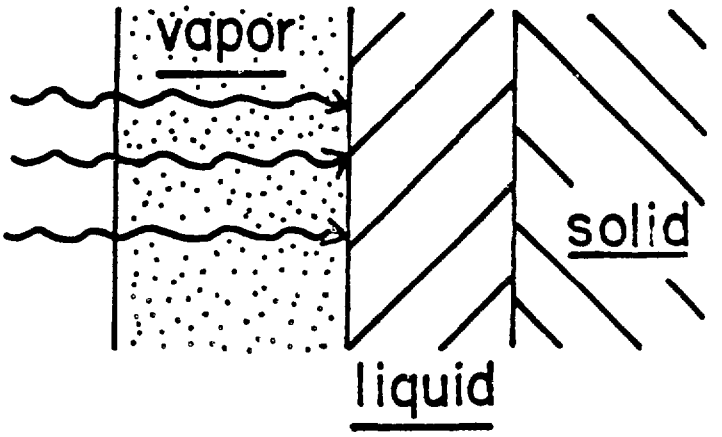
4. EMBRITTLEMENT

5. CREEP/FATIGUE

6. CREEP RUPTURE

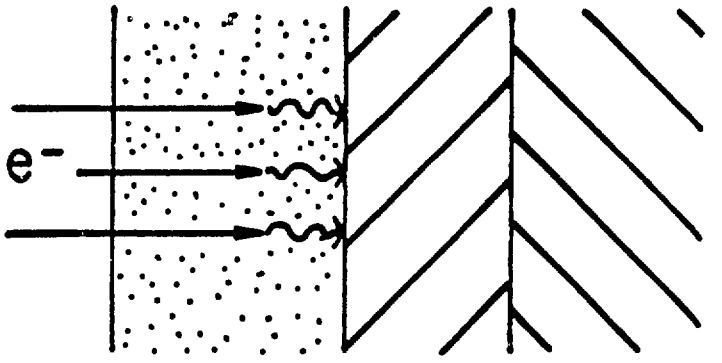
7. SWELLING

Models of the Interaction of Vaporized Material With the Incoming Particles



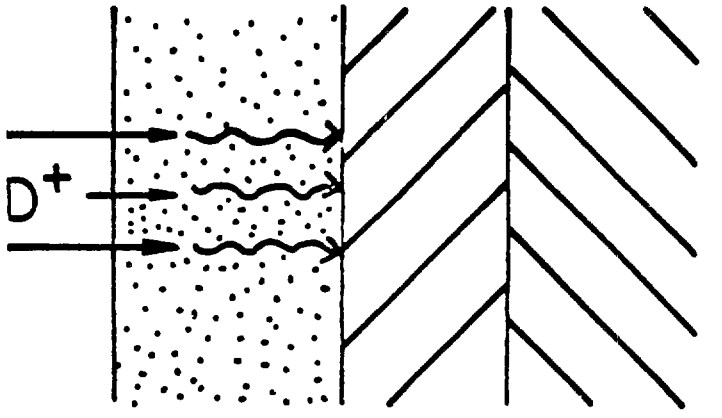
UNSHIELDED

no particle energy loss to vapor



ELECTRON SHIELD

linear electron energy loss based on 25 keV electron range in material



PLASMA SHIELD

linear particle energy loss based on 10 keV deuterium range in the material

Experimental Procedure

- Electron Beam Test Facility - Sandia National Laboratories

- Test Parameters
  - 25 keV electrons
  - 100 to 500 msec
  - 0.5 to 7.0 kJ/cm^2 absorbed energy density

- Electron Beam
  - 0.5 cm at FWHM
  - rastered over 1 cm^2 at 400 Hz
  - uniform energy deposition profile on sample

Experimental Samples

- Test Materials

Al	1100 Al	Cu
Cu-Be	Mo	Ni
SS 304	Ta	TZM
W		

- Sample Geometry - Solid Cylinders 1.25 cm tall, 0.6 to 1.0 cm diameter. Total of 250 tested.

- Weight Loss of Samples Translated into Net Vaporized Thickness.

Conclusions

Theoretical and Experimental Results Show:

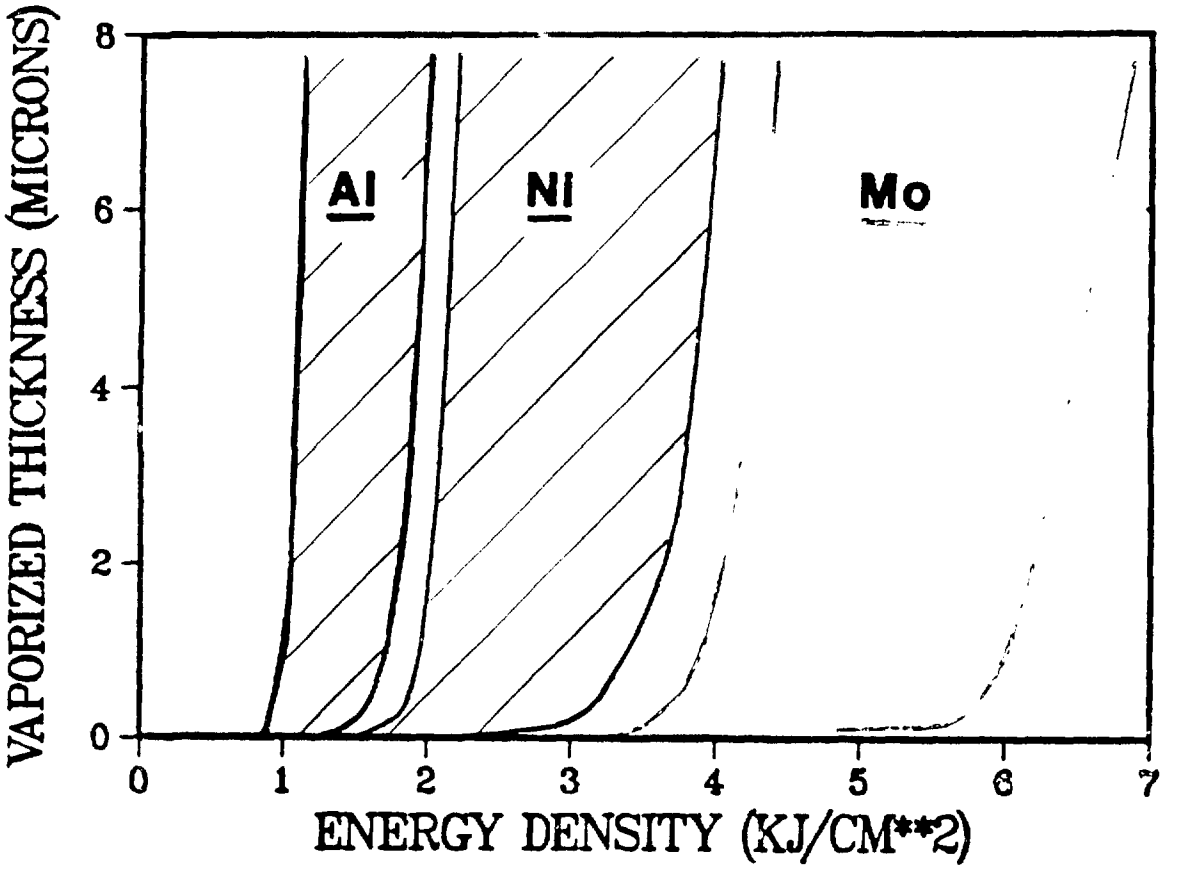
- Vapor Shield Can Reduce Heat Loads to Condensed Phases

- Good Agreement With Respect to Threshold Energy Density for Vaporization

- Same Increase in Vaporization as a Function of Absorbed Energy Density

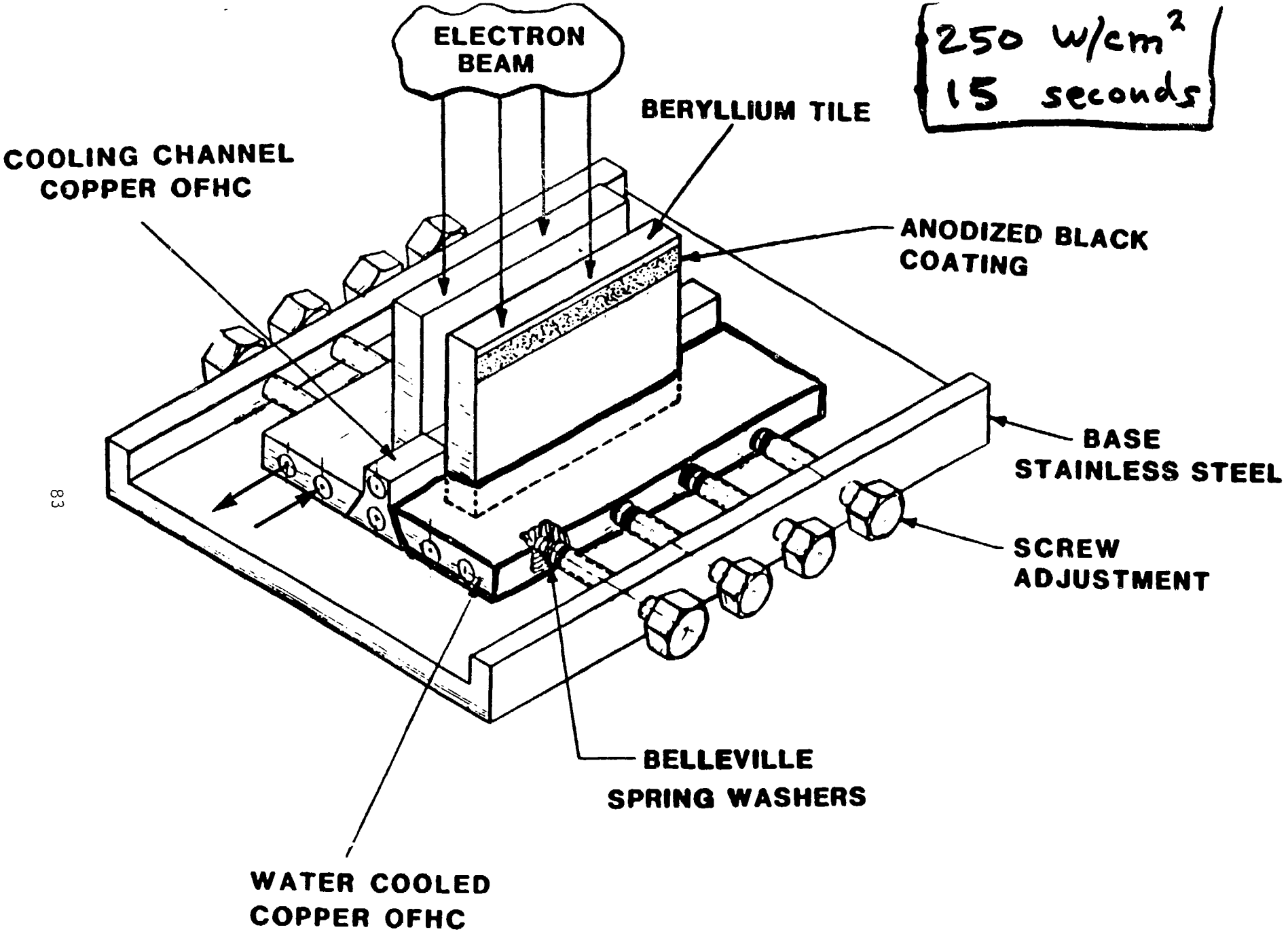
Summary

Electron Beam Experiments Can Be Used To Study Vaporization Models

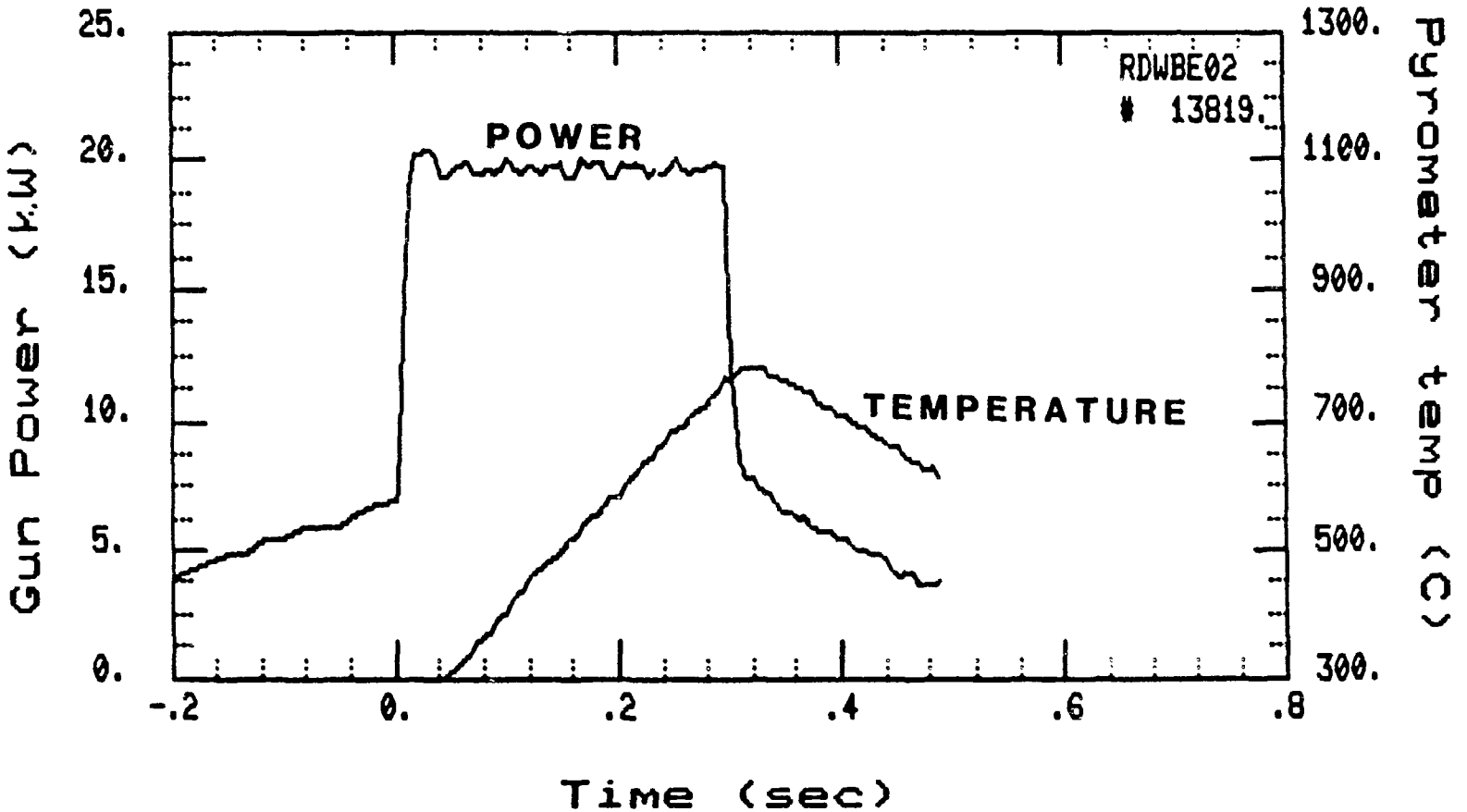


- **Agreement For Wide Range of Thermal Conditions**

- **Agreement for Materials With Vastly Different Properties**

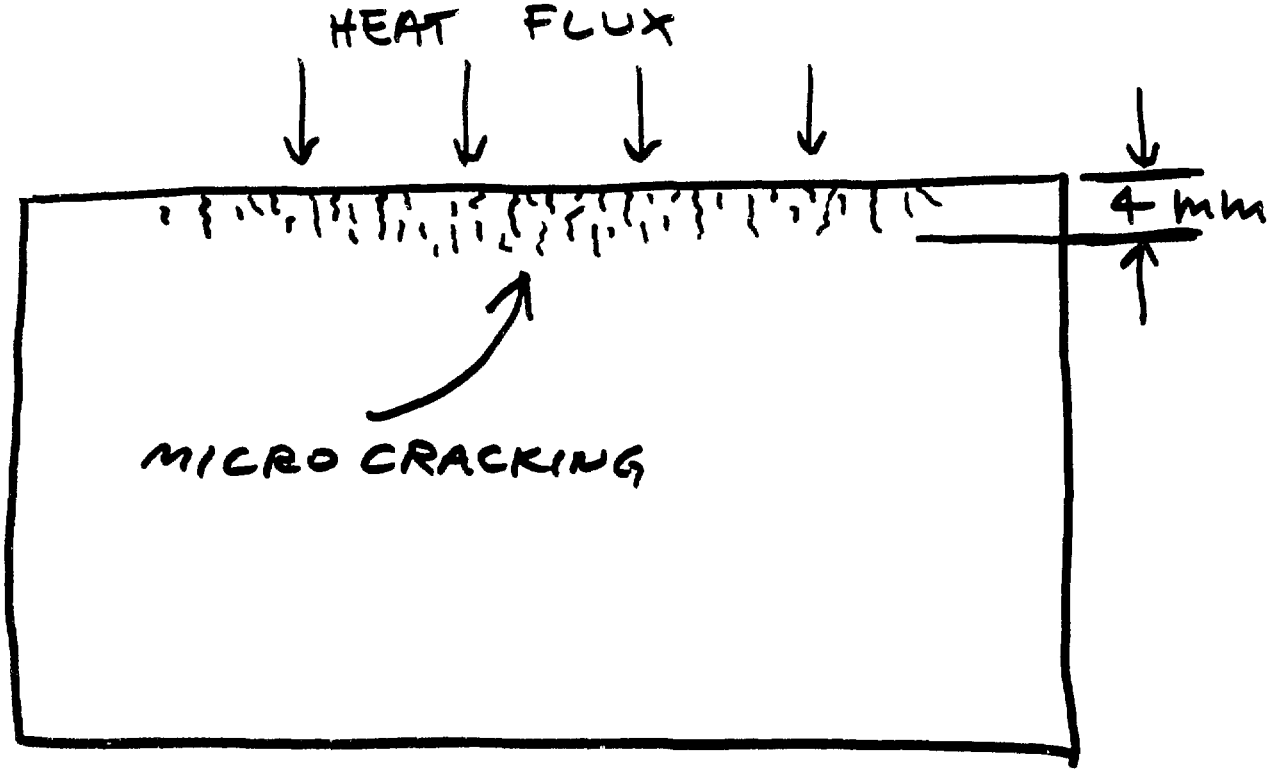

ELECTRON BEAM
250 w/cm²
15 seconds
BERYLLIUM TILE
COOLING CHANNEL
COPPER OFHC
ANODIZED BLACK COATING
BASE
STAINLESS STEEL
SCREW ADJUSTMENT
BELLEVILLE
SPRING WASHERS
WATER COOLED
COPPER OFHC

E-BEAM TEST RESULTS



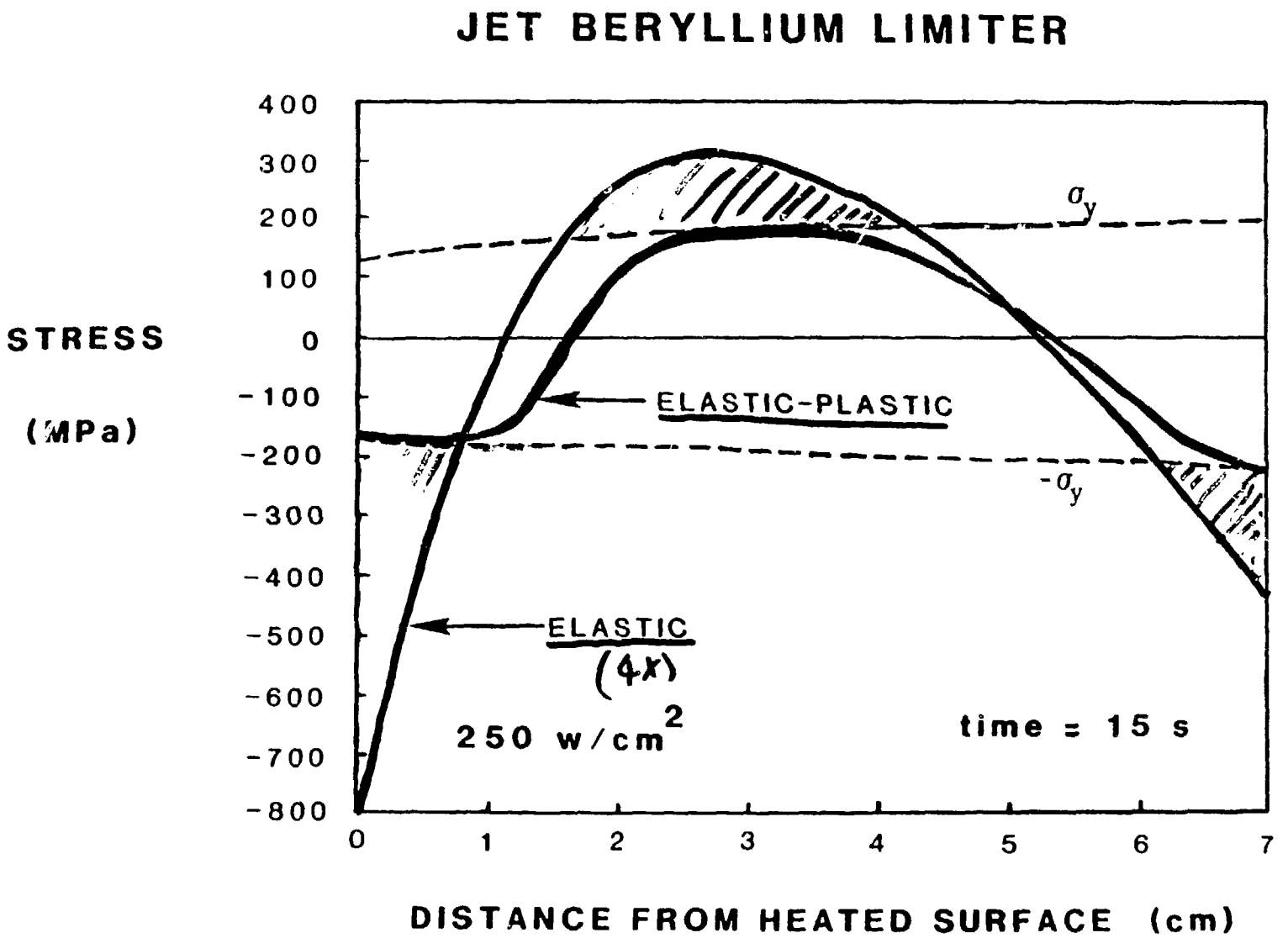
Sandia National Laboratories

- 250 W/cm^2
- 15 SECONDS



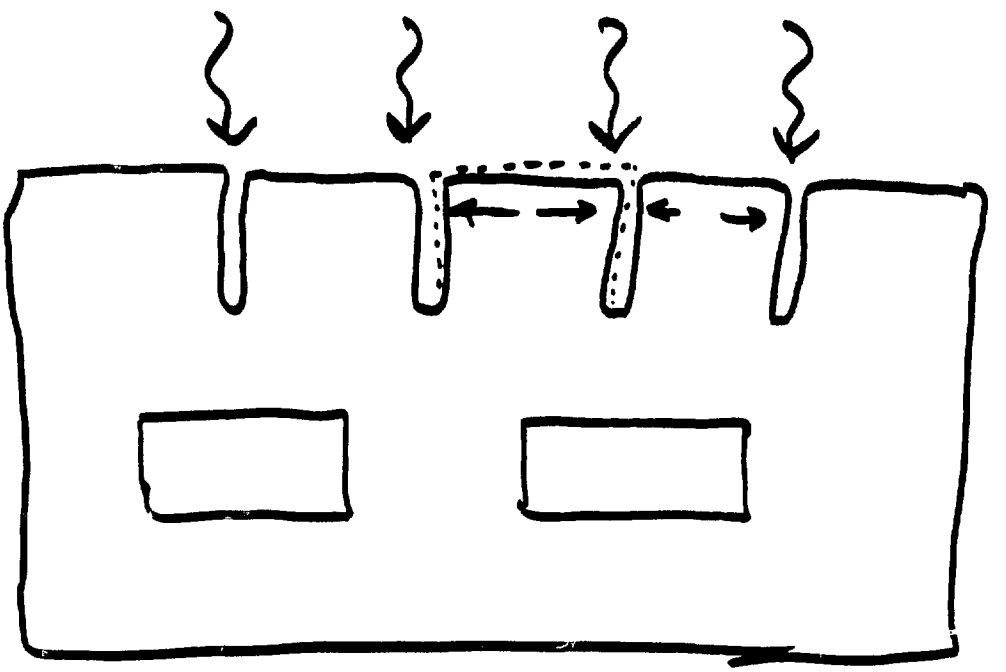
RESULTS

- 10,000 CYCLES WITHOUT FAILURE
- MICROCRACKING CAUSED BY CYCLIC PLASTIC STRAINS
- MICROCRACKS RELIEVE THERMAL STRESSES

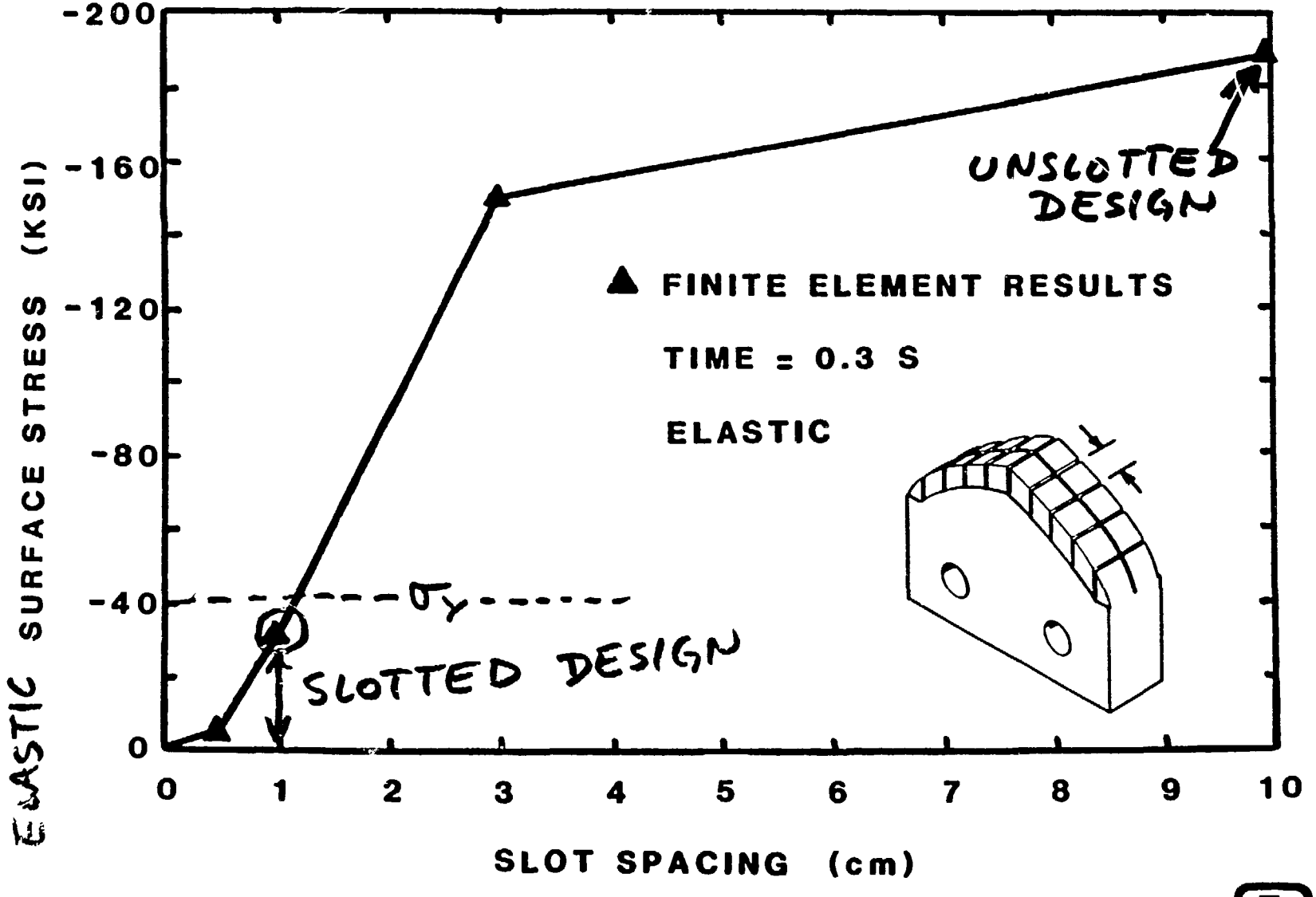

JET BERYLLIUM LIMITER
STRESS
(MPa)
400
300
200
100
0
-100
-200
-300
-400
-500
-600
-700
-800
0
1
2
3
4
5
6
7
DISTANCE FROM HEATED SURFACE (cm)
σ_y
$-\sigma_y$
ELASTIC-PLASTIC
ELASTIC
(4x)
250 w/cm^2
time = 15 s

- TO <u>PREVENT</u> MICROCRACKING...

... SLOT OR CASTILLATE THE HEATED SURFACE!



EFFECT OF SLOT SPACING ON STRESS



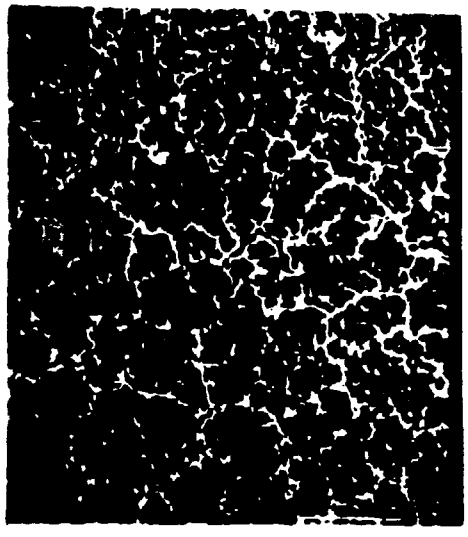
Sandia National Laboratories

ETCHED CUBE

TEST CONDITIONS

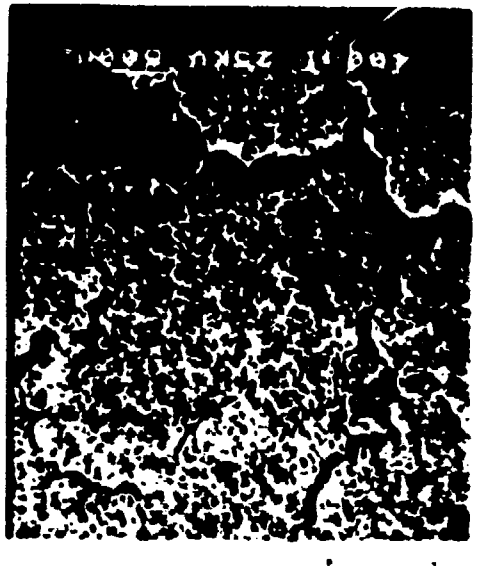
- 2.5 cm S-65-B CUBE
- ETCHED SURFACE
- 2.5 kW/cm^2 HEAT FLUX
- 0.3 SECOND PULSES
- 60 SECOND INTERVALS
- 1000 CYCLES TOTAL

25 CYCLES 500 μ



50 CYCLES 500 μ

500 CYCLES 500 μ



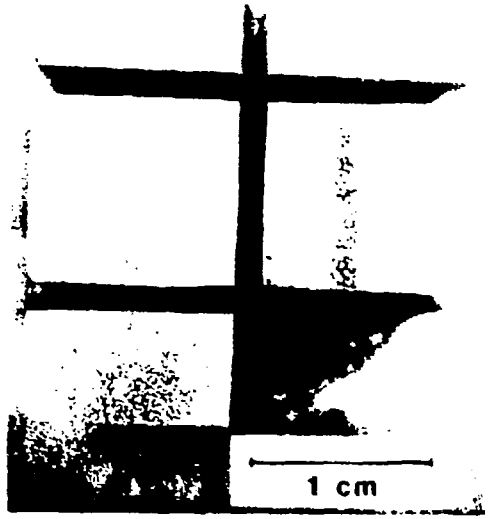
1000 CYCLES 500 μ

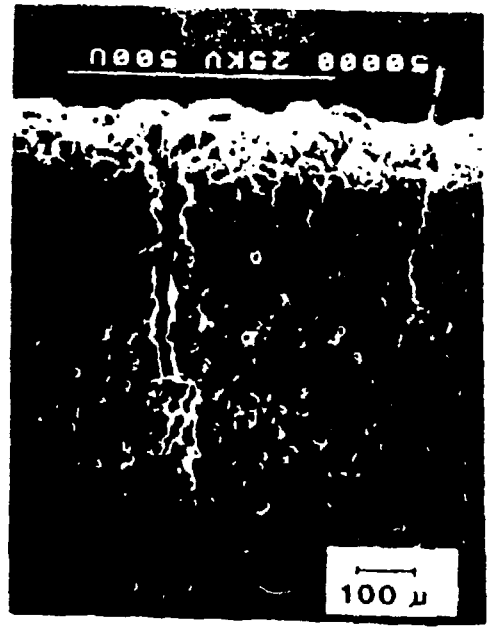
1000 CYCLES

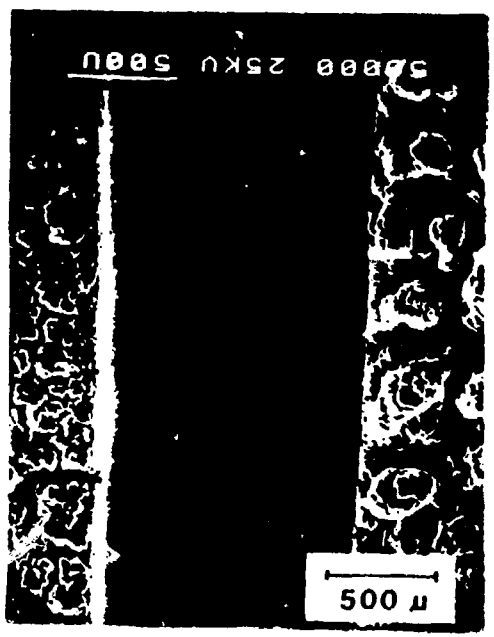
SLOTTED & ETCHED CUBE

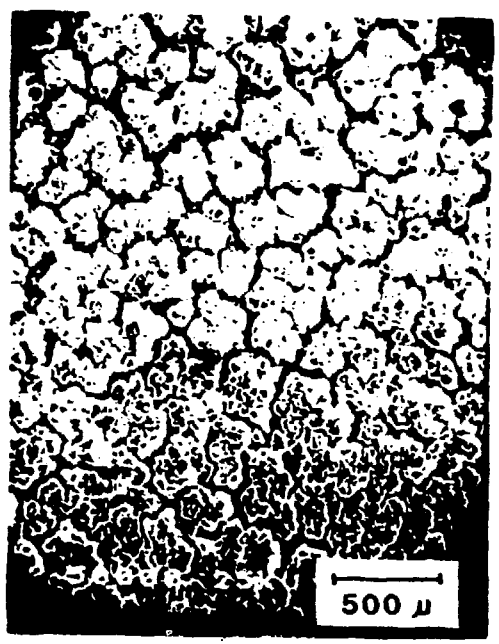
TEST CONDITIONS

- 2.5 cm S-65-B CUBE
- SLOTTED/ETCHED SURFACE
- 2.5 kW/cm^2 HEAT FLUX
- 0.3 SECOND PULSES
- 60 SECOND INTERVALS
- 1000 CYCLES TOTAL









F. ELECTROMAGNETIC RESPONSE

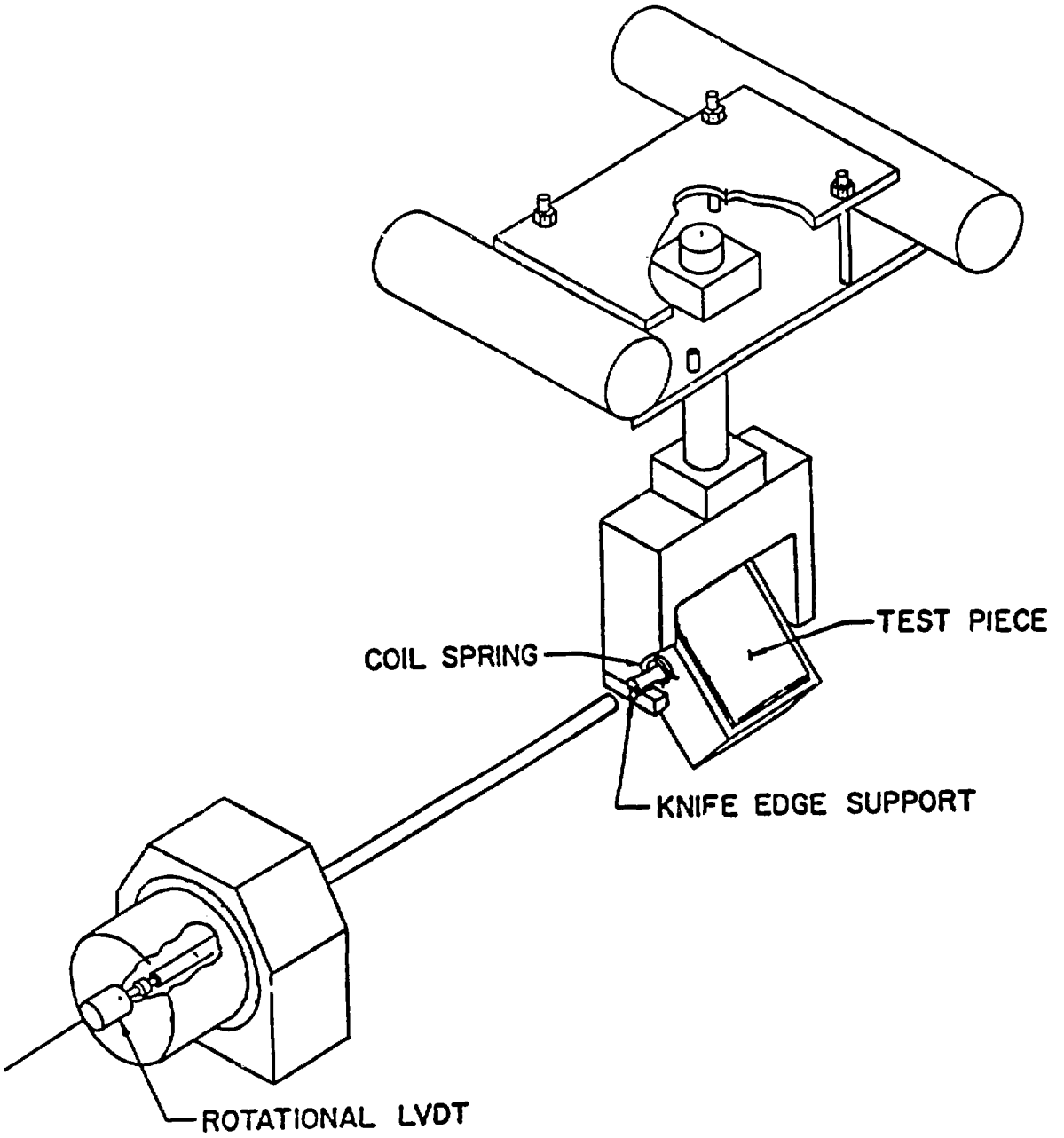
1. 3-D EDDY CURRENT CODE AS DESIGN TOOL

2. INTEGRATION WITH FINITE ELEMENT STRESS ANALYSIS, INCLUDING MAGNETIC DAMPING

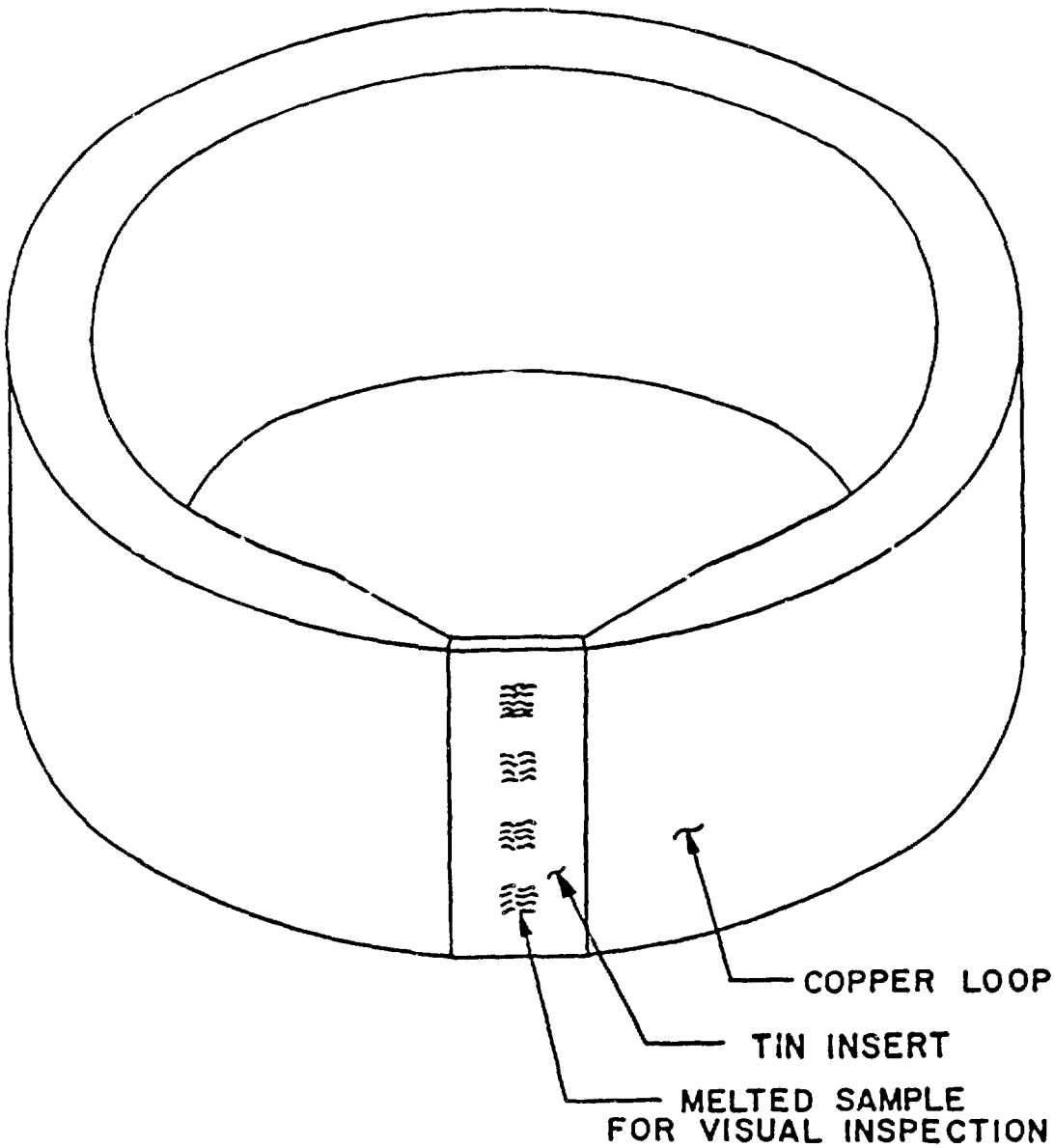
3. BENCHMARK EXPERIMENTS

Codes to be Used for Analyzing FELIX Experiments

Experiment	Codes
1. Cylinders	EDDYNET-3D shell approximation: EDDYNET infinite-length approximation: PE2D, NMLMAP
2. Square Tubes	infinite-length approximation: PE2D, NMLMAP
3. Bricks and Tiles	EDDYNET-3D
4. Limiter Concept	EDDYNET infinite length approximation: PE2D, NMLMAP
5. Segmented Blanket	EDDYNET-3D shell approximation: EDDYNET



Experimental arrangement for measuring torques developed in small test pieces such as TFTR limiter tiles and aluminum bricks. The axis of rotation is perpendicular to both the vertical dipole field and the horizontal solenoid field.



Tin test piece to observe melt layer effects, with copper loop to induce a current.

G. INSTRUMENTATION AND CONTROL

1. CONTINUOUS MONITORING OF PLASMA SIDE OF COMPONENTS

2. CONTROL SCHEMES AND ALGORITHMS

3. RADIATION HARDENING, ROBOTICS

INTERNATIONAL ACTIVITIES (STRATEGY)

W. Gauster
Sandia National Laboratories Albuquerque

INTERNATIONAL ACTIVITIES:

STRATEGY

W. B. GAUSTER

SANDIA NATIONAL LABORATORIES

DOE, GERMANTOWN

MAY 21, 1985

INTERNATIONAL COLLABORATIONS

A. SCOPE

1. VISITS, EXCHANGES

2. PARTICIPATION WITH MODEST HARDWARE

3. JOINT MAJOR PROJECTS

B. COORDINATION WITH NATIONAL PROGRAMS

C. JOINT PLANNING

D. PARITY

KEY ELEMENTS OF FOREIGN PROGRAMS

EUROPE: LONG-PULSE, HIGH POWER DENSITY MACHINES WITH EMPHASIS ON IMPURITY CONTROL ISSUES.

JAPAN: PMI AND HHF RESEARCH PROGRAMS OF BROAD SCOPE;

SUCCESSFUL INTEGRATION OF INDUSTRY INTO PROGRAM.

PRESENT ACTIVITIES

CONFERENCES

VISITS, EXCHANGES

JOINT STUDIES (INTOR, FINESSSE. . . .)

U.S. - JAPAN PROGRAM OF EXCHANGES AND WORKSHOPS

TEXTOR

ASDEX - UG

JET

U.S./JAPAN HHF WORKSHOP

J. Whitley
Sandia National Laboratories Albuquerque

U.S./JAPAN WORKSHOP

ON

HIGH HEAT FLUX MATERIALS

(EXCHANGE Q-34)

MARCH 11 - 13, 1985

HOSTED BY

SANDIA NATIONAL LABORATORIES

ALBUQUERQUE, NEW MEXICO

ATTENDEES

JAPAN

HIROSHI KAWAMURA	JAERI
YOSHIHISA TANAKA	KAWASAKI HEAVY INDUSTRIES
TAKASHI UCHIKAWA	MITSUBISHI HEAVY INDUSTRIES

UNITED STATES

J. B.WHITLEY (CHAIRMAN)	SANDIA NATIONAL LABORATORIES
W. B. GAUSTER	ALBUQUERQUE
R. K. TRAEGER	
R. D. WATSON	
J. G. WATKINS	
J. A. KOSKI	
G. W. BROWN	
R. D. BOYD	
B. L. DOYLE	
A. E. PONTAU	SANDIA NATIONAL LABORATORIES
K. L. WILSON	LIVERMORE
M. ULRICKSON	PRINCETON PLASMA PHYSICS LABORATORY
C. G. BATHKE	LOS ALAMOS NATIONAL LABORATORY
J. N. DOWNING	
C. COPENHAVER	
C. D. CROESSMANN	UNIVERSITY OF WISCONSIN

AGENDA

U.S.-JAPAN EXCHANGE Q-34, HIGH HEAT FLUX MATERIALS

MONDAY, MARCH 11

WELCOME AND INTRODUCTION TO WORKSHOP	G. W. BROWN, SANDIA-ALBUQUERQUE
OVERVIEW OF JAPANESE HIGH HEAT FLUX MATERIALS PROGRAM AND MAJOR FACILITIES	H. KAWAMURA, JAERI
DESIGN OF HIGH HEAT FLUX COMPONENTS AND IMPURITY CONTROL SYSTEMS FOR JT-60	H. KAWAMURA, JAERI
DESIGN OF HIGH HEAT FLUX COMPONENTS FOR FER	Y. TANAKA, KAWASAKI HEAVY INDUSTRY
R & D WORK ON HIGH HEAT FLUX COMPONENTS	H. KAWAMURA, JAERI
DESIGN AND THERMAL TESTING OF GRAPHITE BUMPER LIMITER	T. UCHIKAWA, MITSUBISHI HEAVY INDUSTRIES
DISRUPTION STUDIES	H. KAWAMURA, JAERI Y. TANAKA, KAWASAKI HEAVY INDUSTRIES

LIMITER DESIGN FOR TFTR AND FOR A NEXT MACHINE	M. ULRICKSON, PPPL
HIGH HEAT FLUX MATERIALS ISSUES FOR MIRRORS	K. WILSON, SANDIA-LIVERMORE
COMPONENT DESIGN FOR ZT-H	J. DOWNING, LOS ALAMOS NAT LAB
DIVERTOR DESIGNS IN RFP'S	C. BATHKE, LOS ALAMOS NAT LAB
ANALYSIS OF LIMITER SURFACES AFTER TOKAMAK EXPOSURE	B. DOYLE, SANDIA-ALBUQUERQUE
A STUDY OF COATINGS FOR TFTR LIMITERS	A. PONTAU, SANDIA-LIVERMORE

TUESDAY, MARCH 12

APPLIED RESEARCH IN HEAT REMOVAL TECHNOLOGY	R. BOYD, SANDIA-ALBUQUERQUE
HIGH HEAT FLUX TEST FACILITIES	J. WHITLEY, SANDIA-ALBUQUERQUE
SUMMARY OF MATERIALS EXPERIENCE: BERYLLIUM, GRAPHITE, COATINGS, NEW APPROACHES	J. WHITLEY, SANDIA-ALBUQUERQUE R. WATSON, SANDIA-ALBUQUERQUE
DISRUPTION STUDIES	D. CROESSMANN UNIVERSITY OF WISCONSIN

INFLUENCE OF ION AND NEUTRON IRRADIATION ON HIGH HEAT FLUX COMPONENTS:

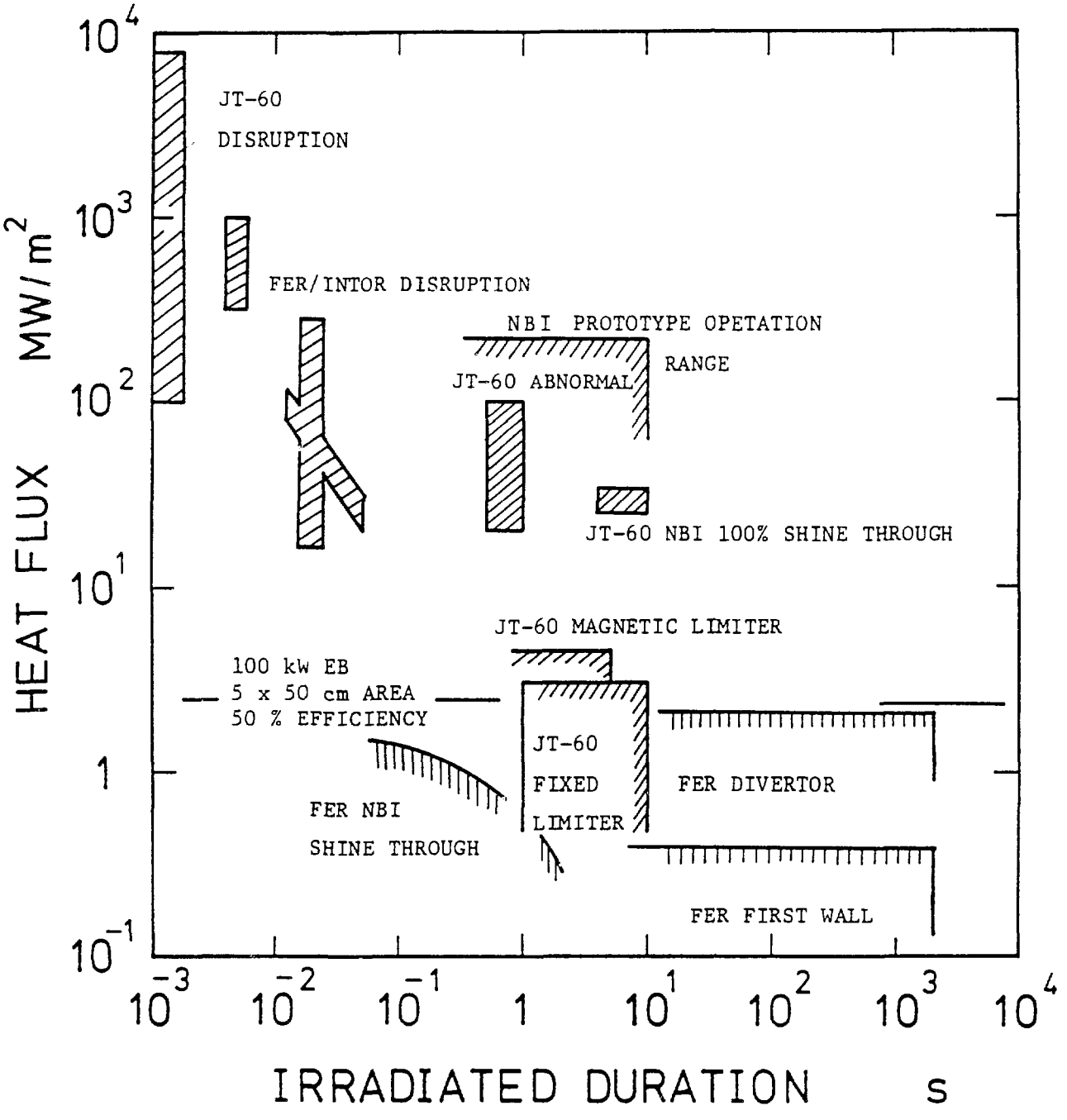
STRUCTURAL AND ACTIVATION ISSUES	J. WHITLEY, SANDIA-ALBUQUERQUE
PERMEATION, RECYCLING AND TRITIUM INVENTORY	K. WILSON, SANDIA-LIVERMORE

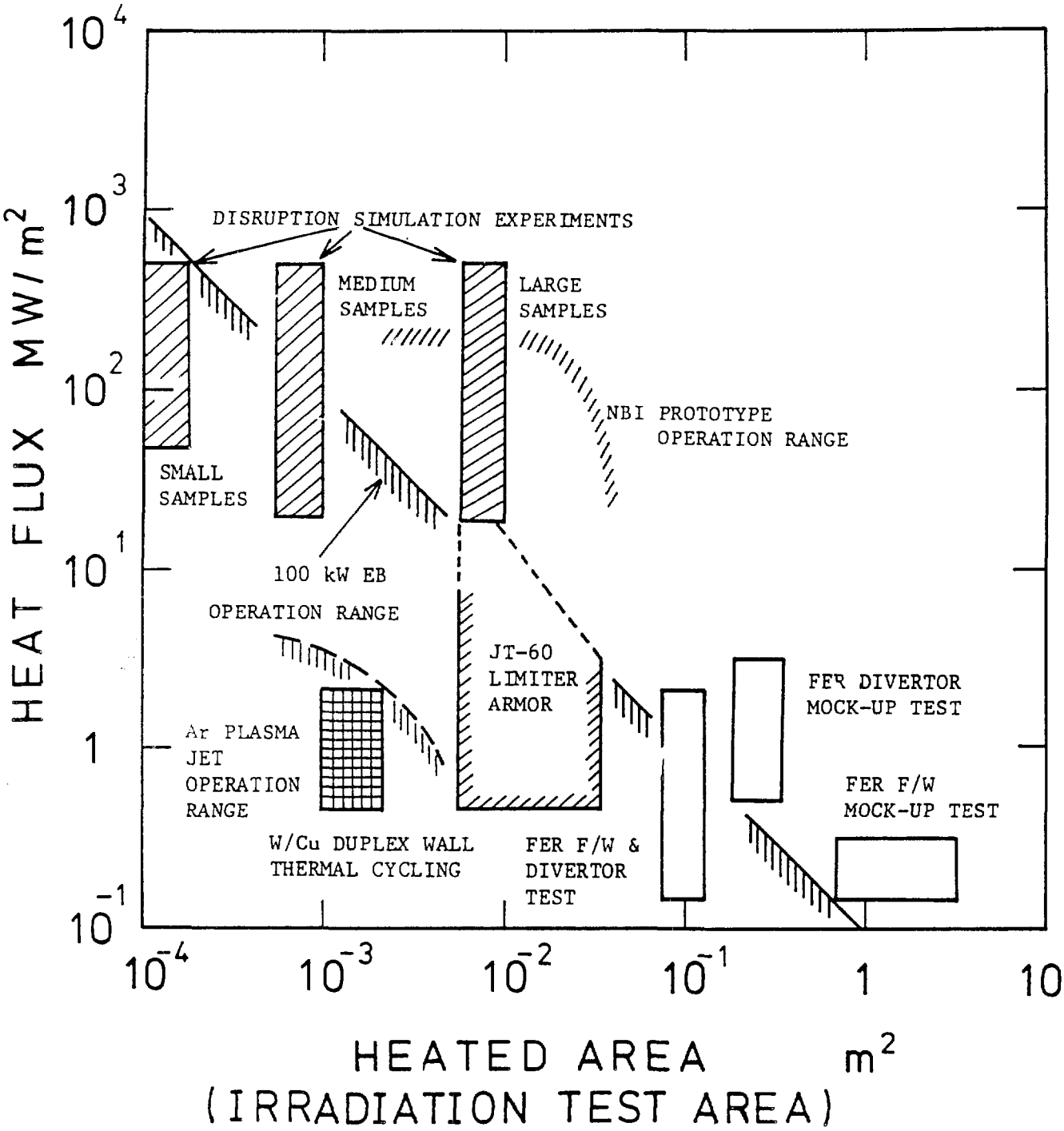
DISCUSSION AND PREPARATION OF SUMMARY

WEDNESDAY, MARCH 13

LABORATORY AND SHOP VISITS

ACCELERATOR LABORATORY	B. DOYLE, SANDIA W. WAMPLER, SANDIA
HEAT TRANSFER LABORATORY	R. BOYD, SANDIA
PLASMA MATERIALS TEST FACILITY BLDGS. 6530, M0146, T-40	J. WHITLEY, SANDIA
TOUR SANDIA SHOPS	C. L. MOSS, SANDIA
BLDGS. 840 & 841	J. L. LEDMAN, SANDIA


HEAT FLUX MW/m2
IRRADIATED DURATION s
JT-60
DISRUPTION
FER/INTOR DISRUPTION
NBI PROTOTYPE OPETATION
RANGE
JT-60 ABNORMAL
JT-60 NBI 100% SHINE THROUGH
JT-60 MAGNETIC LIMITER
100 kW EB
5 x 50 cm AREA
50 % EFFICIENCY
JT-60
FIXED
LIMITER
FER DIVERTOR
FER NBI
SHINE THROUGH
FER FIRST WALL


HEAT FLUX MW/m²
HEATED AREA m²
(IRRADIATION TEST AREA)
DISRUPTION SIMULATION EXPERIMENTS
SMALL SAMPLES
MEDIUM SAMPLES
LARGE SAMPLES
NBI PROTOTYPE OPERATION RANGE
100 kW EB OPERATION RANGE
JT-60 LIMITER ARMOR
FER DIVERTOR MOCK-UP TEST
Ar PLASMA JET OPERATION RANGE
FER F/W MOCK-UP TEST
W/Cu DUPLEX WALL THERMAL CYCLING
FER F/W & DIVERTOR TEST

A FEW OBSERVATIONS ON THE JAPANESE PROGRAM:

- ARE CONSIDERING A PUMP LIMITER EXPERIMENT FOR JT-60 (2 SITES).
- ARE CONSIDERING SWITCH TO C LIMITERS FOR JT-60.
- FOR JT-60, HAVE SELECTED PLASMA CVD TO APPLY TIC ON MO AND HOLLOW CATHODE REACTIVE EVAPORATION TO APPLY TIC TO INCONEL (TI TRANSITION LAZER).
- HAVE FOUR SITES ON JT-60 TO DO IN-SITU DEPOSITION USING REACTIVE EVAPORATION.
- FOR FER, ARE EVALUATING MANY MATERIALS: W ON CU, C, TIC, SIC, BE, ETC.
- FOR TESTING, THEY ARE CURRENTLY UTILIZING SEVERAL EXISTING FACILITIES (E-BEAM AND ARC-JET). THEY HAVE A NEW 100 KW E-BEAM PLANNED TO BEGIN OPERATION IN 1988.

JOINT RECOMMENDATIONS ON COOPERATION FROM U.S. AND JAPANESE DELEGATIONS TO THE WORKSHOP ON HIGH HEAT FLUX MATERIALS

THE U.S.-JAPAN WORKSHOP ON HIGH HEAT FLUX MATERIALS AND COMPONENTS (EXCHANGE Q-34) WAS HELD IN ALBUQUERQUE ON MARCH 11 -13, 1985. THE FOLLOWING DRAFT RECOMMENDATIONS WERE COMPILED BY THE U.S. WORKSHOP CHAIRMAN, DR. JOHN B. WHITLEY (SANDIA) AND DR. HIROSHI KAWAMURA (JAERI). IT SHOULD BE NOTED THAT THESE RECOMMENDATIONS ARE INTENDED AS A DRAFT AND DO NOT REPRESENT A COMMITMENT BY EITHER SIDE.

THE RECOMMENDATIONS ARE DIRECTED TOWARD ACHIEVING TWO GENERAL GOALS: (1) TO PROVIDE FOR EFFICIENT EXCHANGE OF INFORMATION AND USE OF ANALYTICAL CAPABILITIES TO GAIN THE MAXIMUM AMOUNT OF INFORMATION FROM CURRENTLY OPERATING DEVICES, AND (2) TO PROVIDE THE PROGRAMS OF BOTH COUNTRIES WITH THE DATA BASE AND TEST CAPABILITIES NECESSARY TO EFFICIENTLY UNDERTAKE THE DESIGN OF A DEUTERIUM-TRITIUM IGNITION DEVICE.

RECOMMENDATIONS:

A. DESIGN DATA

- PROVIDE FOR THE EXCHANGE AND DISCUSSION OF HIGH HEAT FLUX COMPONENT DESIGN INFORMATION, INCLUDING GENERAL DISCUSSIONS ON BASIC APPROACHES AND CONCEPTS.

B. PROMOTE EXCHANGE ON JT-60

- PROPOSE U.S. PARTICIPATION IN LIMITER EXPERIMENTS TO DETERMINE HEAT LOADS, POWER SHARING, ENERGY BALANCE, PLASMA SCRAPE-OFF LENGTHS, DISRUPTION CHARACTERISTICS, MATERIALS RESPONSE, ETC.;
- UNDERTAKE A FREQUENT EXCHANGE OF INFORMATION ON PUMP LIMITER EXPERIMENTS, INCLUDING EXCHANGE OF PERSONNEL;
- FREQUENT EXCHANGE OF INFORMATION ON MATERIALS BEHAVIOR IN FUSION DEVICES.

C. PROVIDE FOR MATERIALS DATA BASE EXCHANGE

- BULK PROPERTY DATA, ESPECIALLY THERMO-PHYSICAL PROPERTIES, MECHANICAL PROPERTIES AND THERMAL SHOCK/FATIGUE DATA;
- LOW DOSE NEUTRON IRRADIATION EFFECTS DATA, ESPECIALLY ON COATINGS AND CLADDINGS;
- TRITIUM (H ISOTOPE) BEHAVIOR;
- ADVANCED MATERIALS, E.G., CERAMIC DATA.

D. ION BEAM ANALYSIS

- PROPOSE THE USE OF U.S. ION BEAM ANALYSIS CAPABILITIES FOR JT-60 AND OTHER DEVICE COMPONENTS TO STUDY EROSION, DEPOSITION, HYDROGEN LEVELS, ETC., WHERE APPLICABLE.

E. PROMOTE THE EXCHANGE OF HEAT TRANSFER DATA

- SANDIA PROGRAM IS FOCUSING ON TWO-PHASE (SUB-COOLED) BOILING;
- JAERI IS FOCUSING ON SINGLE-PHASE, FORCED COOLING;

THESE PROGRAMS ARE COMPLEMENTARY AND THUS AN ONGOING EXCHANGE OF DATA AND/OR ANALYSIS CODE CAPABILITIES SHOULD BE PLANNED.

F. DISRUPTION STUDIES

- THERE EXISTS IN BOTH COUNTRIES AN ACTIVE PROGRAM TO BETTER UNDERSTAND THIS PROBLEM. FREQUENT EXCHANGES OF INFORMATION WOULD BE VALUABLE IN THIS AREA.

G. PROPOSE JOINT USE OF TEST FACILITIES, WHERE APPLICABLE, INCLUDING SHORT-TERM EXCHANGE OF SCIENTISTS TO PERFORM TESTS

- PLASMA MATERIALS TEST FACILITY, BOTH THE ELECTRON BEAM AND ION BEAM SYSTEMS (U.S.);
- TRITIUM PLASMA EXPERIMENT (U.S.);
- ARGON PLASMA HEATING APPARATUS (ARPHA) (JAPAN).

H. WORKSHOPS

- TO ACHIEVE MANY OF THE ABOVE GOALS, EXCHANGE WORKSHOPS SHOULD BE REGULARLY HELD, ALTERNATING WHEN POSSIBLE BETWEEN THE TWO COUNTRIES.

U.S./CANADA TRITIUM WORKSHOP

K. L. WILSON
SANDIA NATIONAL LABORATORIES
LIVERMORE

EXPLORING MUTUAL INTERESTS IN FUNDAMENTAL STUDIES OF TRITIUM TRANSPORT IN MAGNETIC FUSION ENERGY MATERIALS

U. S. DEPARTMENT OF ENERGY
AND
CANADIAN FUSION FUELS TECHNOLOGY PROJECT

JANUARY 17, 1985

SANDIA NATIONAL LABORATORIES
LIVERMORE, CA 94550

Department of Energy
Washington, D.C. 20545

DEC 10 1984

To Those on the Enclosed List

Gentlemen:

As you probably know, U.S. and Canadian researchers in the areas of tritium transport and retention in magnetic fusion materials have begun informal exploration for areas of mutual interest which might better serve both U.S. and Canadian objectives as elements of a more closely coordinated program. As part of this process, I would like to invite you to a meeting designed to further investigate any commonalities of interest.

This meeting on the topic of "Exploring Mutual Interests in Fundamental Studies of Tritium Transport in Magnetic Fusion Energy Materials," will be held at Sandia National Laboratories, Livermore, California, on January 17, 1985. A tentative agenda and list of attendees are enclosed.

If you have any questions, please feel free to contact Marvin M. Cohen at 301-353-4253.

Sincerely,

Gregory M. Haas

Gregory M. Haas, Chief
Reactor Technologies Branch
Division of Development and Technology
Office of Fusion Energy
Office of Energy Research

List of Attendees

Canada

D. P. Dautovich, Canadian Centre for Fusion Fuels Technology
A. A. Haasz, University of Toronto
G. Kidson, Whiteshell Nuclear Research Establishment

United States

W. L. Barr, Lawrence Livermore National Laboratories
M. I. Baskes, Sandia National Laboratories
W. Bauer, Sandia National Laboratories
R. S. Claassen, Sandia National Laboratories
H. Conrads, Princeton Plasma Physics Laboratory
D. Heikkinen, Lawrence Livermore National Laboratories
N. Hoffman, ETEC
D. F. Holland, Idaho National Engineering Laboratory
P. Hsu, DOE, Idaho Operations Office
G. R. Longhurst, EG&G
W. A. Swansiger, Sandia National Laboratories
K. L. Wilson, Sandia National Laboratories

AGENDA

Meeting to "Explore Mutual Interests in Fundamental Studies of Tritium Transport in Fusion Reactor Materials"
U.S. Department of Energy - Canadian Fusion Fuels Technology Program
Sandia National Laboratories, Livermore, California
January 17, 1985 - Building 905, room 210

Introduction	R. Claassen (VP, SNL)	8:30 a.m.
Summary of U.S. Research Program in Materials	W. Bauer (SNL)	8:45 a.m.
CFFTP Research Program Summary	D. Doutovitch (CFFTP)	9:00 a.m.
Tritium Issues in TFTR and and TFCX	M. Conrads (PPPL)	9:15 a.m.
The RTNS-II Facility	D. Heikkinen (LLNL)	9:30 a.m.
Tritium Retention Studies		9:45 a.m.
CFFTP	A. Haasz (U. of Toronto)	
SANDIA	K. Wilson (SNL)	
INEL	D. Holland (INEL)	
----- Break -----		10:30 a.m.
Effects of Radiation on Tritium Transport: The In-Pile Experiment.	K. Wilson (SNL) G. Longhurst (INEL)	10:45 a.m.
CFFTP Critique	CFFTP Representative	11:15 a.m.
----- Lunch -----		12:00 noon
Explorations of a Possible Collaborative Activity		1:00 p.m.
Summary and Future Plans		2:30 p.m.
Tour of Sandia's Tritium Research Laboratory		3:00 p.m.

CFFTP

OBJECTIVES

- TRANSFER SELECTED CANDU NUCLEAR TECHNOLOGY INTO FUSION
- DEVELOP SELECTED NEW FUSION TECHNOLOGY AS REQUIRED BY INTERNATIONAL PROGRAMS
- ENCOURAGE CANADIAN INDUSTRIAL INVOLVEMENT
- RAISE NATIONAL LEVEL OF CAPABILITY AND KNOWLEDGE IN FUSION TO FACILITATE FUTURE INVOLVEMENT IN FUSION POWER SYSTEMS

OVERALL FOCUS AND ORIENTATION

- TRITIUM
- REMOTE HANDLING
- R&D
- ENGINEERING
- STAFF ATTACHMENTS
- COLLABORATIVE

SCOPE AND BUDGET

- EMBRACE TRITIUM OR NUCLEAR TECHNOLOGY AREAS
  - TRITIUM
  - BREEDING
  - MATERIALS
  - EQUIPMENT (REMOTE HANDLING)
  - SAFETY AND ENVIRONMENT
- ENTERING 4TH OF 5 YEAR CURRENT PROGRAM
- TOTAL BUDGET OF 16.5M
  - 4.2M FOR YEAR 4
  - 4.4M FOR YEAR 5
  - SUPPLEMENTED ~ 30% ADDITIONAL BY PARTICIPANTS
- ANTICIPATE 1M/YEAR EXTERNAL CONTRACTS ARRANGED BY CFFTP

MATERIALS TECHNOLOGY

- BUDGET ~ 0.5M/YR SUPPLEMENTED BY 30% = 0.65 M/YR
- FOCUS ON PERMEATION, BARRIERS, RETENTION, FIRST WALL AND OTHER TRITIUM SYSTEMS

U.S. COLLABORATION

- STRONGLY WELCOMED
- DO NOT EXPECT TO INCREASE PROGRAM SIZE IN MATERIALS AREA
- HOPE TO ARRANGE BETTER FOCUSSING OF EFFORT AND INCREASED RELEVANCE

IV. Recommendations

Recommendations from this meeting are summarized below:

1) There should be the formation of a panel, made up from attendees of this meeting, to act as a forum for future discussions. In particular, this panel should serve to focus research in the area of fundamental tritium-materials interactions and to provide guidance for future directions.

2) Further definition is required to determine how much (if any) the U. S. and Canadian programs should be intermeshed technically.

3) Collaborations should be sought out that are of mutual benefit to both the U. S. and Canadian programs. The previously discussed list of technical points of mutual interest should be explored in more detail.

4) Finally, it is acknowledged that the lack of a U. S. Canadian bilateral agreement is an impediment to future collaborative efforts. We recommend that this agreement should be finalized as quickly as possible. In the absence of ratification, the possibility of a Memorandum of Understanding for specific collaborative experiments should be pursued as a short-term alternative.

AREAS OF MUTUAL INTEREST

Issue	Timeframe Relevancy
1. Tritium properties of redeposited materials (tokamakium)	Current (TFTR, JET)
2. Low atomic number limiter materials (C, Be, etc.) interactions with tritium	Current (TFTR, JET) and beyond
3. Tritium permeation in neutron-irradiated first wall metals	Burning Core Experiment (BCX) and Reactors
4. Multi-layered tritium permeation barriers	BCX and Reactors
5. Gas driven permeation through blanket materials	Reactors

PUMP LIMITER WORKSHOP

D. Goebel
University of California Los Angeles

AGENDA
US/JAPAN WORKSHOP ON PUMP LIMITER PHYSICS AND EXPERIMENTS

Room 4442 Boelter Hall
School of Engineering and Applied Sciences
University of California, Los Angeles
June 18-21, 1985

Day 1, Tuesday June 18

TIME	TITLE	SPEAKER
1:00 p.m.	Welcome (15 min)	R.W. Conn (UCLA)
1:15	Introduction and Workshop Purpose and Objectives (30 min)	A. Miyahara (IPP-NAGOYA)
1:45	Outstanding Issues In Pump Limiter Physics and Experiments (30 min)	R.W. Conn (UCLA)
2:15	Status of US/JAPAN/EUROPE Collaboration on ALT-II and ALT-II Physics Design Status (30 min)	R.W. Conn (UCLA)
2:45	Coffee Break (15 min)	
3:00	Divertor Studies on Big Dee (60 min)	A. Mahdavi (GA)
4:00	Recycling in Tokamaks	M. Shimada
5:00	Close	

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DAY 2, WEDNESDAY JUNE 19

TIME	TITLE	SPEAKER
8:30 a.m.	Experimental Pump Limiter Results on ISX-B (45 min)	P. Miodusewski (ORNL)
9:15	Results from the ALT-I Pump Limiter Experiment on TEXTOR (30 min)	G. Campbell (UCLA)
9:45	Comments on Particle Collection (15 min)	K. Akaishi (Japan)
10:00	Discussion (15 min)	
10:15	Coffee Break (15 min)	
10:30	Results from the Rotatable Pump Limiter Experiment on PLT (30 min)	R. Budny
11:00	Pump Limiter Experiments on JIPP-T-II and JFT-2M (30 min)	Y. Ogawa (Japan)
11:30	Comments on ICRH and Pump Limiters (30 min)	K. Matsuura (Japan)
12:00 - 1:00 p.m.	LUNCH	
1:00	Pellet Injection in D-III with Limiters (30 min)	C. Foster
1:30	Pellet Injection Requirements for ALT-II (30 min)	K.N. Sato (Japan)
2:00	Discussion (15 min)	
2:15	Helium Removal by ALT-I on TEXTOR (30 min)	K.H. Finken (KFA-Juelich)
2:45	Comments on Helium Exhaust (15 min)	K.N. Sato (Japan)
3:00	Discussion (15 min)	

3:15	Coffee Break (15 min)	
3:30	Plasma Radiation and Limiter Heat Flux Measurements in D-III (30 min)	T. Petrie (GA)
4:00	Edge Plasma Diagnostics Necessary for Pump Limiter Experiments (30 min)	K. Kadota (Japan)
4:30	Pump Limiter Physics Experiments in PISCES (30 min)	D. Goebel (UCLA)
5:00	Discussion (15 min)	
5:15- close	Working Group Preliminary Discussions	

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DAY 3, THURSDAY, JUNE 20

TIME	TITLE	SPEAKER
8:30 a.m.	ALT-I and TFTR Materials Issues (30 min)	A. Pontau (SNLL)
9:00	ALT-II: Engineering Design Status (35 min)	J. Koski (SNLA)
9:30	Discussion (15 min)	
9:45	Coffee Break (15 min)	
10:00	Pump Limiter and Plasma Edge Studies on Big Dee (30 min)	T. Taylor (G.A.)
10:30	JT-60 Pump Limiter Design Status (30 min)	A. Miyahara (Japan)
11:00	Particle Guiding by Means of a Plasma Slab	Y. Sakamoto (Japan)
11:30	Discussion (15 min)	
11:45 - 12:45 p.m.	LUNCH	
12:45	Pump Limiter Experiments on Heliotron-E and ATF (30 min)	D. Hillis (ORNL)
1:15	Pump Limiter Experiments on Heliotron-E (15 min)	A. Miyahara (Japan)
1:30 - close	Working Group Discussions: (i) Particle Flows and Impurity Control	P. Miodusewski and K. Akaishi, Co-leaders
	(ii) Power Handling and Materials Issues	Y. Ogawa and T. Petrie, Co-leaders
	(iii) Future Experiments	R. Budny and K. Sato Co-leaders
	(iv) Diagnostics	K. Kadota and D. Goebel Co-leaders

* * * * * * * * * * * * *

DAY 4, FRIDAY, JUNE 21

TIME	TITLE	SPEAKER
9:00 a.m.	Summaries of Working Group Discussions	Co-leaders of each group
10:00	Coffee Break (15 min)	
10:15	Summary Presentations Continued	
11:15	Planning for ALT-II Physics Experiments with Reference to Summaries of Working Group Discussions (30 min)	A. Miyahara R.W. Conn
11:45 - 12:45pm	LUNCH	
12:45	Discussions on Japan/U.S./Europe Collaborative Program on TEXTOR	
1:45	Closing Comments (15 min)	E. Oktay
2:00	Adjourn	

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U.S./JAPAN WORKSHOP ON PMI/HHF NEEDS FOR AN IGNITION DEVICE

K. L. Wilson
Sandia National Laboratories Livermore

U. S. DOE - JAPAN

WORKSHOP Q-52

Office of Fusion Energy,
Division of Development and Technology

"Plasma-Wall Interaction
Data Needs Critical to a
Burning Core Experiment (BCX)"

June 24-28, 1985

Sandia National Laboratories
Livermore, CA 94550

Co-Chairmen: A. Miyahara — IPP Nagoya
K. L. Wilson — Sandia National Laboratories

WORKSHOP GOALS

- DEFINE THE MATERIALS REQUIREMENTS FOR PLASMA INTERACTIVE COMPONENTS IN A BCX.
- REVIEW THE EXISTING MATERIALS DATABASE FOR PMI AND HHF ISSUES.
- PRIORITIZE CRITICAL MATERIALS R & D ISSUES LEADING TO MATERIALS SELECTION FOR BCX.

U. S. DOE - JAPAN

WORKSHOP Q-52

Office of Fusion Energy,
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Co-Chairmen:	A. Miyahara	IPP Nagoya
	K. L. Wilson	Sandia National Laboratories

PRELIMINARY AGENDA

MONDAY, JUNE 24, 1985

SESSION I: BCX OVERVIEW and MATERIALS REQUIREMENTS

Session Chairman: A. Miyahara (IPP Nagoya)

J. Cecchi/J. Schmidt (PPPL)	TFCX and ISP
T. Yang (MIT)	LITE
A. Miyahara (IPP Nagoya) and S. Tsujimura (Mitsubishi)	R Project and FER
R. Behrisch (IPP Garching)	ZEPHYR
EC Representative	NET

-DISCUSSION SESSION-

SESSION II: BCX CANDIDATE MATERIALS

Session Chairman: W. Bauer (SNLL)

1. Graphite

A. Miyahara (IPP Nagoya)	Japanese Workshop Summary
R. Behrisch (IPP Nagoya)	EC Experience with Graphite
B. Doyle and A. Pontau(SNLL) M. Ulrickson and F. Dylla (PPPL)	Analysis of Graphite Performance in TFTR

2. Beryllium

P. Mioduszewski (ORNL) and R. Watson (SNL)	ISX-B Be Limiter
S. Tsujimura (Mitsubishi) and Y. Gotoh (Hitachi)	Japanese Beryllium Studies

3. Advanced Coating and Composite Concepts

S. Tsujimura (Mitsubishi)	JAERI Activities
N. Itoh (Nagoya) and T. Yamashina (Hokkaido)	Ceramics
F. Clinard (LANL)	U. S. Ceramics Studies
T. Yamashina (Hokkaido) and Y. Gotoh (Hitachi)	Thick Coatings
M. Smith (SNL)	Thick Coating Development
A. Kohyama (Tokyo)	Composite Materials
A. Krauss (ANL)	Li-Alloys
P. Trester and G. Hopkins (GA)	C-SiC Alloy

DISCUSSION SESSION-

TUESDAY, JUNE 25, 1985

SESSION III: PLASMA MATERIALS INTERACTION ISSUES FOR BCX

Session Chairman: R. Behrisch (IPP Garching)

1. Conditioning

F. Dylla (PPPL)	Materials Conditioning Studies for TFTR
Y. Sakamoto (RIKEN)	ECR Discharge Cleaning and Carbonization

2. Normal Operation

R. Mattas (ANL)	Erosion/Redeposition Modelling
D. Goebel/Y. Hirooka (UCLA)	Measurements of Erosion/Redeposition
T. Yamashina (Hokkaido) and K. Morita (Nagoya)	Erosion/Redeposition Studies
N. Itoh (Nagoya) and K. Watanabe (Toyama)	Recycling Studies
R.Causey and W. Wampler (SNL)	Hydrogen Effects in Low Z Materials
R. Watson (SNL) and J. Whitley	High Heat Flux Considerations
S. Tsujimura (Mitsubishi) and M. Shibui (Toshiba)	Compatibility and Survivability

3. Off-Normal Operation

M. Ulrickson (PPPL)	Disruption Studies in TFTR
W. Wolfer (SNL)/Croessman (Wisconsin)	Disruption Simulations
M. Shibui (Toshiba)	Disruptions
Y. Gotoh (Hitachi)	Arcing and Shinethrough

4. Neutron Effects

A. Miyahara (IPP Nagoya)	14 MeV Neutron and Runaway Electron Activation
G. Hopkins (GA) and E. Opperman (HEDL)	Neutron Irradiation Effects on Low Z Materials

DISCUSSION SESSION-

WEDNESDAY, JUNE 26, 1985

SESSION IV: RESEARCH FACILITIES

Session Chairman: N. Itoh (Nagoya)

M. Cohen (U.S.DOE)	U.S. PMI and HHF Facilities
A. Miyahara (IPP Nagoya)	Japanese Facilities

-DISCUSSION SESSION-

SESSION V: WORKING GROUP MEETINGS

	Leaders
1. Graphite	K. Morita (Nagoya) R. Behrisch (IPP Garching)
2. Beryllium	S. Tsujimura (Mitsubishi) P. Mioduszewski (ORNL)
3. Advanced Coatings/Composites	T. Yamashine (Hokkaido) W. Gauster (SNLA)
4. Areas of Future Collaboration	N. Itoh (Nagoya) W. Bauer (SNLL)

THURSDAY, JUNE 27, 1985

SESSION VI: WORKSHOP SUMMARY AND CONCLUSIONS

Session Chairman: K. Wilson (SNLL)
A. Miyahara (IPP Nagoya)

FRIDAY, JUNE 28, 1985

- Tour of Sandia Livermore and Lawrence Livermore Magnetic Fusion Energy Research Facilities

- Detailed discussions on collaborative experiments between interested Japanese, U.S., and EC representatives

JAPANESE ATTENDEES

MIYAHARA, Akira

Institute of Plasma Physics, Nagoya University

SAKAMOTO, Yuichi

Chief of Plasma Physics Laboratory, RIKEN

ITOH, Noriaki

Department of Crystalline Materials Science, Faculty of Engineering, Nagoya University

YAMASHINA, Toshiro

Department of nuclear engineering, Hokkaido University

WATANABE, Kuniaki

Tritium Research Center, Toyama University

MORITA, Kenji

Department of Crystalline Materials Science, Faculty of Engineering, Nagoya University

KOHYAMA, Akira

Department of Materials Science, Faculty of Engineering, University of Tokyo

GOTOH, Yoshitaka

Hitachi Research Laboratory, Hitachi, LTD

SHIBUI, Masao

Heavy Apparatus Engineering Laboratory, Toshiba Corporation

TSUJIMURA, Seiichi

Mitsubishi Heavy Industries, LTD

NEW INITIATIVES

W. Gauster
Sandia National Laboratories Albuquerque

INTERNATIONAL ACTIVITIES:

NEW INITIATIVES

W. B. GAUSTER

SANDIA NATIONAL LABORATORIES

DOE, GERMANTOWN

MAY 21, 1985

NEW INITIATIVES

JET: LIMITER MATERIALS

NOVEL LIMITER DESIGNS

TRITIUM PERMEATION AND INVENTORY

FUELING, EXHAUST

GENERAL MATERIALS COLLABORATION:

COORDINATED PROGRAM FOR U.S., E.C. AND JAPAN

JT-60: HOMOGENEOUS WALL AND LIMITER SURFACE

ASDEX UPGRADE: POLOIDAL DIVERTOR EXPERIMENT WITH EMPHASIS ON PLASMA EDGE PROPERTIES (ENERGY REMOVAL, IMPURITY CONTROL, HELIUM PUMPING)

TORE SUPRA: INTEGRATION OF FUELING AND IMPURITY CONTROL ELEMENTS; STEADY STATE HEAT REMOVAL

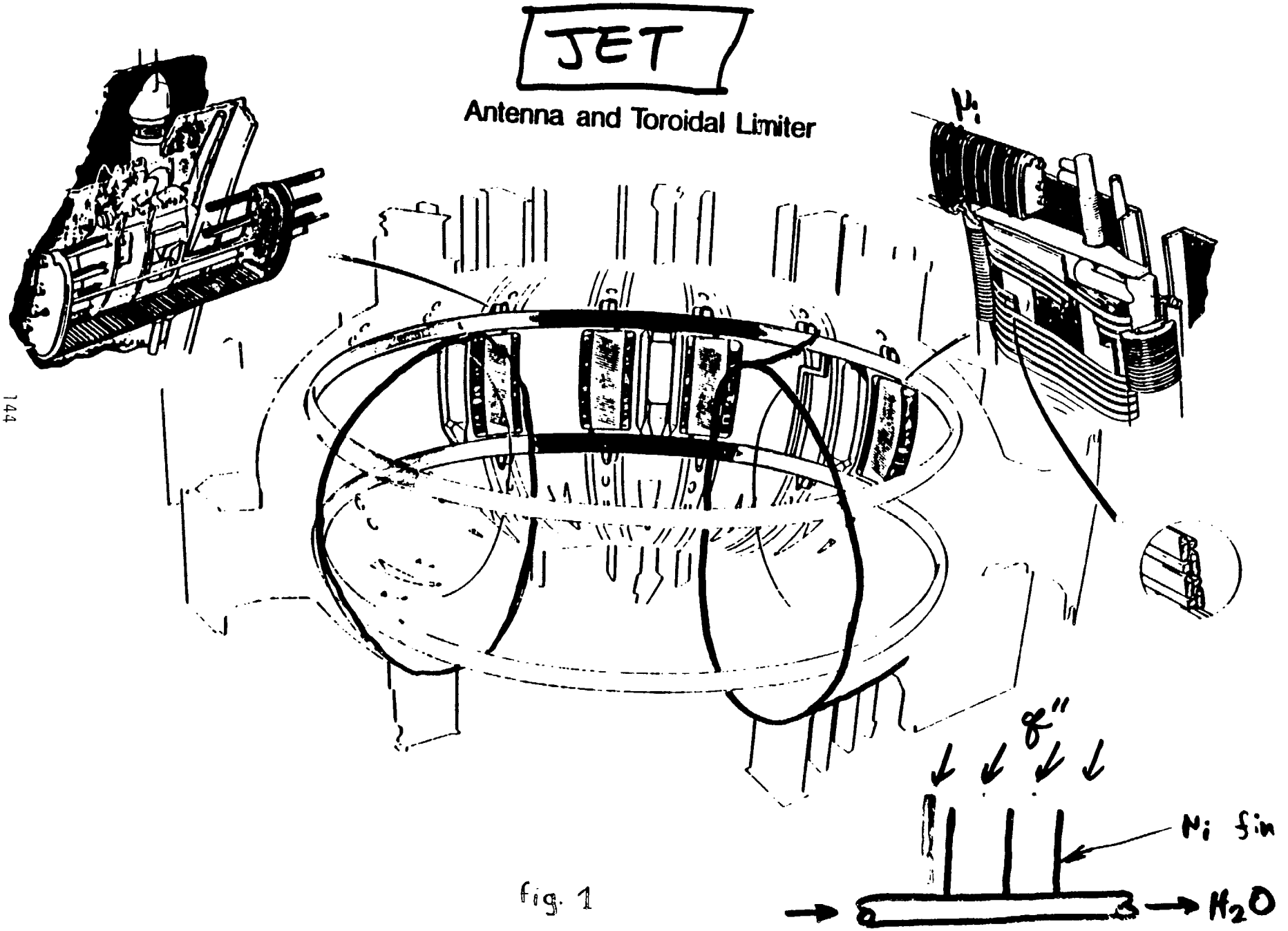


fig. 1

ASDEX UPGRADE:

A POLOIDAL DIVERTOR TOKAMAK

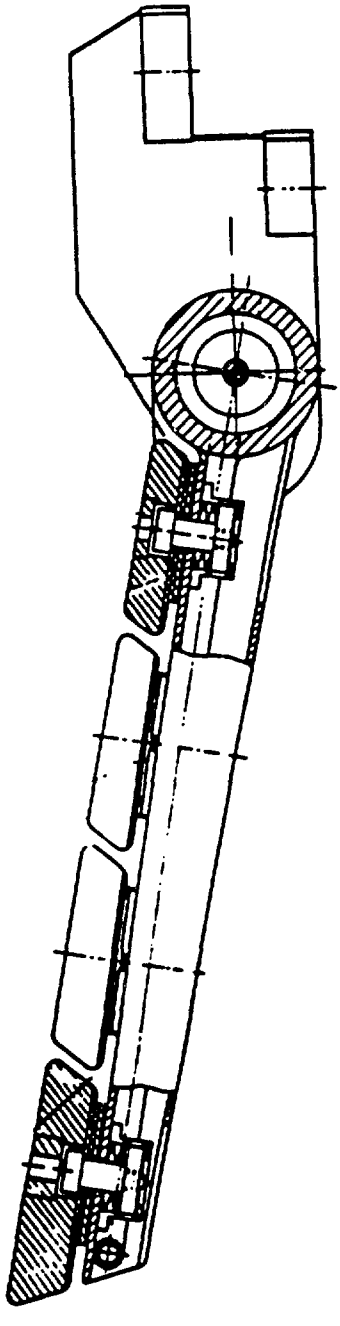
ADAPTED TO REACTOR REQUIREMENTS

Basic data

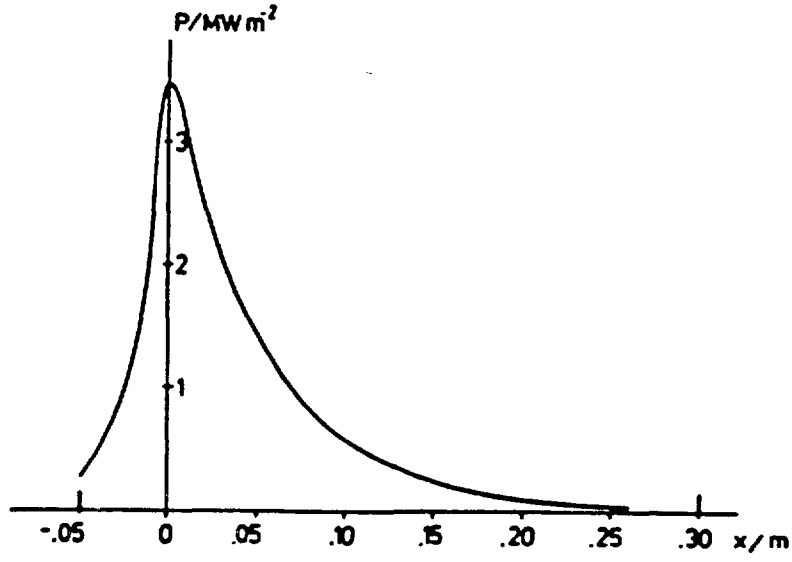
Major plasma radius	R_0	1.65 m
Minor plasma radius	a	0.5 m
Half plasma height	b	0.8 m
Plasma elongation	$s = b/a$	1.6
Plasma aspect ratio	$A = R_0/a$	3.3
Plasma current	I_p	2 MA
Toroidal magnetic field	B_0	4 T
OH flux swing	ϕ	9.5 V s

Operational regimes of AUG

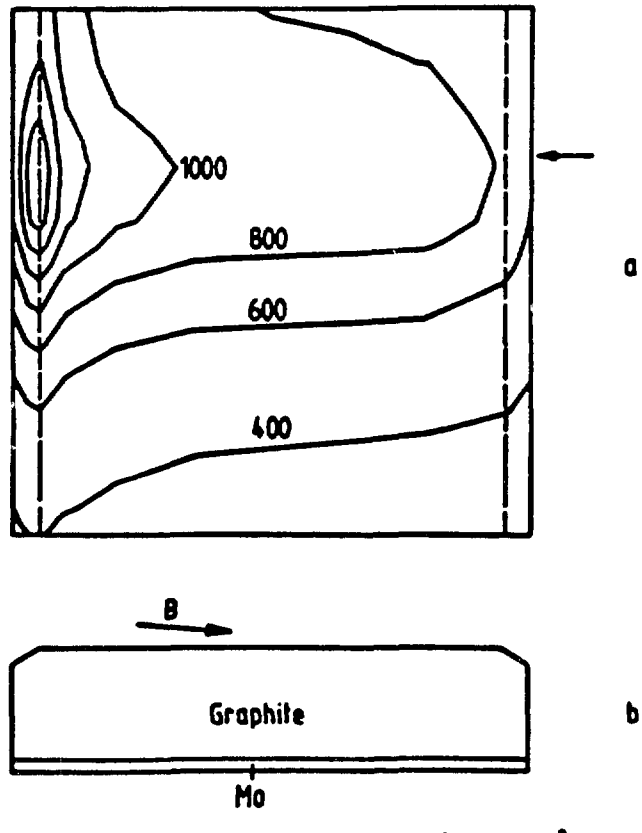
	$I_p B_0$ (MAT)	I_p (MA)	B_0 (T)	q_a	t_D (s)
SN	4.5	1.6	2.7	2.2	7
DN	3.9	1.2	3.25	3.5	5
L	6.5	2	3.25	2.1	5
LP	–	0.5	1	2.6	120



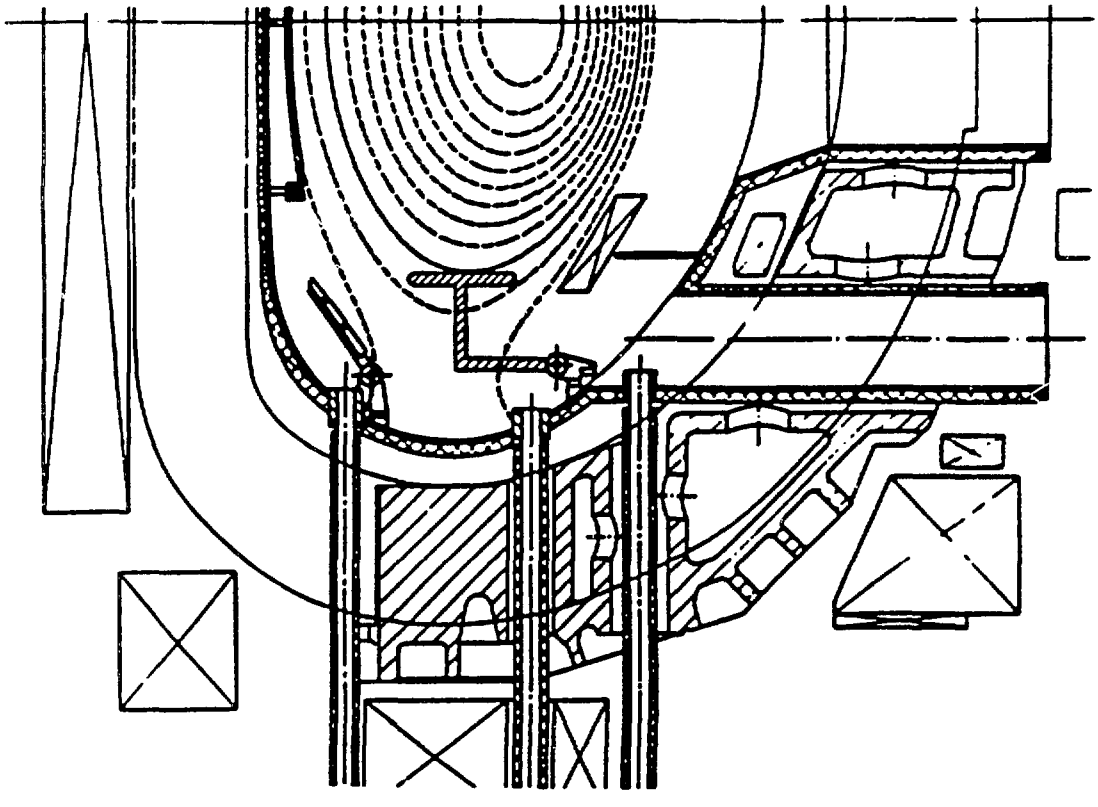
Section through the divertor tiles.



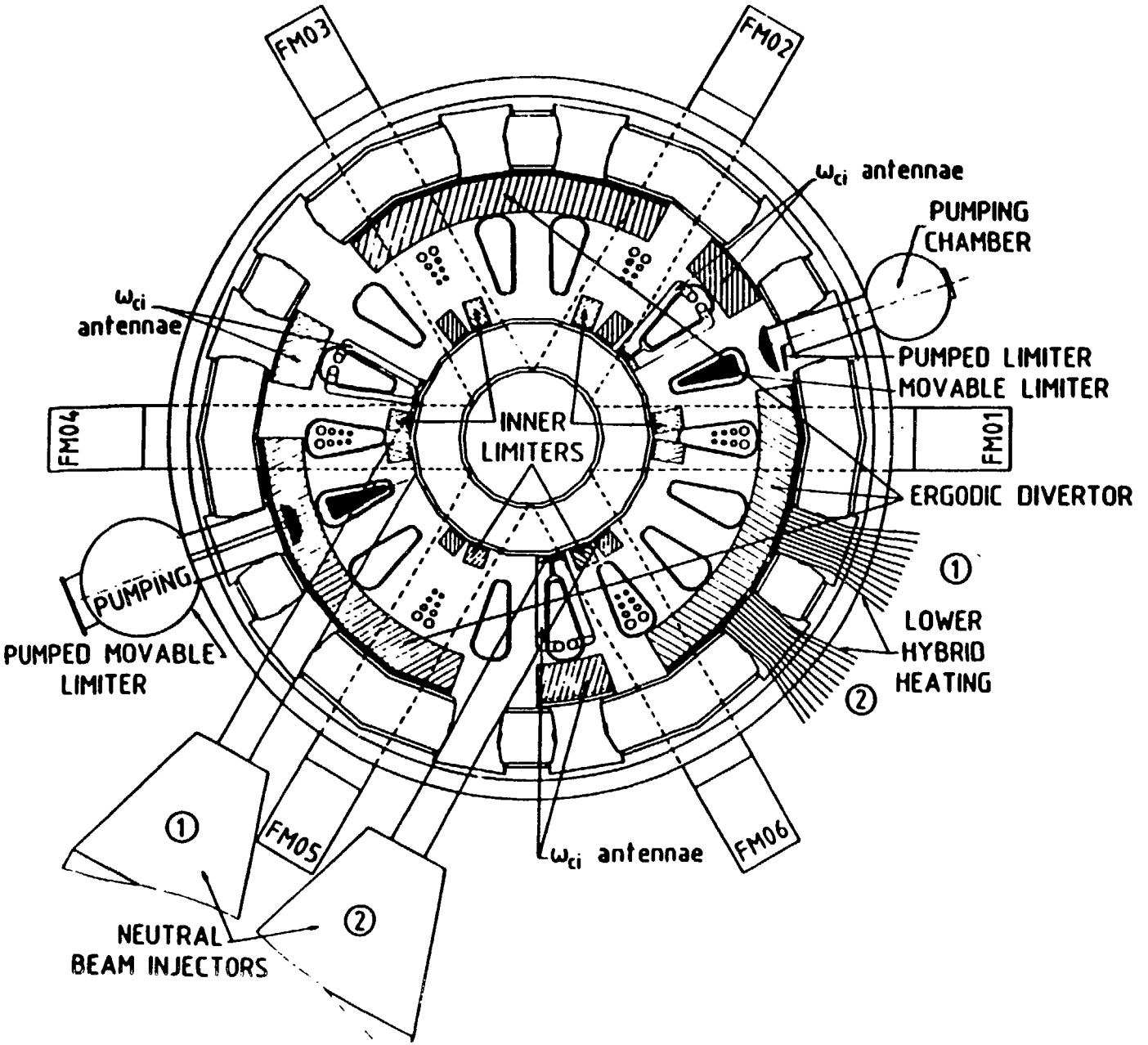
Radial distribution of heat load on the divertor plate. ($x = 0$ is the intersection of the separatrix with the plate).



Surface temperature of a 10×10 cm^2 tile of the DP at the end of a 7 s pulse. (a) Isotherms in 200 K steps. The numbers are temperature in K, base temperature is 300 K. The arrow indicates the line of intersection of the separatrix. (b) Cross-section of the tile. The orientation of the lines of force B is indicated.



Pump limiter arrangement for AUG.

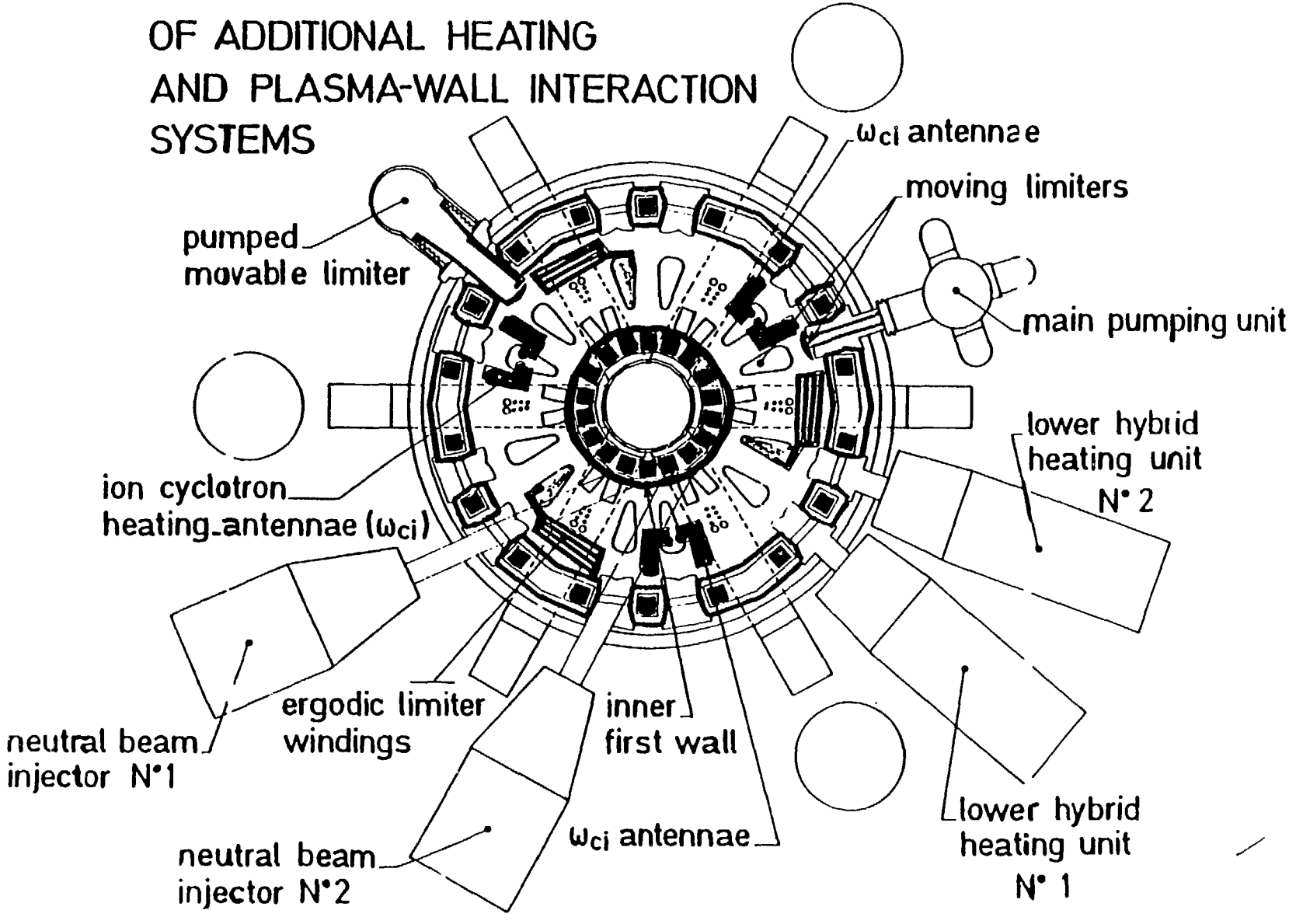

FM03
FM02
ω_{ci} antennae
PUMPING CHAMBER
ω_{ci} antennae
PUMPED LIMITER
MOVABLE LIMITER
FM04
INNER LIMITERS
FM01
ERGODIC DIVERTOR
PUMPING
PUMPED MOVABLE LIMITER
①
LOWER HYBRID HEATING
②
①
FM05
ω_{ci} antennae
FM06
②
NEUTRAL BEAM INJECTORS

Pump limiters

Edge particle τ_p/flux	10 ms/ 2×10^{23} s^{-1}	100 ms/ 2×10^{22} s^{-1}
Edge temperature (eV)	30	300
Edge velocity at limiter (cm/s)	3.4×10^{6}	10^{7}
Scrape off layer thickness (cm)	1–2	3–4
Limiter density (cm^{-3})	10^{13}	10^{13}
Density at limiter tips (cm^{-3})	3×10^{12}	1.5×10^{12}
Particle flux in limiter pumping chamber (at/s)	1.5×10^{21}	2×10^{21}
Recycling coefficient	0.99	0.9
Pumping throughout (trapping coefficient = 1) (torr l/s)	15	30
Pumping surface with Ti getter in horizontal port: 3×10^{4} cm^{2}		

$\bar{n} = 10^{14}/cm^3$, $\overline{nV} = 2\times10^{21}$ particles.

GENERAL LAY-OUT OF THE TORUS SHOWING THE LOCATION OF ADDITIONAL HEATING AND PLASMA-WALL INTERACTION SYSTEMS



OFE TECHNICAL PROGRAM PLANNING ACTIVITY

C. Baker
Argonne National Laboratory

PLANNING AND IMPLEMENTATION IS A THREE STEP PROCESS

Step 1	Establish policy	MFPP
Step 2	Develop technical plans	TPA and Fusion community
Step 3	Implement plans based on budget and other programmatic considerations	DOE/OFE

TECHNICAL PLANNING ACTIVITY (TPA)

The goal is to develop a methodology for planning the national magnetic fusion program and to prepare technical program plans in support of the strategic and policy framework of the Magnetic Fusion Program Plan (MFPP).

Time Scale: Approximately one year

PLANNING IS AN INTERACTIVE ACTIVITY INVOLVING THE ENTIRE FUSION COMMUNITY

DOE/Office of Fusion Energy

- Establishes policy (MFPP)
- Provides overall guidelines for TPA
- Reviews TPA progress
- Budget and programmatic implementation

TPA Organization

- Establishes framework, organization and guidelines for community planning activities
- Reviews community plans for consistency with MFPP and overall TPA guidelines
- Facilitates development of community consensus to help match R&D needs with available resources
- Prepares overall planning documents for DOE

Technical Fusion Community

- Defines technical issues
- Develops individual technical plans based on expert community judgment
- Participates in review of overall TPA process and plans

MFPP Goal

Establish the Scientific and Technological Base Required for Fusion Energy

TPA plans should support goal and three strategic objectives.

Strategic Objectives

Science Objective

Be able to predict, control and optimize the behavior of plasma confined in fusion relevant magnetic configurations

Technology Objective

Show that it is possible to create the unique fusion components and subsystems under conditions relevant to fusion energy sources

Technology Transfer Objective

Provide a range of options for private sector investment and commercial development of fusion

Plasma Science will be planned with an issue orientation.

Fusion Technology will be planned with a component orientation.

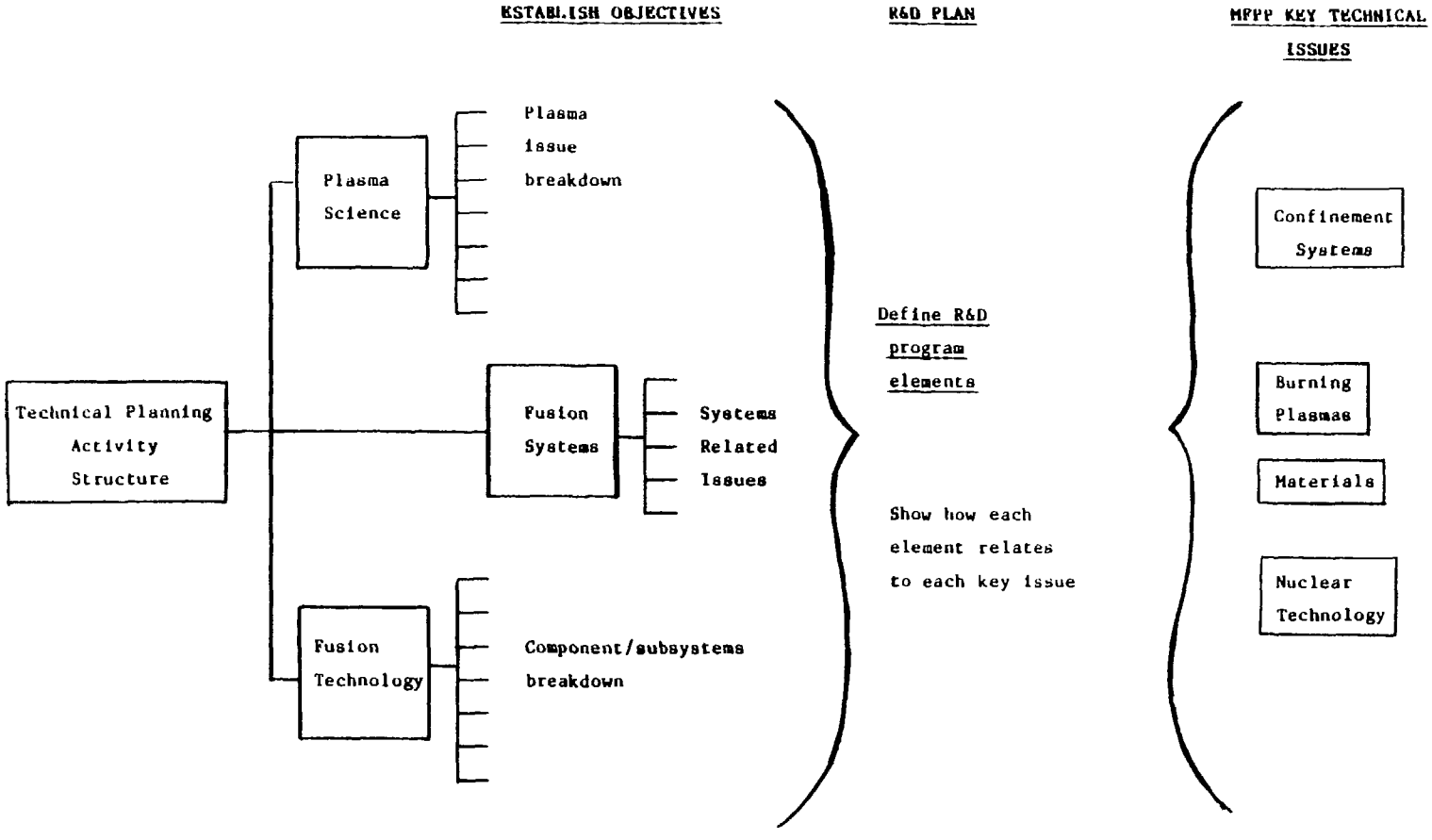
KEY TECHNICAL ISSUES

- Magnetic confinement systems
- Properties of burning plasmas
- Fusion materials
- Fusion nuclear technology

All research and development tasks identified in the TPA should support resolution of the key technical issues.

Key MFPP Features	Implications for TPA
• "Strategy adopted to reach the program goal must take into account the key technical issues, the schedule for program completion and the available resources."	• Planning should be based on realistic budget expectations, but should not be overly constrained by budget assumptions
• "The essence of the program strategy is to maintain a broad domestic R&D program with emphasis on establishing the basic elements (components or subsystems) . . . required for fusion."	• Maintain program breadth • Emphasis is on components and subsystems
• "A key feature . . . is . . . its ability to accommodate deviations from planned annual budgets	• Avoid centerpiece projects which dominate program expenditures
• "The subprogram elements are highly interrelated and are all necessary . . ."	• Need to maintain a critical effort in all four key technical areas
• "The MFPP is a strategy for solving fusion's technical problems within a time frame keyed to the resolution of problems in other areas of energy development."	• Planning horizon is about 15 + 20 years, to the "post-2000" period
• "During the next five years, a concentrated effort will be made to identify cost-effective component and system test facilities for resolving the key technical issues." [Major decisions around 1990]	• Planning emphasis will be placed on next five years. However, a conventional roll-forward approach is not adequate to meet intent of the MFPP.

Key MFPP Features	Implications for TPA
• "The purpose of the U.S. in cooperating internationally is to advance the prospects for establishing a sufficient fusion science and technology base in a timely fashion."	• The planning activity must identify needs and opportunities for effective international collaboration. • The near-term plans (next 5 years) should support the goal of reaching international consensus on the nature of future test facilities, particular integrated test facilities.
• "A number of magnetic confinement systems . . . will be investigated. However, . . . this . . . will emphasize increasing scientific understanding of the unique features of the most promising concepts, rather than attempting to develop each as a separate reactor system."	• Breadth of confinement concepts will be maintained, although the specific mix of concepts can be expected to change. • Planning will emphasize plasma physics issues and the role of various confinement concepts in resolving those issues. • Commonality and cross-fertilization of confinement physics and technology research will be emphasized.
• "Plasma-related technologies will be developed as appropriate to support the advance of experimental programs."	• The R&D requirements of plasma technology (magnets, heating/fueling systems, impurity control, etc.) will follow from the plasma science issues.
• "The focus on a practical energy goal . . . will be provided by fusion system studies. Technology transfer will be pursued by seeking industrial and utility participation in these system studies, as well as in appropriate R&D."	• A systems perspective will be used in the planning process to help maintain a focus on the overall MFPP goal. • Systems studies will also define R&D tasks. • Industrial/utility participation will be included in the plans.
• " . . . support a central research activity in the universities . . ."	• Maintain a strong university role in the plans.


ESTABLISH OBJECTIVES
R&D PLAN
MFPP KEY TECHNICAL ISSUES
Technical Planning Activity Structure
Plasma Science
Plasma issue breakdown
Fusion Systems
Systems Related Issues
Fusion Technology
Component/subsystems breakdown
Define R&D program elements
Show how each element relates to each key issue
Confinement Systems
Burning Plasmas
Materials
Nuclear Technology

PLASMA SCIENCE

PLANNING ELEMENTS

(Tentative)

- Macroscopic equilibrium and stability (β)
  - -- MHD
  - -- kinetic modifications

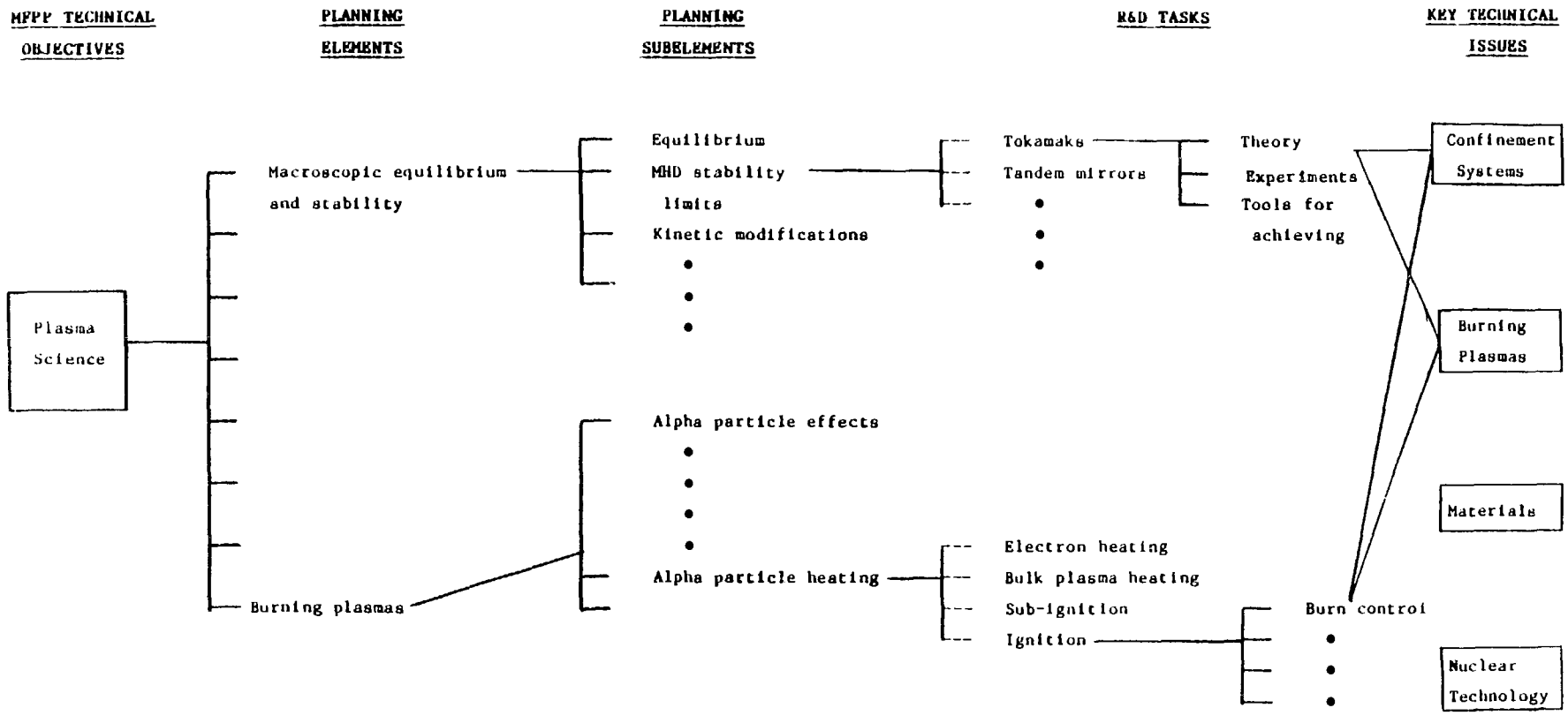
- Transport ($\eta\tau_e$)
  - -- collisional
  - -- anomalous

- Heating/fueling/current drive (T_i)
  - -- RF (LH, ICRF, ECRF)
  - -- NBI

- Impurity control (Z_{eff})
  - -- plasma/wall interactions
  - -- divertors

- Burning plasmas (Q)
  - -- alpha particle effects
  - -- alpha particle heating

EXAMPLE


MFPP TECHNICAL OBJECTIVES
PLANNING ELEMENTS
PLANNING SUBELEMENTS
R&D TASKS
KEY TECHNICAL ISSUES
Plasma Science
Macroscopic equilibrium and stability
Burning plasmas
Equilibrium
MHD stability limits
Kinetic modifications
Alpha particle effects
Alpha particle heating
Tokamaks
Tandem mirrors
Electron heating
Bulk plasma heating
Sub-ignition
Ignition
Theory
Experiments
Tools for achieving
Burn control
Confinement Systems
Burning Plasmas
Materials
Nuclear Technology

FUSION TECHNOLOGY

PLANNING ELEMENTS

(Tentative)

- First wall/blanket
  (including heat transport system)

- Plasma interactive components
  (first wall, limiter/divertors, direct convertors, etc.)

- Tritium processing/vacuum system

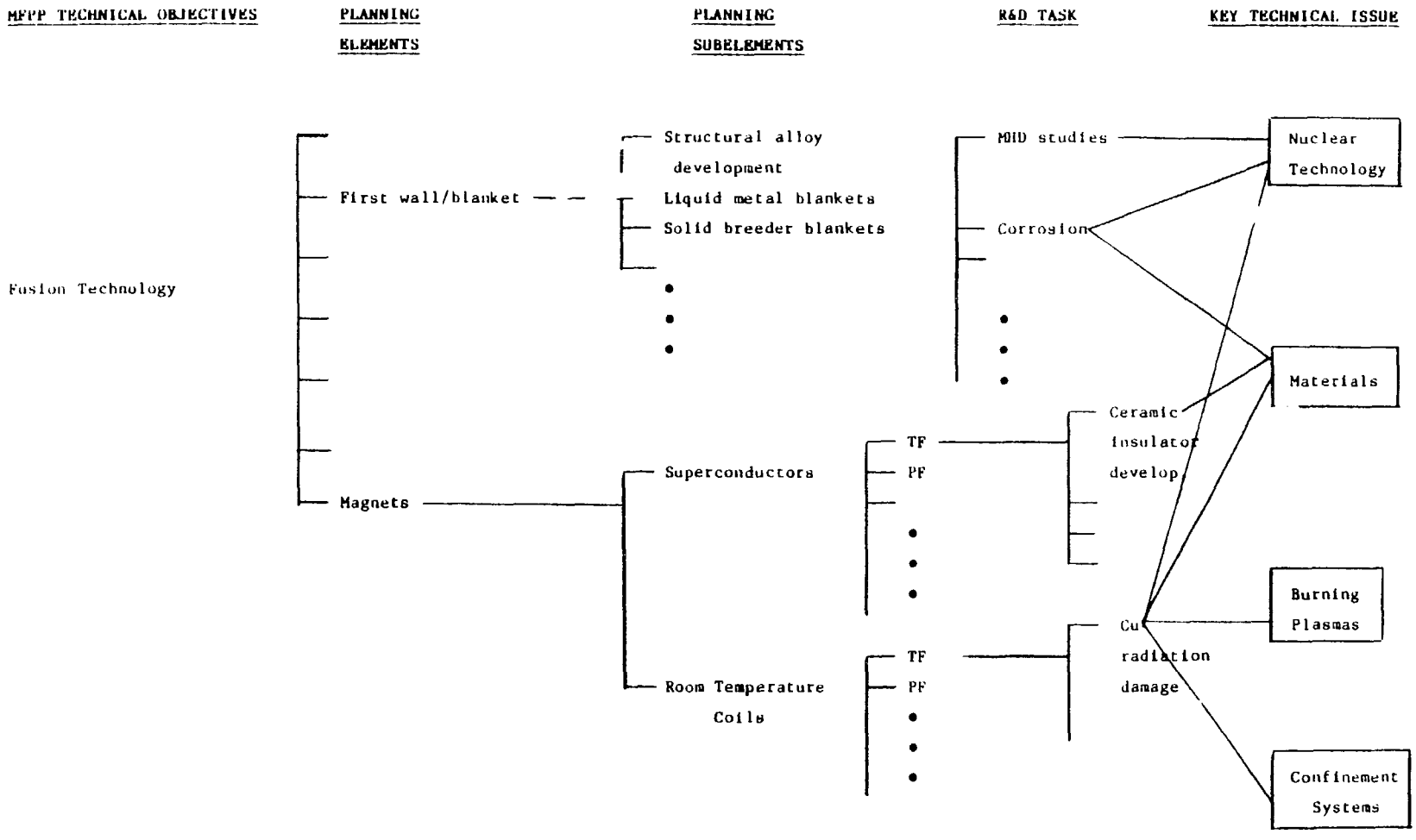
- Magnets
  (including associated power conversion systems)

- Plasma heating/fueling systems

- Remote maintenance

- Instrumentation and control systems

EXAMPLE


MFPP TECHNICAL OBJECTIVES
PLANNING ELEMENTS
PLANNING SUBELEMENTS
R&D TASK
KEY TECHNICAL ISSUE
Fusion Technology
First wall/blanket
Structural alloy development
Liquid metal blankets
Solid breeder blankets
MHD studies
Corrosion
Nuclear Technology
Materials
Magnets
Superconductors
Room Temperature Coils
TF
PF
TF
PF
Ceramic insulator develop
Cu radiation damage
Burning Plasmas
Confinement Systems

FUSION SYSTEMS
PLANNING ELEMENTS
(Tentative)

- Reactor design/assessment
- Fusion test facility design
- Technology development studies
- Non-electrical applications
- Safety and environment

FUSION SYSTEMS GROUP ACTIVITIES

- Initial emphasis

  -- Develop guidelines/perspective on desired features for fusion reactors.

  -- Assess impact on TPA of non-electrical end uses for fusion.

- Continuing emphasis

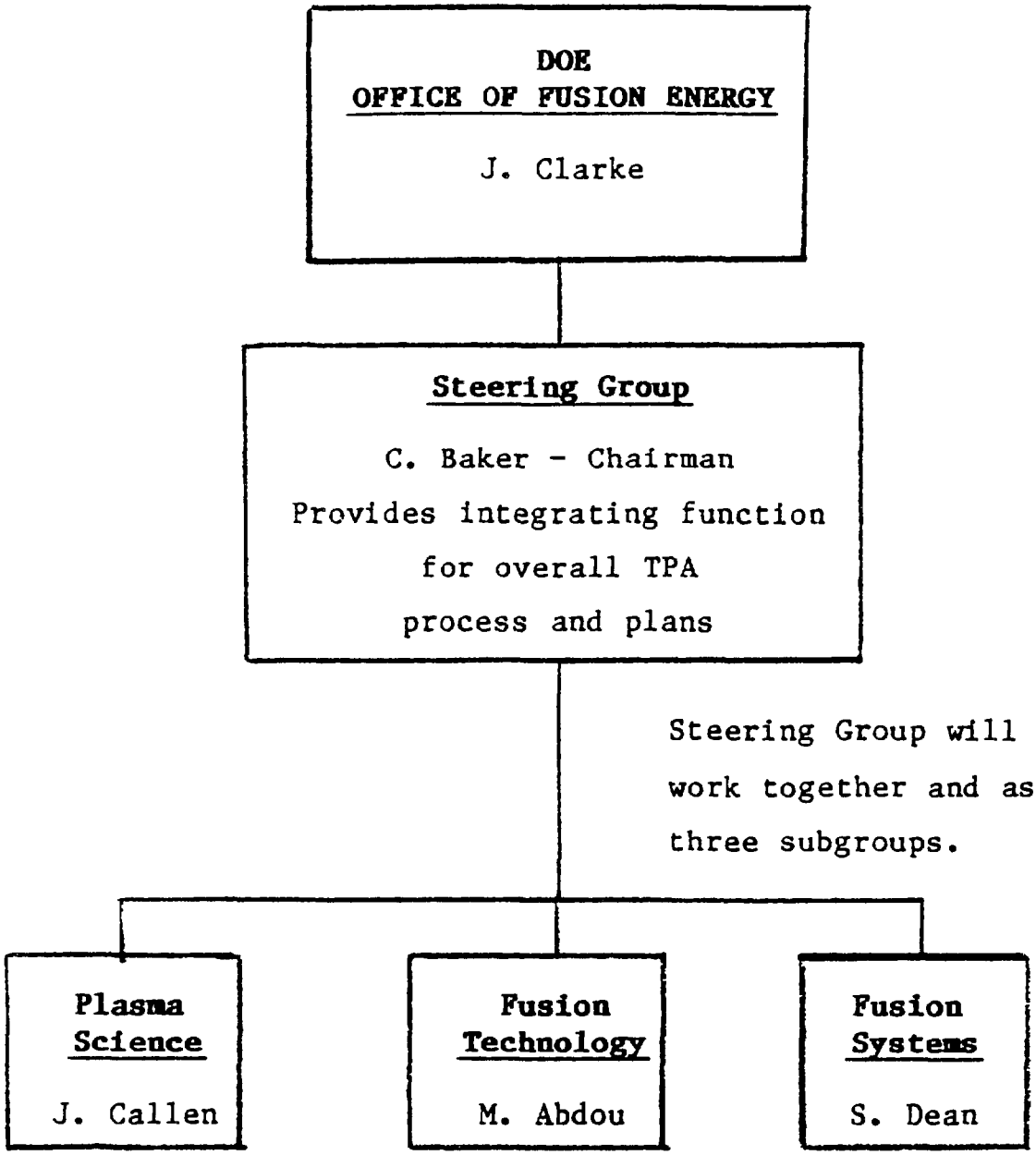
  -- Interact with plasma science and fusion technology groups to provide overall systems perspective.

  -- Develop R&D tasks.

- The general type of information to be included in the plans

  - Definition of specific goals/objectivies
  - Definition of detailed technical issues and research alternatives
  - Required data, information, tests to resolve issues to meet overall goals of MFPP
  - Types of experiments and test facilities, ongoing activities and need for new facilities
  - Technical options and scenarios, decision points, milestones
  - opportunities/needs for international collaboration
  - interfaces with other aspects of the fusion program
  - Correlate research tasks with MFPP's three strategic objectives, four key technical issues and major milestones

- Resource requirements will be estimated during the latter part (i.e., FY-86) of the TPA



- Each subgroup will be composed of about six senior technical experts from the community.

- Subgroups will utilize additional experts and task groups in the community as required.

NEAR-TERM TPA ACTIVITIES

(Next 3 months)

- Collect and review existing plans and related documents (in progress).

- Briefing session for community program directors, leaders and OFE Division Directors - early June

- Establish TPA Steering Group and three subgroups - May (initial meeting - late June)

- Set up TPA Steering Group composed of plasma science, fusion technology and fusion system subgroups.

- Select and develop method to organize planning in plasma science, fusion technology and fusion systems using an issue/component research breakdown structure.

- Develop research goals and objectives which support the MFPP goal and strategic objectives. (TPA will provide guidelines on goal/objective setting.)

- The results of this initial process will be reviewed with OFE and the community.

NEAR-TERM TPA ACTIVITIES (Cont.)

- Continue series of informal discussions
  - -- to date:
    - DOE/OFE Division Directors
    - DOE/COO
    - LLNL, GA, PPPL, MIT
    - Theory community - Sherwood Theory Meeting
    - EPRI Fusion Advisory Committee

- Participate in
  - -- Toroidal Program Review - May
  - -- HHF/PMI Task Groups meeting - May
  - -- Ignition Studies Meeting - June

TECHNOLOGY PROGRAM PLANNING ACTIVITY

M. Abdou
University of California Los Angeles

FUSION TECHNOLOGY
TECHNICAL PLANNING ACTIVITY

MOHAMED ABDOU

BRIEFING TO JOINT HHFMCD/PMI
TASK GROUPS MEETING
WASHINGTON, D.C.
MAY 21, 1985

OUTLINE

- Summary of Key MFPP Points
- TPA Technology Approach
- Experience from the FINESSE Process and Other Activities
- HHFMCD/PMI Task Groups

Note

- TPA is still in the stage of structure formulation
- Ideas presented here are tentative

MFPP SUMMARY

GOAL

"ESTABLISH THE SCIENTIFIC AND TECHNOLOGICAL BASE REQUIRED FOR FUSION ENERGY"

(THE SCIENTIFIC AND TECHNOLOGICAL BASE SHOULD BE SUFFICIENT TO ASSESS THE TECHNICAL, ECONOMIC AND ENVIRONMENTAL POTENTIAL OF FUSION AS AN ENERGY SOURCE).

STRATEGIC OBJECTIVES

1. SCIENTIFIC OBJECTIVE: IS TO BE ABLE TO PREDICT, CONTROL AND OPTIMIZE THE BEHAVIOR OF PLASMA CONFINED IN FUSION RELEVANT MAGNETIC CONFIGURATIONS.

2. TECHNOLOGY OBJECTIVE: IS TO SHOW THAT IT IS POSSIBLE TO CREATE THE UNIQUE FUSION COMPONENTS AND SUBSYSTEMS UNDER CONDITIONS RELEVANT TO FUSION ENERGY SOURCES.

3. TECHNOLOGY TRANSFER OBJECTIVE: IS TO PROVIDE A RANGE OF OPTIONS FOR PRIVATE SECTOR INVESTMENT AND COMMERICAL DEVELOPMENT OF FUSION.

STRATEGY

- ESSENCE: "MAINTAIN A BROAD DOMESTIC RESEARCH AND DEVELOPMENT PROGRAM WITH EMPHASIS ON ESTABLISHING THE BASIC ELEMENTS (COMPONENTS OR SUBSYSTEMS) OF THE SCIENCE AND ENGINEERING TECHNOLOGY REQUIRED FOR FUSION."

MFPP SUMMARY (CONT'D)

- MUST TAKE INTO ACCOUNT:

  KEY TECHNICAL ISSUES
  - MAGNETIC CONFINEMENT SYSTEMS
  - PROPERTIES OF BURNING PLASMAS
  - MATERIALS OF FUSION SYSTEMS
  - NUCLEAR TECHNOLOGY OF FUSION SYSTEMS

  SCHEDULE

  SOLVE FUSION'S TECHNICAL PROBLEMS WITHIN A TIME FRAME KEYED TO RESOLUTION OF PROBLEMS IN OTHER AREAS OF ENERGY DEVELOPMENT

  RESOURCES
  - TECHNICAL PERSONNEL
    - UNIVERSITIES, CREATIVE RESEARCH WITHIN OVERALL PROGRAM
  - BUDGETS
    - SUPPORT DOMESTIC PROGRAM FOR EFFECTIVE INTERNATIONAL COOPERATION
    - SUPPORT APPROPRIATE EXPERIMENTS, FACILITIES
  - INTERNATIONAL COOPERATION

- NEXT 5 YEARS:

  - INTENSIVE EFFORT TO IDENTIFY COST-EFECTIVE COMPONENT AND SYSTEM TEST FACILITIES FOR RESOLVING THE KEY TECHNICAL ISSUES
  - IF MORE INTEGRATED AND EXPENSIVE FACILITIES ARE NEEDED.....DEGREE OF INTERNATIONAL COOPERATION

FUSION TECHNOLOGY COMPONENTS

- FIRST WALL/BLANKET
  (INCLUDING HEAT TRANSPORT SYSTEM)

- PLASMA INTERACTIVE COMPONENTS (PIC)
  (FIRST WALL, LIMITERS/DIVERTORS, DIRECT CONVERTORS, ETC.)

- TRITIUM PROCESSING/VACUUM SYSTEM

- MAGNETS
  (INCLUDING ASSOCIATED POWER SUPPLIES)

- PLASMA HEATING/FUELING SYSTEMS

- INSTRUMENTATION AND CONTROL SYSTEMS

- REMOTE MAINTENANCE

KEY ELEMENTS OF APPROACH FOR TPA TECHNOLOGY

- OBJECTIVES
  - OVERALL OBJECTIVE FROM MFPP
  - DEVELOP MEASURABLE (SUB)OBJECTIVES FOR EACH TECHNOLOGY COMPONENT

- ATTRIBUTES
  - DEVELOP ATTRIBUTES (EVALUATION SCALES) TO MEASURE PROGRESS TOWARD GOALS (FACILITATES COMPARISON OF RELATIVE WORTH OF ISSUES, FACILITIES, ALTERNATIVE PATHWAYS, ETC.)

- CHARACTERIZE ISSUES
  - QUANTIFIED UNDERSTANDING OF KEY ISSUES (POTENTIAL IMPACT, CONDITIONS UDNER WHICH ISSUE BECOMES DOMINANT OR UNIMPORTANT, ETC.)

- QUANTIFY EXPERIMENTAL NEEDS
  - IDENTIFY DESIRED EXPERIMENTS AND KEY EXPERIMENTAL CONDITIONS TO RESOLVE KEY ISSUES

- EVALUATE FACILITIES

  EXISTING
  - EVALUATE CAPABILITIES AND LIMITATIONS
  - IDENTIFY EXPERIMENTS
  - ESTIMATE COSTS, TIME

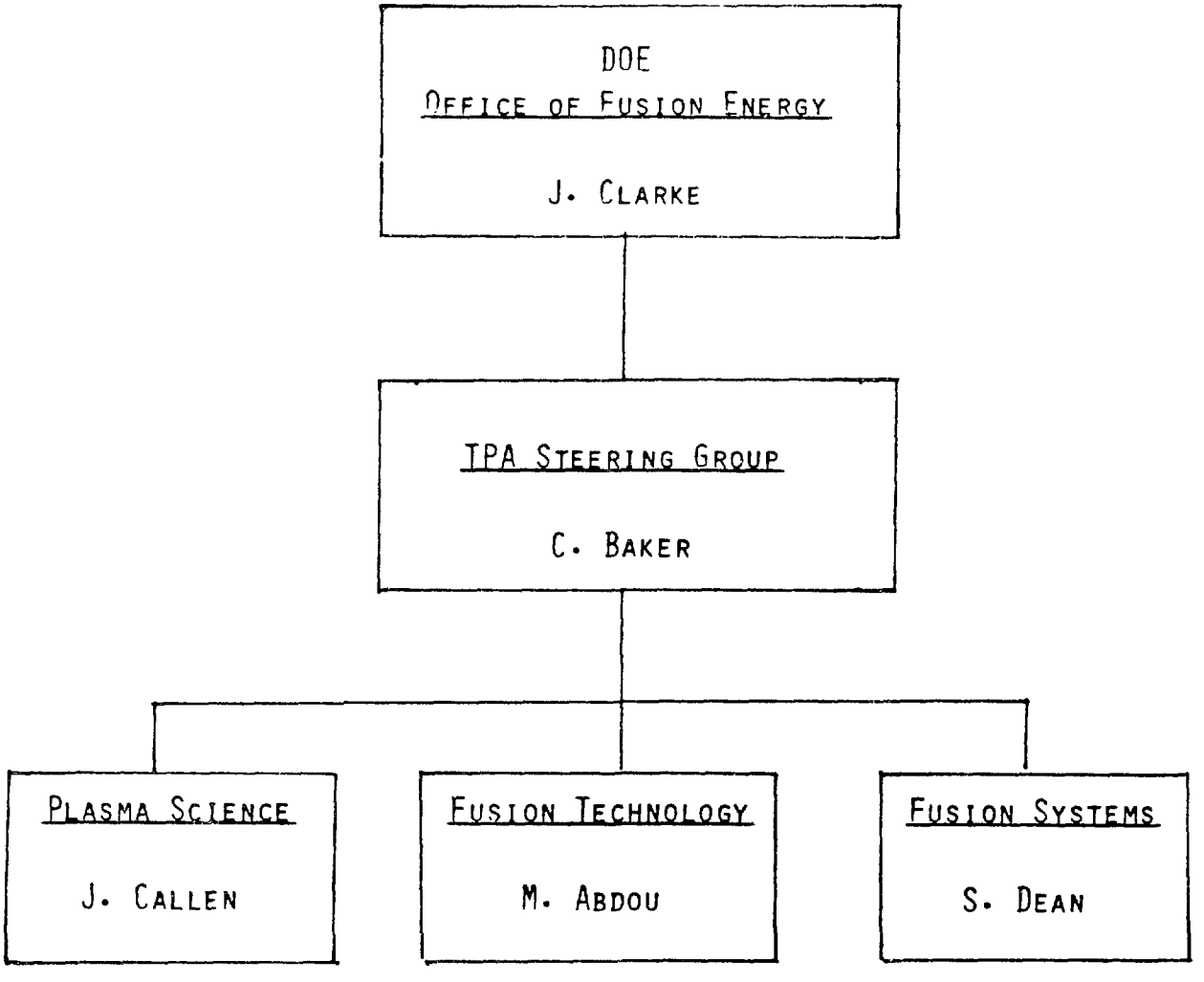
  NEW
  - EXPLORE TESTING IDEAS
  - DEFINE MAJOR NEW FACILITIES
  - ESTIMATE COSTS, TIME

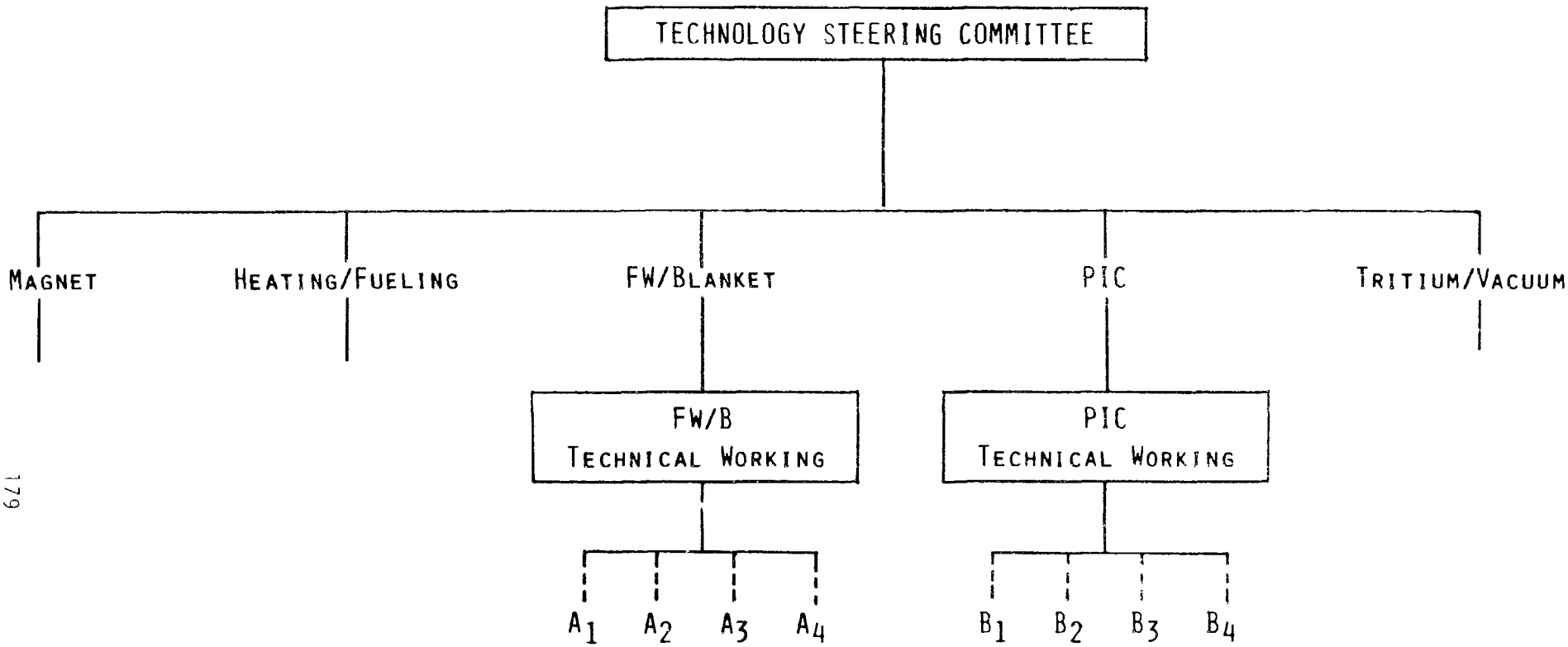
KEY ELEMENTS OF APPROACH FOR TPA TECHNOLOGY (CONT'D)

- DEVELOP TEST PLAN ALTERNATIVES
  - DEFINE ALTERNATIVE R&D PATHWAYS AND LOGIC (DESIGN OPTIONS TO BE INCLUDED, ISSUES TO BE ADDRESSED, EXPERIMENTS TO BE PERFORMED, FACILITIES TO BE USED, SEQUENTIAL OR PARALLEL TIMING, ETC.)
  - ELIMINATE CLEARLY UNACCEPTABLE ALTERNATIVE PATHWAYS
  - PREDICT CONSEQUENCES OF REMAINING ALTERNATIVE PATHWAYS (RESULTS FROM PATHWAY ELEMENTS MAY BE POSITIVE OR NEGATIVE, DEGREE OF PROGRESS TOWARD OBJECTIVES, ETC.)
  - DETERMINE PREFERENCE OF COMMUNITY/OFE TO CONSEQUENCES

- EVALUATE AND COMPARE ALTERNATIVES

- ITERATE


DOE
OFFICE OF FUSION ENERGY
J. CLARKE
TPA STEERING GROUP
C. BAKER
PLASMA SCIENCE
J. CALLEN
FUSION TECHNOLOGY
M. ABDOU
FUSION SYSTEMS
S. DEAN



- TENTATIVE STRUCTURE FOR TPA FUSION TECHNOLOGY
- STEERING COMMITTEE (ABOUT SIX MEMBERS)
- TECHNICAL WORKING GROUP FOR EACH COMPONENT
- (A_1, A_2,...), (B_1, B_2,...) REPRESENTS INPUT FROM EXISTING STUDIES, PROJECTS, TASK GROUPS, ETC.

SUGGESTED ROLE OF HHFMCD/PMI TASK GROUPS IN TPA

- TPA INTENDS TO MAXIMIZE INPUT FROM AND INTERACTION WITH EXISTING STUDIES, PROGRAMS, PROJECTS, TASK GROUPS, ETC.

- TWO MEMBERS OF HHFMCD/PMI TASK GROUPS ARE MEMBERS OF THE TPA STEERING COMMITTEE

- OTHER MEMBERS WILL BE SELECTED FOR THE PIC TECHNICAL WORKING GROUP

- PMI/HHFMCD TASK GROUPS REPRESENT AN IDEAL RESOURCE TO:

  - PERFORM IMPORTANT TPA TASKS ON PIC

  - DEVELOP/CRITIQUE/REVIEW/MODIFY PROMISING ALTERNATIVE PATHWAYS FOR PIC

PLASMA INTERACTIVE COMPONENT ISSUES/FACILITIES MATRIX

Issues	Non-neutron tests					High heat flux facilities				Neutron sources		Fusion devices			
	Benchtop tests	T glove box tests	High plasma flux	Tritium plasma facility	Transient EM facility	Beam source (spot)	Radiative source (modest A)	Multiple beam source (modest A)	Plasma source (large A)	Fission specimen tests	Point source specimen tests	Plasma confinement exp.	Existing DT exp.	Ignition device	FFHF
1. Surface Physics															
a. Erosion/redeposition	L	-	M	-	-	-	-	L	M	L	L	L	L	H	H
b. Surface conditioning	L	L	M	L	-	-	-	L	M	L	L	M	M	H	H
c. Tritium permeation/retention	L	L	L	M	-	-	-	L	L	L	L	L	M	H	H
d. Fluence effects	-	-	-	-	-	-	-	-	-	L	L	-	-	H	H
2. Disruption effects															
a. Eddy current forces/response	L	-	-	-	M	-	-	-	-	-	-	M	M	H	H
b. Melt layer formation/behavior	L	-	-	-	M	-	-	L	L	-	-	-	L	H	H
3. Composite structure behavior															
a. Heat transfer across structure	L	-	L	-	-	-	M	M	M	-	-	M	M	H	H
b. Thermal stresses and fatigue	L	-	-	-	-	L	M	M	M	-	-	M	M	H	H
c. Radiation effects	-	-	-	-	-	-	-	-	L	L	-	-	M	H	H
d. Bond or attachment integrity	L	-	-	-	L	-	L	L	M	L	L	L	L	H	H
4. Insulating materials															
a. Thermal stresses and fatigue	L	-	-	-	-	L	M	M	M	L	L	L	L	H	H
b. Radiation effects	-	-	-	-	-	-	-	-	-	M	M	-	-	H	H
5. Active cooling of large areas															
a. CHF and channel erosion	-	-	-	-	-	L	H	H	H	-	-	L	L	H	H
b. Multiple channel flow behavior	L	-	-	-	L(1)	-	M	M	H	-	-	L	L	H	H
6. Replacement and maintenance	L	L	L	-	-	-	-	-	-	-	-	L	M	H	H

-: No particular value.
L: Useful.
M: Significant, but not definitive.
H: Probably definitive.

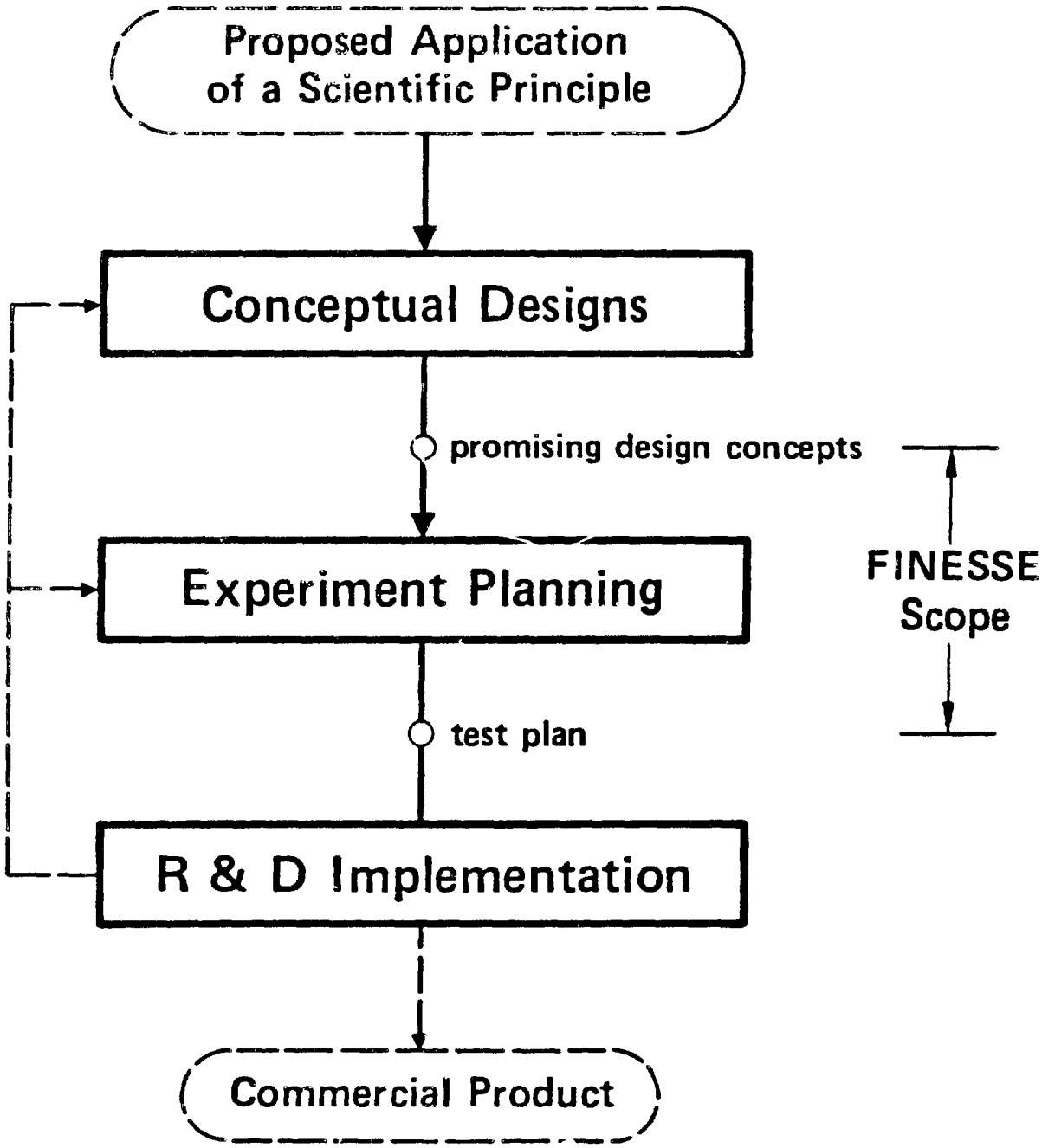
(1) For liquid metal cooled HHFC.

APPENDIX

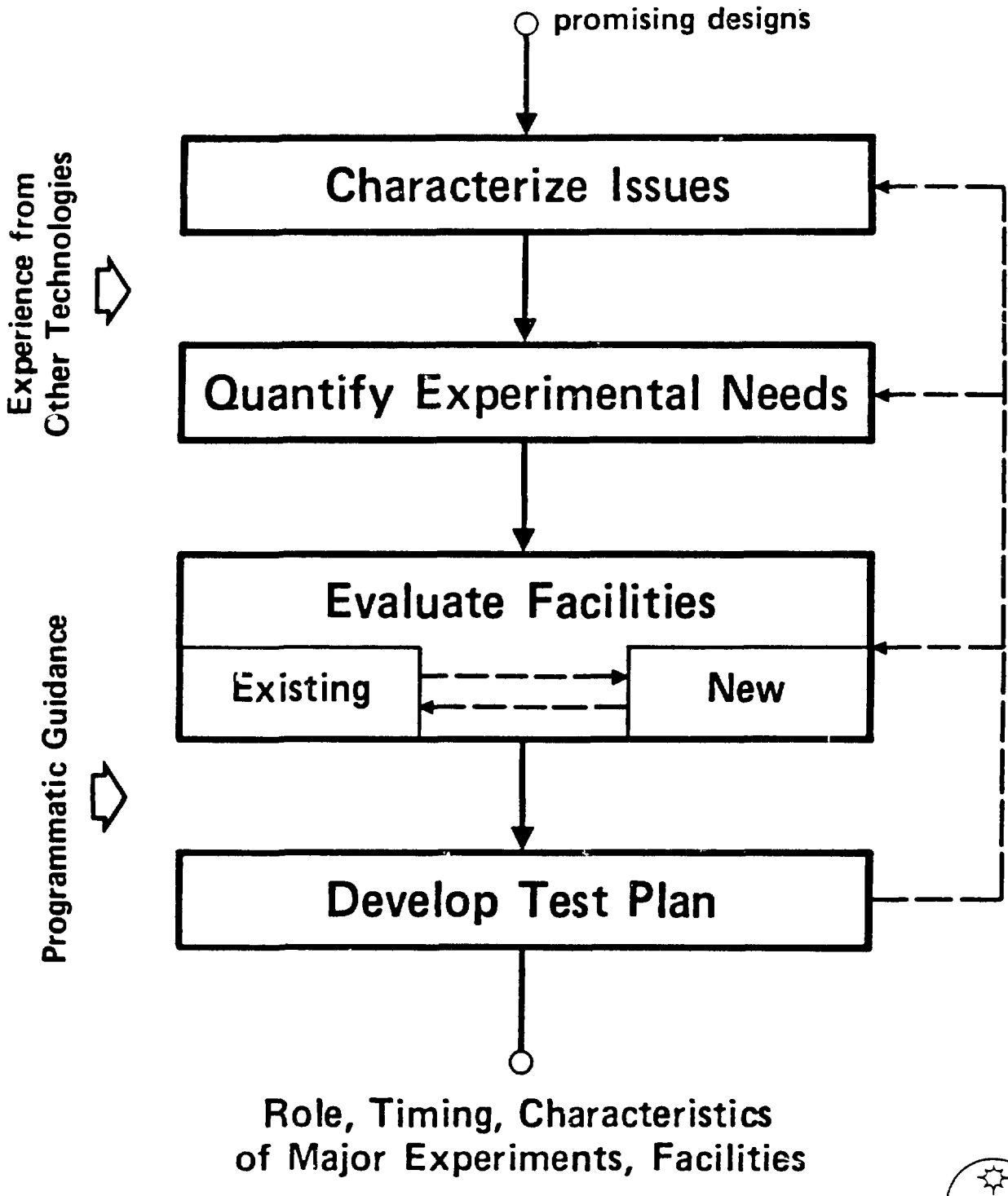
FINESSE PROCESS

IN THE COURSE OF CARRYING OUT FINESSE, A PROCESS FOR EXPERIMENT TECHNICAL PLANNING HAS EVOLVED. THIS PROCESS HAS PROVED USEFUL IN TECHNICAL PLANNING OF FUSION NUCLEAR TECHNOLOGY. THE PROCESS HAS IMPORTANT FEATURES RELEVANT TO TPA. HIGHLIGHTS OF THE PROCESS FOLLOW. DETAILS ARE PROVIDED IN THE FINESSE REPORTS.

EXPERIMENT PLANNING
Is a Key Element of Technology Development



FINESSE PROCESS For Experiment Planning



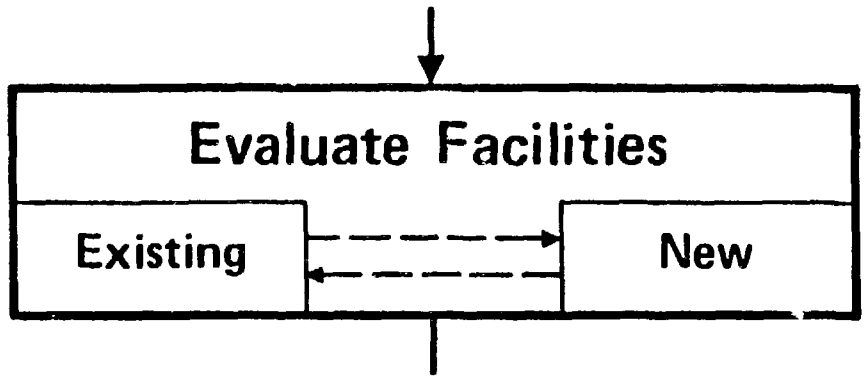
Characterize Issues

- Assess Accuracy and Completeness of Existing Data and Models
- Analyze Scientific/Engineering Phenomena to Determine (Anticipate) Behavior, Interactions and Governing Parameters in Fusion Reactor Environment
- Evaluate Effect of Uncertainties on Design Performance
- Compare Tolerable and Estimated Uncertainties

△ Quantified Understanding of Important Issues, Interactions, Parameters . . .

Quantify Experimental Needs

- Survey Needed Experiments
- Explore Engineering Scaling Options
  (Engineering Scaling is a Process to Develop Meaningful Tests at Experimental Conditions and Parameters Less Than Those in a Reactor)
- Evaluate Effects of Scaling on Usefulness of Experiments in Resolving Issues
- Develop Technical Test Criteria for Preserving Design-Relevant Behavior
- Identify Desired Experiments and Key Experimental Conditions



- Survey (Availability)
- Evaluate Capabalities and Limitations
- Define Meaningful Experiments (Experiment Conceptual Design a Tool)
- Estimate Costs

- Explore Innovative Testing Ideas
- Assess Feasibility of Obtaining Desired Information (e.g. I & C Limitations)
- Develop Preliminary
  - Conceptual Designs of Facilities
  - Cost Estimates
- Trade offs in Sequential and Parallel Experiments and Facilities
- Define Major Facilities

Develop Test Plan

- Define Test Program Scenarios Based on
  - Promising Design Concepts
  - Importance of Issues
  - Desired Experiments
  - Possible Test Facilities
- Compare Risk, Usefulness and Cost of Test Program Scenarios

POTENTIAL IMPACT

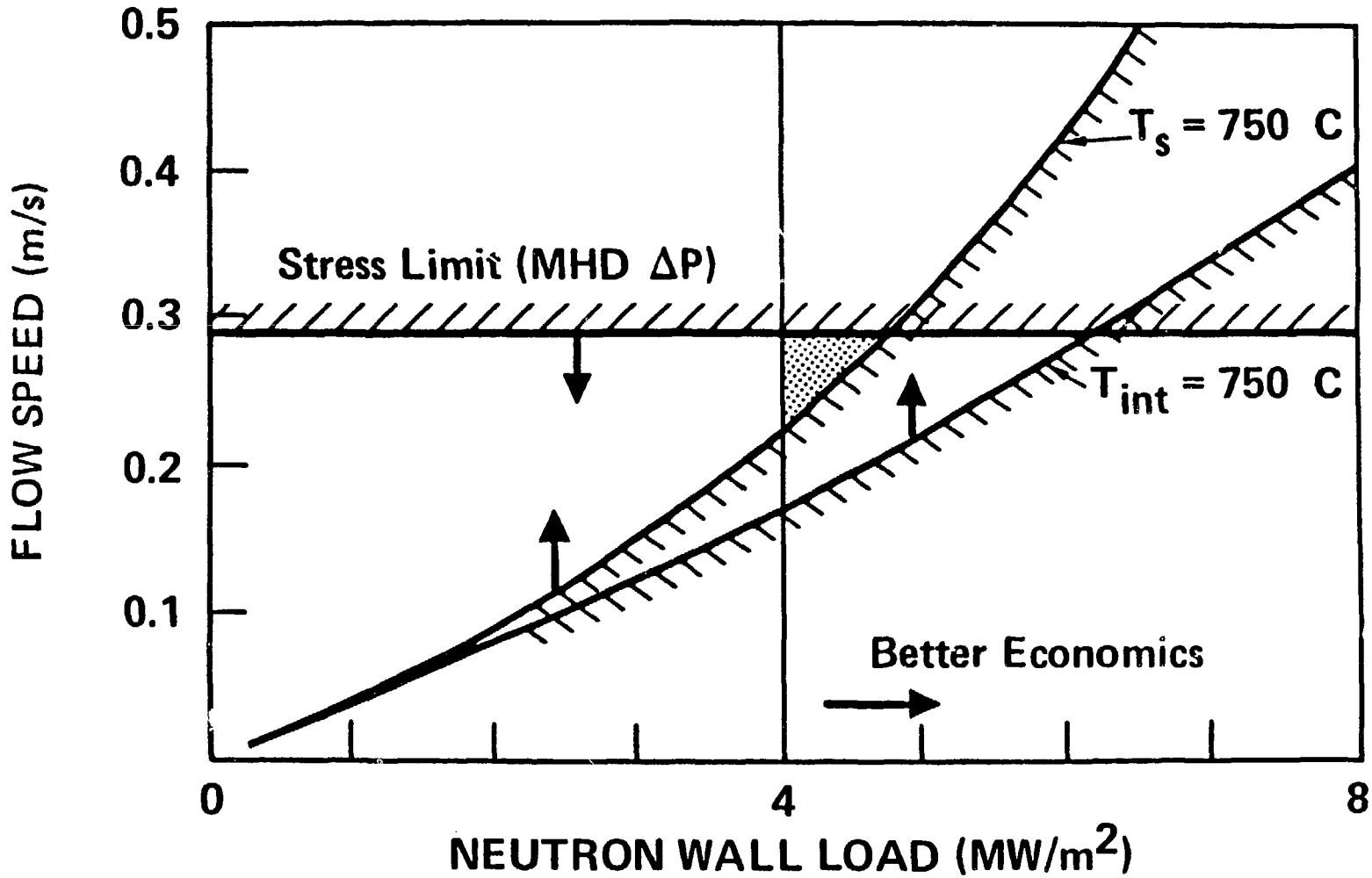
Feasibility Issues

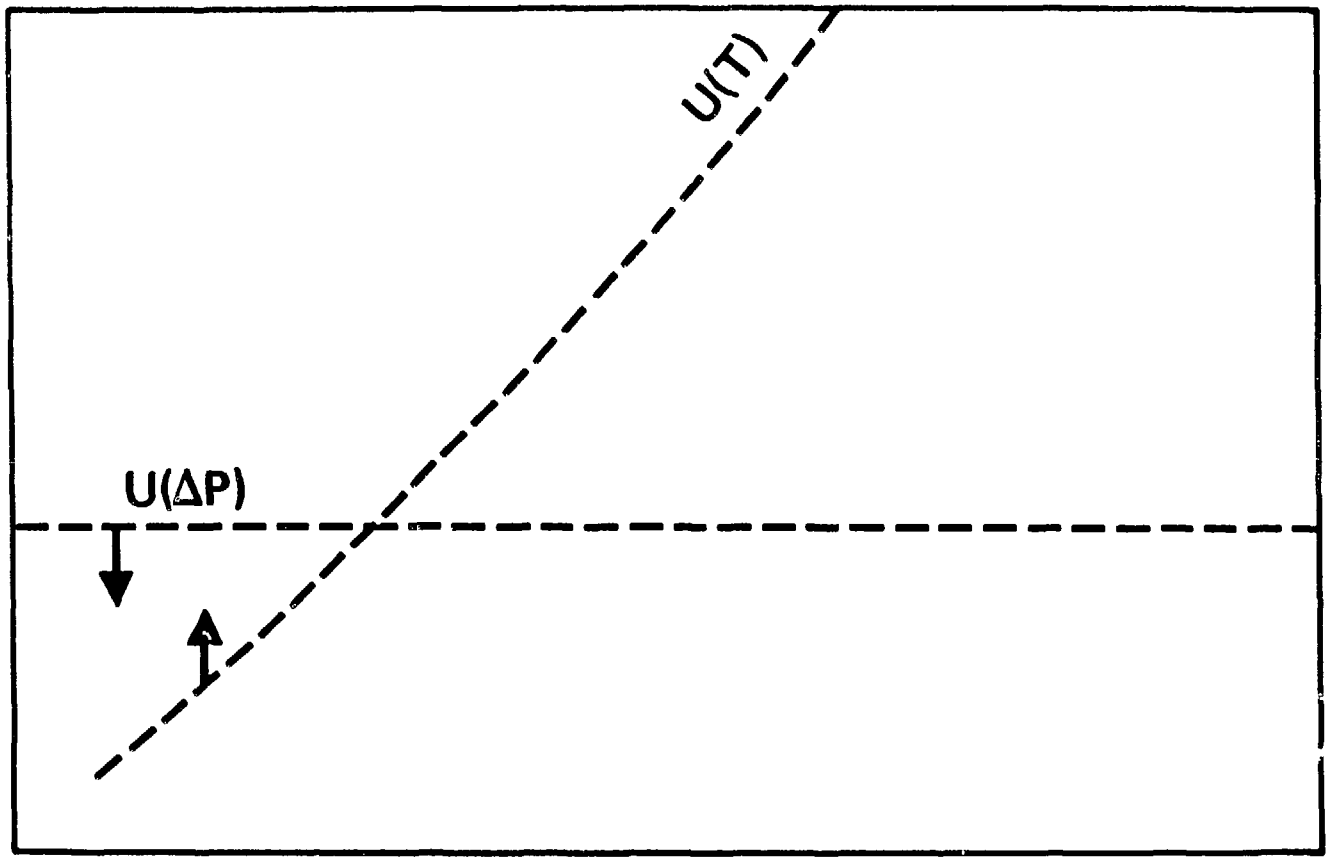
- May Close the Design Window
- May Result in Unacceptable Safety Risk
- May Result in Unacceptable Reliability, Availability or Lifetime

Attractiveness Issues

- Reduced System Performance
- Reduced Component Lifetime
- Increased System Cost
- Less Desirable Safety or Environmental Impact

Design Window Is Narrow For Best Liquid Metal Blanket (Li/V)

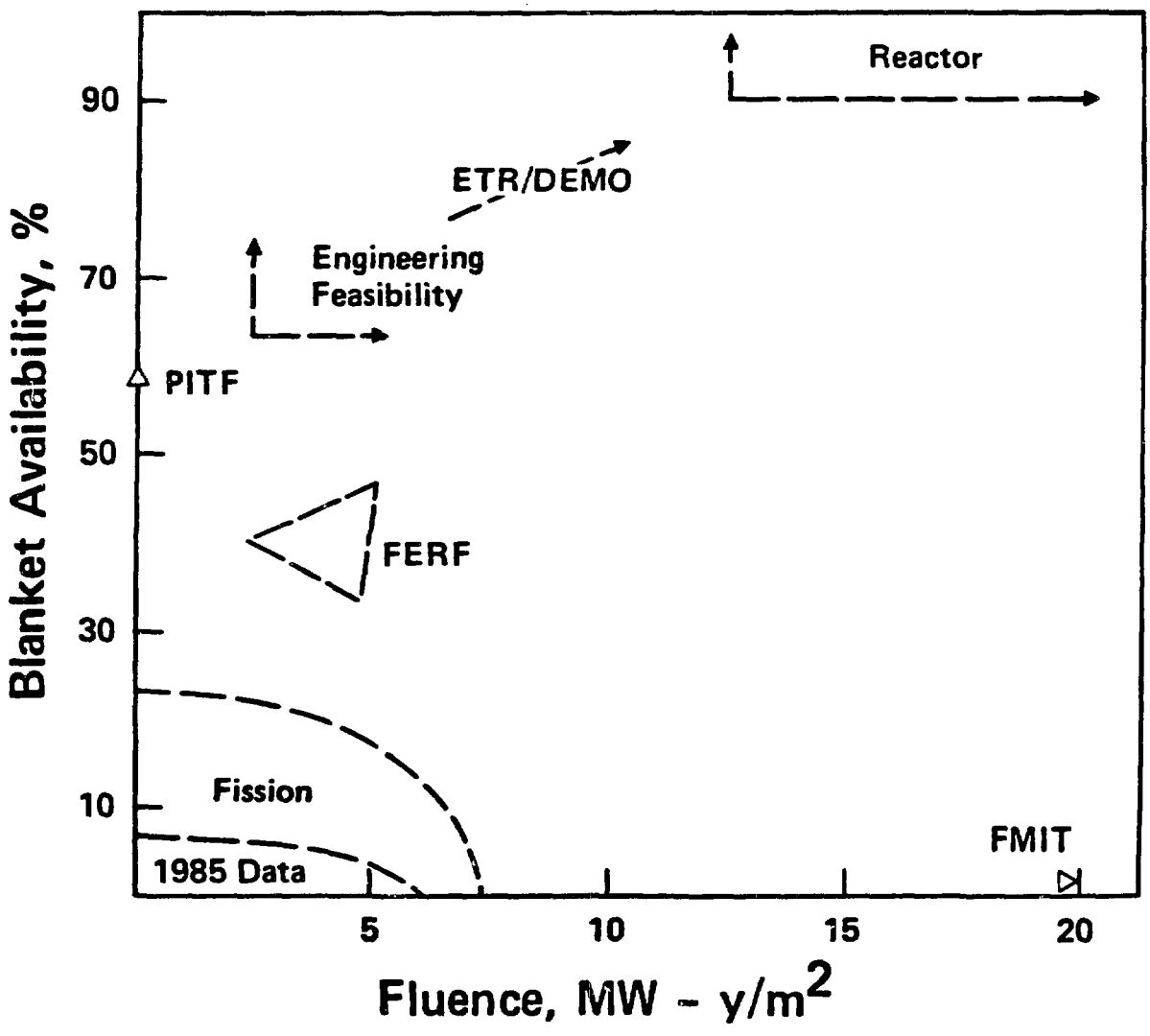




U(T): Any of:
$T_s = 650$ C
$T_{int} = 550$ C
$h_m = 0.7h$

Uncertainties in MHD, Corrosion, Heat Transfer, Radiation Effects Represent Major Issues

Obtaining Availability and Fluence Data For Blanket Is Most Difficult



Role of Facilities For Fusion Nuclear Technology

Type of Test	Basic Tests	Single, Multiple Interaction	Integrated	Component
Purpose of Test	Property Measurement	Phenomena Exploration	Concept Verification	Reliability
Non-Neutron Test Stands	⊢——- - - - ▶	⊢- - - - △ - - ▶ (PITF)		
Point Neutron Sources	⊢- - - - - ▶	⊢- - ▶		
Fission Reactors	⊢- - - - - ▶	⊢- - - △ - - ▶ (MSB)		
Fusion Test Device (FERF)		⊢- - - - - -	- - - - - ▶	
ETR/DEMO			⊢- - - - - -	- - - - ▶

IGNITION MACHINE NEEDS

J. Haines
Washington, D.C.

LIMITER AND FIRST WALL ENERGY REMOVAL FOR COMPACT IGNITION TOKAMAKS

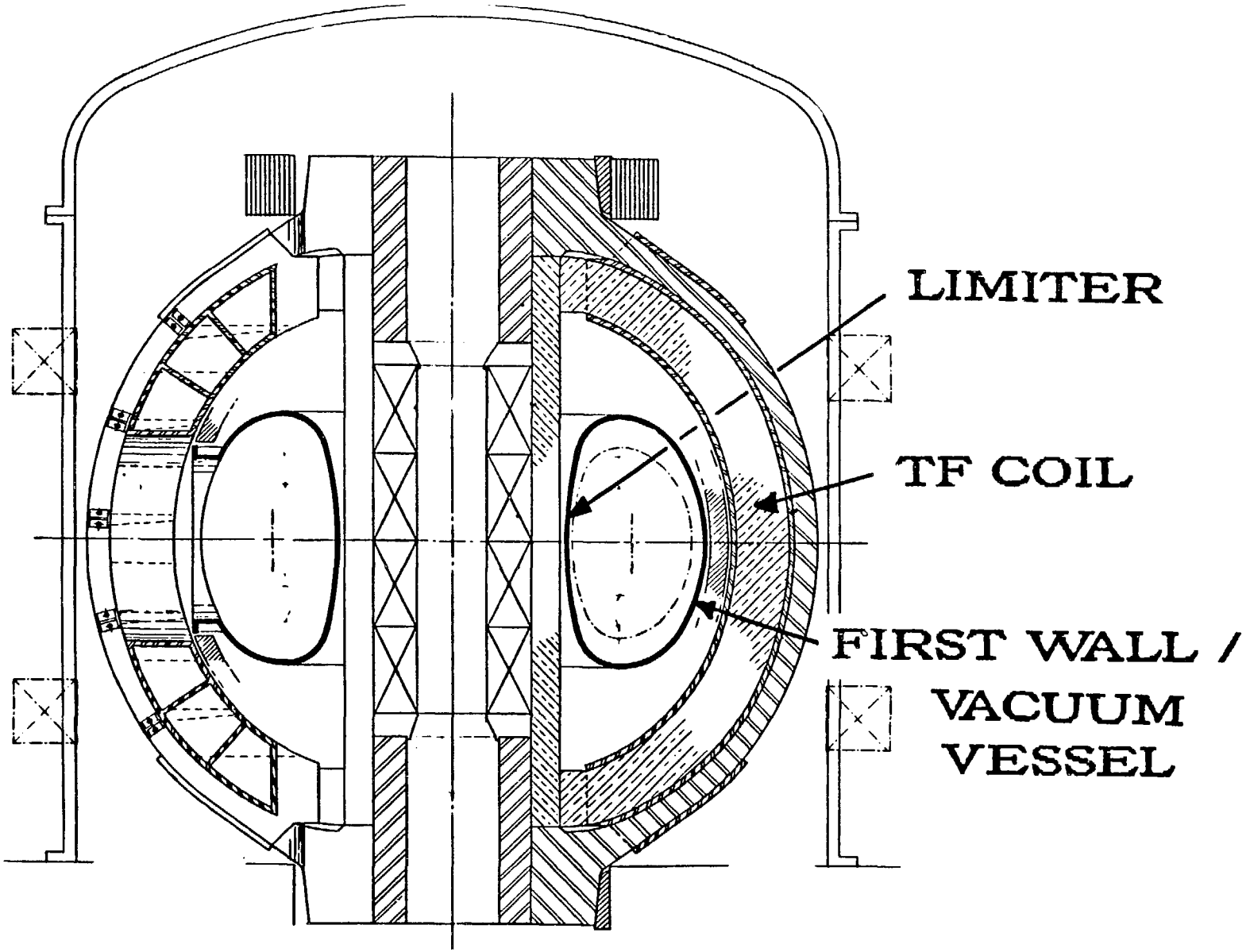
J. R. Haines
FEDC / MDAC
21 May, 1985

LIMITER / FIRST WALL / VACUUM VESSEL DESIGN PHILOSOPHY

- Combined first wall and vacuum vessel
- Limiter surface formed by inboard first wall surface

} MINIMIZE RADIAL BUILD

- No active impurity control during burn (short burn duration)



TYPICAL SECTION

HEATING CONDITIONS FOR LIMITER AND FIRST WALL

<u>For Limiter Design:</u>

- Power to limiter = 0.8 P_α
- Exponential decay thru scrape-off
  - o e-fold distance = 15 mm

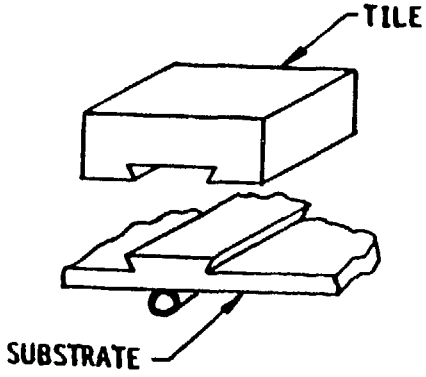
<u>For First Wall Design:</u>

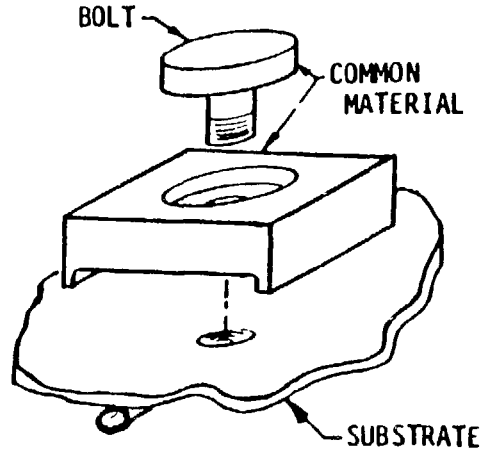
- Power to first wall = 0.5 P_α
- Uniformly distributed

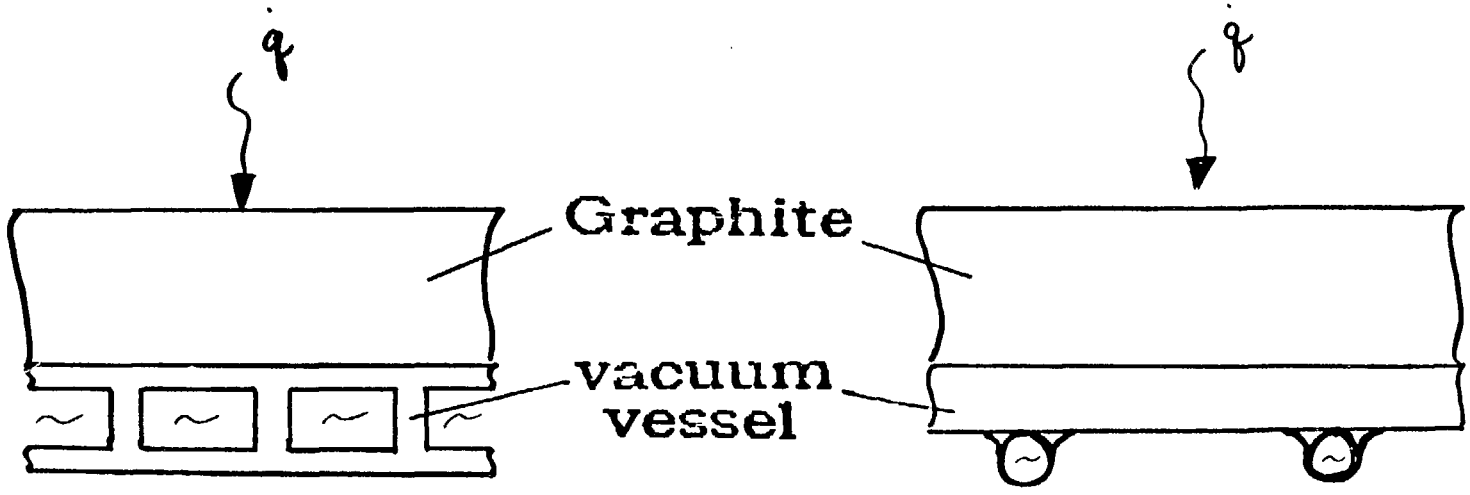
PEAK HEAT FLUXES

Device	P_α (MW)	Peak Heat Flux (MW/m^2) Limiter	Peak Heat Flux (MW/m^2) First Wall
ISP	61	6.7	.6
LITE	84	8.6	.7
IGNITOR	55	14.	1.1

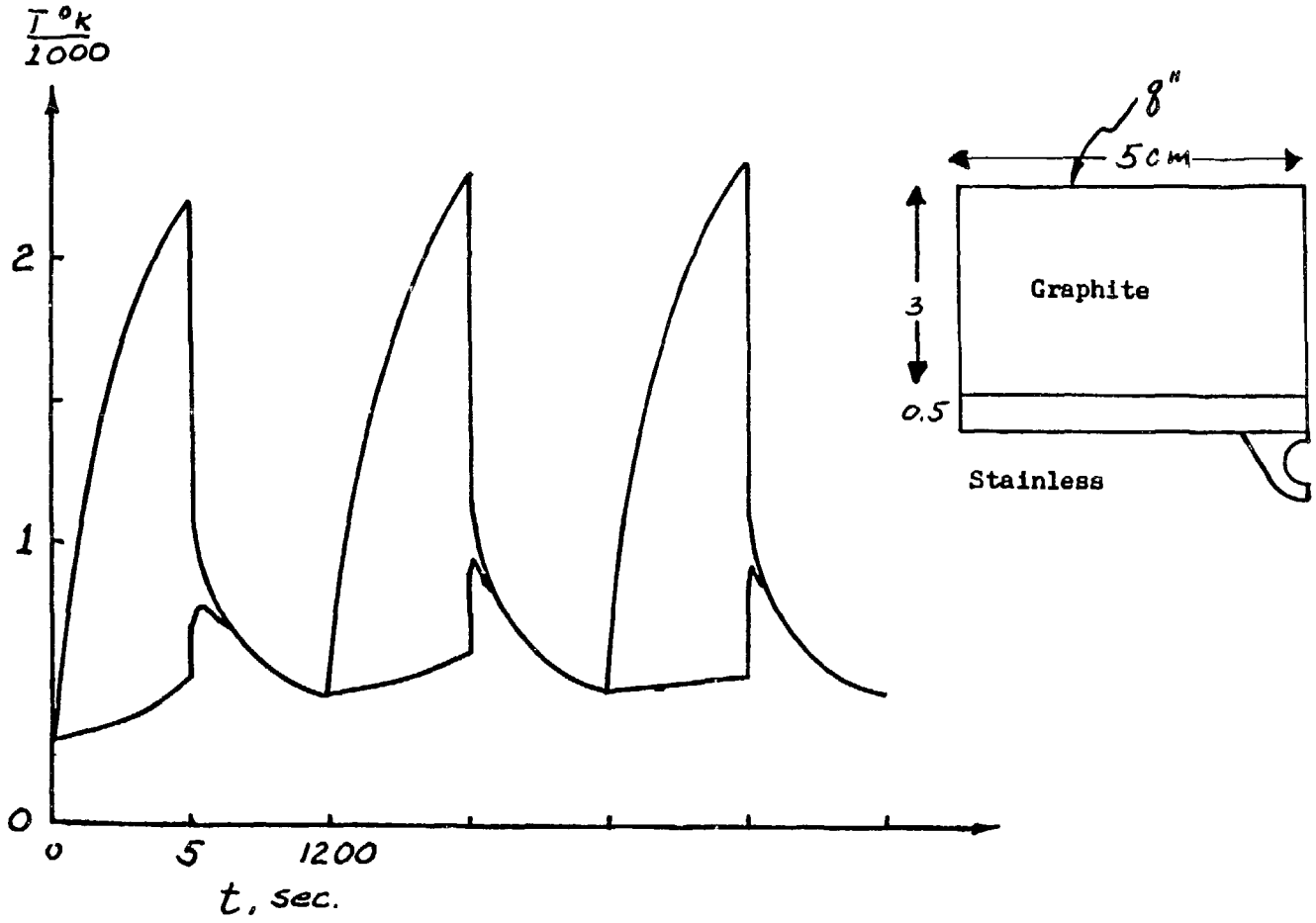
Passively Cooled Design Concepts





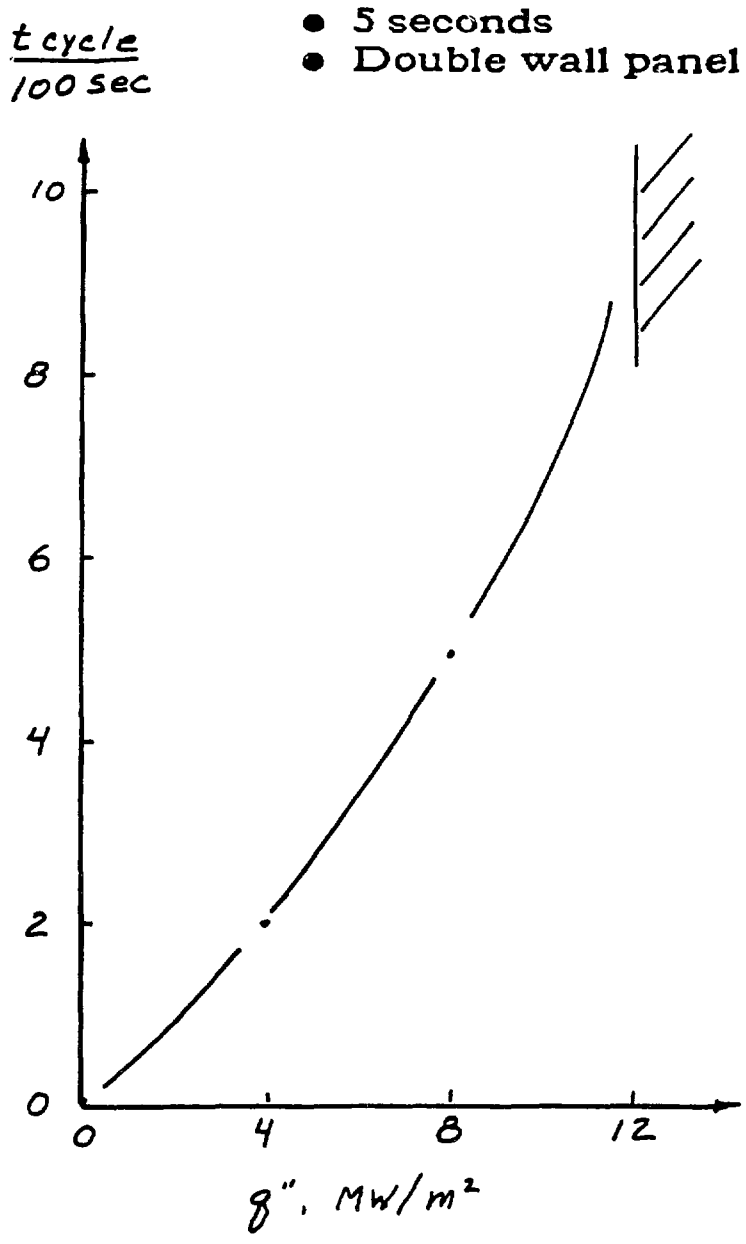


THERMAL RESPONSE OF LIMITER



Maximum Graphite and Stainless Steel Temperatures As A Function of Time for Tube Spacing of 10 cm. Note Time Scale Change at 5 Sec. Conductance of Gap = 1.0 W / (cm^2 degree K). Heat Flux Is 12 M W / m^2 For 5 Seconds. Cross Section of One Half Tile Shown In Upper Right

COOLDOWN TIMES OF ABOUT 10 MINUTES ARE POSSIBLE



Allowable Combinations of Cycle Time and Heat Flux To Limit Stainless Steel Temperature To Less Than 450 Degrees K (150 C)

DISRUPTION HEATING CONDITIONS

Disruption Phase	Duration ms	Energy Density MJ/m^2
Thermal Quench	1	3.8
Current Quench	10	3.2

KEY ISSUES

- Thermal shock during disruptions
- Tile to substrate attachment design
- Tritium retention of graphite
- Graphite temperature limits

CONCLUSIONS

- Low cost ⟶ Compact } High Limiter
  Adv. performance ⟶ Ignition } Heat Fluxes
- Heat fluxes range from about 5 to 15 MW/m^2
- Passively cooled limiter and first wall designs are feasible for burn durations less than 5 seconds
  - Cooldown times less than 1 hour

Energy Division
TRW Space & Technology
Group

TRW-85-LITE-032
T731-85-GL-004
T731-85-DHB-048

April 4, 1985

TO: Distribution

FROM: G. Listvinsky/D. Berwald

SUBJECT: Preliminary List of LITE Parameters

Enclosed please find a preliminary list of parameters for the evolving LITE design. The purpose of this document is a) to provide input information for the design team, and b) to serve as an interface and configuration control document. At this stage, we are most concerned with establishing a listing which is complete with respect to the inclusion of all relevant subsystems and is as complete as possible with respect to the specification of individual parameters. This listing is submitted to you for review, input, and comments. After receiving such input, it will be input to the MFE net and changes will be implemented only via the use of a design change memos which will be coordinated through this office.

In reviewing the listing, please note that the following symbols have been used:

- (Org.)
- TBD

The use of parenthesis indicates that a given specification should be reviewed by the indicated organization. The use of TBD indicates that a sufficient level of detail to enable a preliminary estimate currently does not exist.

In some cases (e.g., coil subsystems), entire subsections are lacking. We request that these be compliled in as much detail as is currently available as soon as possible. The use of TBD is acceptable.

GL/DHB/lmb

LITE - / LIST OF SYSTEM PARAMETERS

I. OVERALL DESIGN REQUIREMENTS

N	Parameter	Value	Comments
1	Number of full power pulses	3000	
2	Number of pulses at 50% stress level	10^5	
3	Number of burn pulses	1000	
4	Max burn time at full power	10 sec	Can be limited by power supply system
5	Total burn time	(2×10^4 sec)	Including burns at lower fields
6	Number of full power plasma disruptions	(300)	
7	Down time for segment replacement	6 month (hot) 2 month (cold)	

II. PLASMA PARAMETERS

N	Parameter	Value	Comments
1	Major radius	R_o = 1.76 m	
2	Aspect ratio	A = 3.2	
3	Elongation	K = 1.6	
4	Triangularity	δ = 0.3	
5	B field at ignition	B_o = 9.4 T	
6	MHD q-value	q = 2.6	
7	Plasma current at ignition	I = 7.0 MA	
8	Plasma current at burn	I = 7.0 MA	
9	Plasma power	P = 420 MW	Full field, full beta value, ave. wall loading 1.7 MW/m^2
10	Total volt-second requirements	(36.9 V-S)	
11	EF system volt-second production	(9.6 V-S)	
12	RF power required (coupled to the plasma)	(15.5 MW)	Varies between 2-23 MW, depending upon assumed energy confinement degradation with RF heating
13	Plasma disruption rate	1 MA/msec	Requires further justification

III. OVERALL ENGINEERING PARAMETERS

N	Parameter	Value	Comments
1	Total Weight	(400) T	
2	Outer Diameter	(7) m	
3	Height	(3.2) m	
4	Coolant Flow Rate	(~ 4500) kg/sec	Including TF, FW/VV, PF coils and shield
5	Segmentation	(12) TF/VV pie sections	TF coil has (12) friction joints in the throat area
6	Access		
	Number of available ports	n = 23 (30 cm x 200 cm)	One opening between bundles occupied by the TF power leads
	RF ports requirements	4 (30 cm x 100 cm)	
	Pump limiter ports reqmts.	6 (30 cm x 60 cm)	Including vacuum ducts
	Diagnostics ports	TBD	
7	Power supplies	(400) MW	
	a) Power:		
	TF	(400) MW	
	OH	( )	
	EF	( )	
	b) Energy:		
	TF	( ) GJ	
	OH		
	EF		
	c) Current:		
	TF	( ) KA	
	OH		
	EF		
	d) Voltage	( ) KV	
	TF	(1.0) KV	
	OH		
	EF		

IV. TOROIDAL FIELD COIL

N	Parameter	Value	Comments
1	Construction type	Continuous slinky grouped into bundles wedging in the throat area	
2	Number of turns	(384)	
3	Number of bundles	(24)	
4	Turn construction	Turn made of inner and outer legs welded together	Each leg had independent coolant pass
5	Openings between bundles	30 cm x 200 cm	
6	TF turn geometry		
	a) TF/plasma gap:		
	Inboard	10 cm	Based on ripple requirements
	Outboard	30 cm	
	Top/bottom	20 cm	
	b) TF builds:		
	Inboard	(41 cm)	Reference numbers
	Outboard	(50 cm)	
	Top/bottom	(44 cm)	
	c) End of wedging	R_{break} = (150) cm	
	d) Inner boundary of TF coil	R_{OH} = 70 cm	
7	Aver. von Mises stress at B_o = 9.4 T	σ =	Near midplane in the throat
8	Max. coil temperature	T_{MAX} =	Same
9	TF coil inductance	L =	
10	TF resistance as SS conditions	R =	Max. for 9.4 T case
11	Max. dissipated power	P = (380) MW	
12	Coolant flow rate	(2000) kg/sec	
13	Coolant pressure:		
	a) Inlet	P_{in} =	
	b) Outlet	P_{out} =	

14	Coolant temperature:	
	a) Inlet	T_{in} =
	b) Outlet	T_{out} =
15	Max. flow velocity	V_{max} = (24) m/sec.
16	TF coil materials:	
	a) Inner leg	Cu-Be-Ni alloy
	b) Outer leg	OFCH copper
	c) Insulator	GT-10-R
17	TF nuclear heating	( ) MW

V. TORQUE FRAME/SHIELD SYSTEM

N	Parameter	Value	Comments
1	Torque frame description	Wedges between bundles connected via top/bottom plates to a torque frame	See memo for details ...
2	Shield		
	a) Description	TF coils and wedges and inserts between TF bundles	
	b) Wedges/inserts construction	80% steel/20% water	
	c) Min. thickness	30 cm	
	d) Energy attenuation: coefficient		
	1) Steel shield	0.11 cm^{-1}	
	2) Water cooled copper coils	(0.13) cm^{-1}	
	e) Energy attenuation:		
	1) Steel shield	96%	
	2) Copper coils	(100)%	
	f) Heating:		
	1) Steel shield	~80 MW	
	2) Copper coils	See Section IV	
	g) Wedges cooling:		
	1) Coolant temp. rise	ΔT = (30°C)	
	2) Coolant pressures		
	3) Coolant flow rate per wedge	(12) kg/sec.	
3	Nuclear heating:		
	a) Wedges and inserts	(80) MW	
	b) TF outer leg	(120) MW	

VI. EQUILIBRIUM FIELD COILS

N	Parameter	Value	Comments
1	Coil 1		
	a) R,Z location		
	b) Cross-sectional dimensions		
	c) Construction type		
	d) Weight		
	e) Materials:		
	1) Conductor		
	2) Insulator		
	f) Total ampere turns		
	g) Max. current		
	h) Peak power		
	i) Self inductance		
	j) Coolant flow rate		
	k) Coolant pressure		
	1) Inlet		
	2) Outlet		
2	Coil 2, etc		
3	Mutual inductances		Memo ... See Sections VII & VIII

VII. OH SYSTEM

N	Parameter	Value	Comments
1	Volt-seconds produced	(27.3) V-S	
2	Construction type		
3	Maximum current		
4	Total ampere turns		
5	Materials: a) Coil b) Insulator		
6	Peak voltage		
7	Peak ohmic power		
8	Resistance		
9	Inductance		Mutual inductance see memo
10	Coupling efficiency		
11	Outer diameter		
12	Inner diameter		
13	Height		
14	Average von Mises stress		Near midplane
15	Maximum OH field		
16	Maximum coil temperature		Near midplane
17	Coolant flow rate:		
18	Maximum flow velocity		
19	Coolant temperature a) Inlet b) Outlet		
20	Coolant pressure a) Inlet b) Outlet		

VIII. VACUUM VESSEL/FW SYSTEM

N	Parameter	Value	Comments
1	Construction type	Double wall, continuous, resistive structure integrated with the FW	No electrical breaks or bellows
2	Coolant sytem arrangement	Poloidal coolant channels	
3	Total number of midplane window ports	23 (30 cm x 200 cm each)	One opening between bunches will be used to bring power leads
4	Limiters	a) Bumper limiter (±90° near inboard midplane, integrated with the VV. b) 12 removable pump limiters located in the window ports.	 See Section IX
5	FW/VV materials:		
	a) FW	Graphite tiles for bumper limiter Be coating outboard	
	b) Substrate (front wall)	CuBe	or CuBeNi
	c) Back wall		
6	Heat fluxes		
	a) Bumper limiter:		
	1) Average	(3.75) MW/M^2	
	2) Peak		
	b) First Wall:		
	1) Average	(0.85) MW/M^2	
	2) Peak		
7	Coolant conditions:		
	a) Flow rate	< 700 kg/sec)	
	b) Inlet temperature	(50°C)	
	c) Outlet temperature	(80°C)	
	d) Inlet pressure		
	e) Outlet pressure		
	f) Coolant velocity		
8	Maximum temperatures:		
	a) Tile		
	b) Substrate		
9	Channel geometry:		
	a) Flow rate		
	b) Hydraulic diameter		
	c) Length		

10	EM time constant	~ 50-100 sec.
11	Maximum stress during plasma disruption	σ =

IX. PUMP LIMITER/VACUUM DUCTS

N	Parameter	Value	Comments
1	Description	Scoop limiters, each with two leading edges, located at outer midplane. Leading edges normal to field lines. Vacuum ducts oriented radially outward between TF coil bunches.	
2	Spacing	6 limiter modules uniformly spaced 30° apart	
3	Orientation of leading edge	Normal to field lines at at outer edge	Angular orientation limits heat flux on top and bottom of limiter module. Preliminary estimate of 15° off vertical
4	Limiter dimensions:		
	a) Uniform width	15 cm	
	b) Length of leading edge	58 cm	
	c) Module clearance required	30 cm x 60 cm	
5	Limiter materials		
	a) Plasma side	Beryllium	or graphite
	b) Substrate	Cu-Be-Ni	
	c) Structure	TBD	
6	Vacuum duct (first leg):		
	a) Height	60 cm	
	b) Width	30 cm	
	c) Length	100 cm	before bend
	d) Pump location	beyond bend	
7	Pumping:		
	a) Limiter efficiency	TBD	Fraction of plasma efflux pumped
	b) Net duct conductance to pump	TBD	
	c) Net duct conductancd to plasma	TBD	
	d) Duct efficiency	TBD	
	e) Net pump efficiency	TBD	20% goal
	f) Equilibrium impurity concentrations:	TBD	
	1) Alphas	10%	Design basis
	2) Beryllium	~ 5%	

8 Heating:

a)	Total power per module	TBD
b)	Heat flux on leading edge	TBD
c)	Coolant:	
	1) Inlet temp.	TBD
	2) Outlet temp.	TBD
	3) Inlet pressure	TBD
	4) Outlet pressure	TBD
	5) Max. velocity	TBD
	6) Volumetric flow	TBD
d)	Structure:	
	1) Max. Temp.	TBD
	2) Max. stress	TBD

X. ICRH SYSTEM

N	Parameter	Value	Comments
1	Power required to the antenna	18 MW	27 MW for worst case scenario
2	Frequency range	142 MHz (9.4 T) - 100 MH (6.6 T)	
3	Number of ports	4 ports (30 cm x 100 cm each)	6 ports for 27 MW
4	Launcher (options under consideration)	1) Loop antenna with shield flush with the FW. 2) Cavity with a similar Faraday shield. 3) Ridged waveguide (dielectricly filled).	Faraday shield will be welded to the VV to provide continuous current path. May not need shield
5	Transmission system	9" or 12", 50Ω, coaxial line with stub turns	85% efficiency
6	Amplifier	Multistage amplifier x 2242 tetrode w/modified tuning cavity	1.25-1.5 MW per tube

XI. DIAGNOSTIC REQUIREMENTS

N	Instrument Type	Access Requirements	Comments

ISP

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PLASMA PARAMETERS

PLASMA RADIUS	m	0.531
MAJOR RADIUS	m	1.621
ASPECT RATIO		3.055
ELONGATION*		1.600
TRIANGULARITY*		0.400
SCRAPEOFF		
INBOARD*	m	0.000
OUTBOARD*	m	0.120
TOP*	m	0.120
FIELD ON AXIS	T	8.95
BETA		0.050
POLOIDAL BETA		0.797
POLOIDAL BETA / ASPECT RATIO		0.261
PLASMA TEMPERATURE*	keV	10.00
IMPURITY SPECIES ATOMIC NUMBER*		8.00
EFFECTIVE CHARGE*		1.50
IGNITION PARAMETER		1.501
IGNITION PARAMETER - PANEL		1.627
IGNITION PARAMETER - MIRNOV		1.501
IGNITION PARAMETER - NEOALCATOR		2.138
PHYSICS PANEL FIGURE-OF-MERIT		20.7
FUSION POWER MULTIPLICATION		467.1
PLASMA INTERNAL ENERGY	MJ	32.3
ENERGY CONFINEMENT TIME	s	0.789
PLASMA HEATING		
ALPHA HEATING	MW	60.9
OHMIC HEATING	MW	0.7
AUXILIARY HEATING	MW	-20.5
SAFETY FACTOR ON EDGE*		2.60
SAFETY FACTOR ON AXIS*		1.00
PLASMA CURRENT	MA	7.83
PLASMA CURRENT RAMP TIME	s	4.636
INTERNAL INDUCTANCE PER UNIT LENGTH		0.649
TOTAL SELF INDUCTANCE	microH	2.62
PLASMA MAGNETIC ENERGY	MJ	80.
PLASMA LOOP VOLTAGE DURING BURN	V	0.083
PLASMA VOLUME	m3	13.7
PLASMA SURFACE AREA	m2	43.3
PLASMA CROSS SECTIONAL AREA	m2	1.39
PLASMA CIRCUMFERENCE	m	4.42
FUSION POWER	MW	305.
NEUTRON WALL LOAD AT PL. EDGE	MW/m2	5.64
FRACTIONAL ALPHA DENSITY*		0.050
ALPHA PARTICLE BUILDUP TIME	s	2.53
FRACTIONAL TRITIUM BURNUP		0.004
FRACTION OF IONS RECYCLED TO PLASMA*		0.900
PARTICLE CONFINEMENT TIME*	s	0.050
DENSITIES		
ELECTRONS	1e20/m3	4.4279
D-T IONS	1e20/m3	3.7687
ALPHAS	1e20/m3	0.2001
IMPURITY IONS	1e20/m3	0.0324
REQUIRED PUMPING SPEED	l/s	1.93e+03
PLASMA BURN TIME	s	5.0
TRITIUM CYCLED PER PULSE	g	1.41e-01

$C_J = 1.1925$

$C_\beta = 0.03$

* - indicates input value

TF SYSTEM PARAMETERS

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TF CENTERING FORCES ARE REACTED BY WEDGING...
THE OH SOLENOID IS LOCATED INSIDE THE TF BORE

NUMBER OF TF COILS		14
TOROIDAL FIELD BR	W/m	14.50
RADIUS OF TF INNER LEG	m	0.891
RADIUS OF TF JOINT	m	0.991
MAXIMUM TOROIDAL FIELD	T	16.271
TF CONDUCT THICKNESS, INNER LEG	m	0.609
TF WINDING THICKNESS, INNER LEG	m	0.881
TF WINDING THICKNESS, OUTER LEG	m	0.665
TOTAL VERTICAL SEPERATING FORCE	N	7.10e+08
FRACTION TAKEN ON INNER LEG		0.233
STRESS IN CONDUCTOR DUE TO VSF	Pa	8.68e+07
SHEAR STRESS IN CONDUCTOR	Pa	2.35e+07
PEAK STRESS IN INNER LEG	Pa	2.69e+08
AVERAGE STRESS IN INNER LEG	Pa	2.37e+08
RADIUS OF TF OUTER LEG	m	2.572
CALCULATED RIPPLE W/O IRON		.0300
REQUIRED RIPPLE W/O IRON		.0300
TF INNER RING THICKNESS	m	0.050
TF OUTER RING THICKNESS	m	0.000
TF SIDEWALL THICKNESS	m	0.050
TF STRONGBACK THICKNESS	m	0.060
ALLOWABLE STRESS IN STRONGBACK	Pa	2.50e+08
TF WINDING WIDTH	m	0.397
TF COIL WIDTH	m	0.497
TF COIL-TO-COIL CLEARANCE	m	0.638
TF INDUCTANCE	H	5.10e-02
TF STORED ENERGY	J	2.11e+09
TF CONDUCTOR CURRENT	A	2.88e+05
WINDINGS PER COIL		18
TF PACKING FRACTION		0.85
INNER LEG MATERIAL - OFHC/BeCu (0.90:0.10) COMPOSITE		
LENGTH	m	3.38
WINDING PACK CURRENT DENSITY	A/m2	2.91e+07
CONDUCTOR CURRENT DENSITY	A/m2	3.80e+07
INITIAL TEMPERATURE	K	77.0
FINAL TEMPERATURE	K	100.8
OUTER LEG MATERIAL - OFHC COPPER - CDA 104		
LENGTH	m	5.83
WINDING PACK CURRENT DENSITY	A/m2	1.96e+07
CONDUCTOR CURRENT DENSITY	A/m2	2.31e+07
INITIAL TEMPERATURE	K	77.0
FINAL TEMPERATURE	K	85.1
CHARGING TIME	s	9.0
RESISTIVE LOSSES, CHARGING	J	1.73e+08
PEAK RES POWER, CHARGING	W	5.36e+07
FLATTOP TIME	s	5.1
RESISTIVE LOSSES, FLATTOP	J	2.99e+08
PEAK RES POWER, FLATTOP	W	6.25e+07
COIL DUMP TIME	s	9.7
ENERGY REQUIRED FROM MGF/GRID	J	2.58e+09
BUS RESISTANCE	OHMS	1.21e-04
PEAK POWER SUPPLY VOLTAGE	V	2000.
POWER SUPPLY INTERNAL RESIST	OHMS	1.67e-03

PF SYSTEM PARAMETERS

OH SOLENOID INNER RADIUS IS 0.911 m
OH SOLENOID OUTER RADIUS IS 0.990 m
PEAK FIELD IN OH SOLENOID IS 4.13 T
WINDING PACK CURRENT DENSITY IS 4.15e+07 A/m2
CONDUCTOR CURRENT DENSITY IS 5.53e+07 A/m2
OH PACKING FRACTION IS 0.75
STRESS DUE TO AXIAL COMPRESSION IS -4.07e+07 Pa
AVG STRESS IN OH SOLENOID IS 1.63e+08 Pa
PEAK STRESS IN SOLENOID IS 1.68e+08 Pa
OH CONDUCTOR MATERIAL IS OFHC COPPER
VOLT-SECONDS REQUIRED ARE 25.51
...FOR BUILDING PLASMA CURRENT 20.51
...FOR RESISTIVE LOSSES DURING STARTUP 4.58
...FOR RESISTIVE LOSSES DURING BURN 0.42
VOLT-SECONDS PROVIDED ARE 25.70
...BY EF 9.27
...BY OH 16.43

0424

RADIAL BUILD

ELEMENT	THICKNESS (m)	RADIUS (m)
		0.010
TF COIL WINDING	0.881	
		0.891
GAP	0.020	
		0.911
OH SOLENOID	0.079	
		0.990
GAP	0.040	
		1.030
VACUUM VESSEL	0.030	
		1.060
INBOARD FIRST WALL	0.030	
		1.090
PLASMA RADIUS	0.531	
		1.621
PLASMA RADIUS	0.531	
		2.152
OUTBOARD SCRAPEOFF	0.120	
		2.272
OUTBOARD FIRST WALL	0.030	
		2.302
VACUUM VESSEL	0.030	
		2.332
GAP	0.020	
		2.352
IRON SHIM	0.150	
		2.502
GAP	0.020	
		2.522
TF COIL INNER CASE	0.050	
		2.572
TF COIL WINDING	0.665	
		3.237
TF COIL STRONGBACK	0.060	
		3.297
GAP	0.100	
		3.397
IGLOO	0.100	
		3.497

VERTICAL BUILD

ELEMENT	THICKNESS (m)	HEIGHT (m)
PLASMA	0.849	
		0.849
PLASMA SCRAPEOFF	0.120	
		0.969
FIRST WALL	0.030	
		0.999
VACUUM VESSEL	0.030	
		1.029
GAP	0.500	
		1.529
TF INNER CASE	0.050	
		1.579
TF WINDING	0.665	
		2.244
TF STRONGBACK	0.060	
		2.304

RFP REQUIREMENTS

J. Downing
Los Angeles National Laboratory
Los Alamos, New Mexico

- RFP Program has been ready to build a next device (~ PLT class) for several years (∞)
- ZT-H Proposed by Los Alamos

  $I = 2-4\,MA$

  $a \sim 0.4\,m$

  $\tau_p \sim 0.25\,s$

  Air Core, Low Field Error
- Industry has proposed a joint project with DoE to build a more <u>aggressive</u> next step to evaluate both the OHTE and RFP concepts.

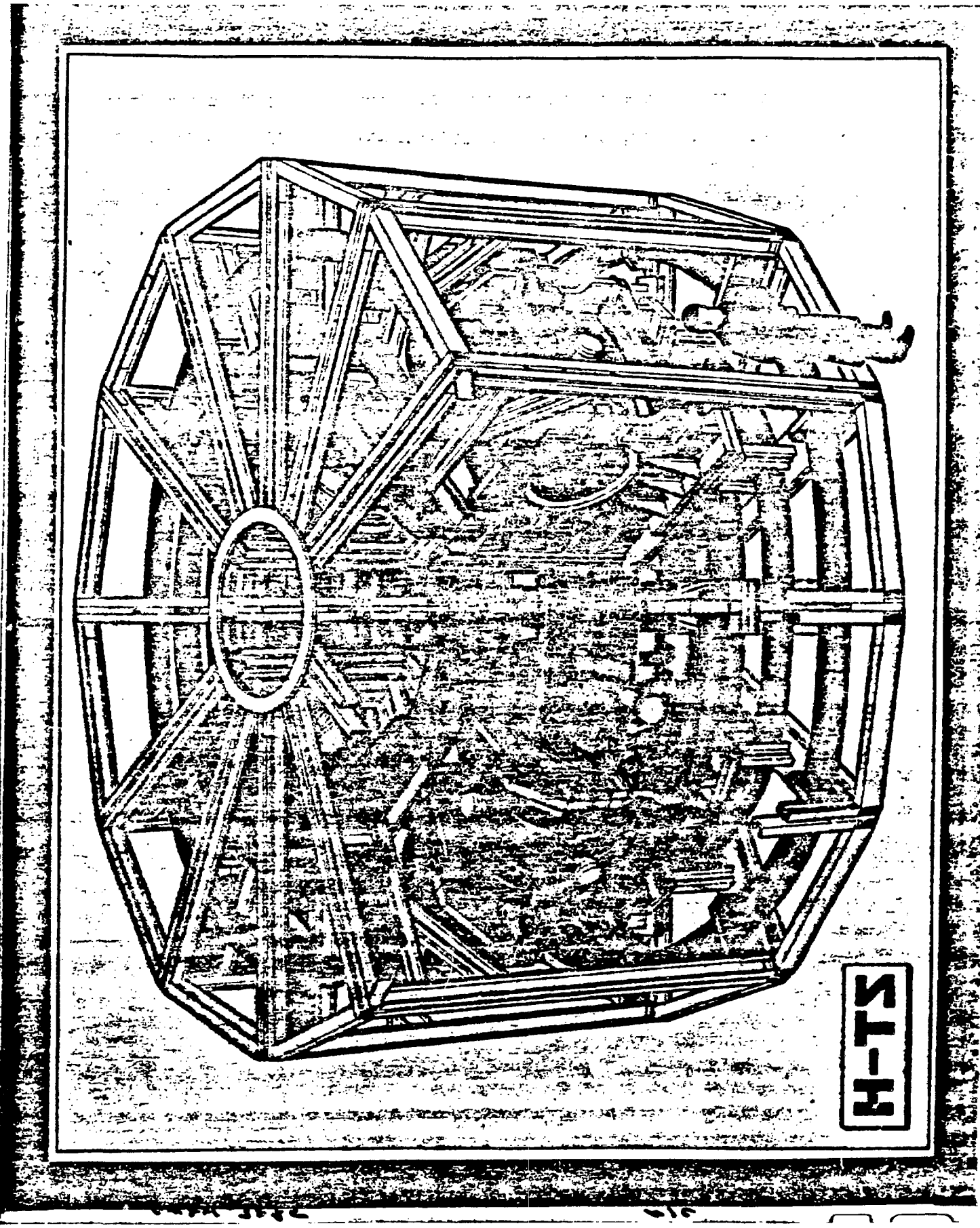
  Industry { GAT, Phillips, Ontario-Hydro }

  DoE / Los Alamos

OVERVIEW

OF

ZT-H PROPOSAL


H-TN

ZT-H PROJECT

DESIGNED TO ACHIEVE

- RFP physics data base – confinement, current and size scaling. Phase IA
- Tests at high current density, high wall loads. Phase IB
- Clear separation of RFP confinement issues and plasma-wall interaction issues.
- Upgrade to 4 MA by adding power supplies. Phase II
- Current magnitude selected by physics extrapolation/cost judgement.

PROGRAM GOAL

- Physics evaluation of potential of RFP to lead to compact reactor unhindered by plasma–wall interaction. (Phase 1A)

- Move to technical issues after evaluation of physics issues. (Phase 1B)

PROGRAM IMPLEMENTATION

Phase 1A – Evaluation

$I_\phi = 2$ MA

$a = 40$ cm

Average $\overline{Q}_W \sim 0.7$ MW/m^2

Peak $Q_{MAX} \sim 7$ MW/m^2

$t_D \leq 0.25$ seconds

PROGRAM IMPLEMENTATION

(continued)

Phase 1B – Technology

$I_\phi = 2$ MA

$a \geq 25$ cm

Average $\bar{Q}_W \sim 3$ MW/m^2

Peak $Q_{MAX} \sim 30$ MW/m^2

$t_D \leq 0.25$ seconds

PROGRAM IMPLEMENTATION

(continued)

Phase II – Scaling – Near ignition–like temperature.

I_ϕ = 4 MA

a = 40 cm

Average $\overline{Q}_W \sim 1\ MW/m^2$

Peak $Q_{MAX} \sim 10\ MW/m^2$

$t_D \leq$ 0.6 seconds

WITH ADVENT OF JOINT PROGRAM BASIC ZT-H DESIGN UPGRADED TO THE 7 MA LEVEL.

$I_\phi = 7$ MA

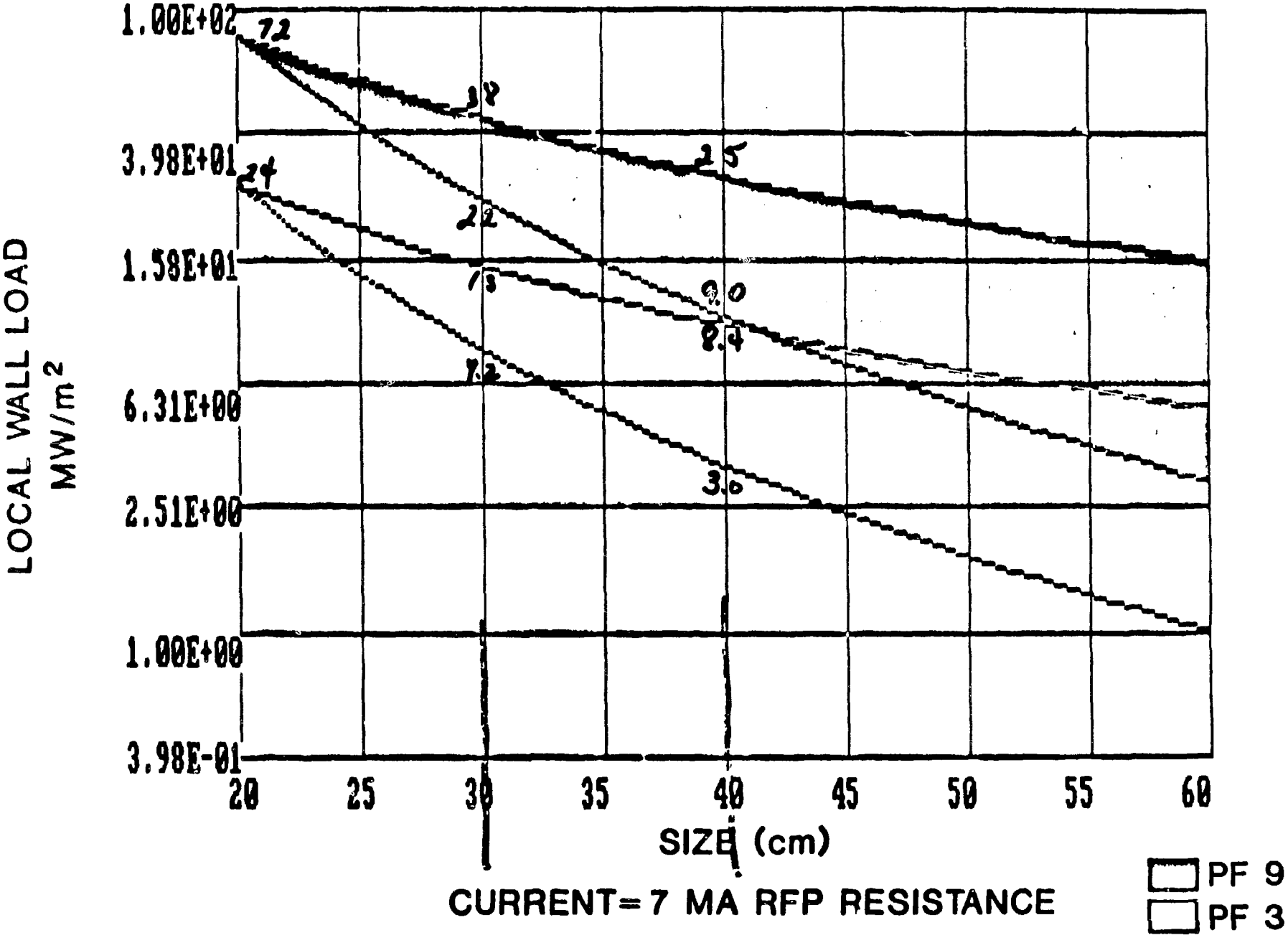
$a = 40$ cm

Average $\bar{Q}_W \sim 1.2$ MW/m^2

Peak $Q_{MAX} \sim 12$ MW/m^2

$t_D \sim 1.4$ seconds

Graphite First Wall


LOCAL WALL LOAD
MW/m²
1.00E+02
3.98E+01
1.58E+01
6.31E+00
2.51E+00
1.00E+00
3.98E-01
20
25
30
35
40
45
50
55
60
SIZE (cm)
CURRENT=7 MA RFP RESISTANCE
PF 9
PF 3
72
38
25
24
22
18
9.0
8.4
7.2
3.6

MARK M. PICKRELL

THE LANL POINT OF VIEW

- The objective of the new machine is to provide knowledge of RFP/OHTE physics.
- The machine must be capable of reliable operation.
- Severe wall loading may have two consequences:

  1. Premature quenching of plasma.
  2. Wall damage.

Simulations + Calculations

Indicate a hard limit for RFPs:

$T = 2300^{\circ}K$

High Impedance → Resistive Runaway

Only Impurity Mechanism Is Evaporation

Only Impurity Is Carbon

Optimistic Scaling Assumed

No Self Sputtering

Area ∝ 1/PF

"TRIGGER" TEMPERATURE

T^*

$T^* \equiv$ The front surface temperature when

Impurity Flux $\approx$ Recycling Flux

$$\Downarrow$$

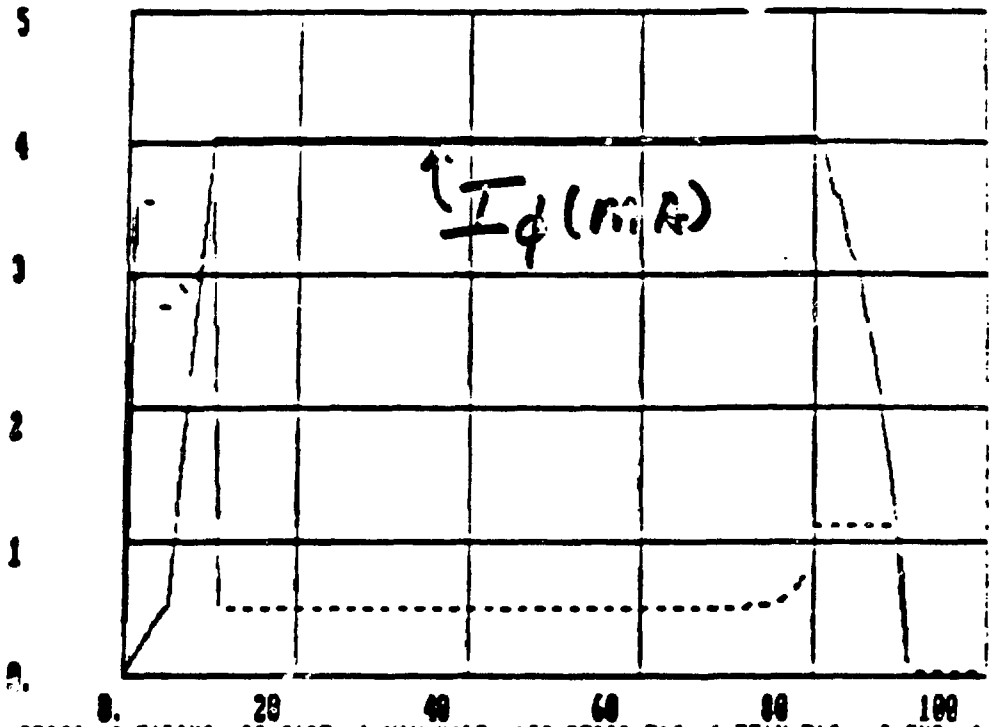
Max. Thermal Wall Load for Discharge Duration (t)

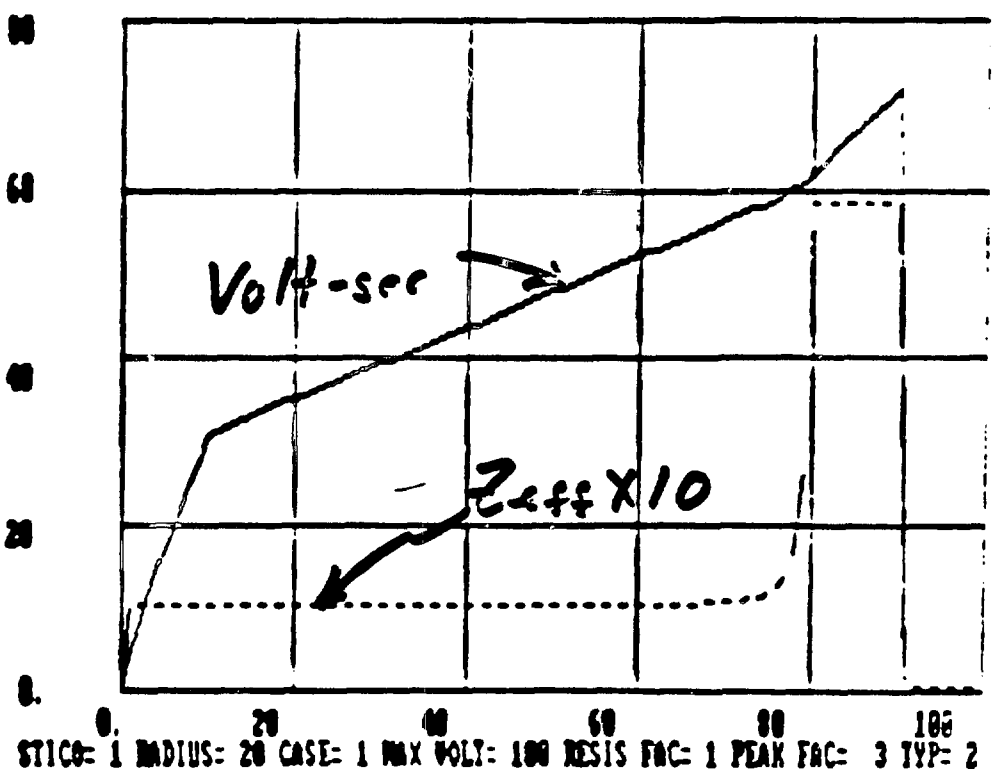
$$Q(MW/m^2) = 21.5/\sqrt{t(s)}$$

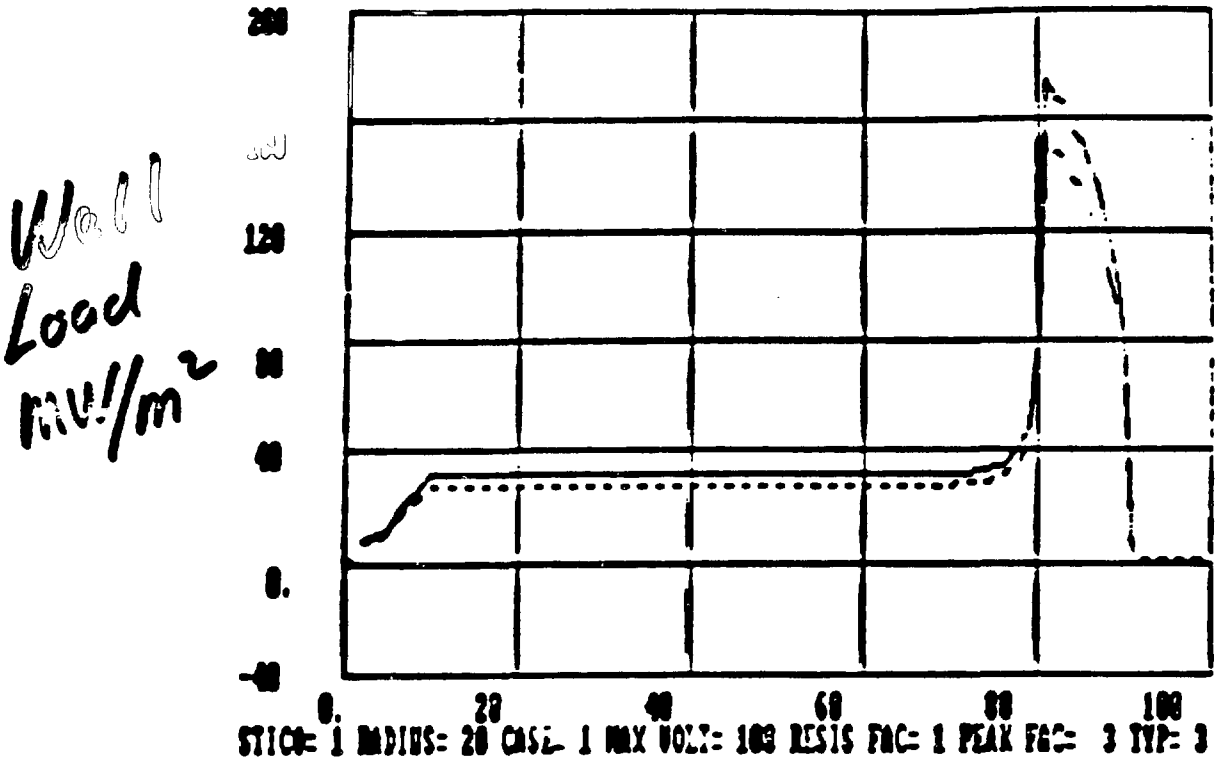
Results

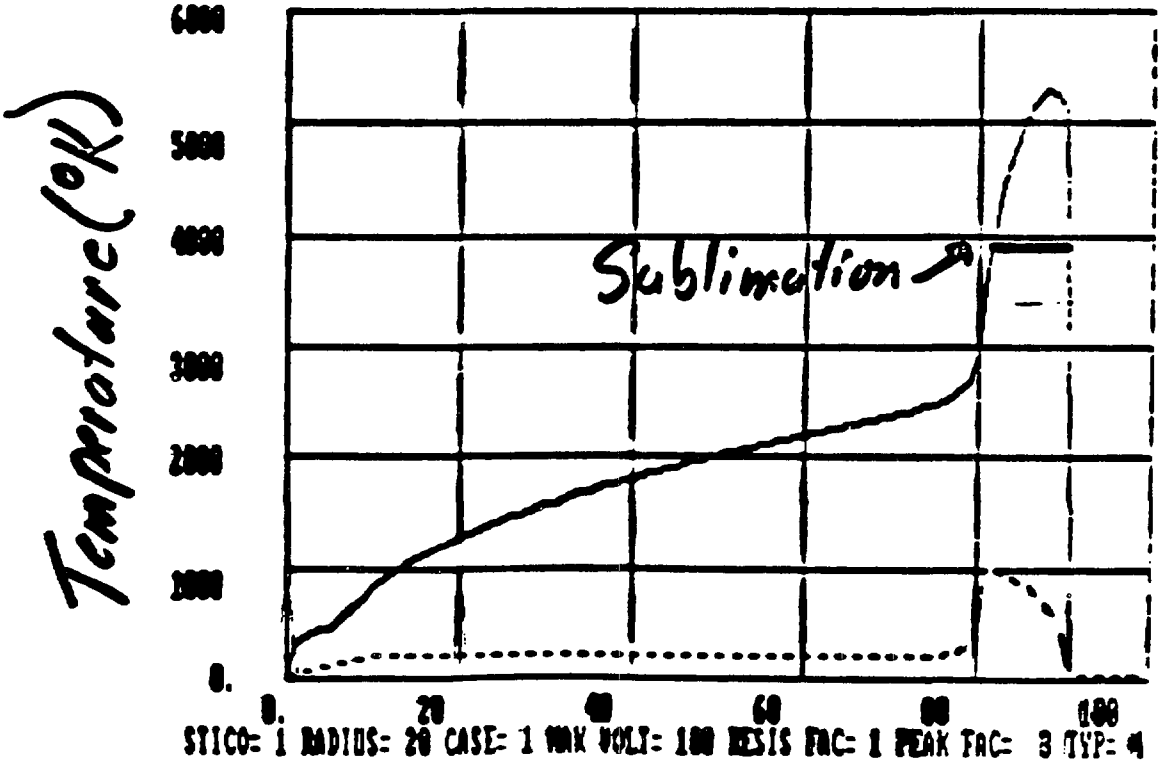
- T^* relatively insensitive to "sticking coefficient" and "peaking factor." [Evaporation Rate strong function of temperature]

- Once T^* is reached, the inductive energy is deposited as heat on the first wall (~ 0.15s), driving the wall to sublimation temperature.

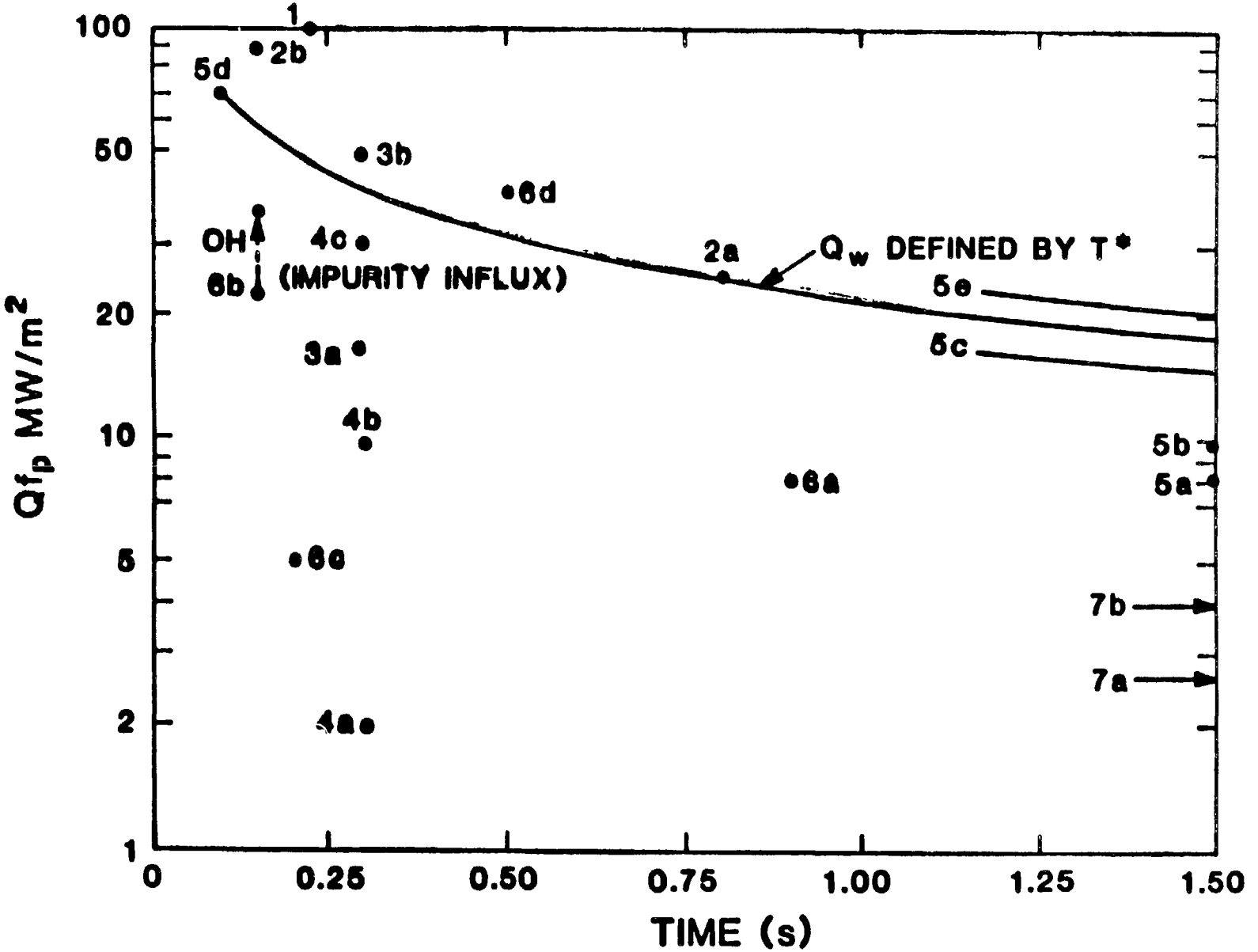

5
4
3
2
1
0.
0.
20
40
60
80
100
I_d (mA)
STICO= 1 RADIUS= 20 CASE= 1 MAX VOLT= 100 RESIS FAC= 1 PEAK FAC= 3 TYP= 1


80
60
40
20
0.
0.
20
40
60
80
100
Volt-sec
$Z_{eff} \times 10$
STICO= 1 RADIUS= 20 CASE= 1 MAX VOLT= 100 RESIS FAC= 1 PEAK FAC= 3 TYP= 2


Wall Load MW/m²
200
160
120
80
40
0.
-40
0.
20
40
60
80
100
STICK= 1 RADIUS= 20 CASE= 1 MAX VOLT= 100 RESIS FAC= 1 PEAK FAC= 3 TYP= 3


Temperature (°K)
6000
5000
4000
3000
2000
1000
0.
Sublimation
0.
20
40
60
80
100
STICK= 1 RADIUS= 20 CASE= 1 MAX VOLT= 100 RESIS FAC= 1 PEAK FAC= 3 TYP= 4

HHF EXPERIENCE


100
50
20
10
5
2
1
0
0.25
0.50
0.75
1.00
1.25
1.50
TIME (s)
Qf_p MW/m^2
1
2b
5d
3b
6d
OH
6b
4c
(IMPURITY INFLUX)
2a
Q_w DEFINED BY T*
5e
5c
3a
4b
5b
5a
6a
6c
7b
7a
4a

5/85clr5865

TABLE 1

Symbol	Machine	Component	Peak Heat Flux	Pulse Length	Remarks	Reference
1.	ISX-B					
		Mushroom Limiter	100 MW/m^2	< 0.20	Z_{eff} < 3, dominated by Oxygen ~ 3000°C.	1, 2
2.	PLT					
		a. Rail Limiter	25 MW/m^2	0.8 s	Inferred from melt-layer Z_{eff} 3-4.	3
		b. Rail Limiter	90 MW/m^2	0.15 s		
3.	Alcator-C					
		a. Poloidal Limiter (two)	16 MW/m^2	< 0.30	Z_{eff} 1.2-1.5 peaking factor of 4 in calculation.	4
		b. Poloidal Limiter (one)	50 MW/m^2	< 0.30		
4.	PDX					
		a. Bumper Limiter	2 MW/m^2	< 0.30	Z_{eff} 1.8-2.9.	
		b. Divertor Plates	10 MW/m^2	< 0.30	Z_{eff} 1.3-1.7.	
		c. Rail Limiter	30 MW/m^2	< 0.30	Impurity influx and frequent disruption if beam pulse length > 0.150 s, Z_{eff} 2-4.	5, 6
5.	TFTR					
		a. Movable Limiter Design	8.5 MW/m^2	1.5 s		
		b. Bumper Limiter Design	10 MW/m^2	1.5 s		
		c. Movable Limiter Oper.	17 MW/m^2 (NBI)	0.5 s	~ 5.5 MW/m^2 OH for 30 s with NBI at 2.5-3.0 s, Z_{eff} ~ 2.0.	One cracked tile and general surface cracking carbon increases by 2. ★
		d. Movable Limiter Design	70 MW/m^2	~ 0.1 s		7,8,9,10,11,17
		e. Movable Limiter Oper.	29 MW/m^2 (NBI)	0.5 s	~ 5.5 MW/m^2 OH for 3.0 s with NBI at 2.5-3.0 s, Z_{eff} ~ 3.4 (1.7-3.8).	
6.	Doublett III					
		a. Primary Limiter	8 MW/m^2	0.9 s	Cracked ★ Tiles	12,13,14,15
		b. Plus NBI	23 MW/m^2	0.15 s		
		c. NBI Armor	5 MW/m^2	0.20 s		
		d. NBI Armor	40 MW/m^2	0.50 s	No plasma, no damage	
7.	JET					
		a. Limiter Operation	2.6 MW/m^2	10 s		
		b. Limiter Design	4.0 MW/m^2	20 s	~ 1000°C, Z_{eff} 3-6	16

★ The cause of the graphite failures is attributed to interactions with hold-down fixtures, stress concentrations and/or errors in assembly.

HHF Issues

- Reliability of First Wall
  1. Large number of units $\sim 10^5$
  2. Difficulty of repair
  3. Possible peaking of thermal loads

$\Rightarrow$ Very low failure Rate

1. Good thermal stress design
2. Testing of a statistically significant number of samples.
3. Material procurement must be approached statistically to select the higher strength materials.
4. Heat Flux measurements in current devices.

PMI Requirements

FINDINGS

- Primary material choice should be low Z ($\lesssim$ 6) unless experiments indicate that T_e at edge can be lowered to < 50 eV. (Carbon has been chosen.)
- Impurity control measures will be required to attain Z_{eff} < 2.0 for edge temperatures of 70eV < T_{edge} < 300eV
- Impurity influx from evaporation will add to the impurity level from sputtering. If evaporation reaches significant levels, impurity control measures will be necessary to attain Z_{eff} < 2.0.
- Z_{eff} due to physical sputtering has a maximum value of 2.4 at 90 eV (T_{edge}) and decreases at <u>higher</u> and <u>lower</u> values of T_{edge}.

- Characterization of PMI in the current devices (ZT-40M and OHTE I)
- Model PMI processes for extrapolation to ZT-H/OHTE II conditions
- Identify any specific issues related to the "compactness" of the system and/or first wall material choice.

COMPACT, HIGH POWER DENSITY REQUIREMENTS

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COMPACT HIGH-POWER-DENSITY REACTORS AND THE ROLE OF HIGH-HEAT-FLUX PLASMA-INTERACTIVE MATERIALS

JOINT MEETING OF THE DOE/OFE
DIVISION OF DEVELOPMENT AND TECHNOLOGY
PLASMA/WALL INTERACTION AND
HIGH-HEAT-FLUX MATERIALS AND COMPONENTS
TASK GROUPS

US DOE HEADQUARTERS
GERMANTOWN, MARYLAND
May 21-22, 1985

R. A. KRAKOWSKI
LOS ALAMOS NATIONAL LABORATORY
LOS ALAMOS, NEW MEXICO 87545

OUTLINE

- COMPACT HPD REACTORS: WHY, HOW AND PAYOFF
- POWER DENSITY (COST) AND HEAT FLUX
- HEAT-FLUX/SPUTTERING/MATERIAL TRADEOFFS
- APPROACHES TO IMPROVED MFE REACTORS
- CRFPR(20) EXAMPLE
- CONCLUSIONS

NOTATION

BLITZ	BERYLIUM/LITHIUM TBR ZONE
ET	ELONGATED (TOKAMAK) TORUS
FPC	FUSION POWER CORE (PLASMA CHAMBER, FIRST WALL, BLANKET, SHIELD, COILS AND RELATED STRUCTURE)
FSR	(TOKAMAK) FIRST STABILITY REGION
HHF	HIGH HEAT FLUX
HPF	HIGH PARTICLE FLUX
NWL	NEUTRON (FIRST)-WALL LOADING
OHC	OHMIC HEATING COIL
RFP	REVERSED-FIELD PINCH (THIRD STABILITY REGION)
SC	SUPERCONDUCTING
SPM	SINGLE-PIECE MAINTENANCE (OF FPC)
SSR	(TOKAMAK) SECOND STABILITY REGION
ST	SPHERICAL (TOKAMAK) TORUS
TBD	TO BE DETERMINED
TBR	TRITIUM BREEDING

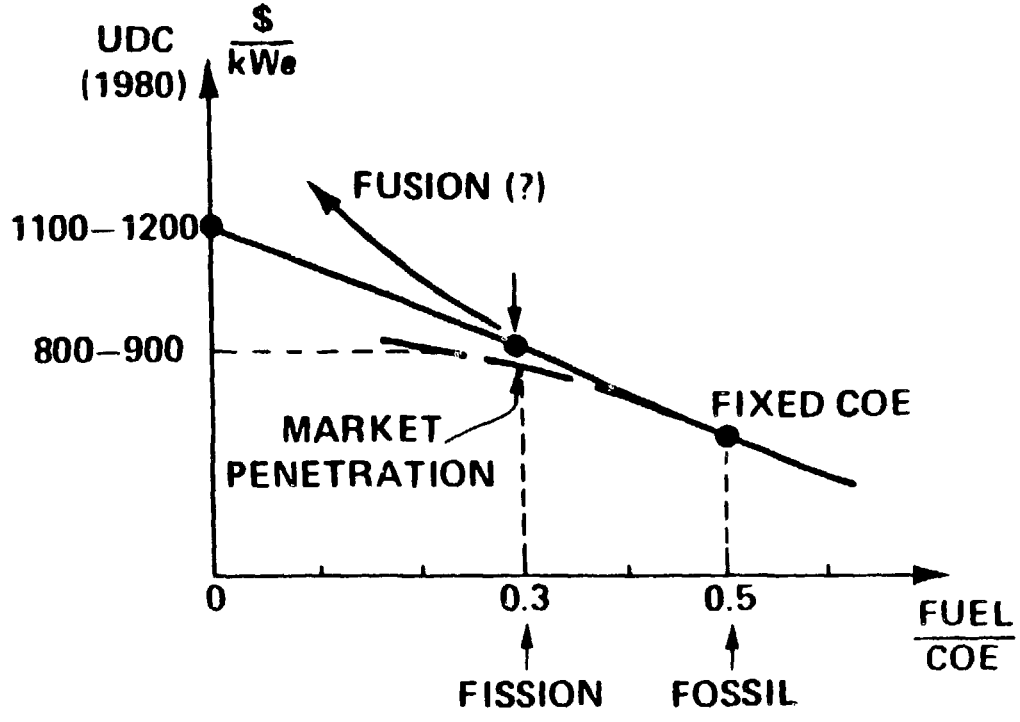
GENERAL CONCLUSIONS

- THE PERFORMANCE OF MFE REACTORS GENERALLY IS LIMITED BY SURFACE HEAT (PARTICLE AND/OR RADIATIVE) LOADS: THE PAYOFF OF HHF ALLOYS IS LARGE FOR ALL APPROACHES TO THE MFE END-PRODUCT

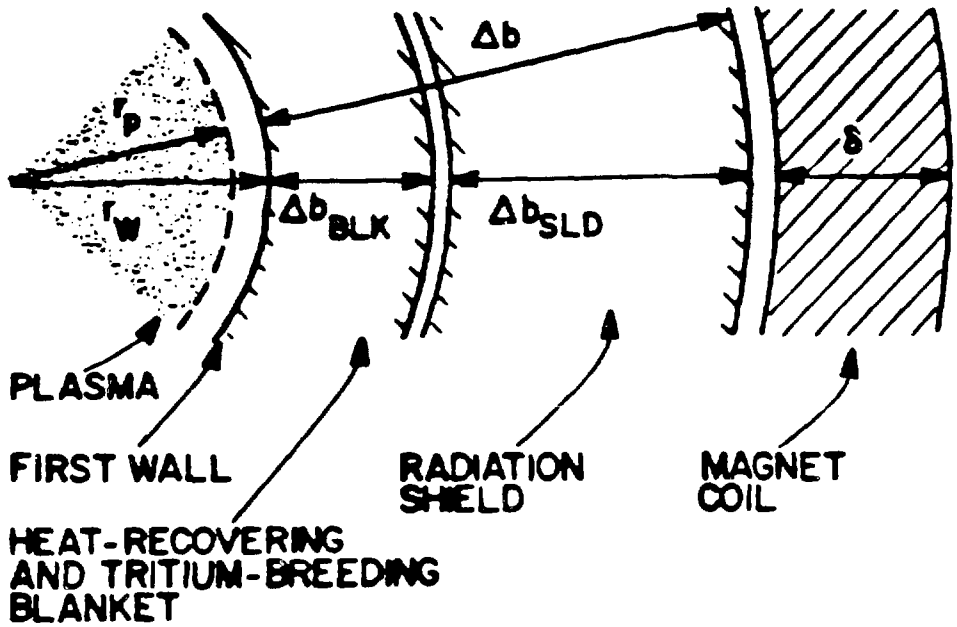
- ALL MFE REACTOR DESIGNS SHARE SIMILAR DESIGN CONSTRAINTS, UNKNOWNS, AND POTENTIAL SOLUTIONS: THE HHF ISSUE IS NOT UNIQUELY A COMPACT REACTOR ISSUE.

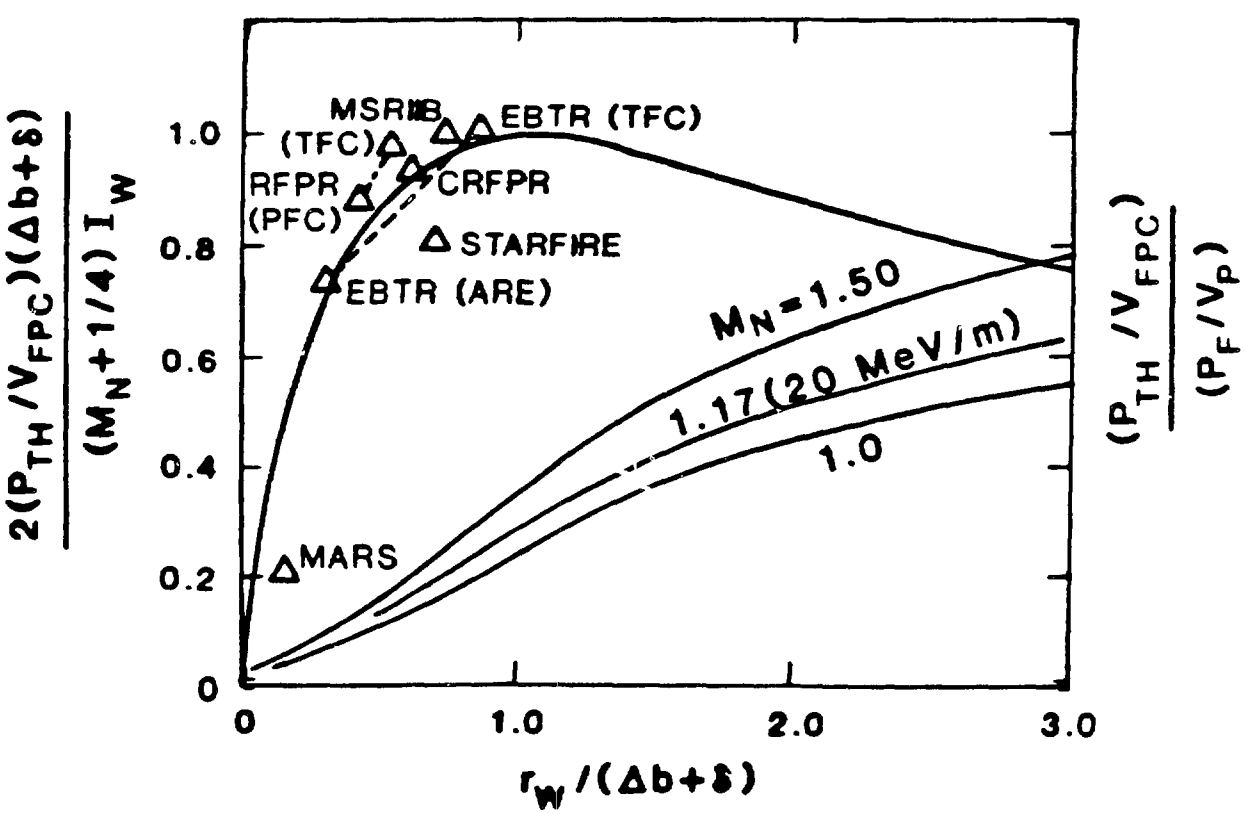
PREVALENT VISION OF MAGNETIC FUSION REACTORS

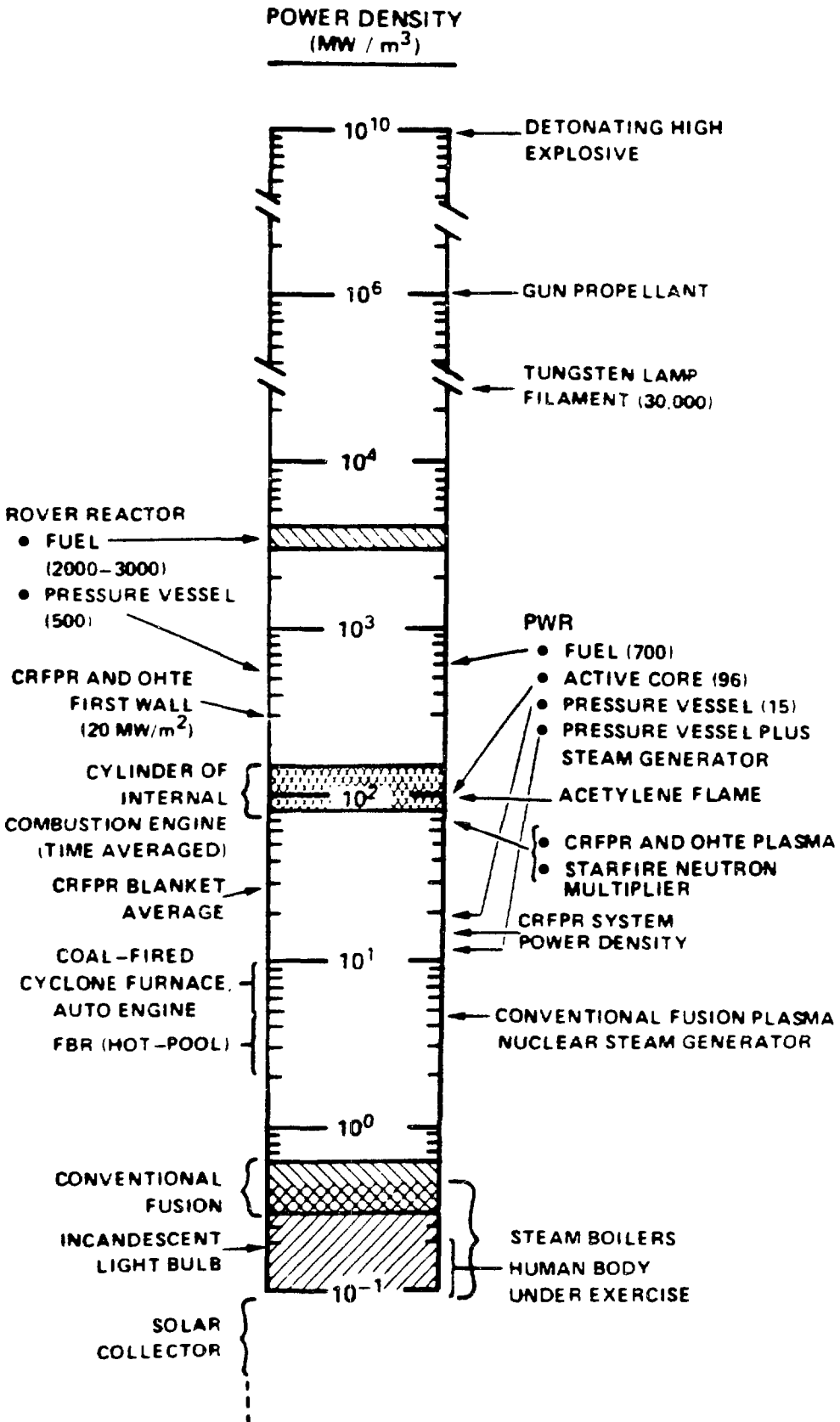
- TOO LARGE AND COMPLEX FOR A BASE–LOADED NUCLEAR POWER STATION
- POWER DENSITY TOO LOW
- COST TOO HIGH, NOT COMPETITIVE
- FUEL COST VS CAPITAL COST TRADEOFF MAY BE IMBALANCED

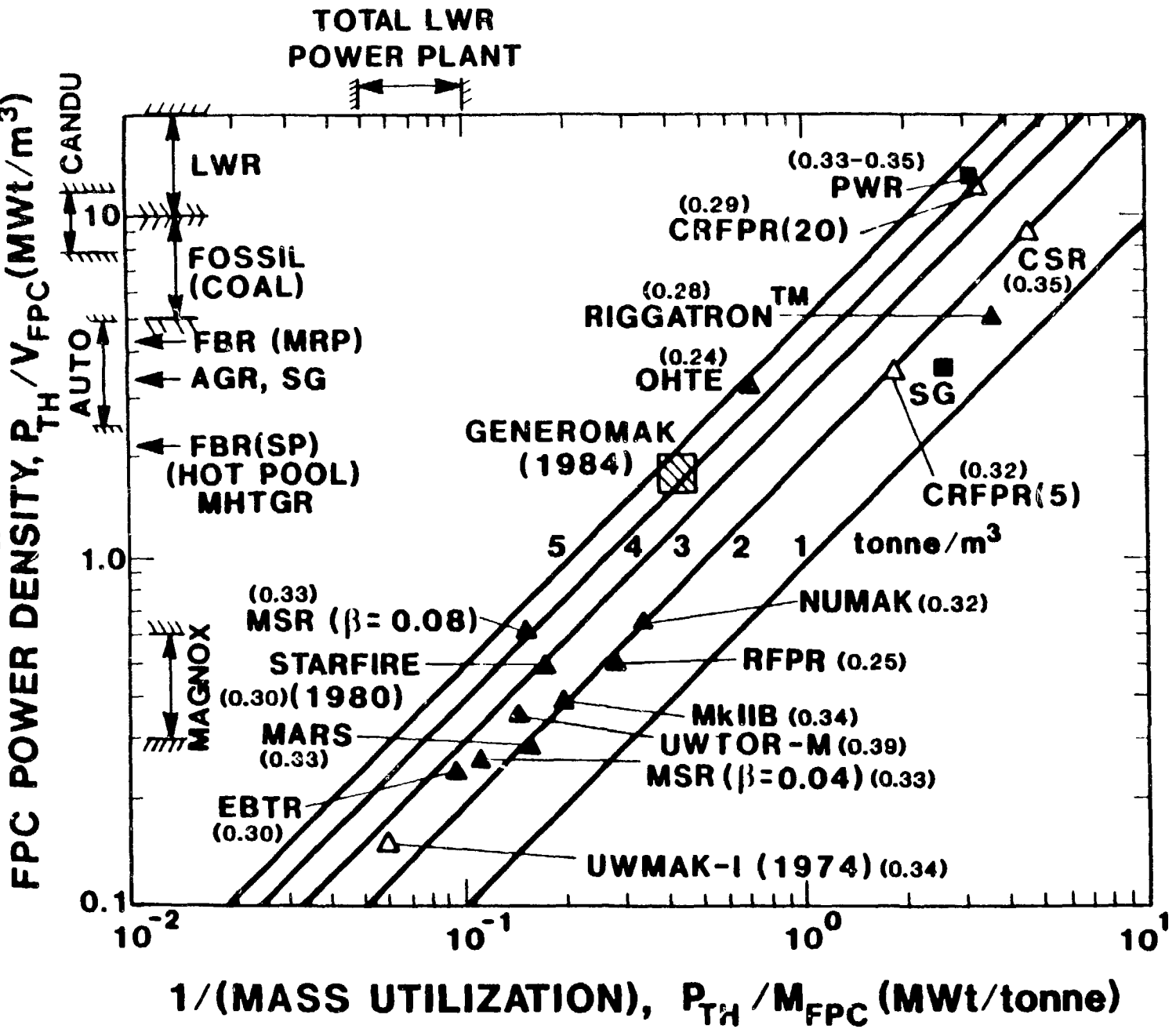


FUSION-POWER-CORE POWER DENSITY






POWER DENSITY
(MW / m3)
10^10
DETONATING HIGH EXPLOSIVE
10^6
GUN PROPELLANT
TUNGSTEN LAMP FILAMENT (30,000)
10^4
ROVER REACTOR
• FUEL (2000–3000)
• PRESSURE VESSEL (500)
10^3
PWR
• FUEL (700)
• ACTIVE CORE (96)
• PRESSURE VESSEL (15)
• PRESSURE VESSEL PLUS STEAM GENERATOR
CRFPR AND OHTE FIRST WALL (20 MW/m2)
CYLINDER OF INTERNAL COMBUSTION ENGINE (TIME AVERAGED)
10^2
ACETYLENE FLAME
• CRFPR AND OHTE PLASMA
• STARFIRE NEUTRON MULTIPLIER
CRFPR BLANKET AVERAGE
CRFPR SYSTEM POWER DENSITY
COAL-FIRED CYCLONE FURNACE, AUTO ENGINE
FBR (HOT-POOL)
10^1
CONVENTIONAL FUSION PLASMA NUCLEAR STEAM GENERATOR
10^0
CONVENTIONAL FUSION
INCANDESCENT LIGHT BULB
STEAM BOILERS
HUMAN BODY UNDER EXERCISE
10^-1
SOLAR COLLECTOR


TOTAL LWR
POWER PLANT
CANDU
LWR
10
FOSSIL
(COAL)
AUTO
FBR (MRP)
AGR, SG
FBR(SP)
(HOT POOL)
MHTGR
1.0
MAGNOX
0.1
(0.33-0.35)
PWR
(0.29)
CRFPR(20)
CSR
(0.35)
(0.28)
RIGGATRON™
(0.24)
OHTE
SG
GENEROMAK
(1984)
(0.32)
CRFPR(5)
5
4
3
2
1
tonne/m³
(0.33)
MSR (β= 0.08)
NUMAK (0.32)
STARFIRE
(0.30)(1980)
RFPR (0.25)
MkIIB (0.34)
MARS
(0.33)
UWTOR-M (0.39)
MSR (β=0.04) (0.33)
EBTR
(0.30)
UWMAK-I (1974) (0.34)
10⁻²
10⁻¹
10⁰
10¹
FPC POWER DENSITY, P_TH/V_FPC (MWt/m³)
1/(MASS UTILIZATION), P_TH/M_FPC (MWt/tonne)

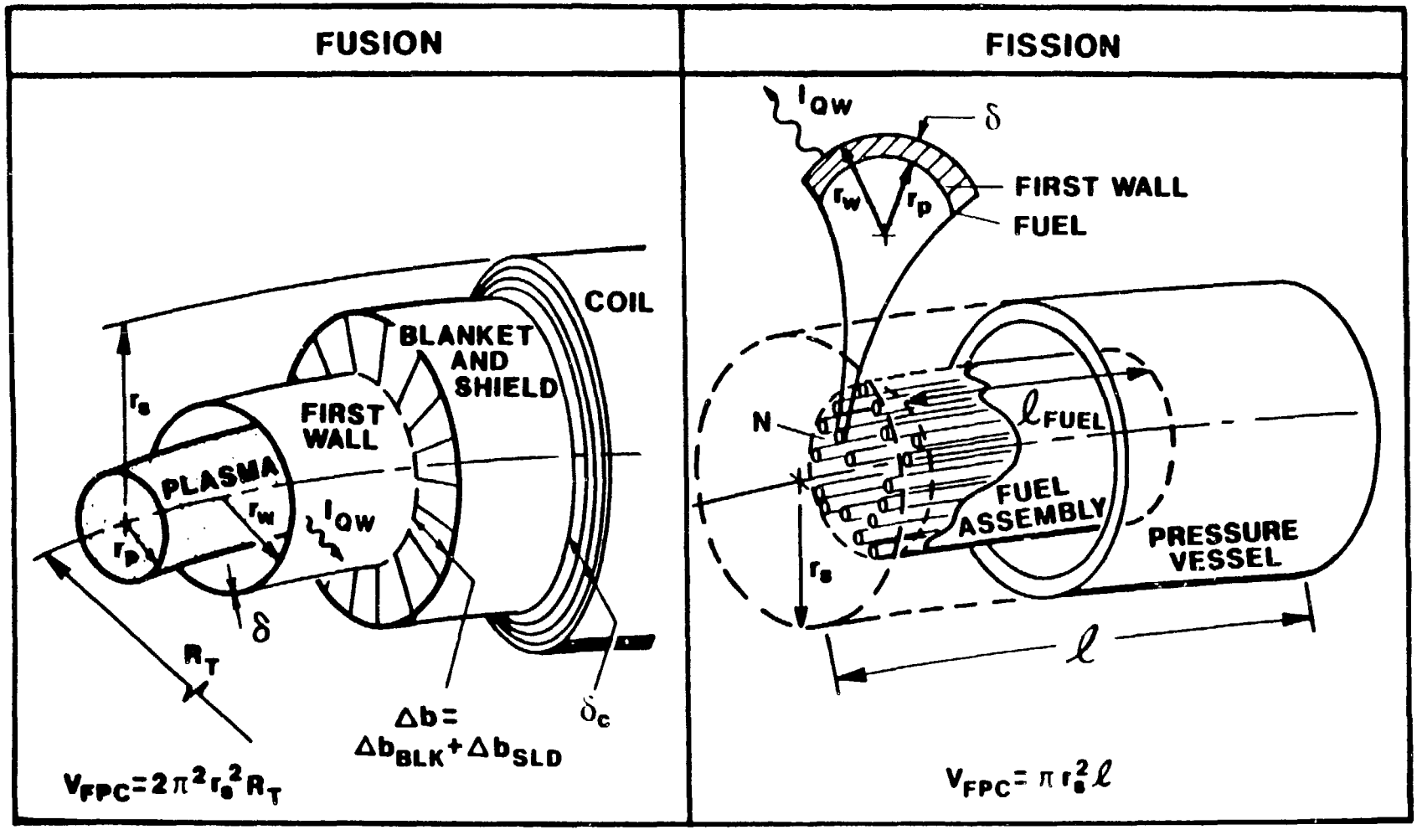
PROMISE OF HIGHER-POWER-DENSITY SYSTEMS

- REDUCE DIRECT COSTS
  - SUPERCONDUCTING FPCs ARE 20–40 ktonne, UDC IS OPTIMISTICALLY 1.5–3.0 TIMES FISSION
  - COMPACT SYSTEMS REDUCE FPC MASS BY >10
- REDUCE UDC SENSITIVITY TO FPC PHYSICS AND ENGINEERING
- REDUCE CONSTRUCTION/LICENSING COSTS AND TIME
  - FACTORY FABRICATION AND ASSEMBLY
  - SHRINK, BETTER–DEFINED NUCLEAR ENVELOPE
  - STANDARDIZATION

PROMISE OF HIGHER-POWER-DENSITY SYSTEMS (cont'd-1)

- SIMPLIFY REPAIR AND MAINTENANCE
  - SINGLE–UNIT FPC (PRETESTED)
  - SHORTEN DOWNTIME
- ACHIEVE OPTIMUM WALL LOADING, MINIMUM COE
- REDUCE DEVELOPMENT COST, TIME, AND RISK
  - SMALLER, LESS COSTLY FPC PROTOTYPES
  - REDUCED STORED ENERGY, DRIVE POWER
  - RAPID FPC TURN–AROUND TIME
  - LESS TECHNOLOGY EXTRAPOLATION

POWER DENSITY COMPARISON



CLAD SURFACE/FUEL VOLUME	
$SV = \dfrac{2}{x^2 r_w}$	$SV = \dfrac{2}{r_w} \dfrac{1}{(1-\delta_c/r_w)^2}$
REACTION VOLUME/REACTOR VOLUME	
$R = \dfrac{x^2}{[1+(\Delta b+\delta_c)/r_w]^2}$	$R = \dfrac{N\pi r_p^2 \ell_{FUEL}}{\pi r_s^2 \ell} \equiv f_{FUEL}$
CLAD SURFACE/REACTOR VOLUME	
$R(SV) = \dfrac{2}{r_w} \dfrac{1}{[1+(\Delta b+\delta_c)/r_w]^2}$	$R(SV) = \dfrac{2}{r_w} \dfrac{f_{FUEL}}{(1-\delta_c/r_w)^2}$
SYSTEM POWER DENSITY	
$P_{TH}/V_{FPC} = \dfrac{I_{QW}(4M_N+1+5/Q_p)\,R(SV)}{1-\eta_p(1-f_{RAD})}$	$P_{TH}/V_{FPC} = I_{QW}\,R(SV)$

SOLUTIONS: MEANS TO INCREASE FPC POWER DENSITY RELATIVE TO FISSION WITH HOPES OF REDUCED COST

$$\frac{(P_{TH}/V_{FPC})_{FUS}}{(P_{TH}/V_{FPC})_{FIS}} = \frac{(I_{Qw})_{FUS}}{(I_{Qw})_{FIS}} \cdot \frac{1}{4f_{FUEL}} \cdot \frac{(r_w)_{FIS}}{(r_w)_{FUS}} \cdot \frac{4M_N + 1 + 5/Q_p}{1 - \eta_D(1 - f_{RAD})}$$

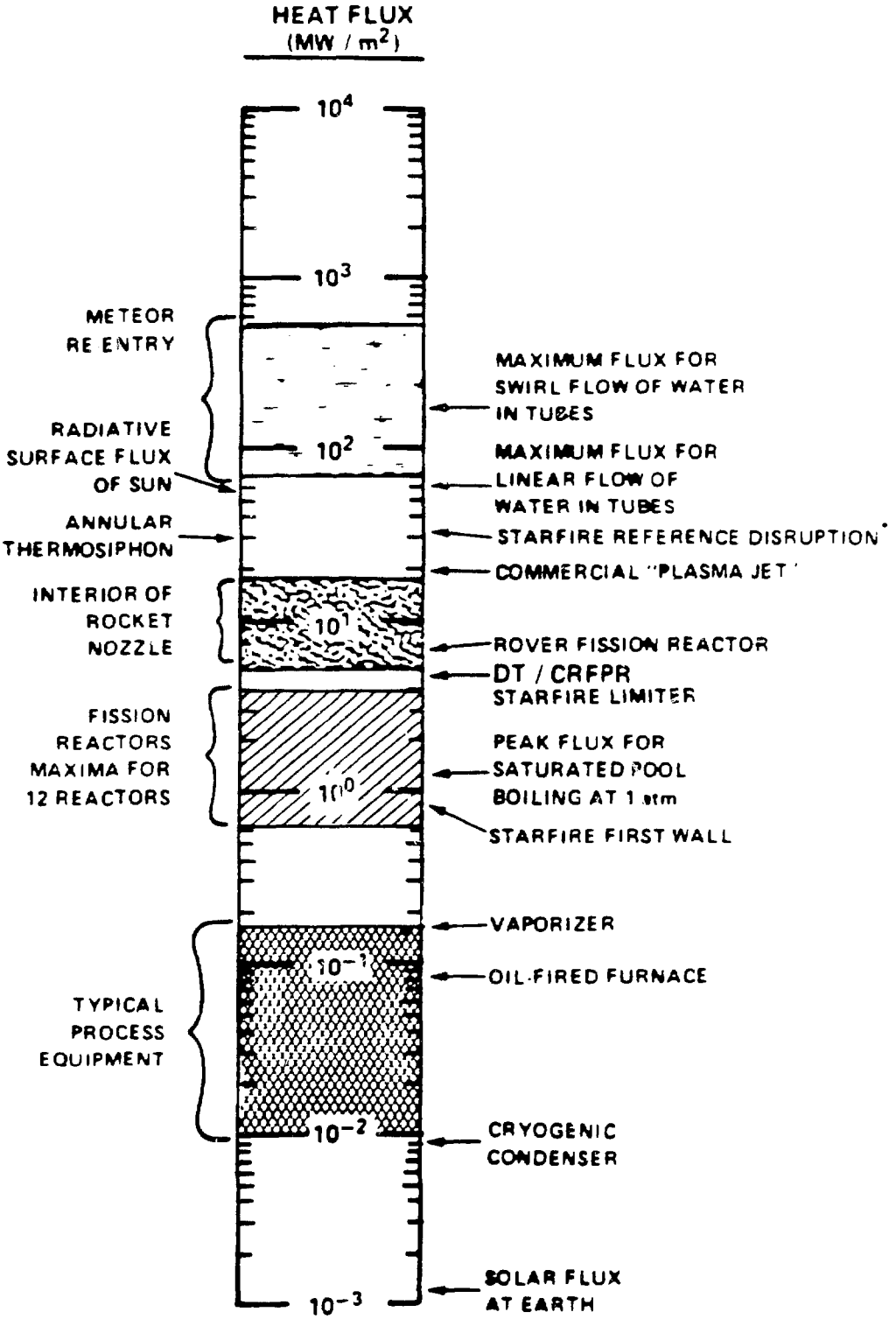
- $(I_{Qw})_{FIS} \simeq 0.5\text{–}1.5\ \mathrm{MW/m^2}$
- $f_{FUEL} \simeq 0.05$ (30% OF CORE, WHICH IS ~ 15% OF PRESSURE VESSEL)
- $(r_w)_{FIS} \simeq 0.01$ m
- FOR $M_N \simeq 1.3$, $\eta_D \simeq 0.0$, $Q_p \gg 1$
  - $(r_w)_{FUS} = 0.75 \rightarrow 3.0$ m
  - $(I_{Qw})_{FUS}/(I_{Qw})_{FIS} = 1 \rightarrow 5$

$$\frac{(P_{TH}/V_{FPC})_{FUS}}{(P_{TH}/V_{FPC})_{FIS}} = 0.1 \rightarrow 2.0$$

SOLUTIONS: MEANS TO INCREASE FPC POWER DENSITY RELATIVE TO FISSION WITH HOPES OF REDUCED COST (cont'd-1)

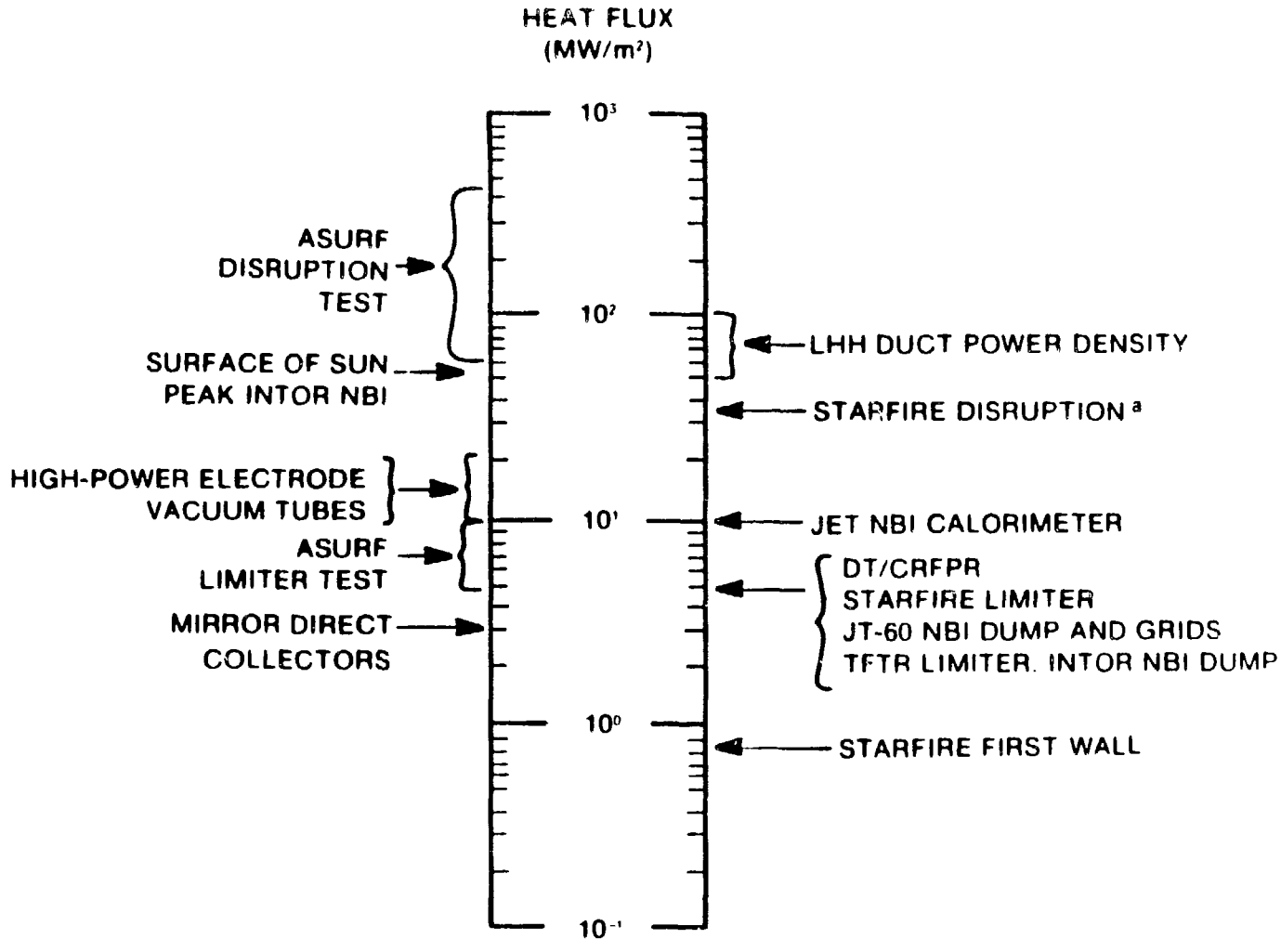
- ROOM FOR IMPROVEMENT EXISTS
  - INCREASED $(I_{Qw})_{FUS}$ POSSIBLE BY MORE FLEXIBLE CHOICE OF MATERIALS AND COOLING SCHEMES NOT AVAILABLE TO (NOR REQUIRED BY) FISSION
  - DECREASED $(r_w)_{FUS}$ WITH INCREASED I_w [INCREASED $(I_{Qw})_{FUS}$], MEANS FOR NOMINALLY FIXED TOTAL POWER OUTPUT THAT:
    - INCREASED PLASMA POWER DENSITY AND $(\beta B^2)_{PLAS}$
    - FOR $r_w \simeq \Delta b + \delta_c$, THIN HPD BLANKETS MAY BE REQUIRED (SELF–COOLED LIQUID METAL, HIGH–ALBEDO BUT THIN SHIELDS, RESISTIVE COILS)

SUMMARY OF HEAT FLUXES



*920 MJ deposited in 100 ms over 30% of the 800-m³ (total) surface area.

SUMMARY OF MFE HEAT FLUXES



[a] 920 MJ deposited in 100 ms over 30% of the 800 · m² (total) surface area

SOLUTIONS AND PROMISE FOR IMPROVED FPC SYSTEMS

$$\frac{(P_{TH}/V_{FPC})_{FUS}}{(P_{TH}/V_{FPC})_{FIS}} = \frac{(I_{Qw})_{FUS}}{(I_{Qw})_{FIS}} \cdot \frac{1}{4f_{FUSL}} \cdot \frac{(r_w)_{FIS}}{(r_w)_{FUS}} \cdot \frac{4M_N + 1 + 5/Q_p}{1 - \eta_D(1 - f_{RAD})}$$

- INCREASED HEAT/PARTICLE LOADS

- REDUCED VOLUME, HPD PLASMAS
- INCREASED βB^2 DECREASED Δb
- RESISTIVE COILS

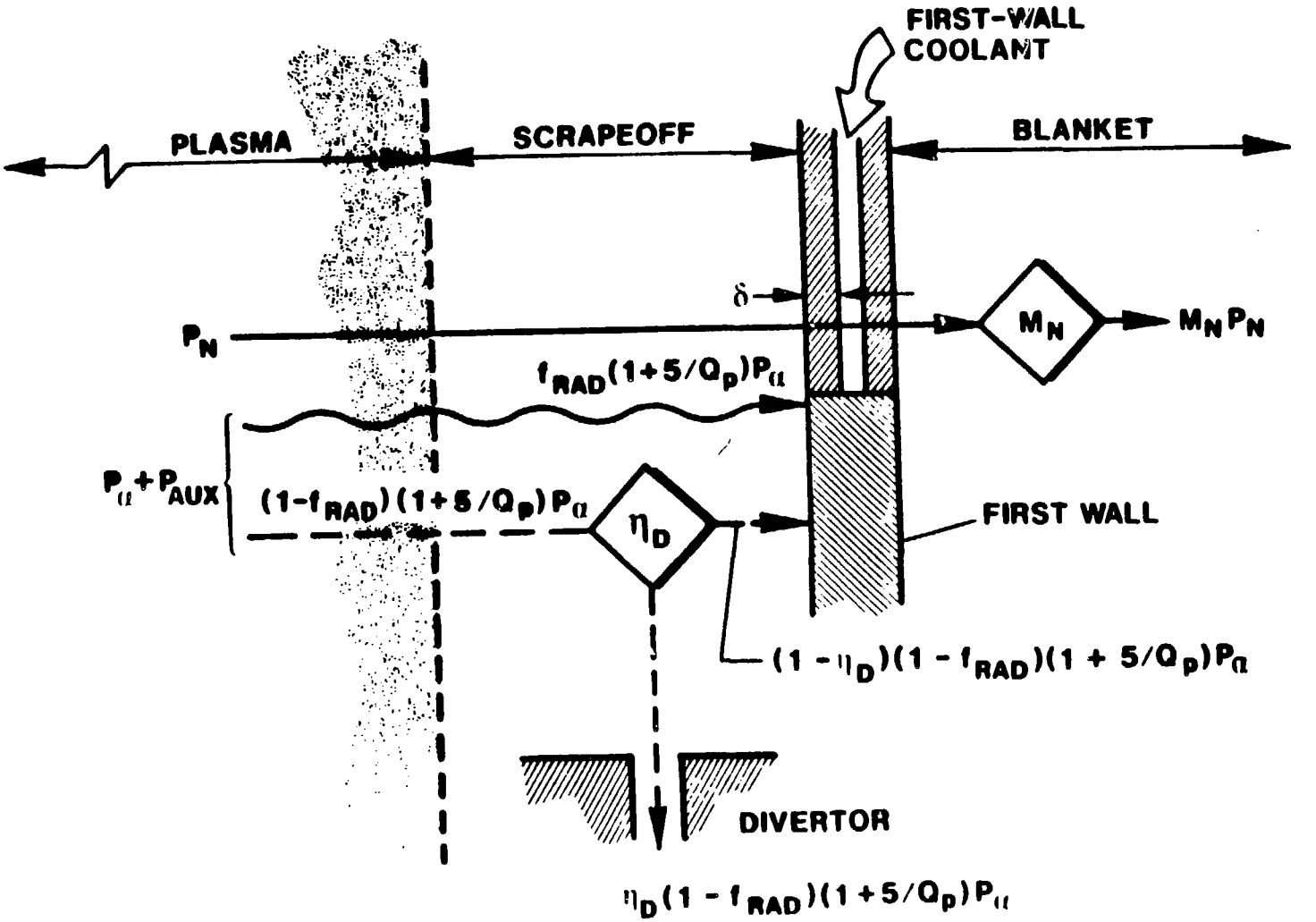
UDC($/kWe)
BOP COST (RPE/TDC)
O&M COST
CONVERSION EFFICIENCY, η_{TH}
RECIRCULATING POWER FRACTION, ϵ
PLANT AVAILABILITY, p_f
S&E COSTS

} **COE**

SIZE/COMPLEXITY
FLEXIBILITY
SYSTEM SOTA
DEVELOPMENT ITEMS

} **COD**

EDGE-PLASMA ENERGY FLOW

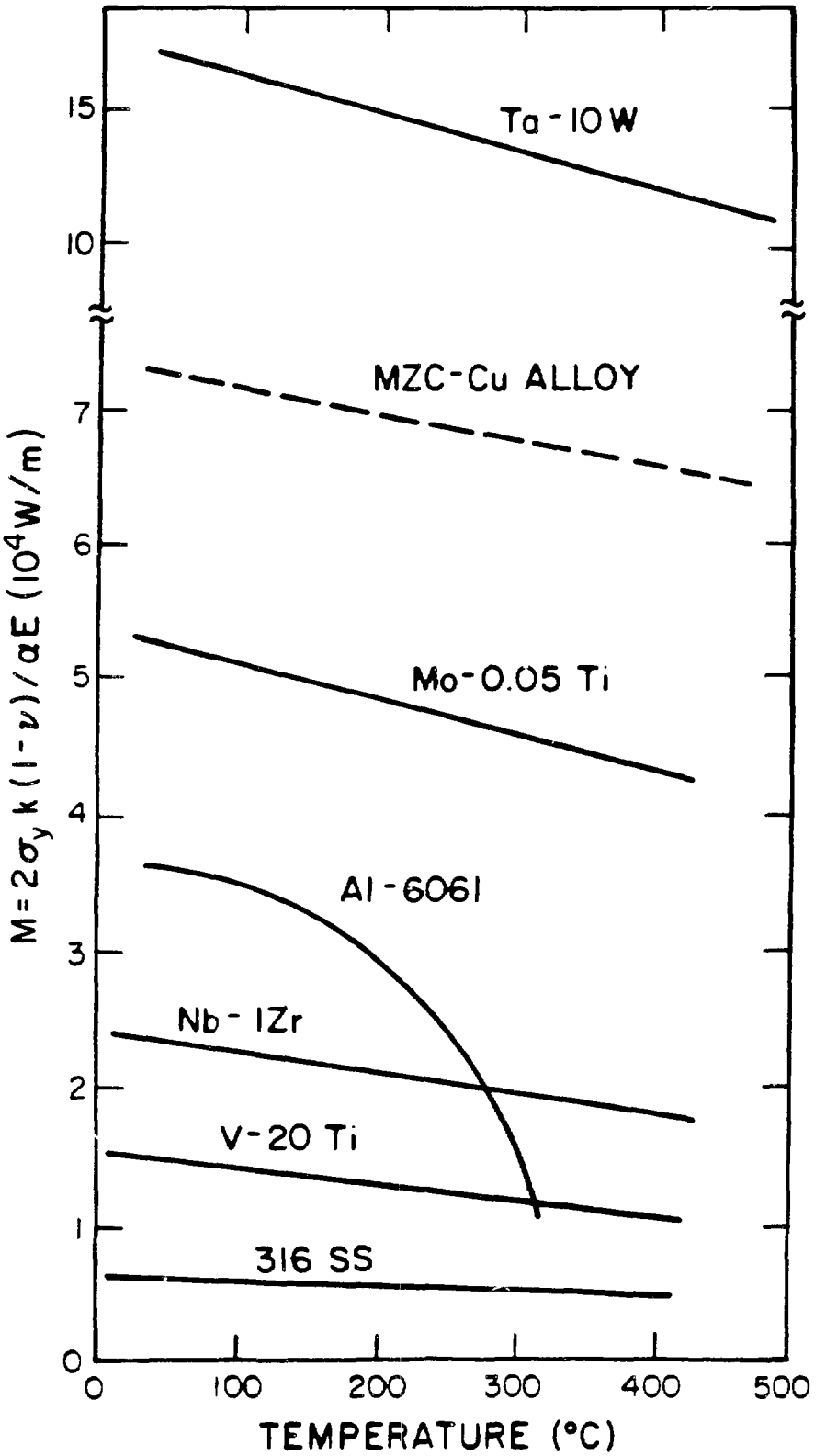


STRESS AND SPUTTERING LIMITATIONS IMPOSED ON I_{Qw}

- STRESS LIMITS ON FW OF THICKNESS δ
  - PRESSURE (PRIMARY) STRESS: $\sigma_p = \dfrac{Pd}{2\delta}$
  - THERMAL (SECONDARY) STRESS: $\sigma_{TH} \simeq \dfrac{E\alpha\Delta T}{2(1-\nu)}$
  - HEAT FLUX: $I_{Qw} \simeq -k\dfrac{\Delta T}{\delta}$
  - DEFINITIONS:
    - STRESS PARAMETER: $M(MW/m) = \dfrac{2\,\sigma_Y(1-\nu)k}{\alpha E}$
    - STRESS MARGIN: $f_Y = (\sigma_p + \sigma_{TH})/\sigma_Y$
  - STRESS–LIMITED HEAT FLUX [NEGLECT (PRIMARY) PRESSURE STRESS]

$$I_{Qw}^{STRESS} = \frac{f_Y M}{\delta}\left[1 - \frac{\hat{\delta}}{2\delta}\right] \quad ; \hat{\delta} = \frac{Pd}{f_Y \sigma_Y}$$

STRESS PARAMETERS



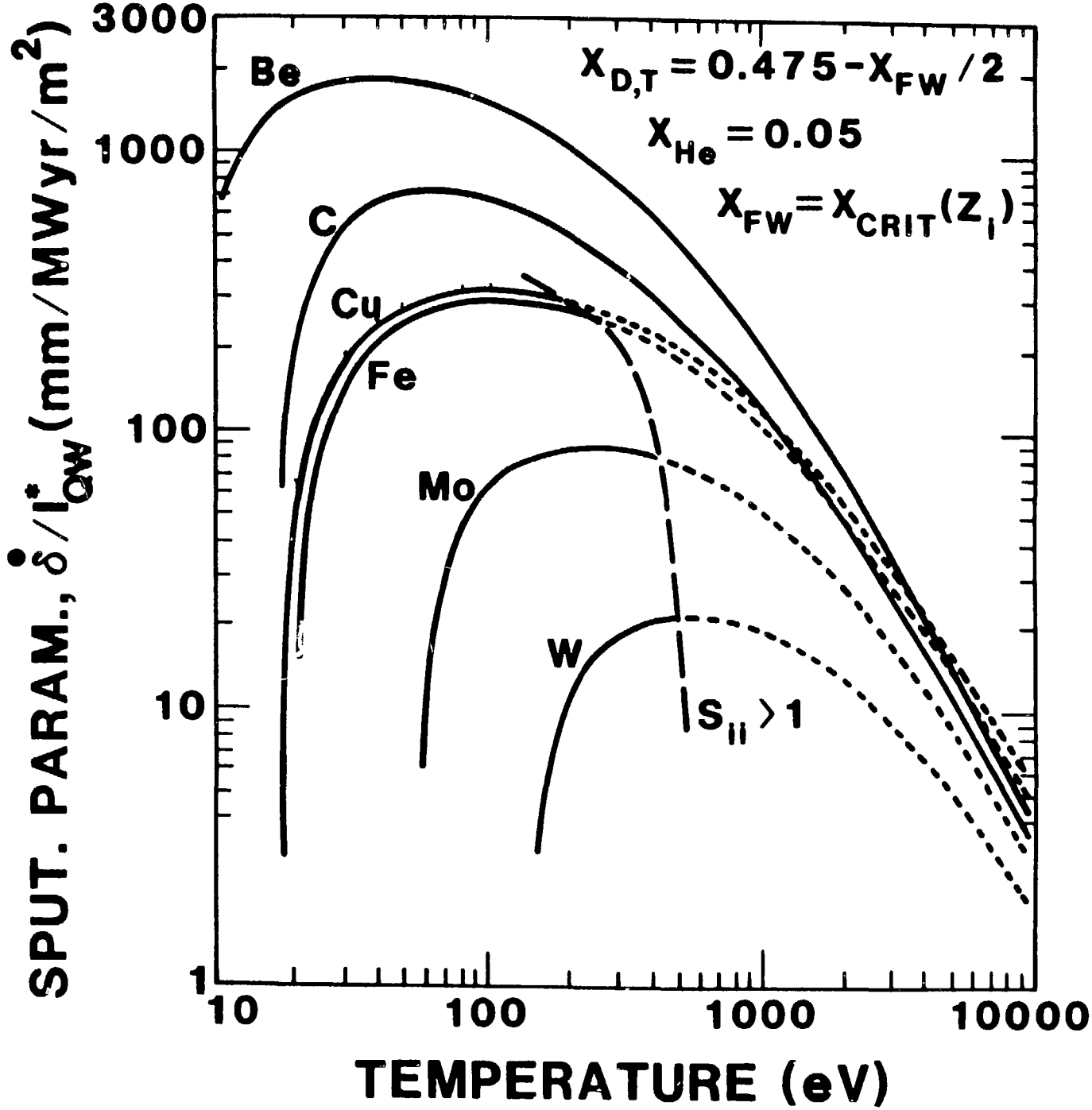
STRESS AND SPUTTERING LIMITATIONS IMPOSED ON I_{Qw} (cont'd-1)

- SPUTTERING LIMITS ON FW OF THICKNESS δ
  - SPECIFY FRACTION f_s OF FW THICKNESS SPUTTERED AWAY DURING FW RADIATION LIFETIME, $I_w \tau$ (MWyr/m^2).
  - $\dot{\delta}$ (mm/yr) SPUTTERING RATE (WITHOUT REDEPOSITION)
  - HEAT FLUX CARRIED BY ENERGETIC PARTICLES:

$$I^*_{Qw} \equiv I_{Qw} \frac{(1 - f_{RAD})(1 - \eta_D)}{1 - \eta_D(1 - f_{RAD})}$$

  - SPUTTERING PARAMETER: $\dot{\delta}/I^*_{Qw}$ (mm/MWyr/m^2)
  - SPUTTERING LIMIT:

$$\delta(\text{mm}) = \frac{(I_w \tau)}{4 f_s} \left[\frac{\dot{\delta}}{I^*_{Qw}}\right] (1 - f_{RAD})(1 - \eta_D)$$


SPUT. PARAM., $\dot{\delta}/I^*_{QW}$ (mm/MWyr/m^2)
3000
1000
100
10
1
10
100
1000
10000
TEMPERATURE (eV)
Be
C
Cu
Fe
Mo
W
$X_{D,T} = 0.475 - X_{FW}/2$
$X_{He} = 0.05$
$X_{FW} = X_{CRIT}(Z_i)$
$S_{II} > 1$

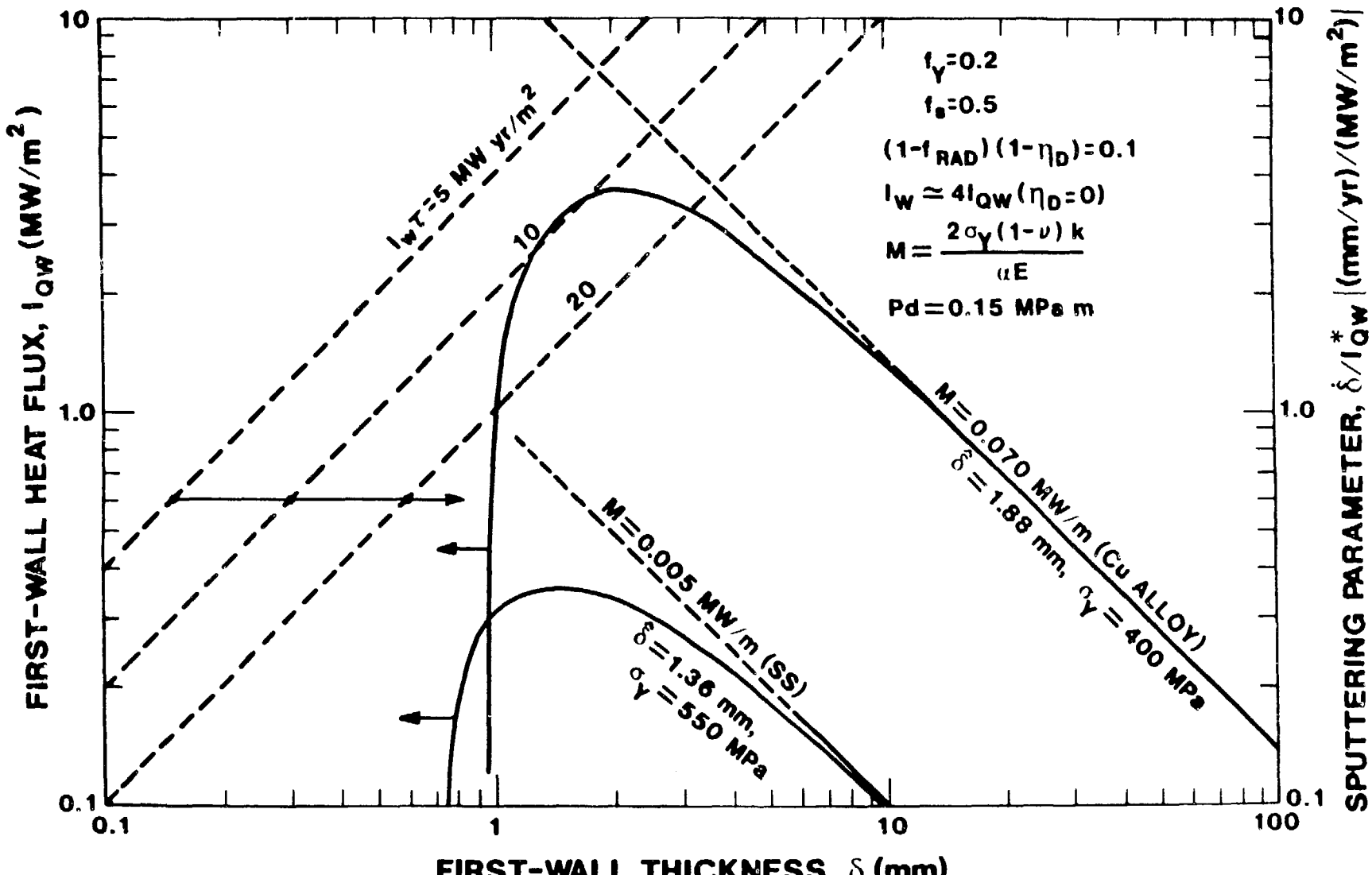
CONSIDERATIONS FOR ACCEPTABLE SPUTTERING PARAMETERS

- RADIATION AND DIVERTOR EFFICIENCIES:

  $$(1 - f_{RAD})(1 - \eta_D)$$

- LOCAL REDEPOSITION
- HIGH EDGE TEMPERATURE FOR LOW–Z FIRST WALL
- LOW EDGE TEMPERATURE FOR HIGH–Z FIRST WALL

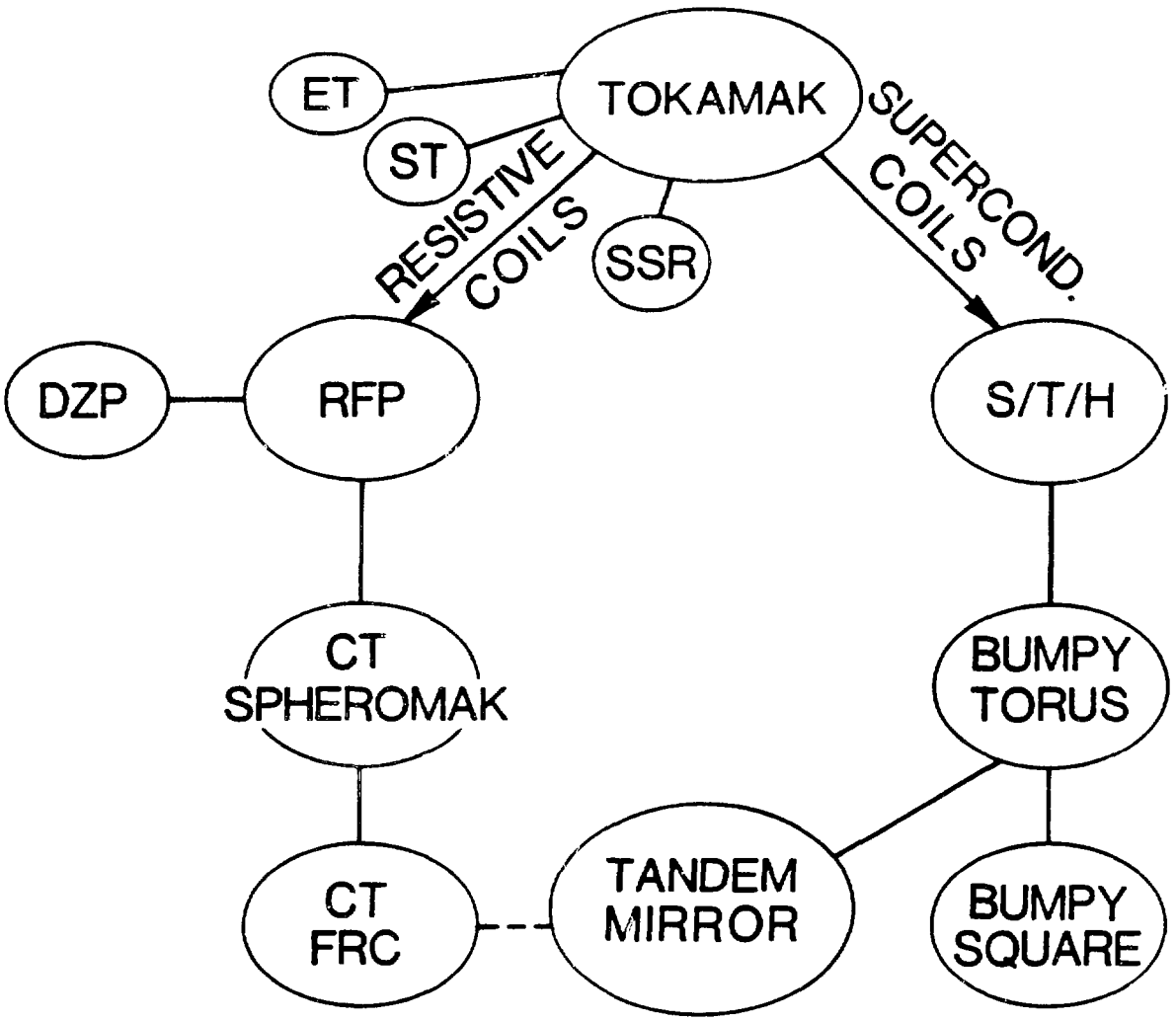
HEAT-TRANSFER, SPUTTERING, AND RADIATION DAMANGE TRADEOFFS



PATHWAYS TO SMALLER FUSION REACTORS

- GENERIC
  - $\beta B^2 \geqslant 5\ T^2$ in $r_p \simeq 0.7$–0.8 m PLASMA
    ($V_p \leqslant 40\ m^3$, $P_F/V_p \simeq 70$–$80\ MW/m^3$)
  - $I_w \simeq 10$–$20\ MW/m^2$, $I_{Qw} \simeq 3$–$5\ MW/m^2$
    - EFFICIENT DIVERTORS ($\eta_D > 0.9$)
    - HIGH FW–COVERAGE LIMITERS
    - HIGH RADIATION FRACTIONS ($f_{RAD} > 0.9$)
  - HPD BLANKETS ($\sim 30\ MW/m^3$ AVERAGE, 200–300 MW/m^3 PEAK)
    - LOW–FIELD, HIGH–FLOW LM BREEDER/COOLANT
    - ACCEPTABLE PRESSURE, PUMPING POWER
  - RADIATION–HARDENED EXOBLANKET COILS
    - LOW RECIRCULATING POWER
    - CLOSE–COUPLED, EFFICIENT DIVERTOR COILS

KEY CONFINEMENT OPTIONS FOR MAGNETIC FUSION ENERGY



ET ELONGATED TORUS
ST SPHERICAL TORUS
SSR SECOND STABILITY REGION
DZP DENSE Z-PINCH
RFP REVERSED-FIELD PINCH
CT COMPACT TOROID
FRC FIELD-REVERSED CONFIGURATION
S/T/H STELLARATOR/TORSATRON/HELIOTRON

PATHWAYS TO SMALLER FUSION REACTORS (Cont-1)

- TOKAMAK
  - IMPROVED STARFIRE
    - - SSR HIGH-BETA PLASMA
    - - ELIMINATE NON-ESSENTIAL MAGNET AND VACUUM-SYSTEM SHIELD
    - - ADVANCED (INSULATOR) SC COILS
    - - THIN SHIELD (NO BIOLOGICAL SHIELD INSIDE COILS)
    - - REDUCE VACUUM-DUCT PENETRATION (GETTER LIMITER)
    - - REDUCE PLASMA CURRENT (EASE rf CURRENT DRIVE)
    - - LOW NWL (2-3 MW/m^2), > 10-YEAR FPC LIFE

PATHWAYS TO SMALLER FUSION REACTORS (Cont-2)

- RESISTIVE (DEMOUNTABLE)-COIL FSR TOKAMAK
  - - LOW-CURRENT, HIGH Q_E DEMOUNTABLE COILS
  - - SPM FOR VACUUM CHAMBER AND BLANKET
  - - EFFICIENT, CAPTIVE PFCs
  - - LONG-PULSED OPERATION
  - - IMPURITY CONTROL: TBD

PATHWAYS TO SMALLER FUSION REACTORS (Cont-3)

- TOKAMAK
  - SPHERICAL TORUS (ST) FSR TOKAMAK
    - - HIGH-BETA BY $\epsilon\uparrow$ and $\kappa\uparrow$
    - - RESISTIVE-COIL (RECIRCULATING POWER) VERSUS SC-COIL (CAPITAL COST) FAVORS FORMER
    - - HIGH PLASMA CURRENTS BUT NO OHC: REQUIRES rf STARTUP WITH OSCILLATING-FIELD (F-θ PUMPING) CURRENT DRIVE
    - - IMPURITY CONTROL: DOUBLE-NULL POLOIDAL DIVERTORS

PATHWAYS TO SMALLER FUSION REACTORS (Cont-4)

- ELONGATED TORUS (ET) FSR TOKAMAK
  - VERY HIGH κ (> 10)
  - RESISTIVE COIL REQUIRED
  - SPM FOR VACUUM TANK AND BLANKET
  - HIGH-EFFICIENCY (SUPER-THIN) BLITZ BLANKET
  - HIGH NWL (> 10 MW/m^2)
  - OHMIC HEATING TO IGNITION
  - IMPURITY CONTROL: TBD

PATHWAYS TO SMALLER FUSION REACTORS (Cont-5)

- REVERSED-FIELD PINCH (RFP)
  - HIGH-BETA PLASMA
  - DEVELOPING, ENCOURAGING PHYSICS DATABASE
  - FULL RANGE OF NORMAL AND SC COIL OPTIONS
  - HIGH-βB^2 PLASMA WITH LOW-FIELD/ CURRENT COILS
  - OHMIC HEATING TO IGNITION
  - OSCILLATING-FIELD (F-θ PUMPING) CURRENT DRIVE
  - IMPURITY CONTROL
    - - HIGH-WALL-COVERAGE POLOIDAL LIMITERS
    - - POLOIDALLY SYMMETRIC TOROIDAL FIELD MAGNETIC DIVERTORS

PATHWAYS TO SMALLER FUSION REACTORS (Cont-6)

- SPHEROMAK
  - HIGH-BETA PLASMA
  - CLOSELY RELATED TO RFP, SIMILAR ADVANTAGES AND UNCERTAINTIES
  - STATIONARY/STEADY-STATE OR TRANSLATING PLASMOID OPTIONS
    - - STATIONARY/STEADY-STATE OPTION PROMISES dc CURRENT DRIVE WITH UNIQUE DIVERTOR OPTIONS
    - - TRANSLATING PLASMOID OPTIONS SEPARATES HIGH-TECHNOLOGY FORMATION STAGE FROM BURN CHAMBER ENVIRONMENT
    - - BOTH REMOVE HHF SURFACE FROM BURN CHAMBER AND INTENSE NWL

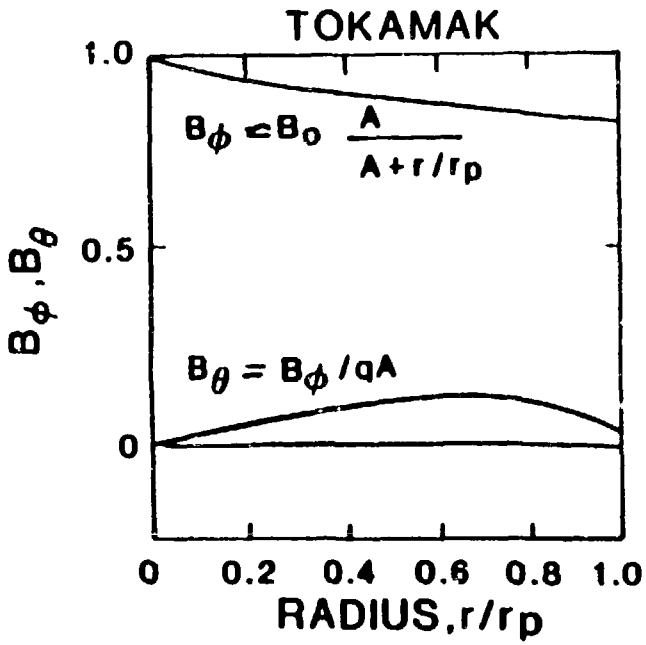
PATHWAYS TO SMALLER FUSION REACTORS (Cont-7)

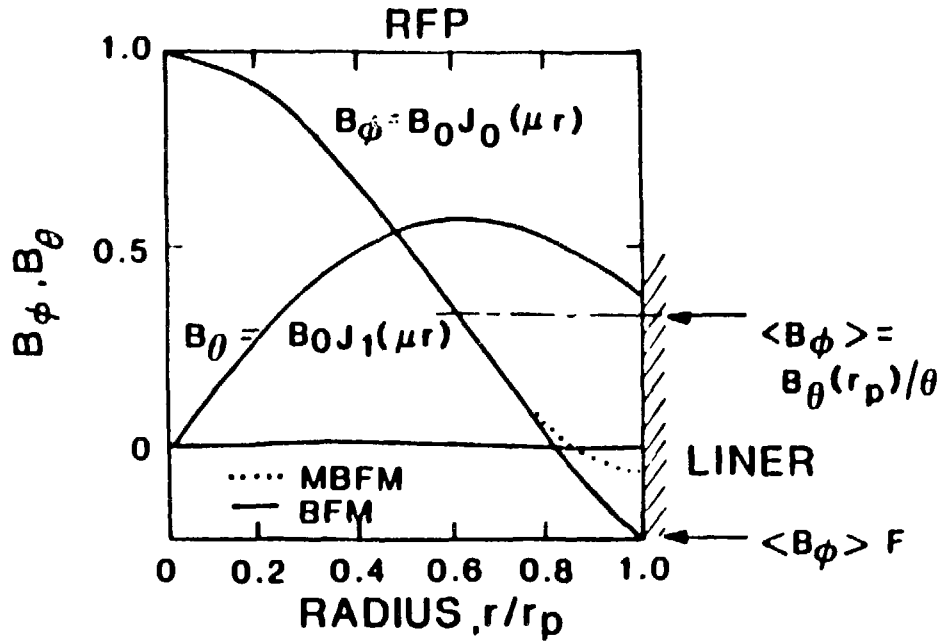
- FIELD-REVERSED CONFIGURATION (FRC)
  - VERY HIGH PLASMA BETA
  - PROMISING, DEVELOPING PHYSICS DATABASE
  - STABILITY/EQUILIBRIUM FAVOR PULSED OPERATION, BUT ION-RING REFLUXING POSSIBLE
    - - EXO-REACTOR FORMATION FOLLOWED BY TRANSLATING BURN OR LINER COMPRESSION AND STATIONARY BURN
    - - IN SITU FORMATION AND STATIONARY BURN
  - IMPURITY CONTROL: NATURAL SEPARATRIX

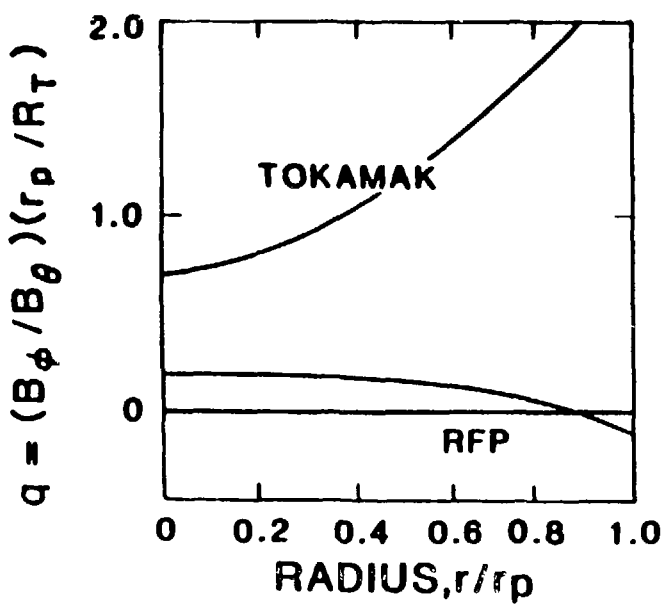
PATHWAYS TO SMALLER FUSION REACTORS (Cont-8)

- OTHER CONCEPTS HAVE NOT BEEN EXAMINED AS HPD REACTOR OPTIONS, BUT ARE DOMINATED BY TOROIDAL AXIAL FIELDS
  - TANDEM MIRROR: HIGH BETA, STEADY STATE, NATURAL DIVERTORS, DIRECT CONVERSION
  - STELLARATOR/TORSATRON/HELIOTRON: STEADY STATE, IGNITED, NATURAL DIVERTORS
  - BUMPY POLYGONS: HIGH-BETA POTENTIAL, STEADY STATE

RFP CONFINEMENT AND REACTOR IMPLICATIONS



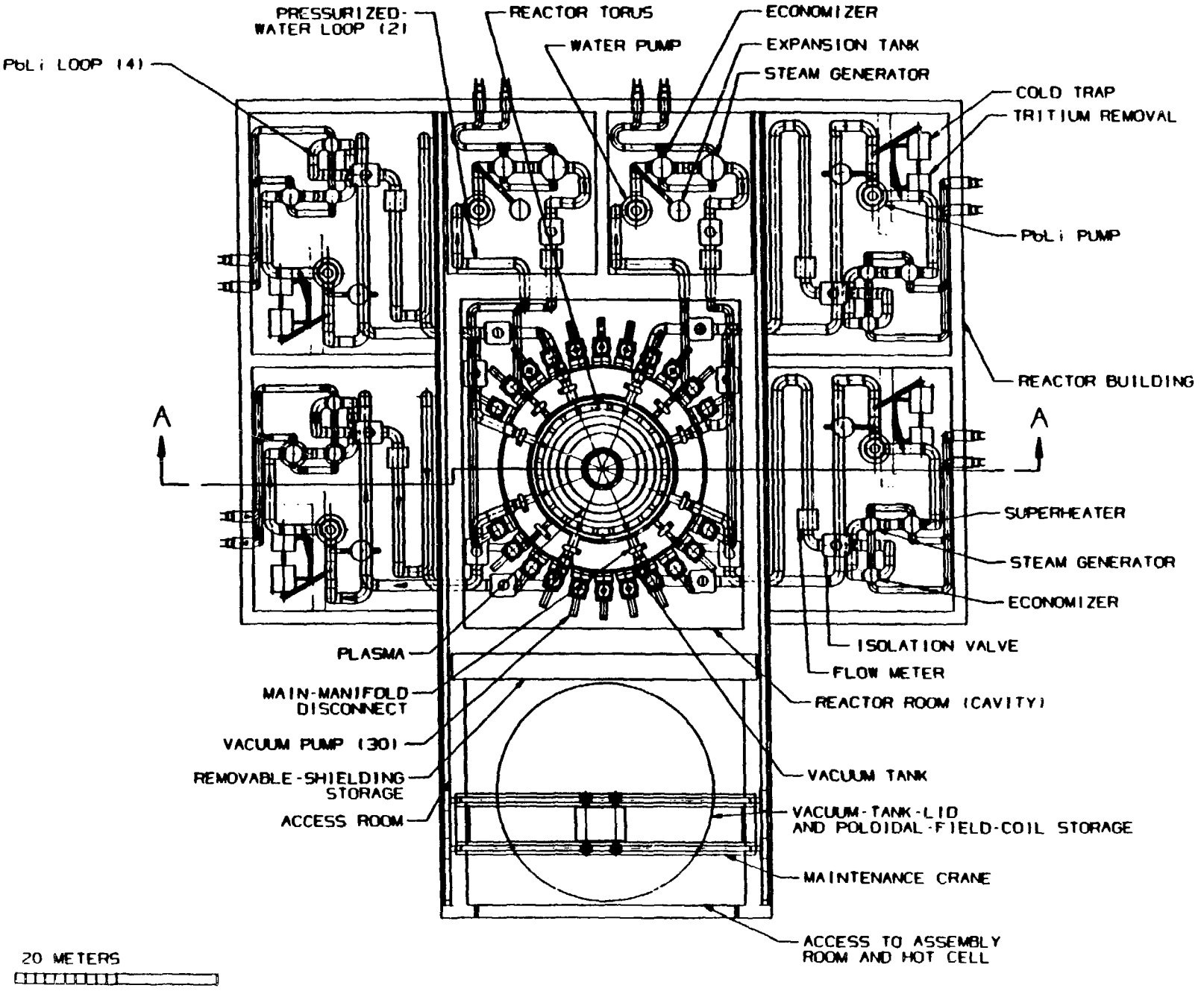


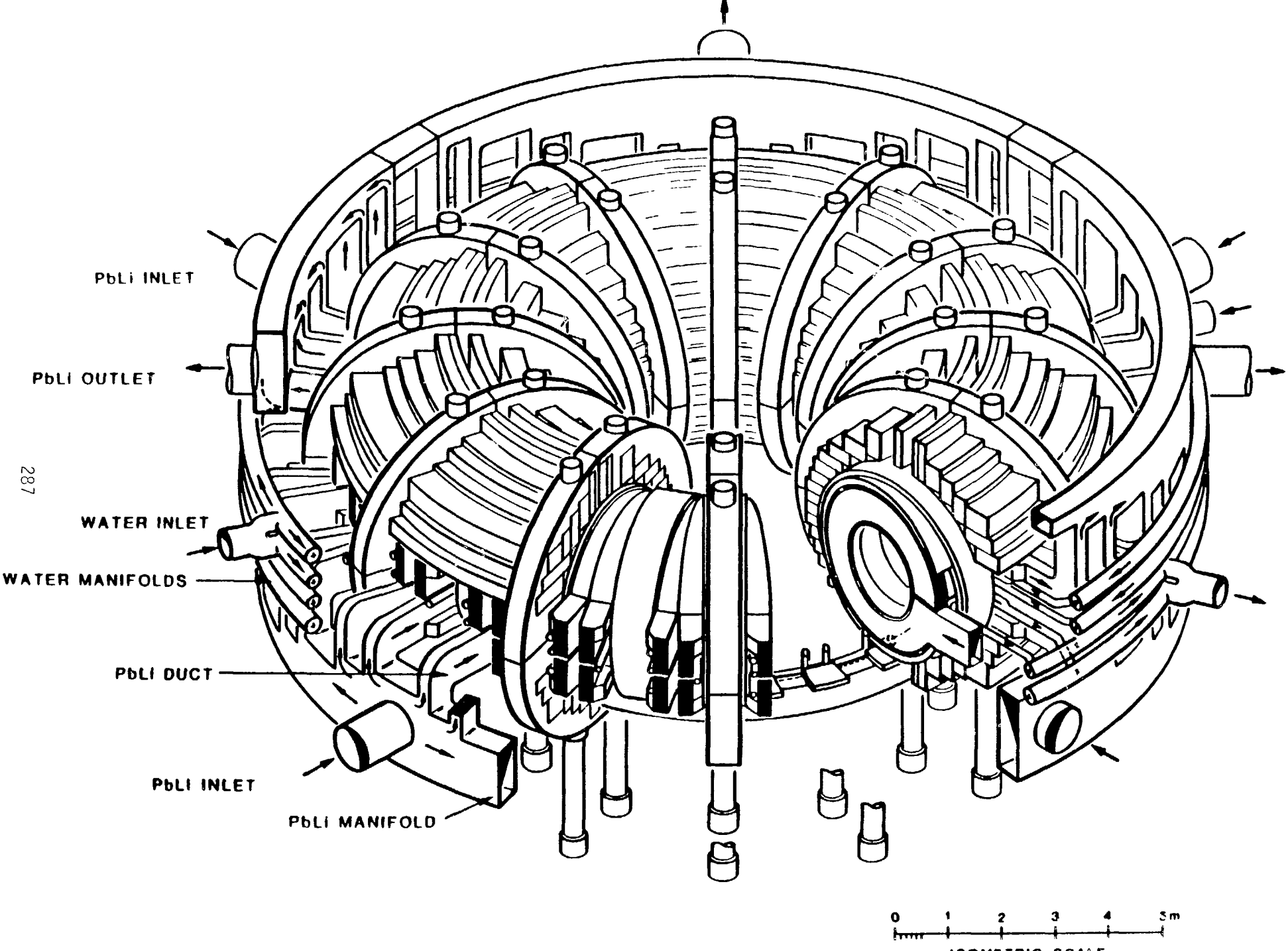


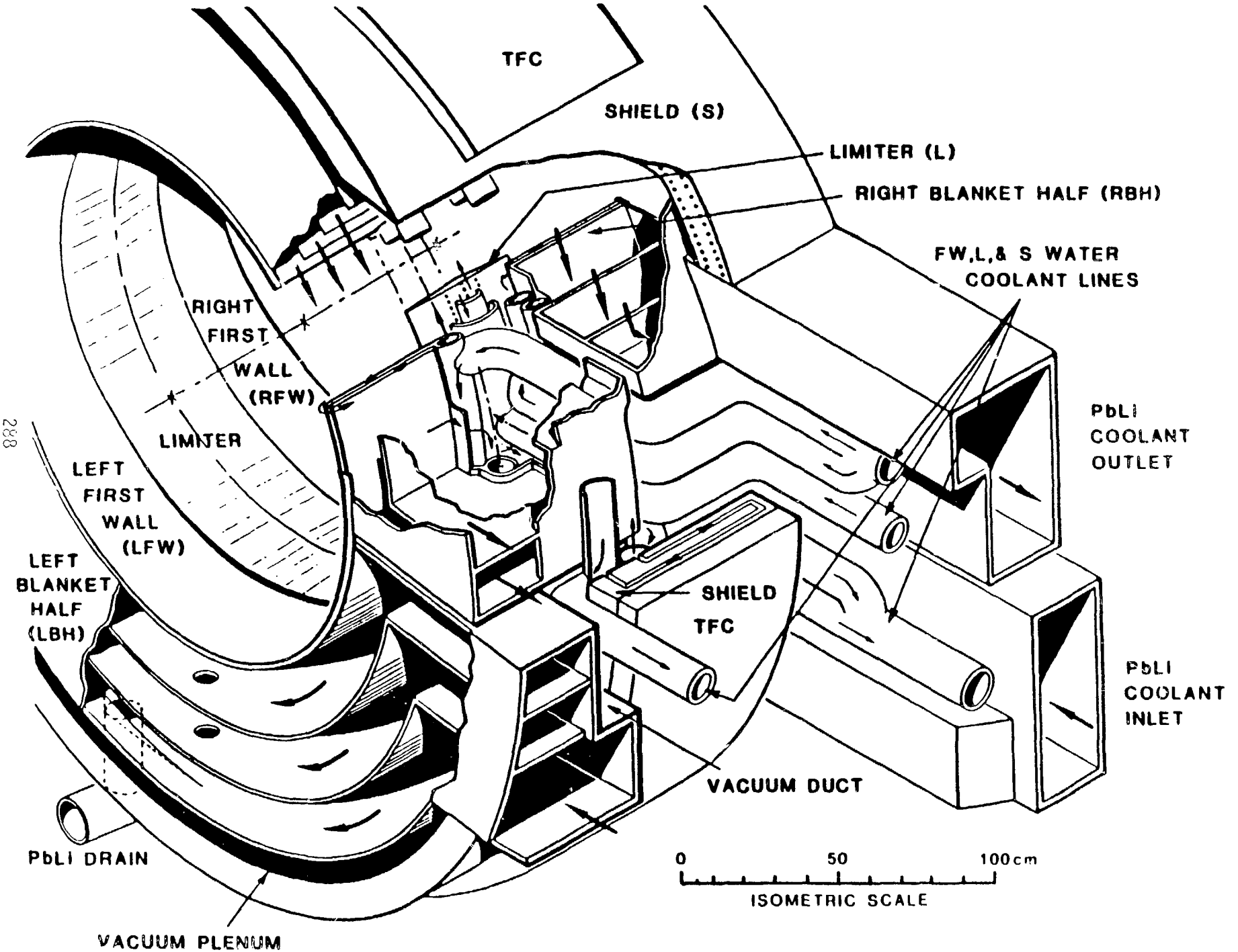
- HIGH $(\beta B^2)_{plasma}$
- LOW FIELDS AND CURRENTS AT COILS
- UNIQUE STEADY-STATE CURRENT DRIVE
- HIGH OHMIC HEATING RATES
- ARBITRARY ASPECT RATIO
- EFFICIENT, SMALL REACTORS

KEY CRFPR(20) DESIGN PARAMETERS

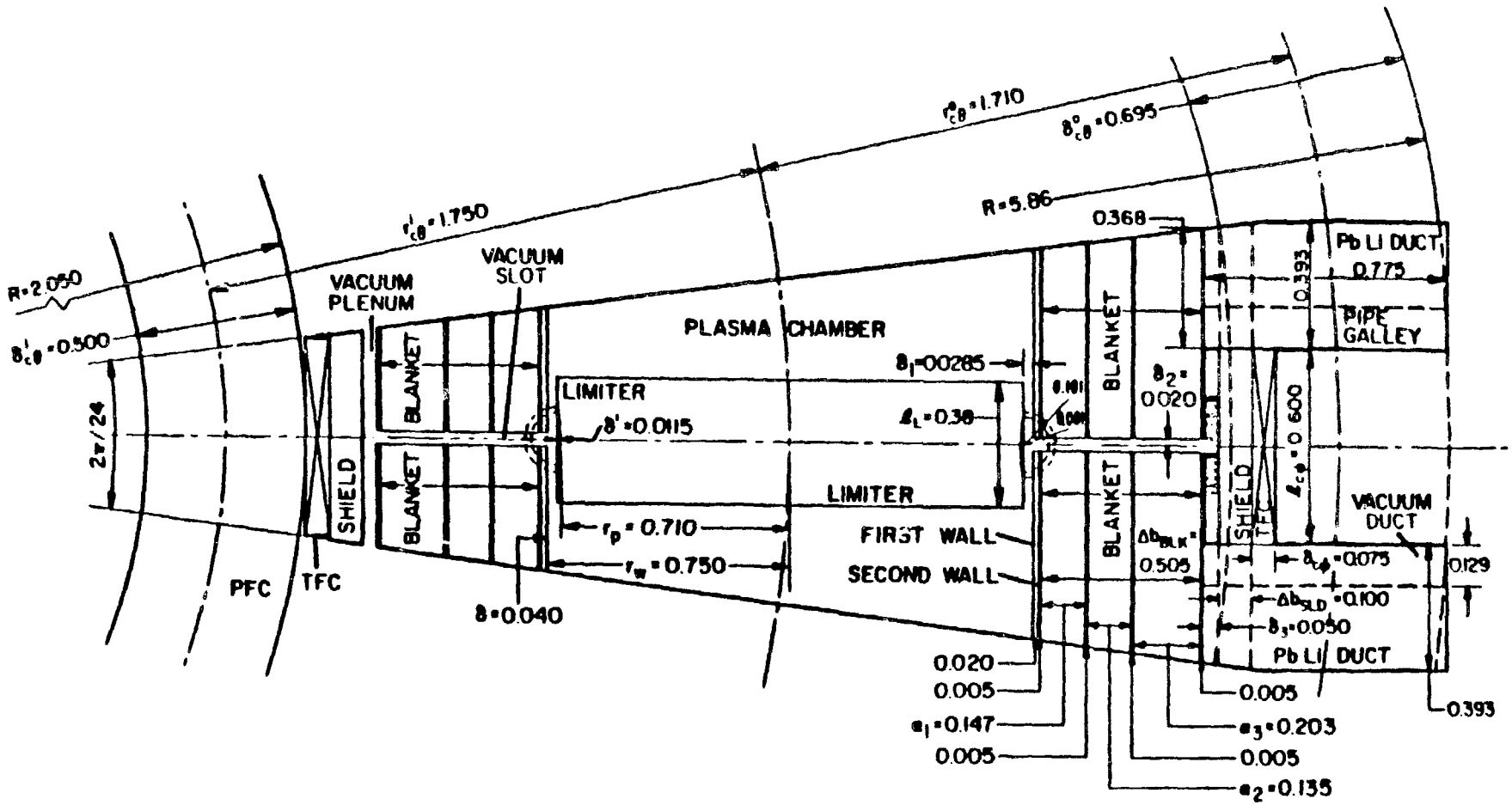
Parameter	Value
Fusion power, P_F(MW)	2733.
Thermal power, P_{TH}(MW)	3472.
Gross electric power, P_{ET}(MWe)	1255.
Net electric power, P_E(MWe)	1000.
Plasma minor radius, r_p(m)	0.71
First-wall radius, r_w(m)	0.75
Plasma major radius, R_T(m)	3.90
Blanket/shield thickness Δb(m)	0.78
Toroidal field at coil, $B_{\varphi c}$(T)	0.72
Number of TFCs, N_{TF}	24.
Poloidal field, B_ϑ(T)	5.18
Peak poloidal field at coil, $B_{\vartheta c}$(T)	4.5
Particle transport, P_{TR}(MW)	580.5
Plasma density, n ($10^{20}/m^3$)	6.55
Plasma current, I_φ(MA)	18.4
Poloidal beta, β_ϑ	0.23
Electron energy confinement time, $\tau_{ce}(s) = 0.05\ I_\varphi\ r_p^2(0.13/\beta_\vartheta)^2$	0.15
Confinement time, $\tau_{pi}(s) = 4\tau_{ce}$	0.59
Global energy confinement time, $\tau_E(s)$	0.23
Edge safety factor, q	0.014
Unit direct cost, UDC($/kWe)	1129.
Then-current COE (mills/kWeh)	50.5

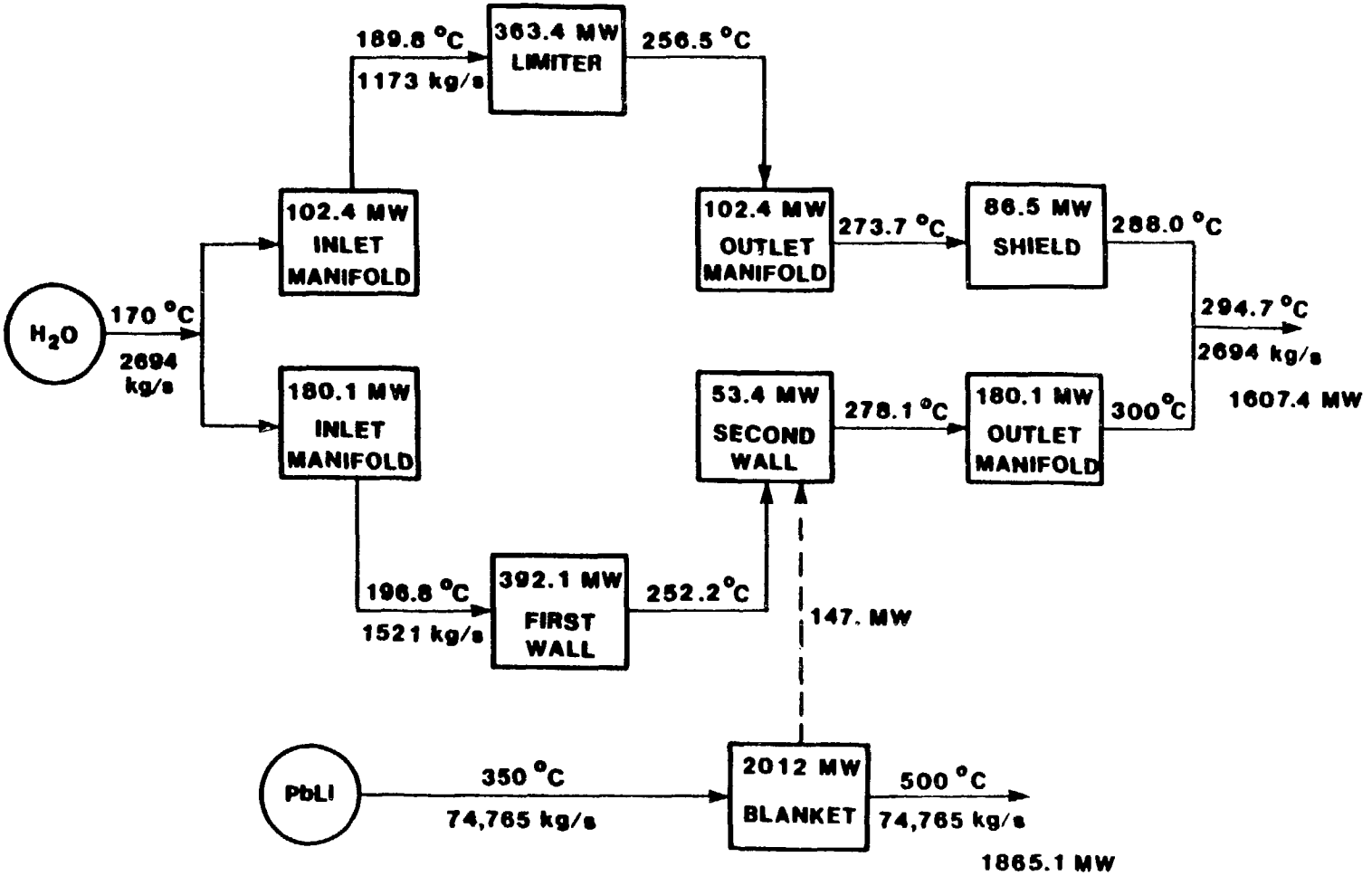

PRESSURIZED-WATER LOOP (2)
REACTOR TORUS
ECONOMIZER
WATER PUMP
EXPANSION TANK
STEAM GENERATOR
PbLi LOOP (4)
COLD TRAP
TRITIUM REMOVAL
PbLi PUMP
REACTOR BUILDING
A
A
SUPERHEATER
STEAM GENERATOR
ECONOMIZER
ISOLATION VALVE
FLOW METER
PLASMA
MAIN-MANIFOLD DISCONNECT
REACTOR ROOM (CAVITY)
VACUUM PUMP (30)
VACUUM TANK
REMOVABLE-SHIELDING STORAGE
ACCESS ROOM
VACUUM-TANK-LID AND POLOIDAL-FIELD-COIL STORAGE
MAINTENANCE CRANE
ACCESS TO ASSEMBLY ROOM AND HOT CELL
20 METERS


PbLi INLET
PbLi OUTLET
WATER INLET
WATER MANIFOLDS
PbLi DUCT
PbLi INLET
PbLi MANIFOLD
0 1 2 3 4 5m
ISOMETRIC SCALE


TFC
SHIELD (S)
LIMITER (L)
RIGHT BLANKET HALF (RBH)
FW,L,& S WATER
COOLANT LINES
RIGHT
FIRST
WALL
(RFW)
LIMITER
LEFT
FIRST
WALL
(LFW)
LEFT
BLANKET
HALF
(LBH)
PbLi
COOLANT
OUTLET
SHIELD
TFC
PbLi
COOLANT
INLET
VACUUM DUCT
PbLi DRAIN
VACUUM PLENUM
0
50
100cm
ISOMETRIC SCALE

CRFPR FUSION-POWER-CORE SECTOR PLAN



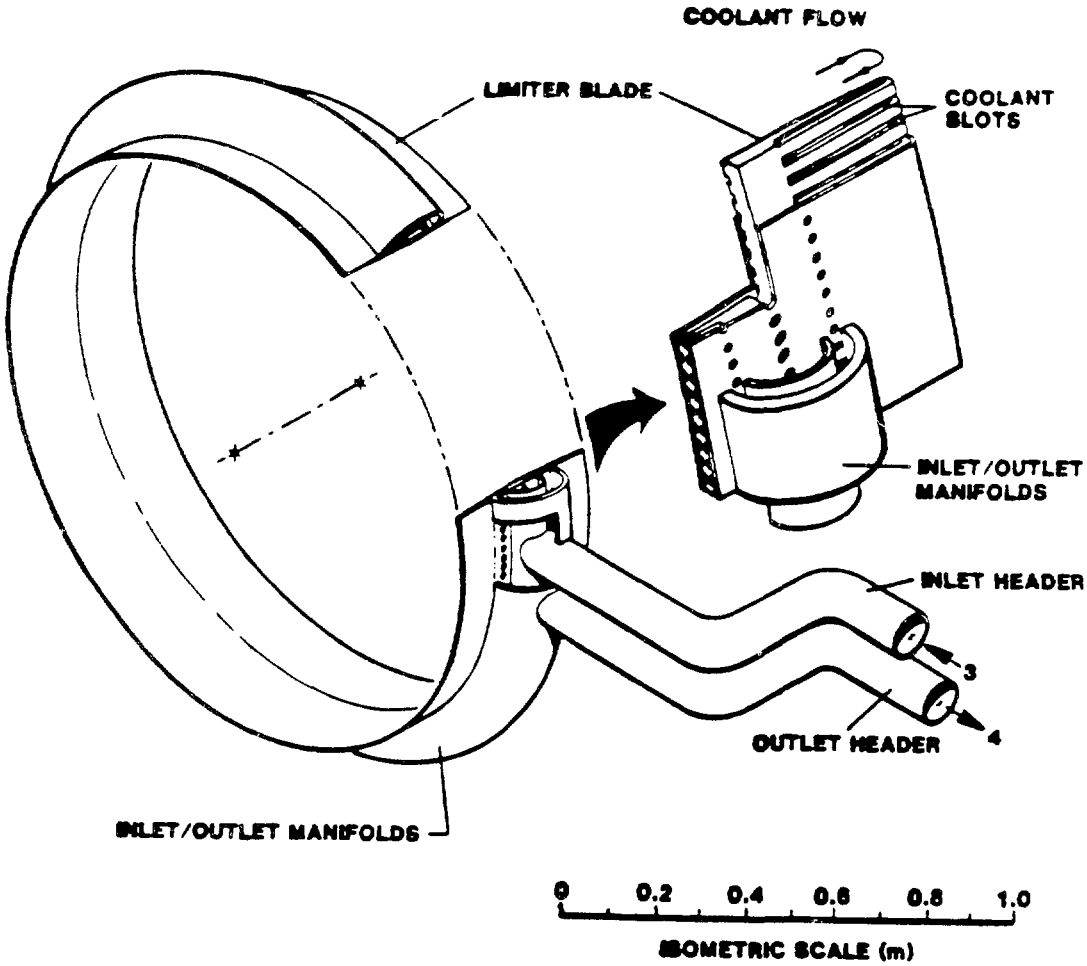


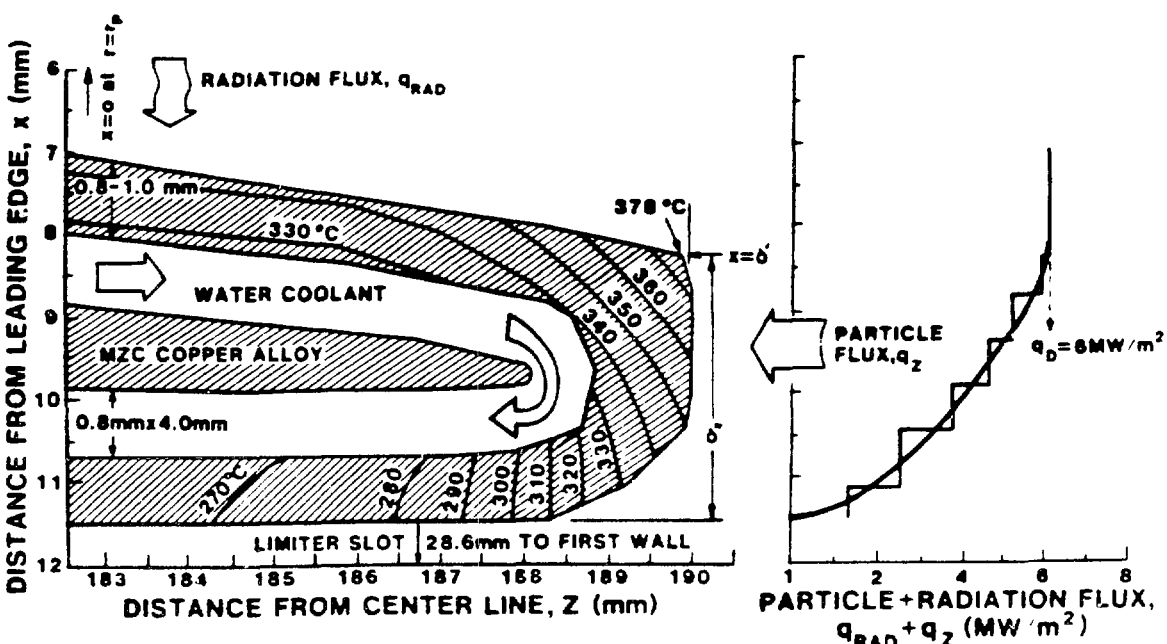
Flow chart showing power ratings, flow rates, and coolant temperatures at various points in the CRFPR(20) power conversion cycle. An optimized steam-cycle design was not performed.

THE FPC THERMAL-HYDRAULIC DESIGN INTEGRATION ACHIEVES FLUID CONDITIONS THAT OPTIMIZE THE DUAL-MEDIA THERMAL EFFICIENCY, MINIMIZES THE PUMPING POWER, AND HOLDS THE FOLLOWING DESIGN CONSTRAINTS.

- PRIMARY AND SECONDARY STRESS FACTOR OF SAFETY, $\sigma_Y/\sigma_D \geqslant 5$
- PbLi BLANKET PRESSURE, $\leqslant$ 100 psi
- PRESSURIZED-WATER COOLANT VELOCITY, $V \leqslant 10$ m/s
- MAXIMUM COPPER-ALLOY HIGH-HEAT-FLUX TEMPERATURE, $\leqslant 400^{o}C$
- MAXIMUM HT-9 FERRITIC ALLOY TEMPERATURE IN CONTACT WITH PbLi, $\leqslant 500^{o}C$
- CRITICAL-HEAT-FLUX LIMITS FOR PRESSURIZED-WATER COOLANT, $\Delta T_{SAT} \geqslant 10$ K
- THERMAL-CONVERSION EFFICIENCY, $\eta_{TH} = 0.75 \quad \eta_{GEN}\eta_I \quad (\eta_{GEN} = 0.95,$ $f_w = 0.46)$
- NO STRUCTURAL SPUTTERING MARGIN (COATINGS, TILES, COLD/DENSE RADIATING PLASMA EDGE REQUIRED)
- PbLi BLANKET MHD PRESSURE MODELED IN ONE DIMENSION WITH NO SANDWICHED INSULATORS

CRFPR POLOIDAL PUMPED LIMITER





PUMPED-LIMITER THERMOHYDRAULIC DESIGN PARAMETERS

Heat Flux and Total Power	
• Heat flux[a] (MW/m^2)	6.2
• Neutron energy absorption (MW)	110.6
• Power absorbed by limiter coolant[b] (MW)	363.4
• Percent of total thermal output[b]	10.5
• Design stress safety factor, σ_Y/σ_D	6.3[c]
Geometry	
• Number of limiters	24.
• Number of channels per limiter side	942.
• Channel length (m)	0.38
• Channel width (mm)	4.0
• Channel height (mm)	0.8
• Wall thickness (mm)	1.0[d]

(a) The plasma side of the limiter would be shaped to maintain a nominally constant plasma heat flux.

(b) In addition, 204.8 MW of neutron and gamma-ray heating is deposited into the inlet/outlet manifolds, giving a total of 568.0 MW or 16.4% of the total thermal power.

(c) Based only on pressure stress applied to a beam-like geometry. Preliminary estimates indicate that the thermal stress is small by comparison.

(d) Although satisfactory from a stress viewpoint, this thickness allows no sputtering margin. Graphite tiles or Be coatings would be used.

SUMMARY OF KEY FPC THERMAL-HYDRAULIC PARAMETERS

Subsystem	Limiter	First wall	Blanket	Shield
Material	Copper alloy	Copper alloy	HT-9 Steel	PCASS
Total cooling rate (MW)	363.4[a]	588.5[b]	1865.1	86.5
Design heat flux (MW/m^2)	6.	4.6	~1.3[c]	-
Design power density (MW/m^3)	266.	169.	21.5[d]	3.9
Coolant configuration				
• direction	toroidal	toroidal	poloidal	toroidal
• channel dimensions (mm)	0.8×4.0	4.0 "D-tube"	200./200./200.[e]	10.
• wall thickness (mm)	0.8[g]	1.07[g]	5.0	20.
• channels per unit	942	767	3	371.
Peak structural temperature (°C)	378	342	500	379
Coolant properties				
• kind	water	water	PbLi	water
• inlet temperature (°C)	190	197	350	274
• outlet temperature (°C)	256	278[f]	500	288
• bulk velocity (m/s)	10.0	9.0	1.25/0.35/0.14[e]	1.7
• total mass flow rate (kg/s)	1,173.	1,520.	74,765.	1,173.
• pressure drop (MPa)	0.1	0.13	0.55	0.01
• pressure (MPa)	15.6	15.6	0.55	15.6
Total pumping power (MW)	0.52	0.80	5.8	0.01

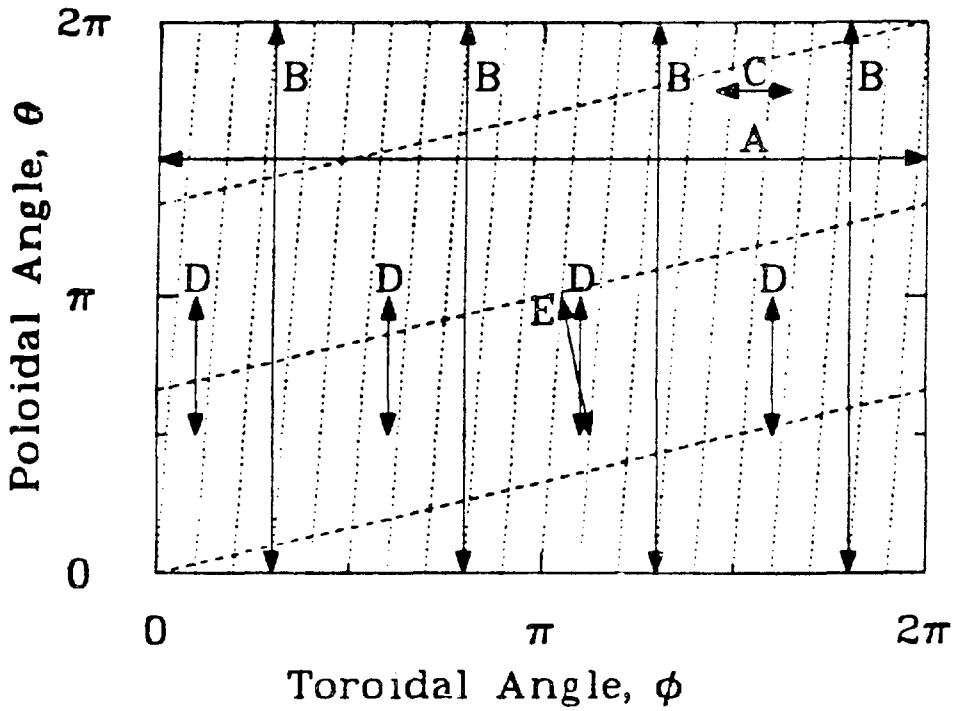
(a) To this is added 204.9 MW deposited in the manifolds plus 86.5 MW from the shield coupling for a total of 654.8 MW.
(b) To this is added 360.2 MW deposited in the manifolds, but 147.0 MW back leakage from blanket to the second wall as well as 53.4 MW nuclear heating in the second wall is included, for a total of 952.7 MW.
(c) Back-leakage flux to second wall.
(d) 350 MW/m^3 peak in PbLi.
(e) Poloidal Channel Dimensions (velocity) with increasing minor radius.
(f) Coolant return via HT-9 second wall.
(g) Does not include sputtering margin, based on factor of safety of 5 relative to yield stress.

DIVERTOR OPTIONS

- KEY TRADEOFFS RELATED TO DIVERTOR KIND, NUMBER, AND POSITION
  - NORMAL-CONDUCTING VERSUS SUPERCONDUCTING
  - INTERLOCKING VERSUS NON-INTERLOCKING COILS
  - EXOBLANKET VERSUS INTRABLANKET LOCATION
    - -- COIL RADIATION DAMAGE LIFE
    - -- RECIRCULATING POWER
    - -- HEAT/PARTICLE FLUXES
    - -- BLANKET NUCLEAR PERFORMANCE
    - -- BLANKET THERMAL EFFICIENCY
    - -- FABRICATION, INSTALLATION, MAINTENANCE
- RATIONALE FOR DIVERTORS
  - TOKAMAK SUCCESSES (ASDEX, DIII, PDX)
  - MOVES PWI OUTSIDE PLASMA CHAMBER
- DESIRABLE TO DIVERT MINORITY FIELD
  - EQUILBRIUM ($\vec{\nabla}P = \vec{j} \times \vec{B}$) AND BETA LEAST AFFECTED
  - CONFINEMENT ($\tau_E \sim B^2$) LEAST AFFECTED
  - LOCAL DRIFTS AT NULL MINIMIZED (MAXIMIZES TRANSPORT INTO DIVERTOR)
  - REDUCED TECHNOLOGY (CURRENTS, CURRENT DENSITY, FORCES, STORED ENERGY)

DIVERTOR OPTIONS

•OPTIONS FOR FIELD-NULL TOPOLOGY



A) Poloidal-Field Toroidally Symmetric Divertor

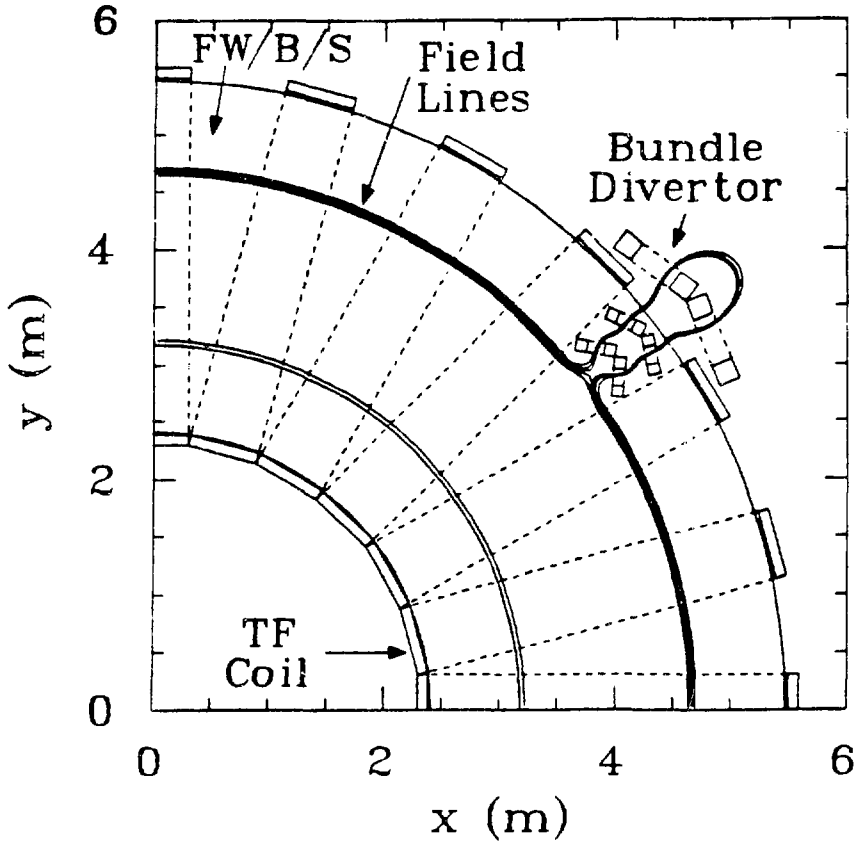
B) Toroidal-Field Poloidally Symmetric Divertor

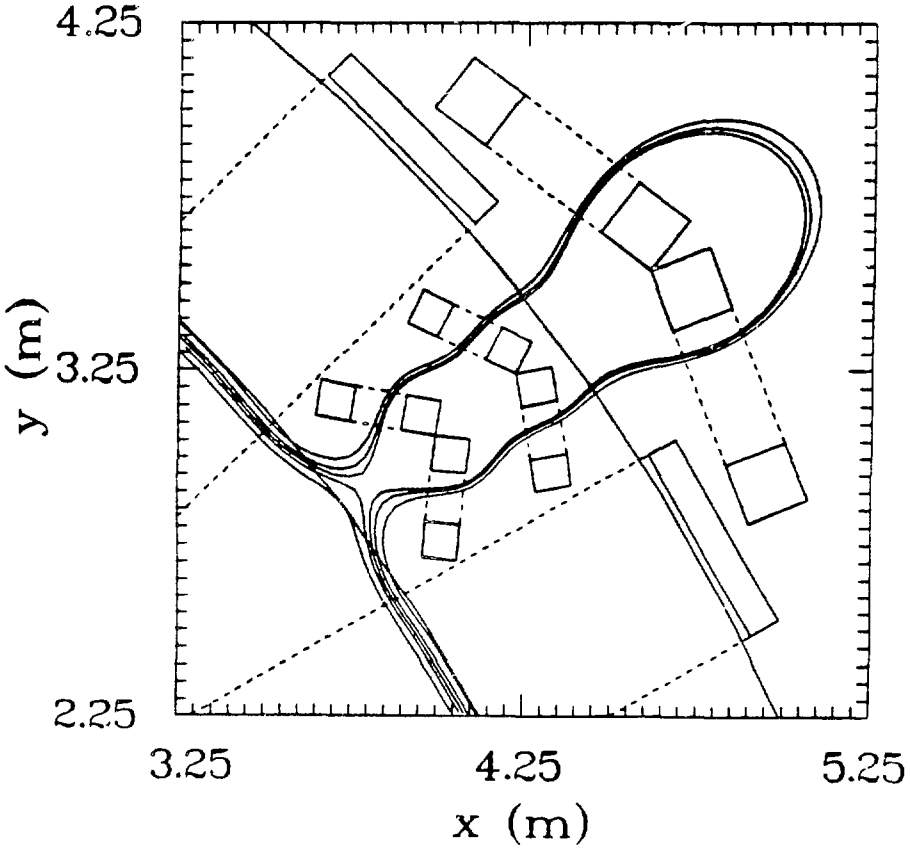
C) Poloidal-Field Bundle Divertor

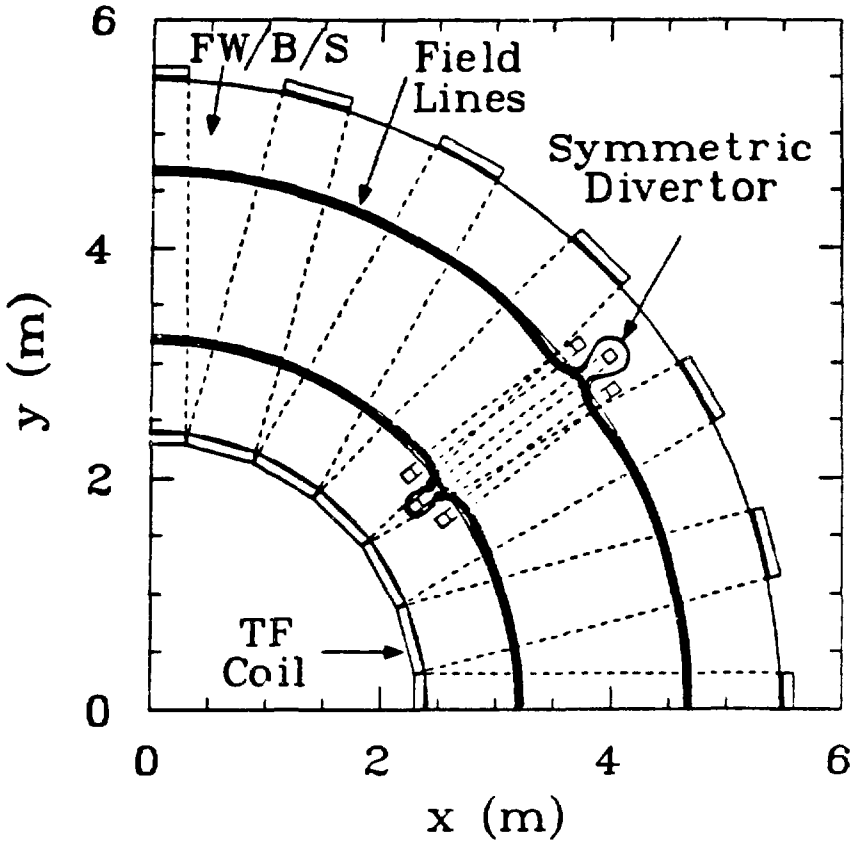
D) Toroidal-Field Bundle Divertor

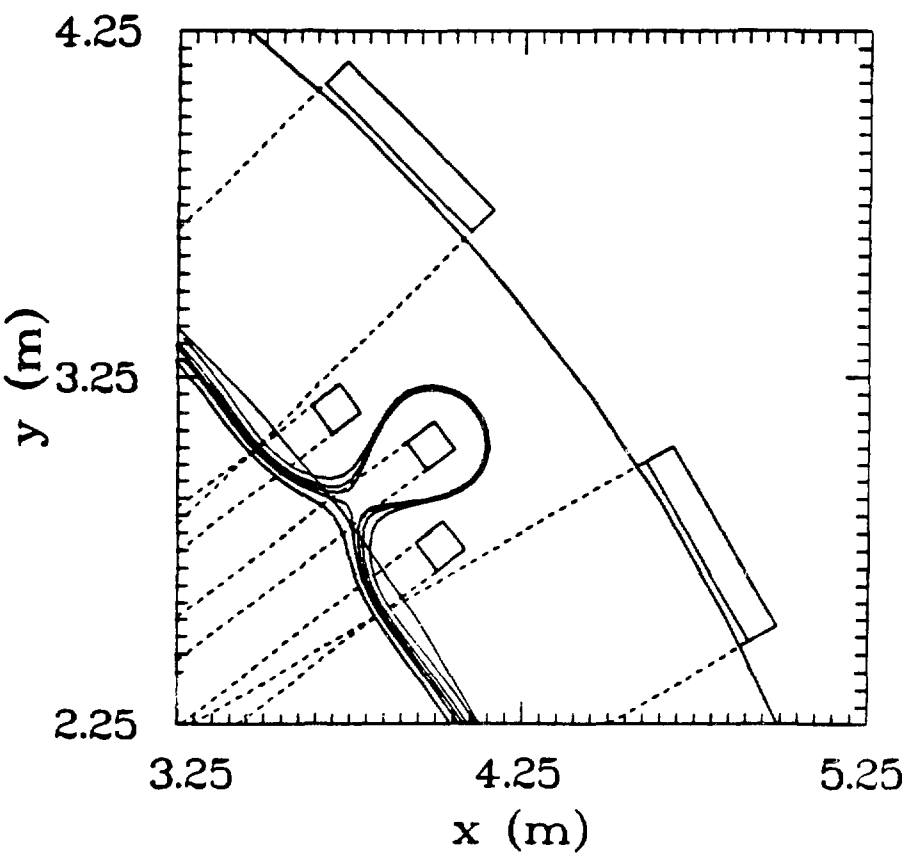
E) Hybrid Bundle Divertor

TOKAMAK	RFP
POLOIDAL-FIELD TOROIDALLY SYMMETRIC - MINORITY FIELD - INTERLOCKING COILS	TOROIDAL-FIELD POLOIDALLY SYMMETRIC - MINORITY FIELD - NON-INTERLOCKING COILS
TOROIDAL-FIELD BUNDLE - MAJORITY FIELD - NON-INTERLOCKING COILS	TOROIDAL-FIELD BUNDLE - MINORITY FIELD - NON-INTERLOCKING COILS


FW/B/S
Field Lines
Bundle Divertor
TF Coil
y (m)
x (m)
0
2
4
6

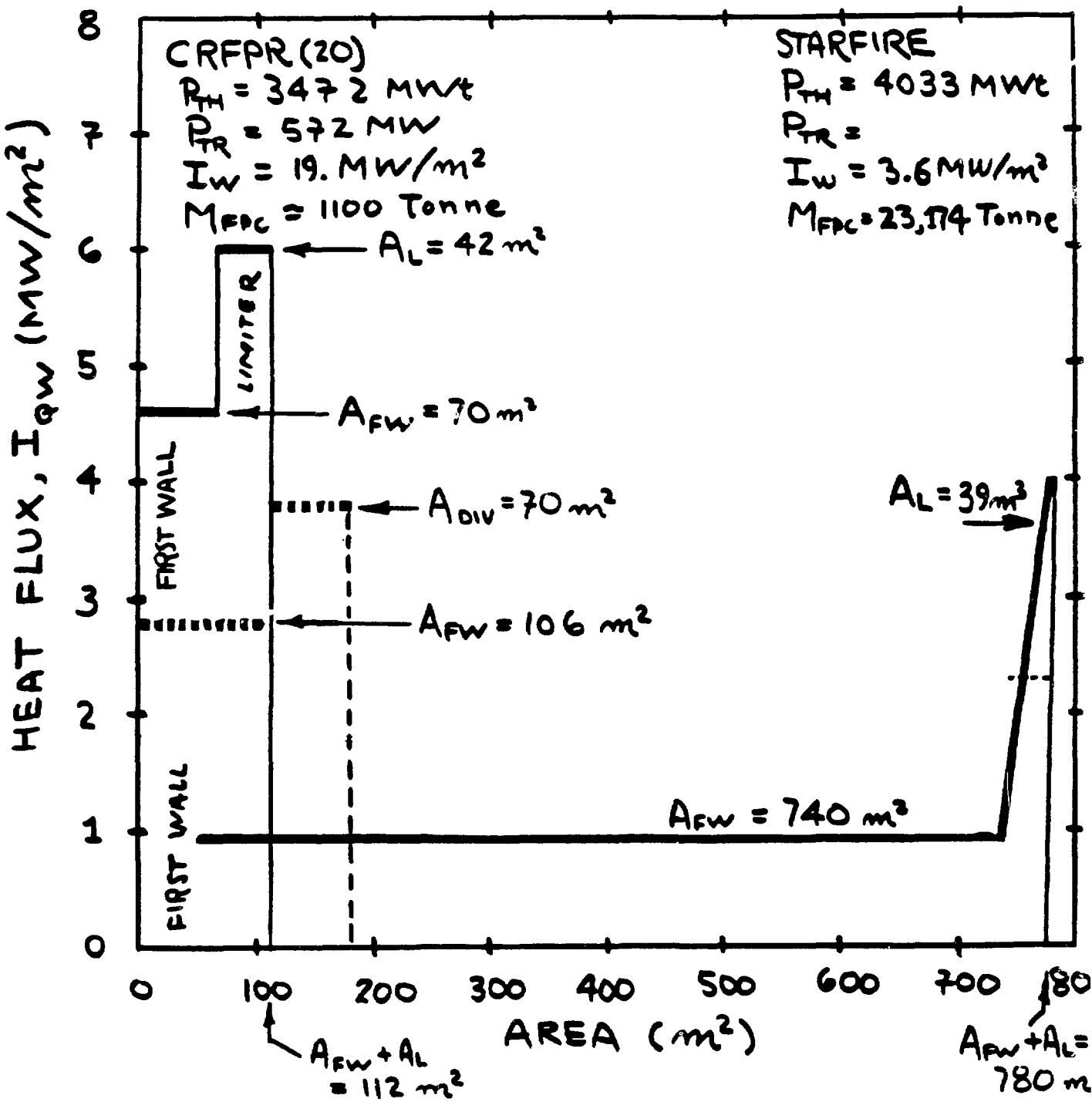

4.25
3.25
2.25
y (m)
3.25
4.25
5.25
x (m)


FW/B/S
Field
Lines
Symmetric
Divertor
TF
Coil
y (m)
x (m)
0
2
4
6


4.25
3.25
2.25
y (m)
3.25
4.25
5.25
x (m)

PRELIMINARY ESTIMATE OF IMPACT ON REF. 10 CRFPR(20) FUSION-POWER-CORE DESIGN USING SD IMPURITY CONTROL

Parameter	Value	
Dimension of model	2D	3D
Number of divertors	4	
Blanket loss (%)	10.4	
Ohmic power (MW)	47.7	
COE increase (%)	5.0	
First-wall area decrease (%)	5.36	
Divertor/first-wall area	0.65	
Divertor efficiency	0.93	0.94
Power to first wall (MW)	305.7	304.3
Power to divertor (MW)	266.1	267.5
First wall heat flux (MW/m^2)	2.87	2.86
Divertor heat flux (MW/m^2)	3.82	3.84
Typical edge plasma conditions		
• Edge-plasma temperature (eV)	143.4	147.7
• Wall-plasma temperature (eV)	50.	
• Edge-plasma density ($10^{20}/m^3$)	1.46	1.38


CRFPR (20)
P_{TH} = 3472 MWt
P_{TR} = 572 MW
I_W = 19. MW/m²
M_{FPC} ≈ 1100 Tonne
STARFIRE
P_{TH} = 4033 MWt
P_{TR} =
I_W = 3.6 MW/m²
M_{FPC} = 23,114 Tonne
A_L = 42 m²
LIMITER
A_{FW} = 70 m²
FIRST WALL
A_{DIV} = 70 m²
A_L = 39 m²
A_{FW} = 106 m²
A_{FW} = 740 m²
FIRST WALL
HEAT FLUX, I_{QW} (MW/m²)
AREA (m²)
$A_{FW}+A_L$ = 112 m²
$A_{FW}+A_L$ = 780 m

COMPARISON OF FIRST-WALL LOADINGS FOR CRFPR(20) AND STARFIRE

	CRFPR(20)	STARFIRE
Average first-wall neutron loading I_w(MW/m^2)	19.	3 6
Average density, n(10^{20}/m^3)	6.55	0.806
Average temperature, T(keV)	10.	20.
Fusion power, P_F(MW)	2733.	3510.
Alpha-particle power, P_α(MW)	547.	702.
Heating power, P_h(MW)	25.	90.
Total power shed by plasma, $P_\alpha + P_h$	572.	792.
First-wall area, A_{FW}(m^3)	70	741.
Limiter area, A_L(m^3)	42.	39.
Total plasma-interactive area, $A_L + A_{FW}$(m^2)	112.	780.
Plasma major radius, R_T(m)	3.8	7.0
Average plasma radius, r_p(m)	0.71	2.83
Plasma volume, V_p(m^3)	37.8	1106.
Global energy confinement time, τ_E(s)	0.23	1.2
Particle confinement time, τ_{pi}(s)	0.59	1.8
Particle flux onto limiter, Γ(10^{20}/s m^2)	10.0	12.7
Average heat load, I_{Qw}(MW/m^2)	5.1	1.0
Peak heat load, I_{Qw}(MW/m^2)	6.0	4.0
Total thermal power, P_{TH}(MWt)	3472.	4033
Gross electric power, P_{ET}(MWe)	1255.	1441.
Net electric power, P_E(MW)	1000.	1200.
Recirculating power fraction, ε	0.20	0.167
Thermal conversion efficiency, η_{TH}	0.36	0.36
Net plant efficiency, $\eta_p = \eta_{TH}(1 - \varepsilon)$	0.29	0.30
FPC mass, M_{FPC}	1117.	23,170.
Mass utilization, M_{FPC}/P_{TH}	0.32	5.75
Mass power density, 1000 P_E/M_{FPC}(kWe/tonne)	895.	52

CONCLUSIONS

- KEY TO COMPACT, HPD FUSION REACTORS
  - INCREASED, MORE–UNIFORM HEAT/PARTICLE LOADS (I_{Qw} ↑ 2–3)
  - HIGHER–POWER–DENSITY PLASMAS (βB^2 ↑ ~ 2) WITH REDUCED VOLUME (r_p ↓ ~ 2–3)
  - DECREASED BLANKET/SHIELD THICKNESSES (Δb ↓ 2–3)
  - USE OF RESISTIVE, EXOBLANKET COILS, PREFERABLY WITH REDUCED TOROIDAL–FIELD COMPONENTS (HIGH–β TOKAMAK, RFP/OHTE, SPHEROMAK)
- SIGNIFICANT DEVELOPMENT AND COMMERCIALIZATION ADVANTAGES EXIST FOR COMPACT, HPD FUSION REACTORS, DEPENDING ON
  - SPECIFIC CONCEPT
  - COMPLEX COST, OPERATIONAL AND SAFETY/ENVIRONMENTAL TRADEOFFS
- MAJOR TECHNICAL ISSUES ARE GENERIC TO MAGNETIC FUSION, NOT UNIQUE TO COMPACT, HPD APPROACHES
  - HHF COMPONENTS
  - SPUTTER EROSION
  - HPD BLANKETS
  - RADIATION–HARDENED RESISTIVE COILS

INVENTION AND INNOVATION IS NEEDED ON A NUMBER OF FRONTS TO IMPROVE THE PROSPECTS OF COMMERCIAL FUSION

- PLASMA PHYSICIST: HIGH-BETA PLASMA WITH EDGE CONDITIONS THAT SIGNIFICANTLY REDUCE SPUTTER EROSION (DENSE AND COLD FOR LIMITER OR HOT AND DIVERTED)
- MATERIAL SCIENTIST: HHF MATERIALS THAT OPERATE AT THERMODYNAMICALLY INTERESTING CONDITIONS WITH ACCEPTABLE RADIATION LIFE
- FUSION NUCLEAR ENGINEER: REMOVE HHF OR HPF COMPONENTS TO REGIONS OF REDUCED NEUTRON FLUX WHILE INNOVATING FUSION NUCLEAR TECHNOLOGIES THAT HANDLE HHF AND HPD

OFF-LINE SIMULATION FACILITIES PISCES

Dan Goebel
University of California Los Angeles

PLASMA-SURFACE INTERACTION EXPERIMENTS

AT UCLA

PISCES

DAN M. GOEBEL

R.W.CONN
Y. HIROOKA
K. LEUNG

OBJECTIVES OF PISCES PROGRAM

PERFORM HIGH PARTICLE FLUX, HIGH FLUENCE STUDIES OF PLASMA MATERIALS INTERACTIONS USING A FACILITY CAPABLE OF CONTINUOUS, CONTROLLABLE PLASMA OPERATIONS.

1. SURFACE MATERIAL AND COATING BEHAVIOR UNDER A HIGH RATE OF PLASMA BOMBARDMENT. EVOLUTION OF THE SURFACE MORPHOLOGY IN A REGIME CHARACTERIZED BY REDEPOSITION OF MATERIAL ON THE SURFACE BY THE PLASMA.

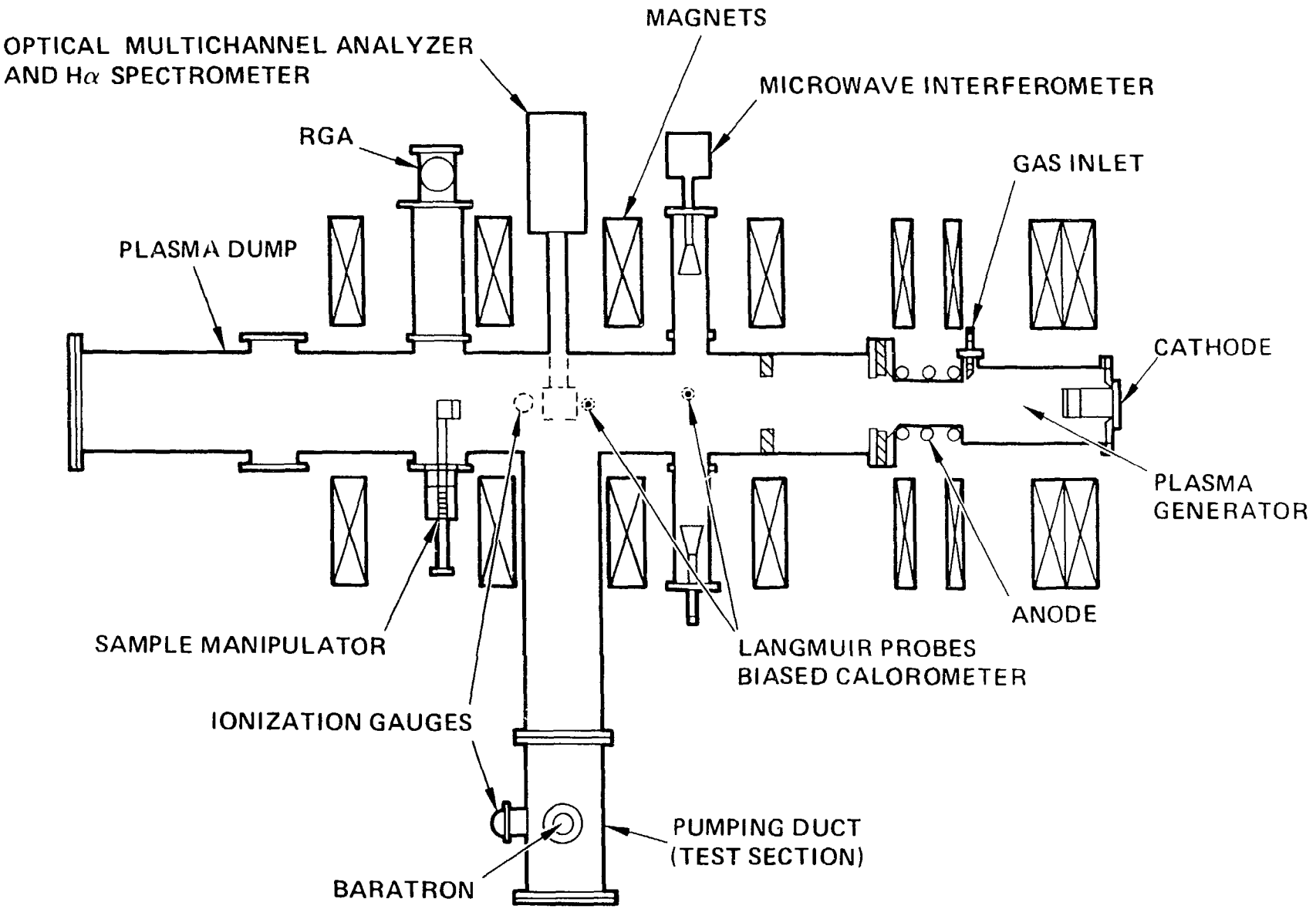
2. PLASMA AND NEUTRAL INTERACTION PHYSICS IN THE PLASMA CHANNEL AND AT THE NEUTRALIZATION PLATES IN DIVERTOR AND PUMP LIMITER GEOMETRIES.

3. DEVELOPMENT, TESTING, AND CALIBRATION OF DIAGNOSTICS FOR USE IN LONG PULSE OR CONTINUOUSLY OPERATING PLASMA-MATERIAL INTERACTION EXPERIMENTS.

4. CONTROLLED EXPERIMENTS FOR COMPARISON AND BENCHMARKING THEORY AND CODES.

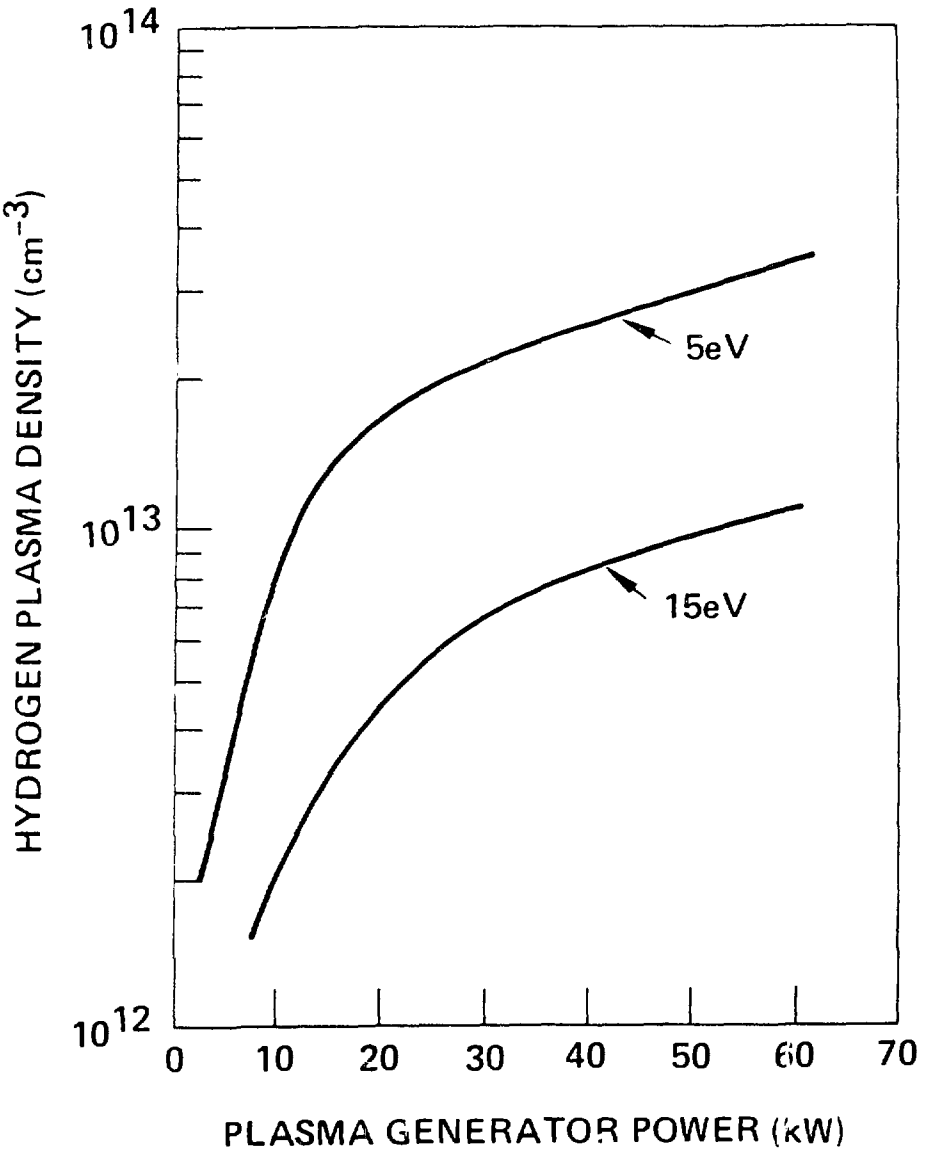
PISCES CONCEPT

- LINEAR, MAGNETIZED PLASMA OF 50-100 CM^2 AREA
- CONTINUOUSLY OPERATING PLASMA GENERATOR
- NO AXIAL MAGNETIC CONFINEMENT
  SLIGHT ELECTROSTATIC CONFINEMENT OF ELECTRONS AXIALLY
- INSERTION OF BIASED SAMPLES AND PLATES FOR EXPERIMENTAL STUDIES
- ALSO POSSIBLE TO INSERT AN ACCELERATOR FOR HIGH FLUX, LOW DENSITY BOMBARDMENT EXPERIMENTS


OPTICAL MULTICHANNEL ANALYZER
AND Hα SPECTROMETER
MAGNETS
MICROWAVE INTERFEROMETER
RGA
GAS INLET
PLASMA DUMP
CATHODE
PLASMA
GENERATOR
ANODE
SAMPLE MANIPULATOR
LANGMUIR PROBES
BIASED CALOROMETER
IONIZATION GAUGES
PUMPING DUCT
(TEST SECTION)
BARATRON

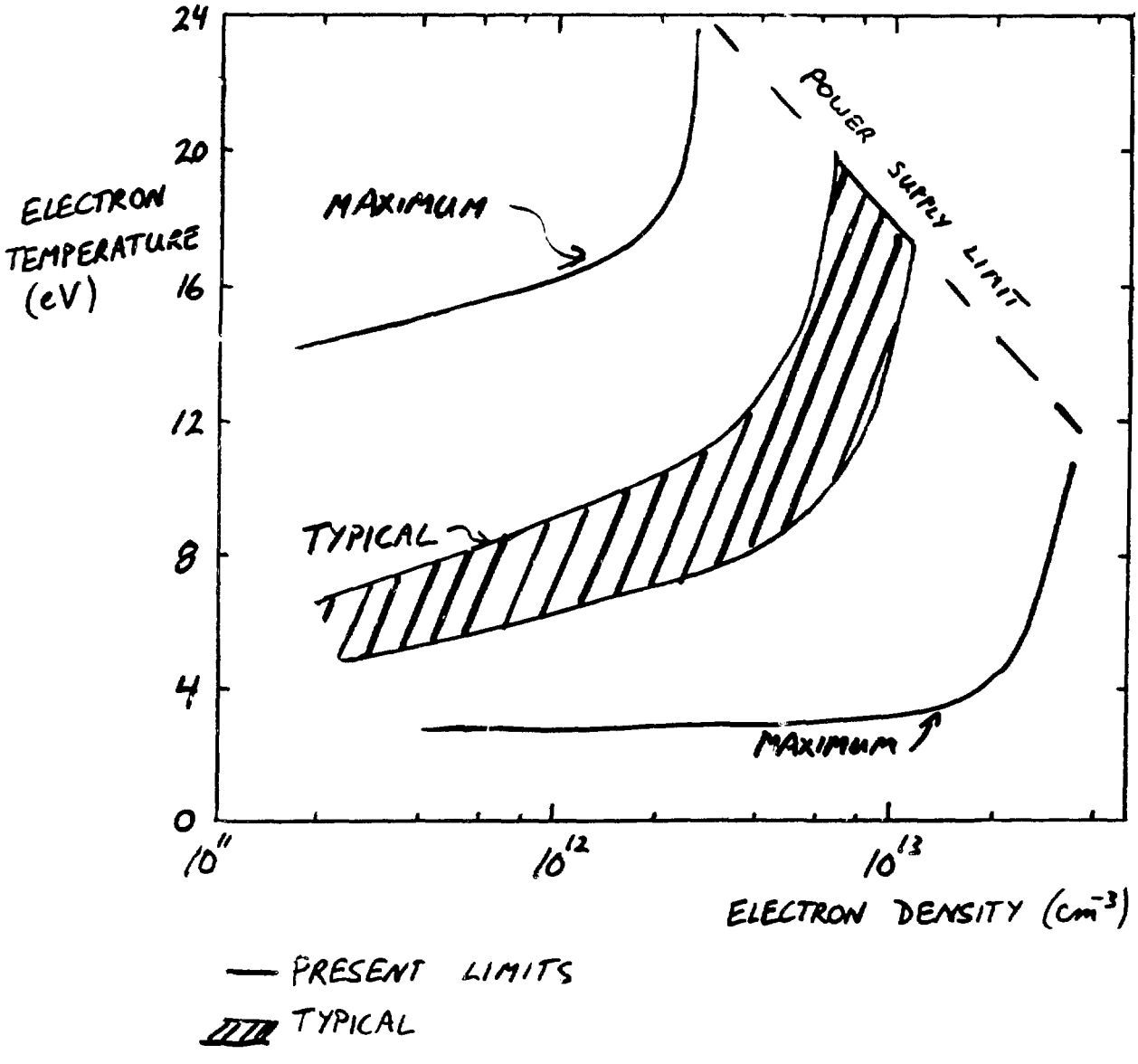
PISCES PARAMETERS

	Min	Max	Typical
Gas Type			H, D, He, Ar
Operating Time	--	Continuous	4-8 hours
Flux (ions/cm²sec)	10^{17}	2×10^{19}	10^{18}-10^{19}
Density (cm^{-3})	10^{11}	5×10^{13}	10^{12}-10^{13}
Plasma Area (cm^{-2})	20	100	50-80
Electron Temp. (volts)	2.5	25	6-20
Ion Energy (volts)	0.1	1	0.5
Sample Bias (volts)	25	1000	50-500
Magnetic Fiels (gauss)	200	2000	250-800
Base Pressure (torr)		Diff. Pumps	10^{-6}
		Turbo Pumps	10^{-8}
Percent Ionization		Disc Cathode	10-50%
		Hollow Cathode	40-90%
Sample Temperature Range			50-450°C
Hydrogen Ionization Length			0.5-200cm
Iron Ionization Length			0.1-50cm


10^{14}
10^{13}
10^{12}
HYDROGEN PLASMA DENSITY (cm^{-3})
5eV
15eV
0
10
20
30
40
50
60
70
PLASMA GENERATOR POWER (kW)

PISCES Electron Temperature vrs. Density

-HYDROGEN-

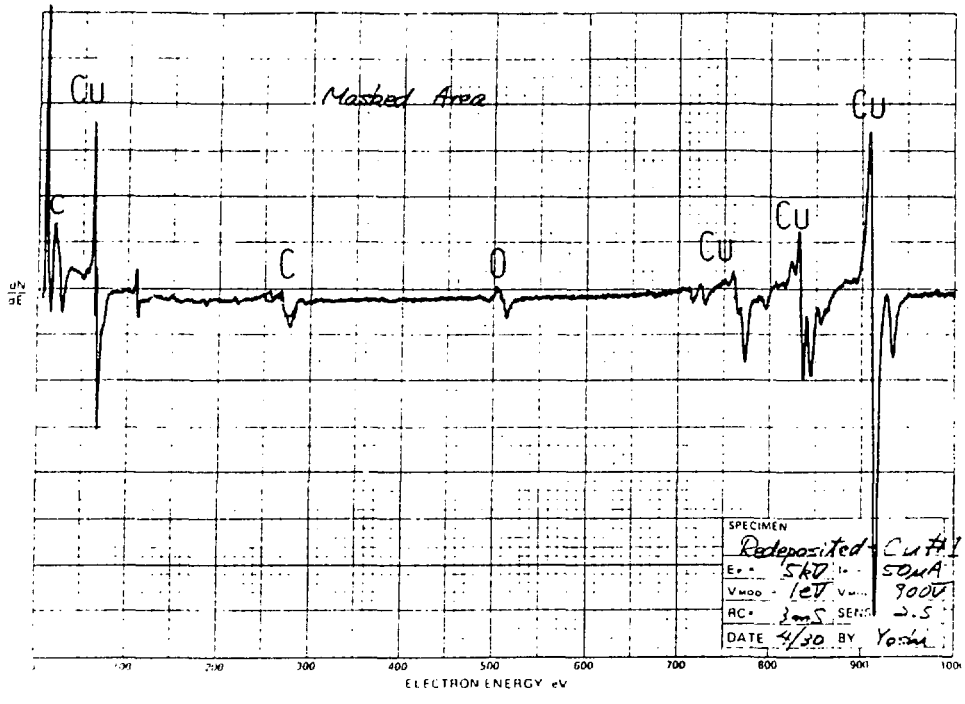


PISCES FY'85 EXPERIMENTS

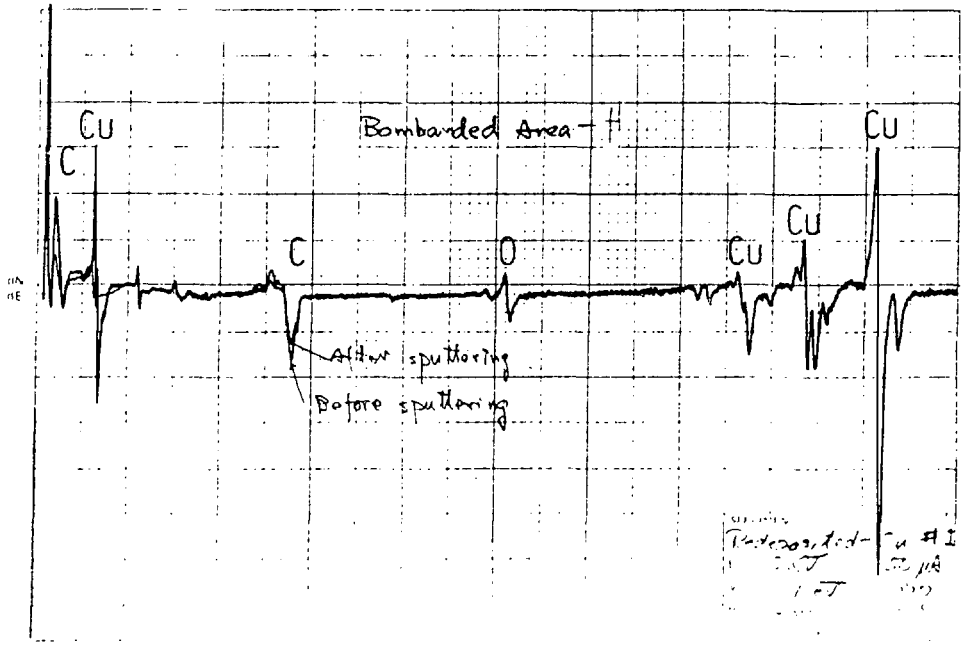
	Month	Year
Materials Studies		
Cooled sample manipulator 50-450° C	November	84
Copper erosion studies	December	84
*Copper-Lithium material studies	January	85
Auger/SIMS surface analysis station	March	85
*Stainless steel redeposition studies	May	85
*Copper-Lithium material studies	June	85
*Carbon redeposition studies	August	85
Pump Limiter Studies		
Open neutralizer plate	October	84
Closed Neutralizer plates	February	85
Divertor Physics Studies		
Chamber Modification	September	85
Experiments	Octorer	85
Spectroscopy Studies		
Diagnose PISCES plasma	January	85
*KFK Germany collaboration	June-July	85
Turbomolecular Pump Installation		
Install pumps, foreline, roots	March-April	85

* Collaboration

AUGER SURFACE ANALYSIS



MASKED COPPER



REDEPOSITED COPPER

PISCES RECENT RESULTS - PRELIMINARY

- MATERIALS EROSION AND REDEPOSITION EXPERIMENTS

  2.5 cm DIAMETER SAMPLES ARE MOUNTED IN A 50-450°C HOLDER. HOLDER MATERIAL IS CRITICAL TO ELIMINATE MATERIAL MIXING. PRESENTLY UTILIZE TUNGSTEN COATED, COOLED COPPER HOLDER.

  IN STAINLESS STEEL AND COPPER EROSION STUDIES. REDEPOSITION DECREASES NET EROSION BY 90% TO DATE.

  REDEPOSITION EFFICIENTLY TRANSPORTS AND MIXES MATERIALS.

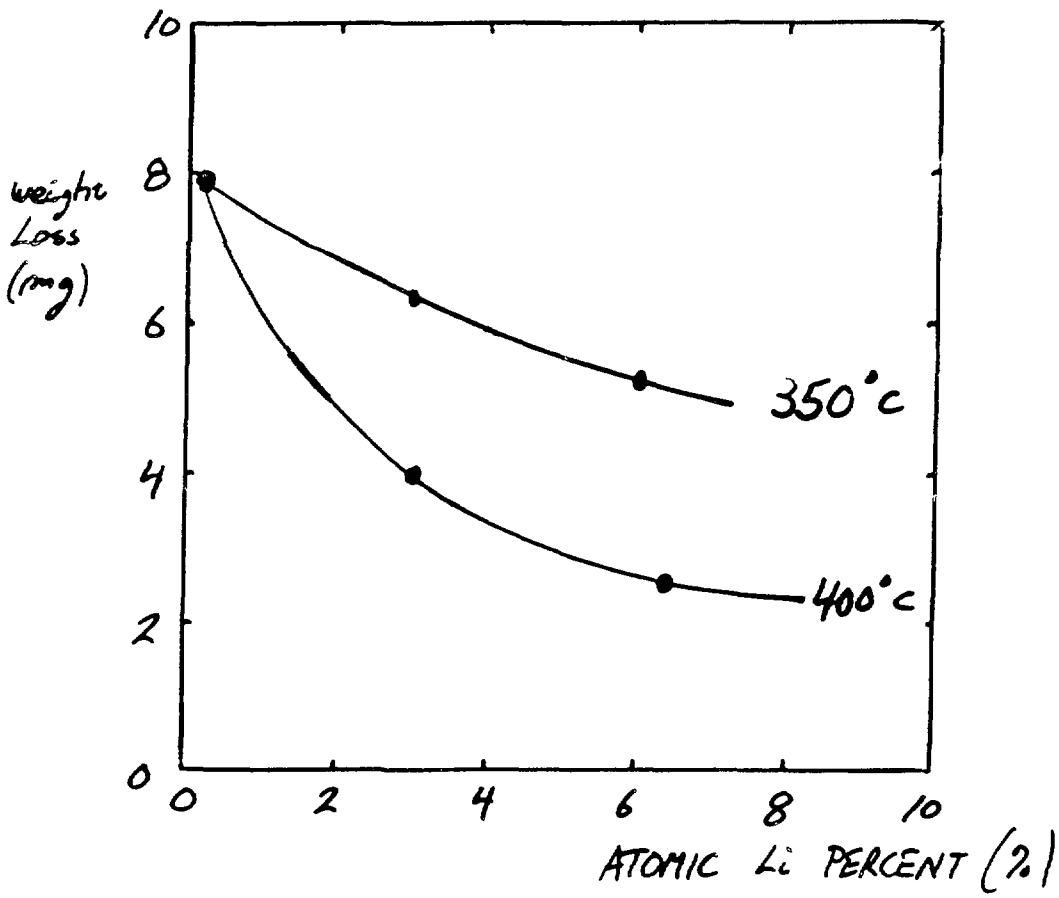
- Cu-Li ALLOY EXPERIMENTS SHOW DECREASED SAMPLE WEIGHT LOSS AT SAMPLE TEMPERATURES OF AT LEAST 400°C WHERE SIGNIFICANT AMOUNTS OF LITHIUM ARE DETECTED BY SPECTOSCOPY IN THE PLASMA. THIS TEMPERATURE IS HIGHER THAN THAT REQUIRED TO PRODUCE Cu SHIELDING DURING LOWER FLUX EROSION EXPERIMENTS.

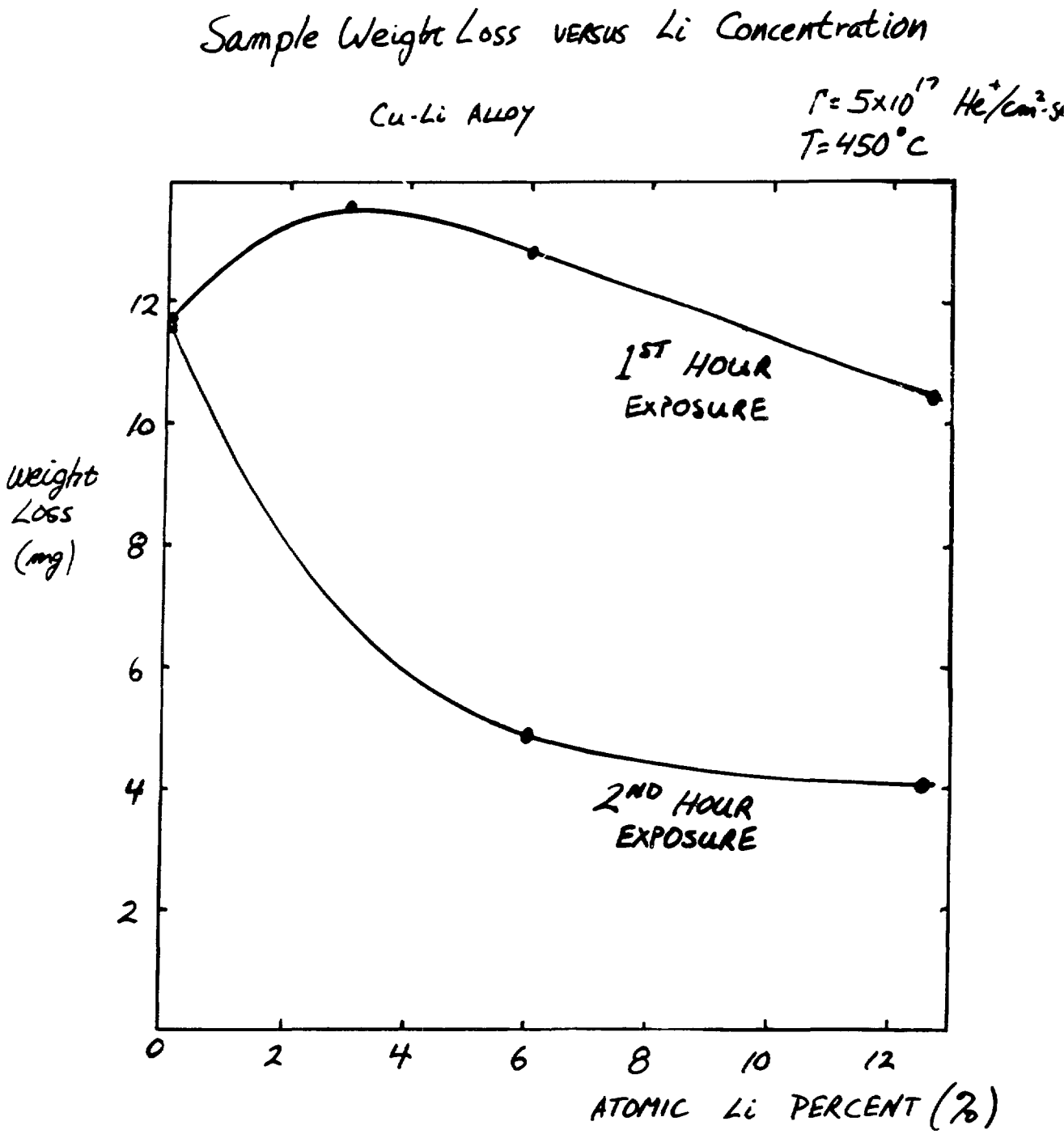
Sample Weight Loss versus Li Concentration

Cu-Li Alloy

$\Gamma = 1 \times 10^{17}$ He^+/cm^2-sec

4 Hour Exposure




Sample Weight Loss VERSUS Li Concentration
Cu-Li ALLOY
Γ = 5×10^17 He+/cm²-s
T = 450°C
Weight Loss (mg)
12
10
8
6
4
2
0
2
4
6
8
10
12
1ST HOUR EXPOSURE
2ND HOUR EXPOSURE
ATOMIC Li PERCENT (%)

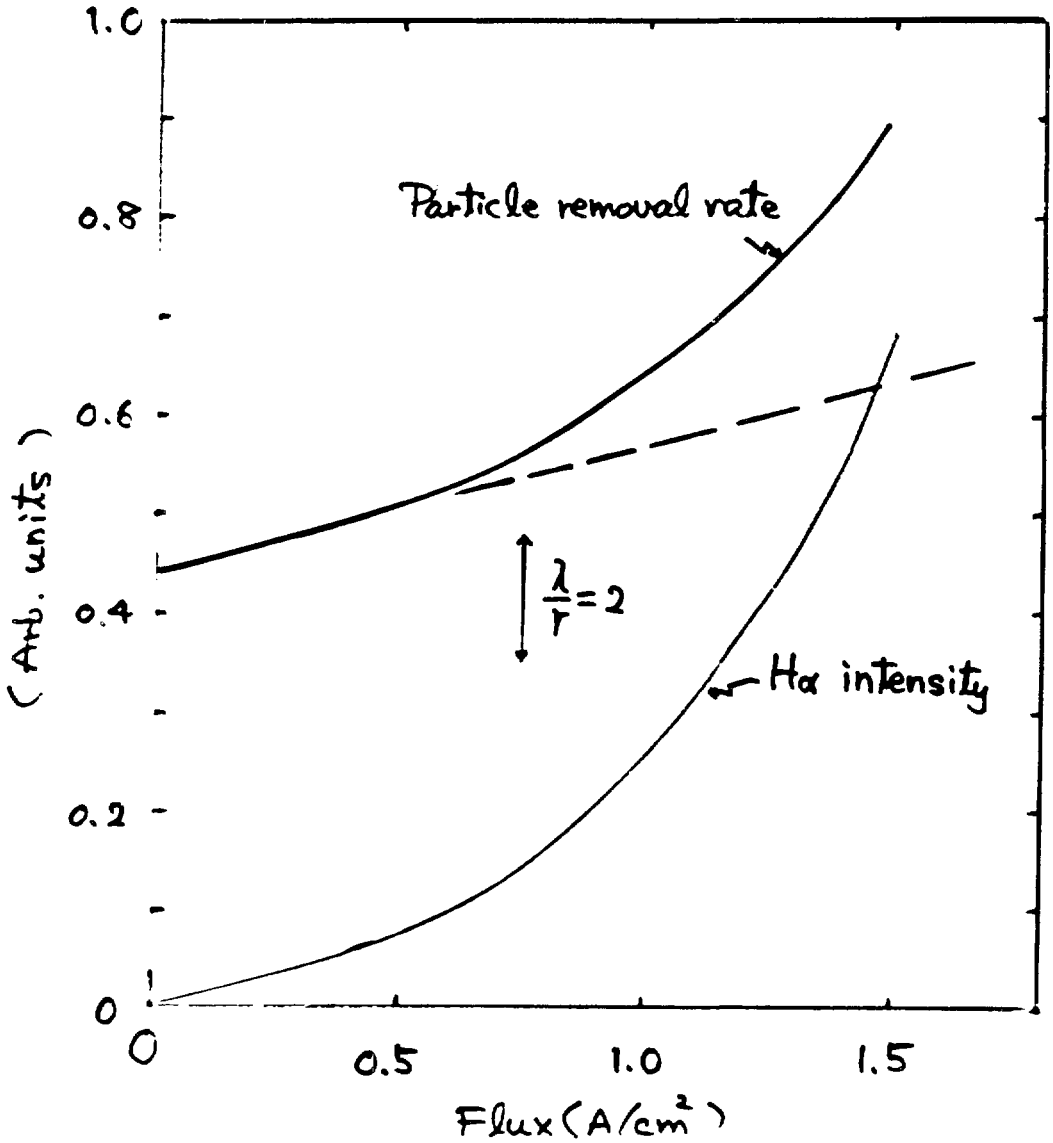
PISCES RECENT RESULTS ON DIVERTOR AND PUMP LIMITER SIMULATIONS

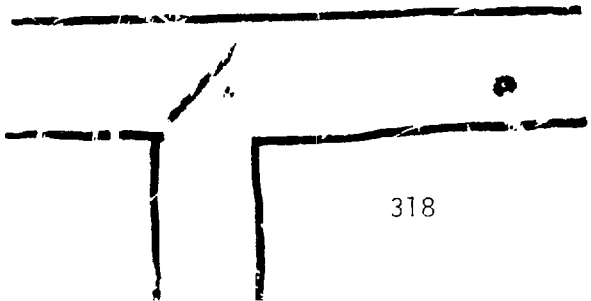
- RECYCLING OF HYDROGEN AT PLASMA NEUTRALIZATION PLATES IN PISCES HAS BEEN DEMONSTRATED.

- PUMP LIMITER SIMULATION EXPERIMENTS SHOW THAT THIS RECYCLING LEADS TO HIGHER PARTICLE REMOVAL RATES THROUGH PUMPING DUCTS LOCATED NEAR THE NEUTRALIZATION PLATES. ENHANCED REMOVAL RATES ARE PRODUCED BY A HIGHER NEUTRAL PRESSURE LOCALIZED AT THE DUCT ENTRANCE WHICH IS CAUSED BY HIGH RECYCLING.

- OPERATION OF PISCES IN A "BEAM-PLASMA" MODE TO INVESTIGATE THE ROLE OF BALLISTICALLY SCATTERED PARTICLES SHOWED NO INCREASE IN PARTICLE REMOVAL WITH INCIDENT PARTICLE ENERGY.

Hα intensity and particle removal rate versus incident flux.





CONCLUSIONS

- HYDROGEN RECYLING ACHIEVED IN PISCES
  PUMP LIMITER AND DIVERTOR EXPERIMENTS IN PROGRESS

- METAL REDEPOSITION EXPERIMENTS STARTED TO DETERMINE NET EROSION RATES AND CHARACTERISTICS OF THE NEW REDEPOSITED SURFACES

STEADY STATE TOKAMAK

Dan Goebel
University of California Los Angeles

PLASMA BOUNDARY PHYSICS AND SURFACE-MATERIALS TECHNOLOGY

MOTIVATION FOR PROGRAM DIRECTION ON CCT

1. HEAT FLOW AND REMOVAL AT BOUNDARY: COOLING IN CW ENVIR.

2. PLASMA FUELLING AND EXHAUST: PLASMA FLOWS IN BOUNDARY LAYER

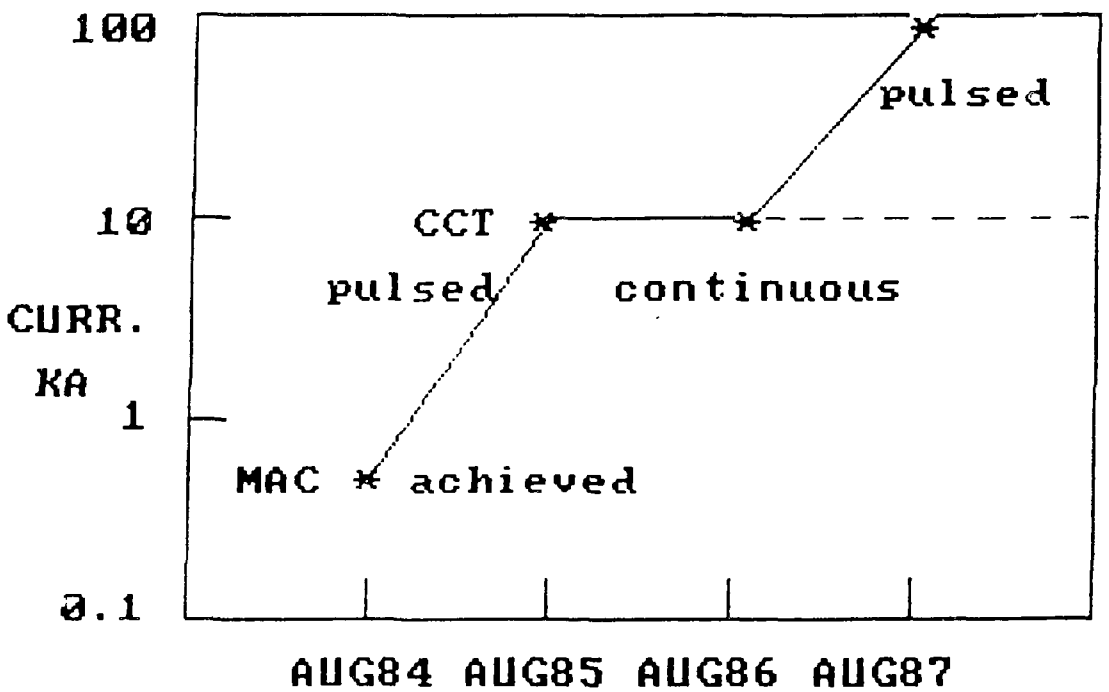
3. MATERIAL EROSION AND RESPONSE TO PLASMA FLOWS: IMPURITY GENERATION AND CONTROL IN CW ENVIR.

4. RELATIONSHIP BETWEEN "OPEN", CW PMI SIMULATION EXPERIMENTS (e.g. PISCE AND CW TOKAMAK EXPERIENCE (e.g. CCT).

Parameters

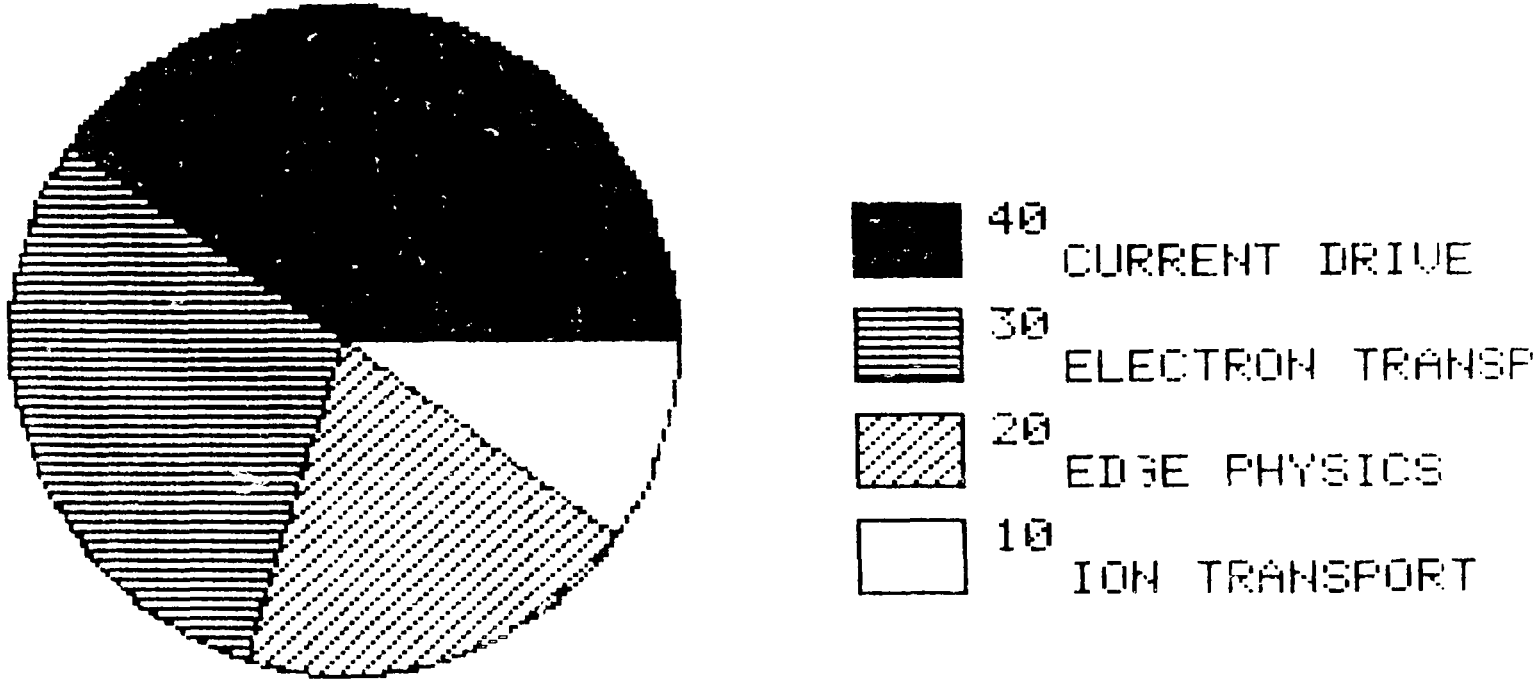
	PLT			CCT		MACRO
	LH-SLOW	-FAST	ICRF	PULSED	CW	CW
R		1.5 m		1.5 m		.9 m
a		.4 m		.4 m		.4 m
B (kG)		20		7 kG	1 kG	.3
I (kA)	200	200	-	100	10	1
Tbulk (kev)	-	1-2	-	.3	.1	10ev
N		2/5(13)		2(13)	3(12)	3e11
F (MHZ)	2500	800	80/30	15	15	3
Kparall	-	-	-	6/m	6/M	
Kperp	-	-	-	60/m	60/m	
P (MWatt)	.3	1	1.5/5	.1	.3	.03
dk/k-spec	-	-	-	0.1	0.1	.1
τ (sec)	1.	-	-	0.3	20000	.1
npara	2	1.5	-	10	10	50
nperp	1000	200	-	30	200	50
n-fluc.	1000	1000	-	1000	1000	
λ	-	-		-	-	
COUPLER	WG	WG/loops	loops(6)	modul(8)	modul(8)	8

OTHER CURRENT DRIVE SCHEME (ECH using LH SOURCES)

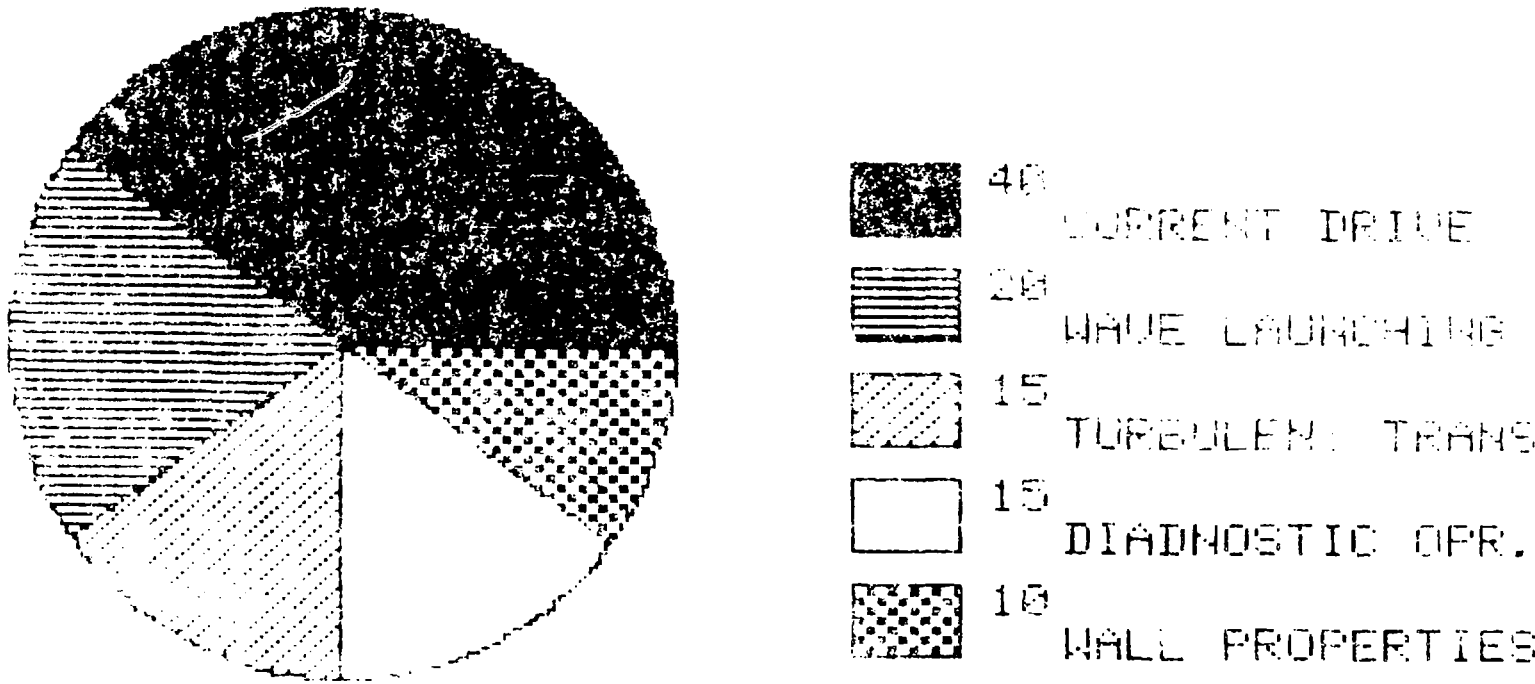


UCLA TOKAMAK IMPROVEMENT PROJECT GOALS

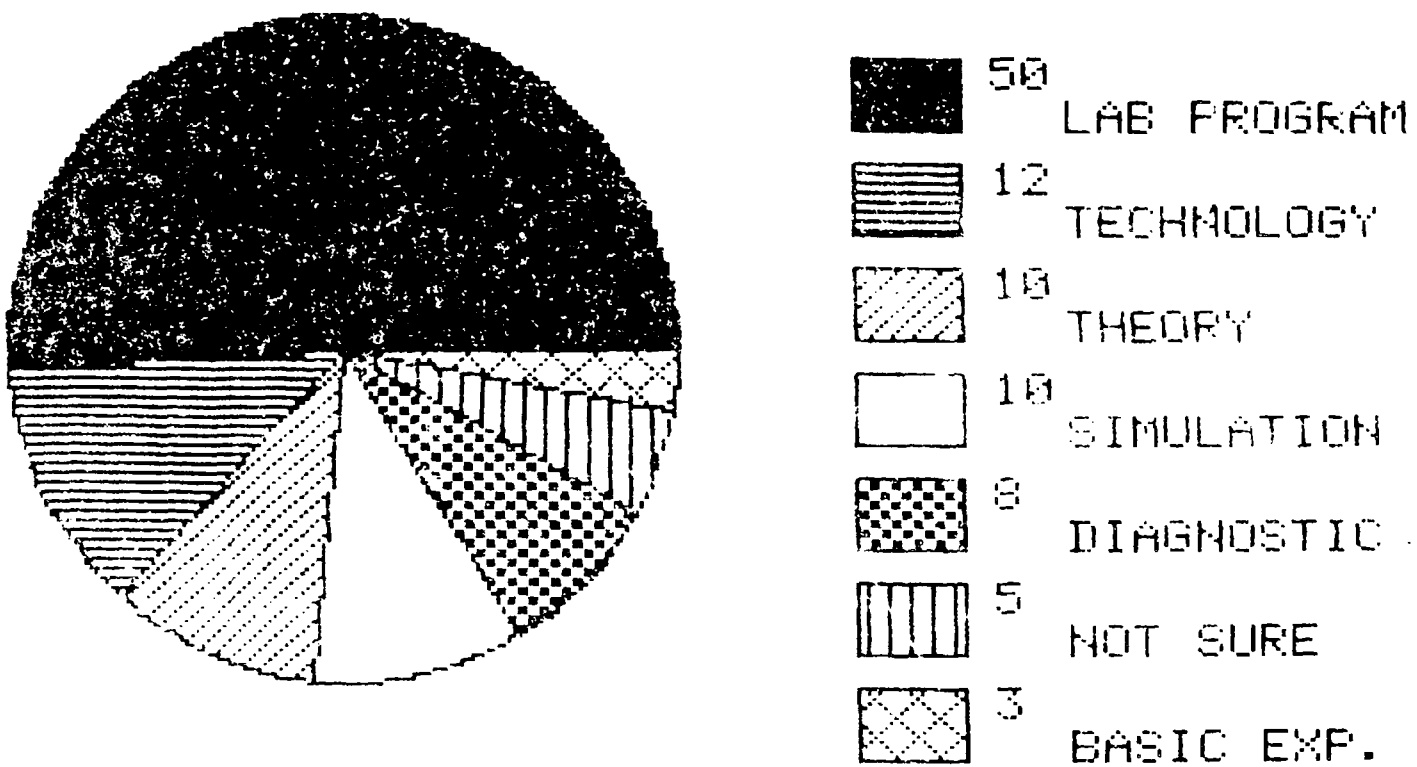
CCT OVERALL PROGRAM PLAN (3/85)



UCLA TOKAMAK LAB DIRECTION (3/85)



COUPLING TO OTHER PROGRAMS (3/85 PROP.)



UNIQUE EXPERIMENTAL DIRECTION: ON CCT

- LONG-TIME EVOLUTION OF PLASMA BOUNDARY FLOWS

- PLASMA "DOSING" EFFECTS
  - EVOLUTION OF SURFACE STRUCTURES AND NATURE OF STEADY-STATE SURFAC
    - SATURATION AND RECYCLING
    - EROSION AND REDEPOSITION
    - HYDROGEN PERMEATION
  - MASS TRANSPORT OF MATERIALS IN THE TOKAMAK
  - CONTINUOUS FUELLING/EXHAUST AND DENSITY/IMPURITY CONTROL

RFTP

D. Swain
Oak Ridge National Laboratory

RFTF AND OTHER FACILITIES FOR PMI AND HHF TESTING AT ORNL

David W. Swain

Assistant Section Head, Plasma Technology Section

Fusion Energy Division

Oak Ridge National Laboratory

Oak Ridge, Tennessee 37831

Joint PMI and HHF Materials and Components Task Groups

DOE/OFE, Germantown, MD

May 21–22, 1985

DWS
5/21/85

THERE ARE SEVERAL FACILITIES AT ORNL THAT CAN BE USED FOR PMI OR HHF TESTING.

- RF TEST FACILITY (RFTF) – STEADY-STATE, MIRROR-CONFINED PLASMA WITH ≤2-MW POWER (OPERATIONAL SEPTEMBER 1985).
- HIGH HEAT FLUX FACILITY (HHFF) – 30-keV H^+ OR He^+ BEAM, 8 kW/cm^2 (PEAK) FOR 1 sec.
- HIGH PARTICLE FLUX FACILITY (HPFF) – 100-eV H^+ OR He^+ BEAM, 2 kW/cm^2 (PEAK) FOR 60 sec.

DWS
5/21/85

THE RADIO-FREQUENCY TEST FACILITY (RFTF) IS BEING BUILT TO TEST RF COMPONENTS IN STEADY-STATE PLASMA CONDITIONS

FACILITY CAPABILITIES ARE:

PORT SIZE 74 cm × 163 cm (LARGER THAN TFTR & DIII-D PORTS)

MAGNETIC FIELD ≤1 T ON AXIS; SIMPLE MIRROR 4.7:1 MIRROR RATIO

200-kW, 28-GHz ECH POWER STEADY STATE

300-kW ICH POWER 5–30 MHz

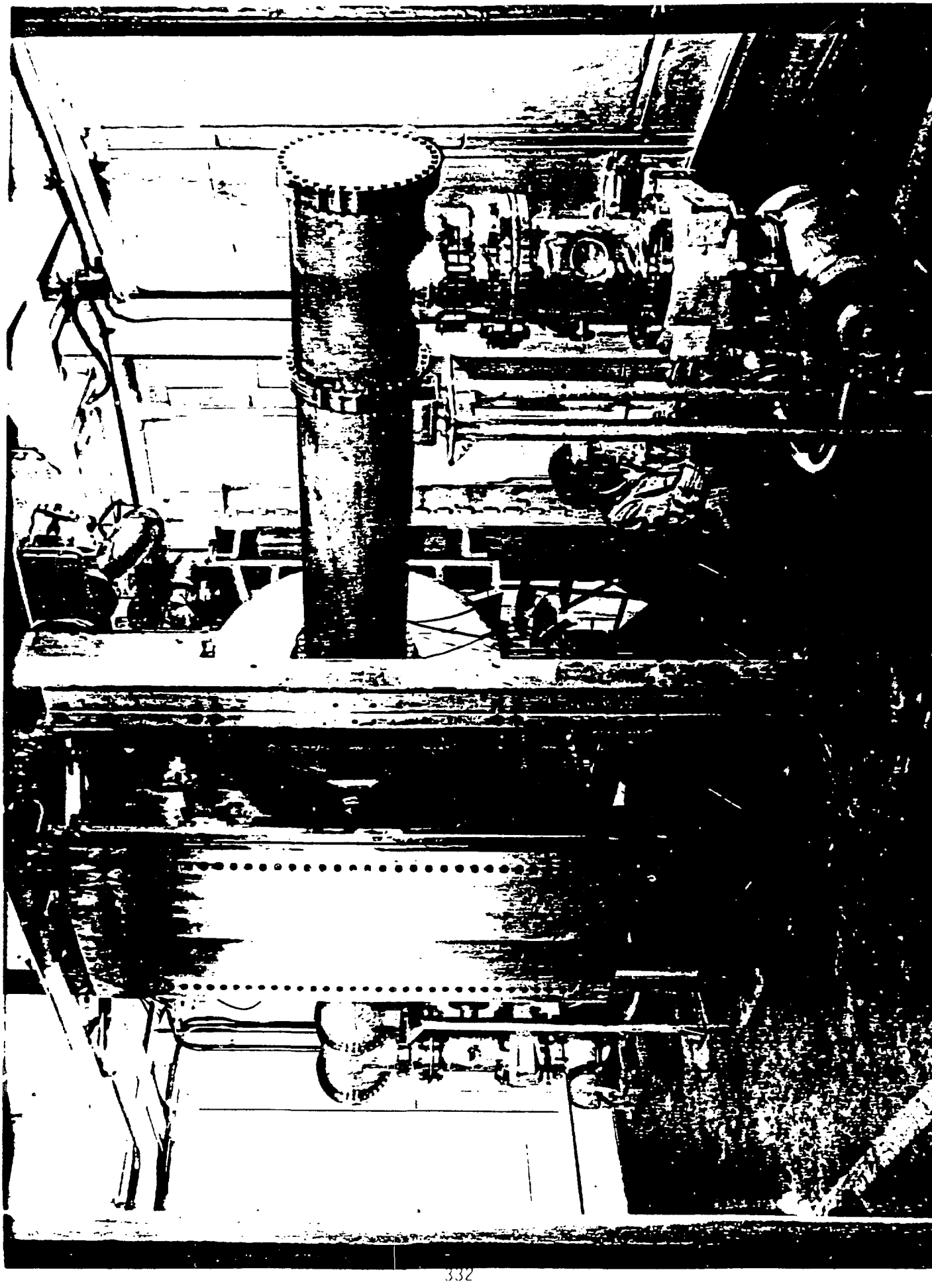
1.5-MW ICH POWER 40–80 MHz (FALL 1986)

PLASMA $\leq 5 \times 10^{18}$ m^{-3}, T_e, T_i = 30–100 eV

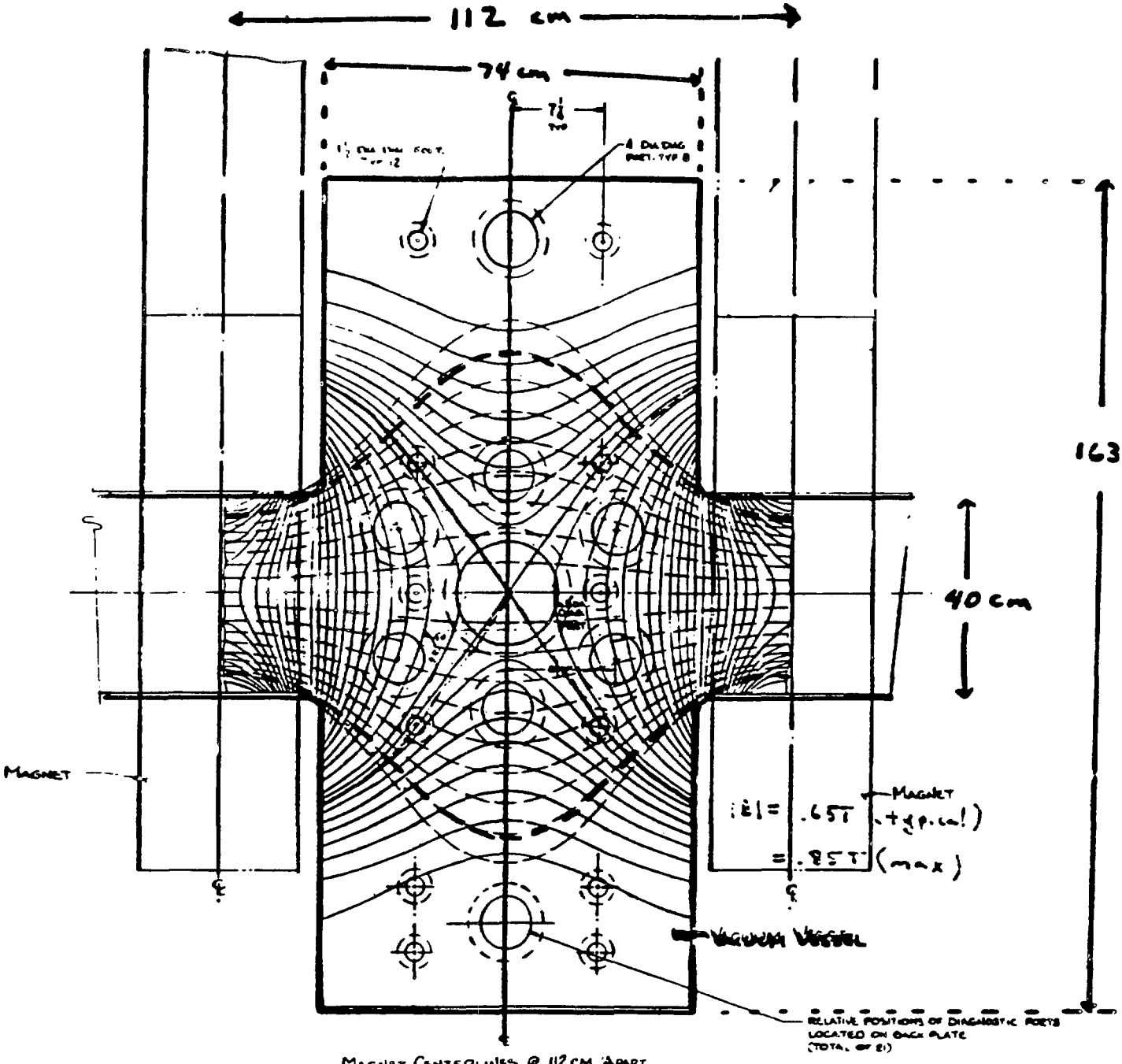
PROJECT COMPLETION AUGUST 1985.

PLASMA PARAMETERS RELEVANT TO MATERIALS TESTING WILL BE GENERATED BY THIS DEVICE.

DWS
5/21/85



RFTF MAGNETIC CONFIGURATION AND VACUUM VESSEL PORTS (HORIZONTAL)



MAGNET CENTERLINES @ 112 CM. APART

ELEVATION - SCALE 1/4" = 1'

FIELD LINES REPRODUCED FROM COMPUTER PLOT DATED 16 APRIL 1974 BY C.M. FLEI

RFTF DEVICE AND PLASMA PARAMETERS

GEOMETRY

r_{plasma} = 0.47 m

V_{plasma} = 0.40 m^3

L_{mirror} = 1.12 m

r_{throat} = 0.16 m

A_{throat} = 0.15 m^2

MAGNETIC FIELD

B_{center} = 0.65 T (0.85 T max)

B_{throat} = 3.1 T (4.0 T max)

Mirror ratio = 4.7

HEATING SOURCES (CW)

ECH	200 kW	28 GHz
ICH	300 kW	5–30 MHz
	1500 kW	40–80 MHz
	2000 kW	

PLASMA PROPERTIES

$n \leq 5 \times 10^{18}\ m^{-3}$

T_e, T_i = 30–100 eV

$\Gamma \leq 1 \times 10^{23}$ particles/m^2 s

$Q \leq 10\ MW/m^2$

DWS
5/21/85

THERE ARE MANY APPLICATIONS FOR RFTF IN THE PMI PROGRAM.

- PLASMA PARAMETERS ARE WELL SUITED TO SIMULATE EDGE CONDITIONS OF CONFINEMENT DEVICES.
- STEADY STATE OPERATION AND LARGE APERTURES ALLOW REALISTIC EROSION / REDEPOSITION STUDIES.
- LARGE APERTURES ARE SUITED TO TEST FULL-SIZE PUMP LIMITER MODULES.
- CONDITIONING OF IN-VESSEL COMPONENTS:
  - LIMITER CONDITIONING STUDIES
  - FULL-SIZE LIMITER CONDITIONING
- DEVELOPMENT AND TEST OF EDGE DIAGNOSTICS:
  - PLASMA FLOW VELOCITY
  - EDGE TEMPERATURE AND DENSITY
- INFLUENCE OF SURFACE PHYSICS ON THE PERFORMANCE OF RF COMPONENTS.
- PROCESSES IN PUMP LIMITER THROAT AND DUCT:
  - RECYCLING REGIME / PLUGGING
  - GEOMETRY / DESIGN OPTIMIZATION
  - NEUTRALIZATION / THERMALIZATION
  - PRESSURE BUILD-UP
  - PUMPING

DWS
5/21/85

DIAGNOSTICS IN ORNL TEST FACILITIES

PRESSURE

- IONIZATION GAUGES
- CAPACITIVE GAUGES
- THERMOCOUPLE GAUGES

GAS SPECIES

- RESIDUAL GAS ANALYZER

SPUTTERING

- UV SPECTROMETRY

EROSION RATE

- CAPACITIVE COLLECTOR PROBE

SURFACE TEMPERATURE

- IR CAMERA
- THERMOCOUPLES

PLASMA TEMPERATURES

- LANGMUIR PROBE
- DOPPLER BOADENING
- LINE RATIO

PLASMA DENSITY

- LANGMULIR PROBE
- MICROWAVE INTERFEROMETER

PARTICLE ENERGY

- THERMOGAUGE-LANGMUIR (TL) PROBE

THERMAL POWER

- ΔT AND FLOW METER FOR COOLANT

DWS

THE ORNL HIGH HEAT FLUX FACILITY (HHFF) IS USEFUL FOR TESTING POWER LIMITS OF MATERIALS FOR USE IN FIRST WALLS, LIMITERS, AND SHIELDS.

PARTICLE: H^+, He^+

ENERGY: 30 keV

PARTICLE FLUX: 10^{18} ions/cm^2 s

POWER: 0.3 MW

PEAK HEAT FLUX: 8 kW/cm^2

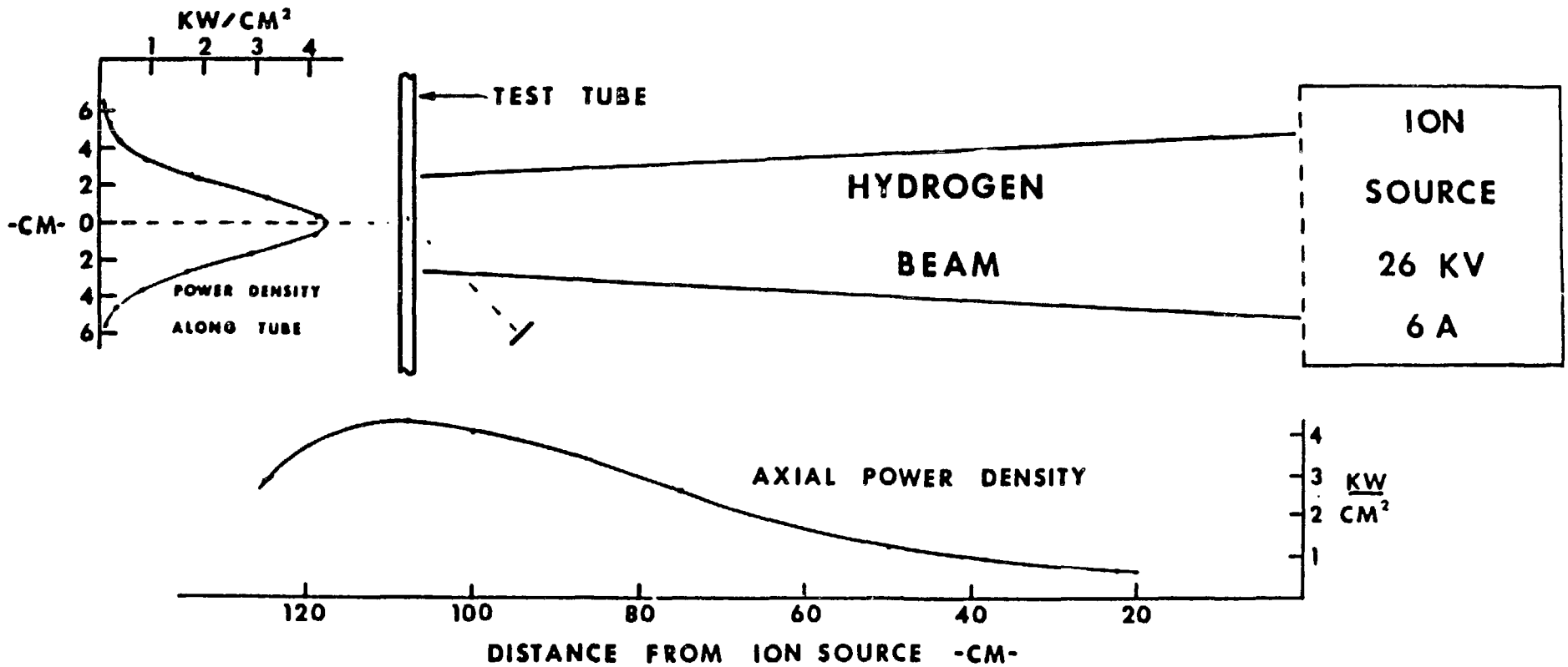
TARGET AREA: 50 cm^2

PULSE LENGTH: 1.5 s EVERY 60 s

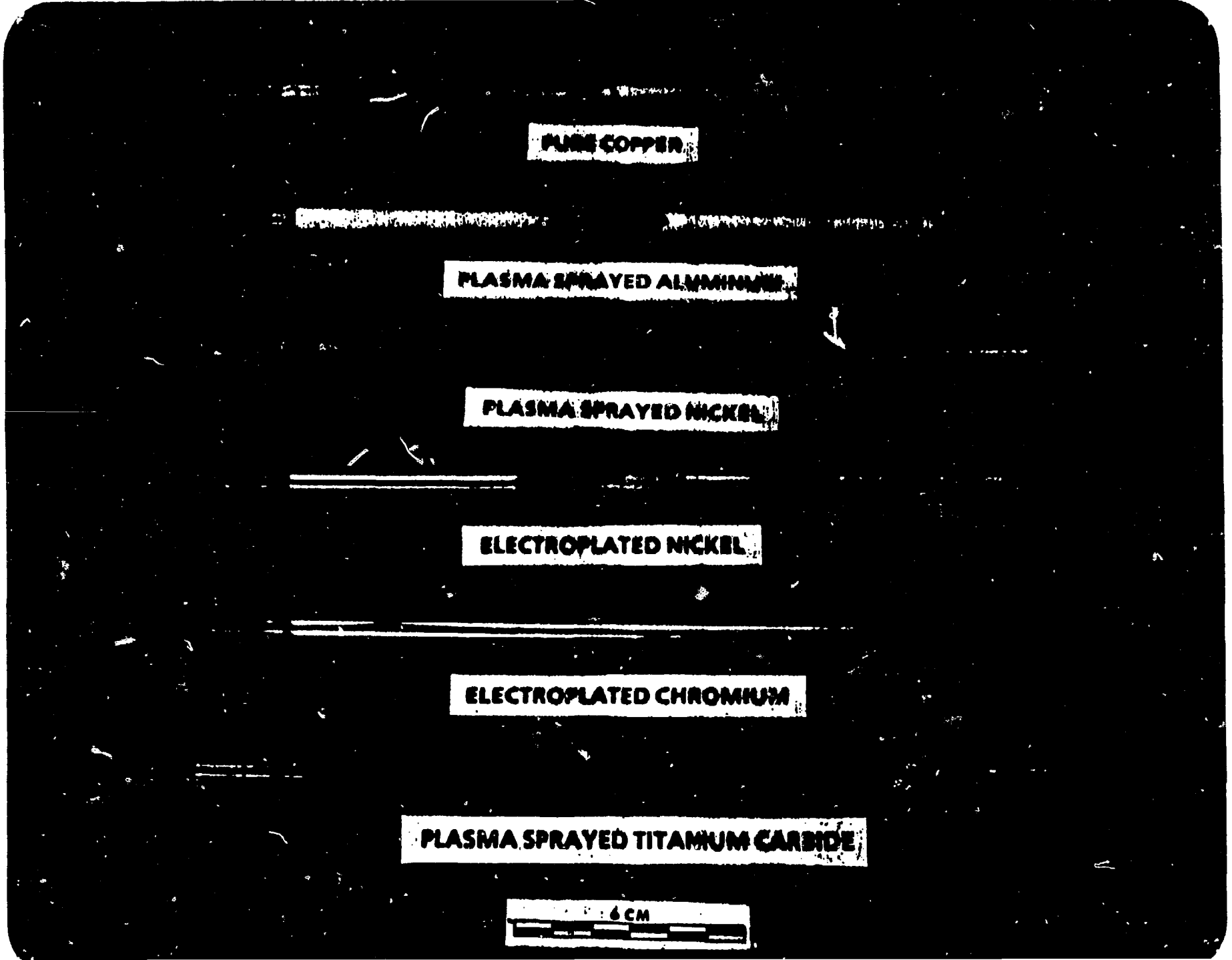
DWS
5/21/85

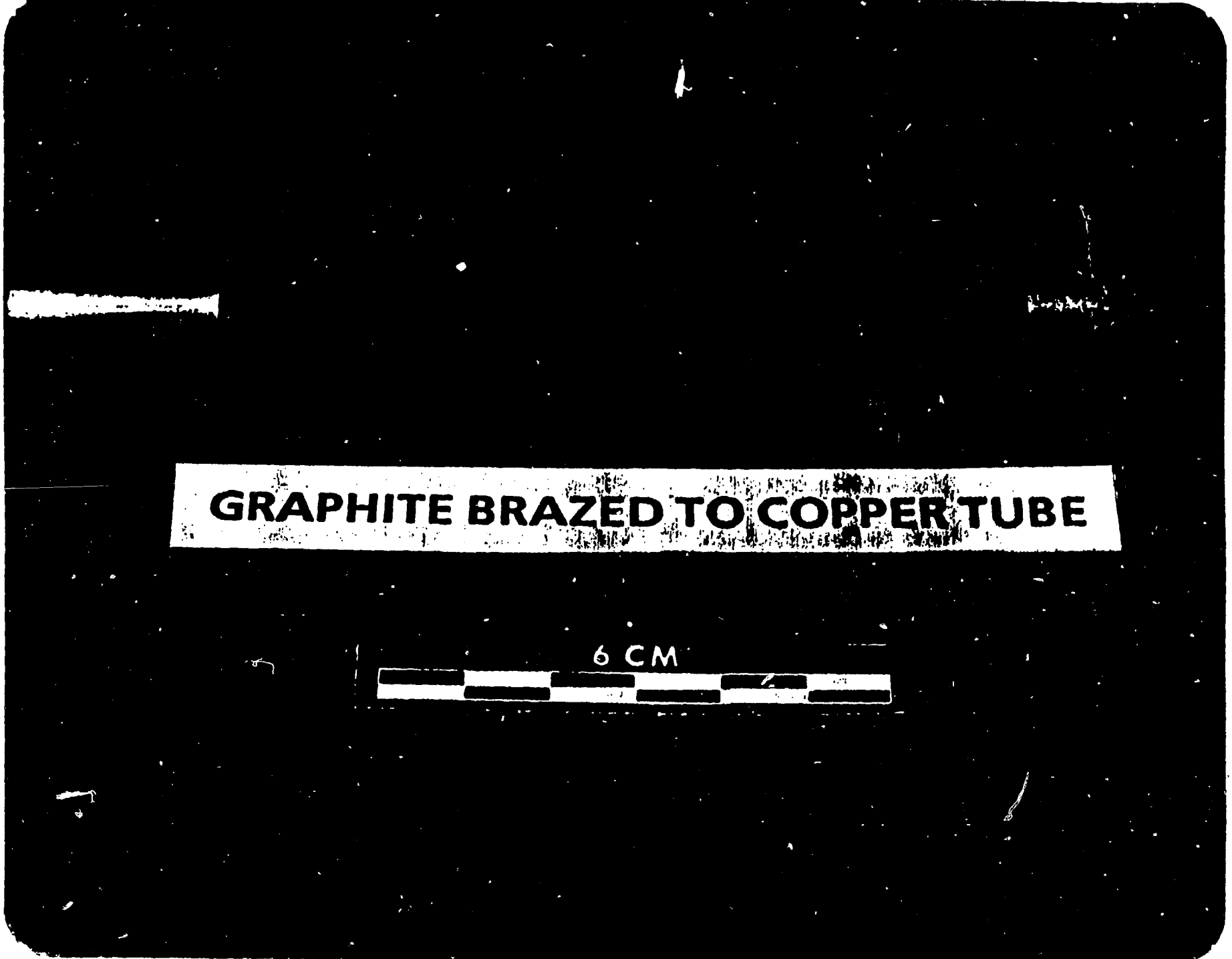
THE HHFF HAS BEEN USED TO STUDY THE POWER HANDLING ABILITY AND EROSION RATES OF WATER-COOLED COPPER SWIRL TUBES COATED WITH DIFFERENT MATERIALS.

EACH TUBE WAS SUBJECTED TO UP TO 2000 2-s PULSES OF 26-keV PROTONS, 4.3 kW/cm².



DWS


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


GRAPHITE BRAZED TO COPPER TUBE
6 CM

THE ORNL HIGH PARTICLE FLUX FACILITY (HPFF) IS A PLASMA ARC FACILITY THAT IS USED TO TEST MATERIAL SPUTTERING AND EROSION RATE.

PARTICLE: H^+, He^+, D^+, e

ENERGY: 100 eV

PARTICLE FLUX: $\leq 10^{19}$ ions/cm^2 s

POWER: 0.3 MW (ARC POWER)

PEAK HEAT FLUX: ≤ 2 kW/cm^2

TARGET AREA: ≥ 10 cm^2

PULSE LENGTH: 60 s EVERY 150 s

DWS
5/21/85

CONCLUSION -

THE RFTF, HHFF, AND HPFF FACILITIES AT ORNL ARE WELL SUITED FOR APPLICATIONS IN THE PMI AND HHF PROGRAMS. THE FACILITIES ARE ALREADY CONSTRUCTED* AND CAN PROVIDE COST-EFFECTIVE TESTING CAPABILITIES.

WE SOLICIT IDEAS FOR USE AND COLLABORATIVE EXPERIMENTS IN THESE FIELDS.

---

*RFTF OPERATIONAL SEPTEMBER 1985.

DWS
5/21/85

PMTF

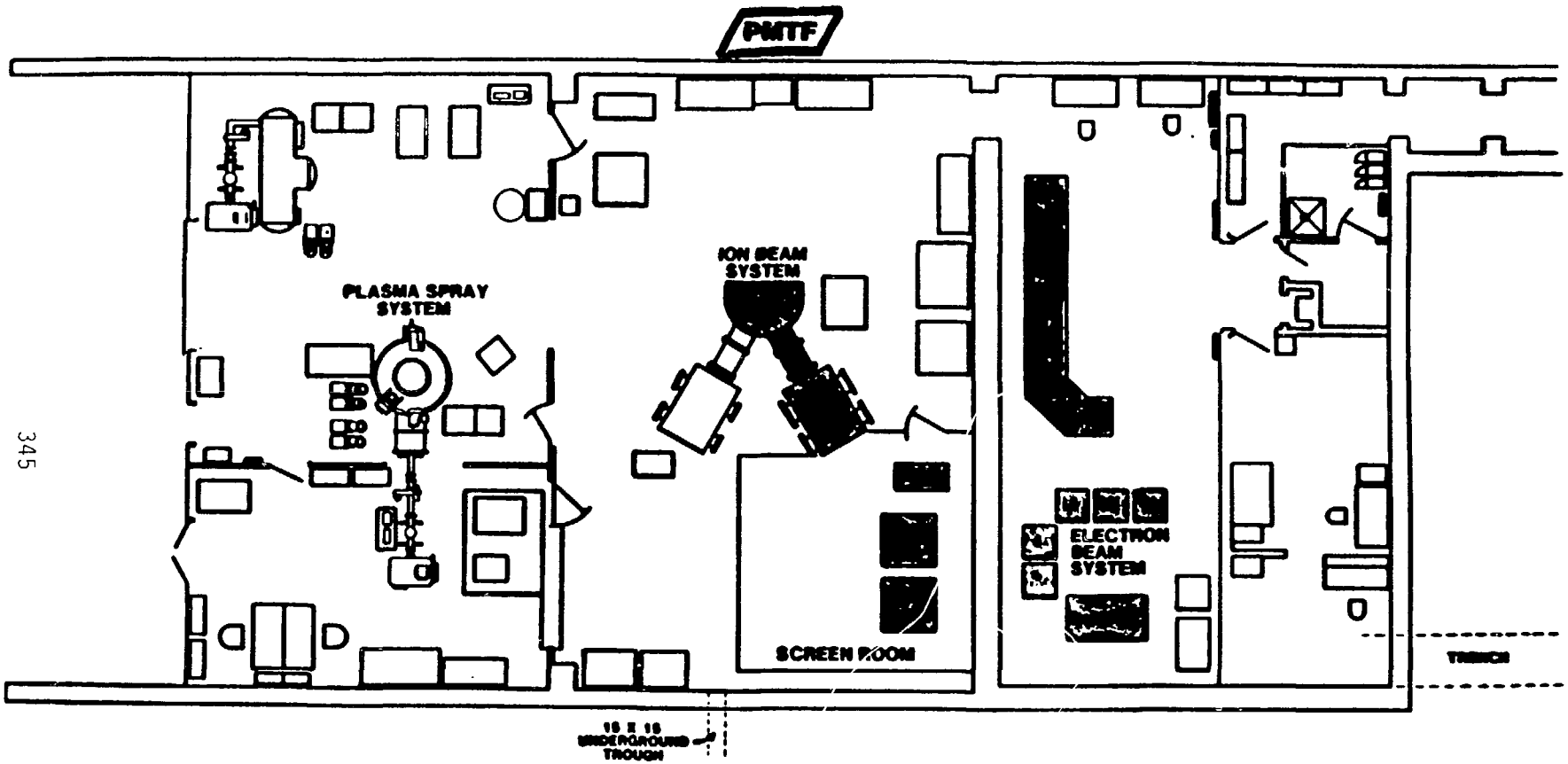
W. Gauster
Sandia National Laboratories Albuquerque

PLASMA MATERIALS TEST FACILITY (PMTF)

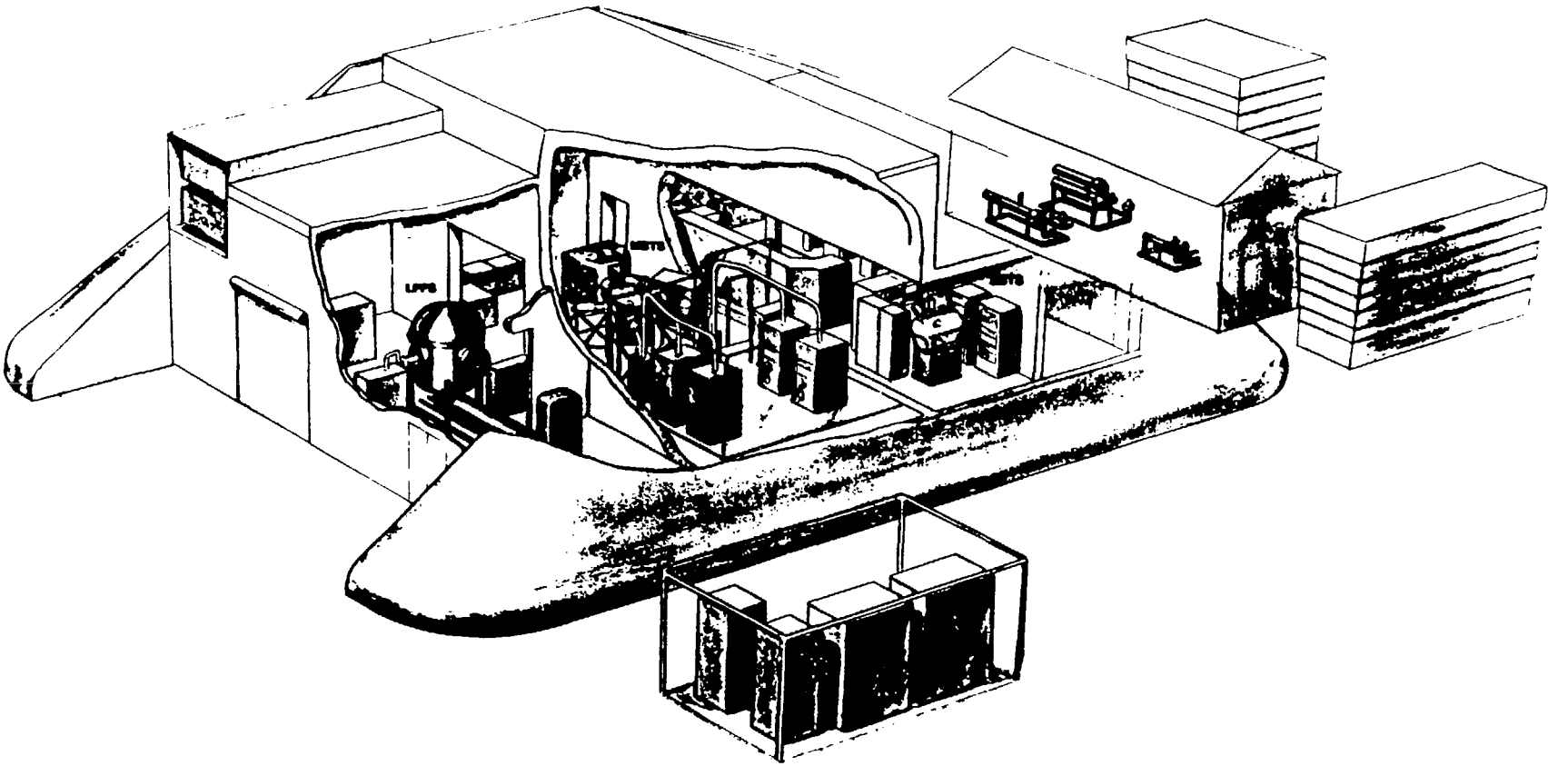
- DEDICATED TO THE DEVELOPMENT AND TESTING OF HIGH HEAT FLUX COMPONENTS FOR MAGNETIC FUSION ENERGY.

- FACILITY CONSISTS OF:
  - ELECTRON BEAM TEST SYSTEM (EBTS)
  - MULTIPLE BEAM TEST SYSTEM (MBTS)

Sandia National Laboratories


PMTF
PLASMA SPRAY SYSTEM
ION BEAM SYSTEM
ELECTRON BEAM SYSTEM
SCREEN ROOM
TRENCH
UNDERGROUND TROUGH

PLASMA MATERIALS TEST FACILITY (PMTF)



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ELECTRON BEAM TEST SYSTEM (EBTS)

- MATERIALS TESTING, DISRUPTION SIMULATION AND STEADY STATE HEAT REMOVAL RESEARCH.

FEATURES:

- 30 kV ELECTRON SOURCE, 30 kW TOTAL POWER
- TARGETS UP TO 30cm BY 60cm, HEATED AREAS FROM 1 to 100 cm^2
- PULSE LENGTH FROM 0.05 SECONDS TO CONTINUOUS
- CLOSED LOOP COOLING SYSTEM
  - 3 LITERS/SECONDS AT 2.0 MPa
- SAMPLE DIAGNOSTICS
  - MASS SPECTROMETER
  - THERMOCOUPLES
  - THERMAL IMAGING
  - OPTICAL VIEWING AND RECORDING
  - WATER CALORIMETRY
  - ACOUSTIC TRANSDUCERS

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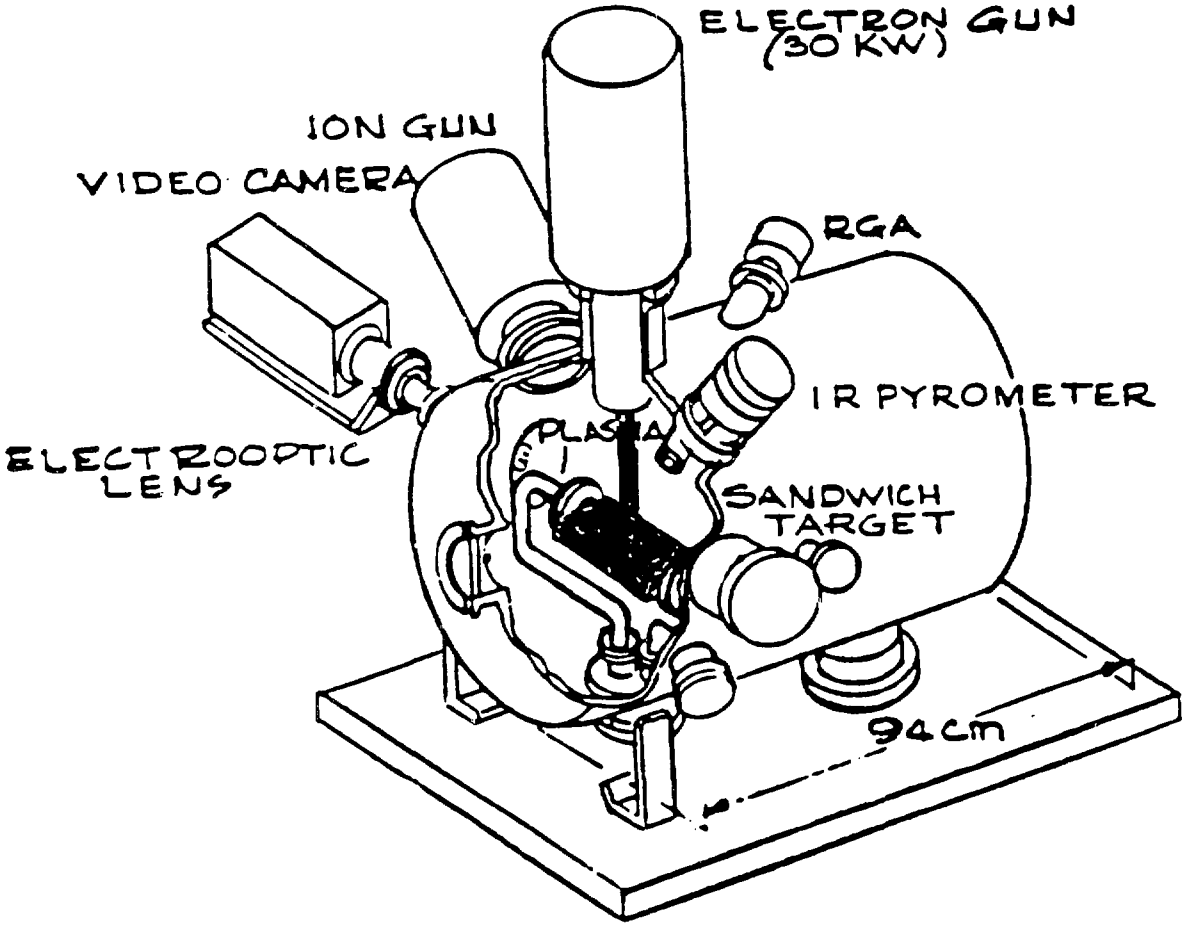
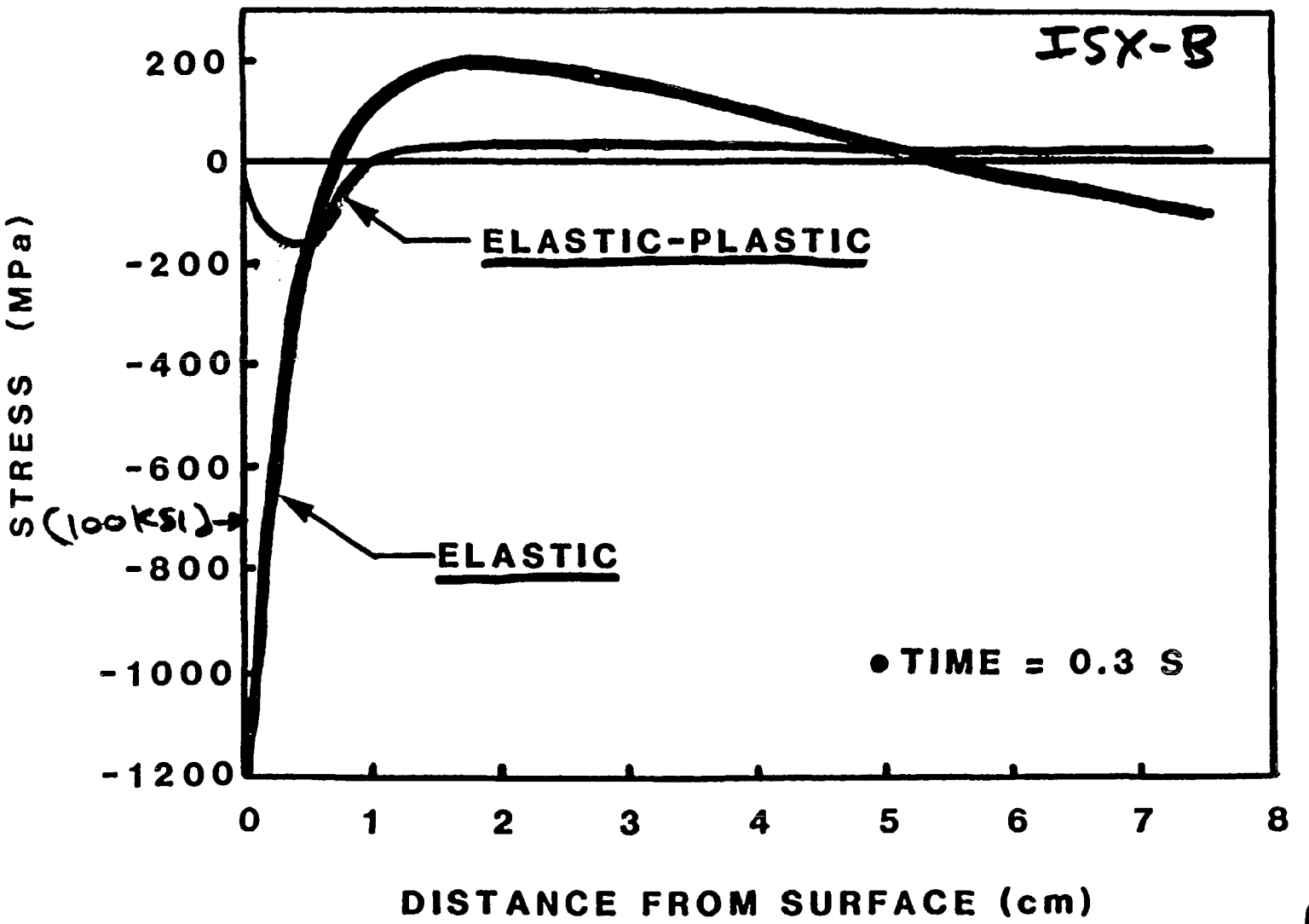

ELECTRON GUN
(30 KW)
ION GUN
VIDEO CAMERA
RGA
IR PYROMETER
PLASMA
ELECTROOPTIC
LENS
SANDWICH
TARGET
94 cm

STRESS PROFILE



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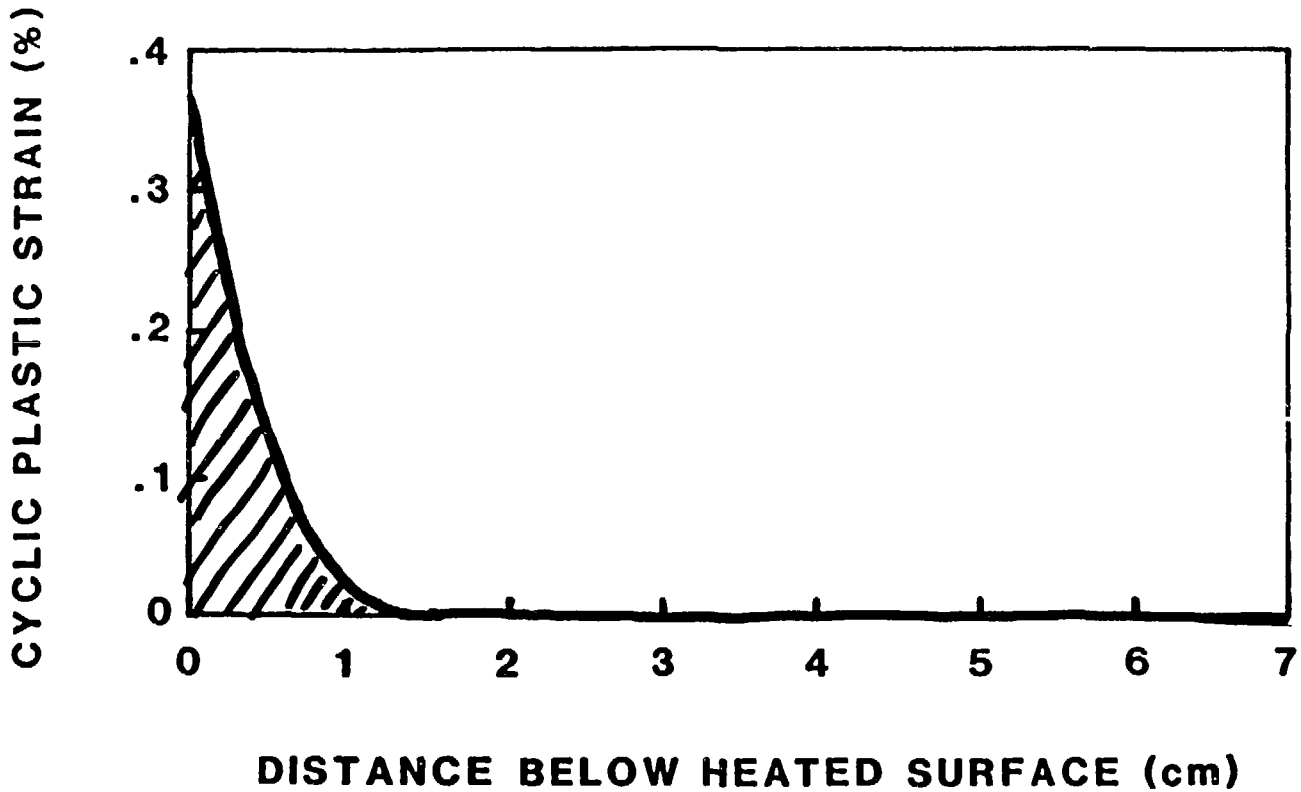
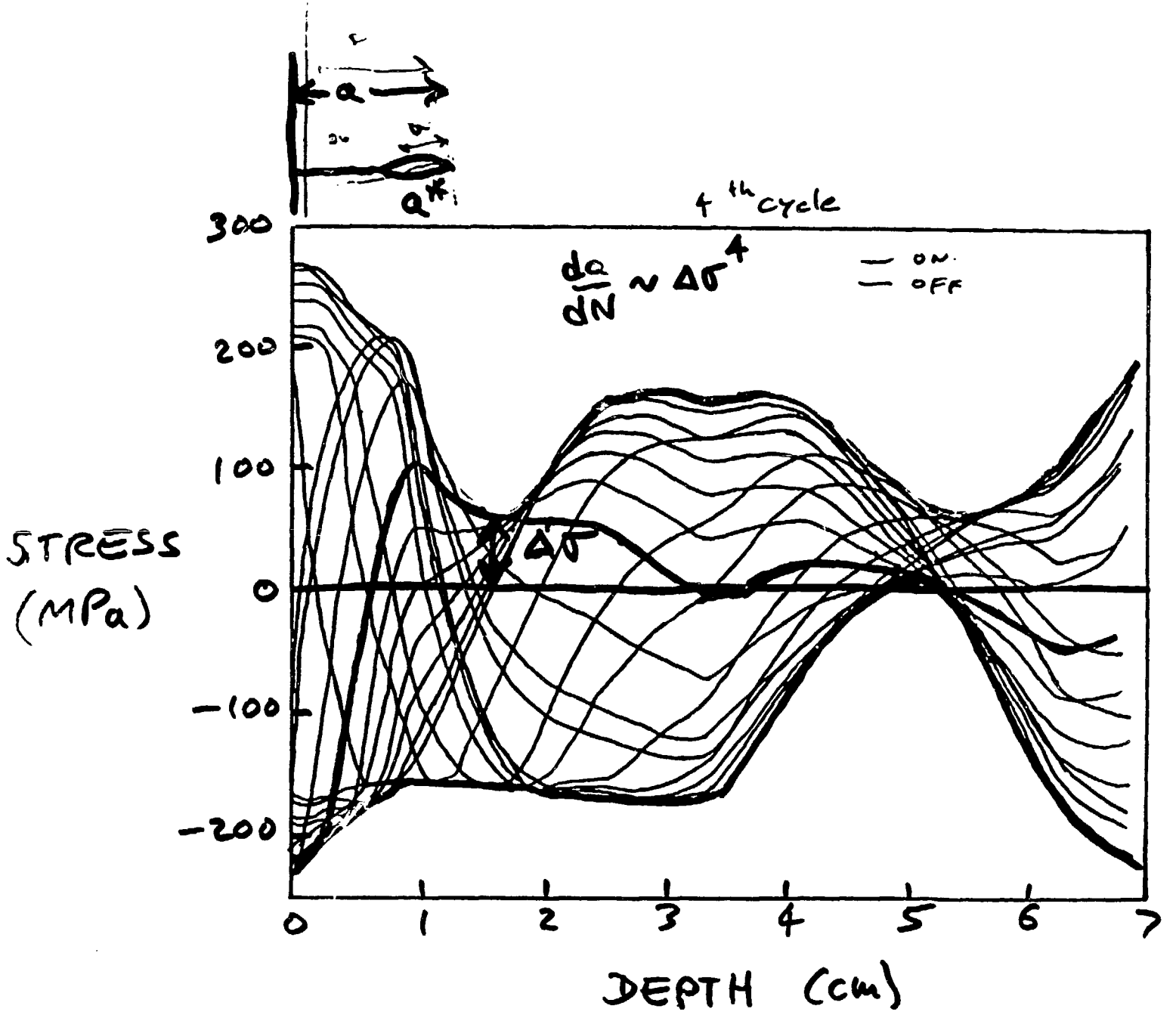
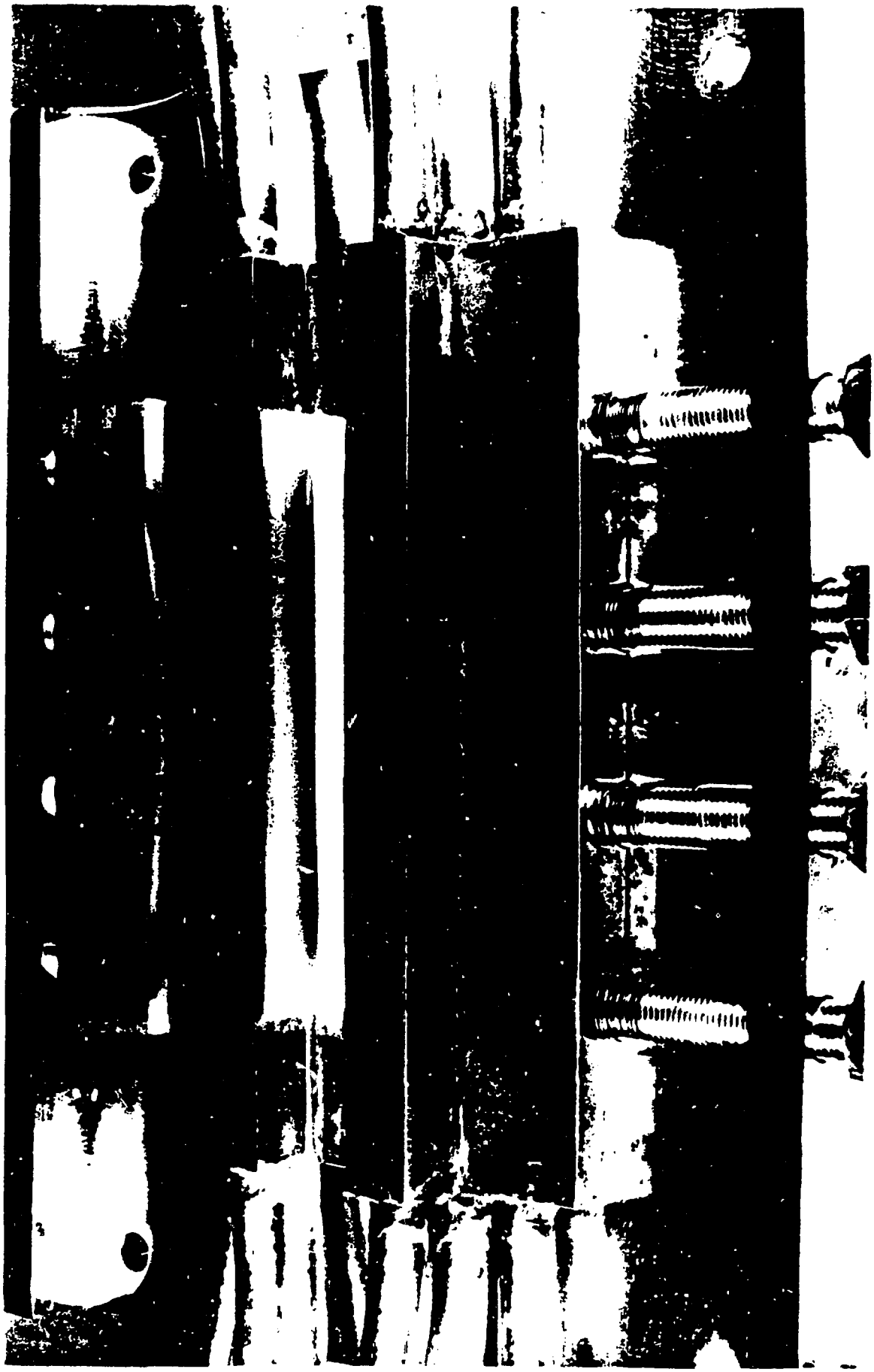
CYCLIC PLASTIC STRAIN PROFILE




Q
Q*
4 th cycle
$\frac{da}{dN} \sim \Delta\sigma^4$
— ON
— OFF
$\Delta\sigma$
300
200
100
0
-100
-200
STRESS (MPa)
0
1
2
3
4
5
6
7
DEPTH (cm)



MULTIPLE BEAM TEST SYSTEM (MBTS)

- DEDICATED MATERIALS AND HIGH HEAT FLUX TEST SYSTEM

FEATURES:

- STEADY-STATE HEAT SOURCES:
  - 40 keV HYDROGEN ION (1.6 MW)
  - ELECTRON BEAM SOURCES (future)
  - HEATED AREAS TO 800 cm^2
- LARGE, VERSATILE TEST CHAMBER
  - 2.7 m^3 TEST VOLUME
  - TEST TARGETS UP TO 1 m x 1 m
- CLOSED LOOP TARGET COOLANT SYSTEM
  - CONTROL OF WATER PURITY
  - FLOW LOOP FULLY INSTRUMENTED
- TARGET DIAGNOSTICS INCLUDE:
  - THERMAL IMAGING
  - MULTIPLE IMBEDDED THERMOCOUPLES
  - ACOUSTIC TRANSDUCERS
  - STRAIN GAUGES
  - DEFLECTION GAUGES

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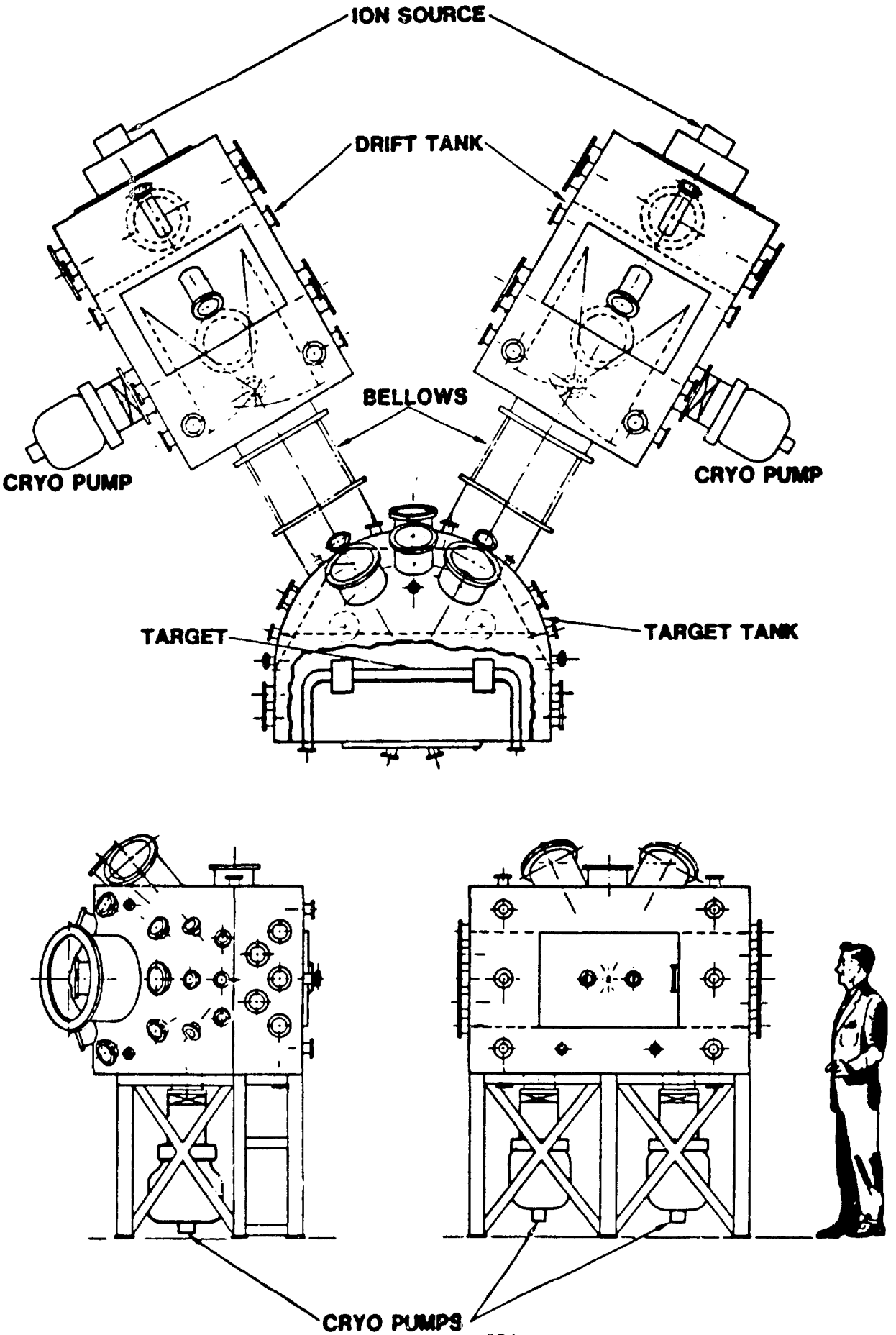

ION SOURCE
DRIFT TANK
BELLOWS
CRYO PUMP
CRYO PUMP
TARGET
TARGET TANK
CRYO PUMPS

RF ION SOURCE SYSTEM FOR PMTF

PROGRAM BRIEF: TRW TO DESIGN, FABRICATE, AND TEST RF ION SOURCE SYSTEM, AND HELP INTEGRATE AND TEST ON PMTF

REQUIREMENTS/GOALS

- 40 kW, 20 A HYDROGEN ION BEAM FOR 2 kW/cm^2 POWER DENSITY ON 200 cm^2 TARGET
- CW OPERATION (MAY BE LIMITED BY GRID SET)

DESCRIPTION

- 33 cm DIAMETER AZIMUTHAL CUSP RF ION SOURCE
- ORNL SUPPLIED 22 cm GRID SET
- APPROXIMATELY 30 kW RF POWER REQUIRED FOR FULL BEAM
- 75 kW RF POWER SYSTEM NOW BEING ORDERED TO ALLOW OPERATION OF FUTURE HIGHER POWER SOURCE OR MULTIPLE SOURCES

STATUS

FINAL TESTING AT TRW SCHEDULED FOR 3-15-85

DELIVERY AT SANDIA - APPROXIMATELY 4-1-85

INSTALLATION COMPLETE - APPROXIMTELY 5-1-85

FACILITY PLANS TO DECEMBER, 1985

EBTS

- o LLNL TUBE TESTS
- o DISRUPTION TESTS
- o GRAPHITE/Be THERMAL SHOCK RESISTANCE
- o TFTR COATING QUALIFICATION
- o ASDEX DIVERTOR TARGETS
- o CRITICAL HEAT FLUX WITH ONE SIDE COOLING

PMTF

o	SOURCE DELIVERY, TESTING STARTED	4-85
o	BEAM LINE DELIVERY	5-85
o	ION BEAM SYSTEM COMPLETE,	
	BEGIN SHAKEDOWN	6-85
o	COOLANT SYSTEM DELIVERY	7-85
o	FIRST TESTS	8-85

PMTF TEST PROGRAM

EXPERIMENTAL SHAKEDOWN — MAY - AUGUST, 1985

- SOURCE CHARACTERIZATION
  - MAXIMUM PULSE LENGTH
  - GRID STABILITY, COOLING
  - BEAM PROFILE
  - BEAM PURITY, COMPOSITION
- CONTROL SYSTEM OPERATION
- CALORIMETER CALIBRATION
- TARGET MOUNTING FIXTURES

MATERIALS EVALUATION — SEPT - NOV, 1985

- THERMAL FATIGUE, BONDING OF THICK (> 1 MM) PLASMA SPRAYED COATINGS TO CU TARGETS (TUBE AND FLAT)
- EROSION CHARACTERIZATION
- SUBSTRATE COMPARISONS
  - CU
  - CU ALLOYS
  - COMPOSITE STRUCTURES
- BONDING OF OVERLAYS

PMTF TEST PROGRAM

UNCOATED TUBE BANK TARGET DEC - JAN, 1986

- -- THERMAL FATIGUE (>50,000 CYCLES)
- -- FLOW STABILITY WITH SUBCOOLED NUCLEATE BOILING
- -- WATER CHEMISTRY EVALUATION

HEAT REMOVAL PHYSICS TARGETS (FLAT PLATE, TUBE TARGETS)

FEB - MARCH, 1986

- -- EFFECT OF FLOW VARIATION (0.3 - 3 m/s)
- -- EFFECT OF PRESSURE VARIATION (300 - 1000 psi)
- -- EFFECT OF INLET WATER TEMPERATURE (50 - 300°C)
- -- EFFECT OF AUGMENTATION
  - -- OPEN CHANNELS
  - -- FINNED CHANNELS
  - -- TWISTED TAPE INSERTS
  - -- TANGENTIAL INJECTION
  - -- HYPERVAPOTRON

TRITIUM PLASMA EXPERIMENT

K. Wilson
Sandia National Laboratories Livermore

THE TRITIUM PLASMA EXPERIMENT (TPX) AT SANDIA IS A UNIQUE FACILITY

- A TRITIUM DISCHARGE DEDICATED TO FUSION MATERIALS RESEARCH

- PURPOSES OF TRITIUM
  - DIAGNOSTICS (AUTORADIOGRAPHY, IMAGING, DISSOLUTION COUNTING)
  - DETECTABILITY
  - ISOTOPE EFFECTS

- OPERATING PARAMETERS
  - ION FLUX: UP TO 5 X 10^{17} CM^{-2} S^{-1}
  - ENERGY RANGE: 10-1000 eV
  - THREE SPECIES IN CONTROLLED RATIOS (E.G., D/T/He)
  - PLASMA DENSITY: 10^{11} CM^{-3}
  - Te: 7 eV
  - GAS PRESSURE: 2-10 m TORR

SANDIA NATIONAL LABORATORIES

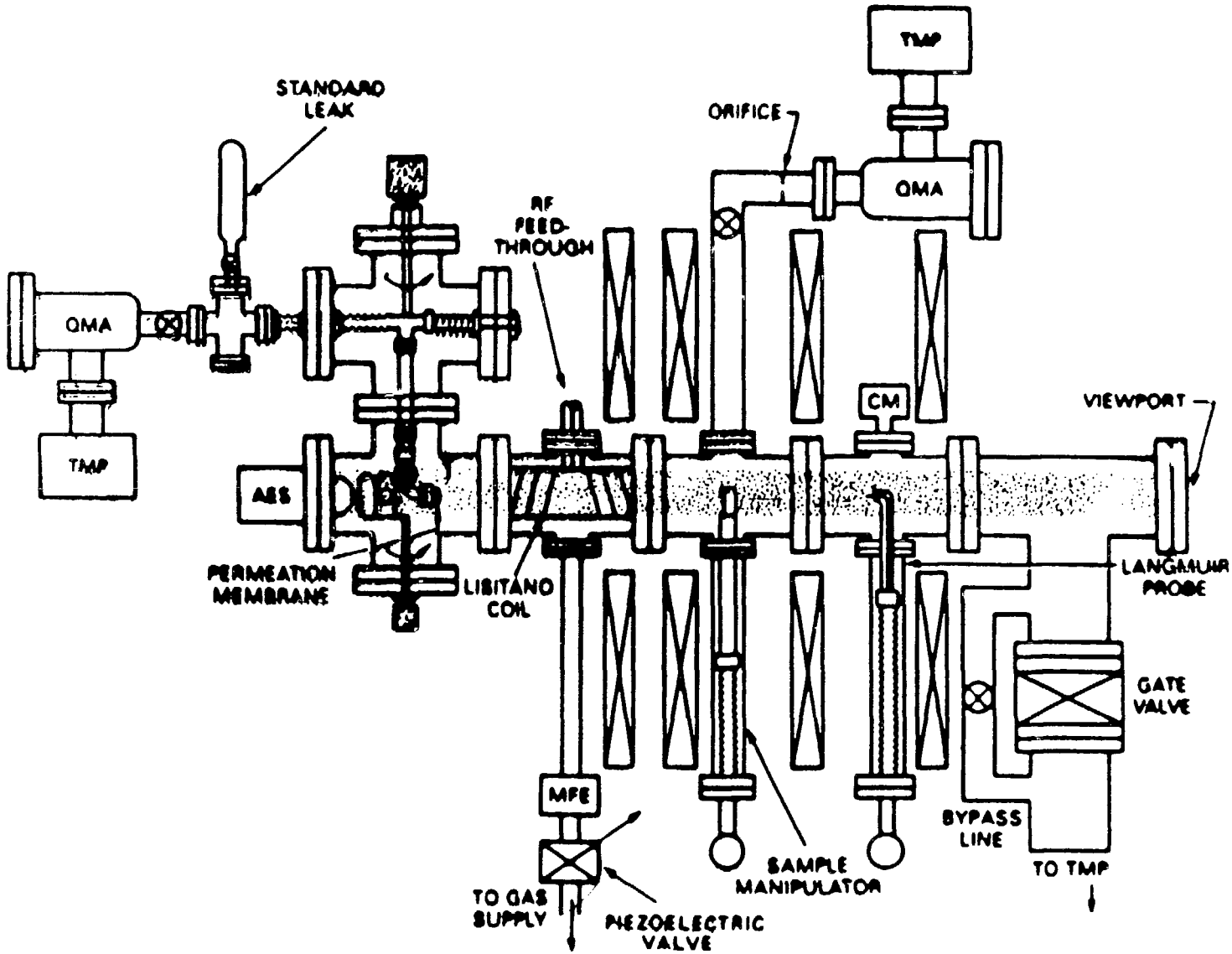
SANDIA PMI FACILITIES

- ACCELERATOR LABORATORY (SNLA)
  - 5 MV TANDEM
  - 3 MV AND 2.5 MV VAN DEGRAFF ACCELERATORS
  - 350 kV ACCELERATOR
  - 200 kV LINTOTT ACCELERATOR
  - TWO LOW ENERGY (0-5 kV) SOURCES

- ACCELERATOR LABORATORY (SNLL)
  - 1 MV TANDEM
  - 450 kV ACCELERATOR
  - FOUR LOW ENERGY (0-10 keV) SOURCES

- TRITIUM RESEARCH LABORATORY (SNLL)
  - TRITIUM PLASMA EXPERIMENT (TPX)
  - T_2 PERMEATION
  - TRITIUM IMAGING
  - TEM, SEM, AES, etc.

TRITIUM PLASMA EXPERIMENT



Schematic diagram of Tritium Plasma Experiment. AES = Auger electron spectrometer, QMA = quadrupole mass analyzer, TMP = turbomolecular pump, MFE = molecular flow element, CM = capacitance manometer.

Sandia National Laboratories

THE TRITIUM PLASMA EXPERIMENT HAS MADE SIGNIFICANT ACCOMPLISHMENTS IN THE STUDY OF ION-SOLID INTERACTIONS

- PLASMA EROSION PROCESSES
  - PHYSICAL SPUTTERING
  - CHEMICAL EROSION
  - BLISTERING

- HYDROGEN - TRANSPORT
  - PLASMA-WALL RECYCLING
  - SURFACE EFFECTS IN PLASMA DRIVEN PERMEATION
  - DIFFUSIVITY IN LOW SOLUBILITY MATERIALS (E.G., TiB_2)

- HYDROGEN - HELIUM SYNERGISMS

- TRITIUM LOADING FOR PLT TRITIUM INJECTION SAMPLES

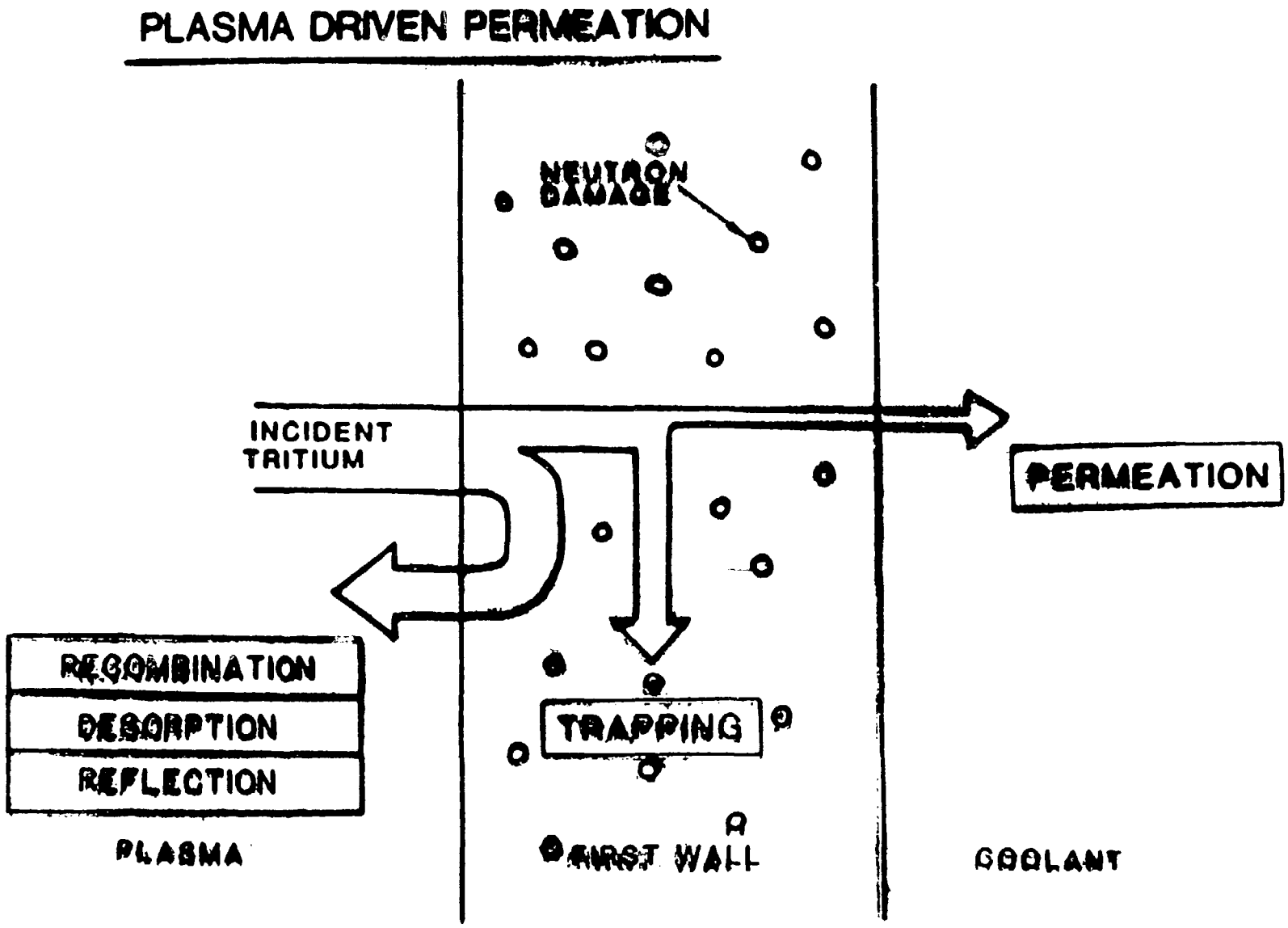
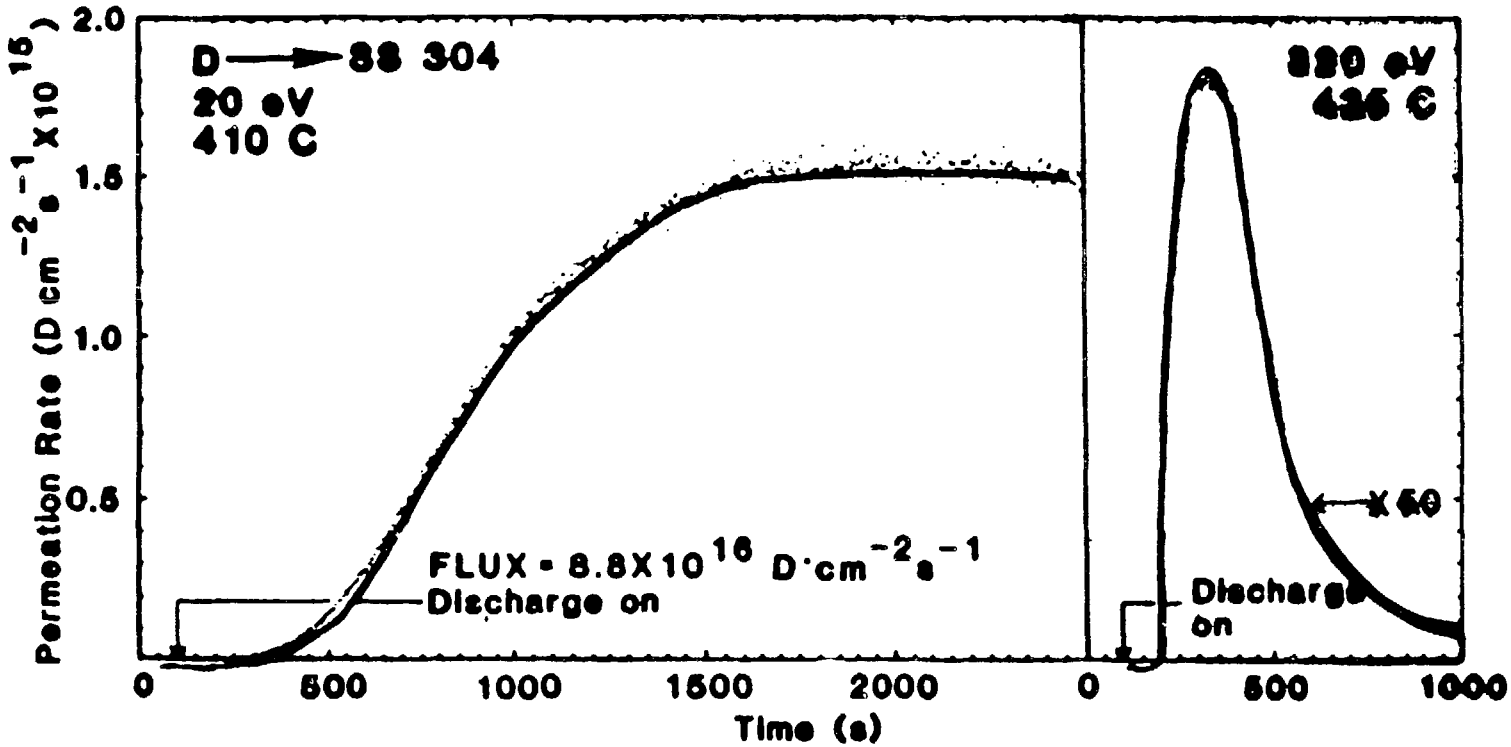


Figure 1-1. An illustration of the various processes involved in plasma driven permeation.

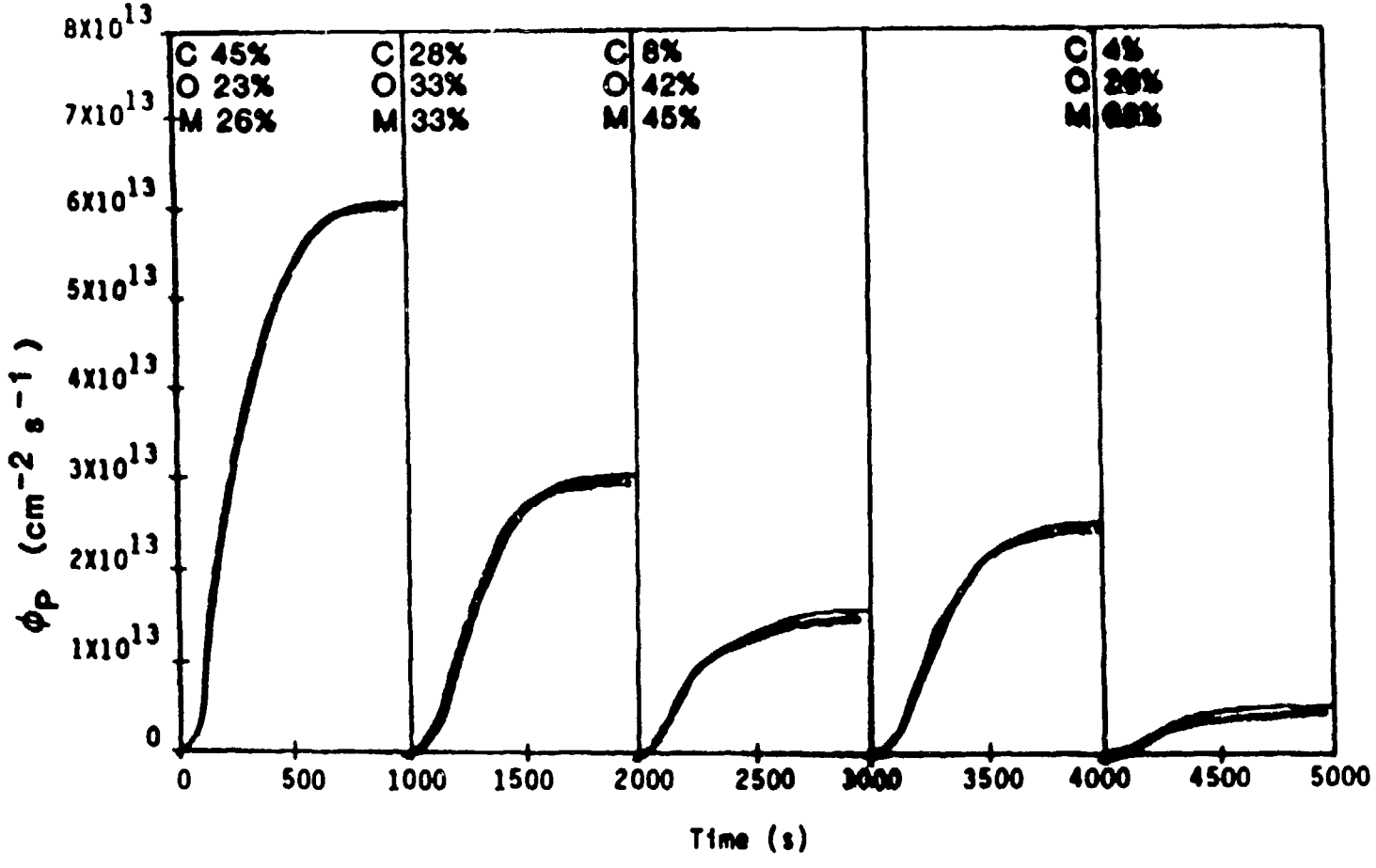
PLASMA DRIVEN PERMEATION
LOW ENERGY vs. HIGH ENERGY



KERST

SURFACE CLEANLINESS CONTROLS PERMEATION

	A	B	C		D
Ion Energy (eV)	20	100	20	100	20
Flux ($D\text{-}cm^{-2}\text{-}s^{-1}$)	6.9×10^{14}	7.6×10^{15}	6.9×10^{14}	9.2×10^{16}	6.9×10^{14}



CAUSEY

TRITIUM STUDIES ARE BEING CONDUCTED IN TPX.

- Clean and impurity-covered graphites and coatings will be studied.
- The effects of surface roughness and porosity will be addressed.
- Laboratory simulations of redeposited materials are being characterized.

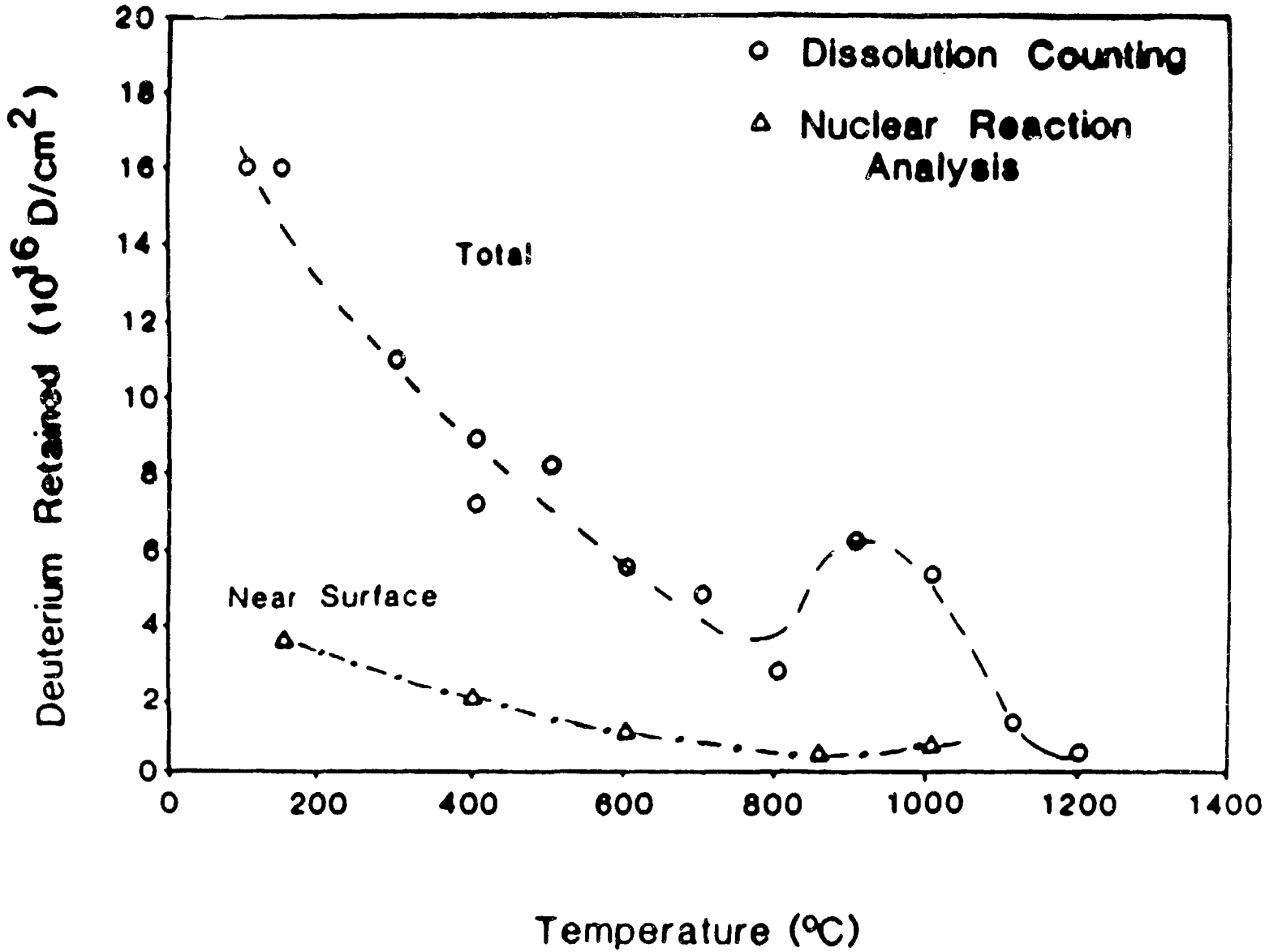
TRITIUM RETENTION IN GRAPHITE STUDIES FOR TFTR APPLICATIONS

- MATERIALS
  - PAPYEX
  - POCO-AFX5Q
  - ATJ
  - GRAPHNOL N3M
  - GREAT LAKES H-451

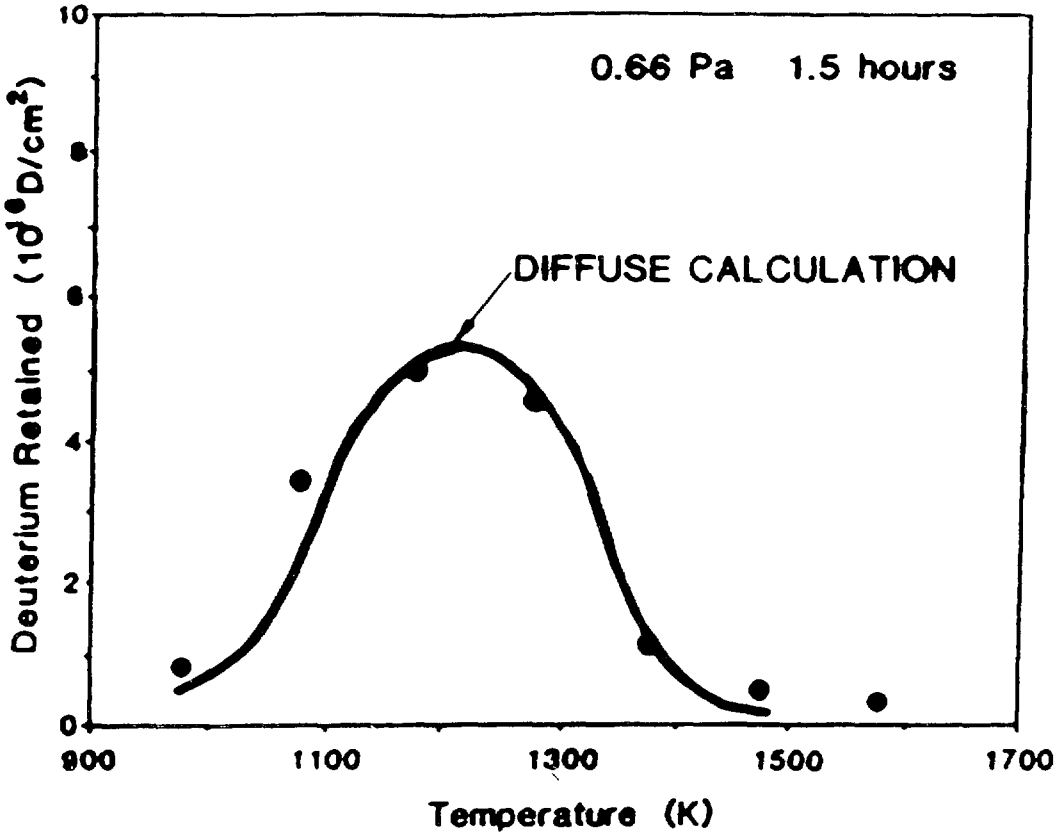
- EXPERIMENTAL CONDITIONS
  - TEMPERATURE - 100°C TO 1500°C
  - ION ENERGY - 15 eV TO 300 eV
  - ION FLUENCE - 5.4E20 D/CM**2
  - BACKGROUND D/T PRESSURE - 5 mtorr
  - EXPOSURE TIME - 1.5 HOURS

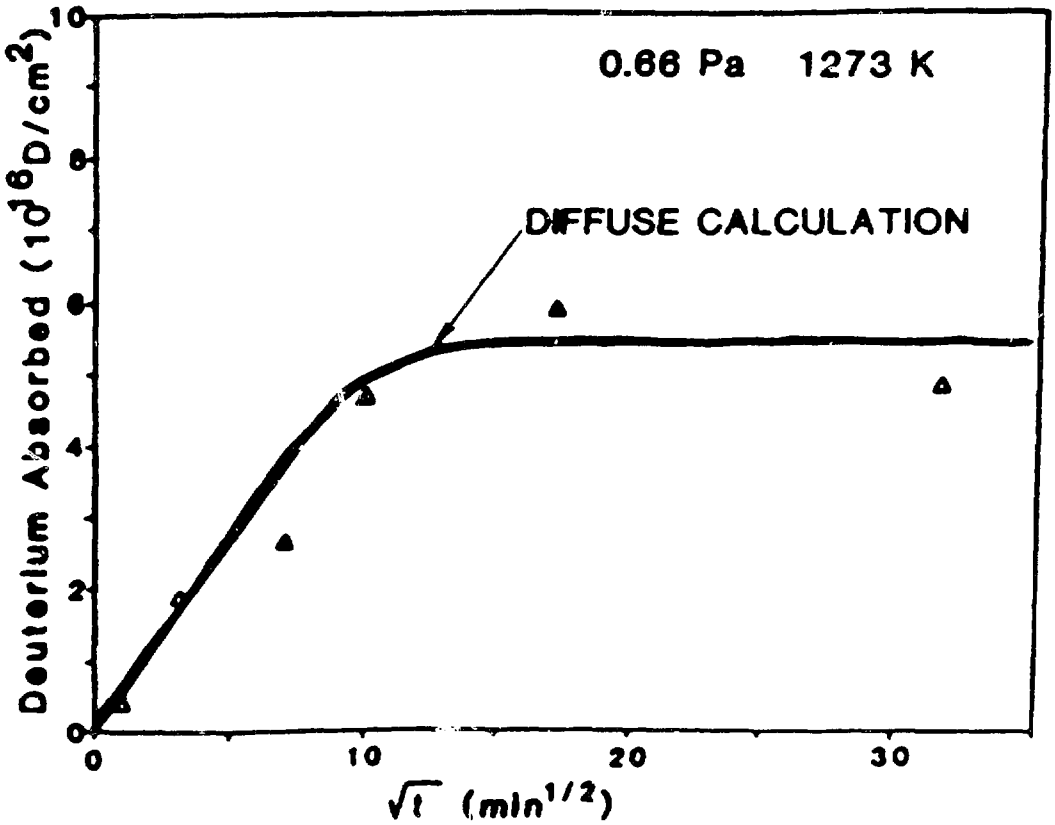
- MEASUREMENT TECHNIQUES
  - DISSOLUTION TRITIUM COUNTING
  - NUCLEAR REACTION PROFILING

DEUTERIUM RETENTION IN PAPYEX



TRITIUM TRACER MEASUREMENTS OF HYDROGEN ISOTOPE UPTAKE IN PAPYEX GRAPHITE





PROPOSED TRITIUM-BERYLLIUM STUDIES FOR JET APPLICATIONS

- MEASURE TRITIUM RETENTION AND PERMEATION IN BERYLLIUM AS A FUNCTION OF:
  - ION ENERGY
  - ION FLUX AND FLUENCE
  - TEMPERATURE

- MEASURE TRITIUM OUTGASSING FROM PLASMA-EXPOSED BERYLLIUM AS A FUNCTION OF:
  - TEMPERATURE
  - PRIOR HISTORY

- ANALYZE DATA TO OBTAIN:
  - TRITIUM DIFFUSIVITY AND SOLUBILITY
  - TRAP ENERGY AND CONCENTRATION
  - RECOMBINATION RATE CONSTANT

- MODEL DATA FOR DETAILED JET SCENARIOS AND COMPARE TO GRAPHITE RESULTS

TRITIUM INTERACTIONS WITH PLASMA-MODIFIED SURFACES

SANDIA IS STUDYING THE INTERACTION OF TRITIUM WITH REDEPOSITED MATERIALS IN TPX:

- REDEPOSITED STAINLESS STEEL SAMPLES FROM PISCES (UCLA).
- CARBONIZED FIRST WALL SURFACES (CFFTP - KFA).
- DYNAMIC STUDIES OF TRITIUM-REDEPOSITION IN THE PROPOSED TPX-UPGRADE.

ICTF

R. Mattas
Argonne National Laboratory

IMPURITY CONTROL TEST FACILITY
(ICTF)

R. F. MATTAS
J. N. BROOKS
ARGONNE NATIONAL LABORATORY

N. HERSHKOWITZ
UNIVERSITY OF WISCONSIN

PRESENTED AT HHF AND PMI TASK GROUP MEETING
DOE HEADQUARTERS
MAY 21, 1985

IMPORTANCE OF IMPURITY CONTROL TECHNOLOGY FOR HHF

- "THE TECHNOLOGY OBJECTIVE IS TO SHOW THAT IT IS POSSIBLE TO CREATE THE UNIQUE FUSION COMPONENTS AND SUBSYSTEMS UNDER CONDITIONS THAT ARE RELEVANT TO FUSION ENERGY SOURCES."
  MFPP- FEB. 1985

  - CLOSE SIMULATION OF EXPECTED FUSION CONDITIONS IS NECESSARY.

- "FUSION MATERIALS RESEARCH SEPARATES NATURALLY INTO TWO CLASSES OF PROBLEMS: THOSE ASSOCIATED WITH INTERACTION OF PLASMA WITH MATERIALS AND THOSE ASSOCIATED WITH THE INTERACTION OF FUSION NEUTRONS WITH THE MATERIALS. BOTH INVOLVE BASIC AND APPLIED RESEARCH. HOWEVER, THE FORMER ARE NEAR TERM PROBLEMS WHICH MUST BE SOLVED TO ADVANCE PLASMA CONFINEMENT RESEARCH."
  MFPP - FEB. 1985

  - PMI AND HHF REPRESENT NEAR TERM DEVELOPMENT ISSUES.

IMPURITY CONTROL ISSUES

- DIVERTOR PUMPING
- LIMITER PUMPING
- IMPURITY TRANSPORT
- HIGH RECYCLING AT NEUTRALIZER PLATES
- LOW ENERGY PARTICLE REFLECTION COEFFICIENTS
- CHEMICAL EFFECTS IN SPUTTERING-GRAPHITE
- EROSION/REDEPOSITION
- SELF PUMPING
- TRITIUM PERMEATION
- PROPERTIES OF REDEPOSITED MATERIALS
- CU-LI ALLOYS
- OPERATING LIMITS FOR HIGH-Z AND LOW-Z MATERIALS
- COMPONENT LIFETIME

- IT IS PROPOSED THAT AN IMPURITY CONTROL TEST FACILITY (ICTF) BE CONSTRUCTED WHICH CAN ADDRESS MOST OF THE CRITICAL IMPURITY CONTROL ISSUES.

OBJECTIVES OF ICTF

- PROVIDE WELL CHARACTERIZED PLASMA ENVIRONMENT THAT SIMULATES THE SCRAPE-OFF ENVIRONMENT.

- PERFORM EXPERIMENTS THAT DIRECTLY VERIFY IMPURITY CONTROL CONCEPTS.

- PERFORM EXPERIMENTS THAT CAN BE USED TO CALIBRATE COMPUTER CODES, WHICH IN TURN WILL BE USED TO DESIGN IMPURITY CONTROL SYSTEMS.

- PRODUCE SPUTTERED AND REDEPOSITED MATERIALS THAT ARE THEN EXAMINED AND TESTED IN OTHER EXPERIMENTS.

MAJOR QUESTIONS FOR ICTF

- ARE ALL IMPORTANT PARAMETERS ADEQUATELY SIMULATED?

- WHAT IS THE CONFIDENCE IN ACHIEVING THE DESIRED OPERATING CONDITIONS?

- CAN THE IMPORTANT PARAMETERS BE MEASURED?

- IS IT POSSIBLE TO VERIFY FUSION DESIGN CODES WITH TEST RESULTS FROM THE FACILITY?

- CAN THE FACILITY BE BUILT IN A RELATIVELY SHORT PERIOD OF TIME?

- CAN THE FACILITY BE BUILT FOR A REASONABLE COST?

PARAMETERS OF INTEREST FOR ICTF

PARAMETER	VERY IMPORTANT	IMPORTANT	SECONDARY
HEAT FLUX		X	
PARTICLE FLUX	X		
PARTICLE ENERGIES	X		
MAGNETIC FIELD	X		
FIELD LINE GEOMETRY	X		
SHEATH POTENTIAL	X		
SPECIMEN SIZE	X		
MATERIAL TEMPERATURES		X	
NEUTRON EFFECTS			X

- THE SIMULATION OF ALL VERY IMPORTANT PARAMETERS IS NECESSARY FOR THE PROPER SIMULATION OF PARTICLE PATHS AND INTERACTIONS.
  - SYNERGYSTIC EFFECTS ARE IMPORTANT.

KEY PARAMETERS

PARAMETER	DESIRED VALUE	IMPACT
MAGNETIC FIELD	4 - 5 T	HIGH FIELDS ARE NEEDED TO REPRODUCE PARTICLE ORBITS, PATHS, IMPACT ANGLES, AND DIFFUSION COEFFICIENTS.
FIELD LINE GEOMETRY	$\lesssim 5°$ TO SPECIMEN	SPUTTERING IS SENSITIVE TO ANGLES OF INCIDENCE, LOW ANGLES ARE NEEDED TO ACHIEVE PROPER PARTICLE TRAJECTORIES FOR SELF-SPUTTERING.
ELECTRON TEMPERATURE	~ 50 eV	HIGH ELECTRON TEMPERATURES ARE NEEDED TO ACHIEVE HIGH ELECTRON IMPACT IONIZATION PROBABILITY, PARTICULARLY FOR MODERATE TO HIGH-Z MATERIALS.
ION TEMPERATURE	50 - 300 eV	SPUTTERING IS STRONGLY DEPENDENT ON ION ENERGY.
SHEATH POTENTIAL	1 - 3 T_E	THE SHEATH POTENTIAL IS LARGELY RESPONSIBLE FOR DETERMINING ENERGIES OF PARTICLES HITTING SURFACE. IT ALSO AFFECTS THE ANGLE OF INCIDENCE.

KEY PARAMETERS (CONTINUED)

PARAMETER	DESIRED VALUE	IMPACT
SPECIMEN SIZE	10 - 100 CM	SPECIMENS NEED TO BE LARGER THAN THE MEAN FREE PATH OF NEUTRALS AND SPUTTERED PARTICLES TO CREATE HIGH RECYCLING.
PLASMA DENSITY	10^{18} - 10^{19} M^{-3}	HIGH PLASMA DENSITY IS NEEDED TO PRODUCE HIGH RECYCLING CONDITIONS.
HEAT FLUX	~ 2 MW/M^2 (@ 5° FIELD/SURFACE ANGLE)	SURFACE HEAT FLUX IS NEEDED TO CREATE DESIRED TEMPERATURE CONDITIONS IN SURFACE MATERIALS.
OPERATING MODE	CW	CONTINUOUS OPERATION IS NEEDED TO ACHIEVE REASONABLE LEVEL OF SPUTTERING AND REDEPOSITION.

CONCLUSIONS
IMPURITY CONTROL TEST FACILITY

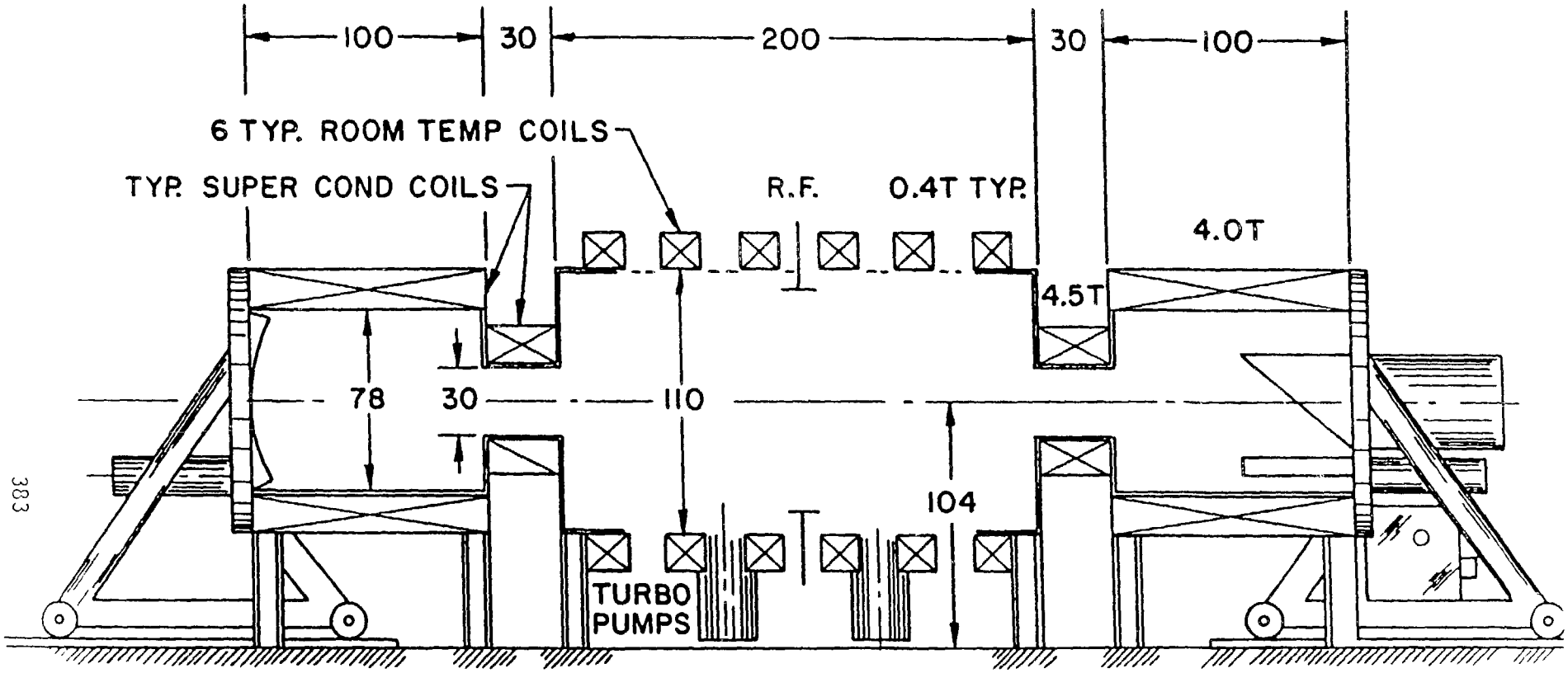
- WORK OVER THE PAST 1½ Y BY ANL AND UW INDICATES THAT THE PLASMA SCRAPE-OFF CAN BE SIMULATED WITH AN RF STABILIZED MIRROR (ANL/FPP/TM-188, 1984).

- PLASMA POWER IS PROVIDED BY ~ 1 MW OF RF @ ~ 2 MHZ.

- TOTAL COST IS ESTIMATED TO BE ~ $4 M.

- DETAILED DESIGN AND CONSTRUCTION IS 2½ - 3 Y.

- ALL IMPURITY CONTROL ISSUES, EXCEPT IMPURITY BUILDUP IN THE MAIN PLASMA, CAN BE ADDRESSED WITH THIS FACILITY.



ALL DIMENSIONS IN CENTIMETERS

1 METER

EXPECTED END CELL OPERATING CONDITIONS FOR ICTF

• Sample size	20 cm x 80 cm
• Angle between magnetic field and test surface	~ 15°
• Heat flux (@ 15° surface angle)	2 MW/m^2
• Plasma ion temperature	10 - 200 eV
• Plasma electron temperature	~ 50 eV
• Plasma density	~ 10^{19} m^{-3}
• Magnetic field	4 T
• Hydrogen ion flux	~ 3 x 10^{22} m^{-2} s^{-1} (@ 50 eV)
• Hydrogen neutral flux (x)	~ 1/2 of ion flux
• Helium flux	~ 5% of H flux
• Operation	CW

WHAT IS THE CONFIDENCE IN ACHIEVING THE DESIRED OPERATING CONDITIONS?

- PHAEDRUS RESULTS
  - PLASMA DENSITY ACHIEVED - 10^{13} CM^{-3}
  - PLASMA TEMPERATURES - IONS - 650 EV
    ELECTRONS - 30-40 EV
  - TEMPERATURES ARE LIMITED BY RF POWER SUPPLY LIMITS
- NO EXPERIMENTAL OR THEORETICAL LIMITS TO CW OPERATION EXPECTED.
- GAS FUELING FOR CW OPERATION NEEDS TO BE LEARNED.
  - NOT PERCEIVED TO BE A PROBLEM
- THERE IS HIGH CONFIDENCE THAT THE PLASMA SCRAPE-OFF CONDITIONS CAN BE SIMULATED.

CAN THE IMPORTANT PARAMETERS BE MEASURED?

- ALL RELEVANT PARAMETERS CAN BE MEASURED

  EROSION RATES
  PLASMA DENSITY
  PLASMA TEMPERATURE
  IMPURITY CONCENTRATION
  NEUTRAL DENSITY
  VACUUM PRESSURE
  SHEATH POTENTIAL
  SURFACE TEMPERATURES

- MEASUREMENTS WILL BE TAKEN OVER A PERIOD OF TIME (S TO MIN), AND DATA ACQUISITION WILL BE COMPUTER CONTROLLED.

- DATA WILL THEN BE COMPARED DIRECTLY WITH CODE PREDICTIONS.

- ICTF CAN ALSO BE USED FOR INSTRUMENTATION DEVELOPMENT FOR LARGE PLASMA DEVICES.

CAN FUSION DESIGN CODES BE VERIFIED?

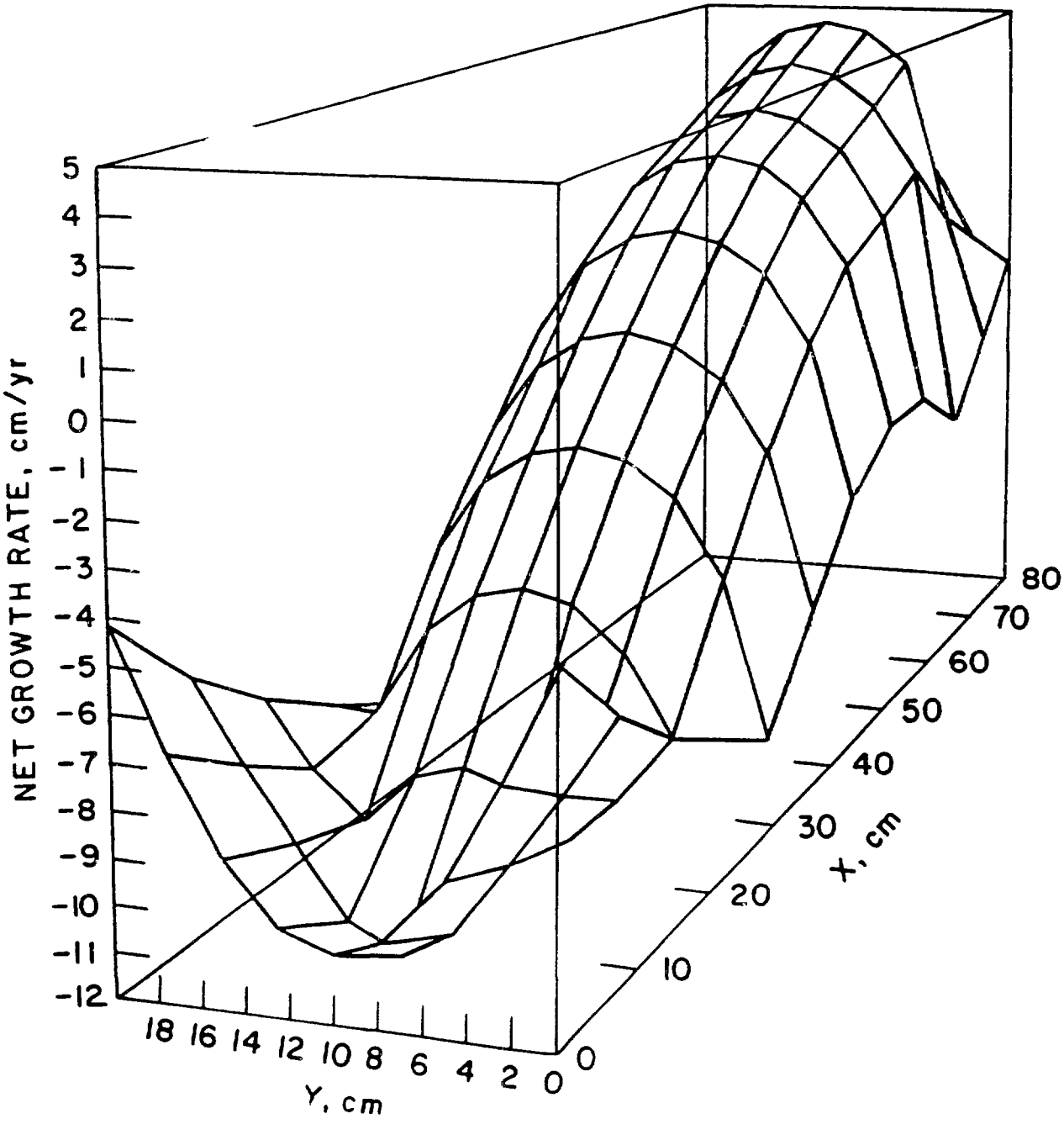
- REDEP CODE 3-D ANALYSIS OF EROSION/REDEPOSITION OF 20 x 80 CM RECTANGULAR PLATE EXPOSED TO ICTF END CELL PLASMA.

- C, BE, V, W COATINGS EXAMINED WITH AND WITHOUT ADDED MATERIAL TO PLASMA STREAM.

- REDEP COMPUTES SPUTTERING, TRANSPORT, IONIZATION, AND REDEPOSITION OF IMPURITIES. PLASMA PROFILES ESTIMATED FROM PHAEDRUS EXTRAPOLATION.

- DEGAS 2-D MONTE CARLO CODE USED TO PROVIDE CHARGE EXCHANGE FLUX AND SPUTTERING DATA AS INPUT TO REDEP.

CARBON EROSION IN ICTF



PLANNING

- JOINT ANL - UW PROJECT

- ICTF SITE - BOTH UW AND ANL SITES ARE BEING CONSIDERED

- RESPONSIBILITIES

  CONSTRUCTION - UW
  ANL

  PHYSICS MISSION - UW

  OPERATION - UW

  PLASMA SIDE COMPONENT TESTING - ANL

- ICTF WILL BE A USER FACILITY

  1. NATIONAL LABORATORY STAFF

  2. UNIVERSITY FACULTY

  3. GRADUATE STUDENT TRAINING

PHYSICS MISSION FOR ICTF

- PHYSICS TESTING TO BE MANAGED BY THE UNIVERSITY OF WISCONSIN.

- ICTF CAN BE UTILIZED AS THE NEXT DEVICE BEYOND PHAEDRUS.

- PRIMARY MISSION

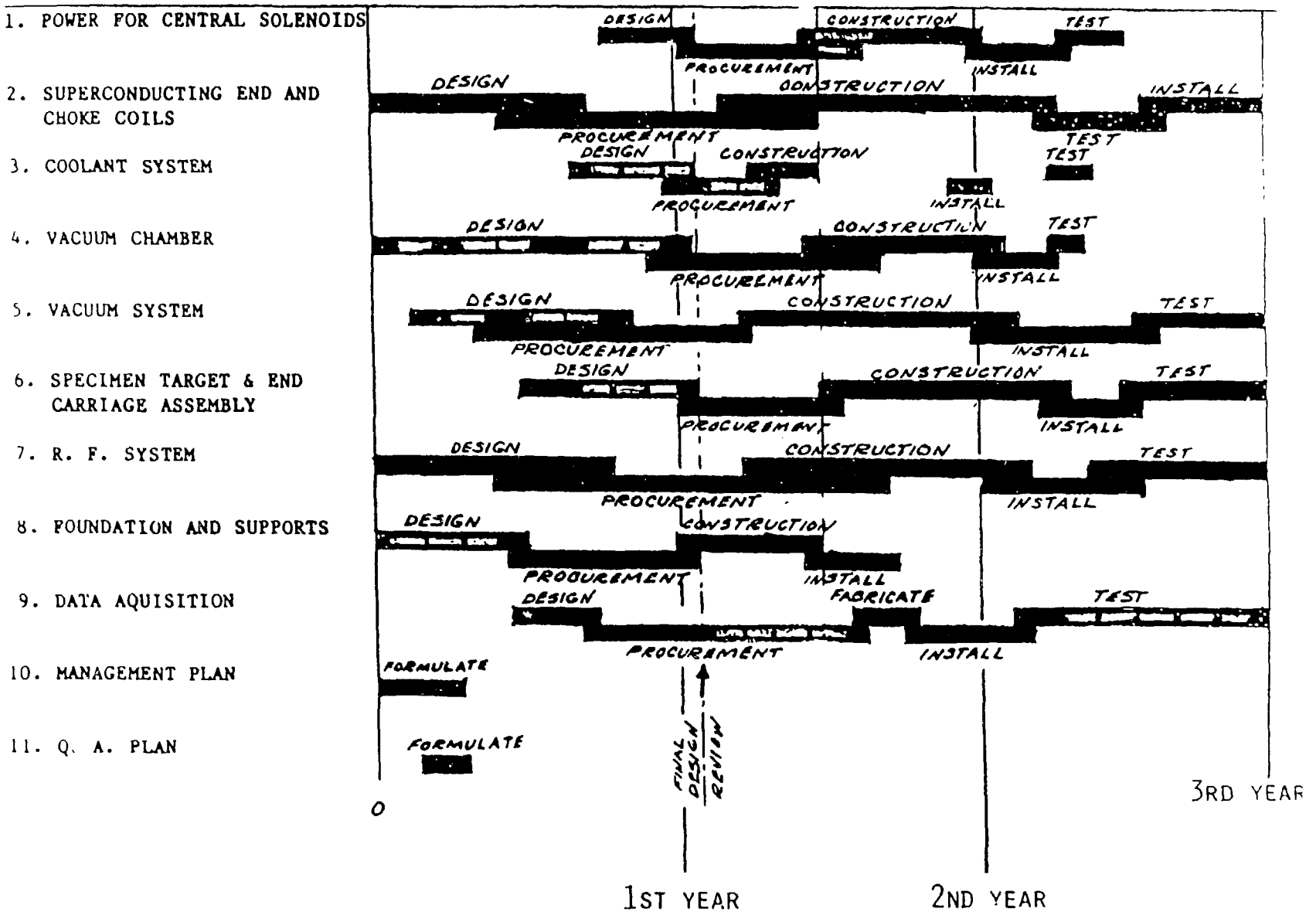
  OPTIMIZE CONFINEMENT AND HEATING AT HIGH VALUES OF nA^2, CORRESPONDING TO REACTOR CONDITIONS. STUDY ALTERNATIVE WAVE PROPAGATION MODES.

- UW WILL HAVE MAJOR RESPONSIBILITY FOR MACHINE OPERATION DURING IMPURITY CONTROL TESTING.

COSTS

RF SYSTEM	~ $1 M
MAGNET SYSTEM	~ $1 M
OTHER VACUUM VESSEL VACUUM PUMPS COOLING STRUCTURAL SUPPORT	~ $1 M
DIAGNOSTICS/DATA ACQUISITION	~ $1 M
	$4 M
ANNUAL OPERATING COSTS	~ $1 M

POSSIBLE SCHEDULE FOR ICTF



SUMMARY

- THERE IS A NEAR TERM NEED FOR A TESTING SYSTEM TO STUDY IMPURITY CONTROL ISSUES.

- A SYSTEM, BASED UPON RF STABILIZED MIRROR OPERATION, CAN BE CONSTRUCTED THAT WILL BE CAPABLE OF ADDRESSING MOST OF THE CRITICAL IMPURITY CONTROL ISSUES.

- PLASMA SCRAPE-OFF CONDITIONS CAN BE CLOSELY SIMULATED WHICH MEANS THAT THERE WILL BE A HIGH DEGREE OF CONFIDENCE IN PREDICTING COMPONENT PERFORMANCE FOR NEXT GENERATION DEVICES AND REACTORS.

- THE DEVICE IS COST EFFECTIVE. BOTH IMPURITY CONTROL AND PHYSICS MISSIONS CAN BE PERFORMED ON A DEVICE COSTING ~ $4 M.

- EXPERIMENTS COULD BEGIN IN ~ 3 Y.

APPENDICES

Division of Development and Technology
Plasma/Wall Interaction
and
High Heat Flux Materials and Components
Task Groups

May 21-22, 1985
Room E-301
U. S. Department of Energy, Headquarters
Germantown, MD

May 21, 1985

9:00 - 9:10 a.m.	Welcome	G. Haas, DOE
9:10 - 9:30 a.m.	Introduction	M. Cohen, DOE
9:30 - 10:00 a.m.	Plasma/Materials Interaction (PMI) Program and Technical Assessment	W. Bauer, SNLL
10:00 - 10:30 a.m.	High Heat Flux (HHF) Materials and Components Program and Technical Assessment	W. Gauster, SNLA
10:30 - 10:45 a.m.	BREAK	
10:45 - 11:30 a.m.	International Activities	
	(Strategy)	W. Gauster, SNLA
	U.S./Japan HHF Workshop	J. Whitely, SNLA
	U.S./Canada Tritium Workshop	K. Wilson, SNLL
	Pump Limiter Workshop	D. Goebel, UCLA
	U.S./Japan Workshop on PMI/ HHF Needs for an Ignition Device	K. Wilson, SNLL
	New Initiatives	W. Gauster, SNLA
11:30 - 11:50 a.m.	OFE Technical Program Planning Activity	C. Baker, ANL
11:50 - 12:15 p.m.	Technology Program Planning Activity	M. Abdou, UCLA
12:15 - 1:30 p.m.	LUNCH	
1:30 - 1:50 p.m.	Ignition Machine Needs	J. Haines, DC
1:50 - 2:10 p.m.	RFP Requirements	J. Downing, LANL
2:10 - 2:30 p.m.	Compact, High Power Density Requirements	R. Krakowski, LANL
2:30 - 2:45 p.m.	BREAK	
2:45 - 5:00 p.m.	Off-Line Simulation Facilities	
	PISCES	D. Goebel, UCLA
	Steady State Tokamak	D. Goebel, UCLA

	Steady State Tokamak	D. Goebel, UCLA
	RFTF	D. Swain, ORNL
	PMTF	W. Gauster, SNLA
	Tritium Plasma Experiment	K. Wilson, SNLL
	ICTF	R. Mattas, ANL

May 22, 1985

1:00 - 3:00 p.m.	Reports of Working Groups	
	Off-Line Facilities	M. Abdou, Chm.
	U.S. Data Base Requirements for an Ignition Machine	K. Wilson, Chm.
	High Power Density Requirements	J. Downing, Chm.
	International Collaboration	W. Gauster, Chm.
3:00 - 4:00 p.m.	Discussion	
4:00 - 4:15 p.m.	Closing	

Department of Energy
Washington, D.C. 20545

MAY 1 1985

To Members of the Plasma Materials Interactions
and High Heat Flux Task Groups

Gentlemen:

You are cordially invited to participate in the Joint Plasma Materials Interactions (PMI) and High Heat Flux (HHF) Task Group Meetings, May 21-22, 1985, at the Department of Energy (DOE), Germantown, Maryland, in Room E-301. The main purposes of this meeting are:

1. To examine U.S. data base requirements for the design and operation of an ignition experiment.
2. To begin revision of the PMI and HHF draft Program Plans in support of the Office of Fusion Energy (OFE) program planning effort.
3. To define the near- and long-term requirements for and utilization of off-line test facilities.
4. To develop a plan of priorities and scope for international collaborations based on our "International PMI and HHF Strategy" document.

The timing of this meeting has been chosen so that it serves as preparation for several international workshops that are scheduled for the summer. It will also help us in the process of developing the PMI and HHF portions of international agreements that are now being worked out. Finally, the Task Groups will be able to provide valuable input to the Technical Plans now being developed by DOE to support the Magnetic Fusion Program Plan (MFPP). This Plan identifies the key technical issues for magnetic fusion to be (1) development of optimum confinement systems, (2) exploration of a burning plasma, (3) development of fusion materials, and (4) fusion nuclear technology. Clearly, the areas represented by our Task Groups play a vital role in each of these topics.

We expect the outcome of the meeting to be documented in written form. In order to achieve this goal, we propose to have some summary presentations on the first day and then to break up into working groups for the remainder of the meeting.

I look forward to your participation. Any questions concerning the meeting may be addressed to Marvin Cohen (301-353-4253; FTS 233-4253).

Sincerely,

Gene R. Nardella

for Gregory M. Haas, Chief
Reactor Technologies Branch
Division of Development and Technology
Office of Fusion Energy
Office of Energy Research

Enclosure
List of Task Group
Members

cc: (w/encl.)
R. Dowling, ER/DOE
M. Roberts, ER/DOE
E. Oktay, ER/DOE
S. Eckstrand, ER/DOE
D. Priester, ER/DOE
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R. Blanken, ER/DOE
W. Dove, ER/DOE
A. Davies, ER/DOE
J. Cecchi, PPPL
B. Montgomery, MIT

Task Group Members

HHF Task Group

M. J. Davis, Chairman, SNLA
R. D. Watson, Secretary, SNLA
M. A. Ulrickson, PPPL
S. Milora, ORNL
D. L. Sevier, GA
J. N. Downing, LANL
M. A. Abdou, UCLA
J. D. Gordon, TRW
B. Lipschultz, MIT
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PMI Task Group

W. Bauer, Chairman, SNLL
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K. Burrell, GA
B. Lipschultz, MIT
J. N. Brooks, ANL
J. N. Downing, LANL

Working Group Membership List

(This is a tentative list; if your interests lie in another one of the task groups, please feel free to change groups.)

Off-Line Facilities	Data Base Requirements for an Ignition Machine	High Power Density Requirements	International Collaboration
UCLA	SNLL	LANL	SNLA
M. Abdou, Chmn.	K. Wilson, Chmn.	J. Downing, Chmn.	W. Gauster, Chmn.
R. Watson, SNLA	M. Ulrickson, PPPL	S. Milora, ORNL	R. Moir, LLNL
J. Gordon, TRW	B. Lipschultz, MIT	W. Wolfer, SNLL	E. Opperman, HEDL
R. Mattas, ANL	S. Fixler, Grumman	K. Burrell, GA	S. Allen, LLNL
D. Goebels, UCLA	W. Bauer, SNLL	J. Haynes, DC	D. Sevieer, GA
H. Conrads, PPPL	S. Cohen, PPPL	J. Whitely, SNLA	J. Brooks, ANL
D. Swain, ORNL	P. Mioduszewski, ORNL	M. Menon, ORNL	F. Clinard, LANL

Working Group on International Collaboration

1. How does the focus of foreign programs in PMI/HHF differ from our own? Are there foreign programs or facilities from which we could benefit in a collaboration?

2. List potential international collaborations with possible benefits for the U.S. HHF and PMI programs and outline potential areas which may be of benefit to each U.S. confinement concept or proposed facilities. Include JT60, JET, and any foreign simulation facilities.

3. How should we update the PMI/HHF "International Strategy" Document to include possible emphasis on high power devices, an ignition machine, and to support the new MFE Program Plan.

4. What can the D&T HHF and PMI program bring to the bargaining table in any potential international collaboration?

5. Outline a strategy for necessary collaboration to develop a PMI/HHF data base for an ignition machine.

Working Group on U.S. Data Base Requirements for an Ignition Machine

1. How do PMI/HHF data base requirements differ for the various ignition machine concepts now being discussed?

2. Can a likely set of requirements be defined in the following areas:

   Wall materials and conditioning
   Erosion/redeposition
   Recycling/T inventory
   Bulk and structural properties
   Heat removal
   Off-normal operation
   Activation

3. Assess the adequacy of present data on:

   Graphite
   Beryllium
   Novel approaches

4. Can you identify gaps in the data base that could be addressed as part of an international program?

Working Group on Off-Line Facilities

1. Group existing off-line facilities by purpose: research, simulation, prototype development and testing, full-scale testing.

2. Considering all confinement schemes, which technical issues are addressed by the facilities in (1)? Where do gaps exist?

3. Are facilities which are not now used by the fusion program available to fill gaps?

4. If gaps exist, define requirements for new off-line facilities with time schedules. Make statements as to the importance of these needs that may aid prioritization in comparisons with other elements of the fusion program. Might any of the facilities presented fill these needs?

5. What are potential opportunities in terms of international collaboration?

Working Group on High Power Density Requirements

1. Highlight differences in technical issues and time schedules between requirements for high power density devices and the mainline approaches followed so far.

2. List specific high priority issues that are not being adequately addressed for the development of high power density devices.

3. Assess the adequacy of the PMI/HHF Technical Assessment vis a vis High Power Density Devices.