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OAK
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Mission Statement for the Engineering Test Facility

MASTER

ETF Design Center Team

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UNION CARBIDE CORPORATION
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DEPARTMENT OF ENERGY

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Engineering Test Facility
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ABSTRACT

This Mission Statement defines the ETF activity during its operating life. The results of those operations must provide the data, knowledge, experience, and confidence to continue to the next steps beyond ETF in making fusion power a viable energy option. The results from the ETF mission (operations are assumed to start early in the 1990's) are to bridge the gap between the base of magnetic fusion knowledge at the start of operations and that required to design the EPR/DEMO devices.

1. INTRODUCTION

In September 1978 John Deutch, Director of Energy Research for the U.S. Department of Energy (DOE), articulated the DOE policy for fusion energy. This policy statement encompassed the efforts in both the magnetic confinement and the inertial confinement approaches. In order to develop fusion energy as an economically attractive and environmentally acceptable energy option, the DOE policy statement on fusion energy outlined a three-phase strategy. Sequentially these phases focus on scientific feasibility, engineering testing, and reactor demonstration.

It is anticipated that scientific feasibility will be achieved within the 1980's for both the magnetic confinement approach and the inertial confinement approach. Following the achievement of scientific feasibility, each of the two approaches would move from the applied research phase into an engineering testing phase. The vehicle by which the fusion program would move into this phase of development is designated the Engineering Test Facility (ETF). The ETF would provide a test-bed for reactor components in a fusion environment. These components would be the essential building blocks of the facilities constructed and operated during the reactor demonstration phase. These reactor demonstration phase facilities are designated the Engineering Prototype Reactor (EPR) and the Commercial Demonstration Reactor (DEMO).

In order to initiate preliminary planning for the ETF decision in the magnetic confinement approach, the Office of Fusion Energy (OFE) established the ETF Design Center activity at Oak Ridge National Laboratory (ORNL) to prepare the design of a tokamak ETF. At the same time, a Mirror ETF design task was established at Lawrence Livermore Laboratory.

ETF design tasks will be considered for other confinement concepts as their physics performance is brought up to the level which has been achieved by the tokamak and mirror experiments. Currently the tokamak ETF effort at the ETF Design Center is receiving the highest level of support because tokamaks have achieved the highest level of plasma performance. It is noted that many of the key technological and engineering problems of magnetic confinement fusion concepts are generic in character. The emphasized effort directed toward the tokamak will be of general value to the magnetic fusion program. Such generic issues are highlighted by the needs in materials, magnets, plasma heating by beams and by radio frequency (rf) energy, impurity control and ash removal, tritium handling, maintenance, and availability/reliability.

As a point of departure for ETF activities, it was deemed essential to establish a well-defined statement on the mission of the ETF in the overall fusion program strategy. In the TNS (The Next Step) activities of FY 1978, the various design teams addressed the issue of the mission for the TNS. The Office of Fusion Energy used the mission statement results of last year's TNS activities to develop a preliminary mission statement for the ETF. In order to develop a more detailed and complete mission statement for the ETF, the ETF Design Center organized and conducted an ETF Mission Workshop held in Knoxville, Tennessee, February 13-15, 1979. The ETF Design Center used the results of the Workshop as a major input in developing the Mission Statement. The deliberations of the Workshop have been documented and can be found in ORNL/TM-6733.

The Mission Statement presented here was prepared by the ETF Design Center, reviewed by the ETF Advisory Committee, and approved by DOE's Office of Fusion Energy. This document represents an initial effort and will be reviewed at least once a year for possible revisions. All revisions require approval by the Office of Fusion Energy.

2. DEFINITION OF THE MISSION STATEMENT

This Mission Statement defines the ETF activity during its operating life. The results of those operations must provide the data, knowledge, experience, and confidence to continue to the next steps beyond ETF in making fusion power a viable energy option. The results from the ETF mission (operations are assumed to start early in the 1990's) are to bridge the gap between the base of magnetic fusion knowledge at the start of operations and that required to design the EPR/DEMO devices.

The ETF mission must represent the most expeditious way to proceed to these demonstration activities even though the magnetic fusion concept choice to be ultimately used is not yet confirmed. The facility is to address the engineering and technology issues of the march toward the fusion energy option. The understanding that most of these issues are generic to any magnetic fusion concept loosens the bounds that might otherwise restrict or delay the choice of concepts and directs the attention to the earliest fusion core that can provide the reactor environment for resolutions that will benefit almost equally the contending magnetic fusion approaches. These generic issues include materials, superconducting magnets, neutral beams, rf energy injection, fueling, impurity control and helium ash removal, tritium handling,

maintenance, plasma disruptions, and availability/reliability/operations/cost. The emphasis on the tokamak as the first fusion core for the ETF is based on its unique advanced stage of scientific feasibility demonstration. The ETF mission will also include planned operations in support of the test and study of nongeneric or alternate-concept-specific engineering and technology issues necessary to achieve the best design foundation for proceeding with any of the probable approaches. The cost effectiveness of these design flexibilities will be carefully considered before inclusion in the ETF design.

3. ANTICIPATED FUSION KNOWLEDGE PRIOR TO ETF OPERATION

The start of the ETF facility operations is assumed to be in the early 1990's. In order to define the required ETF testing program or mission that will provide the achievements needed for EPR/DEMO, the data base of physics, technology, and engineering that is expected to be available prior to the ETF operation must be assumed. These assumptions were made and were based on the guideline that only those machines now planned (plus modest upgrades) are to be considered in estimating the data base. A summary of these assumptions is included in the Appendix. A more detailed treatment is included in ORNL/TM-6733. The comparison of this anticipated pre-ETF operation knowledge with that required to build an EPR/DEMO reveals the gaps that must be filled by advancements resulting from ETF operations.

4. ACHIEVEMENTS/MILESTONES

The ETF achievements that are needed to fill the gap between the fusion understanding before ETF operations and that required for EPR/DEMO are stated below.

Plasma Operations

- Impurity and particle control
 - (1) Achieve reactor prototypical impurity control: low Z_{eff} with low Z impurities for long (hundreds of seconds) pulses,
 - (2) Demonstrate successful fueling and helium removal;
- Dynamic scenarios
 - (1) Optimize startup,
 - (2) Achieve reactor-level β over long pulse (~ 100 sec),
 - (3) Demonstrate stably controlled burn,
 - (4) Optimize the termination of high energy density plasma discharges.

Heating/Fueling Technology

- Beams — obtain high availability ($\sim 90\%$) of 50 MW;
- RF — achieve high availability ($\sim 90\%$) of selected system at power levels of 10-50 MW;
- Pellets
 - (1) Achieve 98% availability in sustained fueling mode,
 - (2) Optimize pellet size, penetration, and feed rate.

Tritium/Particle Collection Technology

- Demonstrate successful particle collection and recycling for long (~ 100 sec) pulse D-T burns;
- Demonstrate the tritium handling and control capabilities necessary for EPR/DEMO designs.

Blanket/First Wall/Shield Technology

- Determine the adequacy of first wall designs for EPR/DEMO applications, withstanding physical and chemical sputtering, load cycling, neutron damage, and plasma disruptions and permitting ready replacement;
- Determine the adequacy of tritium breeding blanket designs for EPR/DEMO applications with respect to breeding ratio, cyclic thermal/hydraulic conditions, neutron damage, and replacement;
- Determine the adequacy of EPR/DEMO shield design concepts, including penetration shields, with regard to shielding effectiveness, activation, shield cooling, repair, and replacement.

Maintenance and Engineering Operations

- Demonstrate maintainability of device components;
- Obtain experience from ETF operation for maintainability and design of EPR/DEMO.

Materials

- Determine the performance of critical EPR/DEMO materials in the fusion environment (requires at least 6 MWyr/m^2).

Alternate Concepts

- Determine specific problems that can be addressed with no major ETF design impact, incorporate necessary flexibility, and accomplish tests.

5. TESTING SCHEDULE REQUIREMENTS

The necessary ETF achievements/milestones can be put into three categories: (1) machine dedicated — other test activities are largely interfered with, (2) noninterference — other concurrent significant test activity can continue, and (3) continuous — activities which are conducted as a part of the normal operation.

There is a recognized need for a hydrogen test period, which is also a shakedown period during which the integrated operation of the ETF is checked out in an essentially hands-on mode. In this period an ambitious test schedule for plasma operations is required, and some of the remote maintenance techniques must be proved. The highlights of the testing needs in the hydrogen test phase are shown in Table 1. Some of the tests within a subgroup area may be done in parallel, so the individual test times do not add up to the total time shown as required for the area.

The highlights of the D-T test phase are shown in Table 2, which indicates a rather extensive set of needs. The selection and timing of these tests, shown in the operations schedule (Fig. 1), required consideration of three priorities. The guidelines used for choosing these priorities are (1) tests on those elements that are considered most

Table 1. Hydrogen phase test needs (~ 1 year)

Subgroup	Test area	Test time ^a
Plasma (assuming 25% machine availability)	Dedicated time ≤ 1 year	
	Achieve adequate cleanliness in hydrogen	3 months
	Optimize I _p initiation and rampup	2 months
	Achieve nτ > 10 ¹⁴ cm ⁻³ sec	7 months
	Achieve adequate heating scenario (physics)	} 4 months
	Produce and control modest β plasmas	
	Optimize shutdown for high energy density hydrogen plasmas	
Heating/fueling technology	Noninterference time ≤ 1 year	
	Achieve necessary beam heating and pellet injection test experience and confidence to enter D-T phase	
Particle collection technology	Noninterference time ≤ 1 year	
	Demonstrate divertor to the extent hydrogen operation will permit	
Maintenance/engineering operations	Noninterference time ≤ 1 year	
	Test maintenance techniques and procedures which cannot be done on major mockups and during machine assembly	

^aTests within a subgroup may be in parallel so that the total subgroup time will not equal the sum of the specific tests times.

Table 2. D-T phase test needs (>15 years)

Subgroup	Test area	Test time
Plasma (assuming 25% machine availability)	Dedicated time ~ 1 year	
Achieve $Q > 5$	}	6 months
Demonstrate thermal control		
Quantify alpha particle heating and transport		
Produce and control high β , ignited, D-T plasma for long times	}	6 months
Demonstrate reactor prototypical impurity control		
Demonstrate fuel depletion and ash accumulation control		
Establish reliable fusion core operation for engineering testing	}	Continuous
Validate scaling laws in reactor-relevant regime		
Optimize fusion plasma performance		
Heating/fueling technology	Noninterference time ~ 7 years	
Demonstrate efficiency and reliability for EPR/DEMO		
Tritium/particle collection technology	Noninterference time ~ 10 years	
Divertor collector tests for EPR/DEMO	~5 years	
Performance and reliability necessary for EPR/DEMO	~2 years	
Demonstrate fuel processing and T_2 inventory control for EPR/DEMO	~8 years	
Blanket/first wall technology	~14 years	
Test and qualify first wall design for EPR/DEMO	~5 years	
Electricity production demonstrated	~5 years	
T_2 breeding blanket design tested and qualified (two tested) for EPR/DEMO	~7 years	
Shield concepts tested and qualified for EPR/DEMO	~10 years	
Synthetic fuel blanket candidates tested and qualified	~4 years	

Table 2 (continued)

Subgroup	Test area	Test time
Maintenance and engineering operations		Continuous
(Maintenance/repair/replacement as needed)		
Materials	Noninterference time 1 year + continuous 9 years ~ 10 years	
Correlation with other test data	~1 year	
Test candidate materials (≥ 6 MWyr/m ²)	~9 years	
Alternate concepts technology		Continuous
Alternate concepts technology needs also met by ETF tests include		
First walls		
Blanket and shield		
Fueling		
Vacuum systems		
Blanket processing (T ₂ and synfuel)		
Power conversion		
Materials		
T ₂ handling		
Reliability/availability		
Alternate concepts technology needs largely met by ETF tests include		
Superconducting magnets		
Neutral beam systems		
RF systems		
Power supplies		
Impurity control and ash removal		
Cryogenic systems		
Heat transport systems		
Remote maintenance		
Alternate concepts technology needs requiring separate tests include		
Instrumentation and control		
Direct power conversion		
Poloidal field energy recovery		

OPERATIONS SCHEDULE FOR THE ENGINEERING TEST FACILITY

Fig. 1. Operations schedule for the Engineering Test Facility.

likely to become the basic components of the EPR/DEMO; (2) activities that determine preferences among competing technologies, components, or approaches for EPR/DEMO; and (3) those operations that are more generic and add to the general data base for future reactor designs.

The first priority tests aim at the establishment of confidence in the reliability and availability of systems that are expected to form the foundation for the EPR/DEMO designs. A test of electricity production would be such an example. A second priority test example would be the testing of rf plasma heating to determine if it is a better approach than neutral beams or if a combination would be preferred. A third priority test would include the evaluation of a synthetic fuel blanket that provides data valuable for all reactor design considerations but not necessarily essential to the EPR/DEMO success.

6. FACILITY DESCRIPTION AND DESIGN REQUIREMENTS

The results of the integration and time phasing of test priorities provide the basis for a general description of a facility with the following characteristics, which are designated the ETF Preliminary Design Requirements:

- (1) The first fusion core, a tokamak, is to be an ignited, long pulse, D-T burning machine.
- (2) The initial conceptual design effort should include a divertor system, and it is expected that a divertor system will be included throughout the Conceptual Design phase. Continuing parallel studies will provide guidance in comparing a bundle (in the present baseline

design) with a poloidal divertor and divertors with divertorless operation. Although it is doubtful that experiments would support the selection of a divertorless ETF design before 1984, the appropriate design modifications to reflect this choice could be made even into the Title I Design Phase.

(3) The device design should include neutral beams as the prime plasma heating approach but provide the flexibility for rf heating at equivalent power levels. Narrowing the rf candidate frequencies to one is desired. The capability for combined rf and neutral beam heating should be planned.

(4) The device availability (defined as the percentage of calendar time when the machine is operational for testing) shall be targeted for 25% during hydrogen operation and the first two years of D-T operation. The target availability thereafter is 50%. All systems shall be designed to their necessary reliability goals to achieve this availability.

(5) Fueling will be provided by pellet injection and gas puffing.

(6) The device design will have a secondary vacuum enclosure.

(7) The ETF maintenance concept shall be reactor relevant.

Design envelopes shall be established for areas in which remote, semi-remote, and hands-on maintenance will be applied. Specific means for repair or replacement of all components within the remote and semi-remote envelopes which are subject to failure during the expected life of the facility must be developed and demonstrated prior to ETF initial operation. Emphasis is to be placed on minimizing the size of the envelopes within which remote and semiremote maintenance will be required, consistent with the need to achieve the lowest mission cost. An ETF

design goal shall be to allow hands-on maintenance external to the toroidal field coil shield.

(8) The means for testing different blanket, first wall, and shield modules will be incorporated. Ease of changeout of test items will be a design requirement. Reactor-relevant electricity and synfuel production modules and tritium breeding blanket modules will be tested.

(9) Material test stations will be provided in the design. Their number and size will be assessed in the Conceptual Design phase.

(10) The device is to provide a time-integrated wall load of $\geq 6 \text{ MWyr/m}^2$ during its mission.

(11) Systems shakedown and check-out will be completed during assembly and prior to the beginning of scheduled operations.

(12) The feasibility and impact of providing for the testing of fusion-fission hybrid blanket modules will be assessed, and recommendations to OFE on their inclusion in the facility will be made in the Conceptual Design phase.

(13) A decommissioning and post-mortem period will be incorporated to permit remote maintenance and disassembly and materials investigation.

(14) Testing and qualification of reactor-relevant diagnostics will be included.

APPENDIX

ANTICIPATED FUSION KNOWLEDGE IN 1990

(Assumes modest program increases and upgrades of present machines.)

Plasma Operations

- Impurity control
 - (1) Understanding of divertor physics and long pulse impurity control feasibility under high power load; demonstrations limited to short (compared to 100 sec) pulses;
 - (2) Divertorless operation will have been explored on a variety of devices.
- Dynamic scenarios
 - (1) Startup — quantifiable information on all aspects;
 - (2) Heating — demonstration of density buildup and over-dense injection heating; demonstration of rf heating feasibility;
 - (3) Stability control — plasma β and its control;
 - (4) Burn — $Q > 1$ operation information from core of TFTR, JET by 1990;
 - (5) Shutdown — understanding of fusion quench and current ramp-down and abort scenarios.

Heating/Fueling Technology

- Neutral beams
 - (1) Positive ion systems operational capability — 150 keV, 5-6-sec pulse, 50-MW systems, 40% efficiency with direct recovery, 2 kW/cm², D⁰;
 - (2) Negative ion beams development tests — ~250 keV.

- RF heating status
 - (1) Significant testing accomplished in
 - ECRF — T-10, ISX, EBT-P
 - ICRF — PLT, PDX, TFTR, . . .
 - Lower hybrid — MW range Alcator C, PLT;
 - (2) Test results will have determined the efficacy of rf pre-ionization and the relative capabilities of the different methods for bulk plasma heating.
- Pellet injection capabilities — 1-3 mm, 1000-3000 m/sec, 20-100 pellets/sec.

Tritium/Particle Collection Technology

- Technology for between pulse pumpdown in hand;
- Divertor requirements resolved and particle collection method demonstrated;
- TSTA will have demonstrated a workable system for fuel processing;
- Tritium supply and control methods verified;
- Security classification and accounting issues resolved.

Blanket/First Wall/Shield Technology

- Substantial data from many machines and facilities though with modest particle and heat fluxes;
- Modest technology advancements made, limited by lack of adequate nuclear test facilities;
- Complete control and/or avoidance of plasma disruptions not established, but controlled disruptions or essentially disruption-free operations can be obtained.

Maintenance and Engineering Operations

- Heavy duty remote maintenance systems including transport pellets and servomanipulators along with the necessary viewing systems will be available;
- Mockups and models will have been built and used to support ETF design and assembly.

Materials

- The testing of materials in various facilities including ORR and FMIT will provide adequate confidence to build ETF;
- Adequate nonirradiated materials properties have been proven by test prior to ETF operation.

Alternate Concepts

- The status of concept-specific data will be in the research or development testing phase.

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