ERDA-76/110/1
UC-20

FUSION POWER
BY MAGNETIC CONFINEMENT

PROGRAM PLAN

VOLUME I

SUMMARY

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Abstract

This Fusion Power Program Plan treats the technical, schedular and budgetary projections for the development of fusion power using magnetic confinement. It was prepared on the basis of current technical status and program perspective. A broad overview of the probable facilities requirements and optional possible technical paths to a demonstration reactor is presented, as well as a more detailed plan for the R&D program for the next five years. The "plan" is not a roadmap to be followed blindly to the end goal. Rather it is a tool of management, a dynamic and living document which will change and evolve as scientific, engineering/technology and commercial/economic/environmental analyses and progress proceeds. The use of plans such as this one in technically complex development programs requires judgment and flexibility as new insights into the nature of the task evolve.

The presently-established program goal of the fusion program is to DEVELOP AND DEMONSTRATE PURE FUSION CENTRAL ELECTRIC POWER STATIONS FOR COMMERCIAL APPLICATIONS. Actual commercialization of fusion reactors will occur through a developing fusion vendor industry working with Government, national laboratories and the electric utilities. Short term objectives of the program center around establishing the technical feasibility of the more promising concepts which could best lead to commercial power systems. Key to success in this effort is a cooperative effort in the R&D phase among government, national laboratories, utilities and industry.

There exist potential applications of fusion systems other than central station electric plants. These include direct production of hydrogen gas and/or synthetic fuels; direct energy production for chemical processing; fissile fuel production; fission product waste disposal; and fusion-fission hybrid reactors. Efforts are in progress to evaluate these applications; the present and planned programs will permit timely information on which decisions can be made to pursue these goals.

The pace of the fusion program is determined by both policy variables and technical variables. A multiplicity of plans, referred to as Program Logics, are outlined. These range from "level of effort research" to "maximum effective effort" and are primarily describable by the presumed level of funding. Within these program logics there are many optional technical paths. A few of the potential paths or options are outlined.

The tokamak is currently the most promising approach to fusion and is closer to achieving a demonstration reactor for commercial application than other fusion concepts; but active programs in other concepts are pursued. The plan permits changes to alternate concepts on a timely basis as the physics and engineering/technology studies evolve.

The total cost to develop fusion power from FY 1978 through the date of operation of the first demonstration reactor is found to be roughly $15 billion dollars in constant FY 1978 dollars. With such funding a demonstration reactor could operate in the time frame 1993 to 2005 depending on near-term funding profiles and progress. A reference case (called Logic III) which aims at a demonstration reactor in 1998 is treated in detail.

The Fusion Power Program Plan consists of five documents as follows:

ERDA 76-110/0	Executive Summary
ERDA 76-110/1	Volume I: Summary
ERDA 76-110/2	Volume II: Long Range Planning Projections
ERDA 76-110/3	Volume III: Five Year Plan
ERDA 76-110/4	Volume IV: Five Year Budget and Milestone Summaries

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I. INTRODUCTION

A. GOALS

The presently-established program goal of the fusion program is to DEVELOP AND DEMONSTRATE PURE FUSION CENTRAL ELECTRIC POWER STATIONS FOR COMMERCIAL APPLICATIONS. The program is based upon the assumption that it is in the national interest to demonstrate safe, reliable, environmentally acceptable and economically competitive production of fusion power in a Demonstration Reactor that extrapolates readily to commercial reactors. Actual commercialization of fusion reactors is assumed to occur primarily through a developing fusion vendor industry working with Government, national laboratories and the electric utilities. Hence it is also an objective of the fusion program to develop sufficient data that utilities and industry can address all critical issues (e.g., capital and operating costs, reliability, safety, etc.) involved in arriving at power plant purchase decisions.

Short term objectives of the program center around establishing the technical feasibility of the more promising concepts which could best lead to commercial power systems. Key to success in this effort is a cooperative effort in the R&D phase among Government, national laboratories, utilities and industry.

There exist potential applications of fusion systems other than central station electric plants. These include:

- Direct production of hydrogen gas and/or synthetic fuels
- Direct energy production for chemical processing
- Fissile fuel production
- Fission product waste disposal
- Fusion-fission hybrid reactors

These applications hold the possibility of increasing the overall impact of fusion power and of hastening its commercial application.

The physical and economic characteristics of these potential applications have been analyzed only partially. Efforts are currently in progress to further evaluate the advantages and disadvantages of these applications; the present and planned programs will provide timely information on which decisions can be made to pursue these goals.

B. FUSION ADVANTAGES

The potential advantages of commercial fusion reactors as power producers would be:

- An effectively inexhaustible supply of fuel -- at essentially zero cost on an energy production scale;
- A fuel supply that is available from the oceans to all countries and therefore cannot be interrupted by other nations;
- No possibility of nuclear runaway;
- No chemical combustion products as effluents;
- No afterheat cooling problem in case of an accidental loss of coolant;
- No use of weapons grade nuclear materials; thus no possibility of diversion for purposes of blackmail or sabotage;
- Low amount of radioactive by-products with significantly shorter half-life relative to fission reactors.

C. FUEL CYCLES

First generation fusion reactors are expected to use deuterium and tritium as fuel. Several environmental drawbacks are, however, commonly attributed to DT fusion power. First, it produces substantial amounts of neutrons that result in induced radioactivity within the reactor structure, and it requires the handling of the radioisotope tritium. Second, only about 20% of the fusion energy yield appears in the form of charged particles, which limits the extent to which direct energy conversion techniques might be applied. Finally, the use of DT fusion power depends on lithium resources, which are less abundant than deuterium resources.

These drawbacks of DT fusion power have led to the proposal of alternatives for longer term application -- for example, fusion power reactors based only on deuterium. Such systems are expected to (1) reduce the production of high energy neutrons and also the need to handle tritium; (2) produce more fusion power in the form of charged particles; and (3) be independent of lithium resources for tritium breeding.

It has also been suggested that materials with slightly higher atomic numbers (like lithium, beryllium, and boron) be used as fusion fuels to provide power that is essentially free of neutrons and tritium and that release all of their energy in the form of charged particles.

Although such alternatives to DT fusion power are attractive, there is an important scientific caveat. To derive useful amounts of power from nuclear fusion, it will be necessary to confine a suitably dense plasma at fusion temperatures (10^8 ^{o}K) for a specific length of time. This fundamental aspect of fusion power is expressible in terms of the product of the plasma density, n, and the energy confinement time, τ, required for fusion power breakeven (i.e., the condition for which the fusion power release equals the power input necessary to heat and confine the plasma). The required product, $n\tau$, depends on the fusion fuel and is primarily a function of the plasma temperature. Of all the fusion fuels under current consideration, the deuterium-tritium fuel mixture requires the lowest value of $n\tau$ by at least an order of magnitude and the lowest fusion temperatures by at least a factor of 5. When the plasma requirements for significant power generation are compared with the anticipated plasma performance of current approaches to fusion power, it is apparent that fusion power must initially be based on a deuterium-tritium fuel economy. However, the eventual use of alternate fuel cycles remains an important ultimate goal and consequently attention will be given to identifying concepts which may permit their ultimate use.

D. FOREIGN EFFORTS

The United States fusion effort is a part of a much larger world effort. At present the U.S. effort is estimated to be about one-third of the world effort as measured by total man-years expended. Extensive collaboration exists among all nations of the world active in fusion R&D. This is effected through bilateral arrangements, both formal and informal, for the exchange of information and manpower and through multilateral arrangements facilitated by the International Atomic Energy Agency and the International Energy Agency. A particularly close collaboration between the

U.S. and the U.S.S.R. has developed during the past three years. This collaboration is supervised by a sixteen member group called the Joint (U.S.-U.S.S.R.) Fusion Power Coordinating Committee (JFPCC).

The program presented in this plan will permit the U.S. to achieve the desired end goal independent of any activity in another nation's program. However, coordination is maintained with other nations which insures that the steps taken in each country are complementary rather than redundant. This procedure leads to a reduction in the risk of failure in the overall effort. Examples of complementary large devices being built or considered in various nations at this time are the Tokamak Fusion Test Reactor (TFTR) in the U.S., the Joint European Tokamak (JET) in Europe, the Japanese Tokamak-60 (JT-60) in Japan, and the Tokamaks T-10M and T-20 in the U.S.S.R. Differences among the devices can be noted, for example, in Figures V-3 and V-4 of Volume II.

E. STRUCTURE

The entire Fusion Power Program Plan consists of five documents as follows:

ERDA 76-110/0, Executive Summary
ERDA 76-110/1, Volume I: Summary
ERDA 76-110/2, Volume II: Long Range Planning Projections
ERDA 76-110/3, Volume III: Five Year Plan
ERDA 76-110/4, Volume IV: Five Year Budget and Milestone Summaries

In Section II of this volume, the contents of the Long Range Planning Projections are summarized. The Long Range Planning Projections treat the R&D program of the 1980's and 1990's and, in particular, consider the range of optional paths to a Demonstration Reactor that may exist for commercial application. The relationship among funding patterns, physics and engineering progress, and the date of achievement of the end goal is described. In Section III of this volume, the contents of the Five Year Plan are summarized.

Data such as that presented in this plan can be used in the performance of cost/benefit analyses which will provide quantitative supporting information to help decide whether increased funding at some level is desirable. The basic framework for performing such cost/benefit analyses is being constructed by ERDA contractors.

II. LONG RANGE PLANNING PROJECTIONS

A. PROGRAM LOGICS

The most significant policy and technical variables that affect the pace of the fusion program are:

Policy Variables:

- The perceived NEED for fusion power
- The nation's INTENT (what is expected by when? What priority does the program have?)
- FUNDING

Technical Variables:

- PHYSICS RESULTS
- ENGINEERING RESULTS

Because NEED, INTENT, and FUNDING are finally decided by others, the fusion program requires a number of plans by which the program can be conducted. The following plans, referred to as LOGICS, are considered.

LOGIC I. LEVEL OF EFFORT RESEARCH

Research and development are supported at an arbitrary level in order to develop basic understanding. (If this pace were continued, a practical fusion power system might never be built.)

LOGIC II. MODERATELY EXPANDING, SEQUENTIAL

Funds are expanding but technical progress is limited by the availability of funds. Established commitments are given funding priority but new projects are not started until funds are available. In spite of limited funding a number of problems are addressed concurrently. (At this rate, a fusion demonstration reactor might operate in the early 21st century.)

LOGIC III: AGGRESSIVE

The levels of effort in physics and engineering are expanded according to programmatic need, assuming that adequate progress is evident. New projects are undertaken when they are scientifically justified. Many problems are addressed concurrently. Funding is ample but reasonably limited. (This program would be aimed at an operating demonstration reactor in the late 1990's.)

LOGIC IV: ACCELERATED

A great many problems are addressed in parallel and new projects are started when their need is defined. Fabrication and construction are carried out on a normal basis with enough priority to minimize delays. The availability of funds is still limited but a secondary factor in program planning and implementation. (This approach would be aimed at demonstration reactor operation in the early to mid-1990's.)

LOGIC V: MAXIMUM EFFECTIVE EFFORT

Manpower, facilities and funds are made available on a priority basis; all reasonable requests are honored immediately. Fabrication and construction are expedited on a priority basis so that completion times for major facilities are reduced to a practical minimum. (An operating demonstration plant around 1990 would be the program goal.)

Although the five Logics are most easily distinguished by costs and end-goal dates, it should also be noted that the degree of risk varies among Logics. Risk can increase under faster-paced Logics. On the other hand, risk can decrease with higher budgets due to increased effort and partial overlapping of facility goals. It is not possible to quantify the net change in risk among the Logics in general; it is necessary, however, to assess the risk at every point along the way.

The interplay among policy variables, technical variables and program Logics is shown in Figure II-1. Real world requirements as perceived by the Division of Magnetic Fusion Energy (DMFE) determine the program goals and objectives and, as perceived by ERDA, OMB, and Congress, fix the policy variables. An interaction takes place between the Division and ERDA, OMB and Congress; eventually ERDA, OMB and the Congress determine which LOGIC the program is to follow. The goals and objectives, as modified by the policy variables, prescribe the R&D program scope. The choice of LOGIC influences the activity within the program scope and a specific path (called a Logic Option) emerges. The results from following that option constitute the technical variables which the Division evaluates in the process of proposing the program goals and adjusting objectives.

The Logics, numbered I through V, are differentiated grossly according to funding levels of the operations budget in Figure II-2. The funding is such that the funding level for Logic I will result in a DEMO far out in time, while the funding level for Logic V will result in a DEMO as soon as is practically possible. It should be noted that the degree of "pessimism" or "optimism" that one assumes

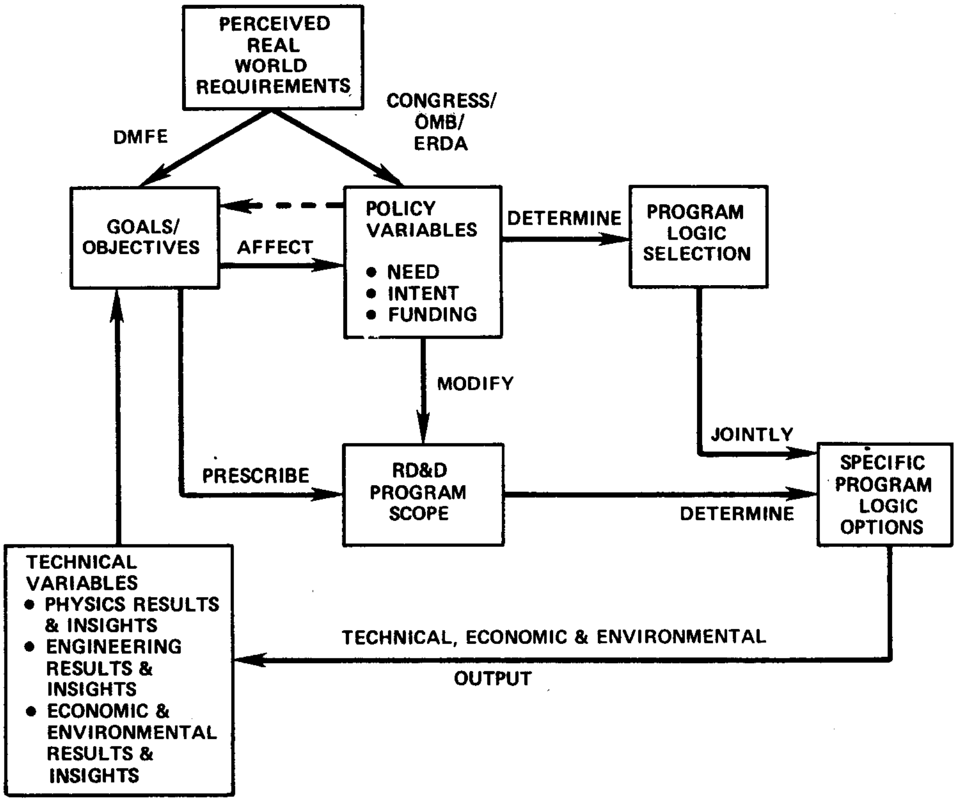
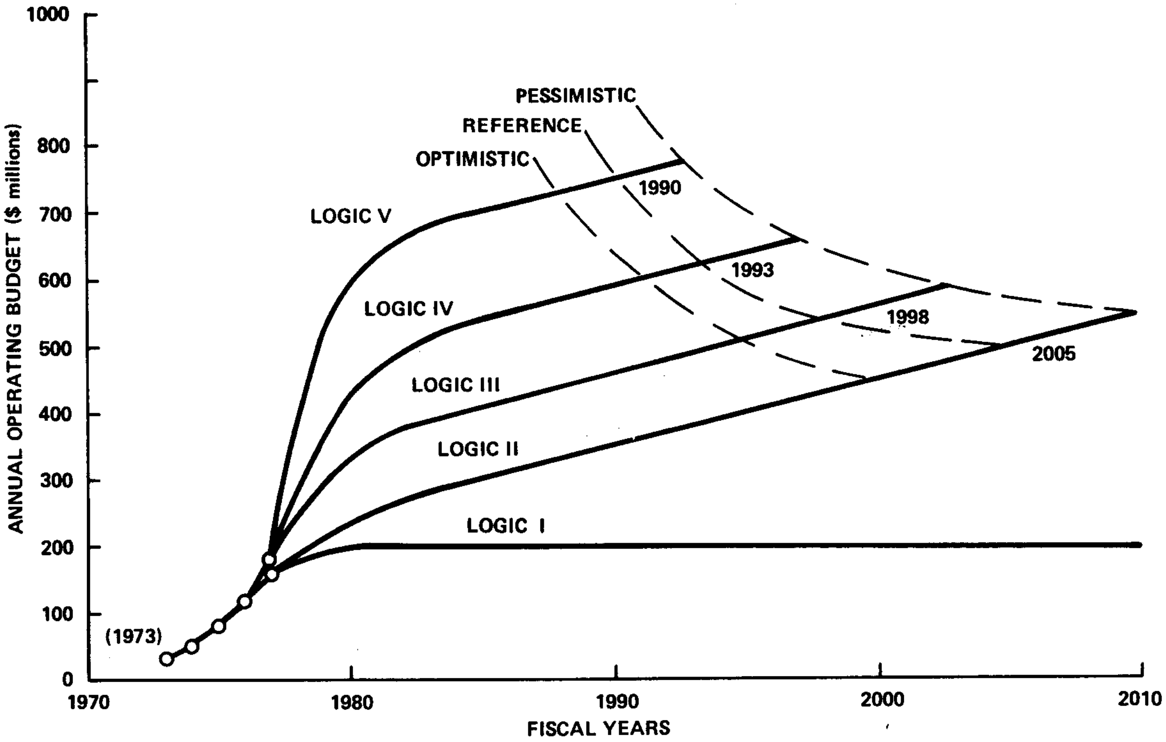


Figure II-1

DMFE PLANNING METHODOLOGY



FUSION R&D PROGRAM OPERATING BUDGET AND LOCI OF DEMO OPERATING DATES FOR LOGIC I THRU V

Figure II-2

substantially affects the projected date for operation of the DEMO. The projected operating date for a DEMO will also be affected by the degree of "risk" the program is willing to accept in moving from one step to the next. Clearly it is possible to aim at the same dates with lower funding, or earlier dates with the same funding if higher risks are taken, i.e., if less R&D and fewer demonstrated results are required to justify succeeding steps. The projected total annual budgets required for the five Logics are shown in Figure II-3.

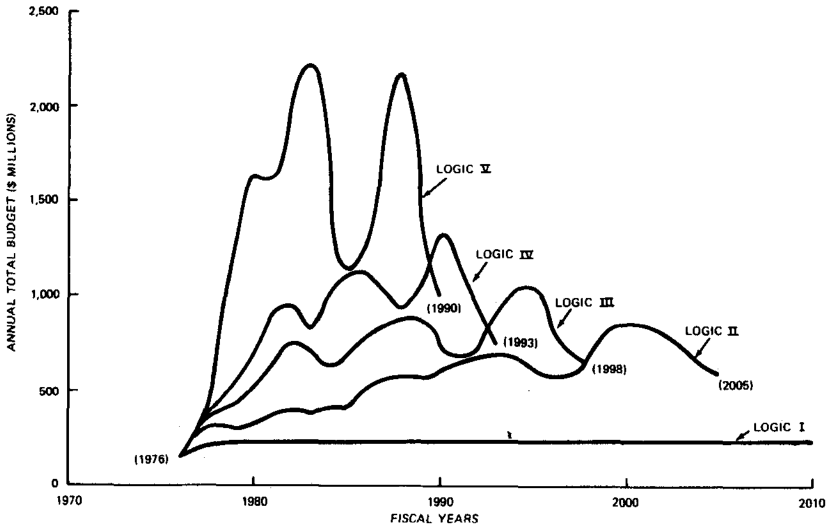
B. LOGIC III OPTIONS

Reference Option

The Logic III Reference Option is shown in Figure II-4. The devices listed in Figure II-4 are the following: Demonstration Reactor (DEMO), Experimental Power Reactor (EPR), Prototype Experimental Power Reactor or Ignition Test Reactor (PEPR/ITR), Tokamak Fusion Test Reactor (TFTR), Doublet III (D-III), Poloidal Divertor Experiment (PDX), Princeton Large Torus (PLT), Fusion Engineering Research Facility or Engineering Test Reactor (FERF/ETR), Large Mirror Experiment (MX), Baseball Mirror Device (BB), 2X Mirror Device (2X), Staged Scyllac (SS). The characteristics of the major new facilities (DEMO, EPR, PEPR/ITR, and TFTR) are given in Volume II, Section IV. For planning and costing purposes, it is assumed that a selection process takes place among the various concepts so that EPR's for two concepts and a DEMO for one concept result. Under the Logic III Reference Option a DEMO would operate in 1998.

- Tokamak Assumptions

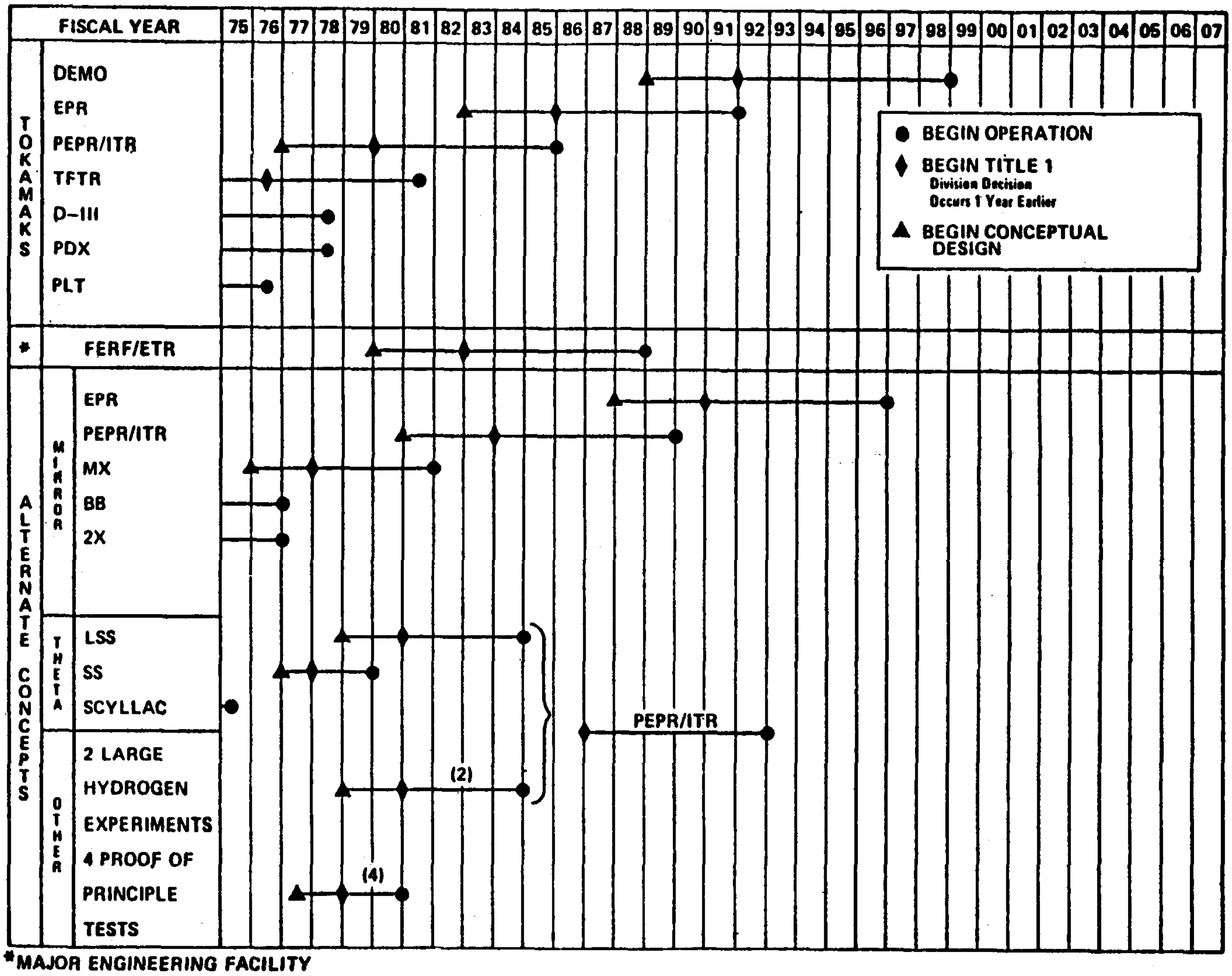
  Four major devices are postulated beyond Doublet III; namely TFTR, PEPR/ITR, EPR and DEMO. In addition a major engineering facility (FERF/ETR), which may be a tokamak, is constructed.



FUSION R&D PROGRAM ANNUAL TOTAL BUDGET FOR LOGICS I THRU V

Figure II-3

LOGIC III REFERENCE OPTION



*MAJOR ENGINEERING FACILITY

Figure II-4

- Alternate Concepts Assumptions

Mirror Assumptions
Three major devices past 2X/BB are postulated; namely MX, PEPR/ITR and EPR. The FERF/ETR could be a mirror. This Logic could result in a mirror DEMO (not shown in Figure II-4 but see Figure II-5) by 2004.

Theta Pinch and Other Alternate Concept Assumptions
Five concepts, including Staged Scyllac, are examined in parallel on a moderate scale for proof-of-principle tests. Once a proof-of-principle has been established the most promising concepts are evaluated in large hydrogen experiments (LHX). Three LHX's, including Large Staged Scyllac, are assumed. After operation of the LHX's, one concept is selected for a PEPR/ITR. This Logic could result in a Theta Pinch or Other Alternate Concept DEMO (not shown in Figure II-4, but see Figure II-5) by 2007.

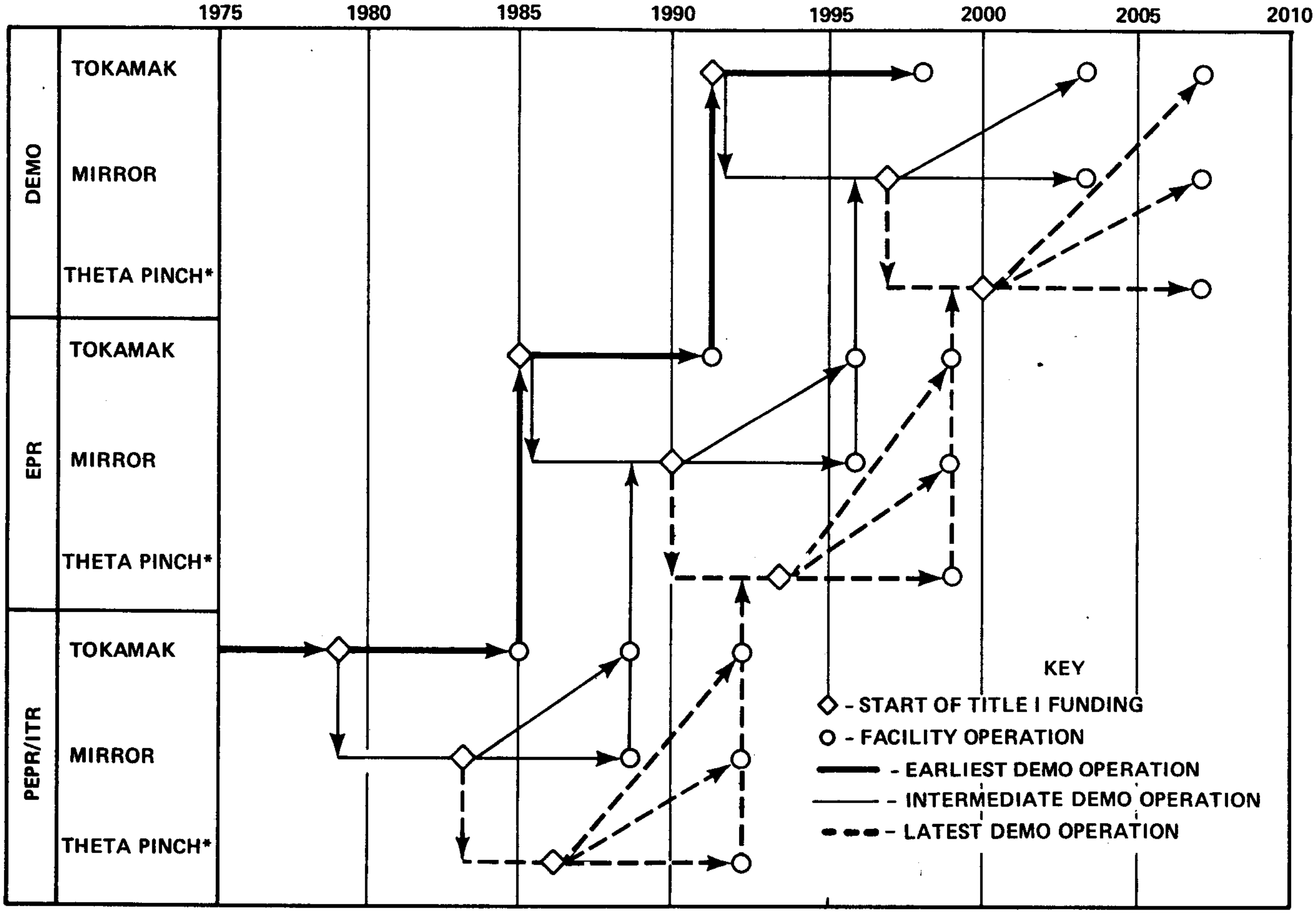
- Logic III Alternate Paths

As decision dates occur for major facilities, it is possible that the decision will be to wait for further information. This is shown in Figure II-5, in which the program path alternatives for the Logic III Reference Option are presented. The circles represent facility operation dates and the diamonds indicate the initiation of Title I funding based upon a decision made the previous year. Note, for example, the first decision along the PEPR/ITR tokamak line. The result of this decision will be to either construct a tokamak PEPR/ITR or delay until more information becomes available for both tokamaks and mirrors. Assuming that the result of the decision is to wait, the next identified decision point is along the mirror PEPR/ITR line. This decision can result in three alternatives: (1) construct a tokamak PEPR/ITR; (2) construct a mirror PEPR/ITR; (3) delay until more information becomes available for all three approaches to magnetic fusion.

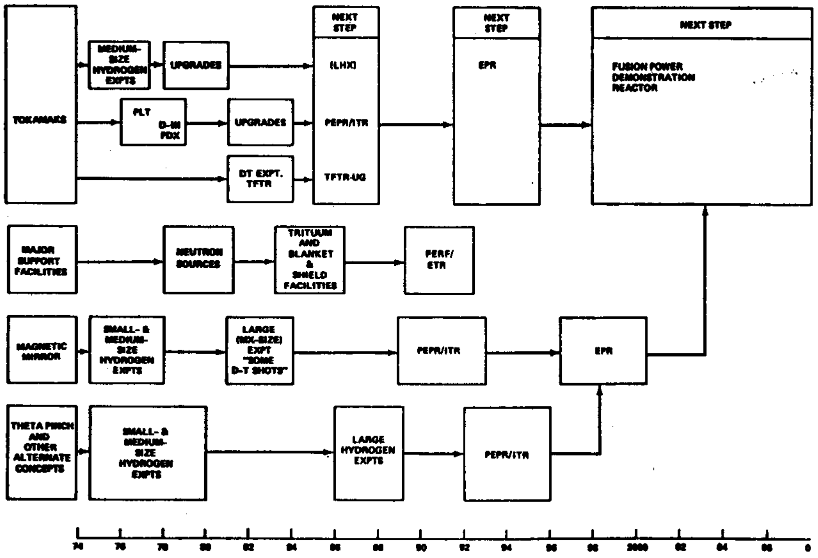
A decision made for one confinement concept (say tokamak PEPR/ITR) will not prevent a second decision, at a later point in time, for a second confinement method (say mirror or advanced concept PEPR/ITR).

Figure II-5

LOGIC III REFERENCE OPTION PROGRAM PATH ALTERNATIVES



* OTHER ALTERNATE CONCEPTS WOULD FOLLOW THE THETA PINCH PATH



General Features of the Logic III Refernence Option

Figure II-6

> The figure shows that the earliest possible Fusion Power Demonstration Reactor would be a tokamak operating around 1998. Note that this operation date could be delayed until 2004 (and could be a mirror) if the 1979 decision resulted in a decision to delay selection of the PEPR/ITR until 1983. This delay would be reduced if one were willing to permit a "continuum" of decision points between 1979 and 1983.

The general features of the Logic III Reference Option are summarized in Figure II-6. The present experimental program consists of several small and medium-sized hydrogen experiments (most notably the ORMAK and Alcator Tokamaks, the 2XIIB Mirror, and the Scyllac Theta Pinch) and the larger PLT at Princeton which came into operation in December 1975. Two other large tokamaks, Doublet III at General Atomic and PDX at Princeton, are in fabrication and scheduled to operate in early 1978. The first DT burning tokamak, the Tokamak Fusion Test Reactor (TFTR), is scheduled to operate in mid-1981. A large mirror experiment, called MX, has been proposed for operation in 1981.

Under a Logic III program each of these devices would be upgraded, primarily by adding more auxiliary heating power, to test physics scaling laws at higher temperatures and higher power density. In the mid- to late-1980's, large device(s) would be built assuming good results are obtained on earlier facilities. The next step in the tokamak line is assumed to be either a Prototype Experimental Power Reactor or an Ignition Test Reactor (PEPR/ITR). TFTR would be upgraded and possibly another large hydrogen experiment might be required. An engineering test reactor (FERF/ETR) is assumed, which could be a tokamak. By the early 1990's an Experimental Power Reactor (EPR) would be built, which makes net electrical power with high reliability. This device would be followed by the Fusion Power Demonstration Reactor in 1998.

The Magnetic Mirror Program is assumed to evolve from the present small- and medium-size experiments, most notably 2XII at Livermore, to a larger device in which a limited number of DT shots would be possible. A major objective of this device would be to test confinement scaling for longer times, and to test methods for improving power balance, a prerequisite to the feasibility of a pure fusion mirror reactor. This would be followed by a PEPR device in the late 1980's. The FERF/ETR could be a mirror. This could be followed by an EPR operating in 1996 and a DEMO around 2004.

For the other Alternate Concepts, larger hydrogen experiments, such as the Large Staged Scyllac, are assumed to operate in the mid-1980's, followed by a PEPR/ITR in the early 1990's. Next could come an EPR in the late 1990's and a DEMO around 2007.

For costing purposes of Logic III, 3 PEPR/ITR devices, 1 FERF/ETR, 2 EPR's, and 1 DEMO are assumed. Depending on progress and periodic assessments, not all the devices and facilities projected in this plan would necessarily be built.

Critical Parameter Assessments

Decisions to move ahead, mark time, retreat, change approach, etc., are based on assessments of the status of the physics and engineering/technology at a given point in time. These assessments include a prognosis on the implications of our current understanding for future commercial fusion reactors. These assessments are called "critical parameter assessments" and currently are scheduled to take place in 1979 for tokamaks, in 1982 for magnetic mirrors and in 1985 for the toroidal theta pinch and other alternate concepts.

Although these assessments clearly involve complex scientific/technical issues, the projected results of these assessments are described herein in simpler terms. Each of the critical parameters is assessed by assigning a "good", "fair", or "poor" rating to that part of the assessment and an overall rating of "good", "fair", or "poor" is then assigned to the physics and engineering/technology parts of the assessment separately. These latter ratings are used in deciding the nature of the best next step in the program.

The definitions of the critical parameters and the proposed definitions of the "good", "fair", or "poor" ratings are given in detail in Volume II, Section III.

Options

In the planning process, assumptions must be made on the range of possible physics and engineering/technology results and the time at which these results will be forthcoming. This gives rise to a multiplicity of potential paths for each approach to fusion power, called "Options". Analysis shows that many of these results lead to decisions to build large devices which are similar in general character, although they may differ in timing and in physics and engineering detail. Consequently the different options are characterized primarily by the nature of the next major facility to which the particular option path leads.

A matrix of possible tokamak options is shown in Figure II-7. In Column (3), "Critical Parameter Results by CY 1979", the assessment is shown by giving a good to poor rating for the physics and engineering/technology assessment discussed above.

Logic Option Matrix for Tokamaks

Option	Description	Results of Critical Parameter Assessment in 1979		Best Next Step	Completion Date	Best Next Step	I/C	Best Next Step	I/C
		Physics	Eng. Techn.						
1. Reference	D-Shaped	G	F	PEPR/ITR FERF/ETR	79/85 82/88	EPR	85/91	DEMO	91/98
2. Optimistic	Doublet	G	G	EPR-I	79/85	EPR-II	84/90	DEMO	88/95
3. Pessimistic	Circular	F	F	LHX PEPR/ITR	79/84 85/91	EPR	91/97	DEMO	98/05
4. Reassessment	Any	P		Reassess in 1982 based upon further results from upgrades and TFTR					
5.	High Field	G	G	PEPR/ITR	79/85	EPR	85/91	DEMO	91/91
6.	High Field	G	F	Reassess					
7.	Doublet	G	F	PEPR/ITR	79/85	EPR	85/91	DEMO	91/98

Figure II-7

A matrix of possible options for mirrors and toroidal theta pinches is shown in Figure II-8.

Alternate concepts are pursued if they offer potential physics, engineering/technology or economic advantages. An aggressive but sequential alternate concepts program is maintained in Logic III to examine all of the potentially promising confinement approaches at least to the point of "proof-of-principle" tests (see Figure II-9). In particular about six proof-of-principle experiments would be completed by 1980-82. Large hydrogen experiments for the two most promising concepts would then be initiated in the early 1980's and completed in FY 1984-86. One PEPR/ITR would be initiated in 1986 and completed in 1992. One EPR could be initiated in 1993 and completed in 1999. A DEMO could be initiated in 2000 and completed in 2007.

Supporting Engineering Facilities are required. The principal ones envisioned are shown in Figure II-10 and described in Volume II, Section IV. The engineering and materials test reactor (FERF/ETR) is the most costly of the supporting facilities.

C. ROLL-BACK PLANNING

In the preceeding sections the primary planning approach may be described as "roll-forward", i.e., the current program is considered and, from that consideration, the nature and timing of the next step is determined. A successful fusion power R&D program requires, in addition, a "roll-back" approach in which

Logic III: Option Matrix for Mirror and Toroidal Theta Pinch Alternate Concepts

Option	Physics Prototype	I/C	Results of Critical Parameter Assessment-1982		Best Next Step	Initiation/ Completion Date	Best Next Step	I/C	Best Next Step	I/C
			Physics	Eng/Tech.						
Mirror										
1. Reference	MX		G	F	PEPR	83/89	EPR	90/96	DEMO	97/04
2. Optimistic	MX		G	G	PEPR	82/88	EPR	88/94	DEMO	93/01
3. Pessimistic	MX	77/81	F	F	LHX PEPR	82/87 88/94	EPR	95/01	DEMO	02/09
4. Reassess			P	P	-					
5. Fusion/Fission	MX	77/81	F	F	F/F PEPR	83/89	F/F DEMO	90/96		
6. FERF/ETR	MX	77/81	F	F	FERF/ETR	82/88	-			
Toroidal θ-Pinch			Assessment-1985							
1. Reference	Large		G	F	PEPR/ITR	86/92	EPR	93/99	DEMO	00/07
2. Optimistic	Staged	80/84	G	G	PEPR/ITR	86/89	EPR	90/96	DEMO	97/04
3. Pessimistic	Scyllac		F	F	LHX PEPR/ITR	85/90 91/97	EPR	98/04	DEMO	05/12
4. Reassess			P	P	-					

Figure II-8

Logic III: Option Matrix for Other Alternate Concepts

Option	Physics Prototype	I/C	Results of Critical Parameter Assessment-1985		Best Next Step	I/C	Best Next Step	I/C	Best Next Step	I/C
			Physics	Eng/Techn.						
Reference	LHX	81/85	G	F	PEPR/ITR	86/92	EPR	93/99	DEMO	00/07

Concept	Principal	I/C	LHX	PEPR/ITR	EPR	DEMO
EBT	EBT-II	78/80	Up to two large hydrogen experiments would be fabricated based on the most promising concepts. Initiation would occur in FY80-82 with completion in FY84-86.	One PEPR/ITR among theta pinch and other alts. would be fabricated based on '85 assessment of critical parameters	One EPR from all alternate concepts could be fabricated based on '89, '92 assessments of critical parameters.	One DEMO from among all fusion approaches could be fabricated based on '90, '96, '99 assessments of critical parameters.
TORMAC	TORMAC VI	78/80				
ZT	ZT-II	79/81				
Linear	Scylla IV-P Long Linear Expt.	74/76 78/82				
Liner	Linus I	78/80				

Figure II-9

the nature of the desired end-product, a Fusion Power Demonstration Reactor that extrapolates readily to commercial reactors, is defined in detail and in which the physics and engineering tests required for a DEMO are identified and programs established to provide the required tests. This "roll-back" approach is discussed in Section V of Volume II . Clearly "roll-forward" and "roll-back" approaches must both be used and be complementary for a successful fusion R&D program.

In order to build a Fusion Power Demonstration Reactor of any type, certain physics understanding must be demonstrated and certain technological subsystems must be developed. These activities may be categorized as "Major Program Elements". Figure II-11 lists twenty-one Major Program Elements identifiable at this time. Inspection of Figure II-11 suggests that there are two basic classes of Major Program Elements; physics and engineering/technology. Elements I-IV are basically Physics Elements and the remainder are basically Engineering/Technology Elements. There are both explicit and implicit relationships among these "Elements". Overall technological and economic outlook is determined by the interrelated progress of each Element towards meeting the needs of a fusion DEMO. Tests of the critical physics and/or the technology of the Elements may be made individually in small test facilities and/or collectively in larger facilities. These tests can be described as falling into four classes of tests as follows:

1. Early Tests
2. High Confidence Level Tests
3. Definitive Tests
4. Full Scale DEMO Prototype Tests

ENGINEERING FACILITIES (LOGIC III)

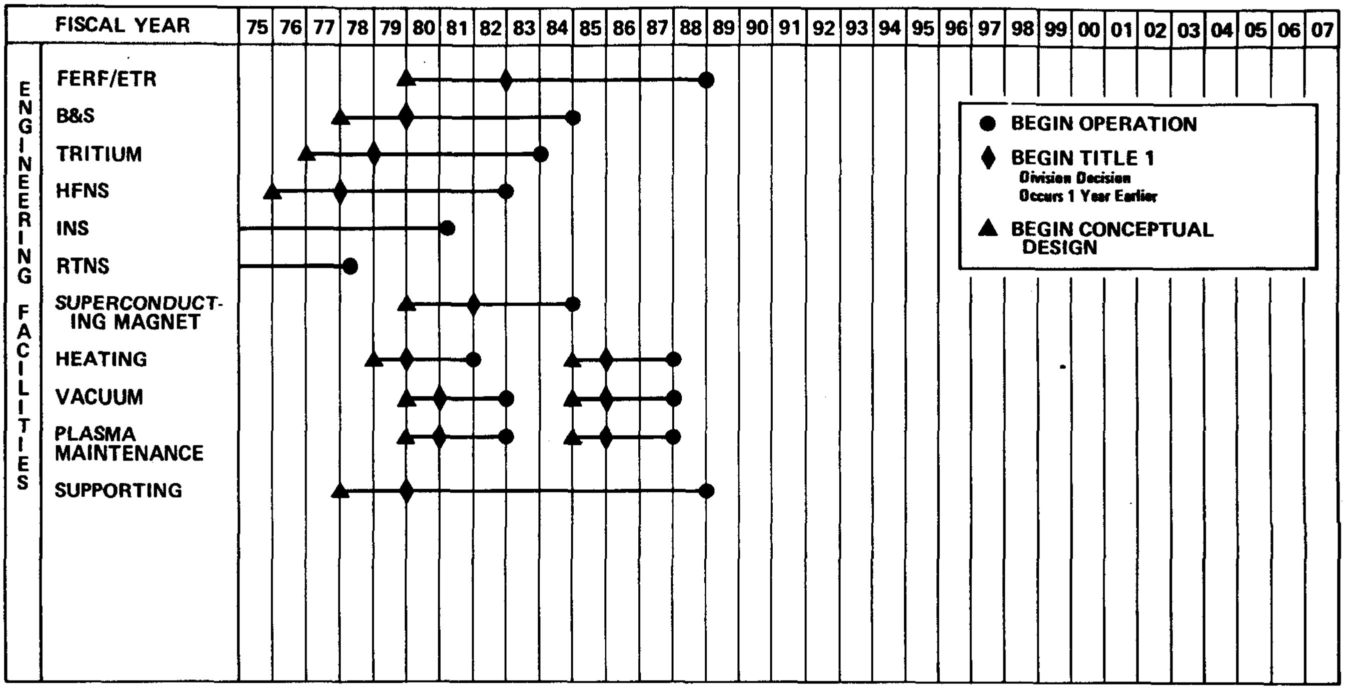


Figure II-10

Major Program Elements
for all Concepts

Physics

I. Scaling

II. Impurity Control

III. Beta Limits

IV. DT Burn Dynamics

Engineering/Technology

V. Plasma Maintenance and Control

VI. Heating Technology

VII. Superconducting Magnets

VIII. Pulsed Energy Systems

IX. Blanket and Shield

X. Tritium Processing and Control

XI. Electrical Subsystems

XII. Power Handling

XIII. Plant Availability

XIV. Instrumentation and Control

XV. Plant Maintenance

XVI. Vacuum Technology

XVII. Materials

XVIII. Balance of Plant

XIX. Systems Integration

XX. Environment and Safety

XXI. Economics

Figure II-11

Gross program progress may be measured and described in the above terms for each fusion concept. Early tests along with theoretical models provide the definition of the problems for the progress of each program element. High Confidence Level tests are conducted via model and machine experiments. Definitive tests provide the understanding of scaling laws necessary for the DEMO design. Full scale DEMO prototype tests demonstrate the readiness for DEMO application.

Major facilities are justified in part, by stating the level of test they will provide for each Major Program Element. Major Program Element tests, at different levels of confidence, are performed at different times depending on the option taken and the fusion concept assumed for DEMO. Figure II-12 is a flow chart showing the times at which various classes of tests are expected in the areas of the twenty-one program elements for the Logic III Reference Option program for the tokamak concept.

Each of the horizontal arrows represents the progress of a Major Program Element. The numbers indicate the various classes of tests expected.

The twenty-one Major Program Elements are discussed in some detail in Volume III, Section V to provide further insight into this planning method. The scope of the discussion covers all the fusion concepts, but more information is provided on the tokamak concept because of the current preeminence of this approach. The elements are general enough to cover all the fusion concepts.

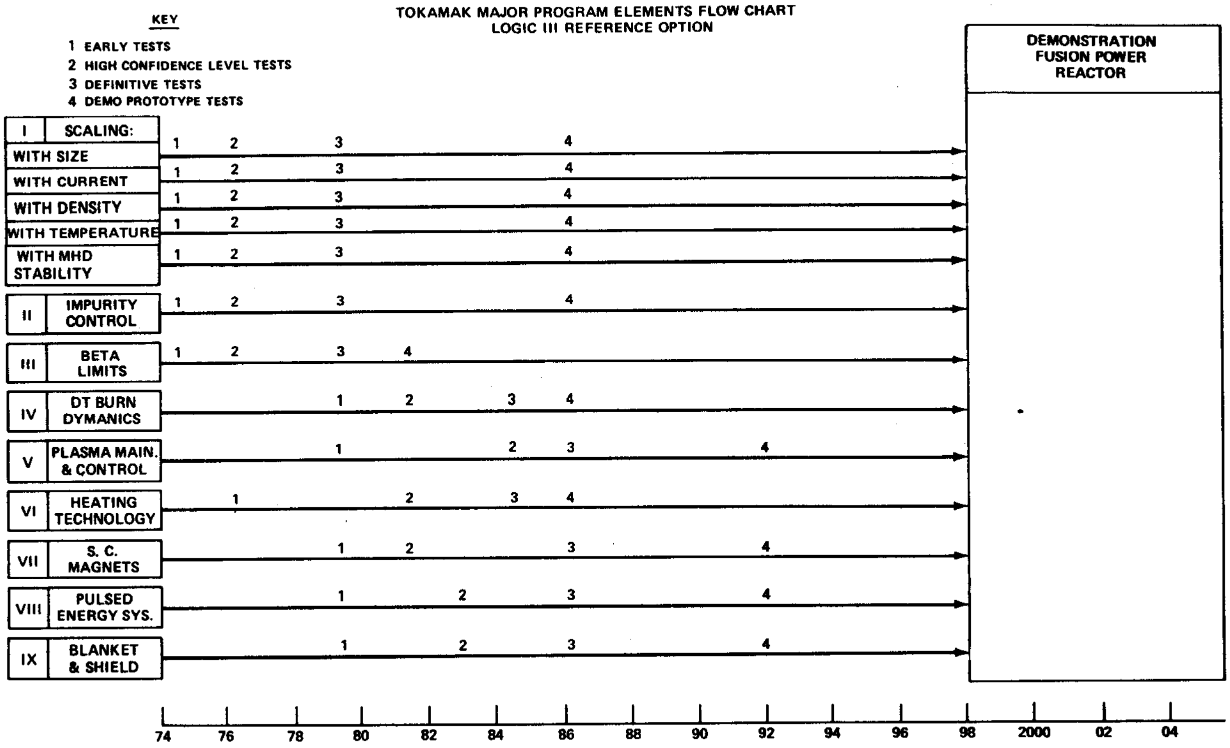


Figure II-12

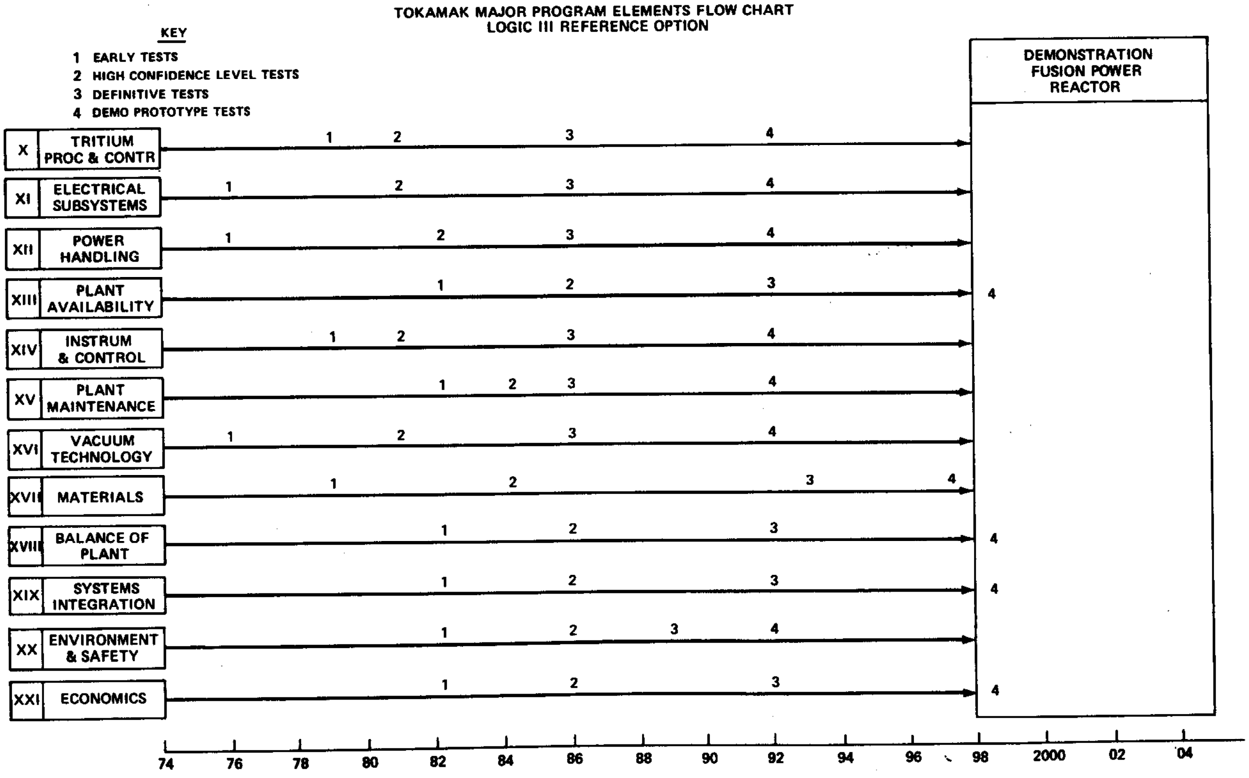


Figure II-12 - continued

D. BUDGET SUMMARY

The total integrated program costs from FY 1978 to the date of initial operation of the DEMO are shown below. All costs are in constant FY 1978 dollars. Details are presented in Figures II-13, 14, 15, 16.

LOGIC	I	II	III	IV	V
TOKAMAK PACE	Indeterminate	2630	2630	2630	4140
ENG. FAC. PACE		875	875	1050	1710
ALT. CONC. PACE		1600	2000	2000	4940
OPERATIONS		10120	9017	8260	8490
EQUIPMENT		1013	992	826	849
TOTAL		16238	15514	14766	20129

Figure II-13 PROGRAM COSTS BY YEAR FOR LOGIC II REFERENCE OPTION ($M)

	FY76	FY77	FY78	FY79	FY80	FY81	FY82	FY83	FY84	FY85	FY86	FY87	FY88	FY89	FY90	FY91
TOKAMAK PACE *............	20	80	95	35	15	35	35	15	40	60	100	100	60	40	0	40
TFTR.....................	20	80	95	35	15	35	35	15	0	0	0	0	0	0	0	0
PEPR/ITR	0	0	0	0	0	0	0	0	40	60	100	100	60	40	0	0
EPR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40
DEMO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ENG. FAC. PACE	2	18	10	10	20	35	56	66	54	25	20	16	44	88	168	163
FERF/ETR	0	0	0	0	0	0	0	0	0	0	0	0	25	75	150	150
HFNS	0	0	0	10	15	20	20	10	0	0	0	0	0	0	0	0
HTTF	0	0	0	0	0	0	0	6	9	0	0	6	9	0	0	0
TF	0	0	0	0	5	10	20	10	5	0	0	0	0	0	0	0
B&S	0	0	0	0	0	5	10	20	10	5	0	0	0	0	0	0
RTNS	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
INS	0	15	10	0	0	0	0	0	0	0	0	0	0	0	0	0
PMCTF	0	0	0	0	0	0	3	5	0	0	0	0	0	3	4	0
VTF	0	0	0	0	0	0	3	5	0	0	0	0	0	0	4	3
SMTF.....................	0	0	0	0	0	0	0	0	10	10	10	0	0	0	0	0
Eng. Test. Fac.	0	0	0	0	0	0	0	10	20	10	10	10	10	10	10	10
ALT. CONC. PACE	0	0	0	15	35	35	15	0	0	0	45	105	105	65	60	120
LHX																
MX	0	0	0	15	35	35	15	0	0	0	0	0	0	0	0	0
LSS	0	0	0	0	0	0	0	0	0	0	15	35	35	15	0	0
#3	0	0	0	0	0	0	0	0	0	0	15	35	35	15	0	0
#4	0	0	0	0	0	0	0	0	0	0	15	35	35	15	0	0
PEPR	0	0	0	0	0	0	0	0	0	0	0	0	0	20	60	120
EPR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL PACE	22	98	105	60	70	105	106	81	94	85	165	221	209	193	228	323
OPERATIONS	120	156	180	210	235	255	270	280	290	300	310	320	330	340	350	360
EQUIPMENT	17	20	18	21	24	26	27	28	29	30	31	32	33	34	35	36
TOTAL PROGRAM	159	274	303	291	329	386	403	389	413	415	506	573	572	567	613	719

*PACE: Plant and Capital Equipment line item construction projects.

Figure II-13 - continued

	FY92	FY93	FY94	FY95	FY96	FY97	FY98	FY99	FY2000	FY2001	FY2002	FY2003	FY2004	FY2005	28yr. Total FY78-2005
TOKAMAK PACE*	80	160	240	160	80	40	50	100	200	250	250	200	100	50	2630
TFTR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	230
PEPR/ITR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	400
EPR	80	160	240	160	80	40	0	0	0	0	0	0	0	0	800
DEMO	0	0	0	0	0	0	50	100	200	250	250	200	100	50	1200
ENG. FAC. PACE	75	25	0	0	0	0	0	0	0	0	0	0	0	0	875
FERF/ETR	75	25	0	0	0	0	0	0	0	0	0	0	0	0	500
HFNS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	75
HTTF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30
TF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50
B&S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50
RTNS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
INS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10
FMCTF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15
VTF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15
SMTF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30
Eng. Test. Fac.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
ALT. CONC. PACE	120	60	20	0	40	80	160	240	160	80	40	0	0	0	1600
LHX															
MX	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
LSS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
#3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
#4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PEPR	120	60	20	0	0	0	0	0	0	0	0	0	0	0	400
EPR	0	0	0	0	40	80	160	240	160	80	40	0	0	0	800
TOTAL PACE	275	245	260	160	120	120	210	340	360	330	290	200	100	50	5105
OPERATIONS	370	380	390	400	410	420	430	440	450	460	470	480	490	500	10120
EQUIPMENT	37	38	39	40	41	42	43	44	45	46	47	48	49	50	1013
TOTAL PROGRAM	682	663	689	600	571	582	683	824	855	836	807	728	639	600	16238

*PACE: Plant and Capital Equipment line item construction projects.

Figure II-14 PROGRAM COSTS BY YEAR FOR THE LOGIC III REFERENCE OPTION ($M)

	FY76	FY77	FY78	FY79	FY80	FY81	FY82	FY83	FY84	FY85	FY86	FY87	FY88	FY89	FY90
TOKAMAK PACE*	20	80	95	50	65	115	140	105	45	15	40	120	240	240	120
TFTR	20	80	95	35	15	35	35	15	0	0	0	0	0	0	0
PEPR/ITR Fac.	0	0	0	15	35	35	15	0	0	0	0	0	0	0	0
PEPR/ITR Dev.	0	0	0	0	15	45	90	90	45	15	0	0	0	0	0
EPR	0	0	0	0	0	0	0	0	0	0	40	120	240	240	120
DEMO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ENG. FAC. PACE	2	18	20	20	45	82	79	60	100	160	172	102	35	0	0
FERF/ETR	0	0	0	0	0	0	0	25	75	150	150	75	25	0	0
HFNS	0	0	10	15	20	20	10	0	0	0	0	0	0	0	0
HTTF	0	0	0	0	0	6	9	0	0	0	6	9	0	0	0
TF	0	0	0	5	10	20	10	5	0	0	0	0	0	0	0
B&S	0	0	0	0	5	10	20	10	5	0	0	0	0	0	0
RTNS	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0
INS	0	15	10	0	0	0	0	0	0	0	0	0	0	0	0
PMCTF	0	0	0	0	0	3	5	0	0	0	3	4	0	0	0
VTF	0	0	0	0	0	3	5	0	0	0	3	4	0	0	0
SMTF	0	0	0	0	0	0	10	10	10	0	0	0	0	0	0
Eng. Test. Fac.	0	0	0	0	10	20	10	10	10	10	10	10	10	0	0
ALT. CONC. PACE	0	0	15	35	35	60	105	105	65	60	120	140	120	140	120
LHX															
MX	0	0	15	35	35	15	0	0	0	0	0	0	0	0	0
LSS	0	0	0	0	0	15	35	35	15	0	0	0	0	0	0
#3	0	0	0	0	0	15	35	35	15	0	0	0	0	0	0
#4	0	0	0	0	0	15	35	35	15	0	0	0	0	0	0
M-PEPR 1	0	0	0	0	0	0	0	0	20	60	120	120	60	20	0
A-PEPR 2.	0	0	0	0	0	0	0	0	0	0	0	20	60	120	120
EPR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL PACE	22	98	130	105	145	257	324	270	210	235	332	362	395	380	240
OPERATIONS	120	183	248	280	321	346	376	390	400	410	420	430	440	450	460
EQUIPMENT	17	23	32	45	55	45	55	55	40	41	42	43	44	45	46
TOTAL PROGRAM	159	304	410	430	427	648	755	715	648	686	794	835	879	875	746

*PACE: Plant and Capital Equipment line item construction projects.

Figure II-14 - continued

	FY91	FY92	FY93	FY94	FY95	FY96	FY97	FY98	21yr. Total FY78-98
TOKAMAK PACE	40	60	120	240	360	240	120	60	2630
TFTR	0	0	0	0	0	0	0	0	230
PEPR/ITR Fac.	0	0	0	0	0	0	0	0	100
PEPR/ITR Dev.	0	0	0	0	0	0	0	0	300
EPR	40	0	0	0	0	0	0	0	800
DEMO	0	60	120	240	360	240	120	60	1200
ENG. FAC. PACE	0	0	0	0	0	0	0	0	875
FERF/ETR	0	0	0	0	0	0	0	0	500
HFNS	0	0	0	0	0	0	0	0	75
HTTF	0	0	0	0	0	0	0	0	30
TF	0	0	0	0	0	0	0	0	50
B&S	0	0	0	0	0	0	0	0	50
TRNS	0	0	0	0	0	0	0	0	0
INS	0	0	0	0	0	0	0	0	10
PMCTF	0	0	0	0	0	0	0	0	15
VTF	0	0	0	0	0	0	0	0	15
SMTF	0	0	0	0	0	0	0	0	30
Eng. Test Fac.	0	0	0	0	0	0	0	0	100
ALT. CONC. PACE	100	140	240	240	120	40	0	0	2000
LHX									
MX	0	0	0	0	0	0	0	0	100
LSS	0	0	0	0	0	0	0	0	100
#3	0	0	0	0	0	0	0	0	100
#4	0	0	0	0	0	0	0	0	100
M-PEPR 1	0	0	0	0	0	0	0	0	400
A-PEPR 2	60	20	0	0	0	0	0	0	400
EPR	40	120	240	240	120	40	0	0	800
TOTAL PACE	140	200	360	480	480	280	120	60	5505
OPERATIONS	470	480	490	500	510	520	530	540	9017
EQUIPMENT	47	48	49	50	51	52	53	54	992
TOTAL PROGRAM	657	728	899	1030	1041	852	703	654	15514

Figure II-15 PROGRAM COSTS BY YEAR FOR LOGIC IV REFERENCE OPTION ($M)

	FY76	FY77	FY78	FY79	FY80	FY81	FY82	FY83	FY84	FY85	FY86	FY87	FY88	FY89	FY90	FY91	FY92	FY93	15yr. Total FY78-93
TOKAMAK PACE*	20	80	95	35	55	105	195	95	120	180	280	180	140	180	360	360	180	60	2630
TFTR	20	80	95	35	15	35	35	15	0	0	0	0	0	0	0	0	0	0	230
PEPR/ITR	0	0	0	0	40	80	160	80	40	0	0	0	0	0	0	0	0	0	400
EPR	0	0	0	0	0	0	0	0	80	180	280	180	80	0	0	0	0	0	800
DEMO	0	0	0	0	0	0	0	0	0	0	0	0	60	180	360	360	180	60	1200
ENG. FAC. PACE	2	18	25	50	102	129	125	140	230	132	87	20	10	0	0	0	0	0	1050
FERF/ETR	0	0	0	0	0	0	50	100	200	100	50	0	0	0	0	0	0	0	500
HFNS	0	0	15	30	40	40	25	0	0	0	0	0	0	0	0	0	0	0	150
HTTF	0	0	0	0	6	9	0	0	0	6	9	0	0	0	0	0	0	0	30
TF	0	0	0	5	10	20	10	5	0	0	0	0	0	0	0	0	0	0	50
B&S	0	0	0	5	10	20	10	5	0	0	0	0	0	0	0	0	0	0	50
RTNS	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
INS	0	15	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10
PMCTF	0	0	0	0	3	5	0	0	0	3	4	0	0	0	0	0	0	0	15
VTF	0	0	0	0	3	5	0	0	0	3	4	0	0	0	0	0	0	0	15
SMTF	0	0	0	0	10	10	10	0	0	0	0	0	0	0	0	0	0	0	30
Eng. Test. Fac.	0	0	0	10	20	20	20	30	30	20	20	20	10	0	0	0	0	0	200
ALT. CONC. PACE	0	0	20	50	90	150	90	40	80	200	160	200	160	200	320	160	80	0	2000
LHX																			
MX	0	0	20	50	30	0	0	0	0	0	0	0	0	0	0	0	0	0	100
LSS	0	0	0	0	20	50	30	0	0	0	0	0	0	0	0	0	0	0	100
#3	0	0	0	0	20	50	30	0	0	0	0	0	0	0	0	0	0	0	100
#4	0	0	0	0	20	50	30	0	0	0	0	0	0	0	0	0	0	0	100
M-PEPR	0	0	0	0	0	0	0	40	80	160	80	40	0	0	0	0	0	0	400
A-PEPR	0	0	0	0	0	0	0	0	0	40	80	160	80	40	0	0	0	0	400
EPR	0	0	0	0	0	0	0	0	0	0	0	0	80	160	320	160	80	0	800
TOTAL PACE	22	98	140	135	247	394	410	275	430	512	527	400	310	380	680	520	260	60	5680
OPERATIONS	120	200	270	350	420	470	490	510	530	540	550	560	570	580	590	600	610	620	8260
EQUIPMENT	17	31	27	35	42	47	49	51	53	54	55	56	57	58	59	60	61	62	826
TOTAL PROGRAM	159	329	437	520	709	911	949	836	1013	1106	1132	1016	937	1018	1329	1180	931	742	14766

*PACE: Plant and Capital Equipment line item construction projects.

Figure II-16 PROGRAM COSTS BY YEAR FOR LOGIC V REFERENCE OPTION ($M)

	FY76	FY77	FY78	FY79	FY80	FY81	FY82	FY83	FY84	FY85	FY86	FY87	FY88	FY89	FY90	13yr. Total FY78-90
TOKAMAK PACE*	20	90	110	230	465	485	385	385	370	150	160	320	600	320	160	4140
TFTR	20	90	110	30	15	35	35	15	0	0	0	0	0	0	0	240
PEPR/ITR	0	0	0	80	180	180	80	0	0	0	0	0	0	0	0	520
EPR I	0	0	0	120	270	270	120	0	0	0	0	0	0	0	0	780
EPR II	0	0	0	0	0	0	150	370	370	150	0	0	0	0	0	1040
DEMO	0	0	0	0	0	0	0	0	0	0	160	320	600	320	160	1560
ENG. FAC. PACE	2	18	40	130	190	260	385	335	180	70	50	50	20	0	0	1710
FERF/ETR	0	0	0	0	0	100	225	225	100	0	0	0	0	0	0	650
HFNS	0	0	30	60	80	60	50	20	0	0	0	0	0	0	0	300
HTTF	0	0	0	10	10	0	0	0	10	10	0	0	0	0	0	40
TF	0	0	0	10	20	20	10	5	0	0	0	0	0	0	0	65
B&S	0	0	0	10	20	20	10	5	0	0	0	0	0	0	0	65
RTNS	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
INS	0	15	10	0	0	0	0	0	0	0	0	0	0	0	0	10
PMCTF	0	0	0	5	5	0	0	0	5	5	0	0	0	0	0	20
VTF	0	0	0	5	5	0	0	0	5	5	0	0	0	0	0	20
SMTF	0	0	0	10	10	10	10	0	0	0	0	0	0	0	0	40
Eng. Test. Fac.	0	0	0	20	40	50	80	80	60	50	50	50	20	0	0	500
ALT. CONC. PACE	0	0	104	364	312	156	520	728	520	156	321	728	728	312	0	4940
LHX																
MX	0	0	52	78	0	0	0	0	0	0	0	0	0	0	0	130
LSS	0	0	52	78	0	0	0	0	0	0	0	0	0	0	0	130
#3	0	0	0	52	78	0	0	0	0	0	0	0	0	0	0	130
#4	0	0	0	52	78	0	0	0	0	0	0	0	0	0	0	130
#5	0	0	0	52	78	0	0	0	0	0	0	0	0	0	0	130
#6	0	0	0	52	78	0	0	0	0	0	0	0	0	0	0	130
M-PEPR	0	0	0	0	0	78	182	182	78	0	0	0	0	0	0	520
M-PEPR	0	0	0	0	0	78	182	182	78	0	0	0	0	0	0	520
A-PEPR	0	0	0	0	0	0	78	182	182	78	0	0	0	0	0	520
A-PEPR	0	0	0	0	0	0	78	182	182	78	0	0	0	0	0	520
EPR	0	0	0	0	0	0	0	0	0	0	156	364	364	156	0	1040
EPR	0	0	0	0	0	0	0	0	0	0	156	364	364	156	0	1040
TOTAL PACE	22	108	254	724	967	901	1290	1448	1070	376	522	1098	1348	632	160	10790
OPERATIONS	120	240	360	510	600	640	660	680	690	700	710	720	730	740	750	8490
EQUIPMENT	17	31	36	51	60	64	66	68	69	70	71	72	73	74	75	849
TOTAL PROGRAM	159	379	650	1285	1627	1605	2016	2196	1829	1146	1303	1890	2151	1446	985	20129

*PACE: Plant and Capital Equipment line item construction projects.

III. FIVE YEAR PLAN

A. ORGANIZATION

To manage the magnetic fusion energy program, the Division of Magnetic Fusion Energy is organized into the following four interrelated programs.

- Confinement Systems (CS) within which experiments are fabricated and operated to model many of the features of fusion reactors, and to study plasmas in order to determine practical methods to achieve the conditions necessary for fusion reactors. Included within the Confinement Systems Program are all of the major tokamak, mirror and theta pinch experiments (with the exception of the construction of the Tokamak Fusion Test Reactor) and two other highly developed Alternate Concepts: the Z-pinch and Elmo Bumpy Torus.

- Technical Projects Office (TPO) which supervises the construction of major devices including the Tokamak Fusion Test Reactor and two neutron sources (RTNS and INS).

- Development and Technology (D&T) within which solutions to the problems associated with the design and construction of the next generation of plasma confinement devices are developed, and a broad technological base is developed in areas important to practical fusion power reactors. Included within the program are neutron radiation damage, superconducting magnet development, development of auxiliary heating systems and power supplies, systems studies and environmental safety.

- Applied Plasma Physics (APP) within which theoretical and experimental studies of fusion-relevant plasmas are conducted that seek the body of knowledge required to understand and predict the behavior of thermonuclear confinement experiments and the operating characteristics of fusion reactors. Applied Plasma Physics supports all of the Division's theoretical work including management of the computer facilities, the basic smaller experiments, diagnostic development, atomic, molecular and nuclear physics, and the smaller and newer exploratory concepts.

The personnel of the Division are listed in Figure III-1.

The fusion program is carried out at five major sites: General Atomic Company, Lawrence Livermore Laboratory, Los Alamos Scientific Laboratory, Oak Ridge National Laboratory, and Princeton Plasma Physics Laboratory. Many smaller programs are also in progress at other laboratories, industries, and universities. Most of them are referenced in Volumes III and IV.

B. CONFINEMENT SYSTEMS

The Confinement Systems Program is responsible for solving the experimental problems connected with the confinement of fusion plasma by magnetic fields; to demonstrate long time confinement of high temperature plasmas at power-producing reactor conditions and to optimize the plasma physics aspects of fusion reactor systems.

The principal approach to the confinement of plasma is the tokamak which is a donut-shaped, long pulse time, moderate-density device. In addition, strong efforts are maintained in two other magnetic confinement concepts. These are magnetic mirror systems, including both open and toroidally linked mirror systems, and high density short-pulsed systems, including the toroidal theta pinch, the straight theta pinch, and the toroidal Z-pinch. Each of these approaches is believed capable of contributing to the major goal of a power producing, economic electrical power plant and/or to one or more of several other possible applications of fusion, e.g., materials testing reactors, fusion-fission hybrid reactors, fission product burners, production of fissionable materials, etc.

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R. Weller, Secretary

R. Mason, Special Assistant
R. Bingham, Coordinator for Plans
G. Hess, Senior Scientific Advisor
S. Horner, Secretary

Administration

J. R. Young, Assistant Director
L. Routzahn, Secretary

J. Anthony
W. Burrier
R. Cunningham
R. Rosselli
R. Zich
  A. Brown, Secretary
F. Valentine, Mail & Records

Technical Projects

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Program Management Branch
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J. Turi

Systems Engineering Branch
R. J. Impara, Chief
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C. Smedira

Reactor Engineering Branch
K. G. Moses, Chief
L. Price
A. Dixon, Secretary

Confinement Systems

S. O. Dean, Assistant Director
A. M. Sleeper, Scientific Coordinator
R. A. Watkins, Secretary

Tokamak Systems Branch
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R. Blanken
D. Ignat
J. Willis
T. Hsu
P. J. Showe, Secretary
P. A. Blickenstaff, Secretary

High Density Systems Brnnch
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E. Oktay
L. K. Worden, Secretary

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W. R. Ellis, Chief
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L. Bogart, Technical Assistant
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C. Finfgeld
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E. Ruby, Secretary

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Magnetic Systems Branch
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Applied Plasma Physics

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Fusion Plasma Theory Branch
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D. Priester
W. Sadowski
J. Hurd, Secretary

Exp. Plasma Research Branch
J. F. Decker, Chief
W. Dove
G. Mischke
P. Stone

Computer Serv. & Tech. Br.
G. R. Ingram, Chief
C. McCoy
J. Esworthy, Secretary

Figure III-1

Each of the three confinement systems approaches has unique problem areas, and each consists of experiments aimed at solving these problems.

Tokamak Systems

The major problem areas of the tokamak physics program are:

- Heating
- Transport and Scaling
- Plasma Shape Optimization
- Impurity Control and Boundary Effects
- Fueling

Heating refers to the process of producing the plasma temperatures necessary for a fusion reactor. Fusion reactors require ion and electron temperatures of about 10 keV. Electron temperatures of 1-2 keV and ion temperatures of 0.5-1.5 keV are typical of today's plasmas. Initial heating is provided by ohmic heating, which is produced by passing an electric current through the plasma. Additional heating by other methods is required to raise the temperature to that which will be required for a reactor. Two methods are being tested: injection of beams of energetic neutral atoms and application of radio frequency power. Fusion reactors may require beam or rf powers of ~ 100 MW. Present day neutral beam experiments are performed with injected powers of ~ 0.3 MW, and a 4 MW beam system is being built for the Princeton Large Torus (PLT). The Tokamak Fusion Test Reactor (TFTR), scheduled for operation in 1981, will have an injected beam power of ~ 20 MW and will have some plasma compression capability as well. Heating with RF power is being tested at the 0.2 MW level in advance of a decision to proceed to higher power levels.

Transport and Scaling refers to the development of the physical laws which describe the measured transport of plasma energy in present experiments and the development of scaling laws to predict plasma behavior in larger, higher temperature devices. This area is, therefore, closely related to the heating program, and research on the two is conducted simultaneously. Fusion reactors are expected to have plasma radii of about 2-4m and plasma currents of about 10 MA. PLT, having begun operation in December 1975, is designed to operate with a plasma radius of ~ 0.5m and a plasma current of ~ 1 MA; it will therefore provide an operating point between existing smaller plasmas and those of a reactor. Present theory predicts a significant change in the plasma transport as electron temperatures increase above 1-2 keV. The PLT experiment will explore the physics of this important regime.

Configurational Stability or Plasma Shape Optimization addresses the possibility, predicted by theory, that non-circular plasma shapes can be confined by lower strength magnetic fields and thus lead to lower fusion power plant costs. The techniques required are in use today on the Doublet IIA experiment, and definitive tests are scheduled on reactor grade plasmas in the Doublet III, beginning in 1978. Slightly elongated plasmas can also be studied on the Poloidal Divertor Experiment, beginning also in 1978.

Impurity Control and Boundary Effects refers to problems resulting from the interaction of the plasma with its material boundaries. These interactions can result in an influx of non-hydrogenic (impurity) atoms into the plasma, which can cool the plasma core directly and/or can cool the plasma edge, causing the plasma to shrink and become unstable. One method of reducing boundary effects will be tested in the Poloidal Divertor Experiment in which additional magnetic fields near the plasma edge will carry escaping particles away from the walls into special pumping regions.

Fueling refers to problems associated with replenishing plasma fuel in reactors with long burn times. This is a long range problem, but initial experiments are planned on PLT, PDX and ORMAK.

A flow chart showing the devices working on tokamak problems is shown in Figure III-2.

Magnetic Mirror Systems

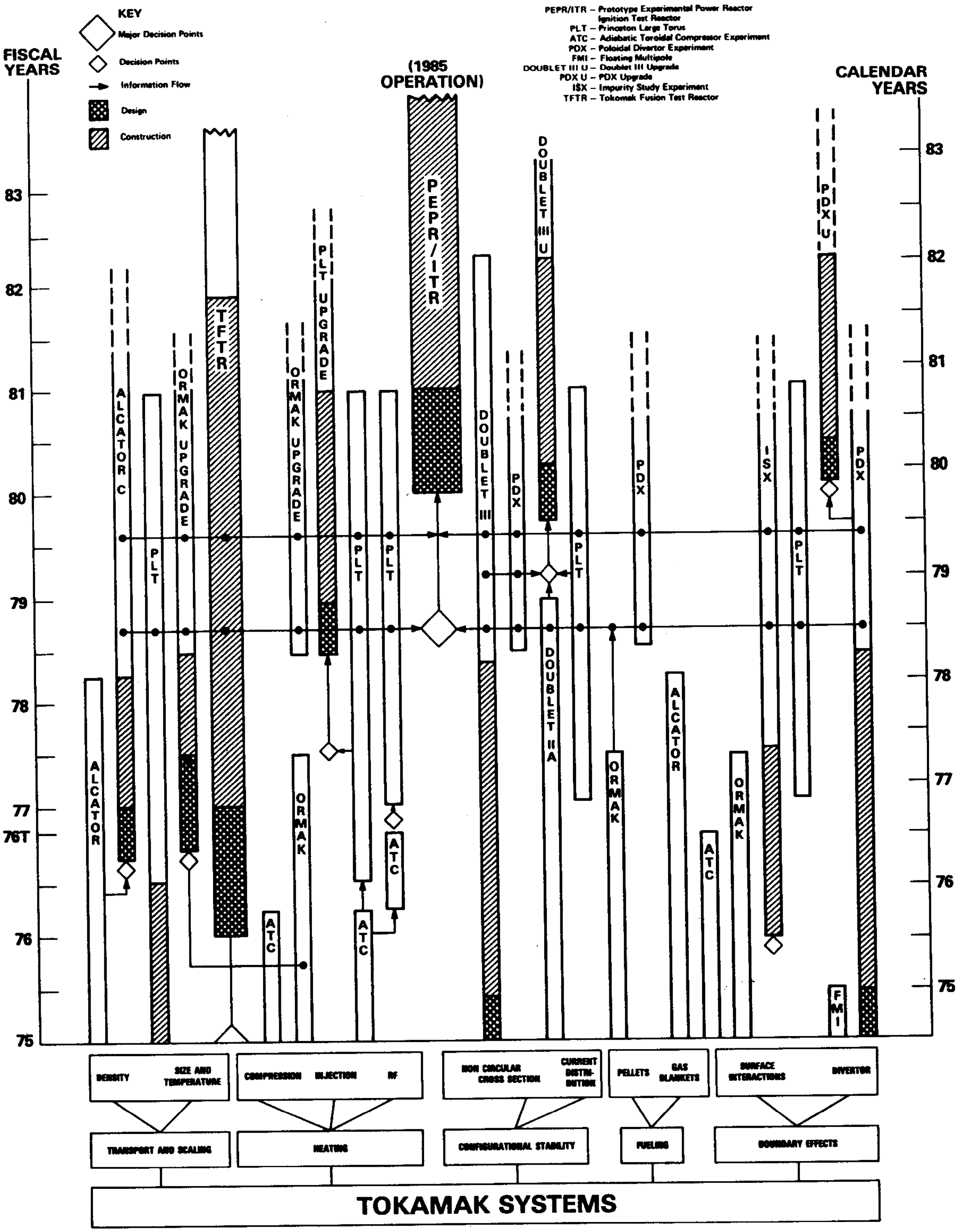
In the Magnetic Mirror Program, the major areas of investigation are open systems (minimum-B configurations) and toroidally-linked mirrors (EBT).

a. Minimum-B Mirrors

The major problem areas for the minimum-B (open) configurations are:

- confinement scaling
- Q-enhancement
- steady-state operation

Confinement scaling refers to the dependence of the confinement time, τ, or more generally the Lawson parameter, $n\tau$, on experimental variables such as the temperature, the amount of warm plasma stream necessary to stabilize the drift cyclotron loss



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Division of Magnetic Fusion Energy
May 1976

Figure III-2

cone (DCLC) mode, the plasma dimensions (in units of the ion gyroradius) R/ρ_i and L/ρ_i, the plasma beta, the angle of neutral beam injection, etc. Classical theory predicts $n\tau \sim T_i^{3/2}$ in the absence of a stabilizing stream, as is predicted in the case of large experiments ($R/\rho_i \gtrsim 40$). This prediction needs to be tested experimentally at ion energies ≥ 50 keV. Present experiments are operating at ion energies up to 13 keV and with $R/\rho_i \simeq$ 2-3. MX will have ion energies of ~ 50 keV and $R/\rho_i \simeq 13$.

Q-enhancement refers to methods for improving the power balance in mirror fusion reactors (Q is a plasma quantity, defined as the ratio of thermonuclear power output to neutral-beam heating power input). Recent mirror reactor designs have been based on classical values of Q in the range ~ 1.0 - 1.1. These low Q values require stringent reactor engineering measures to yield net electrical power. A factor of 2-3 or more improvement in Q would greatly ease the technology requirements and reduce capital costs for mirror reactors.

Steady state operation refers to the achievement of at least multi-second, high throughput vacuum pumping capability, neutral beam sources, and neutral beam power supplies. The multi-second operating regime is important because on this time scale the neutral particle reflux from the walls is predicted to reach an equilibrium rate. The ultimate goal of mirror fusion reactors is steady state operation.

b. Toroidally-linked Mirrors (EBT)

The major problem areas for EBT are:

- plasma stability
- microwave heating
- confinement scaling

Plasma stability refers to the stability of the complex EBT confinement configuration of a toroidal loop within annular rings. MHD stability has been observed in EBT with low toroidal plasma density (2-6 x $10^{12}cm^{-3}$). However, the stability of projected operating densities ($\sim 10^{14}cm^{-3}$) needs to be investigated.

Microwave heating at millimeter wavelengths (ECR) is the method proposed for plasma heating in EBT. A clear understanding of ECR heating at higher densities ($> 10^{13}cm^{-3}$) is thus an important goal of the program.

Confinement scaling refers to the dependence of confinement time on plasma parameters (e.g., density, beta), the frequency and power of the microwave heating source, and the aspect ratio of the device. In a steady-state device, such as EBT, the particle and energy confinement times will depend on equilibrium transport properties. The critical-density limit set by the microwave frequency is important in this regard, since even at 120 GHz ($n_e \sim 2 \times 10^{14}cm^{-3}$), rather long energy confinement times ($\sim$ 1 sec) are required to exceed the Lawson criterion.

High Density Systems

In the High Density Systems Program, the major areas of investigation are the theta pinch and the Z-pinch. Theta pinch research is concerned with both linear and toroidal devices. Z-pinch research is presently conducted only in tori.

a. Toroidal Theta Pinch

In the toroidal theta pinch program, the major problem areas are:

- plasma confinement
- staged heating

Plasma confinement refers to the problem of creating a stable toroidal equilibrium for the theta-pinch-like plasma column in Scyllac. Equilibrium requires that the plasma column be formed initially in an approximate force balance near the center of the toroidal discharge tube. The plasma column should have the appropriate equilibrium surface distortion required by the presence of higher order multipole fields (ℓ = 0, 1, 2) which, in addition to the usual theta pinch magnetic field B_0, provide the toroidal force balance. Stability requires that the equilibrium plasma, once formed, remain confined in spite of small perturbations in position. In the Scyllac experiments, this stability is achieved by means of a fast feedback stabilization system which drives ℓ =2 multipole windings. A more efficient stabilization technique, wall stabilization, is planned for theta pinch reactors, and will be tested in the Staged Theta Pinch (STP) experiment and on Staged Scyllac.

Staged heating refers to the separate application, or staging, of the two phases of heating in theta pinches: implosion (or shock) heating and adiabatic compression. Projected toroidal theta pinch experiments, such as Staged Scyllac and LSS, require separation and control of these two heating phases to achieve greater implosion heating and less adiabatic compression. The resulting "fat" plasma has a large ratio of plasma radius to wall radius, which is both economically advantageous for reactors and essential for effective stabilization of the m =1 (sideward) mode by the wall.

b. Linear Theta Pinches

In the linear theta pinch program, the major problem areas are:

- end loss
- high field operation

End loss refers to the loss of both particles and energy (in the form of heat conduction) from the open ends of linear systems. Without some form of end-stoppering, plasma ions will stream out of the ends at roughly the ion thermal velocity. Without steps to correct this situation, a fusion reactor based on the linear theta pinch would be impractically long (many kilometers). A variety of flow barriers, both material and electromagnetic, are currently under investigation. Axial thermal conduction by electrons along field lines is a potential source of heat loss to the central plasma column, even in the absence of particle end loss, and studies to reduce this effect are in progress.

High field operation refers to the practical necessity of operating a linear fusion reactor at rather large values of the magnetic field. Since reactor length scales as B^{-2}, an increase in the magnetic field from, say, 50 kG to 500 kG, can yield dramatic reductions in reactor length requirements.

c. Z-Pinch

In the Z-pinch program, the major problem areas are:

- heating
- profile optimization

Heating refers to the process of achieving plasma temperatures relevant to a fusion reactor i.e., ≥ 5 keV. Z pinches are, in principle, capable of being heated to ignition by joule heating alone, without the addition of auxiliary heating techniques such as neutral beams or r f. Shock heating may also play an important role in reaching ignition temperatures in Z pinches and is being studied.

Profile optimization refers to the tailoring of pressure and magnetic profiles to achieve MHD stability in the Z-pinch. Non-ideal MHD mechanisms, such as plasma transport in the form of diffusion and heat conduction will modify the programmed profiles. Confinement time, which has been diffusion limited in ZT-1, is predicted to scale with the square of the minor radius.

Summary

A summary of the critical problem areas and the key experimental programs addressing these problems is shown in Figure III-3. Note that many of the experiments are designed to address more than one critical problem.

C. TECHNICAL PROJECTS OFFICE

The Technical Projects Office (TPO) is responsible within DMFE for the management of the design and construction of large complex fusion facilities, including development programs in direct support of the projects. During FY 1976 TPO has provided program management of the Tokamak Fusion Test Reactor (TFTR) at Princeton Plasma Physics Laboratory. PPPL is the prime contractor for the design and fabrication of the TFTR device and the associated hardware, much of which will be engineered and fabricated in industry. The ERDA Princeton Area Office is responsible for administration of the project, including prime contracting for the conventional facilities. PPPL will operate the experiment and facilities when construction is complete. Within DMFE, the Confinement Systems program will manage the experimental program after completion of construction.

Critical Problem Area	Key Experiments
Tokamaks	
• Heating	ATC, ORMAK, PLT
• Transport and Scaling	ORMAK, Alcator, PLT
• Plasma Shape Optimization	Doublet IIA, Doublet III, PDX
• Impurity Control and Boundary Effects	Alcator, ATC, ISX, PDX
• Fueling	PDX, ORMAK
Minimum-B Mirrors	
• Confinement Scaling	2X-IIB, BB, LITE
• Q-enhancement	2XIIB, BB, LITE, FRTP
• Steady-state Operation	BB, LITE
Toroidally-linked Mirrors	
• Plasma Stability	EBT-I
• Microwave Heating	EBT-I
• Confinement Scaling	EBT-I, EBT-S
Toroidal Theta Pinch	
• Plasma Confinement	Scyllac, STP
• Staged Heating	STP, IHX
Linear Theta Pinch	
• End Loss	Scylla IV-P, Scylla IC
• High Field Operation	Scylla IV-P
Z-Pinch	
• Heating	ZT-1, ZT-S
• Profile Optimization	ZT-1, ZT-S

Critical Problem Areas and Key Experiments Addressing These Problems in the Confinement Systems Program.

Figure III-3

In addition, the Technical Projects Office manages the design and construction of facilities capable of producing intense sources of high energy neutrons required to determine the effects of high energy neutrons on reactor materials. The Rotating Target Neutron Source (RTNS) at LLL embodies known technology and is scheduled for completion in FY 1978. The Intense Neutron Source (INS) at LASL, authorized for funding in FY 1977, is scheduled for completion in FY 1981.

Conceptual design studies performed in the Development and Technology program will identify specific goals and design criteria for future large fusion facilities. Responsibility for the final design and construction will be transferred to the Technical Projects Office.

Tokamak Fusion Test Reactor

The Tokamak Fusion Test Reactor (TFTR) will be the nation's first magnetic confinement fusion device to experimentally demonstrate the release of fusion energy from the deuterium-tritium reaction under conditions projected for future experimental power reactors. TFTR will represent an intermediate step between present, relatively small zero-power physics experiments and future experimental reactors planned for the mid-1980's. The TFTR will be located at the Princeton Plasma Physics Laboratory (PPPL) near Princeton, New Jersey. The construction project should be completed in mid-1981 at a total cost of $228M, including escalation.

The TFTR has major objectives in both physics and engineering. The principal objectives are:

- To demonstrate fusion energy production from the burning of deuterium and tritium (DT) in a magnetically confined toroidal plasma system.

- To build a neutral beam heated tokamak in which hydrogen, deuterium and DT plasma can be inserted in order to:
    - Study the physics of large tokamaks, and
    - Verify advanced engineering concepts for DT tokamak systems.
- To experimentally demonstrate physics and engineering understanding of large fusion systems.

The TFTR will serve as an intermediate step to help bridge the gap between current, relatively small, hydrogen plasma confinement experiments and the first Experimental Power Reactor. The unique features required are its DT burning capability, its size which permits physics experiments in the EPR range of interest and some of its engineering features, not heretofore tested. The experience to be gained in design, construction and operation, and the information to be gathered in physics and engineering will provide a sound foundation for EPR design and construction.

The specific objectives of the TFTR project are:

- Attain reasonably pure hydrogenic plasma conditions at 5-10 keV temperature, approximately 10^{14}cm^{-3} density, and provide stable confinement with $n\tau_E$ equal to or greater than $10^{13}\text{cm}^{-3}\text{sec}$.
- Provide a neutral beam injection system capable of injecting into the plasma 20 MW of 120 keV D^o beam, for at least 0.5 sec.
- Provide a toroidal magnetic field of about 5 tesla (50 kG) (on vacuum chamber axis), for at least 3 sec flattop time, with a 5 min. repetition rate.
- Develop plasma handling techniques and provide hardware capable of initiation, control (including feedback control and major radius compression), and dissipation of tokamak discharges up to 2.5 MA.

- Provide a vacuum chamber of adequate size (2.7m major radius and 1.1m minor radius), equipped for high-power discharge cleaning and capable of achieving base pressures below 5×10^{-8} Torr.
- Provide capability for routine pulsed operation with H-H; D-D; D-He^3; or DT plasmas, with safe and reliable gas handling and support systems.

Rotating Target Neutron Source

The Rotating Target Neutron Source (RTNS-II) will be the first high energy, high intensity neutron irradiation facility dedicated to the fusion reactor materials program. The RTNS-II will provide the neutron sources and support facilities required to provide the "pure" 14 meV neutron energy component necessary as a base line for displacement and transmutation studies. This facility will be located at the Lawrence Livermore Laboratory (LLL), Livermore, California. LLL is the prime contractor for the design and fabrication of the facilities. LLL will operate the facility when completed in 1978. The total construction cost is $5M, including escalation.

This 14 meV source is intended to provide:

- high energy damage information at low fluences required for verification of theories of fission data extrapolation;
- surface and defect data for comparison with high energy spectra such as those arising from the Be(D, n) and Li (D, n) stripping reactions which have tentatively been identified as possible upon which to base a higher intensity, larger volume neutron source;
- cross-section measurement data;
- synergistic effects on materials due to the interaction of neutron damage with other plasma radiation; and
- comparison with ion simulation.

The design requirement and overall performance specification for RTNS-II is for two source strengths of 4 x 10^{13}n/sec. The source is based on the DT reaction produced by impinging an accelerated deuterium beam on a solid, rotating, titanium tritide target.

Intense Neutron Source

The Intense Neutron Source (INS) is the second high energy neutron irradiation facility dedicated to the fusion reactor materials program, the first being RTNS-II. The INS will provide higher 14 meV neutron source intensities and a larger experimental volume than RTNS-II. This facility will be used to study the behavior of candidate materials for fusion devices under radiation-damage conditions similar to that anticipated in large fusion reactors. The facility will provide prototype neutron flux levels and will have expanded volumetric capability to investigate microstructures, to perform initial screening for mechanical properties of candidate materials, and to examine blanket moderated spectrum effects. This facility will be located at the Los Alamos Scientific Laboratory (LASL), Los Alamos, New Mexico. LASL is the prime contractor for the design and fabrication of the facilities. LASL will operate the facility when completed in 1981, at a total construction cost of $25.4M, including escalation.

This 14 meV source is intended to provide:

- high energy damage information at high fluences required for verification of theories of fission data extrapolation;

- microstructural and mechanical property data for comparison with high energy spectra such as those arising from the Be (D, n) and Li (D, n) stripping reactions which have tentatively been identified as possible reactions upon which to base a higher intensity, larger volume neutron source;
- neutronic studies in tritium breeding blankets;
- mock fusion reactor first wall life tests;
- neutron cross-section measurement data; and
- data on tritium behavior and handling.

The design requirement and overall performance specification for INS is for two source strengths of 1 x 10^{15}n/sec. This source is based on the DT reaction produced by accelerating a tritium beam to react with a supersonic deuterium gas target.

D. DEVELOPMENT AND TECHNOLOGY

The Development and Technology Program (D&T) provides both near term engineering/subsystems support to existing and proposed experiments and longer term development of the necessary technology base to permit fusion energy to become a commercial reality. These both remain as the fundamental objectives of the D&T program; only the emphasis will change as the program moves into the fusion reactor engineering phase of Fusion Power R&D.

Development and Technology program activities presently are organized in five related subprograms:

Magnetic Systems

This activity sponsors research and development of large superconducting magnet systems needed for fusion reactor engineering experiments within the next ten years. These systems are necessary for both plasma confinement and energy storage.

Plasma Engineering

This activity is directed principally at the development of efficient plasma heating systems (neutral particle beams, radio-frequency waves, and electromagnetic plasma implosion systems) that are essential for all approaches to commercial fusion energy by magnetic confinement. Additional responsibilities include plasma fueling subsystem development, plasma maintenance subsystem development (e.g., divertors), direct energy converters, and high capacity vacuum systems which are compatible with the fusion reactor environment.

Fusion Reactor Materials

This long lead-time activity is assigned the responsibility to develop (or invent) the materials required to permit the economical generation of energy from the fusion process. The principal focus is on materials that will be placed within the first ten centimeters or so of the plasma where the fusion radiation environment imposes the most difficult materials requirements. Other areas of responsibilities include development of those materials unique to a fusion reactor environment (e.g., both hot and cryogenic insulators, special structural materials).

Fusion Systems Engineering

This activity focuses principally on the next generation and longer term fusion power reactor designs. Specifically, a major responsibility is to support the reactor designs necessary for Congressional approval (and funding) to build the first large fusion prototype experimental power reactor presently planned to operate in 1985 or 1986. Other Fusion Systems

Engineering responsibilities now include systems studies of fusion applications and economics, blanket and shield engineering, tritium processing and control, plasma systems, and plant systems design and test. A major near-term activity will be the development and prototyping of engineered tritium processing and control systems that will be required for tritium burning experimental fusion reactors.

Environment and Safety

This activity is charged with the responsibility of assuring that fusion power reactors will operate with the minimum possible hazard either to the environment or to plant personnel and nearby populations. At this time, Environment and Safety efforts focus on environmental impact analysis, facility safety analysis, and reactor safety research.

Summary

The five subprograms described above are in a continuously evolving state and are expected to grow and, when necessary become partitioned, as different elements of Development and Technology, and become more emphasized. Details of the milestones of these subprograms are presented in Volumes III and IV.

E. APPLIED PLASMA PHYSICS

The Applied Plasma Physics program seeks the body of knowledge that predicts the behavior of fusion plasma confinement experiments and the operating characteristics of fusion power reactors. The program management is composed of three branches: Fusion

Plasma Theory, which manages all of the Magnetic Fusion Energy Division's theoretical activities, including its computational component; *Computer Services and Technology*, with responsibility for the National DMFE Computer Center with its associated User Service Centers and Data Communications Network; and *Experimental Plasma Research*, which supports a broad spectrum of experiments to attack problems related to the production and confinement properties of fusion plasma.

The Applied Plasma Physics Program's theoretical studies have had a continuing impact on fusion research since the early days of primitive plasma confinement experiments. Theory explained the gross instabilities that plagued the early experiments, and it has provided the guidance to eliminate these instabilities. It continues to provide the basis for understanding plasma behavior in the present generation of magnetic confinement experiments. Plasma theory has now matured to the point where it can be used to explain or to predict many features of experimental plasmas.

For example, the nonlinear theory of loss cone instabilities in velocity space was recently able to explain the high temperatures and long energy confinement times achieved on 2XII. Stability studies on the Doublet III design led to significant changes in the shape of the chamber of that device.

Although the physics of magnetic confinement can still be only approximately described by abstract and sometimes inadequate models, large scale computational efforts have provided quantitative predictions of plasma properties such as equilibrium stability and energy transport through the use of 1- and 2-D computer codes. Of crucial importance in this effort are analytical models on which these codes are built. Large scale digital computers will play a particularly cost effective role in the design of devices. They will be used to simulate specific characteristics of plasma confinement experiments and fusion power reactors, and eventually they will make possible the simulation of proposed systems before actual construction.

The Fusion Plasma Theory effort provides theoretical studies on all the aspects of confinement devices that have been discussed under the section on the Confinement Program. It also provides theory related to TFTR and to D&T activities such as superconducting magnets or reactor studies.

The Applied Plasma Physics program's experimental activities have contributed significantly to overall fusion research progress in the past. Specialized plasma experiments, such as Q machines and multipoles, have been used to test and verify features of plasma theory. Many of the instruments to measure the properties of plasmas in magnetic confinement systems experiments were conceived, designed, tested, and perfected in conjunction with some of the special purpose experiments in the Applied Plasma Physics Program. In addition, important advances have been made in plasma production and heating by control of low and high level plasma turbulence, by neutral beam injection, and by relativistic electron beams.

In the future, the experimental component of the Applied Plasma Physics program will provide continuing research into novel methods of plasma confinement and heating, improved instrumentation, detailed data on relevant atomic and molecular processes, and finally, critical tests of the validity and applicability of evolving plasma theory.

Computer Services and Technology provides computing support for the entire fusion program. Among its functions are systems and software support at the National Computer Center. Computer networking to tie the major components of the fusion program into the central computing facility and the development of specialized computers to provide the most cost-effective computing for the large codes required by the program.

Details of the milestones of these subprograms are presented in Volumes III and IV.

F. BUDGET SUMMARY

A summary of the five-year budget requirements are presented in Figure III-4. Details are given in Volumes III and IV.

Budget Detail	Fiscal Years ($M)								
	1976	1976T	1977	1978	1979	1980	1981	1982	Total 78-82
Total Operation	120.0	37.0	183.3	247.1	280.3	327.1	346.8	376.0	1577.3
Confinement Systems	61.9	19.3	79.6	110.0	125.0	140.0	140.0	150.0	665.0
Tokamaks	43.2	13.8	57.4	70.0	75.0	80.0	80.0	80.0	385.0
Mirror Systems	10.9	3.5	14.0	30.0	36.4	41.1	36.9	40.7	185.0
High Density Systems	7.8	2.0	8.2	10.0	13.6	18.9	23.1	29.3	95.0
Technical Projects	0.4	1.0	11.3	18.0	12.3	22.1	25.8	25.0	103.2
TFTR	0.4	1.0	10.0	15.6	10.5	20.2	23.7	25.0	95.0
RTNS	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0	1.1
INS	0.0	0.0	0.0	1.5	1.8	1.9	2.1	0.0	7.3
Development & Technology ...	33.5	9.2	58.0	75.0	95.0	110.0	126.0	146.0	552.0
Magnetic Systems	7.4	1.9	17.7	19.0	25.0	28.0	32.1	37.2	141.3
Plasma Engineering	10.2	3.7	19.7	21.0	25.0	26.0	29.8	34.5	136.3
Fusion Reactor Materials .	6.9	1.7	9.3	16.0	20.0	23.0	26.3	30.5	115.8
Fusion Systems Eng.	8.6	1.8	10.3	18.0	23.0	30.0	34.4	39.9	145.3
Environ. and Safety	0.4	0.1	1.0	1.0	2.0	3.0	3.4	3.9	13.3
Applied Plasma Physics	24.3	7.7	34.4	44.1	48.0	55.0	55.0	55.0	257.1
Fusion Plasma Theory	12.3	3.6	13.6	17.7	21.0	25.0	25.0	25.0	113.7
Experimental Plasma Res. .	8.8	3.1	15.8	17.4	18.3	20.0	20.0	20.0	94.1
Comp. Services & Tech. ...	3.2	1.0	5.0	9.0	8.7	10.0	10.0	10.0	45.2
Equipment	17.4	4.6	23.0	32.0	44.6	56.0	45.2	55.1	232.9
Confinement Systems	7.7	2.5	7.1	15.2	17.4	17.3	18.5	20.4	88.8
Technical Projects	0.1	0.1	1.0	1.8	3.5	3.3	1.4	0.0	10.0
Development & Technology ...	5.2	1.0	4.4	11.2	15.3	16.4	19.2	20.0	82.1
Applied Plasma Physics	4.4	1.0	7.3	19.5	8.4	19.0	6.1	14.7	67.7
Construction	17.6	5.5	97.5	130.0	105.0	145.0	257.0	324.0	961.0
TFTR	15.0	5.5	80.0	95.0	35.0	15.0	35.0	35.0	215.0
PEPR/ITR	0.0	0.0	0.0	0.0	15.0	50.0	80.0	105.0	250.0
High Field Neutron Source ..	0.0	0.0	0.0	10.0	15.0	20.0	20.0	10.0	75.0
Tritium Facility	0.0	0.0	0.0	0.0	5.0	10.0	20.0	10.0	45.0
Blanket and Shield	0.0	0.0	0.0	0.0	0.0	5.0	10.0	20.0	35.0
RTNS	2.5	0.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0
INS	0.1	0.0	15.0	10.0	0.0	0.0	0.0	0.0	10.0
Engineering Test Facilities.	0.0	0.0	0.0	0.0	0.0	10.0	32.0	39.0	81.0
MX	0.0	0.0	0.0	15.0	35.0	35.0	15.0	0.0	100.0
LSS	0.0	0.0	0.0	0.0	0.0	0.0	15.0	35.0	50.0
LHX (2)	0.0	0.0	0.0	0.0	0.0	0.0	30.0	70.0	100.0
TOTAL	155.0	47.1	303.8	409.0	429.9	528.1	649.6	755.1	2771.2

Figure III-4

IV. Bibliography

The following selected list of documents provides additional substantive background to the DMFE planning activities and are representative of the kind of information available to management on a continuing basis.

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