FUSION NUCLEAR TECHNOLOGY
ISSUES AND DEVELOPMENT NEEDS

MOHAMED A. ABDOU
SCHOOL OF ENGINEERING & APPLIED SCIENCE
UNIVERSITY OF CALIFORNIA, LOS ANGELES

FUSION POWER ASSOCIATES ANNUAL MEETING
APRIL 2, 1984
LAWRENCE LIVERMORE NATIONAL LABORATORY

FUSION REACTOR ELEMENTS

- PLASMA
- ENGINEERING COMPONENTS
  - MAGNETS
  - PLASMA HEATING
  - NUCLEAR COMPONENTS

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

FUSION NUCLEAR COMPONENTS: IMPORTANCE OF R&D

- MANY OF FUSION UNRESOLVED ISSUES ARE IN NUCLEAR TECHNOLOGY

- THESE ISSUES RELATE TO:

  - **FEASIBILITY** (TECHNOLOGY COMMUNITY ACCEPTANCE)

  - **ECONOMICS** (UTILITY ACCEPTANCE)

  - **SAFETY, ENVIRONMENT** (PUBLIC ACCEPTANCE)

- RESOLVING THESE ISSUES;

  - APPEARS TO BE RELATIVELY COSTLY (REQUIRES NEUTRONS IN TEST ENVIRONMENT)

  - REQUIRES **LONG LEAD TIME**

- THE U.S. (AND OTHER INTERNATIONAL PROGRAMS) MUST SEEK **SUCCESSFUL** AND **TIMELY** RESOLUTION OF THE FUSION NUCLEAR ISSUES

FINESSE

FUSION NUCLEAR TECHNOLOGY DEVELOPMENT STUDY

- OBJECTIVE:

  INVESTIGATE THE **TECHNICAL** AND PROGRAMMATIC **ISSUES** IN THE **DEVELOPMENT** OF FUSION **NUCLEAR** COMPONENTS

- TWO-YEAR STUDY (STARTED IN NOVEMBER, 1983)

- MAJOR PARTICIPATION BY KEY **U.S. ORGANIZATIONS**:

  - UCLA, ANL, EG&G, HEDL, MDAC, TRW
  - LLNL, PPPL
  - COORDINATION WITH OTHER DOE AND EPRI PROGRAMS

- BROAD PARTICIPATION BY FUSION COMMUNITY: ADVISORY COMMITTEE, WORKSHOPS

- SIGNIFICANT **INTERNATIONAL** PARTICIPATION

  - GERMANY (KFK), JAPAN (JAERI, UNIVERSITIES), CANADA
  - IMPORTANCE:
    - ◇ ALL WORLD PROGRAMS FACE THE SAME ISSUES
    - ◇ INTERNATIONAL COOOPERATION ON NT, VIABLE, ECONOMICAL

FINESSE PRINCIPAL TECHNICAL TASKS

I. IDENTIFICATION OF ISSUES AND REQUIRED NUCLEAR TESTS

II. QUANTIFYING TEST REQUIREMENTS

   A. REQUIREMENTS ON TEST CONDITIONS (E.G., WALL LOAD, FLUENCE, SIZE, T, B)

   B. ISSUES OF ENGINEERING SCALING

   C. NEED FOR NEUTRONS AND INTEGRATED TESTING

   D. FIGURES OF MERIT FOR TEST FACILITY MAJOR PARAMETERS

III. EVALUATION OF EXPERIENCE FROM OTHER TECHNOLOGIES

   A. FISSION   B. AEROSPACE

IV. SURVEY AND EVALUATION OF NEUTRON-PRODUCING TEST FACILITIES

   A. NON-FUSION DEVICES   B. FUSION DEVICES

V. COMPARATIVE EVALUATION OF TEST FACILITIES, SCENARIOS

   TFCX + COMPLEMENTARY FACILITIES + ?

VI. RECOMMENDATIONS ON FUSION NUCLEAR TECHNOLOGY DEVELOPMENT STRATEGY

NUCLEAR TECHNOLOGY ISSUES AND TESTING NEEDS

- COMPREHENSIVE CHARACTERIZATION OF FUSION NUCLEAR ISSUES AND TESTING NEEDS IS UNDERWAY (FINESSE)

- THE FOLLOWING ARE **ONLY EXAMPLES** OF ISSUES AND TESTING NEEDS

CRITICAL FEASIBILITY ISSUES: SOLID BREEDER BLANKETS

- TRITIUM BREEDING
- TRITIUM INVENTORY IN SOLID BREEDER
- DESIGN PRACTICABILITY
  - LOW K, HIGH POWER DENSITY, NARROW ΔT
  - CONTROL OF THERMAL CONDUCTANCE AT BREEDER/STRUCTURE INTERFACE
  - BREEDER PHYSICAL INTEGRITY AND CONTAINMENT
  - ABILITY TO ACCOMMODATE POWER VARIATION
  - LIFETIME LIMITATIONS (HIGH BURNUP, ETC.)
- TRITIUM FORM (T_2, T_2O) PERMEATION
- ISSUES RELATED TO SPECIFIC SOLID BREEDERS, E.G., Li_2O REACTIVITY WITH H_2O TO FORM LiOH
- ISSUES RELATED TO SPECIFIC COOLANT, E.G.,
  - H_2O: TRITIUM PERMEATION/REMOVAL
  - He: LEAKAGE OF TRITIUM CONTAMINATED He

CRITICAL FEASIBILITY ISSUES: LIQUID METAL BREEDING BLANKET

- CORROSION
  - RADIOACTIVE MASS TRANSFER/DEPOSITION
  - TEMPERATURE LIMIT AT LIQUID METAL/STRUCTURE INTERFACE
- MHD (PRESSURE DROP)
  - HIGH PRESSURE/STRESS ON STRUCTURE
  - LARGE PUMPING/RECIRCULATING POWER
- SAFETY
  - LITHIUM: REACTIVITY WITH AIR AND WATER
  - LI-PB: TRITIUM PERMEATION
- HYDRAULICS
  - WITH HIGH HEAT FLUX: HIGH T (INTERFACE)/T (MEAN)
  - SOLUTION: FLOW MIXING - INCREASES MHD
- TRITIUM BREEDING
  - WITH LITHIUM (IMPOSSIBLE TO ELIMINATE INBOARD BLANKET)
  - (LI-PB HAS THE HIGHEST BREEDING POTENTIAL)

SUMMARY OF TESTING NEEDS: TRITIUM RECOVERY ISSUES IN SOLID BREEDERS

Issue Description		Test Requirements	
Issue	Consequences	Need for Neutrons	Test Parameters
Radiation Effects on Solid Breeder Tritium Diffusivity and Solubility	High Tritium Inventory	R,D	F,T,I,S,ϕ
Purge Flow Impurity Effects	Tritium Recovery from (T_2, T_2O); Very High or Very Low Soluble Inventory	R	I,T,ϕ,G,F
Solid Breeder/Structure Gap Thermal Conductance	Temperatures Outside Design Window; Breeder/Clad Contact Failure and High Tritium Inventory	D,H	T,σ,F,G,I
Thermal Conductivity of Solid Breeder	Temperature Outside Design Window, Breeder/Clad Contact Failure and High Tritium Inventory	D	F,T,P,G,I
Solid Breeder Restructuring/ LiOT Transport	Decreased Porosity or Thermal Conductivity; High Tritium Inventory	R,H,D	T,F,G,I,ϕ
Tritium Extraction System Efficiency	High Tritium Inventory; High Tritium Losses and Chronic Worker Exposure	-	T,I,V

NEED FOR NEUTRONS:
- \- No Need
- H Heating
- R Specific Reactions
- D Materials Damage

TEST PARAMETERS:
- B Magnetic Field
- F Fluence
- G Geometry
- I Impurities
- S Spectrum
- T Temperature
- V Velocity
- σ Stress
- ϕ Flux

SUMMARY OF TESTING NEEDS: STRUCTURAL AND MATERIALS ISSUES

Issue Description		Test Requirements	
Issue	Consequences	Need for Neutrons	Test Parameters
Irradiation Effects on Thermo-physical Chemical and Mechanical Properties	Invalidate Design, Cause Early Failure	H,R,D	F,T,S
Mechanical Response of Structure to Primary Loading	Unstable Mechanical Failure, Geometric Changes	H,D	G,F,T,σ,S,B
Embrittlement of Structural Alloys	Unexpected Failure at Nominal Stresses	H,R,D	F,T,ϕ,S,I (Li,LiPb,H_2O)
Swelling and Creep of Structural & Solid Breeder Materials	Geometric Changes, Interaction Stresses	H,R,D	G,F,T,σ,S
Mechanical Interaction of Structure/Solid Breeder	Tritium Mechanical Failure	H,R,D	G,F,T,σ,S
Wear and Fatigue (Creep/Fatigue) from Cyclic Loading	Unexpected Failure	-	G,T,σ,V

SUMMARY OF TESTING NEEDS: STRUCTURAL AND MATERIALS ISSUES
(CONTINUED)

Issue Description		Test Requirements	
Issue	Consequences	Need for Neutrons	Test Parameters
Thermal Stress Effects	Local High Stress, Cooldown Tension/ Cracking	H,D	G,T,σ
Tritium Trapping in or Permeation through Structure	Safety	H,R,D	G,F,T,S
Erosion, Redeposition and Disruption Effects of First Wall		H,D	F,S
Welds/Joints	Weakening at Welds, DBTT Increase, Local Stress/Failure	H,R,D	F,T,S,σ,ϕ,G,I

Need for Neutrons:
- \- No Need
- H Heating
- R Specific Reactions
- D Materials Damage

Test Parameters:
- B Magnetic Field
- F Fluence
- G Geometry
- I Impurities
- S Spectrum
- T Temperature
- V Velocity
- σ Stress
- ϕ Flux

Summary of Testing Needs: Thermal Hydraulics and Corrosion/Compatibility Issues

Solid Breeder Issues

Issue Description		Test Requirements	
Issue	Consequences	Need for Neutrons	Test Parameters
Breeder/Structure Interface Heat Transfer	Unacceptable Tritium Recovery from Loss of Temperature Control	H,D	G,F,T,σ
Temperature Distribution Uncertainties	Reduced Performance, High Temperatures, Structural Failure	H,D	G,T,F
He Purge System Flow Characteristics	High Tritium Inventory and Loss Rate to Coolant	H,D	G,F,T,σ
Multiple Channel Flow Stability and Vibrations	Reduced Blanket Lifetime from Fatigue	-	G,T,V
Flow Sensitivity to Geometry	Increased Temperatures and Stresses	H	G,T,V
Stress-Related Corrosion Failure	Loss of Containment of Breeder, Tritium and Multiplier	H,D	F,T,V,σ,I
Corrosion Mass Transport	Coolant Channel and Heat Exchanger Plugging	HD	T,V,I,G,σ
Burnup Effects (Corrosion and Properties Changes)	Loss of Breeder Containment or Shortened Lifetime	H,D,R	T,σ,F

Need for Neutrons:
- \- No Need
- H Heating
- R Specific Reactions
- D Materials Damage

Test Parameters:
- B Magnetic Field
- F Fluence
- G Geometry
- I Impurities
- S Spectrum
- T Temperature
- V Velocity
- σ Stress
- ϕ Flux

SUMMARY OF TESTING NEEDS: THERMAL HYDRAULICS AND CORROSION/COMPATIBILITY ISSUES

LIQUID METAL ISSUES

ISSUE DESCRIPTION		TEST REQUIREMENTS	
ISSUE	CONSEQUENCES	NEED FOR NEUTRONS	TEST PARAMETERS
FIRST WALL COOLING AND HOT SPOTS	REDUCED PERFORMANCE, HIGH TEMPERATURES, STRUCTURAL FAILURE	H	G,T,V
STRESS-RELATED CORROSION FAILURE	STRUCTURE FAILURE, LOSS OF COOLANT CONTAINMENT	H,D	F,T,V,σ,I
CORROSION MASS TRANSPORT	COOLANT CHANNEL AND HEAT EXCHANGER PLUGGING	H,D	G,T,V
MHD PRESSURE DROP	HIGH PRESSURE STRESSES, CLOSURE OF TEMPERATURE OPERATING WINDOW	?	G,V,T,B
FLOW DISTRIBUTION EFFECTS	INCREASED TEMPERATURES AND STRESSES, LOWER PERFORMANCE	-	G,V
HE BUBBLE FORMATION	LOSS OF TEMPERATURE CONTROL, HOT SPOTS	R	G,V,ϕ

NEED FOR NEUTRONS:
- \- NO NEED
- H HEATING
- R SPECIFIC REACTIONS
- D MATERIALS DAMAGE

TEST PARAMETERS:
- B MAGNETIC FIELD
- F FLUENCE
- G GEOMETRY
- I IMPURITIES
- S SPECTRUM
- T TEMPERATURE
- V VELOCITY
- σ STRESS
- ϕ FLUX

TYPES OF TESTS IN TECHNOLOGY DEVELOPMENT

- BASIC TESTS (SPECIMEN)
  - BASIC DATA

- SEPARATE-EFFECT TESTS (SPECIMEN, ELEMENT)
  - SIMULATION OF ONE ENVIRONMENT ELEMENT
  - PHENOMENOLOGICAL, VERIFY SINGLE-EFFECT PREDICTION CAPABILITY

- MULTIPLE-EFFECT TESTS (ELEMENT, SUBMODULE)
  - SIMULATION OF TWO OR MORE ENVIRONMENTAL ELEMENTS
  - INTERACTION AMONG TWO OR MORE EFFECTS
  - VERIFY PREDICTION CAPABILITY FOR SPECIFIC INTERACTIONS

- INTEGRATED TESTS (MODULE, VARIOUS SCALES)
  - ALL ENVIRONMENT ELEMENTS AND INTERACTIVE EFFECTS
  - DISCOVER "UNKNOWNS"
  - FAILURES, FIXES
  - DATA BASE AND INITIAL VERIFICATION OF A DESIGN CONCEPT

- COMPONENT TESTS (FULL SCALE)
  - COMPONENT TESTED IN ACTUAL OPERATION
  - STAGES FOR DESIGN VERIFICATION AND RELIABILITY GROWTH
    - ◇ TEST/DEVELOPMENTAL REACTORS
    - ◇ PROTOTYPE
    - ◇ NEAR-COMMERCIAL

IMPORTANCE OF NEUTRONS

IN TESTING FUSION COMPONENTS

WHAT NEUTRONS DO

- SOURCE OF "BULK" HEAT
- INDUCE CHANGES IN MATERIAL PROPERTIES, "RADIATION EFFECTS, MATERIAL DAMAGE"
- PRODUCE SPECIFIC REACTIONS TO SERVE PARTICULAR FUNCTION, E.G., (N,T)

WHY NEUTRONS A MUST

- NEUTRONS REPRESENT THE ONE INGREDIENT IN THE FUSION ENVIRONMENT THAT:
  - IS MOST HARSH
  - PRODUCES LARGEST EFFECTS/CHANGES
  - CAUSES NUMEROUS CRITICAL FEASIBILITY ISSUES
  - IS LEAST UNDERSTOOD
- THERE ARE NO SUBSTITUTES FOR NEUTRONS:
  - HEATING (CORRECTNESS OF SIMULATION, ECONOMICS)
  - RADIATION EFFECTS (MUST)
  - SPECIFIC REACTIONS (MUST)

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 LM 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 LM
- ACTIVATION AND CORROSION PRODUCTS TRANSPORT
- TRITIUM AND HELIUM HOLDUP AND EFFECTS IN ALL ELEMENTS
- LiOT TRANSPORT (IN Li_2O)

IMPORTANCE OF NEUTRONS
FOR BLANKET/FIRST WALL TESTS

(CONTINUED)

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

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

NEUTRON PRODUCING FACILITIES

- ACCELERATOR-BASED "POINT" SOURCES
- FISSION REACTORS
- FUSION REACTORS

POINT NEUTRON SOURCES

- NECESSARY/USEFUL FOR SPECIFIC PURPOSES
  - RADIATION EFFECTS IN CAPSULES (FLUENCE)
  - NEUTRONICS (TRITIUM BREEDING, SHIELDING)
  - NOT SUITABLE FOR MULTIPLE-EFFECT/INTEGRATED TESTS

FISSION REACTORS

- LARGER (BUT LIMITED) VOLUME THAN POINT SOURCES
- SUITABLE FOR CAPSULE AND SUBELEMENT TESTS, E.G., TRITIUM RECOVERY
- ARE BEING USED AND WE NEED TO CONTINUE TO USE THEM
- BUT, THEY CANNOT SUBSTITUTE FOR FUSION TESTING
  - LIMITATIONS ON VOLUME
  - LIMITATIONS ON SIMULATING ENVIRONMENT ELEMENTS (E.G., ELECTROMAGNETIC)
  - LIMITATIONS ON SIMULATING ENVIRONMENTAL PARAMETERS, E.G., POWER DENSITY, SPATIAL/TIME DEPENDENCE, ETC.
  - SPECTRAL DIFFERENCES FROM FUSION NEUTRONS

FUSION FACILITIES FOR TESTING NUCLEAR COMPONENTS

ARE THEY NEEDED?

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

WHY?

- 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 2×10^{18}-10^{19} N/S
  OBTAINABLE ONLY IN FUSION REACTOR

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

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

LIMITATIONS/PROBLEMS OF FUSION DEVICES AS TEST FACILITIES

- COST
  - RELATIVELY HIGH ON A SINGLE CAPITAL INVESTMENT BASIS
  - NOT EXPENSIVE ON A PER NEUTRON BASIS AS COMPARED TO OTHER NON-FUSION NEUTRON SOURCES

- RISKS IN DEVICE PERFORMANCE/OPERATION
  - PLASMA PERFORMANCE: DATA BASE FOR SOME TYPE OF "NEUTRON-PRODUCING PLASMA?"
  - ENGINEERING COMPONENTS:
    - ◇ RELIABILITY/AVAILABILITY?
    - ◇ DEVELOPMENTAL NEEDS ARE IN THE MAINSTREAM OF OVERALL FUSION ENGINEERING DEVELOPMENT REQUIREMENTS? SERVE AS A FOCUSING/FORCING FUNCTION?

- POTENTIALLY SERIOUS LIMITATIONS ON SIMULATING ENVIRONMENTAL PARAMETERS
  - COST FORCES SCALED-DOWN CONDITIONS
  - "LOOK-ALIKE" TEST MODULES ARE USELESS
  - "ACT-ALIKE" TEST MODULES ARE BEING EXAMINED
  - MANY DIFFICULTIES ARE ENCOUNTERED; COMPLEX ISSUES WITH ENGINEERING SCALING ARE BEING ADDRESSED

FUSION NUCLEAR ENGINEERING TEST DEVICE

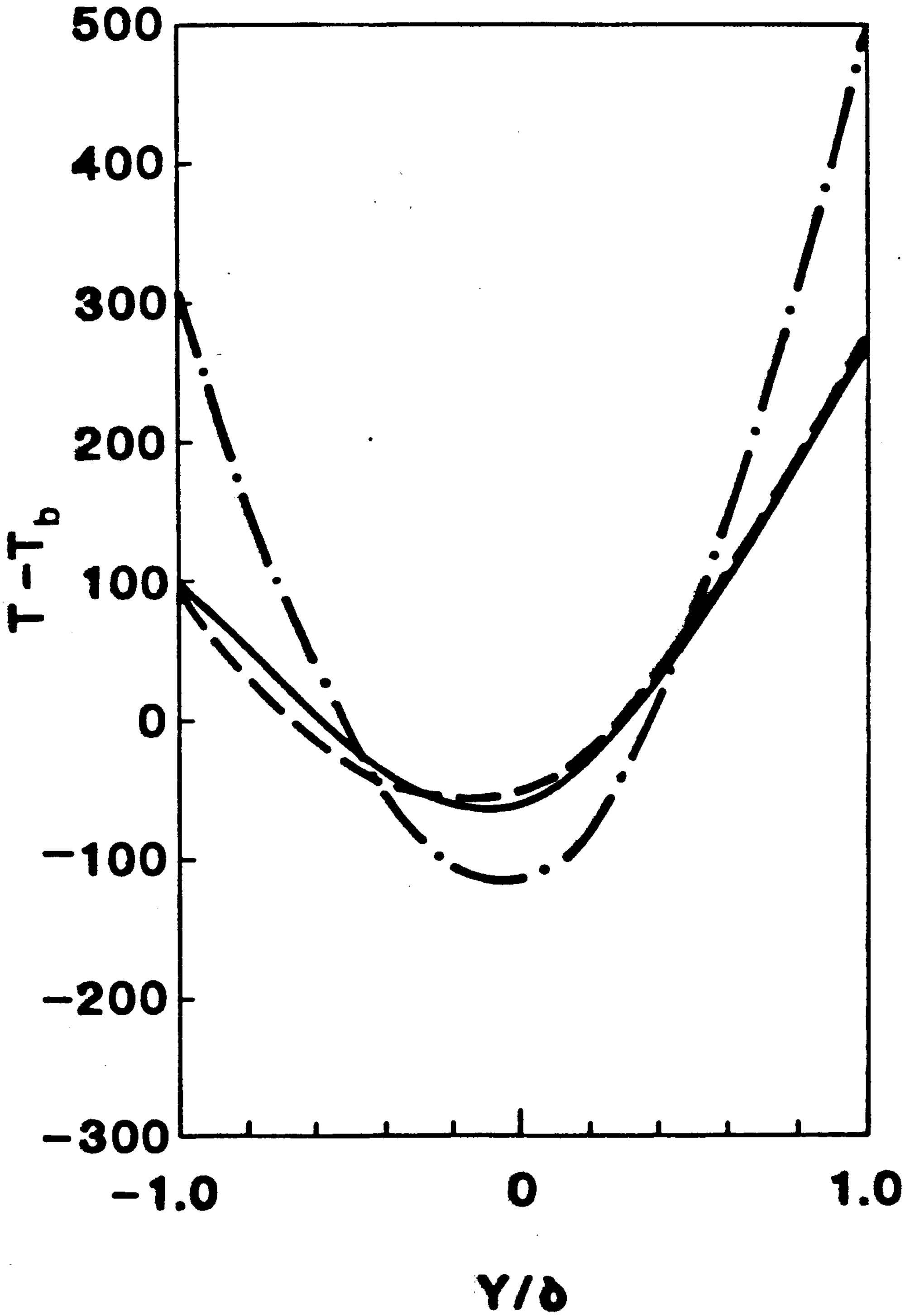
KEY TESTING/COST PARAMETERS

MAJOR PARAMETERS THAT ARE:

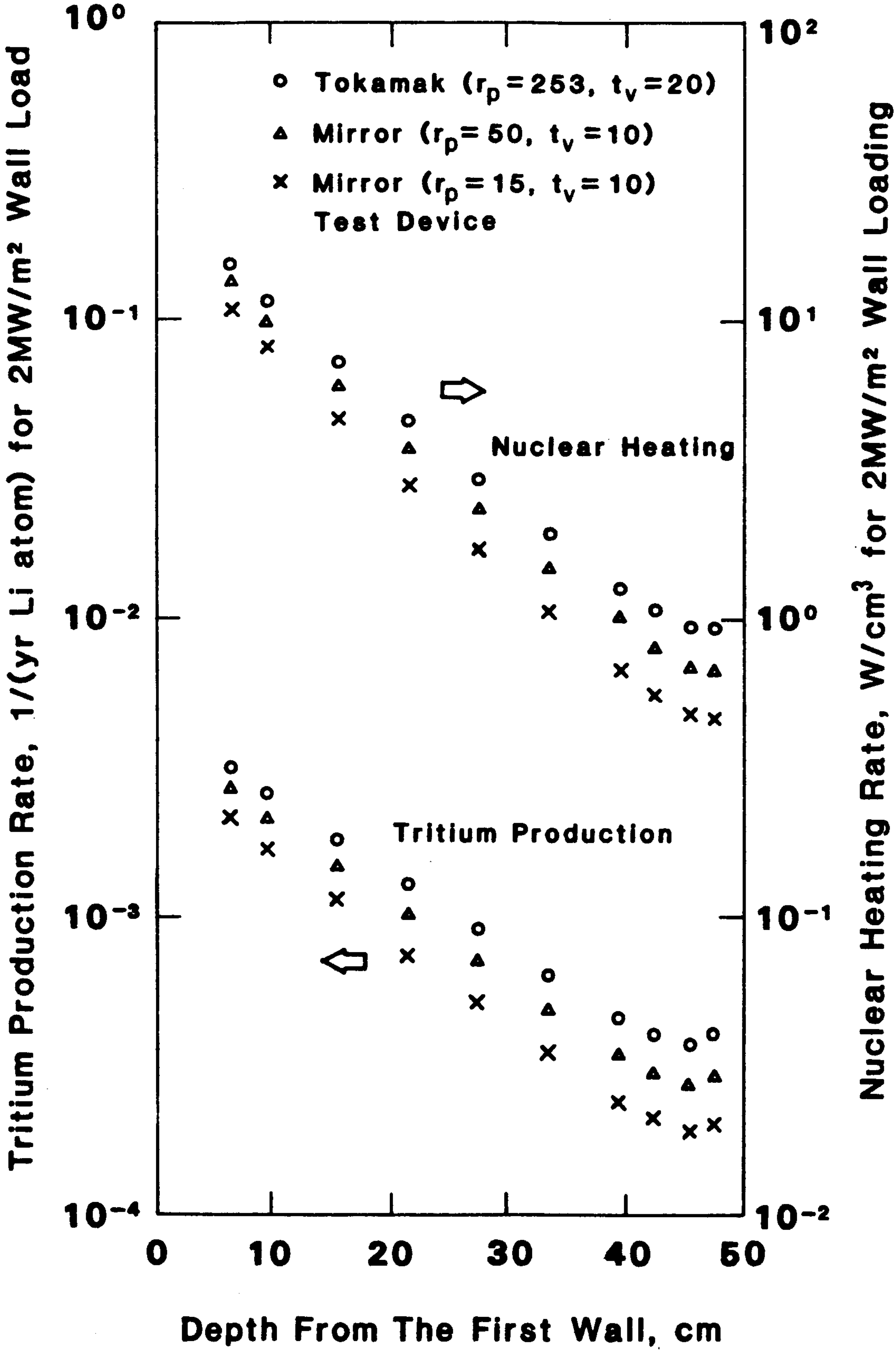
- CRITICAL TO SUCCESSFUL TESTING
- DRIVERS ON TESTING DEVICE COST

1. NEUTRON WALL LOAD (POWER DENSITY)
2. SURFACE HEAT LOAD
3. FLUENCE (FLUENCE ~ WALL LOAD X LIFETIME X AVAILABILITY)
4. MINIMUM CONTINUOUS (100% AVAILABILITY) OPERATING PERIOD
5. PLASMA BURN CYCLE (BURN/DWELL TIME)
6. MAGNETIC FIELD STRENGTH
7. SURFACE AREA FOR TESTING:
   - SURFACE AREA FOR TESTING ELEMENT
   - TEST MATRIX
8. VOLUME FOR TESTING:
   - DEPTH OF TEST ELEMENT
   - TEST MATRIX

HEAT TRANSFER COEFFICIENT IN LIQUID METALS DEPENDS ON <u>BULK</u> HEATING



FOR THE SAME WALL LOAD,



FISSION EXPERIENCE AND LESSONS LEARNED

- MAJOR TECHNOLOGICAL DEVELOPMENTS REQUIRE EXTREMELY LONG LEAD TIMES

  LMFBR ~ 40 YEARS AFTER PROOF OF PRINCIPLE

  CLEMENTINE AND EBR-I (1940'S)

- PRESENT DIFFICULTIES ENCOUNTERED BY FISSION PROGRAM ARE ATTRIBUTED TO:

  - ECONOMICS (ULTIMATE INDUSTRY ACCEPTANCE TEST)

    LMFBR (POTENTIAL)

    LWR (COSTLY DELAYS, REGULATIONS, ETC.)

  - PUBLIC ACCEPTANCE

  - REGULATIONS

- CONFIRMATION OF A NEW, SOPHISTICATED TECHNOLOGY REQUIRES:

  A. A SERIES OF DEMONSTRATION AND PROTOTYPE PLANTS OF PROGRESSIVELY LARGER SIZE

  OR

  B. A VIGOROUS COMPONENT DEVELOPMENT AND TESTING PROGRAM IN CONJUNCTION WITH SELECTIVELY FEWER DEMONSTRATION PLANTS

FISSION EXPERIENCE AND LESSONS LEARNED

(CONTINUED)

- TEST FACILITIES HAVE PLAYED AN INDISPENSABLE ROLE IN THE DEVELOPMENT OF THE LMFBR PROGRAM
  - NEW TEST FACILITIES: CLEMENTINE, EBR-I, SEFOR, EBR-II, EFFBR, FFTF
  - NEW SPECIAL-PURPOSE FACILITIES: MANY
  - USE OF EXISTING FACILITIES: EXTENSIVE

- FISSION HAD AN ADVANTAGE IN THAT IN-PILE TESTING FACILITIES WERE ALWAYS AVAILABLE

- PREMATURE EXPANSION OF SOME OF THE EARLY TECHNOLOGY BEYOND ITS LIMITS RESULTED IN COSTLY FAILURES AND DELAYS. THESE DELAYS WERE CAUSED BY USING COMPONENTS THAT HAD NOT BEEN THOROUGHLY TESTED. WHEN A SINGLE IMPORTANT COMPONENT FAILED, THE ENTIRE FACILITY WAS SHUT DOWN. SUCH DELAYS RESULTED IN FURTHER MOVEMENT TOWARD EXTENSIVE TESTING OF COMPONENTS PRIOR TO SYSTEM INTEGRATION.

- ALTHOUGH EARLY PROGRAM PLANNING TENDED TO DIFFERENTIATE BETWEEN PHENOMENOLOGICAL (SEPARATE-EFFECTS) TESTS AND INTEGRAL TESTS, IT WAS SEEN THAT FREQUENTLY SMALL-SCALE TESTS THAT ADDRESSED SEPARATE EFFECTS HAD TO BE EVOLVED INTO LARGE INTEGRAL TESTS. IN OTHER CASES, HOWEVER, DISTINCTION BETWEEN THE TWO TYPES PERSISTED TO THE POINT OF REQUIRING DIFFERENT IN-REACTOR FACILITIES.

FISSION EXPERIENCE AND LESSONS LEARNED

(CONTINUED)

- ADMIRAL RICKOVER ALWAYS INSISTED ON BUILDING A COMPLETE PROTOTYPE OF A REACTOR FOR TESTING. EXPERTS CREDIT THIS FOR THE SUCCESS OF HIS PROGRAM.

- MOST OF THE SIGNIFICANT ECONOMICS DECISIONS IN THE FISSION INDUSTRY WERE MADE BASED PRIMARILY ON THE INITIAL CAPITAL COST WHILE THE AVAILABILITY WAS REPRESENTED BY A RATHER ARBITRARY CONSTANT. SOME EXPERTS THINK THIS WAS A MISTAKE. A BETTER SYSTEM WOULD HAVE BEEN POSSIBLE IF IMPROVED **AVAILABILITY** AND **MAINTANCE** HAD BEEN EMPHASIZED MORE.

- EARLY **INDUSTRIAL INVOLVEMENT**, INCLUDING THE UTILITY INDUSTRY, IS ESSENTIAL TO COMMERCIAL ACCEPTANCE.

WHY SHOULD RESEARCH BE CARRIED OUT NOW ON BLANKET, MATERIALS AND NUCLEAR ISSUES?

- THE DEVELOPMENT OF A VIABLE FIRST WALL AND BLANKET CONCEPT REPRESENTS A MAJOR, UNRESOLVED FEASIBILITY ISSUE FOR FUSION

- THE SELECTION OF A FIRST WALL AND BLANKET CONCEPT CAN SIGNIFICANTLY IMPACT PLASMA ENGINEERING ISSUES AND VICE VERSA. EXAMPLES INCLUDE:

  - IMPURITY CONTROL OPTIONS

  - ACCESS AND MAINTENANCE

- OPERATION OF ANY FUSION DEVICE THAT BURNS TRITIUM FOR A SIGNIFICANT PERIOD OF TIME WILL REQUIRE CONSTRUCTION OF A TRITIUM-PRODUCING BLANKET

- THE PERCEPTION OF FUSION'S SAFETY AND ENVIRONMENTAL FEATURES IS LARGELY DETERMINED BY NUCLEAR/MATERIALS TECHNOLOGY CONSIDERATIONS

- FUSION ECONOMICS WILL GREATLY DEPEND ON THE PERFORMANCE OF THE NUCLEAR SYSTEM

- THE TIME SCALE FOR THE DEVELOPMENT OF NUCLEAR COMPONENTS IS LONG

- LESSONS LEARNED FROM OTHER TECHNOLOGY DEVELOPMENT STRONGLY SUGGEST WORKING ON LONG LEAD TIME ITEMS EARLY

SUMMARY AND RECOMMENDATIONS
(CONTINUED)

FUSION NUCLEAR TECHNOLOGY DEVELOPMENT

- INVOLVES MANY FUSION UNRESOLVED ISSUES IN:
  - FEASIBILITY (TECHNOLOGY COMMUNITY ACCEPTANCE)
  - ECONOMICS (INDUSTRY, UTILITY ACCEPTANCE)
  - SAFETY, ENVIRONMENT (PUBLIC ACCEPTANCE)

  THEREFORE, A STRONG PROGRAM ON FUSION **NUCLEAR** TECHNOLOGY IS A **NECESSARY** ELEMENT OF THE NATIONAL/INTERNATIONAL FUSION PROGRAM

- CHARACTERISTICS OF NUCLEAR DEVELOPMENT
  - REQUIRES LONG LEAD TIME
    - ◇ START **NOW**
    - ◇ REALISM IN TIME SCHEDULE
  - RELATIVELY EXPENSIVE
    - ◇ CAREFUL PLANNING
    - ◇ INTERNATIONAL OPTIONS
  - COMPLEX
    - ◇ UNDERSTAND ISSUES AND TESTING NEEDS
    - ◇ QUANTIFY TEST REQUIREMENTS
    - ◇ INVESTIGATE, DEVELOP ENGINEERING SCALING RELATIONSHIPS

- **DEVELOPING DATA BASE IN PHYSICS AND ENGINEERING**

  I. PLASMA

    A. PHYSICS: SMALL DEVICES PLUS A MAJOR DEVICE (TFCX)

    B. PLASMA-INTERACTIVE COMPONENTS: PARTIALLY IN PHYSICS DEVICES

  II. ENGINEERING

    A. SUPERCONDUCTING MAGNETS: EITHER IN MAJOR PHYSICS DEVICE OR MAJOR ENGINEERING TEST DEVICE

    B. AUXILIARY HEATING: IN BOTH PHYSICS AND ENGINEERING DEVICES

    C. NUCLEAR COMPONENTS/ENVIRONMENT:

      - SEPARATE AND MULTIPLE-EFFECT TESTS (MOST CRITICAL TIME FRAME: 1985-1995)

        ◇ SOME ARE IN PROGRESS

        ◇ NEED ADDITIONAL IMPORTANT SMALL SCALE FACILITIES AND TESTS IN NEUTRON-PRODUCING NON-FUSION FACILITIES

      - INTEGRATED TESTS

        ◇ SIGNIFICANT TESTS TO START BY THE MID 1990'S

        ◇ DEDICATED FUSION NUCLEAR TESTING FACILITY?

SUMMARY AND RECOMMENDATIONS
(CONTINUED)

- **KEY REQUIREMENTS IN THE R&D STRATEGY**

I. FOCUS ON:

A. MAJOR FEASIBILITY ISSUES IN PHYSICS AND ENGINEERING

- REALISTIC TESTS
  - ◇ SINGLE/MULTIPLE EFFECT TESTS
  - ◇ INTEGRATED TESTS
- ANALYTICAL/COMPUTATIONAL MODELING

B. ATTRACTIVENESS ISSUES

- LEARN PHYSICS AND ENGINEERING LIMITS FROM REALISTIC TESTS
- ENCOURAGE INNOVATIVE IDEAS
- FOCUS STUDIES AND R&D ON ISSUES RELATED TO:
  - ◇ COST OF ENERGY
  - ◇ SMALLER SIZE UNITS/LOWER CAPITAL COST
  - ◇ IMPROVED SAFETY (BUT CREDIBLE AND ECONOMICAL)

II. STRIVE TO MAINTAIN BALANCE IN R&D AMONG MAJOR FEASIBILITY ISSUES IN PHYSICS AND ENGINEERING

- **JUDGING THE POTENTIAL**

A. WHAT TO BE JUDGED

CONCEPTUAL DEFINITION OF END PRODUCT

PLUS

DATA BASE

B. JUDGEMENT CRITERIA

1. FEASIBILITY

   - HARD AND CONVINCING DATA FROM REALISTIC TESTING
   - EXPERIENCE TO SHOW THAT MAJOR FEASIBILITY ISSUES ARE RESOLVED

2. POTENTIAL ATTRACTIVENESS OF END PRODUCT

   - CREDIBLY EXTRAPOLATED DATA BASE
   - ECONOMICS
   - SAFETY AND ENVIRONMENT

SUMMARY AND RECOMMENDATIONS

- CLEARLY DEFINED **INTERMEDIATE** AND **ULTIMATE GOALS** FOR FUSION ARE FUNDAMENTAL TO PROGRAM DIRECTION AND **DEVELOPMENT** STRATEGY

    - ◇ THERE IS NO SINGLE UNIQUE BEST STRATEGY

    - ◇ BEST STRATEGY IS THE ONE THAT ACHIEVES THE GOALS WITH MINIMUM TIME, COST

- GOALS:

  - ULTIMATE

    COMMERCIAL POWER REACTORS

  - INTERMEDIATE (~ YEAR 2000)

    DEVELOP SUFFICIENTLY **CREDIBLE** DATA BASE TO PERMIT THE NATION TO QUANTITATIVELY JUDGE THE **POTENTIAL** OF FUSION