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ORNL Fusion Power Demonstration Study: An Illustrative Example of Planning for the Demonstration of the Commercial Feasibility of Tokamak Fusion Power in This Century (A Demonstration Study)

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ORNL FUSION POWER DEMONSTRATION STUDY: AN ILLUSTRATIVE EXAMPLE OF PLANNING FOR THE DEMONSTRATION OF THE COMMERCIAL FEASIBILITY OF TOKAMAK FUSION POWER IN THIS CENTURY (A DEMONSTRATION STUDY)

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FOREWORD

In the FY 1976 and 1977 ORNL Fusion Power Demonstration Study: Interim Report,[1] a number of innovative concepts were developed, namely, the cassette blanket, the vacuum containment building, and the committed fusion site. The interim report[1] contains the basic findings of the study and sets a context for each of the innovative concepts. A fuller exploration of each of the first two concepts is contained in the separate documents (ORNL/TM-5964, ORNL/TM-5664). This document represents the thoughts on the committed site concept as it was originated in early 1977. Since that time, the idea has received an increasing amount of attention leading to the initiation in early 1978 of a study aimed at evaluating the committed fusion site concept.

1. INTRODUCTORY SUMMARY

1.1 INTRODUCTION

The objective of the tokamak fusion power program (as defined for this planning exercise) is to secure a national fusion power option. More specifically, the objective is to develop and demonstrate the entire fusion power energy system concept to the point where commercial development can be initiated.

An illustrative project planning exercise aimed at the achievement of a commercial prototype demonstration or tokamak fusion power by the end of this century has been prepared based upon the approach suggested in the ORNL Fusion Power Demonstration Study: Interim Report.[1] The primary theme of this approach is that a committed site with shared facilities (defined in Sect. 1.2) could be developed to demonstrate sequentially the various phases of a demonstration program. This demonstration program would consist of the following three phases and associated facilities (defined more fully in Sect. 3.2) after the Tokamak Fusion Test Reactor (TFTR).

Phase No.	Function	Common Name-Acronym
I	Ignition or primitive power demonstration†	Ignition Test Reactor - ITR*
II	Net power or power technology demonstration†	Experimental Power Reactor - EPR
III	Commercial prototype demonstration	Demonstration Reactor - Demo

*In concurrent studies, DMFE's TNS teams are investigating what is possible for The Next Step after TFTR, which encompasses the ITR and a step midway between the ITR and EPR, namely, the prototype EPR (PEPR). In the Fusion Power Demonstration Study, TNS has been assumed (for the sake of definiteness) to be an ITR. The logic is not altered if TNS is in fact one-half step ahead, i.e., a PEPR.

†Throughout this document the brief references - ignition (ITR) and power technology (EPR) will be used for convenience to mean ignition and/or primitive power demonstration and net power and/or power technology demonstration.

In this brief project planning exercise, broad strategic scope and timing considerations are examined and major programmatic assumptions, driving forces, constraints, and decision points are postulated in Sect. 2. An implementation plan for executing the program strategy is presented in Sect. 3, conclusions are presented in Sect. 4, and recommendations for continued development of this approach are discussed in Sect. 5.

1.2 STRATEGY

The central feature of the proposed strategy[1] is that the plasma characteristics required for the commercial prototype demonstration (Demo) are essentially the same as those required for an ignition demonstration device (ITR). Thus, many of the components developed for the ignition demonstration phase will be applicable to the commercial prototype demonstration phase. This is an important factor and contributes to the possibility of minimizing the number of facilities required for the demonstration programs. The necessary and desirable step-by-step transfer of technology, engineering, and physics understanding from one experience to another will be achieved through the three phases of the program.

The committed site consists of two major components — the shared facilities and the specific demonstration modules. In the shared facilities will be the traditional "balance of plant" items such as buildings and other facilities, and the particular, sharable high-cost items peculiar to fusion such as the pulsed electrical power, cryogenic plants, tritium handling, and maintenance. Within the demonstration modules will be a first unit that is envisioned to have an initial target of ignition and burning for minimal electrical power, with an upgrade capability for net electrical power production. A second unit is envisioned to be the commercial prototype demonstration unit.

1.3 SUMMARY

This exercise supports the thesis that the committed fusion site concept provides the framework for a reasonable path to the rapid demonstration of fusion power as an energy option for our country. The specific end date depends upon the ability to initiate the demonstration program and upon the outcome of the underlying research and development programs. Assuming that a start within a year is possible and that the outcome of the supporting research and development programs is favorable, then an endpoint of a commercial feasibility demonstration by the beginning of the twenty-first century is projected.

The three-phase plan at a committed site to provide this demonstration of the fusion option is illustrated in Fig. 1.1. The word "option" implies that, in addition to a strictly technical demonstration, a national capability to deploy the concept will be in place when needed. Since the current objectives of the DOE program do not explicitly include commercialization of fusion power, the capability to move toward widespread commercial deployment must await a favorable national commitment.

We have assumed that the associated research and development programs will be implemented on a timely basis as required to support the physics and technology uncertainties. The TNS Study Programs in FY 1977 have identified the major R&D requirements for the tokamak ignition device.[2,3]

This exercise is clearly only the first small step toward identification and implementation of a fusion demonstration strategy. The ORNL Fusion Power Demonstration Study: Interim Report[1] contains more technical discussions about the nature of fusion reactor design relevant to shared facilities; the GA Facilities Study[4] contains a much more detailed study of the facilities' aspects of another demonstration strategy. This exercise has been based on the assumption that the tokamak approach is the principal path to demonstration. This assumption could be replaced with either a broader premise that postulates a class of alternate initial approaches or one that postulates changing from one approach to another during the evolution of the demonstration plan. An example of the former would be a committed site designed to accommodate tokamaks, mirror, EBT, and other approaches; an example of the latter would be a site planned for a tokamak ignition phase allowing for the possibility of a mirror or EBT follow-on.

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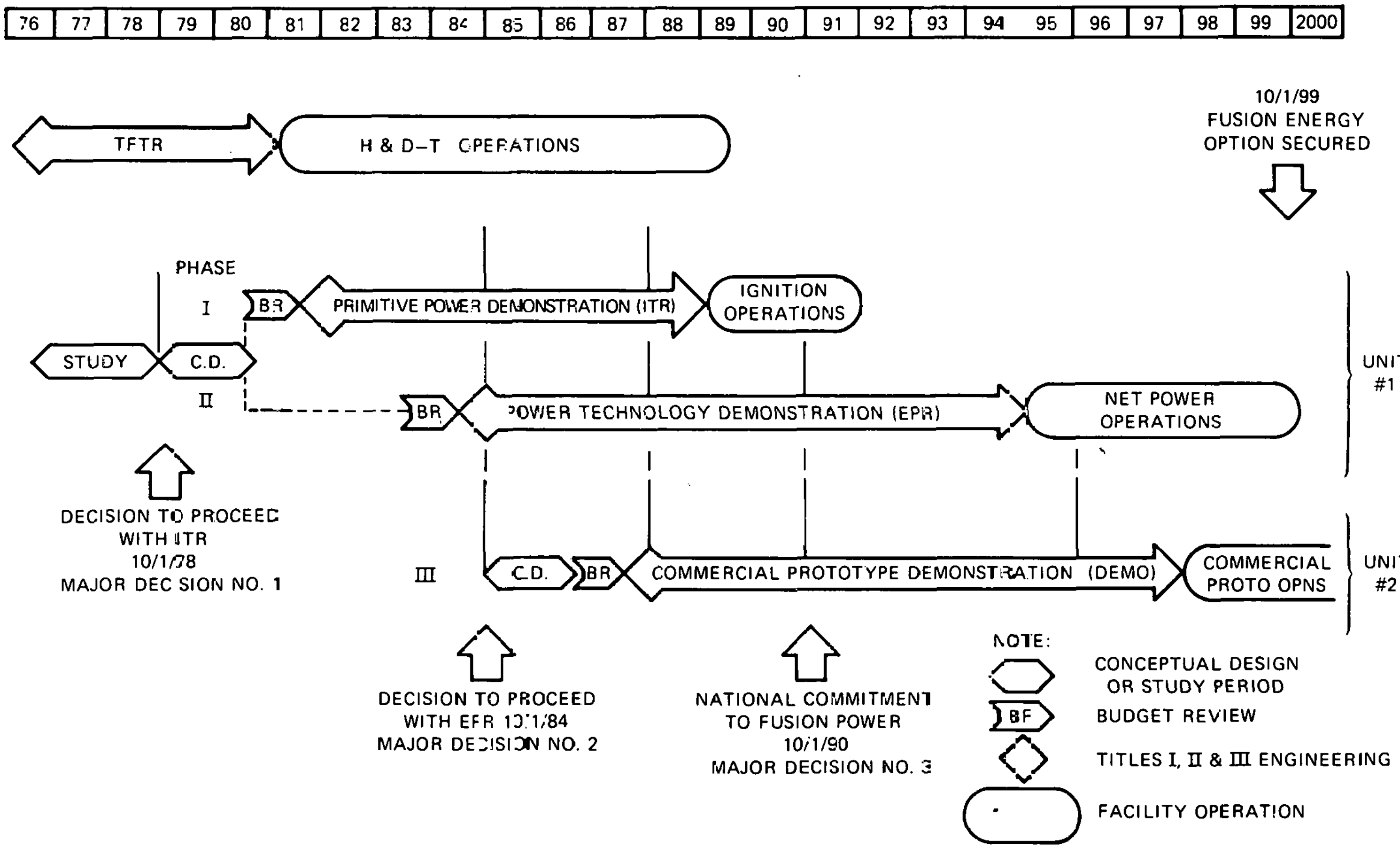

Fig. 1.1. Summary schedule of three-phase power demonstration plan.

Finally, the promise of the committed site can only be enjoyed through a detailed design consideration of the advantages and disadvantages of the committed site versus separate sites. Specifically, a study must be made of the details of which systems can be shared to what financial savings and at what financial risk, and of the impacts on the device and facility designs, both positive and negative, from the constraints of the committed site.

2. PROJECT PLANNING BASIS

The program described in this plan is one of development and demonstration. It does not extend explicitly, at this time, to commercialization. The program strategy must, however, recognize and be consistent with an assumed degree of urgency for fusion power deployment as well as the hurdles and constraints in the path of development and demonstration. The assessment of need and risk used in this plan is similar to the Logic III-IV levels set out in an earlier ERDA-DMFE planning exercise:[5] i.e., an aggressive program propelled by the overall program needs but triggered by technical achievement.

For this planning exercise, the following assumption is made. The motivation and major driving force for the fusion power option is *the prospect* of this energy source filling the energy gap produced by *ever decreasing* natural resources such as gas, oil, coal, and uranium and *ever increasing* national power requirements. To be specific, the particular definition and timing of the match between need and achievement of the fusion power option (being dependent on total electrical load growth and the competition among alternative sources of electrical energy) is commercial prototype demonstration by the end of this century.

2.1 INTERACTION OF PROJECTS

As a means of developing a credible self-consistent schedule, the commercial prototype demonstration operation requirement is assumed to be FY 1998. This assumption, in turn, drives the schedule for the ignition and net power demonstration projects,

ITR................FY 1988
EPR................FY 1995.

As is evident in Fig. 1.1, these operational date requirements derived from "back to front" planning do turn out to be consistent with "front to back" planning if the ITR commitment is made in FY 1982 and the EPR and Demo commitments are made in FY 1984.

2.1.1 Ignition Demonstration (ITR)

The commitment date for the ignition demonstration was chosen as FY 1982.* It is assumed that by this date the physics, technology, and engineering issues will have been qualified sufficiently (as a result of on-going R&D projects such as TFTR, TSTA, ISX, D-III, LCP, PDX, Alcator, etc.) to proceed with an ignition device at minimum risk. Assuming a two to three year design and design-specific development and prototyping period before "cutting metal," then large financial commitments would not be required before FY 1984-85. By FY 1984-85, the U.S. fusion program† will have yielded:

- >3-6 years of operational experience in such R&D devices as ISX, PLT, PDX, D-III, etc.,
- 3-4 years of H and D-T operation in TFTR,
- 2-3 years of detailed ITR device design having the "same" scale as the EPR and Demo plants,
- 2-3 years of the "same" scale design-specific R&D and prototype "out-of-plant" test results, and

*The planning for ITR is more extensively discussed in the "Draft Program Plan for TNS - The Next Step after TFTR," ORNL/TM-5982,[2] ORNL/TM-5983,[6] ORNL/TM-5984,[7] and WFPS-TME-044.[8]

†In this exercise, the contributions of the major European, Japanese, and Soviet programs have not been explicitly included. As the longer range portions of these three program plans become clear, then they must be included in the evolution of this planning exercise.

- sufficient environmental, safety, waste handling information, and experience to ensure licensability of the EPR and Demo plants.

It is on the basis of these experiences that a commitment to large-scale manufacturing costs would be made in FY 1984-88.

2.1.2 Power Technology Demonstration (EPR)

With the expected program accomplishments in the FY 1984-1985 period as listed above, it is assumed that the physics, engineering, and technology issues are further qualified to the point where a FY 1984-85 commitment can now be made to proceed with the EPR at a reasonable risk. This commitment is to the Title I funding phase for the power technology demonstration and to the conceptual design phase of the commercial prototype demonstration (see Fig. 1.1). Assuming, further, a three-year design and licensing phase and a seven-year construction period, the EPR Title I commitment phase in FY 1984 would be followed with large financial commitments commencing about FY 1988. By FY 1988 the U.S. fusion program will have yielded:

- >5-8 years of operational experience on such R&D devices as ISX, PDX, D-III, etc.,
- 7 years of H and D-T operation on TFTR,
- 6 years of detailed device design on the "same" scale as the commercial plants,
- >6 years of the "same" scale design specific R&D, and prototype "out-of-plant" test results,
- demonstration of licensability of a commercial scale fusion power plant, i.e., construction permit for EPR in FY 1988, and
- start of ITR, "proof of principle," and preoperational testing.

Again, it is on the basis of these substantial experiences that the commitment to large-scale manufacturing would be made.

2.1.3 Commercial Prototype Demonstration (Demo)

By FY 1988, with further physics, technology, and engineering issue qualifications, as noted in the fusion program yields above, the Demo commitment can be made. Major financial commitments, again, would not be required until after the three-year design and licensing period ended in FY 1991 and most important, not until after three years of ITR operations for "proof of principle."

2.2 EXPERIENCE TRANSFER AND THE TIME PHASING OF SUCCESSIVE PROJECTS

Another factor governing the scope and timing of the fusion power program is experience transfer. Time-phasing of successive projects should be such as to allow a substantial degree of experience transfer consistent with schedules compressed to a point determined by the judgment of acceptable risk.

There are at least two principal factors to be considered here about experience transfer. One concerns the development of experience and the phasing of projects to allow useful application of the experience developments. The other concerns the capabilities of a given project team to perform the actual transfer of experience. With regard to the first factor, maximum experience transfer occurs, and scale-up risks are minimized when projects are widely displaced in time, allowing more milestones of one project to be achieved before a follow-on project is initiated. However, this consideration must be weighed against the loss of national benefits that would accrue from earlier fusion power introduction, and, indeed, considering the second factor, against the potential loss of experience transfer due to long-term discontinuities in project teams.

In an extreme case, one would not start design of a follow-on project until the preceding project had operated for, say, two years. This "serial" plan would allow identification of essentially all generic deficiencies in the preceding project before the follow-on is committed. However, in this serial plan, without a parallel and properly timed, phased program of similar activities, cyclical mobilization and demobilization of design teams and manufacturing capability would result in major program discontinuity. This discontinuity would be a result in addition to the inherently long schedule.

The following general groundrules are followed in establishing relative timing of fusion power plant projects in this planning exercise:

1. Design of a plant would start when most of the design of the preceding plant is complete, when the construction permit has been awarded, and when construction has been started on the preceding plant. This assures continuity of design expertise and effective transfer of design, procurement, and licensing experience.
2. Component and system testing for the third phase project occurs simultaneously with the design and licensing phase of the second phase project and before construction starts on the first phase project.
3. Project commitment is assumed to occur at the start of detailed design. Detailed design and licensing (for a construction permit) typically require three years. Construction, which commences when a construction permit is awarded, typically requires seven years. Then, the total assumed commitment-to-operation lead time is ten years.

Another parameter which affects risk, in addition to the relative timing of successive projects, is the degree of scale-up, or the scale-up factor. The ITR (Phase I), upgraded to EPR (Phase II) is of the "same" scale as the Demo plant (Phase III) which leads to a minimum scale-up risk; the ITR and its upgrade to EPR are called Unit #1 on Fig. 1.1 and the Demo plant is called Unit #2.

2.3 DECISION MILESTONE CONSIDERATIONS

Consideration of the necessary interactions between projects and the time-phasing scheme for the required experience transfer along with the assumption of reasonable, business-as-usual, construction times for each project resulted in the planning exercise schedule found in Fig. 1.1. This schedule considers the critical path of physics understanding by imposing the project interaction overlaps, the overall technological and engineering critical path by imposing the experience transfer time-phasing scheme, and the construction time-critical path by using business-as-usual construction times. Each of the three areas of consideration is indicated as a critical path since a slippage in time in any one of these areas will cause an equal amount of time delay in all downstream activities. If, for example, it took nine years to construct the ITR, then the EPR and Demo would slip two years.

These three rather detailed, complicated critical paths can be summarized into three major decision milestone points which become the overall critical path:

#1. (10/1/78) decision to proceed with ITR (i.e., start formal conceptual design),

#2. (10/1/84) decision to proceed with EPR (i.e., start formal Title I design), and

#3. (10/1/90) decision to proceed with Demo (i.e., order major components).

If, at the time of milestones 1, 2, or 3, any of the "required input or performance" items for the physics, technological and engineering, or construction spans has not been satisfied, thus delaying the decision point, then all downstream activities are delayed an equal amount of time.

2.4 PHYSICS, TECHNOLOGY, AND ENGINEERING CONSIDERATIONS

The final factor governing the scope and timing of the fusion power program is the set of outstanding physics, technology, and engineering issues. The TNS R&D Study[2] identified the ignition device issues and laid out preliminary schedular requirements. These issues have also been confronted in the ORNL Fusion Power Demonstration Study: Interim Report.[1] In the interim report the question of finding the "correct" set of physics, technology, and engineering directions was addressed in the following way:

> As a final point, it must be emphasized that there is no unique set of technological directions, engineering designs, or plasma parameters which offers promise for the demonstration of commercial feasibility. Several such sets, no doubt, do exist. In this study, we seek to define one promising set

of technologies, design approaches, and plasma characteristics. Thus, our objective is to develop *a* plan, not *the* plan, for demonstrating commercial feasibility.

Rather than search for *the* "correct" plan, then, this illustrative exercise is pointed toward development of a feasible plan. In doing so, it assumes that an acceptable set of physics parameters, technological directions, and engineering designs will be available to support the successive project experiences as they accumulate up to the time of major financial commitment for the Demo facility in FY 1991. This 14-year period from today should give the nation enough time to explore and develop this promising energy source as a useful energy option.

3. PROJECT IMPLEMENTATION PLAN

Based upon the factors discussed in Sect. 2, an elementary plan of costs and schedules tied to an overall Work Breakdown Structure (WBS) can be developed for further consideration. This section presents the overall WBS as an organizing framework, the objective of the three phases, projected costs, and schedules for them.

3.1 OVERALL WBS FOR FUSION DEMONSTRATION

An overall WBS is a systematic method of presenting all the elements of a given program.[7] The demonstration elements in the fusion program are ignition or primitive power, power technology, and commercial prototype. Most of the research and development activity and facilities are tied explicitly to requirements of these projects, and in this way, project objectives and schedules drive most of the DOE fusion power program. Part of the R&D programs are technology and physics understanding programs not directly identified with specific projects. The goals of these generic programs are to provide a broad base of physics understanding and technology which: (1) provides as contingency alternatives when problems arise in the demonstration projects and (2) produces improvement beyond the demonstration programs.

The upper level WBS (Fig. 3.1) presents each of the demonstration project tasks (the level 2), project specific R&D tasks, and generic

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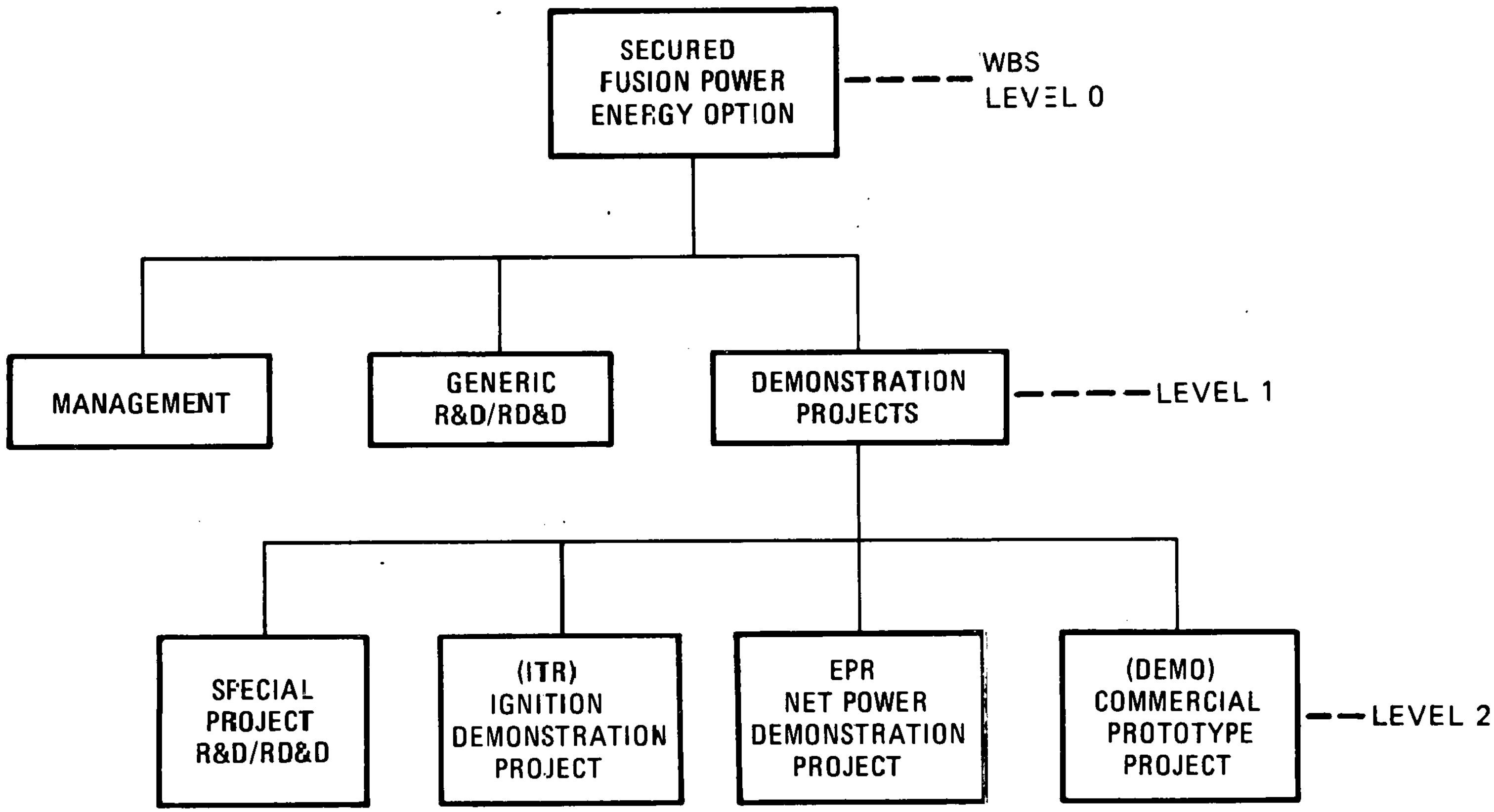

Fig. 3.1. Top level work breakdown structure of three-phase power demonstration plan.

program tasks in relation to the ultimate program objective — a secured energy option. In level 3 of the WBS (Fig. 3.2), each of the level 2 projects is broken down into the principal tasks, management systems, device systems, facilities systems, power conversion systems (Phases II and III only), preoperational and operational systems, and project specific R&D. At level 4, the systems task packages are divided into subsystem task packages. Each package includes the design, procurement, fabrication, assembly, installation, and construction activities needed to accomplish the task. These breakdowns at the fourth level are developed and presented in Fig. 3.2.

3.2 INDIVIDUAL PROJECT OBJECTIVES

3.2.1 Ignition Demonstration Project (ITR)

Key Objective: to demonstrate the elements of a controlled fusion energy power system.

Critical Objectives:

- to provide a research fusion reactor which will generate a reactor core plasma, using moderate extensions of the technology that will be qualified by FY 1982-84, from which systems integration experience can be gained,
- to provide a forcing function of fusion technology,
- to provide a "proof of principle" that the tokamak approach to a plasma fusion core is soundly based, and
- to obtain initial design and construction experience that will provide capability for the further project modification to a power technology demonstration "proof of technology" project.

Thus, this phase is concerned with producing a minimal amount of electricity using elementary versions of all the systems expected in a reactor plant and is not concerned with extensive power conversion, tritium breeding, and recovery.

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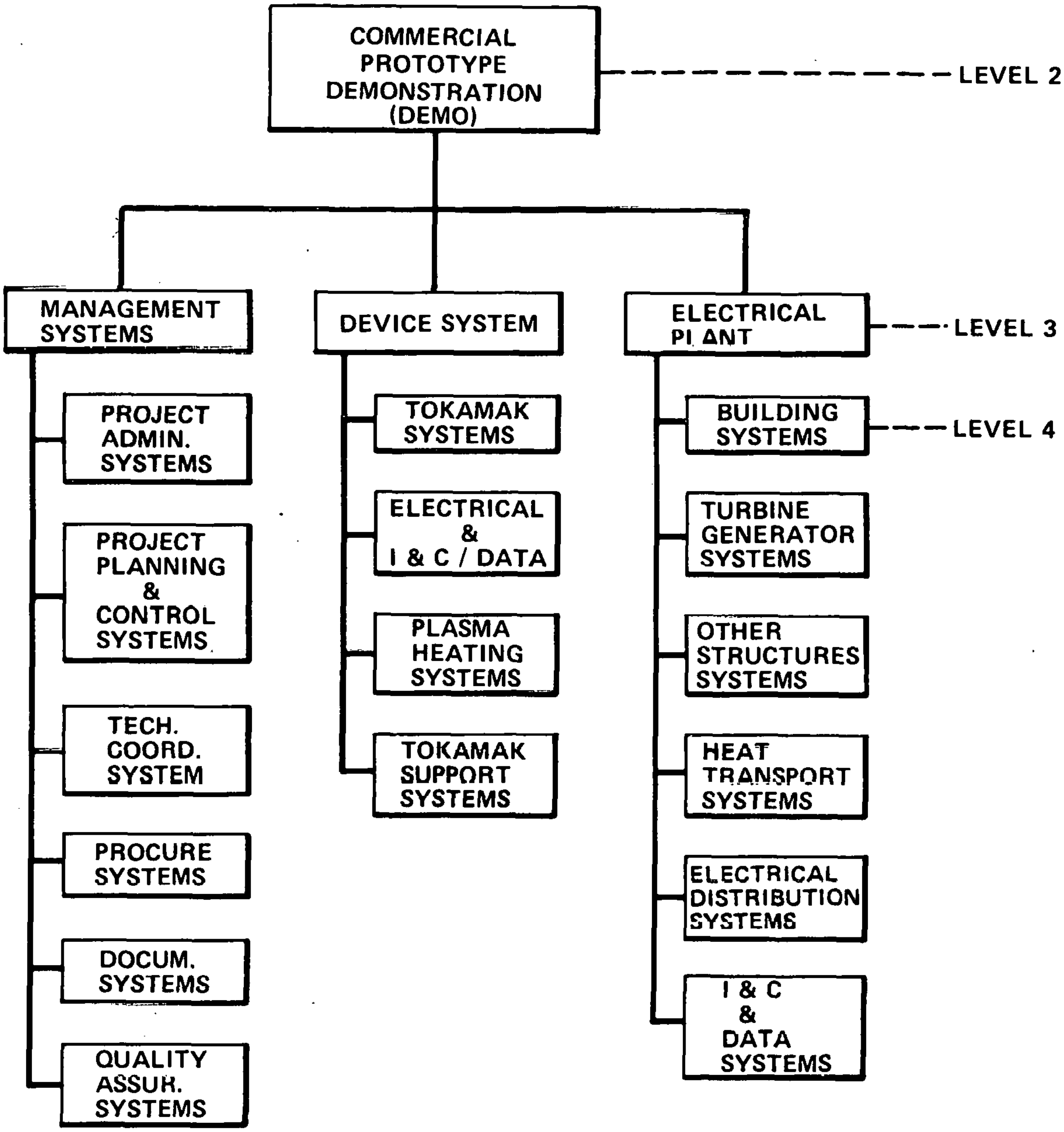

Fig. 3.2. Detailed work breakdown of three-phase power demonstration plan.

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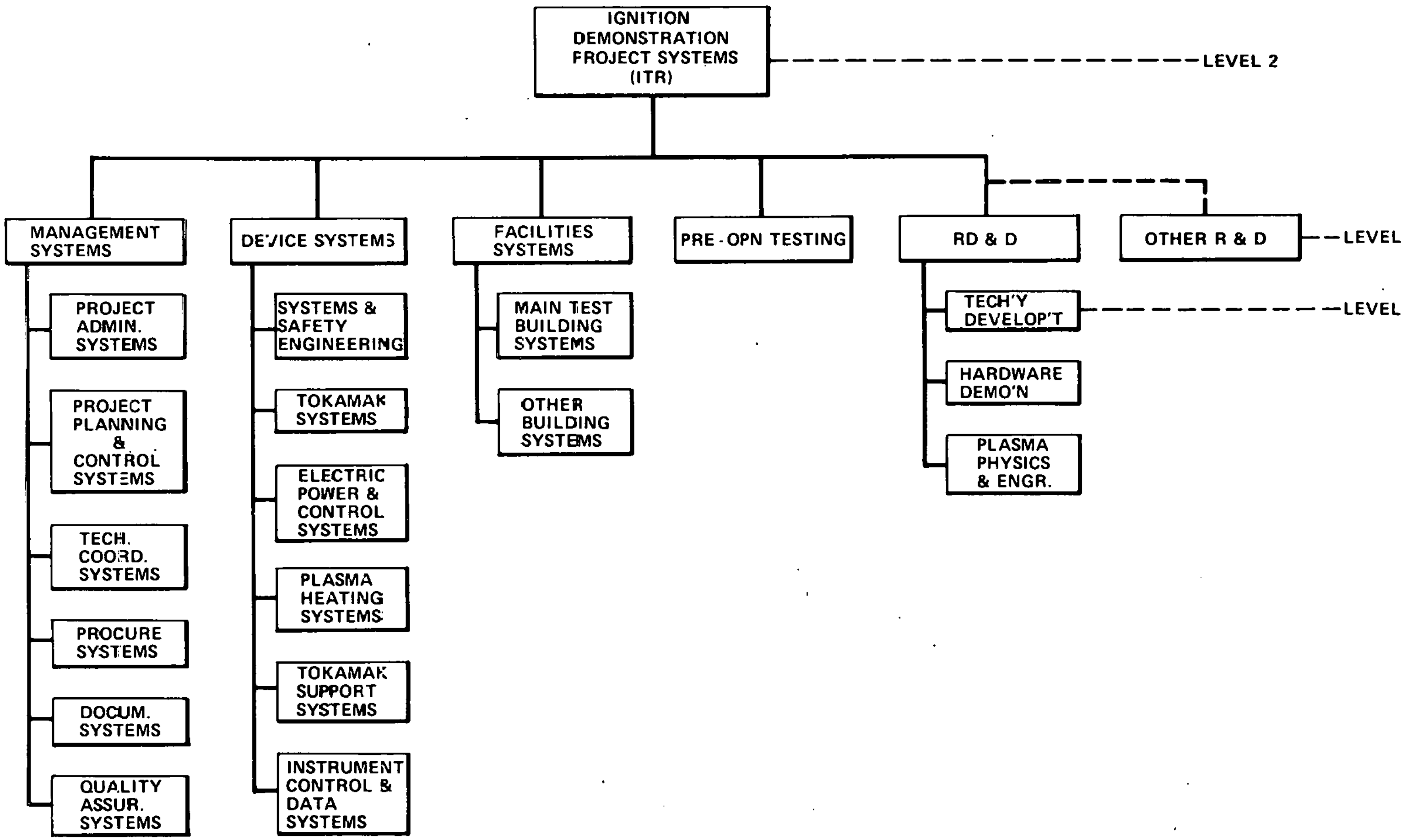

Fig. 3.2 (continued)

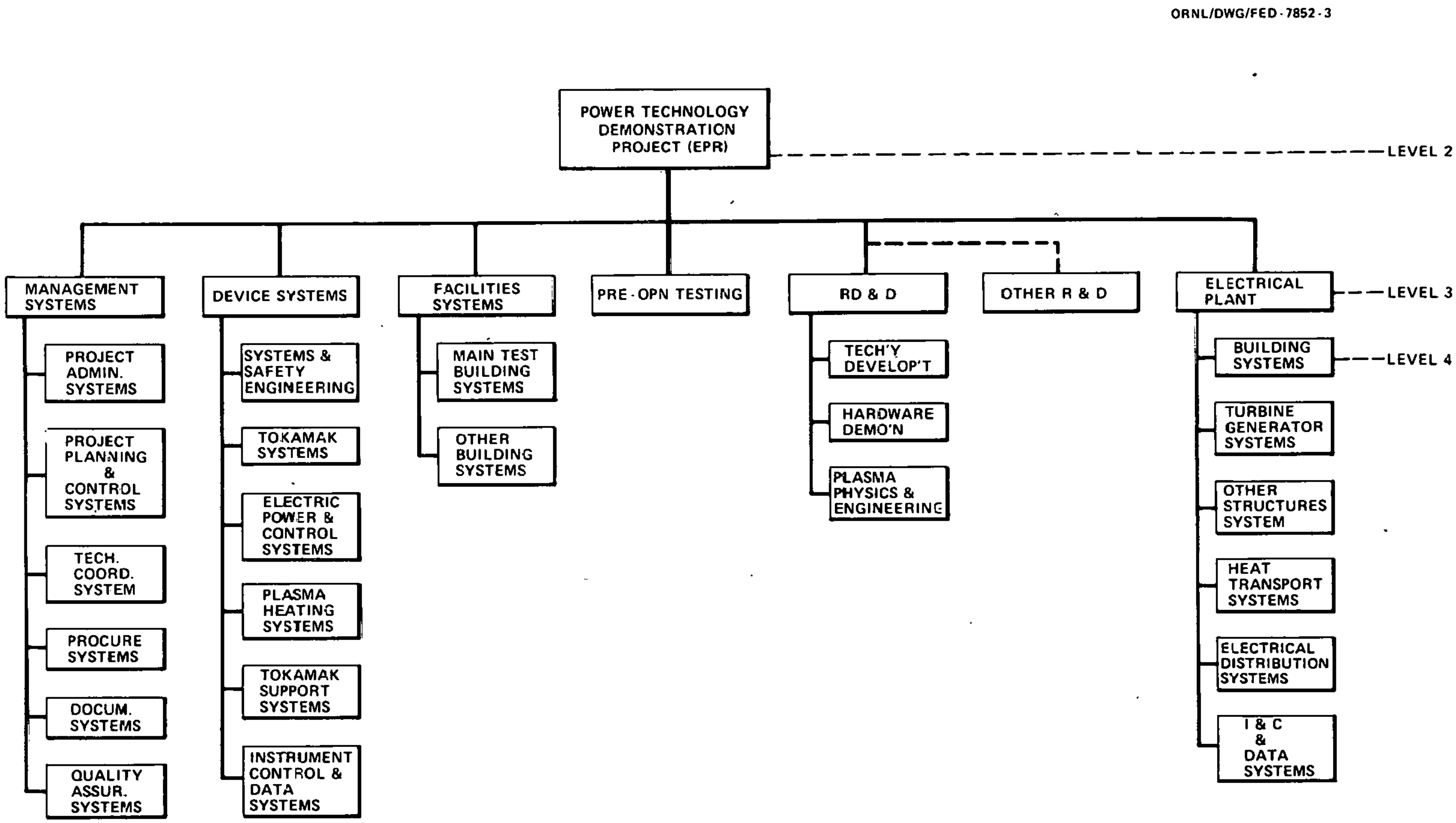

Fig. 3.2 (continued)

3.2.2 Power Technology Demonstration (EPR)

Key Objective: to demonstrate power technology operations.

Critical Objective:

- to provide a full-scale tokamak electrical power generating plant that will result in a "proof of technology."

Project Justification

At the time this project will get the go-ahead (FY 1985), ten to fifteen years of actual experimentation and study experience with the tokamak fusion power concept will have been accomplished. This experience includes all the tokamak-specific R&D projects such as ORMAK, PLT, ISX, TFTR, D-III, etc., in addition to three to five years of actual "full-scale" design and project-specific R&D experience on the Phase I ignition demonstration project (ITR). At this time, the tokamak fusion power concept will be sufficiently qualified for the second major decision milestone — to proceed with the EPR project and to be made with minimum economic or technical risk.

3.2.3 Commercial Power Demonstration (Demo)

Key Objective: to demonstrate the feasibility of commercial fusion power.

Critical Objectives:

- to provide a basis for the fusion power option that will engender public and utility confidence,
- to document the feasibility of the industrial park fusion power concept, and
- to form the groundwork from which the fusion power option can be secured and expanded.

Justification of Demo Project

A commercial prototype demonstration plant (Demo) is needed to engender the confidence of the public and utility companies. This prototype operation is needed specifically to demonstrate reliable, efficient, economical, and safe fusion power operations in order to secure the fusion option.

The 10/1/90 major decision milestone commits major funds to proceed with the Demo. At this time, the tokamak concept will have been studied, designed, and operated (with several years of ignition operation experience on the ignition demonstration project) with at least 20 years of multiple project experimentation results. Minimum risk will be involved at this time.

Generic and Project-Specific R&D

The Demo Study interim report[1] and the TNS Program Plan[2] discuss the generic and project specific R&D requirements. Elaboration of these findings is not in the scope of this illustrative plan.

3.3 COST PLAN

This single site, minimum scale-up, sequential, fusion power demonstration plan could be implemented with a total construction cost of approximately $1.6 billion (see Table 2.6, Ref. 1) (in FY 1976 dollars). This does not include engineering and contingency cost, nor does it include development costs or escalation.

The cost projections above are obviously speculative due to the preliminary nature of the program. Nonetheless, fusion power project cost projections by project area per year are considered to be a necessary part of this plan. The intent of this yearly costing data is therefore to give some indication of *major funding period requirements* recognizing the absence of any specific design studies for the three phases that would support the accuracy of the numbers used. The following project costs are therefore assumed.

Groundrules for demonstration projects

Construction costs ($ in billion)
(see Table 2.6, Ref. 1)

Unit #1	ignition (ITR)	$0.65 (FY 1976 $)
(Upgrade)	net power (EPR)	0.25 (FY 1976 $)
Unit #2	commercial prototype (Demo)	0.7 (FY 1976 $)

Groundrules to arrive at total estimated cost (TEC)

R&D (project-specific)	15% of construction costs
Engineering	35% of construction costs
Program management	15% of construction costs
Contingency	40% of the above
Escalation	8% per year (compounded)

ITR

Ignition demonstration total estimated cost in FY 1976 $ ($ in million)

Construction costs	$650
Engineering @ 35% of construction costs	230
Program management @ 15% of construction costs	100
R&D project-specific @ 15% of construction costs	100
Subtotal	1,080
Contingency @ 40% of the above subtotal	420
Total estimated cost (FY 1976 $)	$1,500

EPR

Power technology demonstration total estimated costs in FY 1976 $ ($ in million)

Construction costs	$250
Engineering @ 35% of construction costs	90
Program management @ 15% of construction costs	40
R&D project-specific @ 15% of construction costs	40
Subtotal	180
Total estimated cost (FY 1976 $)	$600

Demo

Commercial prototype demonstration total estimated costs in FY 1976 $ ($ in million)

Construction costs	$700
Engineering @ 35% of construction costs	250
Program management @ 15% of construction costs	100
R&D project-specific @ 15% of construction costs	100
Subtotal	$1,150
Contingency @ 40% of the above subtotal	450
Total estimated cost (FY 1976 $)	$1,600

Total estimated costs for projects (Escalated costs) ($ in million)

ITR	$2,600
EPR	1,300
Demo	3,400
Grand total estimated costs	$7,300

Table 3.1 summarizes the project costs by year with costs escalated from FY 1976 dollars. This total of the capital costs of the three major fusion program demonstration elements through completion in FY 1997 is $7.3 billion (this does not include operation costs). It can be seen by the yearly totals that the funding requirements peak in FY 1992. The total funds expended up to the Demo commitment date (FY 1991) is $3.6 billion which represents about 50% of the total program. This is the cost to arrive at the "go no-go point," where the remainder of the costs can be spent with minimum risk.

As noted, these costs include large factors for contingency (40%), engineering and management (50%), and a 15% factor for developmental costs. These have purposely been chosen high at this time, reflecting the uncertainties in the early stage of fusion power development. Subsequent reductions in these factors could bring the program costs down.

3.4 SCHEDULE PLAN

Figure 3.3, Fusion Power Demonstration Master Schedule, presents the master schedules for each of the demonstration projects with the activity interrelationships shown. Also indicated are each project's status milestones which are defined in Table 3.2.

In order to verify the schedular logic and activity interrelationships, the illustrative plan was run on the IBM computer (PMS-4/E-Z-PERT) pert program. The results verify the illustrative plan logic.

Table 3.2 presents the status milestones, and it also indicates that the overall plan critical path goes through each of the plan major decision milestones. This critical path means that, for any reason (such as lack of qualification of "proof of principle") when a time slippage occurs in any one of these decision milestones, all downstream milestones of all demonstration projects will slip an equal amount of time.

4. CONCLUSIONS

1. Assuming successful resolutions of the physics, technology, and engineering uncertainties by 1990, the commercial feasibility of tokamak fusion could be established in this century with a

Table 3.1. Demo study cost planning

FY	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	2000		Totals
DOE official escalation factors from FY 1976 $ @ 8% per year	1.48	1.56	1.64	1.74	1.8	1.88	1.96	2.04	2.12	2.2	2.28	2.36	2.44	2.52	2.60	2.68	2.76	2.84	2.92		
<u>Ignition demonstration</u> (TTR)																					
Schedule of yearly costs — %	10	15	20	25	15	10	5														100%
TEC — FY 1976 $ ($ × M)	150	225	300	375	225	150	75														$ 1,500M
TEC — Escalated $ ($ × M)	222	351	492	653	405	282	147													ITR TEC = (escalated)	$ 2,550M
																				USE	$ 2,600M
<u>Net power demonstration</u> (PTD)																					
Schedule of yearly costs — %				5	5	5	10	10	15	20	15	10	5								100%
TEC — FY 1976 $ ($ × M)				30	30	30	60	60	90	120	90	60	30								$ 600M
TEC — Escalated $ ($ × M)				52	54	56	118	122	191	264	205	142	73							PTD TEC = (escalated)	$ 1,277M
																				USE	$ 1,300M
<u>Commercial prototype demonstration</u> (Demo)																					
Schedule of yearly costs — %							5	5	5	10	15	15	15	10	5	5					100%
TEC — FY 1976 $ ($ × M)							80	80	80	160	240	240	240	160	80	80					$ 1,600M
TEC — Escalated $ ($ × M)							157	163	170	352	547	566	586	403	208	214				DEMO TEC = (escalated)	$ 3,366M
																				USE	$ 3,400M
Escalated totals by FY	222	351	492	705	459	338	422	285	361	616	752	708	659	403	208	214				GRAND TEC	$ 7,300M

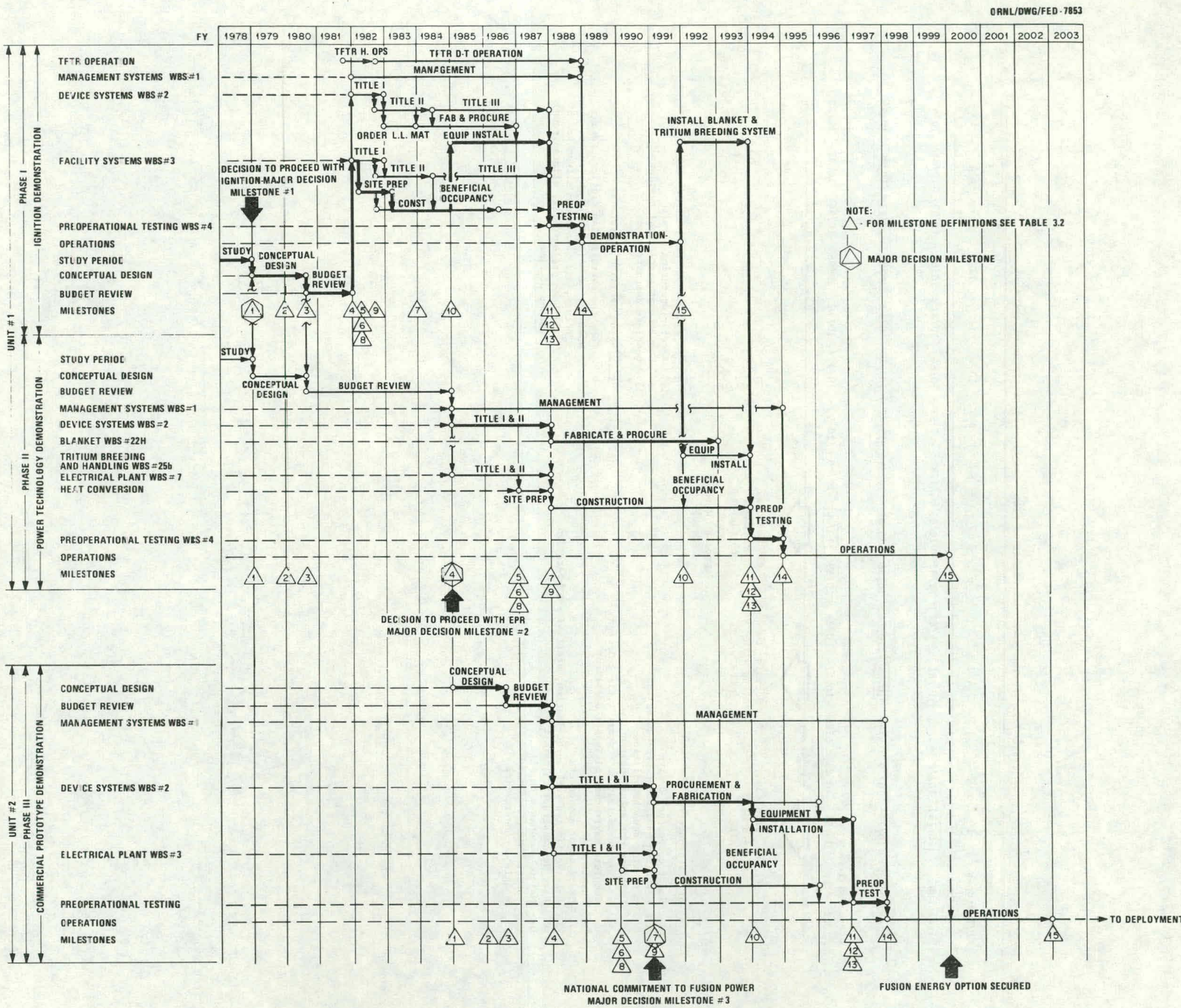

Fig. 3.3. Fusion power demonstration master schedule.

Table 3.2. Fusion power demonstration plan — major project status milestones

Project Milestones	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Ignition	10/78	10/79	5/80	10/81	1/82	1/82	10/83	1/82	7/82	10/84	10/87	10/87	10/87	10/88	10/91
Power technology	10/78	10/79	5/80	10/84	10/86	10/86	10/87	10/86	10/87	10/91	10/93	10/93	10/93	10/94	10/99
Commercial prototype	10/84	10/85	5/86	10/87	10/89	10/89	10/90	10/89	10/90	10/93	10/96	10/96	10/96	10/97	10/02

#1 Decision to proceed with ITR

#2 Decision to proceed with EPR

#3 National commitment to fusion power (proceed with Demo)

List of milestones

1. Start conceptual design
2. Establish management procedures and funding responsibilities
3. Complete conceptual design
4. Receive authorization — start Title I design
5. Complete environmental Impact Statement
6. Submit PSAR
7. ORDER major components
8. Receive limited work authorization, start site preparation
9. Receive construction permit
10. Major components on site
11. Submit PSAR
12. Complete construction
13. Receive operating permit
14. Complete preoperational testing
15. Complete demonstration

☐ Major decision milestones

Form the overall plan critical path
When a time slippage in any one of these occurs, all downstream milestones of all Demo projects will slip an equal amount of time.

carefully considered demonstration plan based upon the committed site concept.

2. Including escalated capital costs for the three demonstration elements, the preliminary total program cost is estimated to be $7.3 billion plus operating costs to achieve commercial feasibility.
3. Three major milestone dates are identified for minimum risk.

Milestones	Date	% Total TEC obligated before date
• Decision to proceed with ITR	10/1/78	0%
• Decision to proceed with EPR	10/1/84	15%
• Decision to proceed with Demo	10/1/90	50%

4. The three-phase approach schedule appears to allow a high degree of experience transfer consistent with acceptable risk. It also provides program continuity in terms of management and design teams and manufacturing capability.
5. The elements of a project plan have been laid out as a basis for further discussion and refinement.

5. RECOMMENDATIONS

The concept of a single site dedicated to the development of fusion reactors from an "ignition" device through a prototype of a commercial power reactor has many potential benefits. If such a committed site concept is to be implemented, then it is important that the process of identifying site requirements and initiating development begins soon. Therefore, it is recommended as an initial step that a set of requirements and characteristics be developed covering both generic power plant considerations and more importantly the specifics of site and device interfaces capable of supporting an evolving program leading to demonstration. The second recommended step in this process is to develop plans for the design of site facilities intended to maximize the cost- and schedule-effectiveness of placing multiple devices on a single site in a sequential manner, sharing costly items and incorporating technical improvements as they become available.

In addition to the site considerations, it is recommended that design criteria be developed and the physics, technology, and engineering questions be defined relative to the construction schedules and costs to determine their impact, and most importantly, their feasibility of timely accomplishment.

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