FUSION NUCLEAR TECHNOLOGY DEVELOPMENT STRATEGY

MOHAMED A. ABDOU
UCLA

NOVEMBER, 1983

BACKGROUND ON STRATEGY FOR FUSION DEVELOPMENT

OLD STRATEGY

- ONE ENGINEERING TEST REACTOR FOR PHYSICS AND TECHNOLOGY
  EXAMPLE: FED, INTOR
- PROBLEMS: DEVICES ARE TOO COSTLY, RISKY

TRENDS IN PRESENT STRATEGY

TFCX	FOR PHYSICS TESTING
?	FOR NUCLEAR TECHNOLOGY TESTING

FINESSE PROGRAM SCOPE

- IS A NEW FUSION DEVICE DEDICATED TO NUCLEAR TESTING NEEDED?
- WHAT IS THE BEST DEVICE?

FUSION NUCLEAR TECHNOLOGY DEVELOPMENT STRATEGY

OBJECTIVES

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

EMPHASIS

ISSUES RELATED TO INTEGRATED NUCLEAR TESTS

FOCUS

INTEGRATED NUCLEAR TESTS THAT REQUIRE A SIGNIFICANT NEUTRON FIELD AS A KEY ELEMENT OF THE TEST ENVIRONMENT

GENERAL FEATURES OF THE PROGRAM

- Two-Year Study Starting November 1, 1983. Higher Level of Effort in FY 1985.
- UCLA is Lead Technical Organization
  - Core Group
  - Assure Objectivity
- Subcontractors (being Negotiated)
  - ANL
  - EG&G Idaho
  - HEDL
  - TRW
  - Others
- International Participation
  - Strong Interest in Japan, Europe
  - World Programs Face the Same Issue
  - A Nuclear Technology Development Facility can possibly be Built through International Cooperation
- Very High Priority in the U.S.
  - OFE - Strong Support and Enthusiasm
  - MFAC - Endorsed Idea/Principle (Panels III, IV, and VI)
  - LLNL - Strongly Supportive
  - PPPL - Very Supportive
  - "Nuclear" Organizations

APPROACH/SCOPE/TASKS

I. IDENTIFICATION OF NEEDED NUCLEAR TESTS

- EMPHASIZE NEUTRON-RELATED TESTS
- CLASSIFY ACCORDING TO NEUTRON FUNCTION, HEATING, RADIATION EFFECTS, SPECIFIC REACTIONS

II. QUANTIFYING REQUIREMENTS ON TEST CONDITIONS AND DEVELOPING INFORMATION WITH WHICH TO JUDGE USEFULNESS OF INFORMATION FROM VARIOUS TEST FACILITIES

III. EVALUATION OF EXPERIENCE FROM OTHER TECHNOLOGY DEVELOPMENT (FISSION, AEROSPACE)

IV. SURVEY & EVALUATION OF NEUTRON-PRODUCING FACILITIES

A. NON-FUSION DEVICES (FISSION REACTORS, ACCELERATOR-BASED NEUTRON SOURCES)

B. FUSION DEVICES (MIRRORS, TOKAMAKS, OTHERS)

V. COMPARATIVE EVALUATION OF NON-FUSION AND FUSION DEVICES

- SATISFYING TECHNICAL REQUIREMENTS
- COST
- SCHEDULE

TASK I. IDENTIFICATION OF NEEDED NUCLEAR TESTS

- IDENTIFY KEY ISSUES FOR ALL NUCLEAR COMPONENTS: BLANKET, SHIELD, LIMITER/DIVERTOR, RF, TRITIUM, SAFETY, ETC.

- CHARACTERIZE THE OPERATIONAL ENVIRONMENT AND KEY RESPONSES
  OPERATIONAL ENVIRONMENT: THERMOMECHANICAL, ELECTROMAGNETIC, NUCLEAR
  RESPONSES: TEMPERATURE, STRESS, TRITIUM BREEDING RATIO, ETC.

- EXAMINE THE IMPORTANCE OF NEUTRONS TO EACH RESPONSE

  A. NEUTRON-MATERIAL INTERACTION RESULTING IN CHANGES OF MATERIAL PROPERTIES

  B. SOURCE OF HEAT

  C. SPECIFIC NEUTRON INTERACTIONS TO SERVE PARTICULAR FUNCTIONS, E.G., (N,T), FOR TRITIUM BREEDING OR SHIELDING

Table 1. Examples of Nuclear Technology Issues

Technology Area	Major Issues	Examples of Key Factors
In-Vessel Components (First Wall, Limiter, Divertor)	• Efficient Heat Recovery	• Radiation damage, plasma erosion, plasma disruptions coolant corrosion, thermal stresses, electromagnetic forces
	• Plasma-Wall Interaction	• Physical and chemical sputtering, redeposition, PMI during disruptions, tritium permeation, arcing
	• Thermal Energy Recovery Efficiency	• Temperature limits, surface heating rates, coolant pressure
Blanket Components	• Tritium Production	• Nuclear data, calculational methods, breeding material, neutron multiplier, structure, coolant
	• Tritium Recovery	• Solid breeders/liquid metals, tritium solubility and diffusion, tritium production rate spatial distribution, heating/temperature distributions, radiation effects
	• Compatible Materials Combination	• Structure/coolant, breeder/coolant, multiplier/structure, multiplier/coolant, corrosion rates, mass transfer, electromagnetic effects, radiation effects
	• Efficient Heat Recovery	• Temperature limits, pumping power, thermal-hydraulic and thermomechanical response
	• Acceptable Lifetime	• Radiation effects in structure/breeder, thermal/mechanical electromagnetic loadings
Radiation Shield	• Prediction Capability	• Nuclear data, neutron and gamma transport codes, response function codes, materials physical integrity
	• Radiation Protection Criteria	• Personnel and reactor component protection
Other Related Components	• rf Launchers	• Structure/cooling requirements, dielectric properties
	• Neutral Beam Cryopanels	• Heating, radiation effects
	• Magnets	• Superconductor current density, stabilizer resistivity, insulator mechanical & dieletric properties

TASK II. QUANTIFYING THE TESTING REQUIREMENTS

- Critical Task: Quantify the Requirements on the Test Environment Conditions and Develop Evaluation Criteria for Judging the Usefulness of Information from Various Facilities

1. Determine the Neutron Field (Magnitude and Spectrum) and Appropriate Neutron Responses in the Components of Typical Fusion Reactors

2. Derive Requirements on Test Conditions (i.e., Define Necessary Conditions for Each "Neutron-Related" Test)

3. Establish Scaling Relationships and Minimum Test Element Size for Acceptable Engineering Scaling

4. Define the Test Matrix

   - Number, Size, Other Features of Test Elements
   - Test Matrix Should Account for Test Variables (Temperature, Stress, Etc.)

5. Test Module/Test Element Design

   - To the Extent Necessary to Quantify 1, 2, and 3

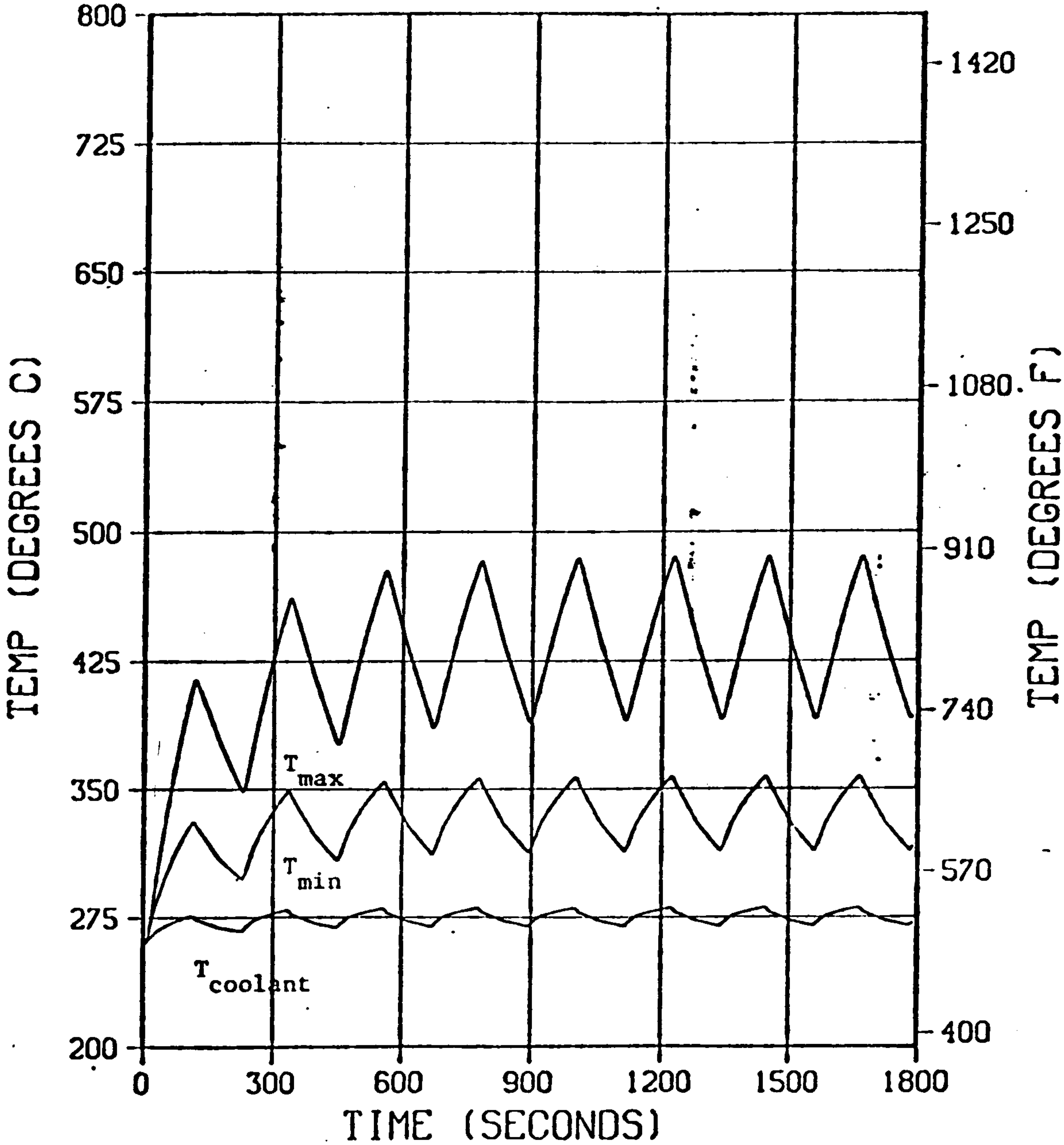

Fig. 1. Variation of the maximum and minimum temperature in a solid breeder with irradiation time. The blanket is exposed to a 14 MeV neutron planar source with 4×10^{13} n/cm^2 · s ($\sim$ 1MW/m^2). The initial condition is a uniform temperature of 260°C. The neutron pulse is assumed to be 100 s long and the time between pulses is 80 s.

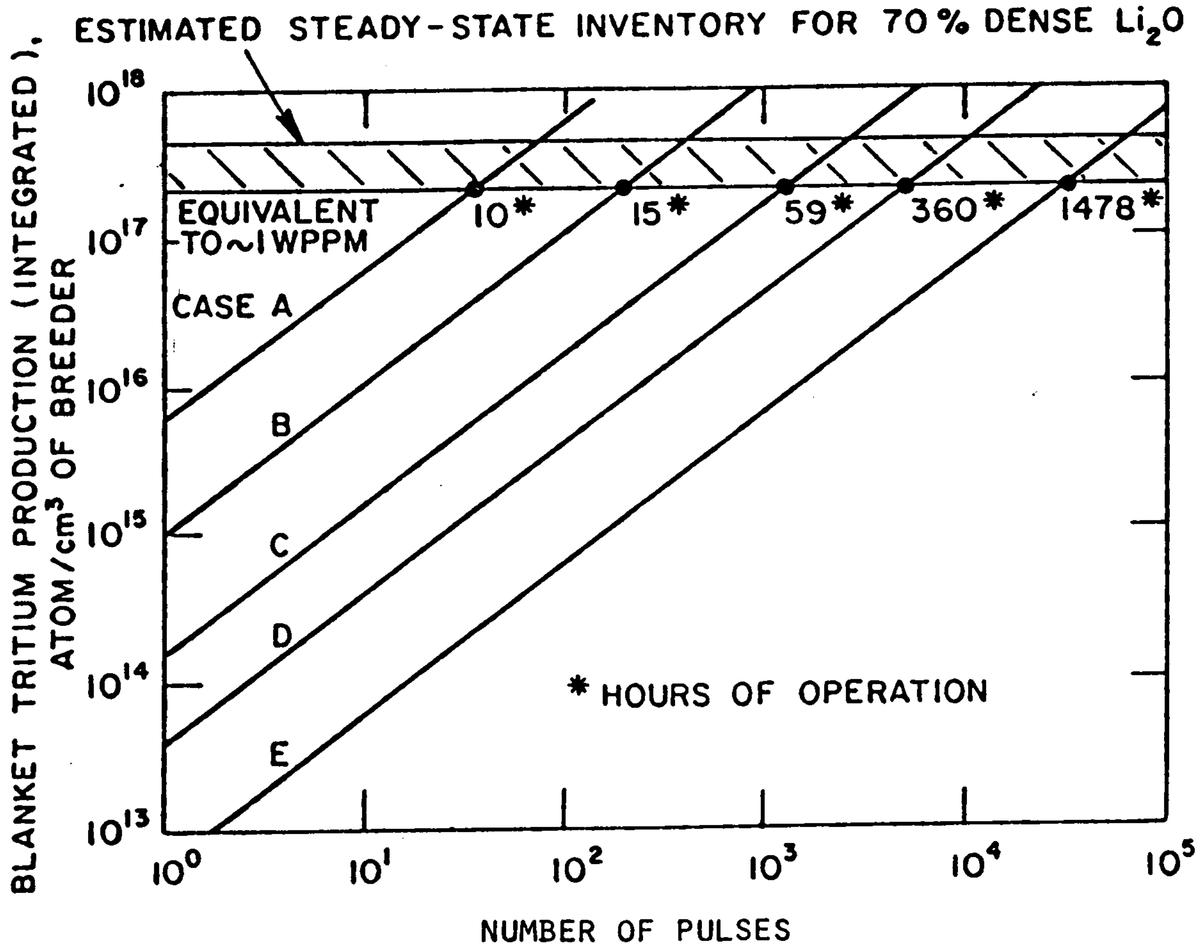

Fig. 2. Number of burn cycles and operating time for various test conditions (wall load and burn time). Case A: P_w = 2 MW/m^2, t_b = 1000 s; Case B: 1.3 MW/m^2, t_b = 200 s; Case C: P_w = 0.4 MW/m^2, t_b = 100 s. Cases D and E are similar to Cases B and C, respectively, but tritium production is measured at the back region of the blanket rather than immediately behind the first wall. In all cases, the dwell time is 50 s.

TASK III. EXPERIENCE FROM OTHER TECHNOLOGIES

- OBJECTIVE: LEARN FROM EXPERIENCE IN DEVELOPING OTHER TECHNOLOGIES (E.G., FISSION REACTORS, AEROSPACE)
- APPROACH:
  - FORM A TECHNOLOGY DEVELOPMENT PANEL
    - MEMBERSHIP: SENIOR REPRESENTATIVES FROM OTHER TECHNOLOGIES
    - PANEL MEMBERS WILL PREPARE BRIEFINGS ON LESSONS LEARNED
    - PANEL MEMBERS WILL ANSWER SPECIFIC QUESTIONS FORMULATED BY FINESSE
    - PARTICIPATE WITH OTHER SENIOR MEMBERS OF THE FUSION COMMUNITY IN REVIEWING FINESSE APPROACH, RESULTS, AND RECOMMENDATIONS
  - WHERE APPROPRIATE, SPECIAL GROUPS WILL BE ASKED TO ADDRESS SPECIFIC AREAS
  - FOR EXAMPLE: SUMMARY OF EXPERIENCE FROM FISSION REACTOR TESTING
    - PREPARE SUMMARY OF FAST BREEDER TEST FACILITIES, INCLUDING OBJECTIVES, KEY FEATURES, COSTS, ETC.
    - WHAT ISSUES REQUIRED INTEGRATED TESTING?
    - WHAT TYPES OF FACILITIES WERE PROPOSED? WHAT APPROACH WAS TAKEN TO IDENTIFY SUCH FACILITIES? HOW WERE THE FINAL DECISIONS MADE?
    - WHAT PROBLEMS COULD HAVE BEEN AVOIDED IF MORE INTEGRATED TESTING WAS DONE?

FUSION INTEGRATED NUCLEAR TESTING MAY REQUIRE NEW AND INNOVATIVE APPROACHES

- ALL FACILITIES (INCLUDING FUSION DEVICES WHICH CAN BE BUILT IN THE LATE 1980'S AND 1990'S) HAVE SHORTCOMINGS

- CAN WE IMPROVE THE USEFULNESS OF TESTS?
  - EXAMPLE: LOW POWER DENSITY ISSUE; CAN WE ENHANCE IT (RF HEATING, SOME URANIUM)?

- GENERAL ISSUES
  - NOT ALL TEST CONDITIONS CAN BE MET
  - FULL SIZE MODULE TESTING MAY BE USELESS IN MOST CASES (E.G., TEMPERATURE, STRESS, TRITIUM RECOVERY, ETC.)

- CONCLUSION: MUST DESIGN TEST ELEMENTS FOR SPECIFIC TYPES OF TESTS
  - HOW CAN WE GROUP EFFECTS THAT CAN BE TESTED SIMULTANEOUSLY IN THE SAME TEST ELEMENT?
  - HOW CAN WE SYNTHESIZE RESULTS FROM VARIOUS TEST ELEMENTS?
  - HOW CAN WE GET INFORMATION ON FAILURE RATES, FAILURE MODES, AND OTHER EFFECTS DIFFICULT TO OBTAIN IN SIMULATED CONDITIONS?

TASK IV. SURVEY & EVALUATION OF NEUTRON-PRODUCING FACILITIES

- INCLUDE AVAILABLE, PLANNED, AND PROPOSED FACILITIES

- INCLUDE NON-FUSION FACILITIES AND FUSION FACILITIES

  - NON-FUSION FACILITIES:

    - ACCELERATOR-BASED SOURCES (ASSUMPTION: FMIT WILL BE AVAILABLE)

    - FISSION REACTORS (THERMAL, FAST)

  - FUSION FACILITIES:

    - MFTF-B UPGRADE (α + T)

    - TFTR UPGRADE

    - OTHER MIRROR AND TOKAMAK OPTIONS (DEDICATED NEW FACILITY)

TASK IV.

(COMPLEMENTARY) NON-FUSION FACILITIES

- Accelerator-Based Neutron Sources will be Reviewed Briefly
  - Appropriate for Specific Purposes: Material Capsule Tests, Neutronics (Tritium Breeding, Shielding), Others?
  - In General, Not Suitable for Integrated Tests
- Fission Reactors will be Examined in Detail
  - Survey and Characterization of Available Test Facilities
  - Technical Evaluation of Their Usefulness for Fusion Tests
- Survey and Characterization of Fission Reactors as Test Facilities
  - Maximum Testing Volume
  - Fluxes, Spectra
  - Cost of Testing
  - Availability to Fusion Testing (New and Over the Next 20 Years)
  - Are Major Modifications Required?
  - General Limitations on Testing

TASK IV.

(COMPLEMENTARY) NON-FUSION FACILITIES (CONTD.)

- TECHNICAL EVALUATION OF USEFULNESS
  - USING RESULTS FROM:
    - SURVEY AND CHARACTERIZATION SUBTASK
    - QUANTIFYING THE FUSION TEST REQUIREMENTS SUBTASK
  - EXAMPLES OF KEY ANTICIPATED ISSUES:
    - EFFECTS OF FISSION/FUSION SPECTRAL DIFFERENCES
    - DIFFERENCES IN POWER DENSITY
    - BURNUP RATE
    - LIMITATIONS ON TEST VOLUME
    - DIFFICULTIES IN SUPERIMPOSING NON-NUCLEAR CONDITIONS (E.G., ELECTROMAGNETICS)
    - FLUENCE
    - FLUX DEPRESSION

TASK IV.

FUSION DEVICES AS NUCLEAR TEST FACILITIES

- This Subtask will Focus on Evaluation, Selection and Preliminary Design of a NEW Fusion Device DEDICATED to Nuclear Testing

- Options: Mirrors; Tokamaks; Wide Range of Design, Operation and Cost Conditions

- General Issues
  - Minimum Physics Performance Required from Nuclear Testing Viewpoint
  - Risk in Attaining Such Performance
    Physics: e.g., β in Tokamaks, Halophysics in Mirrors
    Technology: Device Availability/Reliability
  - Size
  - Cost
  - Schedule
  - Type of Facility

- Key/Critical Design Parameters
  - Neutron Wall Load
  - Surface Heat Load/Erosion
  - Plasma Burn Time
  - Plasma Dwell Time
  - "Continuous" Operating Period (100% Availability)
  - Fluence
  - Surface Area for Testing
  - Volume for Testing

TASK IV.

TOKAMAKS AS NUCLEAR TEST FACILITIES

- ISSUES:
  - NEUTRON (PLASMA) PULSE LIMITED (IN THE NEAR TERM) TO ONLY 10-100 SECONDS
    - CAN WE GET STEADY STATE IN THE LATE 1980'S WITH REASONABLE ASSURANCE AND MODERATE COST?
  - MINIMUM DEVICE SIZE IS DICTATED BY PHYSICS
    - LARGE SIZE NEEDED FOR HIGH WALL LOAD
  - DEVICE SIZE IS GREATLY AFFECTED BY FLUENCE REQUIREMENTS (SHIELD THICKNESS/MAGNETIC FIELD)

- WHY DO WE NEED TO CONSIDER TOKAMAKS AS TEST FACILITIES?
  - CANNOT BE CERTAIN MIRRORS WILL WORK; NEED TOKAMAKS AT LEAST AS BACKUP
  - NEW IDEAS MIGHT MAKE TOKAMAKS A STRONG CONTENDER

- TOKAMAK WORK WILL BE LED BY PPPL WITH STRONG SUPPORT FROM ANL

TASK IV.

MIRRORS AS TEST FACILITIES

- PRIMARY ADVANTAGES:
  - DECOUPLING OF POWER DENSITY AND REACTOR SIZE
  - STEADY STATE APPEARS ATTAINABLE
  - PHYSICS BASIS CAN BE VERIFIED IN THE 1980'S
- DISADVANTAGES:
  - END CELLS ARE COSTLY
  - TO KEEP THE CENTRAL CELL COST LOW, ONE MUST COMPROMISE ON TEST VOLUME, SURFACE AREA
- PROPOSALS HAVE BEEN MADE IN RECENT YEARS:
  - LLNL: MFTF-B UPGRADE (α+T)
  - LLNL: TDF
  - GERMANY/U. OF WISCONSIN: TASKA, TASKA-M
  - JAPAN/U. OF TSKUBA
- MIRROR WORK IN FINESSE WILL BE LED BY TRW WITH STRONG SUPPORT FROM LLNL

TASK V.

COMPARATIVE EVALUATION AND RECOMMENDATION ON STRATEGY

- Compare Various Types (Non-Fusion and Fusion, Mirrors, Tokamaks, Etc.) of Facilities on the Basis of:
  - Technical Capabilities
  - Cost
  - Time
  - "Cost/Benefit/Risk"

- Evaluate Several Strategies, Such as:
  - FMIT and Fission Reactors Alone; No Dedicated Fusion Test Facility
  - FMIT and Fusion Device; No Fission Reactors
    - Mirror α+T Upgrade
    - New Mirror Facility
    - New Tokamak Faculity
  - Mix of Fusion, Non-Fusion Facilities
  - Others

- Recommendations will be Made on the Strategy for Developing Nuclear Components in the U.S. (and Possibly Other Countries)