FINESSE

A STUDY OF THE ISSUES, EXPERIMENTS AND FACILITIES FOR FUSION NUCLEAR TECHNOLOGY R&D

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FINESSE

A STUDY OF THE ISSUES, EXPERIMENTS AND FACILITIES FOR FUSION NUCLEAR TECHNOLOGY R&D

- OBJECTIVE: INVESTIGATE THE TECHNICAL AND PROGRAMMATIC ISSUES IN THE DEVELOPMENT OF FUSION NUCLEAR TECHNOLOGY.

- TWO-YEAR STUDY STARTED IN NOVEMBER, 1983.

FINESSE WORKSHOP
NOVEMBER 7-8, 1984

PURPOSES OF WORKSHOP

1. TO INFORM THE FUSION COMMUNITY OF THE RESULTS FROM FINESSE OBTAINED DURING THE FIRST YEAR OF THE STUDY.

2. TO PROVIDE THE STUDY WITH INPUT FROM THE FUSION COMMUNITY ON AREAS OF EMPHASIS DURING THE SECOND YEAR.

3. TO PROVIDE A FORUM FOR THE FUSION COMMUNITY TO DISCUSS KEY ASPECTS OF THE FUSION NUCLEAR TECHNOLOGY DEVELOPMENT STRATEGY.

4. TO ATTEMPT TO DEVELOP A U.S. CONSENSUS ON THE FUSION NUCLEAR ISSUES AND FACILITIES AND THE ROLE OF INTERNATIONAL COOPERATION; THIS IS IMPORTANT IN VIEW OF THE INTERNATIONAL WORKSHOP TO BE HELD ON THIS SUBJECT ON MARCH 11-13, 1985.

AGENDA FOR FINESSE WORKSHOP

WEDNESDAY, NOVEMBER 7

SECOND FLOOR LOUNGE, ACKERMAN UNION

MORNING SESSION (SESSION CHAIRMAN: K. THOMASSEN)

9:00 - 9:10	WELCOME	KASTENBERG
9:10 - 9:20	OFE REMARKS	DOWLING
9:20 - 10:45	OVERVIEW	ABDOU
10:45 - 11:00	DISCUSSION	
11:00 - 11:15	COFFEE BREAK	
11:15 - 11:55	SOLID BREEDER ANALYSIS AND TEST REQUIREMENTS	GIERSZEWSKI
11:55 - 12:05	DISCUSSION	
12:05 - 1:15	LUNCH	

AFTERNOON SESSION (SESSION CHAIRMAN: K. SCHULTZ)

1:15 - 2:10	LIQUID METAL ANALYSIS AND TEST REQUIREMENTS	TILLACK
2:10 - 2:35	TOKAMAKS	JASSBY
2:35 - 3:20	MIRRORS	BERWALD
3:20 - 3:40	COFFEE BREAK	
3:40 - 4:00	NON-NEUTRON TEST STANDS	BAKER
4:00 - 4:40	FISSION REACTORS	DEIS
4:40 - 5:00	POINT NEUTRON SOURCES	HOLMES
5:00 - 5:30	DISCUSSION	

EVENING

6:30	COCKTAILS
7:30	DINNER

WESTWOOD HUNGRY TIGER RESTAURANT, 936 WESTWOOD BOULEVARD

SPEAKER: DR. STEPHEN O. DEAN, PRESIDENT, FUSION POWER ASSOCIATES

Thursday, November 8 - Morning

Sessions A: Second Floor Lounge, Ackerman Union

Session B: Room 2408, Ackerman Union

Session A: Non-Fusion Facilities and Test Requirements (Second Floor Lounge) (Session Chairman: E. Bloom, Co-Chairman: D. Smith)

8:30 - 9:00	Liquid Metal MHD	Madarame
9:00 - 9:30	Solid Breeder Tritium Recovery	Billone/ Hollenberg
9:30 - 10:00	Fluence Goals, Interactive Effects	Straalsund/ Puigh
10:00 - 10:15	Discussion	
10:15 - 10:30	Coffee Break	
10:30 - 12:30	Workshop Discussions of Specific and General Questions (Non-Fusion Facilities and Test Requirements)	
12:30 - 2:00	Lunch	

Session B: Fusion Facilites and Development Scenarios (2408 Ackerman Union) (Session Chairman: R. Conn, Co-Chairman: R. Krakowski)

8:30 - 9:25	Fusion Development Scenarios & Device Availability	Berwald
9:25 - 9:45	Alternate Concepts (Preliminary)	Krakowski
9:45 - 10:10	Discussion	
10:10 - 10:30	Coffee Break	
10:30 - 12:30	Workshop Discussions on Specific and General Questions (Fusion Facilities and Development Scenarios)	
12:30 - 2:00	Lunch	

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Thursday, November 8 - Afternoon

Second Floor Lounge, Ackerman Union

Reports by Advisory Committee and Session Chairmen
(Session Chairman: C. Baker)

2:00 - 3:00	Report(s) on Non-Fusion Facilities	Bloom, AC
3:00 - 3:15	Discussion	
3:15 - 4:15	Report(s) on Fusion Facilities	Conn, AC
4:15 - 4:30	Discussion	
4:30 - 5:00	General Remarks, Comments	

FINESSE ORGANIZATION

- MAJOR PARTICIPATION BY KEY U.S. ORGANIZATIONS:
  - UCLA, ANL, EG&G, HEDL, MDAC, TRW
  - LLNL, PPPL
  - COORDINATION WITH OTHER DOE AND EPRI PROGRAMS
- SIGNIFICANT INTERNATIONAL PARTICIPATION:
  - GERMANY (KFK), JAPAN (JAERI, UNIVERSITIES), CANADA
  - IMPORTANCE:
    * ALL WORLD PROGRAMS FACE THE SAME ISSUES
    * INTERNATIONAL COOPERATION ON NUCLEAR TECHNOLOGY: VIABLE, ECONOMICAL
- BROAD PARTICIPATION BY FUSION COMMUNITY: ADVISORY COMMITTEE, WORKSHOPS

FINESSE ADVISORY COMMITTEE

CHARLES C. BAKER, CHAIRMAN (ANL)

EVERETT C. BLOOM (ORNL)

JOHN W. DAVIS (MDAC)

ROBERT A. KRAKOWSKI (LANL)

JAMES A. MANISCALCO (TRW)

JOHN A. SCHMIDT (PPPL)

KENNETH R. SCHULTZ (GA)

THOMAS E. SHANNON (FEDC)

JERRY L. STRAALSUND (HEDL)

KEITH I. THOMASSEN (LLNL)

NUCLEAR COMPONENTS AND COMPONENTS AFFECTED BY THE NUCLEAR ENVIRONMENT

- Blanket
- Shield
- Plasma Interactive and High Heat Flux Subsystems:
  - First Wall
  - Impurity Control
  - RF Antennas, Launchers and Waveguides
- Tritium and Vacuum Systems
- Instrumentation and Control
- Magnets
- Remote Maintenance
- Heat Transport and Power Conversion

FINESSE

FINESSE PRINCIPAL TECHNICAL TASKS

I. IDENTIFICATION OF ISSUES

II. QUANTIFYING TEST REQUIREMENTS
   - A. SURVEY OF TESTING NEEDS
   - B. QUANTIFYING TEST REQUIREMENTS

III. EVALUATION OF EXPERIENCE FROM OTHER TECHNOLOGIES
   - A. FISSION
   - B. AEROSPACE

IV. SURVEY AND EVALUATION OF TEST FACILITIES
   - A. NON-FUSION DEVICES
   - B. FUSION DEVICES

V. COMPARATIVE EVALUATION OF TEST FACILITIES, SCENARIOS

VI. RECOMMENDATIONS ON FUSION NUCLEAR TECHNOLOGY DEVELOPMENT STRATEGY

TASK I: IDENTIFICATION OF ISSUES

SCOPE

IDENTIFY AND CHARACTERIZE THOSE FUSION NUCLEAR TECHNOLOGY ISSUES FOR WHICH NEW KNOWLEDGE IS REQUIRED THROUGH EXPERIMENTS.

RESULTS

- IDENTIFIED AND CHARACTERIZED 120 ISSUES.
- DOCUMENTED IN DETAIL IN CHAPTER 3.
- ISSUES HAVE BEEN CHARACTERIZED AS TO:
  - POTENTIAL IMPACT
  - DESIGN SPECIFICITY
  - LEVEL OF CONCERN
  - IMPORTANCE OF NEUTRONS
  - IMPORTANCE OF OTHER OPERATING ENVIRONMENTS.
- THERE ARE MANY CRITICAL FEASIBILITY AND ATTRACTIVENESS ISSUES.

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.

CRITICAL FUSION NUCLEAR TECHNOLOGY ISSUES

1. DT Fuel Cycle Self Sufficiency

 - Achievable tritium breeding

   e.g., Effects of blanket material choices and internal details

   Extent of plasma coverage (choice of RF vs. neutral beams, limiter vs. divertor)

   Uncertainties in neutronics methods and data

 - Required tritium breeding

   e.g., Dependence on plasma recycling (limiter vs. divertor, pumping efficiency)

   Tritium inventory in blanket

   Tritium extraction and processing systems efficiencies and inventories

2. Thermomechanical Loading and Response of Components under Normal and Off-Normal Operation

 - Liquid metal MHD effects: relationship of fluid flow, heat transfer, corrosion, and stresses with full geometric complexity

 - Interaction of primary and secondary stresses and deformation

 - Effect of swelling and creep on stress concentrations

 - Consequences of plasma disruptions

 - Sources and consequences of hot spots

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CRITICAL FUSION NUCLEAR TECHNOLOGY ISSUES (CONTD.)

3. MATERIALS COMPATIBILITY

- EFFECT ON DESIGN LIMITS

  E.G., LIQUID METAL CORROSION TEMPERATURE LIMITS
  LiOT AND LITHIUM BURNUP EFFECTS

- INFLUENCE ON FAILURE MODES

  E.G., LIQUID METAL EMBRITTLEMENT AND STRESS CORROSION CRACKING

- IMPACT ON SAFETY AND RELIABILITY

4. IDENTIFICATION AND CHARACTERIZATION OF FAILURE MODES/RATES

5. TRITIUM INVENTORY AND RECOVERY IN THE SOLID BREEDER UNDER ACTUAL OPERATING CONDITIONS

- RADIATION EFFECTS ON TRITIUM DIFFUSIVITY AND SOLUBILITY

- VARIABILITY IN TEMPERATURE DUE TO MECHANICAL AND MATERIALS INTERACTIONS (GAP CONDUCTANCE, CRACKING, SWELLING, CREEP, ETC.)

CRITICAL FUSION NUCLEAR TECHNOLOGY ISSUES (CONTD.)

6. TRITIUM PERMEATION AND INVENTORY

- MAGNITUDE IN IN-VESSEL COMPONENTS UNDER ACTUAL OPERATING CONDITIONS (PLASMA-SIDE CONDITIONS, RADIATION, ETC.)
- FORM OF TRITIUM (T_2, T_2O) RELEASED FROM SOLID BREEDERS
- EFFECTIVENESS OF CONTROL METHODS/PERMEATION BARRIERS

7. IN-VESSEL COMPONENTS THERMOMECHANICAL RESPONSE AND LIFETIME

- EROSION AND REDEPOSITION MECHANISMS AND RATES UNDER VARIOUS PLASMA EDGE CONDITIONS
- HEAT REMOVAL TECHNIQUES
- STRUCTURAL INTEGRITY OF COMPONENTS AND BONDS

8. RADIATION SHIELDING

- ACCURACY OF PREDICTION
- DATA ON RADIATION PROTECTION REQUIREMENTS

9. ACCURACY AND SURVIVABILITY OF INSTRUMENTATION AND CONTROL

- ACCURACY AND DECALIBRATION IN THE FUSION ENVIRONMENT
- LIFETIME LIMITS DUE TO RADIATION EFFECTS

SURVEY OF EXPERIMENTAL (TEST) NEEDS

- EXPERIMENTS REQUIRED TO RESOLVE FUSION NUCLEAR TECHNOLOGY WERE SURVEYED.

- EACH IDENTIFIED TEST IS CHARACTERIZED BY:
  - IMPORTANCE OF NEUTRONS
  - IMPORTANCE OF FUSION NEUTRON SPECTRUM
  - OTHER REQUIRED ENVIRONMENTAL CONDITIONS (E.G., MAGNETIC FIELD, VACUUM)
  - TYPICAL TEST ARTICLE SIZE
  - NUMBER OF TEST ARTICLES
  - USEFULNESS AND LIMITATIONS OF NON-FUSION FACILITIES (NON-NEUTRON TEST STANDS, POINT NEUTRON SOURCES, FISSION REACTORS)

- RESULTS ARE DOCUMENTED IN DETAIL IN CHAPTER 4.

- THE IDENTIFIED ISSUES AND EXPERIMENTAL REQUIREMENTS PROVIDE A DETAILED STATEMENT OF NEEDS FOR FUSION NUCLEAR TECHNOLOGY.

TYPES OF EXPERIMENTS (TESTS)

- BASIC Tests

  BASIC DATA

- SEPARATE EFFECT Tests

  EXPLORE A SINGLE EFFECT OR PHENOMENA

- MULTIPLE EFFECT/MULTIPLE INTERACTION Tests

  MULTIPLE ENVIRONMENTAL CONDITIONS, MULTIPLE INTERACTION AMONG PHYSICAL ELEMENTS

- PARTIALLY INTEGRATED Tests

  AIMED AT "INTEGRATED" INFORMATION WITHOUT SPECIFIC ENVIRONMENTAL CONDITION, E.G., WITHOUT NEUTRONS

- INTEGRATED Tests

  ALL ENVIRONMENTAL CONDITIONS, ALL PHYSICAL ELEMENTS

- COMPONENT Tests

  FULL-SIZE COMPONENT UNDER PROTOTYPICAL CONDITIONS

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INTERACTIVE EFFECTS PRESENT IMPORTANT ISSUES AND EXPERIMENT REQUIREMENTS

- THE FUSION ENVIRONMENT EXPERIENCED BY NUCLEAR COMPONENTS IS UNIQUE AND LEADS TO MANY NEW PHENOMENA/EFFECTS THAT RESULT FROM THE INTERACTION AMONG:

  - FUSION ENVIRONMENTAL CONDITIONS

    PLASMA PARTICLES, NEUTRONS, γ-RAYS, MAGNETIC FIELD, HEATING, TRITIUM, VACUUM

  - ELEMENTS WITHIN A COMPONENT

    E.G., SB BLANKET: BREEDER/CLAD, COOLANT, STRUCTURE, GAS PURGE, ETC.

  - MULTIPLE COMPONENTS

    E.G., BLANKET-MAGNET, FIRST WALL-PLASMA

- THESE NEW PHENOMENA/EFFECTS RESULT IN MANY CRITICAL FEASIBILITY, ECONOMICS, AND SAFETY ISSUES

- R&D FOR FUSION NUCLEAR TECHNOLOGY MUST EMPHASIZE INTERACTIVE EFFECTS

  - EXPERIMENTS MORE EXPENSIVE THAN SINGLE EFFECT
  - TEND TO REQUIRE LARGER VOLUME

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<u>NEUTRONS</u> ARE <u>NECESSARY</u> FOR MANY INTERACTIVE EFFECTS EXPERIMENTS

- NEUTRONS REPRESENT THE ONE INGREDIENT IN THE FUSION ENVIRONMENT THAT:
  - IS MOST HARSH
  - PRODUCES LARGEST SINGLE AND INTERACTIVE EFFECTS/CHANGES
  - CAUSES NUMEROUS CRITICAL FEASIBILITY ISSUES
  - IS LEAST UNDERSTOOD

- THERE ARE NO SUBSTITUTES FOR NEUTRONS:
  - HEATING (CORRECTNESS OF SIMULATION, ECONOMICS)
  - RADIATION EFFECTS (<u>MUST</u>)
  - SPECIFIC REACTIONS (<u>MUST</u>)

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IMPORTANCE OF NEUTRONS FOR BLANKET/FIRST WALL TESTS

Heating

- Temperature distribution in breeder, multiplier, structure and interfaces
  - Thermal stresses
  - Thermally activated restructuring
  - Tritium recovery
  - Others
  - "Unknowns"

- Examples of unexpected effects:
  - Heat transfer coefficient in liquid metals depends on bulk heating

Specific Reactions

- Tritium
- Helium
- Atomic displacements
- Transmutations

- Tritium recovery in the presence of other neutron effects
- Tritium permeation and containment
- Helium bubble formation rate, effects in liquid metals
- Activation and corrosion products transport
- LiOT transport (in Li_2O)

IMPORTANCE OF NEUTRONS FOR BLANKET/FIRST WALL TESTS
(CONTD.)

MATERIALS DAMAGE

- RADIATION-INDUCED CHANGES IN BASIC PROPERTIES (E.G., THERMOPHYSICAL) IN SOLID BREEDERS, MULTIPLIERS AND STRUCTURE
- RADIATION-INDUCED DIMENSIONAL CHANGES IN SOLID BREEDERS, MULTIPLIERS AND STRUCTURE (SWELLING, CREEP, ETC.)
- RADIATION-INDUCED EMBRITTLEMENT IN STRUCTURE
- NUMEROUS RADIATION EFFECTS IN SOLID BREEDERS CRITICAL TO TRITIUM RELEASE/RETENTION
- RADIATION EFFECTS IN STRUCTURE INFLUENCING TRITIUM PERMEATION/INVENTORY
- RADIATION-INDUCED SENSITIVITY OF STRESS-CORROSION
- RADIATION EFFECTS IN WELDS, JOINTS
- RADIATION DAMAGE TO INSTRUMENTATION
- MANY OTHER KNOWN EFFECTS
- UNKNOWNS

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IMPORTANCE OF NEUTRONS FOR OTHER (NON-BLANKET) COMPONENTS TESTS

SHIELDING

- MANDATORY FOR RADIATION TRANSPORT/STREAMING TESTS

IMPURITY CONTROL AND EXHAUST

- NEUTRON ENVIRONMENT AT PLATES AS HARSH AS THE FIRST WALL
- RADIOACTIVE EROSION PRODUCTS TRANSPORT
- RADIATION EFFECTS IN CRYOPUMPS

AUXILIARY HEATING

- ANTENNA, WAVEGUIDES, ETC.: MANY RADIATION EFFECTS AS THE FIRST WALL
- ADDITIONAL EFFECTS IN SUPPLEMENTARY SUBSYSTEMS, E.G., CRYOPANELS, COAXIAL CABLES

SUPERCONDUCTING MAGNETS

- DEGRADATION OF MECHANICAL AND DIELECTRIC PROPERTIES OF INSULATORS
- INCREASE IN ELECTRICAL RESISTIVITY OF STABILIZER
- REDUCTION IN CRITICAL CURRENT DENSITY OF SUPERCONDUCTOR

INSTRUMENTATION AND CONTROL

- RADIATION EFFECTS, HEATING IMPEDING PROPER FUNCTIONING

EXPERIMENTS INVOLVING NEUTRONS: SPECIMEN VS. VOLUME

- MOST OF THE KEY ISSUES INVOLVING NEUTRONS RELATE TO INTERACTIVE EFFECTS (AMONG PHYSICAL ELEMENTS OF COMPONENTS AND EFFECTS PRODUCED BY OTHER ENVIRONMENTAL CONDITIONS) RATHER THAN MERELY THE PROPERTY CHANGES IN SINGLE MATERIALS

- THESE INTERACTIVE EFFECTS OCCUR AT MUCH LOWER FLUENCE THAN INDIVIDUAL EFFECTS IN SINGLE MATERIALS

- IMPORTANCE OF EXPERIMENTS WITH SIGNIFICANT VOLUME (FOR MULTIPLE EFFECTS) RELATIVE TO SPECIMEN TEST:

    IS LARGER TEST VOLUME (MULTIPLE EFFECT) TEST CAPABILITY MORE IMPORTANT THAN HIGH FLUENCE (SPECIMEN, SINGLE EFFECT) CAPABILITY?

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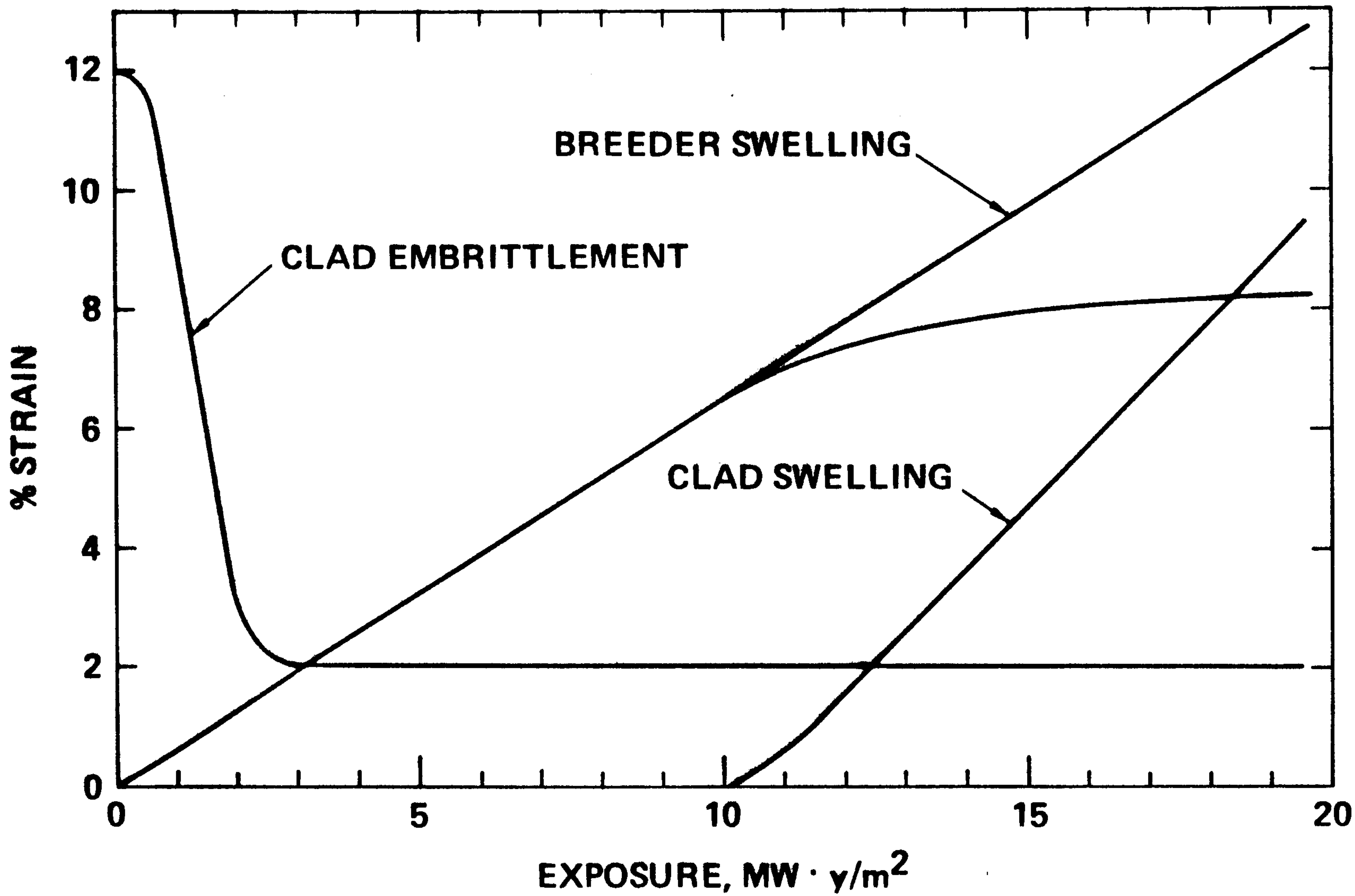
CLAD/BREEDER MECHANICAL INTERACTION
(ESTIMATES FOR Li_2O/HT-9/He)



EXAMPLES OF TESTS REQUIRING NEUTRONS

Test Type	Typical Size cm x cm x cm	Number of Articles
Basic Tests		
Materials Irradiated Properties	1 x 1 x 2	22,000
Single Effect Tests		
Structure Thermomechanical Response	10 x 10 x 10	50
Multiple Effect/Multiple Interaction Tests		
Thermal, Mechanical & Corrosion		
Liquid Metal Blankets[A]	100 x 100 x 30	5
Solid Breeder Blankets	10 x 50 x 30	5
Partially Integrated & Integrated Tests		
Neutronics	50 x 50 x 100	4
Integrated Behavior (Thermal, Mechanical, Corrosion, T Recovery):		
Liquid Metal Blankets[A]	100 x 100 x 50	5
Solid Breeder Blankets	100 x 100 x 50	5
Biological Dose Verification	DT Device	

[A]Some liquid metal blanket concepts require much larger test article size.

NEUTRON-PRODUCING FACILITIES

- Accelerator-Based "Point" Source
- Fission Reactors
- Fusion Devices

POINT NEUTRON SOURCES FOR FUSION MATERIAL IRRADIATION TESTING

Facility	Status	Peak Flux* n/cm^2·s	Testing Volume
RTNS-II	In Use	~ 5 x 10^{12}	~ 0.1 cm^3
LAMPF A-6	Operational	1 x 10^{13}	~ 0.02 m^3
FMIT	Design Completed Project Deferred	1 x 10^{15}	~ 10 cm^3
Super-FMIT	Scoping Study	5 x 10^{13}	~ 0.016 m^3

*Neutron flux in fusion first wall at 5 MW/m^2 wall load is:

2 x 10^{15} n/cm^2·s

FISSION REACTORS

- ONLY SOURCE OF NEUTRONS AVAILABLE FOR "BULK HEATING"

- USEFUL FOR UNIT CELL EXPERIMENTS

- SUITABLE FOR SOLID BREEDERS; NOT SUITABLE FOR LIQUID METALS

- BUT, CANNOT SUBSTITUTE FOR FUSION TESTING

  - LIMITATIONS ON VOLUME
    * SIZE OF TEST ELEMENTS
    * NUMBER OF TEST LOCATIONS

  - SPECTRAL DIFFERENCES

  - LIMITATIONS ON SIMULATING FUSION ENVIRONMENT (ELECTROMAGNETIC, SURFACE HEAT FLUX, ETC.)

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FISSION REACTORS

Maximum Flux* $n/cm^2 \cdot s$	Test Assembly Maximum Dimension, cm		
	5	10	15
5×10^{13}	167	30	1
5×10^{14}	49	13	0
5×10^{15}	40	4	0

*Compare to required flux to simulate fusion first wall at 5 MW/m^2 of:

Nuclear Heating: 2×10^{15} $n/cm^2 \cdot s$
DPA: 6×10^{15} $n/cm^2 \cdot s$
Helium: 5×10^{17} $n/cm^2 \cdot s$ (exceptions)

Slab tests at side of core:
Maximum Flux = 5×10^{13} $n/cm^2 \cdot s$
Maximum Dimension = 50 cm

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A FUSION FACILITY IS NECESSARY FOR CRITICAL FUSION NUCLEAR EXPERIMENTS

- WE HAVE NOT YET FOUND AN ALTERNATIVE TO SATISFYING THE IDENTIFIED CRITICAL TESTING NEEDS

- VOLUME/SURFACE AREA OF TEST ELEMENT/MODULE
  SOME TESTS REQUIRE: ~ 1 M X 1 M X 0.5 M
  OBTAINABLE ONLY IN FUSION TEST DEVICE

- TOTAL VOLUME/SURFACE AREA OF TEST MATRIX
  NEED: UNIFORM STEADY NEUTRON SOURCE WITH > 10^{19} N/S
  OBTAINABLE ONLY IN FUSION DEVICE

- SIMULATION OF ALL ENVIRONMENTAL CONDITIONS
  - NEUTRONS
  - ELECTROMAGNETICS
  - PLASMA PARTICLES
  - TRITIUM
  - VACUUM

- NEUTRON SPECTRUM
  - 14 MEV SOURCE NEUTRONS
  - COMPLEX "SLOWING DOWN/BACKSCATTERING" SPECTRUM

ACCELERATOR-BASED POINT NEUTRON SOURCES

IRRADIATION

- PRESENTLY AVAILABLE SOURCES ARE VERY LIMITED IN CAPABILITIES: RELATIVELY LOW FLUX, SMALL CAPSULE (< 1 cm^3)

- FMIT HAS BEEN DEFERRED

- NEW INITIATIVES LIKELY? SHOULD THESE BE PURSUED?

  - PRIMARY "TRADITIONAL" ADVANTAGES OF ACCELERATOR-BASED SOURCES ARE: 1) SIMPLICITY, 2) LOW COST AND 3) GOOD SIMULATION OF FUSION SPECTRUM

  - NEW INITIATIVES FOR MORE POWERFUL SOURCES SEEM TO SUFFER FROM INCREASED COMPLEXITY, HIGH COST AND LESS EFFECTIVE SPECTRUM SIMULATION

  - LIMITATIONS ON CAPABILITY TO PERFORM MULTIPLE EFFECT TESTS ARE SERIOUS

OTHERS

- IMPORTANT APPLICATIONS IN NEUTRONICS AND SHIELDING; PRESENT FACILITIES ARE BEING USED

GENERAL QUESTIONS ON FUSION TEST FACILITY

CONCLUSION: A FUSION FACILITY IS NEEDED FOR FUSION NUCLEAR EXPERIMENTS AS PART OF FUSION DEVELOPMENT

QUESTION 1: WHAT ARE THE FACILITY PERFORMANCE REQUIREMENTS (E.G., WALL LOAD, FLUENCE, MAGNETIC FIELD) TO SATISFY THE NUCLEAR TECHNOLOGY DEVELOPMENT NEEDS?

QUESTION 2: WHAT TYPE OF FUSION FACILITY IS BEST IN SATISFYING THE REQUIREMENTS AT A MINIMUM COST AND RISK (E.G., TOKAMAK, MIRROR)? SHOULD IT BE DEDICATED OR PART OF A COMBINED PHYSICS/TECHNOLOGY FACILITY?

QUESTION 3: ARE THERE INCENTIVES TO BUILDING A FUSION NUCLEAR TECHNOLOGY (NEUTRON-PRODUCING) FACILITY OTHER THAN THOSE OF FUSION DEVELOPMENT?

E.G., APPLICATIONS TO SCIENCE/TECHNOLOGY OUTSIDE FUSION?

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TASK II.B: QUANTIFICATION OF TEST REQUIREMENTS

DESCRIPTION OF PROBLEM

- THE COST OF A FUSION DEVICE INCREASES WITH THE MAJOR DEVICE PARAMETERS (WALL LOAD, FLUENCE, ETC.)
- REALISTIC COST CONSTRAINTS DICTATE THAT FUSION TESTING MUST BE PERFORMED UNDER SCALED-DOWN CONDITIONS
- "LOOK ALIKE" TEST MODULES UNDER SCALED-DOWN CONDITIONS ARE USELESS IN MOST CASES

SCOPE OF TASK II.B

- UNDERSTAND BASIC PHENOMENA GOVERNING THE BEHAVIOR OF NUCLEAR COMPONENTS
- DEVELOP ENGINEERING SCALING APPROACH
- INVESTIGATE "ACT-ALIKE" DESIGNS
- PROVIDE QUANTITATIVE GUIDANCE TO REQUIRED DEVICE PARAMETERS
  - MINIMUM VALUES IF ANY
  - TRADEOFFS AMONG PARAMETERS

QUANTIFICATION OF TEST REQUIREMENTS

GENERAL OBSERVATIONS ON RESULTS

- IN MANY CASES, A TRUE INTEGRATED TEST IN THE STRICTEST SENSE CANNOT BE PERFORMED UNDER SIGNIFICANTLY SCALED-DOWN CONDITIONS FOR CERTAIN PARAMETERS (E.G., POWER DENSITY, SURFACE HEAT LOAD, GEOMETRY)

- UNDER SCALED-DOWN ENVIRONMENTAL CONDITIONS, THE FUNCTION OF AN INTEGRATED TEST MODULE HAS TO BE DIVIDED INTO TWO OR MORE "ACT-ALIKE" TESTS. EACH ACT-ALIKE TEST EMPHASIZES A GROUP OF ISSUES/PHENOMENA.

- WHILE AN OVERLAP AMONG THE VARIOUS ACT-ALIKE TESTS CAN BE INCLUDED TO ACCOUNT FOR CERTAIN INTERFACES, A CONCERN ABOUT POSSIBLY MISSING SOME PHENOMENA REMAINS

- PERFECT QUANTITATIVE ENGINEERING SCALING IS NOT POSSIBLE BECAUSE IT REQUIRES COMPLETE QUANTITATIVE MODELS FOR ALL (INCLUDING INTERACTIVE) PHENOMENA

- IF FUSION TESTING WILL HAVE TO BE CARRIED OUT UNDER SCALED-DOWN CONDITIONS, AS APPEARS NOW TO BE THE CASE, THEN:
  - ENGINEERING SCALING NEEDS TO CONTINUE TO BE NOURISHED AS A KEY TECHNICAL DISCIPLINE IN FUSION
  - THE NEED FOR A MORE THOROUGH UNDERSTANDING OF PHENOMENA AND MORE ANALYTICAL MODELING WILL BECOME MORE CRITICAL

REQUIREMENTS ON KEY PARAMETERS OF A FUSION ENGINEERING RESEARCH FACILITY

- **WALL LOAD**
  - MINIMUM: > 1 MW/M^2
  - SUBSTANTIAL BENEFITS: 2-3 MW/M^2
  - MUCH HIGHER WALL LOADS CAN BE EXTREMELY BENEFICIAL AND WILL ALTER STRATEGY (ACCELERATED TESTING, MORE AMBITIOUS TECHNOLOGY PERFORMANCE GOALS FOR FUSION, ETC.)

- **SURFACE HEAT LOAD**
  - CRITICAL FOR TESTS OF FIRST WALL, SOLID BREEDER BLANKETS, LIQUID METAL BLANKETS
  - NEEDED IN TEST FACILITY
    - FOR TOKAMAK BLANKETS: > 20 W/CM^2
    - FOR MIRROR BLANKETS: < 20 W/CM
  - MEANS TO ENHANCE SURFACE HEAT FLUX IN FUSION TEST FACILITIES ARE REQUIRED

- **PLASMA BURN CYCLE**
  - PULSING SHARPLY REDUCES THE VALUE OF MANY TESTS
  - MINIMUM BURN TIME: > 1000 S
  - MAXIMUM DWELL TIME: < 100 S
  - PREFER STEADY STATE

- **MINIMUM CONTINUOUS TIME**
  - MANY PERIODS WITH 100% AVAILABILITY
  - DURATION OF EACH PERIOD
    - CRITICAL: SEVERAL DAYS
    - IMPORTANT: SEVERAL WEEKS

- **AVAILABILITY**
  - MINIMUM: 20%
  - SUBSTANTIAL BENEFITS: 50%

REQUIREMENTS ON KEY PARAMETERS FOR A FUSION ENGINEERING RESEARCH FACILITY
(CONTD.)

- **FLUENCE**
  - IN ALL CASES, HIGHER FLUENCES ARE DESIRABLE BUT COSTLY; MODEST FLUENCES ARE STILL EXTREMELY VALUABLE
  - SIGNIFICANT VOLUME (FOR MULTIPLE EFFECT) TESTS ARE PREFERABLE EVEN AT LOW FLUENCE OVER SPECIMEN TESTS AT HIGH FLUENCE
  - CRITICAL: 1-2 MW·Y/M^2
    VERY IMPORTANT: 2-4 MW·Y/M^2
    IMPORTANT: 4-10 MW·Y/M^2

- **MINIMUM SIZE OF TEST ASSEMBLY**
  - INTERACTIVE TESTS (SUBMODULE): ~ 0.2 M x 0.2 M x 0.1 M
  - INTEGRATED TESTS (MODULE): 1 M x 1 M x 0.5 M
    (SOME LIQUID METAL BLANKETS TEND TO REQUIRE LARGER SIZE, SECTOR SCALE?)

- **TEST SURFACE AREA**
  - CRITICAL: > 5 M^2
    VERY IMPORTANT: > 10 M^2
    IMPORTANT: 15-20 M^2

OPTIONS FOR FUSION NUCLEAR EXPERIMENTS DEVICE

CONFINEMENT TYPE

- TOKAMAK
- MIRROR
- ALTERNATE CONCEPT

MISSION

- COMBINED WITH PLASMA PHYSICS EXPERIMENTS
- DEDICATED TO NUCLEAR EXPERIMENTS

PLASMA PHYSICS

- DOES THE PLASMA OPERATING MODE IN A DEDICATED FUSION NUCLEAR TECHNOLOGY FACILITY NEED TO BE REACTOR RELEVANT?

FINESSE

COMBINING PHYSICS AND NUCLEAR TESTING IN A TOKAMAK MANDATES A TRITIUM-PRODUCING BLANKET IN THE TEST DEVICE

Neutron/Tritium Requirements

A. Physics Only (Tokamak)

~ 380 m^2, 1.3 MW/m^2

DT burn: 2×10^5 s

Number of neutrons = 4.4×10^{25}

Tritium consumption = 0.22 kg

B. Nuclear Testing Only (assume a device not physics limited)

~ 10 m^2, 1.3 MW/m^2

DT burn: 5 continuous years

Number of neutrons = 9×10^{26}

Tritium consumption = 4.5 kg

C. Combined Physics and Nuclear Testing in Single Tokamak

~ 380 m^2, 1.3 MW/m^2

DT burn: 5 continuous years

Number of neutrons: 3.4×10^{28}

Tritium consumption: 171 kg

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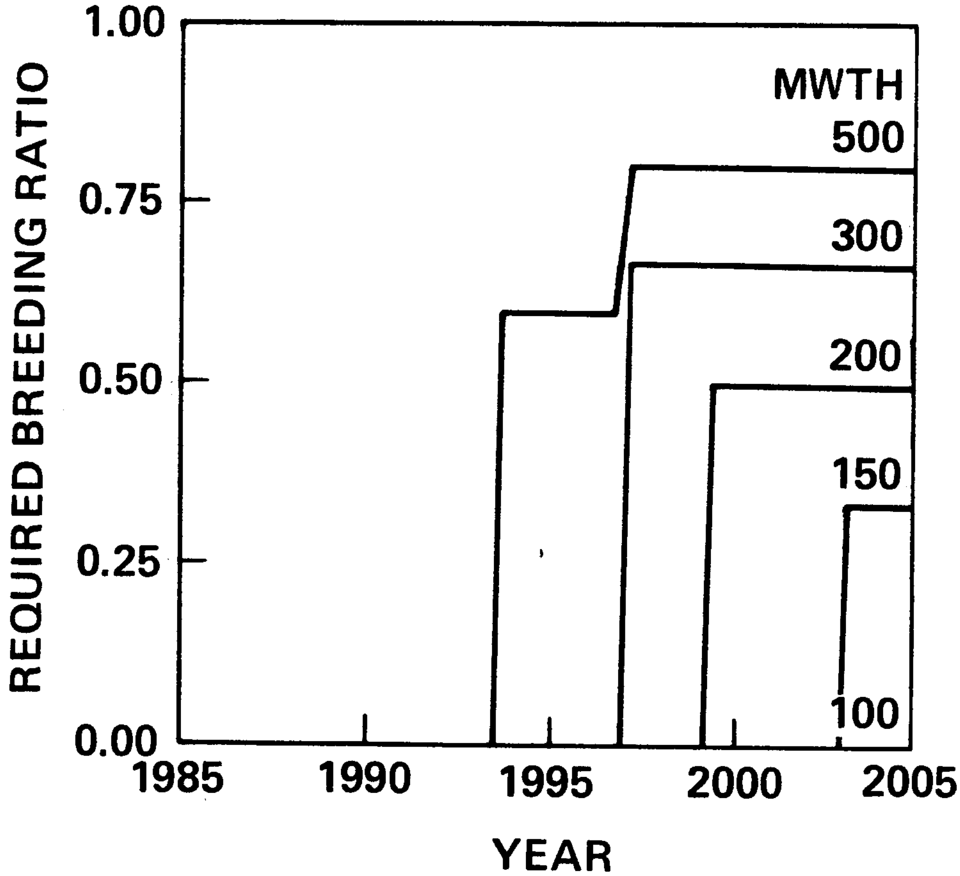
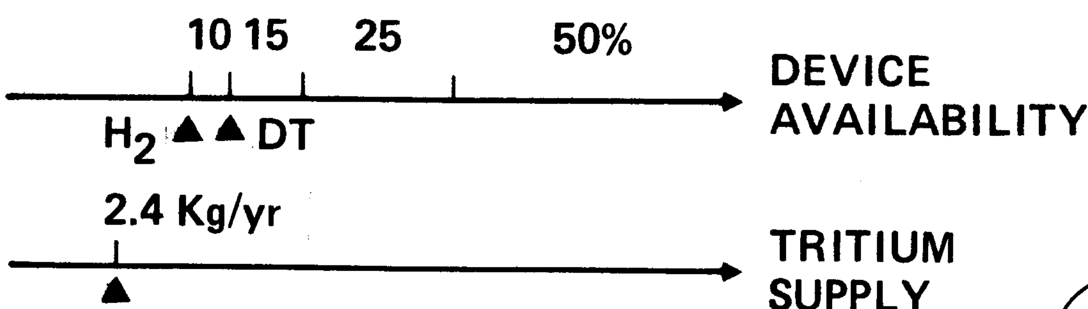
THE NEED FOR A TRITIUM-PRODUCING BLANKET IN A FUSION TEST REACTOR STRONGLY DEPENDS ON FUSION POWER AND FLUENCE GOALS





LOW FUSION POWER, HIGH POWER DENSITY ARE KEY REQUIREMENTS

- NUCLEAR TECHNOLOGY EXPERIMENTS REQUIRE ONLY LOW POWER (< 50 MW), AND HIGH WALL LOAD (> 1 MW/m^2)

- DEVICES WITH LARGE FUSION POWER (> 100 MW), WITH HIGH FLUENCE (> 3 $MW \cdot y/m^2$), REQUIRE A TRITIUM-BREEDING BLANKET

- A BREEDING BLANKET WITHOUT PRIOR FUSION TESTING WILL HAVE A VERY LOW DEVICE AVAILABILITY, HIGH RISK, AND HIGH COST

- FUSION DEVICES MOST SUITED FOR NUCLEAR EXPERIMENTS ARE THOSE IN WHICH POWER AND POWER DENSITY ARE DECOUPLED

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TOKAMAK TEST FACILITIES

ADVANTAGE

- GOOD PHYSICS DATA BASE

DISADVANTAGES

- STRONG COUPLING BETWEEN FUSION POWER AND WALL LOAD
- OBTAINING LONG PLASMA BURN IN NEAR-TERM DEVICE APPEARS DIFFICULT

EFFORT

- PPPL (D. JASSBY, ET AL) ATTEMPTED TO DESIGN A MINIMUM COST TOKAMAK DEDICATED TO NUCLEAR EXPERIMENTS

MAJOR FEATURES OF A TOKAMAK TEST FACILITY DESIGN

DESIGN FEATURES

- COPPER TF COILS
- IGNITED OPERATION
- QUASI-OHMIC HEATING TO IGNITION
- PUMPED LIMITERS

MAJOR PARAMETERS

FUSION POWER	185 MW
WALL LOAD	1.2 MW/m^2
CIRCULATING POWER	190 MW
$\langle\beta\rangle$, BEAN-SHAPED	23%
MAJOR RADIUS	2.55 M
ASPECT RATIO	3.4
PULSE LENGTH	> 1000 s

COSTS

CAPITAL	> $1 BILLION
ELECTRICITY (50% AVAILABILITY)	$35 MILLION/YR
TRITIUM (50% AVAILABILITY)	$75 MILLION/YR

CONCLUSIONS

FURTHER EFFORT IS NEEDED. COSTS AND RISKS ARE HIGH.

MIRROR TEST FACILITIES

- ADVANTAGE: ABILITY TO PRODUCE HIGH POWER DENSITY IN A LOW FUSION POWER CENTRAL CELL
- POTENTIAL HAS BEEN RECOGNIZED FOR SEVERAL YEARS

EFFORT (TRW/LLNL)

- SURVEYED PREVIOUS EFFORTS
- COMPARED MFTF-B UPGRADE (MFTF-α+T) AND TDF
- EXPLORING NEW IDEAS

FINESSE

ADEQUATE COMPARISON AMONG FUSION FACILITY OPTIONS CANNOT BE MADE YET

	MFTF-α+T	TDF	JAS	INTOR
Fusion power	17	36	185	620
Neutron wall loading, MW/m^2	2.0	2.1	1.3	1.3
Nuclear experimental area, m^2	1.6	3.2	(15)	(15)
Availability, %	10?	40?	40?	35?
Lifetime fluence, MW·y/m^2	2	8	5	5
Capital cost, $M	400	1300	1300	2600
Annual electrical cost, $M/yr	7	44	35	46
Annual tritium cost, $M/yr	2	16	90	124
Total cumulative cost, $M (?)	1000	2800	3200	6000
Cost/(fluence x area), $/MW·y	(310)	(110)	(42)	(86)
Risk	?	?	?	?

FINESSE

GENERAL FRAMEWORK FOR FUSION NUCLEAR TECHNOLOGY DEVELOPMENT

1985-1995

- UTILIZE EXISTING FACILITIES
  - TEST STANDS
  - FISSION REACTORS
  - POINT NEUTRON SOURCES

- CONSTRUCT A NUMBER OF NEW SMALL-SCALE FACILITIES
  MULTIPLE EFFECTS EXPERIMENTAL FACILITIES APPROPRIATE FOR FUSION ARE NOT A FORTHCOMING LEGACY FROM OTHER TECHNOLOGIES

- CONSTRUCT PITF
  PARTIALLY INTEGRATED TEST FACILITY
  E.G., FACILITY FOR LIQUID METAL BLANKET AND TRANSPORT LOOP WITH ALL ENVIRONMENTAL CONDITIONS (VACUUM, TRITIUM, MAGNETIC FIELD) EXCEPT NEUTRONS

AFTER 1995

- THERE IS A CRITICAL NEED FOR A FERF

FUSION ENGINEERING RESEARCH FACILITY

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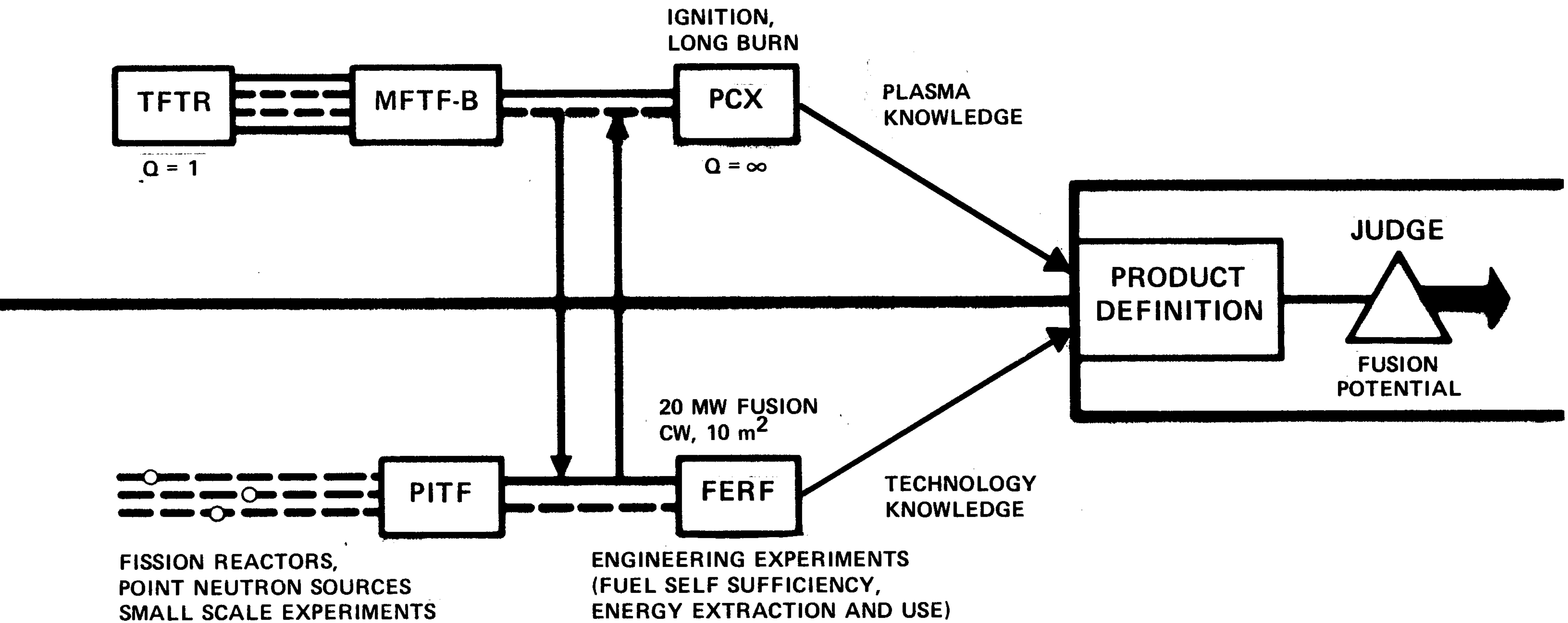
PHYSICS

- UNDERSTAND PLASMAS
- IMPROVE REACTOR CONCEPTS
  - ENGINEERING SUPPORTS CONFINEMENT EXPERIMENTS



TECHNOLOGY

- UNDERSTAND FUSION ENGINEERING SCIENCES
- LEARN MATERIALS, ENGINEERING LIMITS IN FUSION ENVIRONMENT
- IMPROVE REACTOR CONCEPTS
  - PLASMA PHYSICS SUPPORTS FUSION ENGINEERING EXPERIMENTS (AND PROVIDES FEEDBACK TO PRIMARY PLASMA PATH)

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ISSUES IN ENHANCING FUSION TECHNOLOGY

A. Programmatic : COST

1. US : Suplemental Funding

   Fusion Technology Must Proceed on Its Own Merit because of Importance to Fusion AND Science/Technology

2. International Cooperation : Prime Area

   - User Type Facilities
   - Share Cost/Benefit without Necessarily Agreeing on a Common Path

B. Technical : Credible/Inexpensive FERF?

- Requirement : Low Power (20 MW), High Power Density (2 MW/m^2)
- From Technology : Plasma is Only a Neutron Producer
- New Plasma Mode May Enhance Discoveries
- FERF Goals can Capture the Imagination of the Nation
  - Produce : 20 MW/2 MW/m^2 of Fusion Power
  - Use : Most Intense Neutron Source with Unique Fusion Environment to Gain New Knowledge from Important Engineering Research Experiments

FINESSE

FINESSE EFFORT PLANNED FOR FY 1985

GENERAL

- COMPLETE TASKS II, IV AND V
- DEVOTE MORE EFFORT TO NON-BLANKET COMPONENTS

A. NON-FUSION FACILITIES AND EXPERIMENTS

A.1 NON-NEUTRON TEST STANDS

- CRITICAL STUDY OF ENVIRONMENTAL ELEMENTS AND CONDITIONS NEEDED FOR MULTIPLE-EFFECT EXPERIMENTS
- IDENTIFY THE NEW REQUIRED FACILITIES
  - EMPHASIS ONLY ON MAJOR MILESTONES
  - NUMBER OF FACILITIES: < 5
  - COST PER FACILITY: $5-15M
- STUDY THE NEED FOR AND FEASIBILITY OF
  PITF
- EXPECTED: A PRIMARY PATH FOR LIQUID METAL BLANKETS

A.2 FISSION REACTORS

- DEVELOP A TECHNICAL PLAN FOR UTILIZATION OF EXISTING FISSION REACTORS
- EMPHASIS ON MULTIPLE EFFECT EXPERIMENTS
- EXPECTED: A PRIMARY PATH FOR SOLID BREEDERS
- BALANCE BETWEEN SPECIMEN/HIGH FLUENCE TESTS AND VOLUME/MULTIPLE EFFECT/LOW FLUENCE TESTS

A.3 NEUTRON SOURCES

- UTILIZATION OF EXISTING FACILITIES
- SMALL EFFORT ON EXISTING FACILITIES

FINESSE EFFORT PLANNED FOR FY 1985
(CONTD.)

B. Fusion Facilities and Experiments

B.1 Mirrors

- Conceptual features of improved FERF
- Issues in conducting experiments

  e.g., simulation of tokamak liquid metal blankets requires poloidal and toroidal field, large area, surface heat load

B.2 Tokamaks

- Work with other groups exploring ideas

  e.g., spherical torus, OHTE, etc.

B.3 Alternate Concepts

- Work with other groups to evaluate suitability

C. Scenarios and R&D Plan

- Components candidate concepts pathways, test matrices, schedule, cost