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FINAL REPORT

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# EVALUATION OF A COMMITTED FUSION SITE

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PREPARED BY
BECHTEL NATIONAL, INC.
P.O. Box 3965
San Francisco, California 94119

UNDER SUBCONTRACT NUMBER 7503
FOR
OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE 37830
OPERATED BY
UNION CARBIDE CORPORATION
FOR THE
DEPARTMENT OF ENERGY

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# 1.0 INTRODUCTION

In many cases, the committed or centralized site for the development and commercialization of a new or advancing technology has been highly successful. The committed site helps reduce development time, centralizes and focuses development effort, and promotes maximum economy of resources. Examples of such committed sites are Houston and Cape Kennedy for the United States Space Program, Dounrey for the British fast breeder reactor program, and Karlsruhe for German physics and nuclear research.

The fusion program is entering a transition stage. The recent progress in plasma physics has been rapid and the large devices that will come on line in the next few years are expected to provide the information needed to proceed to larger engineering-oriented experiments. These experiments will be expensive and require costly supporting facilities.

The committed site concept for fusion power development emerged from GFY76-77 studies conducted by the Advanced Systems Program of the Fusion Energy Division of Oak Ridge National Laboratory. The Committed Fusion Site Project for FY78/79 was conducted by Bechtel under subcontract with the Oak Ridge National Laboratory operated by Union Carbide Corporation, who provided technical direction. The objective of this study was to evaluate the

technical and economical merits of a committed fusion development site for magnetically confined fusion concepts, dedicated to major engineering experiments, not proof-of-principle. There are many advantages to such an approach. A committed site could provide a strong focus for the basic fusion power research and development program that is presently being conducted at many locations throughout the United States. A committed site can maximize the utilization of common facilities. A major potential advantage is a reduction in the overall time and cost for fusion development by eliminating the need to repeatedly select and develop sites for each step in a fusion power reactor development program; a program that may require as many as four development stages (The Next Step, Engineering Power Reactor, Demonstration Plant, and a Commercial Plant).

Disadvantages of the committed site approach are that it may require near term fusion program budget increases to cover the development of the site and its administrative maintenance. Also, it may prematurely subject fusion development to the restrictions of licensing and regulatory considerations. Further, under closer examination, the expected technical, programmatic, and cost advantages of a committed site may turn out to be illusory. As a first step in evaluating the merits of a committed site for the U.S. fusion program, Bechtel undertook a first-cut evaluation of the concept for the Office of Fusion Energy under the technical direction of Oak Ridge National Laboratory (ORNL). The objective of this study was to make a

preliminary evaluation of the technical and economic merits of a committed site dedicated to major engineering experiments.

Even though the plans and requirements for fusion development and the characteristics of the devices which might be placed at a committed site are not precisely known at this time, general requirements and characteristics can be sufficiently well established to make a valid evaluation. This study is based on syntheses of characteristics and development scenarios by Bechtel and ORNL developed from information supplied by major fusion development laboratories. There is no intent to imply a preference for any scenario or fusion concept either by virtue of inclusion or exclusion in the scenarios presented; they <u>only</u> provide a representative basis for evaluating the potential merits of a committed site.

The technical approach taken in this study is shown in Figure 1-1. The work was divided into four major tasks. Task 1 was primarily information gathering to determine the fusion site needs as perceived by some of the major fusion development laboratories. Several laboratories were visted and the literature on development plans was reviewed. Based on this information, baseline site characteristics defining an expected envelope were defined.

In Task 2, these data were analyzed to determine common characteristics, site/facility interfaces, and other site requirements. A number of site development scenarios were

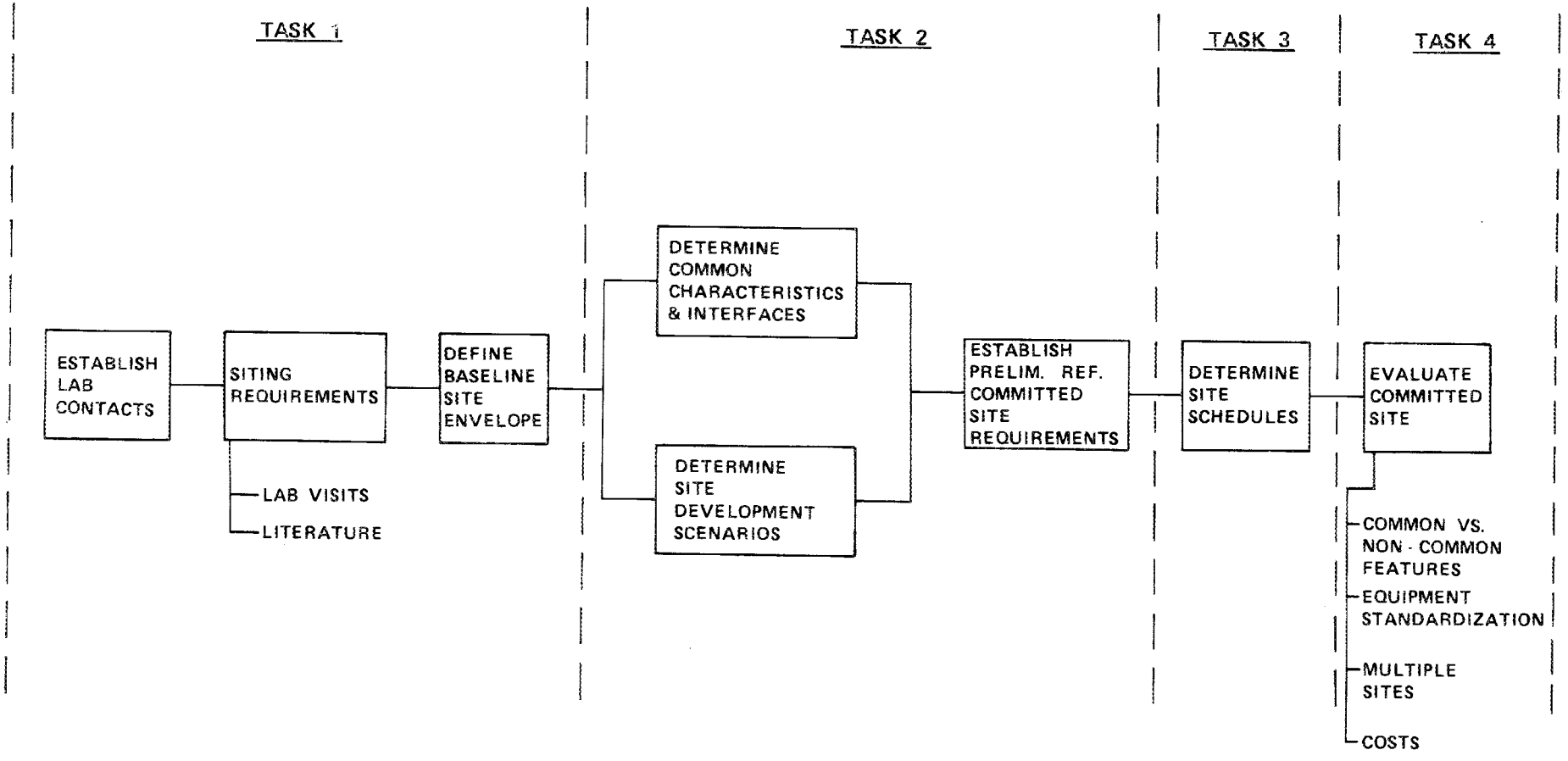


Figure 1-1
TECHNICAL APPROACH

defined to cover different approaches to the development of fusion power and a preliminary selection was made of several for more detailed evaluation. In Task 3, schedules for site construction, technical input from the fusion program, and device testing were developed. Analysis, evaluation, and comparions of the committed site concept were carried out in Task 4. Common, sharable, and noncommon features for the various scenarios were determined. A major part of this task was the development of order-of-magnitude costs for economic comparisons of the scenarios.

This report is divided into five technical sections. Section 2 is a summary. In Section 3, which covers device and site analyses, the major characteristics of devices that might be placed at the site, as envisioned by major fusion laboratories, are described; the characteristics of a site (baseline site) which would accommodate these devices are defined; and various approaches to a committed site meeting the baseline site requirements are discussed. Section 4 describes the scenarios selected to represent possible site development outcomes; these scenarios are evaluated with respect to comparative cost and schedule effects. Section 5 presents a brief evaluation of the effects fusion-fission hybrids might have on the committed site. Major conclusions and recommendations are discussed in Section 6.

## 2.0 SUMMARY

The Committed Fusion Site evaluation consisted of the following four major technical tasks:

- Definition of Baseline Site Requirements
- Development of Site Characteristics
- Technical Implications of Site Development
- Evaluation of Committed Site Development and the Feasibility of a Committed Site

The work accomplished during the first two tasks is summarized in separate interim letter reports, which are included in the appendices as Appendix A and Appendix B. The balance of the work is described and summarized in this final report.

Technical background information was supplied by the following Fusion Development Laboratories for the concepts noted:

Argonne National Laboratory (Tokamak)
General Atomic Company (Tokamak)
Lawrence Livermore Laboratory (Tandem Mirror)
Los Alamos Scientific Laboratory (Reversed Field Pinch)
Massachusetts Institute of Technology (Tokamak and Torsatron)
Oak Ridge National Laboratory (Tokamak and Elmo Bumpy Torus)
Princeton Plasma Physics Laboratory (Tokamak)

The limited depth of technical information available relative to site development requirements reflects the development stage of fusion at the present time. Most of the effort has been concentrated on developing an understanding of the fundamentals of fusion and little work has been performed to develop integrated plant designs and site requirements. Information on the process support and auxiliary systems is, in most cases,

sketchy, and frequently estimates were based on Bechtel experience in engineering power distribution systems, power plants, and large test installations.

It is suggested that, as the development of the fusion reactor concepts progresses into the stage of engineering devices, a parallel effort should be initiated to develop integrated fusion plant conceptual designs, including all process support and auxiliary facilities and systems. These facilities and systems, commonly called the balance-of-plant (BOP), make possible the utilization of nuclear/thermal energy for electric power generation or, in the case of experimental facilities, support the device operation and remove generated energy. The interaction between the reactor and the BOP facilities and systems may greatly influence the overall economy of the plant. The cost of the BOP generally accounts for more than 70 percent of the total cost of the plant. Because of this interaction, simultaneous engineering and integration of the BOP and the nuclear system results in technical and economical compromises which lead to a more effective overall plant design.

After the integrated fusion plant design concepts are developed, the committed fusion site concept should be reviewed and reevaluated. The preliminary conclusions reached by this study may be reinforced or invalidated by future consideration of better defined requirements for integrated fusion reactor plants or changes in program approach.

## 2.1 FINDINGS

If the fusion development program demands the parallel exploration of the feasibility of several fusion concepts, the committed fusion site approach is the most cost effective and efficient approach to follow. The potential advantages the committed fusion site offers, especially with development of multiple concepts, are many and must therefore be seriously considered.

To highlight the maximum potential that exists for the committed site approach, a case assuming that the devices for each development phase of three fusion concepts are constructed and operated on separate individual sites has been compared to all devices for various groupings of the three fusion concepts being placed on a single committed site. Table 2-1 shows the cost comparison for this case. The costs shown in this table are not total plant costs, but are the sum of the major cost elements of site preparation and common device support systems. These are defined in Subsection 3.2, Costing Qualifications, and are summarized in Table 3-4.

Due to the fact that several laboratory organizations are involved with the development of the tokamak concept, it was necessary to conceive a "generic" tokamak to serve as a cost baseline for the tokamak devices required for each development phase. This was done with assistance from Oak Ridge National Laboratory, and the resulting generic devices are identified in

TABLE 2-1

COST COMPARISON OF SINGLE AND MULTIPLE FUSION CONCEPTS
IF CONSTRUCTED ON
INDIVIDUAL SITES VS. ON A COMMON, COMMITTED SITE

| SINGLE OR MULTIPLE FUSION CONCEPTS | | COST, MILLION $ | | | |
|---|---|---|---|---|---|
| | | TNS | EPR | DEMO/PROTO* | TOTAL |
| GENERIC TOKAMAK | ON INDIVIDUAL SITE | 225.1 | 385.5 | 583.4 | 1,194.0 |
| | ON COMMITTED SITE | 225.1 | 160.4 | 197.9 | 583.4 |
| | SAVINGS | 0 | 225.1 | 385.5 | 610.6 |
| TANDEM MIRROR * | ON INDIVIDUAL SITE | 104.8 | 168.9 | | 273.7 |
| | ON COMMITTED SITE | 104.8 | 64.1 | | 168.9 |
| | SAVINGS | 0 | 104.8 | | 104.8 |
| ELMO BUMPY TORUS | ON INDIVIDUAL SITE | 210.4 | 365.7 | 514.4 | 1,090.5 |
| | ON COMMITTED SITE | 210.4 | 155.3 | 148.7 | 514.4 |
| | SAVINGS | 0 | 210.4 | 365.7 | 576.1 |
| GENERIC TOKAMAK AND TANDEM MIRROR * | ON INDIVIDUAL SITE | 329.9 | 554.4 | 583.4 | 1,467.7 |
| | ON COMMITTED SITE | 292.7 | 222.5 | 197.9 | 713.1 |
| | SAVINGS | 37.2 | 331.9 | 385.5 | 754.6 |
| GENERIC TOKAMAK AND ELMO BUMPY TORUS | ON INDIVIDUAL SITE | 435.5 | 751.2 | 1,097.8 | 2,284.5 |
| | ON COMMITTED SITE | 378.9 | 310.6 | 328.0 | 1,017.5 |
| | SAVINGS | 56.6 | 440.6 | 769.8 | 1,267.0 |
| GENERIC TOKAMAK, TANDEM MIRROR* AND ELMO BUMPY TORUS | ON INDIVIDUAL SITE | 540.3 | 920.1 | 1,097.8 | 2,558.2 |
| | ON COMMITTED SITE | 460.3 | 378.9 | 344.5 | 1,183.7 |
| | SAVINGS | 80.0 | 541.2 | 753.3 | 1,374.5 |

* No information is available on demonstration/ prototype size tandem mirror device; therefore, only the tokamak and EBT costs are shown in the Demonstration/Prototype Phase.

NOTES:
1. For individual sites, it is assumed that each device of each concept is constructed on its own individual site.
2. For committed sites, it is assumed that all devices of all considered concepts are constructed on a common committed site.
3. Costs shown are not total plant costs, but only the sums of site selection and preparation and major elements of supporting system costs, as discussed in Section 3.2 of this report.

Tables 3-1 through 3-3 for The Next Step (TNS), Engineering Power Reactor (EPR) and Demonstration/Prototype phases, respectively (see Subsection 3.1). Generic descriptions of the Elmo Bumpy Torus (EBT) and tandem mirror devices were not necessary since only one laboratory was involved in each case. However, since designs have not yet been developed by Lawrence Livermore Laboratory for the Demonstration/Prototype phase of the tandem mirror concept, this development phase of the tandem mirror could not be included in the cost comparison.

Table 2-1 shows that if each development phase of each concept is constructed on separate individual sites, each requiring site selection, certification, site improvements, and process support facilities and systems, the total cost would be approximately twice the amount required to do the same on a single, committed site.

It is conceivable that one individual site will be dedicated for the development of each fusion concept, where the devices for all development phases of that one concept would be constructed and operated on that site. In this case, site selection, certification, and site improvement activities would have to be performed only once for each candidate fusion concept to be developed. Process support facilities and systems could then be shared by each device, but not by different fusion concepts. Table 2-2 compares this case, where individual sites are dedicated to the overall development of each concept, with the

TABLE 2-2

COST COMPARISON OF MULTIPLE FUSION CONCEPTS
IF CONSTRUCTED ON
INDIVIDUAL SITES VS. ON A COMMON, COMMITTED SITE

| MULTIPLE FUSION CONCEPTS | | COST, MILLION $ | | | |
|---|---|---|---|---|---|
| | | TNS | EPR | DEMO/PROTO* | TOTAL |
| GENERIC TOKAMAK AND TANDEM MIRROR * | ON INDIVIDUAL SITE | 329.9 | 224.5 | 197.9 | 752.3 |
| | ON COMMITTED SITE | 292.7 | 222.5 | 197.9 | 713.1 |
| | SAVINGS | 37.2 | 2.0 | - | 39.2 |
| GENERIC TOKAMAK AND ELMO BUMPY TORUS | ON INDIVIDUAL SITE | 435.5 | 315.7 | 346.6 | 1,097.8 |
| | ON COMMITTED SITE | 378.9 | 310.6 | 328.0 | 1,017.5 |
| | SAVINGS | 56.6 | 5.1 | 18.6 | 80.3 |
| GENERIC TOKAMAK, TANDEM MIRROR * AND ELMO BUMPY TORUS | ON INDIVIDUAL SITE | 540.3 | 379.8 | 346.6 | 1,266.7 |
| | ON COMMITTED SITE | 460.3 | 378.9 | 328.0 | 1,167.2 |
| | SAVINGS | 80.0 | 0.9 | 18.6 | 99.5 |

* No information is available on demonstration/ prototype size tandem mirror device; therefore, only the tokamak and EBT costs are shown in the Demonstration/Prototype Phase.

**NOTES:**

1. For individual sites, the values listed are the sum of the costs for completely developing each concept at its own dedicated site.
2. For committed sites, it is assumed that all devices of all considered concepts are constructed on a common, committed site.
3. Costs shown are not total plant costs, but only the sums of site selection and preparation and major elements of supporting system costs, as discussed in Section 3.2 of this report.

costs of all devices for various groupings of the three fusion concepts being placed on a single committed site.

The costs indicated in this table, as with the cost data in Table 2-1, are the sums of the cost elements considered in Subsection 3.2, and not total plant costs. Tandem mirror requirements in the demonstration/prototype phase are not known, therefore, the cost of combinations involving tandem mirror devices do not include the demonstration/prototype costs.

The comparison of even these partial costs reveals that the committed site approach offers significant economic advantages. The potential savings vary between approximately $105 million to $1,375 million over the case where all concepts and all their associated devices are constructed on separate individual sites (Table 2-1) and between $40 and $100 million over the case where individual sites are dedicated to the overall development of each concept (Table 2-2). The savings in total plan cost could be significantly higher.

Schedule advantages are harder to evaluate, but it is estimated that the completion of EPR experiments for the three different fusion concepts can be accomplished five to ten years sooner on the committed site, than on individual sites. A detailed discussion of schedule aspects of the committed site is provided in Subsections 4.2.1 and 4.2.2.

Licensing, safety, and environmental aspects of the committed site were explored in two principal areas:

- Regulations which address environmental impact and external effects. These regulations are generally independent of the internal power plant design and are presently known.
- Regulations which address nuclear safety issues, related to the internal fusion power plant concept or design. These requirements are largely unknown or uncertain at present.

Both categories are discussed in detail in Section 6.0 of Appendix B, Licensing and Environmental Requirements, and Issues of the Task 200 Interim Report.

The effects of placing fusion-fission hybrid devices on the committed site stem from the presence of significant quantities of new and irradiated fission fuel on the site. The major aspects of the committed site, that might be expected to be affected by locating a fusion-fission reactor there, are site selection, licensing, obtainment of permits, site security, special nuclear material accountability, transport and handling of fission fuels, and radioactive waste handling and disposal. A more detailed discussion of these aspects is presented in Section 5.0 of this report.

### 2.1.1 Site Selection and Certification

The selection and certification of a grass-root site for the construction and operation of a nuclear power generating facility involves a lengthy and expensive procedure. If a committed site is dedicated for the construction and operation of several fusion devices, the time involved and the expenditures incurred in this procedure occur once. Assuming the construction of three different fusion concepts and their operation in each of the TNS, EPR, and prototype/demonstration phases on the committed site, the cost of site selection and certification, and the time required to obtain the construction permit, could approach one third of that required to place the same three concepts at three different locations.

Time and cost involved in site selection and certification can further be reduced if the committed fusion development site is located on a government reservation. Most of the site information required for the certification (geology, seismicity, meteorology, hydrology, topography, etc.) are readily available for the reservations. The licensing procedure is also likely to be simpler and more effective on government reservations. An equally well characterized non-government site would have the same advantages regarding information availability, but would not have the advantage in the area of licensing.

### 2.1.2 Site Improvements

After the site has been selected, a series of construction operations must be performed to prepare the site for receiving the fusion devices. These operations involve the construction of connecting roads, railroads, bridges (if necessary), fencing, security system, rough grading and drainage, temporary power and water supply, sanitary sewage system, construction office, and shop and warehousing facilities to serve the needs of the contractors performing the construction operations for the fusion plants. The time and expenses for these activities are approximately the same for each individual site dedicated for the development of a single concept, as for the committed site, accommodating several fusion concepts. With the committed site approach these activities are performed only once, while with the individual site approach, these activities must be performed for each site. Therefore, the committed site approach has significant economic and schedule advantages over the individual sites.

### 2.1.3 Shareability of Process Related Facilities and Systems

Review of the technical requirements for the different fusion concepts as presented by the laboratories shows that there is great diversity. It is assumed that by the time the committed fusion site becomes a reality, some of the diversity in plant requirements will be eliminated either by standardization or managerial direction.

There are some basic plant requirements where a substantial diversity can be accommodated with no great technical difficulty. These are:

- Electrical system.
  The site substation, fed by utility transmission lines and presumably owned and operated by the local electrical utility, can be provided to serve several fusion devices either by designing it for the full capacity forecasted or for successive expansion to meet the increasing demand at the site.

  The plant switchyard can be designed in such a way that its capacity is expandable as the electrical power demand increases at the site.

  Of the device related electrical system, pulsed power supplies and neutral beam injector power supplies are also good candidates for sharing by several devices if the voltage and power needs can be brought to compatible levels. It is conceivable that appropriate sequencing of the pulses can be achieved through control systems, making these expensive power supplies capable of serving multiple devices simultaneously.

  Plant auxiliary power can also be provided for several devices from a centralized switchyard.

- Process water and heat rejection systems.
  It represents no great technical difficulty to design enough flexibility into these systems to make them capable of accommodating the simultaneous operation of several devices. Circulating water pumps and forced draft cooling tower units can be selected in increments which are adaptable to the possible fluctuation in service needs. Fire water and domestic water systems are site, rather than device related. A single system for all of these services, sized to accommodate the requirements for multiple devices, should not cost substantially more than the ones which would be needed for a single device on an individual site.

- Other shareable facilities and systems.
  There are numerous facilities which are needed for the operation of the fusion devices which have approximately the same building or system requirements whether they are serving single or multiple devices.

Administration, engineering, and scientific support facilities can be shared by the personnel assigned to the development of different fusion concepts.

Chemical, tritium, and materials testing laboratory facilities are easily shareable.

Magnet fabrication and winding and mechanical equipment can serve different fusion concepts with ease. General, nonradioactive maintenance shops can serve all fusion devices on the site.

One mock-up building would likely be adequate to accommodate the needs of the entire national fusion program. One turbine building, housing the turbine generator and its auxiliary systems, appears to be capable to serve up to three fusion devices in the EPR phase. A second larger unit may be required if the demonstration/prototype phase devices are to be constructed on the committed site also.

Mobile maintenance equipment, like trenchers, mobile cranes, fork lifts, cherry pickers, and passenger cars can be pooled to serve all devices at the site.

## 2.2 ADVANTAGES OF THE COMMITTED FUSION SITE

The advantages the committed fusion development site has over individual sites for each of the candidate fusion concepts can be categorized into three general areas:

- Economic
- Schedule
- Intangible

### 2.2.1 Economic Advantages

A detailed cost estimate for the devices constructed on individual and on the committed site is outside of the scope of this study. The preliminary nature of the technical information available for the candidate fusion concepts do not warrant a major costing effort.

In Subsection 4.1, a qualified cost comparison of the scenarios is presented, based on certain selected cost items. Reference is made to Tables 2-1 and 2-2, wherein these cost comparisons are summarized. Table 2-1 shows that the committed site, with the devices of all three concepts operated on it, is approximately 92 percent ($1,375 million) cheaper than individual sites where all devices are constructed on separate, individual sites.

Table 2-2 shows that the committed site, with the devices of all three concepts operated on it, is approximately 8 percent ($100 million) cheaper than the individual sites, where individual sites are dedicated to the overall development of each concept. Since many of the cost items, discussed in Subsection 4.1, cover the purchase price of equipment only, with no installation and field distributable costs, the overall saving in total cost would be greater.

### 2.2.2 Schedule Advantages

The principal schedule advantage of the committed site is that the time needed for selection, certification, and improvement of the site must be done only once; before construction, during the TNS phase of the first fusion concept. Once the second device is ready for construction, it can be started immediately, with essentially no time requirement for siting and very little, if any, for licensing.

The immediate availability of administrative, engineering, laboratory, regular maintenance facilities, as well as the plant substation and switchyard, process water, and heat rejection systems which may require minor additions or upgrading, are likely contributors to a significant improvement in device construction and possible operating schedule.

It is difficult to estimate how long it would take to complete EPR phase experimentation with three devices if they were constructed on individual sites. Schedule estimates indicate that twenty-seven years after the construction of the first (TNS) device commences on the committed site, the EPR phase experimentation of the third concept can be completed. The time required to accomplish the same goal, having individual sites for all concepts, may be five to ten years longer. This time difference is based on judgement without factual substantiation, but is considered a realistic one.

### 2.2.3 Intangible Advantages

There are intangible advantages of the committed fusion site concept that cannot be quantified in terms of money or schedule. Nevertheless, they are believed to be real and significant.

The concentration of scientific and technical staff at one location may have a beneficial influence on the national fusion development program. Cross fertilization of ideas concerning solutions to the many technical problems which are bound to surface during the development of the candidate fusion concepts is more likely than if different teams were working on similar problems great distances apart.

The construction of first-and-one-of-a-kind fusion devices will require highly skilled technicians and craftsmen. The committed fusion site creates the opportunity to concentrate this talent in one place and utilize it efficiently. Technical development and on-the-job training would also be readily available and easily organized at a central location.

The experience gained by the operators of one device would also be readily available to apply to the operation of the successive devices.

Construction of the first (TNS phase) device would be closely followed by construction of the second TNS device, which in turn would be followed by the upgrading activities of the first device to switch over to EPR phase operation, and so on. The construction facilities needed for the first phase of construction would be available for all successive construction operations requiring virtually no extra expenditures. The construction labor force, or at least a great percentage of it, would find long, continuous employment at one location. This would tend to minimize the problem of possible labor shortages.

## 2.3 DISADVANTAGES OF THE COMMITTED FUSION DEVELOPMENT SITE

The list of advantages of the committed site, presented in the preceeding section, is long. It must be remembered, however, that they were developed, or in some cases just postulated, on the bases of very preliminary technical information. Assumptions have been made which tend to favor the committed site concept. No design work was performed to determine the real needs and requirements for shareable or upgradable site facilities and systems. Aside from the uncertainties caused by the conceptual or very preliminary type technical information, there are a few areas where some disadvantages of a centralized fusion development site can be identified.

- <u>Diverse development requirements.</u>
  It has been pointed out earlier that process support system requirements, especially electric power requirements, show a great diversity from device to device. If the assumption made in the preceeding section is correct, and voltage and

power requirements can be made compatible for several devices, then the goal of sharing expensive power supply systems can be accomplished. However, if the opposite is shown during the more detailed development work on the competing fusion concepts, the presence of a power supply system on the committed site, the adoptation of which would provide serious performance compromises for the second concept in line, would provide neither technological, nor economical advantages. Also if, at the time of the establishment of the committed site, a flexibility is demanded of the facilities and systems provided to be able to accommodate any reasonably foreseable diversity in device requirements, the cost of this flexibility may be prohibitive.

- Obsolescence.
  The requirements for site facilities and systems needed for the operation of the first devices will probably be well defined when the committed site is established. These requirements may change rather rapidly not only because of the introduction of a different concept to the committed site, but also because of the experiences gained during the operation of the first device. Improvement and upgrading demands may be so great that the retention of the site facilities and systems originally provided for the first device could mean a setback. There is a real danger that systems which were contemplated to serve several devices may become obsolete and have to be replaced way before their useful life span due to technological advancements.

- Limitation on the pursuit of new concepts.
  The establishment of a committed fusion development site, based on the requirements of selected fusion concepts and development phases, would set the path of fusion reactor development. The committed fusion development site, dedicated to the testing and operation of relatively advanced development phases might not suit the near-term exploration of the feasibility of new alternate fusion concepts. The initial laboratory scale experiments with new alternate concepts could probably be carried out most effectively within the facilities of the developing fusion research laboratories. When these experiments prove the merits of further development, the design of the TNS scale device either must take into consideration what site facilities and process service systems are available at the committed site or the changes and modifications necessary to site facilities to accommodate the operation of the new concept.

## 2.4 FURTHER WORK

There are several areas, where further work is necessary for the full definition of the potential benefits of a committed fusion site. These are:

- The necessity for early development of integrated fusion plant designs was pointed out in the first part of this summary. Due to the great influence of the BOP facilities and systems on the overall plant economy, it is mandatory that the design of the nuclear systems of the plant be integrated with the design of the process support systems and facilities. Close cooperation between the nuclear component designer and the BOP designer results in beneficial compromises and improved economics for both. Integrated plant design based on such close cooperation will improve understanding of the benefits and possible drawbacks of the committed site concept.

- Benefits which the committed site concept may offer can be increased if the design of devices, device components, and process support systems is performed with the committed site in mind. The development of some basic design criteria for major plant components and systems which are to be adhered to in the development of all fusion concepts may be beneficial and greatly improve the effectiveness of shareable, site-provided facilities and systems for all devices which are to be constructed and operated at the committed site. Some areas where this is expected to be particularly beneficial are:

  - Voltage and power levels for device power supply systems
  - Electrical energy storage systems
  - Magnetic energy dissipation systems
  - Heat rejection systems
  - Heat transport system components
  - Radioactive waste handling and disposal systems
  - Maintenance facilities

- Laboratory facilities
- Administrative and engineering support buildings

- Further benefits can be derived from standardizing systems or components common to several devices. Some candidates for standardization are:
  - Neutral beam injectors and components
  - Refrigeration system units
  - Vacuum systems
  - Fluid system equipment: valves, pumps, etc.

Aside from the direct benefits of using standardized systems or components in several devices, the requirement for maintaining fewer spare parts and the simplification of maintenance are supplemental advantages of standardization.

# 3.0 DEVICE AND SITE ANALYSIS

This Subsection contains a comparative analysis of the fusion devices based on information supplied by the development laboratories (Subsection 3.1), costing qualifications (Subsection 3.2), and a discussion of the characteristics the committed site must have to accommodate the construction and possible simultaneous operations of several fusion devices (Subsections 3.3 and 3.4).

There is a very noticeable diversity in requirements from concept to concept for all major plant process systems. As the development of the fusion concepts progresses, some of this diversity will undoubtedly be reduced. Standardization of some, mainly electrical, device components may help the utilization and shareability of the high cost power supply equipment to be installed at the committed site.

Cryogenic system requirements are mainly "guesstimates." Further work is necessary to define the requirements in more detail and to evaluate the shareability of cryogenic systems.

Energy storage requirements are another area that requires further, more detailed work to clarify the requirements and to better understand the possibilities of sharing these systems among several devices. The use of homopolar generators for energy storage is promising, but experience with large units is not available.

Better definition of building space requirements for the reactor block, as well as for the process support systems, would be highly desirable. Little or no building layout and equipment location drawings were available for this study. As soon as the design of the reactor components and other major process equipment progresses to a stage that main outline dimensions can be determined, the layout of the heat transport system(s) should be initiated, since experience indicates that these systems and their space requirements have a more decisive influence on building sizes than the size and configuration of the reactor or heat exchangers. The BOP costs (and the structures needed to shelter and support the nuclear and process service components, which are considered as part of the BOP) may equal or exceed the cost of the nuclear components; therefore, a functional and economical utilization of building space has a great influence on total plant costs.

## 3.1 SUMMARY OF MAJOR DEVICE CHARACTERISTICS

The major device characteristics as presented in the Task 100 interim letter report (Appendix A) were augmented by telephone confirmation with the laboratories and are summarized in Tables 3-1 through 3-3 for TNS, EPR, and demonstration/prototype devices.

# TABLE 3-1

## SUMMARY OF MAJOR DEVICE CHARACTERISTICS
## TNS Fusion Devices

| CONCEPT DEVELOPING LAB. THERMAL RATING $MW_t$ | ELECTRICAL POWER REQUIREMENTS | | | | | | | | | | | CRYOGENIC SYSTEM | | NUCLEAR ISLAND STRUCTURES | | CIRC. WATER SYSTEM | | | POWER CONVERSION SYSTEM | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | STEADY STATE MAGNET POWER SUPPLY | | | NBI dc POWER SUPPLY | | | PULSED ELECTRIC POWER | | | PLANT AUXILIARY ac POWER SYSTEM | | | | | | | | | | |
| | Volts | Amps | Cost $10^6$ $ | Volts | Amps | Cost $10^6$ $ | Stored energy MJ | MVA rating | Cost $10^6$ $ | $MW_e$ | Cost $10^6$ $ | Refrig. Cap. kW | Cost $10^6$ $ | Volume $m^3$ | Cost $10^6$ $ | Flow l/sec | Pumping power HP | Cost $10^6$ $ | Gen. Cap. $MW_e$ | Cost $10^6$ $ |
| TOKAMAK G.A. 750 MWt | 100 | 10,000 | 0.8 | 150,000 | 400 | 4.6 | 550 | 1,500 | 40.2 | 44 | 22.2 | 48 | 9.7 | 206,400 | 94.9 | 14,700 | 11,500 | 15.2 | - | - |
| TOKAMAK ORNL 1,775 MWt | 1,300 | 15,000 | 1.9 | 120,000 | 1,300 | 7.2 | 4,300 | 1,200 | 51.5 | 87 | 44.3 | 100 | 48.1 | 217,200 | 81.7 | 38,200 | 30,000 | 18.6 | - | - |
| TANDEM MIRROR LLL 300 MWt | Undefined | | Allow 1.0 | 300,000 | 800 | 11.6 | N | o | n | e | 10.7 | Not available | | 61,500 | 26.4 | 5,200 | 4,000 | 4.5 | - | - |
| ELMO BUMPY TORUS ORNL 1,000 MWt | T.F.(1) 20 ARE(2) 1600 | T.F. 75,000 ARE 3,000 | 2.1 | 120,000 | 1,000 | 13.0 | N | o | n | e | 16.1 | 7 | 3.7 | 194,900 | 78.4 | 10,800 | 8,400 | 6.8 | - | - |
| TOKAMAK GENERIC 1,000 MWt | 1,200 | 12,000 | 1.2 | 120,000 | 1,000 | 6.2 | 3,000 | 1,000 | 40.0 | 45.0 | 28.0 | 40 | 18.5 | 153,500 | 61.3 | 17,100 | 13,400 | 17.1 | - | - |

(1) Toroidal Field Coils

(2) Aspect Ratio Enhancement Coils

# TABLE 3-2

## SUMMARY OF MAJOR DEVICE CHARACTERISTICS
## EPR Devices

| CONCEPT DEVELOPING LAB. THERMAL RATING $MW_t$ | ELECTRICAL POWER REQUIREMENTS | | | | | | | | | | | CRYOGENIC SYSTEM | | NUCLEAR ISLAND STRUCTURES | | CIRC. WATER SYSTEM | | | POWER CONVERSION SYSTEM | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | STEADY STATE MAGNET POWER SUPPLY | | | NBI dc POWER SUPPLY | | | PULSED ELECTRIC POWER | | | PLANT AUXILIARY ac POWER SYSTEM | | | | | | | | | | |
| | Volts | Amps | Cost $10^6$ $ | Volts | Amps | Cost $10^6$ $ | Stored energy/ MJ | MVA rating | Cost $10^6$ $ | $MW_e$ | Cost $10^6$ $ | Refrig. Cap. kW | Cost $10^6$ $ | Volume $m^3$ | Cost $10^6$ $ | Flow l/sec | Pumping power MW | Cost $10^6$ $ | Gen. Cap. $MW_e$ | Cost $10^6$ $ |
| TOKAMAK ORNL 2,260 MWt | 1,300 | 15,000 | 1.9 | 120,000 | 1,300 | 7.2 | 4,3000 | 1,200 | 51.5 | 87 | 44.3 | 100 | 48.1 | 217,200 | 81.7 | 34,100 | 26,800 | 27.0 | 750 | 180.0 |
| TOKAMAK ANL 600 MWt | 72 | 60,000 | 2.5 | 5,000 | 4,000 | 1.9 | 3,000 | 500 | 12.7 | 34 | 17.4 | 20 | 9.2 | 102,000 | 40.7 | 8,500 | 6,700 | 6.4 | 200 | 62.4 |
| ELMO BUMPY TORUS ORNL 1,000 MWt | T.F.(1) 20 ARE(2) 1,600 | T.F. 75,000 ARE 3,000 | 2.07 | 120,000 | 1,000 | 13.0 | N | O N | E | 23.5 | 16.1 | 7 | 3.7 | 194,900 | 78.4 | 10,800 | 8,400 | 6.8 | 300 | 117.5 |
| TOKAMAK GENERIC 1,000 MWt | 1,200 | 12,000 | 1.2 | 120,000 | 1,000 | 6.2 | 3,000 | 1,000 | 40.0 | 45.0 | 28.0 | 40 | 18.5 | 153,500 | 61.3 | 17,100 | 13,400 | 17.1 | 300 | 93.9 |

(1) Toroidal Field Coils

(2) Aspect Ratio Enhancement Coils

TABLE 3-3

SUMMARY OF MAJOR DEVICE CHARACTERISTICS
Prototype/Demonstration Devices

| CONCEPT DEVELOPING LAB. THERMAL RATING $MW_t$ | ELECTRICAL POWER REQUIREMENTS | | | | | | | | | | | CRYOGENIC SYSTEM | | NUCLEAR ISLAND STRUCTURES | | CIRC. WATER SYSTEM | | | POWER CONVERSION SYSTEM | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | STEADY STATE MAGNET POWER SUPPLY | | | NBI dc POWER SUPPLY | | | PULSED ELECTRIC POWER | | | PLANT AUXILIARY ac POWER SYSTEM | | | | | | | | | | |
| | Volts | Amps | Cost $10^6$ $ | Volts | Amps | Cost $10^6$ $ | Stored energy MJ | MVA rating | Cost $10^6$ $ | $MW_e$ | Cost $10^6$ $ | Refrig. Cap. kW | Cost $10^6$ $ | Volume $m^3$ | Cost $10^6$ $ | Flow l/sec | Pumping power HP | Cost $10^6$ $ | Gen. Cap. $MW_e$ | Cost $10^6$ $ |
| REVERSED Filled PINCH LASL PROTOTYPE 2,980 MWt | No steady state magnets | | | No NBI's are required | | | 11,300 | 500 | 69.0 | 73 | 42.2 | 72 | 33.0 | 271,000 | 108.3 | 33,800 | 26,500 | 33.8 | 998 | 323.9 |
| TOKAMAK HPCTR MIT PROTOTYPE 2,470 MWt | 212 | 11,000 | 4.05 | 80,000 | 1,664 | 9.73 | 1,100 | 4,000 | 105.5 | 192 | 91.4 | 300 | 140.0 | 233,200 | 93.2 | 28,940 | 22,700 | 28.9 | 775 | 264.6 |
| TORSATRON MIT PROTOTYPE 4,340 MWt | 1,000 | 500,000 | 21.3 | 120,000 | 4,166 | 24.54 | N | O | N | E | 61 | 36.5 | 60 | 29.6 | 366,100 | 146.4 | 50,700 | 39,800 | 50.7 | 1,370 | 417.3 |
| ELMO BUMPY TORUS ORNL DEMONSTRATION 2,000 MWt | T.F.(1) 20 ARE (2) 1,600 | T.F. 75,000 ARE 3,000 | 2.07 | 120,000 | 1,000 | 8.00 | N | O | N | E | 47 | 29.6 | 7 | 3.7 | 235,500 | 94.1 | 36,000 | 28,200 | 28.5 | 700 | 279.5 |
| TOKAMAK PPPL PROTOTYPE 5305 MWt | 48,000 At low Current | 10,000 At low Voltage | 8.7 | 5,000 | 4,000 | 1.35 | 10,000 | 510 | 62.8 | 144 | 72.6 | 280 | 129.5 | 411,600 | 164.6 | 55,900 | 43,800 | 55.9 | 2,030 | 571.6 |
| GENERIC TOKAMAK 2,000 MWt | 2 - 1000 MWt EPR Devices will be used in PROTO/DEMO Phase. | | | | | | | | | | | | | | | | | | | |

(1) Toroidal Field Coils

(2) Aspect Ratio Enhancement Coils

The tables cover the electrical characteristics, including steady state magnet power supply, neutral beam injector dc power supply, pulsed electric power and plant auxiliary ac power system requirements, cryogenic system requirements, reactor block building volume requirements, circulating water system requirements, and power generation system requirements. The associated costs are also indicated. As far as the indicated costs are concerned, reference is made to Subsection 3.2, Costing Qualifications. Schedule and budgetary limits did not permit a detailed cost estimate of each of the fusion devices considered, nor is it felt that the feasibility of the committed site is affected significantly by the total cost of the candidate devices.

The device characteristics tabulated in Tables 3-1 through 3-3 serve as the basis for determining the characteristics of the committed site. It is particularly significant to note the apparent diversity in system requirements and the broad range of thermal ratings.

Recognizing that the probability of constructing more than one series of devices for the tokamak concept is very low, a "GENERIC" tokamak was defined for the purposes of this study based on guidance from Oak Ridge National Laboratory. The thermal rating was assumed to be 1,000 MWt in the TNS and EPR phases, with a generating capacity of 300 MWe in the EPR phase. For the demonstration/prototype phase, a combination of two EPR-

size devices was assumed. The total thermal rating is 2,000 MWt and the generating capacity is 600 MWe.

The costs indicated on the tables are partial costs only and do not represent total system costs. Reference is made to Subsections 3.2.1 through 3.2.9, Costing Qualifications, of this report for a detailed explanation of what the indicated costs do or do not include.

## 3.2 COSTING QUALIFICATIONS

The capital cost estimate of any engineered facility is composed of direct field costs, indirect field costs, engineering costs, a contingency allowance, owner's costs, and the costs of advanced funds during construction. The largest category is direct field costs. Short descriptions of the various cost components are given below.

- Direct field costs.
  Direct field costs are the costs for permanent plant equipment, materials, labor and subcontract items, and form the major part of the field costs. They include the purchase and/or subcontract costs of bulk materials, like concrete, form work, fabricated reinforcing steel, fabricated structural steel, embedded steel, sheet metal roofing and siding, prefabricated and field run piping, electrical wire and cable, connection materials, etc.

  The purchase price of process-related or service-related permanent plant equipment is also included in the direct field costs.

  The third component of direct field costs is the construction or installation labor associated with the field operations required to prepare the

facilities and plant equipment for their intended function in the completed plant.

- Indirect (distributable) field costs.
  The main categories of indirect field costs are:
  Temporary construction facilities, like field office, shops, temporary electric supply and distribution systems, temporary water supply, and sanitary facilites, etc.

  Miscellaneous construction services, like construction, equipment and tool rental, their maintenance costs, consumable construction material costs (bolts, welding rods, nails, etc.), material handling, welder testing, soil and concrete laboratory testing, wages of security personnel, clean-up, etc.

  Field office costs, like supervision, engineering, planning and scheduling, quality control, administration, warehousing, field purchasing, medical/first aid, overhead, etc.

  Others, including insurance, taxes, and miscellaneous field expenses.

  These expenses are distributed across the entire facility and are expressed as a percentage of the total direct field labor costs. This is why they are called distributable field costs in the construction industry.

- Engineering, home office costs and fees.
  These expenses cover the engineering services required for the design of all facilities, systems, and components for the plant, including preliminary and final designs, preparation of system and equipment specifications and documentation required to obtain all permits for the construction and operation of the plant.

  Home office costs also cover cost engineering, planning and scheduling services, procurement, start-up, quality assurance and project management.

  Fee is normally a function of the total project cost and there are commonly accepted guidelines on appropriate schedules.

- Contingencies.
  Contingency is the sum of money added to an estimate to provide for items not specified in engineering detail but which are known from experience to be a necessary part of a facility. Implicitly, it will be used and it is not a

drawdown fund to compensate for overruns or changes and additions to the project scope.

- Other Owners Costs.
  These include the owner's general office and accounting costs, start-up and operator training, spare part and inventory costs, and enviromental impact studies.

- Cost of Advanced Funds During Construction (Interest during construction).
  The center of gravity of cash flow is normally taken at the 2/3rd point of the construction period and interest during construction is calculated at a certain percentage of the total construction cost for an agreed upon number of years.

Table 3-4 shows what cost elements were considered in the cost comparisons of the different fusion concepts and development phases. The costing methods are given in greater detail in Subsections 3.2.1 through 3.2.8, and the summary of the costing qualifications is presented in Subsection 3.2.9.

The costs shown in Tables 3-1, 3-2, and 3-3 are by no means total installed system costs. The items in these tables were selected on the basis of their impact on overall plant costs, availability of system definition, similarity of the system requirements to those of light water reactors, liquid metal cooled fast breeder reactors or fossil power plants, and in case of dc power supplies, similarity of the requirements to those applicable to heavy industrial installations using large dc power systems like aluminum reduction plants.

TABLE 3-4

COST ELEMENTS CONSIDERED IN THE COMPARATIVE COSTING OF DEVICES

| COST ELEMENTS | | ELECTRICAL SYSTEMS | | | | CRYOGENIC SYSTEM | STRUCTURES | CIRC. WATER SYSTEM | POWER CONVERSION SYSTEM |
|---|---|---|---|---|---|---|---|---|---|
| | | STEADY STATE MAGNET POWER SUPPLY | NBI OR RF HEATER DC POWER SUPPLY | PULSED POWER | PLANT AUXILIARY AC POWER | | | | |
| DIRECT FIELD COSTS | BULK MATERIAL COSTS (CONCRETE, REINF. STEEL, LINERS, STRUCT. STEEL, PIPE, WIRE, CABLE, ETC.) | | | | X | | X | X | X |
| | EQUIPMENT PURCHASE COST | X | X | X | X | X | | X | X |
| | DIRECT CONSTRUCTION/INSTALLATION LABOR COSTS | | | | X | | X | X | X |
| INDIRECT FIELD COSTS (DISTRIBUTABLE FIELD COSTS) | | | | | | | X | X | |
| ENGINEERING, HOME OFFICE COSTS AND FEES | | | | | | | | | |
| CONTINGENCIES | | | | | X | | X | X | X |
| OTHER OWNER'S COSTS | | | | | | | | | |
| COST OF ADVANCED FUNDS DURING CONSTRUCTION | | | | | | | | | |
| COST OF SPECIAL MATERIALS (LITHIUM, HELIUM ETC.) | | | | | | | | | |
| TOTAL CAPITAL COST IN CURRENT $'S | | | | | | | | | |

With the exception of the General Atomic Company (GA) tokamak, no plant layouts or plot plans were provided by the laboratories, therefore, the building volume requirements were extrapolated from the G.A. tokamak building volumes, using judgement as to how the difference in fusion concept requirements and plant size (thermal rating) might affect the size of structures. Past experience indicates that estimated preliminary building volumes grow substantially when more detailed plant layouts are developed. Past experience also indicates that the floor area and building volume requirements are more influenced by the stress considerations of the pipes and ducts for the primary heat transport system, than the physical size of the nuclear reactor itself. Since no layout is available for the primary heat transport pipe or duct system at this time, there was no basis for judgement whether the G.A. plant layout provides adequate space for the heat transport and other piping systems, and the presumably extensive electrical tray and conduit systems.

An explanation of what the indicated costs cover is delineated in the following subsections.

### 3.2.1 Electrical Power Requirements - Steady State Magnet Power Supply

Costs shown cover the purchase price of dc conversion equipment, including the rectifier transformers with the associated oil circuit breakers and rectifiers. They do not cover the costs of the ac step-down transformers to reduce the power line voltage, or the costs of any regulating auto transformers required for

variable ac voltage control. Costs of buses connecting the power supply to the magnets and system installation costs are excluded.

### 3.2.2 Electrical Power Requirements - NBI dc Power Supply

Costs shown cover the purchase price of dc conversion equipment only, excluding installation. Costs of insulated cable bus connecting the power supply to the neutral beam injectors are excluded.

### 3.2.3 Electrical Power Requirements - Pulsed Electric Power

There is a wide range of unit costs for pulsed electric power supplies available in published fusion reports. After much discussion of the appropriate unit cost, Oak Ridge National Laboratory and Bechtel agreed that, for the purposes of the present study, $0.005 per Joule of stored energy and $25.00 per kVA rating of the converter power supply would be used, for both the motor-generator-flywheel and the homopolar generator energy storage system. The cost calculated on this basis is assumed to cover equipment purchase price only, excluding installation and any other (start-up, calibration, etc.) costs.

### 3.2.4 Electrical Power Requirements - Plant Auxiliary ac Power System

Costs were estimated based on the plant auxiliary power system costs of a recently completed liquid metal fast breeder reactor

study, with due consideration of plant size and somewhat reduced auxiliary power requirement of the fusion reactor plants. Costs shown include auxiliary power distribution, transformers, motor control centers, load centers, etc. They include equipment and bulk material (wire and cable), connection material costs and installation labor costs, but exclude field distributables and any other costs.

### 3.2.5 Cryogenic System

The cost shown for this item is based on a letter quotation from CTI-Cryogenics for an 8-kilowatt helium refrigeration unit, comprised of a cold box, compressor, associated controls, etc. The quoted purchase price of such a unit (the compressor power input requirement is 4,000 kW), escalated to 1979 price level, is $3,700,000. This price excludes installation and cryogenic piping.

G.A. obtained a quote for their cryogenic system at substantially lower cost, but since the purpose of this study is not the economic comparison of the various fusion concepts, and uniformity among the fusion concept requirements is not easily obtainable, the above cost $3.7 million per unit was applied uniformly to each concept and development phase.

### 3.2.6 Nuclear Island Structures

Reactor block structure requirements were estimated based on the conceptual plant layout developed by G.A. for their upgradable Tokamak TNS device. This was the only available, relatively complete plant layout. Due consideration was given to plant size (thermal rating) in scaling the space requirements for each device. The reactor block structures are assumed to be comprised of the following:

- Reactor confinement
- Control room
- Reactor component maintenance (hot cell)
- Radwaste handling facilities
- Tritium handling (for both blanket and exhaust processing)
- Vacuum finishing pump area
- Cryogenics system area

Based on a recent cost estimate for a liquid metal cooled fast-breeder reactor, the unit cost of the reactor confinement was estimated at $460 per cubic meter. This cost includes the reinforced concrete foundation and superstructure, carbon steel liner plate throughout, and basic building services like lighting, plumbing, and conventional heating, ventilating, and air-conditioning. All bulk material costs (concrete, reinforcing steel, roofing) and field labor, including field distributables, are included.

The rest of the reactor block structures were estimated at $320 per cubic meter. This cost covers similar items as the unit cost of the reactor confinement. It is assumed, however, that a steel liner will be required only in selected areas where radioactive material is handled. Basic building services are included, as are all material, labor, and field distributable costs.

### 3.2.7 Circulating Water System

The unit cost of the circulating water system is based on experience with similar systems in light water reactor and liquid metal cooled fast breeder reactor plants. The costs indicated in Tables 3-1, 3-2, and 3-3 include the earthwork and reinforced concrete structures for the intake (cooling tower basin) and discharge basins, the support structure and enclosure of the circulating water pumps, the mechanical components, pumps, underground supply and discharge pipe lines, the cost of structures and mechanical equipment associated with the forced draft cooling towers, and an allowance for electrical and control equipment.

The estimated unit cost for the total system is $17.00 per kilowatt of rejected heat ($5,000 per million Btu's per hour). This unit cost includes all material and field labor costs, including field distributables, but excludes any other (engineering, home office, interest during construction, other owner's cost, etc.) costs.

### 3.2.8 Power Conversion (Thermal) System

The cost shown for this system covers the steam generator building, turbine building and turbine pedestal structural costs, the mechanical component and systems costs associated with the steam generator system, and the component and system costs of the turbine generator and its auxiliaries. Allowance is included to cover normal building services, like lighting, plumbing, and conventional heating, ventilating and air-conditioning. Bulk material costs, purchase costs of system components and piping are also covered, as is field installation labor. Distributable field costs and other owner's costs are excluded.

The basis for the unit costs used in costing this system was a recently completed estimate for a liquid metal cooled fast breeder reactor plant study, with consideration of differences in steam generation systems and plant size. The building space requirements for the turbine building and steam generator building were based on the size of the Clinch River Breeder Reactor facilities, due to the similarity in power generating capacity of the EPR fusion devices to that of Clinch River (380 MWe gross, 350 MWe net).

### 3.2.9 Summary of Costing Qualifications

After examining the available information on fusion devices, it became obvious that an economic evaluation of the committed site must be based on the relative cost of selected systems which have a major impact on overall costs (costs driver sytems), where relative cost levels can be established with a reasonable degree of confidence. The main thrust of the fusion development program to date has been directed more toward the understanding of plasma behavior, rather than toward the development of integrated fusion plant designs, thus, only limited information is available on plant and auxiliary systems.

The requirements for the process support systems are not defined in sufficient detail to enable preparation of a complete cost estimate for any of the devices, hence, the selected items shown in Tables 3-1, 3-2, and 3-3 represent only a fraction of the total cost of a fusion plant. The costs shown for the different systems do not have a consistent basis either. In some cases, it was only possible to develop approximate equipment purchase prices; no information was available on the cost of installation labor and associated field distributable costs. For some an attempt was made to include field installation costs, but there was no basis to establish field distributable costs. For others, there was enough statistical information at Bechtel to estimate total direct field costs, including material and/or equipment, construction/installation labor, and field distributable costs. In no case, was it possible to include engineering, home office

costs, fees, contingencies, other owner's costs, and costs for advanced funds during construction.

One might consider development of system costs on such inconsistent bases to be of limited value. However, the purpose of developing these costs was to show relative potential savings of siting the fusion facilities on a committed site versus individual sites, and not to establish total plant costs.

The pricing of each system was consistently carried out for each concept and development phase, based on the qualifications described in Subsections 3.2.1 through 3.2.8. No total is shown on the right-hand side of the tabulations for any of the devices because the pricing of the systems does not have common bases and it was desired to avoid the impression that total plant costs were being presented.

## 3.3 SUMMARY OF BASELINE SITE CHARACTERISTICS

The committed fusion development site will provide the land (with site improvements) with the electric power and process water required for the operation of the fusion devices constructed on it.

- Land.
  400 hectares of land is needed to accommodate up to three fusion concepts in their TNS, EPR, and demonstration/prototype development phases.

- Electric power.

Electric power will be provided by 2-230 kV transmission lines, feeding the 230 kV ring bus of a utility-owned site substation. A plant switchyard, fed from the site substation through 3-230 kV/34.5 kV main transformers, contains a 34.5 kV switchyard bus which in turn feeds the 3-13.8 kV switchgear through 3-70 MVA and 1-30 MVA, 34.5 kV/13.8 kV switchyard transformers. The 3-13.8 kV switchgear supply the power for the magnets, stored energy systems and plant auxiliary power systems. The power supplies for the neutral beam injectors will be fed from the 34.5 kV switchyard bus through 2-130 MVA, 34.5-80/120/300 kV transformers. This system will meet the needs of up to three fusion concepts in all of their development phases.

- Process water.
  800 liters per second capacity process water system will be provided to supply the circulating water, makeup, demineralized water, fire water and domestic water needs necessary for the operation of up to three fusion concepts in all their development phases.

A detailed description of the baseline site characteristics is given in Subsection 3.4, Committed Site Definition.

## 3.4 COMMITTED SITE DEFINITION

The committed fusion development site must satisfy the needs of as many fusion concepts as deemed suitable for full development and ultimate commercialization. The primary purpose of the committed site would be to provide for the construction, test, and operation of medium to large scale fusion devices in the most cost and schedule effective way. Advantage must be taken of as many shareable site facilities and service systems as the logical operation of the devices permit.

It is not contemplated that smaller scale, proof-of-principle type devices will be placed at the committed site. No technical objection has been identified against locating them there also, if the needs of these devices can be accommodated and their operation fitted into the operating schedule of the larger devices.

The committed fusion development site should have provisions for all facilities and process support systems which are not unique to any fusion concepts. The site would include facilities and systems which are useable or shareable by successive development phases of a single fusion concept, or, preferably, by several fusion concepts in all of their development phases.

The requirements of the site location itself are land, electric power, and process water. Based upon the envelope of requirements developed from the device characteristics for the TNS, EPR, and demonstration/prototype development phases of the tokamak, tandem mirror, and EBT concepts the following requirements were established:

- Land.
  400 hectares of land is required for the committed site, selected and certified for the construction and operation of multiple fusion facilities. It must be technically (soil and geologic characteristics, seismic characteristics, meteorology, hydrology, aircraft flight patterns, transportation facilities) and environmentally acceptable.

  Exclusion area, low population zone and population center distance have to conform to a yet to be established set of criteria for fusion reactor plants.

Site improvement activities, as listed in Appendix A, Subsection 5, Subsections 5.4.1 through 5.4.5, Task 100 Interim Letter Report, must be completed before construction of device related structures and facilities could commence.

- Electric Power.
  Electric power must be available for the committed fusion development site from two 230 kV transmission lines from the local electric utility company. These lines will feed a 230 kV ring bus of the site substation, which is assumed to be owned and maintained by the local electric utility company. The ring bus of the site substation will feed the primary side of the three 230 kV-34.5 kV, 200/238 MVA main transformers of the plant switchyard. A 34.5 kV plant switchyard bus is supplied with power from the secondary side of the main transformers, through three oil circuit breakers, rated at 4,000 A each. The 34.5 kV plant switchyard bus will supply all the electrical needs of the three fusion concepts through the demonstration/prototype phase. The electrical system, beyond the 34.5 kV plant switchyard bus, is considered device related, and as such, its construction is needed only for the operation of the devices placed at the committed site.

  A preliminary simplified single line diagram is included in Subsection 4.1.10, depicting a concept for the electrical system of the committed site at its full development, capable of suppling up to three devices with electric power for the demonstration/prototype phase (see Figure 4-2). Should it be decided that the committed site will be used for EPR phase devices only, the electrical requirements can be reduced accordingly.

  Electrical system information supplied by the laboratories is shown and described in Appendix B, Task 200 Interim Letter Report, Table 3-1 and Subsection 3.2.

- Process Water.
  Process water requirements for the committed site are primarily determined by the circulating (cooling) water make up needs for the devices. The demineralized and domestic water requirements add approximately ten percent to the circulating water make-up needs.

  Taking into consideration the operating schedule of the fusion devices in all development phases, as

discussed in Subsection 4.2, the total water requirement for the committed site is estimated at 800 liters per second. This amount satisfies the maximum water flow demand at the full development of the site,

There are several facilities which are device-related, but once the basic design parameters of the devices are determined, their design and even construction can proceed. The administration, engineering, laboratory, regular maintenance shop facilities, and the turbine building come to mind first in this category. These structures may be considered as site facilities, constructed parallel with the site improvement activities and made available for all fusion devices and development phases, as needed.

### 3.4.1 Grassroot Site Versus Government Reservation

During the study it was assumed that the committed fusion development site will be located on grassroot land, subject to all licensing and regulatory procedures required for obtaining the construction permit for any other proposed nuclear power generating facility.

The procedure to certify a grassroot site for the construction of a nuclear facility and obtain a construction permit is a lengthy and costly one. Reference is made to Subsection 4.2 for the description and Figure 4-3 for the schedule of the steps necessary to obtain a construction permit. The time necessary for a construction permit is about five years and the cost of

this procedure, based on recent experience, is estimated to be $15 million.

Locating the committed fusion site within the boundaries of an existing government nuclear testing reservation would offer significant savings. Much of the cost associated with site soil and seismic explorations, and with the collection of other site data needed for the certification of a grassroot site, can be saved, since these data are readily available for most reservations.

The time required for licensing a grassroot site could also be shortened considerably if the committed fusion site is located on a government reservation. The licensing procedure can be concentrated on real safety issues and exclude issues with extremely low hypothetical risks frequently raised by certain segments of the public, often causing years of delay.

### 3.4.2 Fully Self-Contained Committed Site Versus Bare-Bone Provisions Only

During the early phases of this study the question was raised of what the effects would be of establishing only the reactor block and essential service facilities versus providing a full self-contained fusion development center on the committed site.

As far as it can be determined, the facilities needed for establishing a complete fusion development center would require a

modest additional capital investment over that of the bare-bone type installation.

The list of facilities which are not essential for the construction and operation of the fusion devices, or which can be provided in reduced version, is rather short:

- Laboratories.
  General chemical and materials testing laboratory services can be obtained from offsite facilities. A tritium laboratory, however, would be essential for the committed site.

- Maintenance shops.
  Maintenance shop facilities can be reduced to the essential reactor component maintenance cells (hot cells) and some emergency repair/maintenance facilities, if it is assumed that scheduled maintenance operations for larger, nonradioactive components can be carried out in offsite shops.

- Administration, engineering and scientific support facilities.
  It is conceivable that some of the managerial, administrative, engineering, and scientific supporting activities can be carried out off site. In this case, the facilities required at the committed site can be reduced substantially, only making provisions for the functions directly related to the operation of the devices.

The total cost of the listed facilities represents approximately three percent of the cost of reactor block and process service related structures. The saving which can be realized by eliminating or reducing these facilities must be carefully weighted against the inconveniences, transportation costs, and problems as well as the time delays associated with the maintenance, laboratory, engineering, and administrative operations partially carried out offsite.

## 4.0 SCENARIOS SELECTED FOR THE DEVELOPMENT OF THE COMMITTED SITE

There was sufficient information available to establish major characteristics for thirteen fusion devices. The following matrix identifies the devices.

| Device | Lab | TNS | EPR | Proto/Demo |
|---|---|---|---|---|
| Tokamak | ANL | | 600 MWt | |
| Tokamak | GA | 750 MWt | | |
| Tokamak HFCTR | MIT | | | 2,470 MWt |
| Tokamak | ORNL | 1,775 MWt | 2,260 MWt | *6,780 MWt |
| Tokamak | PPPL | | | 5,305 MWt |
| Tandem Mirror | LLL | 300 MWt | | |
| EBT | ORNL | 1,000 MWt | 1,000 MWt | 2,000 MWt |
| Reversed Field Pinch | LASL | | | 2,980 MWt |
| Torsatron | MIT | | | 4,340 MWt |

*3-EPR units, at 2,260 MWt each.

The possibility of construction and operation of TNS and EPR devices at the committed site is easily visualized based on the currently available technical information on these devices. Whether the construction and operation of the prototype/demonstration size devices are practical and advisable at the committed fusion development site is not clear. Involvement of the electric power generating utilities may have a

decisive influence where these larger devices are to be built and how they will be operated. It is suggested, therefore, that the question of locating prototype/demonstration devices be reevaluated when plans for them are more definitive.

It is assumed that of the five tokamak concepts, only one will be selected for construction and operation on the committed site.

Even with this simplifying assumption, if every magnetic fusion device remains a candidate for installation and operation, the number of all possible combinations would be quite large.

In order to keep the evaluation of the committed site within reasonable limits, the following scenarios were established:

- Scenario I: Any one of three fusion concepts, placed on the committed site, and devices constructed and operated for the TNS, EPR, DEMO/PROTOTYPE development phases.
- Scenario II: Any one of the above three fusion concepts placed on the committed site in combination with any one or both of the other concepts, and the devices operated independently of each other.

As a further refinement of the above two basic scenarios, the following subsets were established:

- Scenario Ia: Tokamak devices are constructed and operated through all three development phases.
- Scenario Ib: Tandem mirror devices are constructed and operated through all three development phases.

- Scenario Ic: Elmo Bumpy Torus devices are constructed and operated through all three development phases.

- Scenario IIa: Tokamak devices and tandem mirror devices are constructed at the committed site and both of them are operated independently through all three development phases.

- Scenario IIb: Tokamak devices and Elmo Bumpy Torus devices are constructed at the committed site, and both of them are operated independently through all three development phases.

- Scenario IIc: Tokamak devices, tandem mirror devices and Elmo Bumpy Torus devices are constructed consecutively on the committed site, and all three of them are operated independently through all three development phases.

As to the selection of the devices in the listed scenarios, certain assumptions have been made:

Tokamaks. Instead of using any of the devices developed by the laboratories to date, a generic tokamak has been assumed, which has a thermal rating of 1,000 MWt in the TNS and EPR development phases. In the EPR phase, a steam generating system and turbine generator will be added, providing the capability to generate approximately 300 MWe power. For the demonstration/prototype phase, it is assumed that a second EPR-size tokamak reactor will be added, doubling the power generating capacity to 600 MWe. This would, of course, require the addition of a second 300 MWe capacity turbine generator. The alternative of a new, larger device for the demonstration/prototype phase was not considered.

Elmo Bumpy Torus. It has been agreed with Oak Ridge National Laboratory that the Elmo Bumpy Torus (EBT) designated as a TNS

device during the information gathering phase of this study (500 MWt thermal rating) is really a proof-of-principle and not a TNS device. Oak Ridge suggested that for the purposes of the present study, a 1,000 MWt rated TNS device be considered for the EBT concept. In the EPR phase, this device will be upgraded by installing a blanket, a steam generator system, and a 300 MWe turbine generator. For the demonstration/prototype phase, the plasma power density in the EPR reactor will be increased to raise the thermal rating to 2,000 MWt, making the device capable of generating approximately 600 MWe power. For that capacity, the steam generator's capacity has to be increased and a second 300 MWe capacity turbine generator added.

Reversed Field Pinch and Torsatron Devices. Information on requirements for TNS and EPR Reversed Field Pinch and Torsatron devices is not available at this time. If scaled down versions of the demonstration/prototype size machines of these concepts are developed, preferably in the 1,000 MWt thermal rating range, there is no reason why they cannot be substituted for the EBT concept, if so desired, or the number of scenarios expanded to also include these devices.

## 4.1 COST EVALUATION OF THE SELECTED SCENARIOS

The cost evaluation of the selected scenarios is presented in Tables 4-1 through 4-6. All costs are in 1979 dollars.

TABLE 4-1

COST EVALUATION OF SELECTED SCENARIOS

SCENARIO Ia

GENERIC TOKAMAK

Thermal Rating: 1,000 MWt (TNS and EPR mode)
2,000 MWt (PROTO/DEMO mode)

Generated Power (Gross Electric): 300 MWe (EPR mode)
600 MWe (PROTO/DEMO mode)

| COST ITEM | COST, MILLION $ | | |
|---|---|---|---|
| | TNS | EPR | PROTO/DEMO |
| 1. SITE SELECTION AND CERTIFICATION | 15.0 | - | - |
| 2. SITE IMPROVEMENTS | 9.6 | - | - |
| 3. STRUCTURES: | | | |
| 3.1 Reactor block structures | 61.3 | - | 40.2 |
| 3.2 Process service related structures | 29.7 | 4.4 | - |
| 3.3 Admin.,engineering, maintenance and shop structures | 5.5 | - | - |
| 4. SELECTED COST DRIVER PROCESS SYSTEMS: | | | |
| 4.1 Electrical: | | | |
| 4.1.1 Steady state magnet power supply | 1.2 | - | 0.9 |
| 4.1.2 NBI dc power supply | 6.2 | - | - |
| 4.1.3 Pulsed electric power | 40.0 | - | - |
| 4.1.4 Plant auxiliary ac power | 21.0 | 5.1 | 10.5 |
| 4.2 Cryogenic system | 18.5 | - | 13.7 |
| 4.3 Circ. water system | 17.1 | - | 5.8 |
| 4.4 Thermal power conversion system | - | 150.9 | 126.8 |
| Total (Rounded) | 225 | 160 | 198 |
| TOTAL for TNS and EPR | 385 | | — |
| TOTAL for TNS, EPR and PROTO/DEMO | 583 | | |

TABLE 4-2

COST EVALUATION OF SELECTED SCENARIOS

SCENARIO Ib

TANDEM MIRROR

Thermal Rating: 300 MWt (TNS & EPR mode)

Generated Power: (Gross Electric): 100 MWe (EPR mode)

| COST ITEM | COST, MILLION $ | | |
|---|---|---|---|
| | TNS | EPR | PROTO/DEMO |
| 1. SITE SELECTION AND CERTIFICATION | 15.0 | | |
| 2. SITE IMPROVEMENTS | 9.6 | | |
| 3. STRUCTURES: | | | |
| 3.1 Reactor block structures | 24.8 | - | |
| 3.2 Process service related structures | 11.7 | 1.6 | |
| 3.3 Admin.,engineering, maintenance and shop structures | 5.5 | - | |
| 4. SELECTED COST DRIVER PROCESS SYSTEMS: | | | |
| 4.1 Electrical: | | | |
| 4.1.1 Steady state magnet power supply | 1.0* | - | |
| 4.1.2 NBI dc power supply | 11.6 | - | |
| 4.1.3 Pulsed electric power | - | - | |
| 4.1.4 Plant auxiliary ac power | 7.5 | 1.8 | |
| 4.2 Cryogenic system | 11.6 | - | |
| 4.3 Circ. water system | 6.5 | - | |
| 4.4 Thermal power conversion system | - | 60.7 | |
| Total (Rounded) | 105 | 64 | |
| TOTAL for TNS and EPR | 169 | | ——— |
| TOTAL for TNS, EPR and PROTO/DEMO | - | | |

* Allowance for transition coil power supply.

TABLE 4-3

COST EVALUATION OF SELECTED SCENARIOS

SCENARIO Ic

ELMO BUMPY TORUS

Thermal Rating: 1,000 MWt (TNS and EPR mode)
2,000 MWt (PROTO/DEMO mode)

Generated Power (Gross Electric): 300 MWe (EPR mode)
600 MWe (PROTO/DEMO mode)

| COST ITEM | COST, MILLION $ | | |
|---|---|---|---|
| | TNS | EPR | PROTO/DEMO |
| 1. SITE SELECTION AND CERTIFICATION | 15.0 | - | - |
| 2. SITE IMPROVEMENTS | 9.6 | - | - |
| 3. STRUCTURES: | | | |
| 3.1 Reactor block structures | 78.4 | - | - |
| 3.2 Process service related structures | 28.1 | 4.4 | - |
| 3.3 Admin.,engineering, maintenance and shop structures | 5.5 | - | - |
| 4. SELECTED COST DRIVER PROCESS SYSTEMS: | | | |
| 4.1 Electrical: | | | |
| 4.1.1 Steady state magnet power supply | 2.1 | - | - |
| 4.1.2 NBI dc power supply | 5.2 | - | - |
| 4.1.3 Microwave heating | 25.0 | - | - |
| 4.1.4 Plant auxiliary ac power | 18.0 | - | 16.1 |
| 4.2 Cryogenic system | 6.4 | - | - |
| 4.3 Circ. water system | 17.1 | - | 5.8 |
| 4.4 Thermal power conversion system | - | 150.9 | 126.8 |
| Total (Rounded) | 210 | 155 | 149 |
| TOTAL for TNS and EPR | 366 | | ——— |
| TOTAL for TNS, EPR and PROTO/DEMO | 514 | | |

TABLE 4-4

COST EVALUATION OF SELECTED SCENARIOS

SCENARIO IIa

GENERIC TOKAMAK AND TANDEM MIRROR DEVICES

Combined Thermal Rating: 1,300 MWt (TNS and EPR modes)
2,000 MWt (PROTO/DEMO modes)*

Combined Generated Power (Gross Electric): 400 MWe (EPR mode)
700 MWe (PROTO/DEMO mode)*

| COST ITEM | COST, MILLION $ | | |
|---|---|---|---|
| | TNS | EPR | PROTO/DEMO* |
| 1. SITE SELECTION AND CERTIFICATION | 15.0 | - | - |
| 2. SITE IMPROVEMENTS | 9.6 | - | - |
| 3. STRUCTURES: | | | |
| 3.1 Reactor block structures | 85.4 | - | 40.2 |
| 3.2 Process service related structures | 38.8 | 4.4 | - |
| 3.3 Admin.,engineering, maintenance and shop structures | 6.9 | - | - |
| 4. SELECTED COST DRIVER PROCESS SYSTEMS: | | | |
| 4.1 Electrical: | | | |
| 4.1.1 Steady state magnet power supply | 2.2 | - | 0.9 |
| 4.1.2 NBI dc power supply | 17.8 | - | - |
| 4.1.3 Pulsed electric power | 40.0 | - | - |
| 4.1.4 Plant auxiliary ac power | 26.7 | 6.5 | 10.5 |
| 4.2 Cryogenic system | 28.2 | - | 13.7 |
| 4.3 Circ. water system | 22.1 | - | 5.8 |
| 4.4 Thermal power conversion system | - | 211.6 | 126.8 |
| Total (Rounded) | 293 | 222 | 198 |
| TOTAL for TNS and EPR | 515 | | ——— |
| TOTAL for TNS, EPR and PROTO/DEMO | 713 | | |

* No information is available on Prototype/Demonstration size tandem mirror device; therefore, only the tokamak's rating and costs are shown in the Prototype/Demonstration Phase.

TABLE 4-5

COST EVALUATION OF SELECTED SCENARIOS

SCENARIO IIb

GENERIC TOKAMAK AND ELMO BUMPY TORUS DEVICES

Combined Thermal Rating: 2,000 MWt (TNS and EPR modes)
4,000 MWt (PROTO/DEMO modes)

Combined Generated Power (Gross Electric): 600 MWe (EPR mode)
1,200 MWe (PROTO/DEMO modes)

| COST ITEM | COST, MILLION $ | | |
|---|---|---|---|
| | TNS | EPR | PROTO/DEMO |
| 1. SITE SELECTION AND CERTIFICATION | 15.0 | - | - |
| 2. SITE IMPROVEMENTS | 9.6 | - | - |
| 3. STRUCTURES: | | | |
| 3.1 Reactor block structures | 133.3 | - | 40.2 |
| 3.2 Process service related structures | 54.1 | 8.8 | - |
| 3.3 Admin.,engineering, maintenance and shop structures | 6.9 | - | - |
| 4. SELECTED COST DRIVER PROCESS SYSTEMS: | | | |
| 4.1 Electrical: | | | |
| 4.1.1 Steady state magnet power supply | 3.3 | - | 0.9 |
| 4.1.2 NBI dc power supply+Microwave HT'G | 30.2 | - | - |
| 4.1.3 Pulsed electric power | 40.0 | - | - |
| 4.1.4 Plant auxiliary ac power | 32.8 | - | 9.8 |
| 4.2 Cryogenic system | 24.9 | - | 13.7 |
| 4.3 Circ. water system | 28.8 | - | 9.8 |
| 4.4 Thermal power conversion system | - | 301.8 | 253.6 |
| Total (Rounded) | 379 | 311 | 328 |
| TOTAL for TNS and EPR | 690 | | — |
| TOTAL for TNS, EPR and PROTO/DEMO | 1,018 | | |

TABLE 4-6

COST EVALUATION OF SELECTED SCENARIOS

SCENARIO IIc

GENERIC TOKAMAK, TANDEM MIRROR AND ELMO BUMPY TORUS DEVICES

Combined Thermal Rating: 2,300 MWt (TNS & EPR modes)
4,000 MWt (PTOTO/DEMO mode)*

Combined Generated Power (Gross Electric): 700 MWe (EPR mode)
1,200 MWe (PROTO/DEMO mode)*

| COST ITEM | COST, MILLION $ | | |
|---|---|---|---|
| | TNS | EPR | PROTO/DEMO* |
| 1. SITE SELECTION AND CERTIFICATION | 15.0 | - | - |
| 2. SITE IMPROVEMENTS | 9.6 | - | - |
| 3. STRUCTURES: | | | |
| 3.1 Reactor block structures | 164.5 | - | 40.2 |
| 3.2 Process service related structures | 66.9 | 10.0 | - |
| 3.3 Admin.,engineering, maintenance and shop structures | 8.3 | - | - |
| 4. SELECTED COST DRIVER PROCESS SYSTEMS: | | | |
| 4.1 Electrical: | | | |
| 4.1.1 Steady state magnet power supply | 4.3 | - | 0.9 |
| 4.1.2 NBI dc power supply + Microwave HT'G | 41.8 | - | - |
| 4.1.3 Pulsed electric power | 40.0 | - | - |
| 4.1.4 Plant auxiliary ac power | 39.8 | 6.4 | 9.8 |
| 4.2 Cryogenic system | 36.0 | - | 13.7 |
| 4.3 Circ. water system | 34.1 | - | 9.8 |
| 4.4 Thermal power conversion system | - | 362.5 | 253.6 |
| Total (Rounded) | 460 | 379 | 328 |
| TOTAL for TNS and EPR | 839 | | — |
| TOTAL for TNS, EPR and PROTO/DEMO | 1,167 | | |

* No information is available on Demonstration/Prototype size tandem mirror device; therefore, only the tokamak and EBT rating and costs are shown in the Demonstration/Prototype phase.

The cost items shown in these Tables are similiar to the ones shown in Tables 3-1 through 3-3, Summary of Major Device Characteristics, with a few additions:

- The cost of site selection and certification assuming a grass roots site has been added.
- The cost of site improvements, covering fencing, rough grading and drainage, plant access road and railroad spur, connecting the site to the nearest highway and major railroad line respectively, plant water supply and potable water distribution system, sanitary sewage collection and treatment facilities, and temporary electric power supply have been added.
- In addition to reactor block structures, the cost of process service-related, and administration, engineering maintenance, and shop structures have been added.

### 4.1.1 Cost Evaluation Qualifications

The cost elements considered in costing the selected cost items are identical to those presented in Table 3-4 and described in Subsubsections 3.2.1 through 3.2.9. Scenarios Ia, Ib, and Ic are costed considering the same cost items, assuming that a single concept is developed at the site through the TNS, EPR, and demonstration/ prototype phases. Scenarios IIa, IIb, and IIc are costed assuming construction and simultaneous operation of all devices for two or three concepts.

The combined cost of the facilities and/or systems, serving the devices is not necessarily the arithmetic sum of the costs of the same facilities and systems of the individual devices, because some of them can be shared (even when simultaneous operation of

multiple devices is assumed) and some of them benefit from economy of scale.

The means of determining the costs of the selected items in each of the scenarios are described in the following subsections.

### 4.1.2 Scenario Ia - Generic Tokamak

This Scenario assumes the construction of a single tokamak reactor plant on the committed site, suitable for TNS phase operation. At the conclusion of this phase of operation, the same reactor plant will be upgraded to accommodate the EPR requirements by adding a full or partial blanket, steam generation, and turbine generator system. In the demonstration/prototype phase, a second tokamak reactor, with blanket, steam, and power conversion system will be added.

The cost evaluation of this scenario is shown in Table 4-1. The cost evaluation covers the following cost items:

- Site Selection, Certification and Site Improvements
- Structures
- Selected Cost Driver Process Systems

This category covers the process systems which have a major bearing on the total cost of the fusion reactor plants, namely the Electrical, Cryogenic, Circulating Water, and Thermal Power Conversion Systems.

- Site Selection, Certification, and Site Improvements.
  Site selection and certification and site improvement costs are site, rather than device related. The site selection and certification effort and the site improvement work has to be complete before the construction of site facilities and process service systems for the TNS phase device can commence. No significant expenditures are required for these categories in the EPR and demonstration/prototype phases.

- Structures.
  Reactor block structures constructed in the TNS phase will serve the EPR phase without any major additional expenditures. In the demonstration/prototype phase, a second confinement structure will be required to house the second 1,000 MWt capacity tokamak reactor.

  TNS process service structures will have to be expanded in the EPR phase to accommodate tritium processing and handling.

  Administration, engineering, maintenance, and shop structures constructed for the TNS phase are assumed to be adequate for the EPR and demonstration/prototype phase also, without the need for significant additional expenditures.

- Selected Cost Driver Process Systems
  Electrical.
  Steady state magnet power supply - The system constructed for the TNS phase is assumed to be satisfactory for the EPR phase. The demonstration/prototype phase will require expansion to accommodate the needs of the second 1,000 MWt tokamak reactor. Some economy of scale is assumed for this expansion, however.

  NBI dc power supply. - The power supply installed for the TNS device is assumed to be adequate for EPR and demonstration/ prototype devices by proper phasing of the pulses for the two reactors in the demonstration/prototype phase.

  Pulsed electric power supply. - The power supply, serving the EF coils and ohmic heating, installed for the TNS device, is assumed to be shareable in both the EPR and demonstration/prototype phases, without any significant additional expenditure.

  Plant auxiliary power. - This system, installed in the TNS phase, must be upgraded some in the EPR phase, and upgraded rather significantly to accommodate the needs for the second reactor and

thermal power conversion system during the demonstration/prototype phase. Some economy of scale can be realized for the expansions.

Cryogenic system.
The system installed for the TNS tokamak device will also satisfy the needs of the EPR phase, but must be doubled to serve the second 1,000 MWt rated reactor in the demonstration/prototype phase. Some economy of scale can be realized.

Circulating water system.
The system installed for the TNS device is more than adequate for the EPR phase, since in the TNS phase practically all generated thermal power has to be rejected while in the EPR phase only approximately two-thirds of the thermal power needs to be rejected. In the demonstration/prototype phase, an approximate 40 percent expansion will be required.

Thermal power conversion system.
This system will be installed to upgrade the TNS device to a power generating EPR device, producing approximately 300 MWe gross electrical power. In the prototype/demonstration phase, a second steam generation system and a second 300 MWe capacity turbine generator will be added, increasing the electric power generating capacity to 600 MWe.

The major conclusions that can be drawn from the cost data in Table 4-1 are:

Essentially all facilities and systems of the TNS device can be shared or reused by the EPR device. If the TNS and EPR devices were constructed on different, individual sites, the partial cost of the TNS device would be the same as on the committed site, i.e. $225 million. The partial cost of the EPR device, however, would be the sum of the costs for the TNS and EPR devices, i.e. $385 million, and the combined cost of the TNS and EPR devices if built separately would be $610 million (225+385). Thus, constructing the TNS and EPR phase devices consecutively on a

committed site results in a saving of $225 million. Of this, the saving resulting from the elimination of duplicating the cost of site selections and improvements is $25 million. Applying the same logic by incorporating the demonstration/prototype devices, the cost would be $583 million, and the combined cost of all three development phases if built on separate sites would be $1,193 million (225+385+583), as opposed to $583 million on the committed site, resulting in a total saving of $610 million. It must be emphasized that these savings are calculated from partial cost assessment and the total savings in plant cost could be substantially higher.

### 4.1.3 Scenario Ib - Tandem Mirror

Requirements for the tandem mirror devices are not as well defined as for the tokamak devices. The limited information available at this time covers only the TNS and EPR development phases. The cost evaluation of this scenario is shown in Table 4-2.

- Site Selection, Certification and Site Improvements. These costs, as for the tokamak devices described in Subsection 4.1.2, are incurred at the beginning of the establishment of the site and need not be repeated for the EPR phase.

- Structures.
  Reactor block structures. - The structures, constructed for the TNS phase will satisfy the requirements of the EPR phase without any major additional expenditures.

  Process service related structures. - The facilities provided for the TNS phase must be augmented by tritium and lithium handling and

process facilities in the EPR phase.

Administration, engineering, maintenance, and shop structures. - These structures, constructed for the TNS phase, are assumed to be adequate for the EPR phase without the need for significant additional expenditures.

- Selected Cost Driver Process Systems

Electrical.

Steady state magnet power supply. - The requirements for this system are not defined at this time. An allowance of $1,000,000 was provided in the Cost Evaluation Sheet (Table 4-2) and this amount is believed to cover the anticipated equipment cost for the transition coil power supply, for both the TNS and EPR phases.

NBI dc power supply. - The system provided for the TNS device needs no upgrading to satisfy the requirements in the EPR phase.

Pulsed electric power. - No pulsed electric power is required for tandem mirror devices.

Plant auxiliary ac power. - This system, installed in the TNS phase, must be upgraded somewhat in the EPR phase due to the increased auxiliary power requirements of the steam operation and turbine generator. The required increase in auxiliary ac power demand is estimated at approximately 30 percent.

Cryogenic system.

The system installed in the TNS phase is assumed to be adequate to serve the needs of the EPR phase also. Therefore, no additional expenditures will be needed in the EPR phase.

Circulating water system.

This system must be capable of rejecting practically all thermal power generated in the TNS phase (300 MWt), while in the EPR phase 100 MWe electric power is assumed to be generated, therefore the rejected thermal power will be approximately two-thirds that of the TNS requirement. The circulating water system installed in the TNS phase, therefore, is more than adequate for the EPR phase.

Thermal power conversion system.

This system will be installed to upgrade the TNS tandem mirror device to an EPR device, capable of generating 100 MWe power.

The conclusions that can be drawn from the cost data in Table 4-2 are:

Essentially all facilities and systems provided for the TNS phase can be shared or reused in the EPR phase. If the TNS and EPR devices were constructed on different, individual sites, the partial cost of the TNS device would be the same as on the committed site, i.e. $105 million. The cost of the EPR device, however, would be the sum of the TNS and EPR devices, i.e. $169 million, and the combined cost of the TNS and EPR devices if built on separate sites would be $274 (169+105) million. Hence, constructing the TNS and EPR phase devices on the committed site results in a saving of $105 million. Of this, the saving resulting from the elimination of duplicating the cost of site selection and improvements is $25 million. Again, it must be emphasized that the above savings are calculated from a partial cost assessment and the saving in total plant costs could be substantially higher.

Information on demonstration/prototype phase tandem mirror devices is not available at this time, therefore, the cost associated with this phase cannot be evaluated.

### 4.1.4 Scenario Ic - Elmo Bumpy Torus

As discussed earlier, a thermal rating of 1000 MW is assumed for the EBT in the TNS phase. This will be upgraded in the EPR phase to a 300 MWe electric power generating capacity, and further

upgraded to 2,000 MWt thermal, and 600 MWe electric power generating capacity in the demonstration/prototype phase. This will be done by increasing the plasma power density and, thus, the wall loading. The cost evaluation for this scenario is shown in Table 4-3.

- Site Selection, Certification, and Site Improvements. These costs, as for the tokamak devices described in Subsection 4.1.2, are incurred at the beginning of the establishment of the site and need not be repeated for the EPR or demonstration/prototype phases.

- Structures.
  Reactor block structures. - The structures constructed for the TNS phase will satisfy the requirements of the EPR and demonstration/prototype phases, without any major additional expenditures.

  Process service related structures. - The facilities provided for the TNS phase must be augmented by tritium and lithium handling and process facilities in the EPR phase.

  Administration, engineering, maintenance, and shop structures. - These structures, constructed for the TNS phase are assumed to be adequate for the EPR and demonstration/prototype phases, without the need for significant additional expenditures.

- Selected Cost Driver Process Systems
  Electrical.
  Steady state magnet power supply. - The steady state power supply in the TNS phase is sized to satisfy the requirements for the reactor operating in the demonstration/prototype mode, i.e. producing 2,000 MWt thermal power. This power supply will satisfy the lesser requirements of the TNS and EPR phases. In these modes, however, the reactor will be operated at reduced plasma power density. No additional expenses will be involved in the subsequent EPR and demonstration/prototype phases.

  NBI dc power supply. - The comments on the steady state magnet supply in the preceding paragraph are also applicable for the NBI dc power supply system. This system will be sized for the requirements of the prototype/demonstration thermal output, but installed in the TNS mode.

Microwave heating. - The system provided in the TNS phase will satisfy the requirements for the EPR and demonstration/prototype phases also.

Plant auxiliary ac power. - The system provided for the TNS phase will satisfy the requirements for the EPR phase and needs minor upgrading in the demonstration/prototype phase to meet the higher requirements of the steam generation system and the second turbine generator.

Cryogenic system.
The cryogenic system provided for the TNS phase will satisfy the requirements of the EPR and prototype/demonstration phases without any upgrading or extra expenditure.

Circulating water system.
The circulating water system provided in the TNS phase will satisfy the requirements for the EPR phase also, but will require an upgrading in the demonstration/prototype phase to meet the approximately 40 percent increase in rejected heat.

Thermal power conversion system.
This will be installed to upgrade the TNS phase device to EPR, making it capable of generating 300 MWe gross electric power. In the demonstration/prototype phase, the capacity of both the steam generation and turbine generator system must be doubled, increasing the electric power generating capacity from 300 MWe, to 600 MWe gross.

The conclusions that can be drawn from the cost data in Table 4-3 are:

Essentially all facilities and systems provided for the TNS phase device can be shared or reused in the subsequent phases. If the TNS and EPR devices were constructed on different, individual sites, the cost of the TNS phase would be the same as on the committed site, i.e. $210 million. The cost of the EPR device, however, would be the sum of the TNS and EPR devices, i.e. $366 million, and the combined cost of TNS and EPR devices if built on

separate sites would be $576 million (210+366). The construction of the TNS and EPR devices consecutively on the committed site, thus, results in a saving of $210 million. Of this total, the saving resulting from the elimination of duplication the site selection and improvement costs is $25 million. Extending the same logic by incorporating the demonstration/prototype device on the committed site, the cost would be $514 million, and the combined cost of all three devices built on separate sites would be $1,090 million (210+366+514), as opposed to the $514 million on the committed site, resulting in a total saving of $576 million. Again, it must be emphasized that this saving is calculated from a partial cost assessment and the saving in total plant cost could be substantially higher.

### 4.1.5 Scenario IIa - Generic Tokamak and Tandem Mirror Concepts

In this scenario, it is assumed that the devices for two different fusion concepts are constructed consecutively and operated simultaneously and independently on the committed site in all three development phases. The two concepts selected for this scenario are the generic tokamak and the tandem mirror. The demonstration/prototype phase of the tandem mirror concept is not defined at this time, therefore the cost evaluation could not be completed to cover all three phases. The cost evaluation of this scenario is shown in Table 4-4, and explained below.

- Site Selection, Certification, and Site Improvements.

The activities and expenditures associated with these cost items have to be carried out and incurred to certify and establish the site, more-or-less independently of what kind or how many nuclear devices will be operated on it. Therefore, they do not have to be repeated if another device is constructed or another development phase of any one concept is to be started.

- Structures.

Reactor block structures. - Building volume requirements for this scenario are practically the sum of the requirements for the tokamak and tandem mirror devices with the exception of the control building. It is assumed that the control building for the tokamak devices would require only a 50 percent addition to satisfy the combined requirements of the tokamak and tandem mirror devices.

Process service related structures. - Because some of the service systems can be shared (tritium handling and process system, NBI power supply system, magnet fabrication and testing, mock-up building, etc.), the cost for the combined process service-related structures is assumed to be somewhat less than the sum of the cost of these structures for the two concepts. The total cost of the process service-related structures for the TNS devices of the tokamak and tandem mirror concepts was calculated by adding the thermal rating of the devices for the two concepts and multiplying this sum by the average unit cost per megawatt thermal rating, raised to an exponent derived from statistical data for multiple unit fossil and nuclear (fission and LMFBR) power plants. In mathematical form:

$$C_c = T_t \left( \frac{C_1 + C_2}{T_t} \right)^n, \text{ where}$$

$C_c$ = Combined cost for the two concepts in million dollars

$T_t$ = Total thermal rating of the devices for the two concepts in megawatts

$C_1$ = Total cost of the process service related structures for the tokamak concept in million dollars

$C_2$ = Total cost of the process service related structures for the tandem mirror concept in million dollars

n = Exponent, as defined above

Administration, engineering, maintenance, and shop structures. - It is assumed that the structures provided for the tokamak devices would have to be expanded by 25 percent of the tandem mirror device building volume (as defined in Scenario Ib) to satisfy the requirements for both concepts.

- Selected Cost Driver Process Systems

Electrical.

Steady state magnet power supply. - Combined system requirements for the tokamak and tandem mirror are assumed to be the sum of the individual requirements of the two concepts, in all three development phases.

NBI dc power supply. - Combined system requirements for the tokamak and tandem mirror concepts are assumed to be the sum of the individual requirements of the two concepts in all three development phases.

Pulsed electric power. - Since the tandem mirror device does not require pulsed electric power, the combined requirement for the two concepts is identical to the requirement for the tokamak concept.

Plant auxiliary ac power. - The plant auxiliary ac power system of the tokamak has to be upgraded to accommodate the additional requirements for the tandem mirror. Some economy of scale is assumed to result. The cost of the combined system is calculated by the method described for the process-related structures.

Cryogenic system.

The cryogenic system for the tokamak devices has to be upgraded to satisfy the combined requirements for both concepts. Some economy of scale is assumed to result.

Circulating water system.

The circulating water system for the tokamak devices has to be upgraded to accommodate the combined requirements for both concepts. Some economy of scale is assumed to result.

Thermal power conversion systems.

The cost of the thermal power conversion system for the tokamak and tandem mirror is the sum of the system costs for each.

The conclusions that can be drawn from the cost data shown in Table 4-4 are:

Essentially all facilities and systems provided for the TNS phases of both concepts can be shared or reused in the subsequent development phases of the respective concept. A further economic advantage of the committed site is that some facilities provided for the tokamak reactor need only a partial extension to accommodate the requirements of both concepts. The control building, administration and engineering building, shops, laboratories, warehouses, plant substation, and switchyard are in this category.

If all development phases for both the tokamak and the tandem mirror reactors were constructed on separate, individual sites, the combined cost of the two TNS devices would be $330 million ($225 from Table 4-1 plus $105 from Table 4-2), as opposed to $293 million (Table 4-4), if they were built on the committed site. The resulting saving is $37 million. The combined cost of the two EPR devices would be $554 million ($385 from Table 4-1 plus $169 from Table 4-2) on individual sites, and $222 million (Table 4-4) on the committed site. The resulting saving is $332 million. As no information was available for the demonstration/prototype phase of the tandem mirror reactor, the combined cost of this phase shown in Table 4-4 is only the demonstration/prototype phase cost of the tokamak. If the

demonstration/prototype phase of the tokamak, the EPR phase of the tokamak and the tandem mirror and the TNS phase of the tokamak and tandem mirror are all placed on separate, individual sites, the combined cost of this program would be $1,467 million ($225 from Table 4-1 plus $105 from Table 4-2 plus $385 from Table 4-1 plus $169 from Table 4-2 plus $583 from Table 4-1) as opposed to $713 million (from Table 4-4) if the same devices are constructed consecutively on the committed site. The resulting saving is $754 million.

As for the previous scenarios, these savings are calculated from partial cost assessments and the savings in total plant costs could be substantially higher.

### 4.1.6 Scenario IIb - Generic Tokamak and Elmo Bumpy Torus

In this scenario, it is assumed that the devices for two different fusion concepts, the generic tokamak and the EBT, will be constructed consecutively and operated simultaneously and independently on the committed site in all three development phases. The cost evaluation of this scenario is shown in Table 4-5, and explained below:

- Site Selection, Certification, and Site Improvements. The comments made for Scenario IIa are also fully applicable to Scenario IIb.

- Structures.
  Reactor block structures. - Reactor block building volume requirements are practically the sum of the tokamak and Elmo Bumpy Torus requirements, with the exception of the control building. It is assumed

that the control building volume for the tokamak would require only an addition of 50 percent that of the EBT space requirements to satisfy the combined need for the devices of both concepts.

Process service related structures. - The comments on the combined requirements for these structures, as discussed in Subsection 4.1.5, are also applicable here.

Administration, engineering, maintenance, and shop structures. - The building space provided for the tokamak devices would have to be expanded by 25 percent of the EBT building space requirements to accommodate the needs for both concepts.

- Selected Cost Driver Process Systems

Electrical.

Steady state magnet power supply. - The combined system costs for the tokamak and EBT devices will be the sum of the individual system costs of each of the two concepts in all three development phases.

NBI dc power supply. - It is assumed that by successful coordination of voltage and power requirements for the tokamak and EBT devices, the NBI power supply provided for the tokamak devices will be capable of satisfing the start-up needs for the EBT devices without any major additional expenditure. The EBT devices, however, require a microwave heating system, which is not required for the tokamak. In Table 4-5, the combined cost of NBI dc power supply and microwave heating system is shown.

Pulsed electric power. - Pulsed electric power is not required for the EBT's. The cost shown in Table 4-5 is, therefore, the one associated with the tokamak requirement only.

Plant auxiliary ac power. - Combined system requirements for the tokamak and EBT devices are assumed to be exponentially proportional to the ratio of individual thermal rating of one device to the combined thermal rating of both devices. The cost of the combined system was calculated by the method described in Subsection 4.1.5 under Process Service Related Structures.

Cryogenic system.

The cost of the cryogenic systems for the tokamak and EBT devices is assumed to be the sum of the two individual systems.

Circulating water system.
The comments on the cost of the plant auxiliary ac power system for the two devices are assumed to be applicable to the circulating water system costs also.

Thermal power conversion system.
The combined cost for the thermal conversion systems for the tokamak and EBT devices is the sum of the system costs for each.

The conclusions that can be drawn from the cost data shown in Table 4-5 are as follows:

Essentially all facilities and systems provided for the TNS phases of both concepts can be shared or reused in subsequent development phases of each concept. Similarly to Scenario IIa, further saving is achievable because some of the facilities (control building, administration and engineering building, shops, laboratories, warehouses, plant substation, and switchyard) provided for the tokamak reactor, need only a partial extension to accommodate the requirements for both concepts.

If all development phases for both the tokamak and EBT reactors were constructed on separate, individual sites, the combined cost of the two TNS devices would be $435 million ($225 from Table 4-1 plus $210 from Table 4-3), as opposed to $379 million on the committed site (Table 4-5). The resulting saving is $56 million. The combined cost of the two EPR devices would be $751 million ($385 from Table 4-1 plus $366 from Table 4-3) on individual sites and 311 million (Table 4-5) on the committed site, the saving is $440 million in favor of the committed site. The combined cost of the demonstration/prototype devices would be

$1,097 million ($583 from Table 4-1 plus $514 from Table 4-3) on individual sites and $328 million (Table 4-5) on the committed site, the saving being $769 million in favor of the committed site. The total program cost for developing the tokamak and EBT devices from TNS through the demonstration/prototype phases would be $2,283 million ($435 for TNS plus $751 for EPR plus $1,097 for demo/proto) if all development phases for both concepts are constructed on separate, individual sites, as opposed to $1,018 million (Table 4-5), if the same program is carried out consecutively on a common committed site. The saving is $1,265 million.

As for the previous scenarios, these savings are calculated from partial cost assessments. The saving in total plant cost could be substantially higher.

### 4.1.7 Scenario IIc - Generic Tokamak, Tandem Mirror and Elmo Bumpy Torus

In this scenario, it is assumed that the devices for three different concepts, the generic tokamak, tandem mirror and EBT, will be constructed consecutively and operated simultaneously and independently on the committed site in all three development phases. It must be noted, however, that the tandem mirror information in the demonstration/prototype phase is lacking at this time, so it cannot be costed. The cost evaluation sheet for this scenario, shown in Table 4-6, covers only the tokamak and EBT in the demonstration/prototype phase.

- Site Selection, Certification, and Site Improvements.
  The comments made for Scenario IIa are fully applicable for Scenario IIc also.

- Structures.
  Reactor block structures. - Reactor block building volume requirements are practically the sum of the Scenario IIb and the EBT requirements, with the exception of the control building. It is assumed that the control building volume for Scenario IIb would require only an addition of 50 percent that of the tokamak-tandem mirror combined space requirements to satisfy the combined need for all three concepts.

  Process service related structures. - The comments on the combined requirements of these structures, discussed in Subsection 4.1.5, are applicable here also.

  Administration, engineering, maintenance, and shop structures. - The building space provided for the tokamak and tandem mirror devices would have to be expanded by 25 percent of the EBT building space requirements to accommodate the needs for all three concepts, in all development phases.

- Selected Cost Driver Process Systems
  Electrical.
  Steady state magnet power supply. - The combined system costs for the tokamak, tandem mirror and EBT devices will be the sum of the individual system costs of each of the three in all development phases.

  NBI dc power supply. - The total system cost for the three concepts is the sum of Scenario IIa, plus the system cost of the EBT. It is noted, however, that the EBT also requires a microwave heating system. The NBI requirements of the EBT can be supplied from the tokamak's NBI power supply, therefore a separate supply is not required.

  Pulsed electric power. - Pulsed electric power is not required for either the tandem mirror or the EBT, the combined requirement therefore is the same as for the tokamak.

  Plant auxiliary ac power. - The comments made in Subsection 4.1.6 are also fully applicable here.

  Cryogenic system.
  The combined cost of the cryogenic systems for all three concepts is the sum of the cost of the individual systems. Some economy of scale may be realized.

Circulating water system.
The combined system costs are assumed to be exponentially proportional to the combined thermal rating of the three concepts.

Thermal power conversion system.
The combined cost for all three concepts is assumed to be the sum of the system costs for each.

The conclusions that can be drawn from the cost data shown in Table 4-6 are as follows:

Essentially all facilities and systems provided for the TNS phases of all three concepts can be shared or reused in subsequent development phases. Similarly to Scenario IIa, further saving is achievable because some of the facilities (control building, administration and engineering building, shops, laboratories, warehouses, plant substation and switchyard) provided for the tokamak reactor, need only partial extension to accommodate the requirements for all three concepts.

If all development phases for all three concepts (tokamak, tandem mirror, and EBT) were constructed on separate, individual sites, the combined cost of the three TNS devices would be $540 million ($225 from Table 4-1 plus $150 from Table 4-2 plus $210 from Table 4-3), as opposed to $460 million on the committed site. The resulting saving is $80 million. The combined cost of the three EPR devices would be $920 million ($385 from Table 4-1 plus $169 from Table 4-2 plus $366 from Table 4-3) on individual sites and $379 million on the committed site, the saving is $541 million in favor of the committed site. As no information is available for the demonstration/prototype phase of the tandem mirror reactor, the combined cost of this phase, as shown in

Table 4-6, is only the combined demonstration/prototype phase cost of the tokamak and EBT reactor plants. Thus, the combined cost of the development program involving the tokamak and EBT reactors in TNS, EPR, and demonstration/prototype phases, and the tandem mirror in the TNS and EPR phases, would be $2,557 million ($540 for TNS plus $920 for EPR plus $1,097 for demo/proto) if each of the concepts and each development phase were constructed on separate, individual sites, and $1,167 million, if they were constructed consecutively on the committed site. Adopting the committed site concept will save $1,390 million in program costs.

As for the previous scenarios, the savings shown are calculated from partial cost assessments. The real saving in total plant costs could be substantially higher.

### 4.1.8 Scenario with Phased Operation of the Selected Fusion Devices (Scenario IIc-1)

The scenarios described in Subsections 4.1.2 through 4.1.7 assume simultaneous and independent operation of the fusion devices at the committed site. With the assumed thermal ratings and generating capacities of the devices in the EPR and demonstration/prototype phases, this kind of operation would ultimately require increasing the steam generating systems capability and providing turbine-generator capability for operation of all the devices. This would require the following turbine generators:

1 - 300 MWe turbine generator serving the needs of the tokamak EPR device

1 - 300 MWe turbine generator to boost the generating capacity to 600 MWe, to serve the requirements for the demonstration/prototype tokamak device

1 - 100 MWe turbine generator for the tandem mirror EPR device

1 - 300 MWe turbine generator for the EBT EPR device

1 - 300 MWe turbine generator for the EBT demonstration/prototype device, boosting the generating capacity to 600 MWe in this development phase

The probability that the development of fusion devices will take this path is rather small.

It is suggested that only two turbine generators be installed at the committed site:

1 - 300 MWe turbine generator, to serve the EPR phases of all three concepts, and

1 - 600 MWe turbine generator, to serve the demonstration/prototype phases of all three concepts.

It will be shown that this arrangement (Scenario IIc-1) will not interfere with the operation of the TNS devices, and the needs for the demonstration/prototype phases can be satisfied by some phasing in the operation of these reactors.

Figure 4-6 in Subsection 4.2.2 shows the schedule for the installation and operation of all three concepts in all three development phases in bar-chart form. The cost evaluation of this scenario (Scenario IIc-1) is shown in Table 4-7.

This schedule also shows that if the decision is made to limit the committed site for the construction and operation of EPR

TABLE 4-7

COST EVALUATION OF SELECTED SCENARIOS

SCENARIO IIc-1

GENERIC TOKAMAK, TANDEM MIRROR AND ELMO BUMPY TORUS DEVICES

Combined thermal rating and combined generated power as in Table 4-6.

One-300 MWe Turbine Generator installed in TNS Phase.

One-600 MWe Turbine Generator installed in PROTO/DEMO Phase.

| COST ITEM | COST, MILLION $ | | |
|---|---|---|---|
| | TNS | EPR | PROTO/DEMO |
| 1. SITE SELECTION AND CERTIFICATION | 15.0 | - | - |
| 2. SITE IMPROVEMENTS | 9.6 | - | - |
| 3. STRUCTURES: | | | |
| 3.1 Reactor block structures | 164.5 | - | 40.2 |
| 3.2 Process service related structures | 66.9 | 10.0 | - |
| 3.3 Admin.,engineering, maintenance and shop structures | 8.3 | - | - |
| 4. SELECTED COST DRIVER PROCESS SYSTEMS: | | | |
| 4.1 Electrical: | | | |
| 4.1.1 Steady state magnet power supply | 4.3 | - | 0.9 |
| 4.1.2 NBI dc power supply+ Microwave HT'G | 41.8 | - | - |
| 4.1.3 Pulsed electric power | 40.0 | - | - |
| 4.1.4 Plant auxiliary ac power | 39.8 | 6.1 | 10.9 |
| 4.2 Cryogenic system | 36.0 | - | 13.7 |
| 4.3 Circ. water system | 34.1 | - | 9.8 |
| 4.4 Thermal power conversion system | - | 279.4 | 238.0* |
| Total (Rounded) | 460 | 296 | 313 |
| TOTAL for TNS and EPR | 756 | | ——— |
| TOTAL for TNS, EPR and PROTO/DEMO | 1,069 | | |

* Does not include the upgrading costs of the tandem mirror's steam generating system for PROTO/DEMO operation.

devices only, as suggested elsewhere in this report, a single 300 MWe turbine generator can serve three fusion devices with no interference in operation. Comparing the bottom lines in Tables 4-7 and 4-6 one can conclude that by adopting Scenario IIc-1, the total program cost, as qualified at the end of the conclusion paragraph for Scenario IIc, can be reduced by approximately $98 million at the committed site and thus the saving in favor of the committed site against the separate individual sites for all development phases and all three concepts, will increase from $1,390 million to $1,488 million.

### 4.1.9 Conceptual Site Plan for the Committed Site

A conceptual site plan has been developed for Scenario IIc, assuming the sequential operation of three (tokamak, tandem mirror, and EBT) fusion reactors in the EPR phase.

The arrangement of all major facilities in this scenario is shown in Figure 4-1. The three reactors (1, 13, and 20) are closely clustered around the control building (4) and it's extensions (19 and 24) and the turbine generator building (6). This arrangement results in relatively short cable runs between the reactors, the turbine building and the control building. The length of steam lines from the steam generator buildings (5, 16, and 23) to the steam header and valve gallery (7) also are reasonably short. The steam header, through proper valving and controls, could feed the turbine from any of the three reactors.

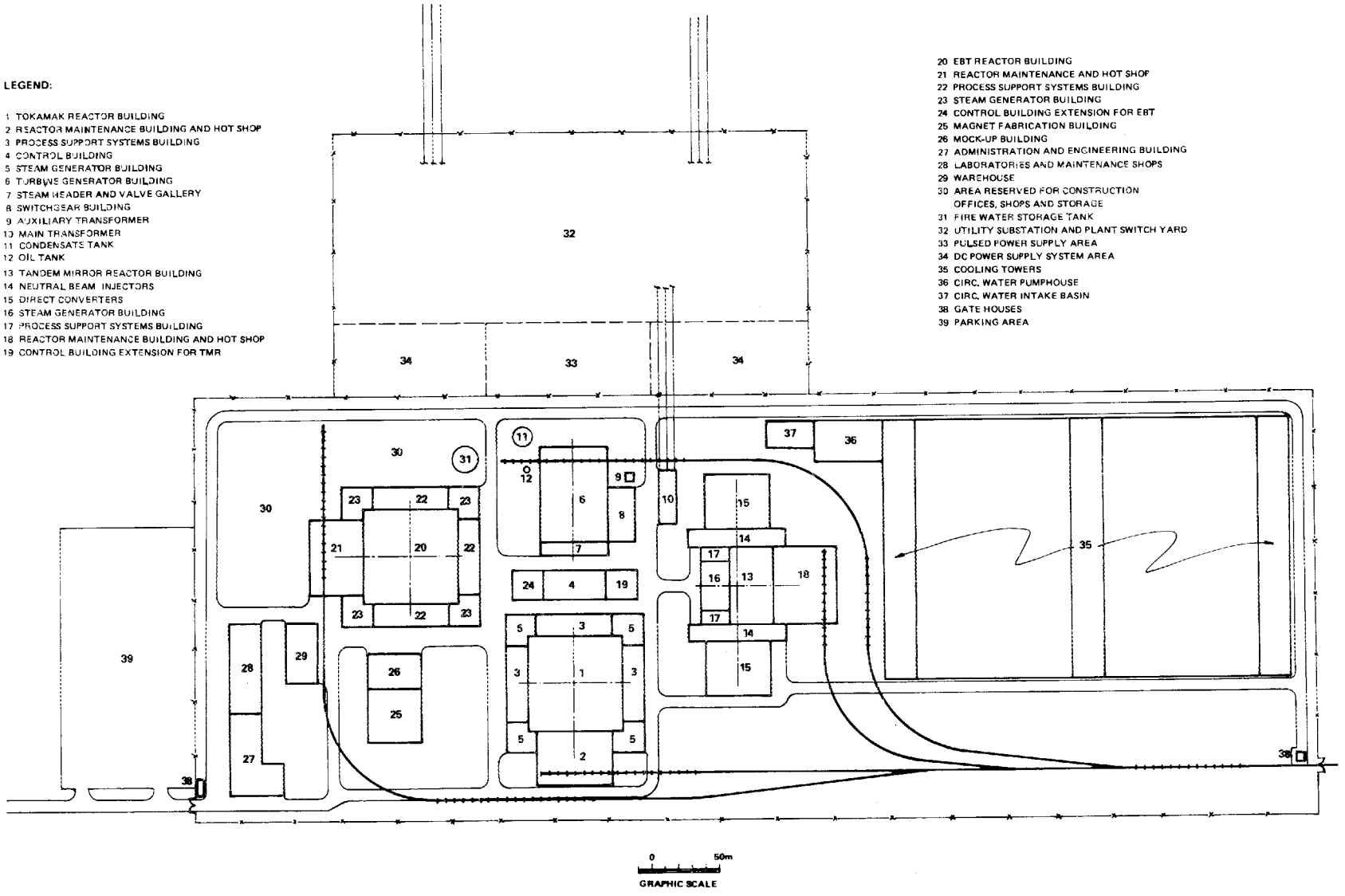


**Figure 4-1**

**COMMITTED FUSION DEVELOPMENT SITE**
**CONCEPTUAL SITE PLAN**
**OPERATION OF THREE DEVICES IN EPR PHASE**

The magnet power supply and NBI/RF heater power supply equipment 33 and 34) are located next to the utility substation and plant switchyard (32) and at a reasonable distance from the reactors they serve. The supply bus run's length is judged to be reasonable.

The circulating water line can be run straight from the circulating water intake basin (37) to the turbine building with minimal change in direction.

The location of the cooling towers (35) was based on the assumption that the prevailing wind direction is 45 degrees down from the top left corner of the sketch, thus, the vapor will not be blown onto the switchyard.

The reactor maintenance and hot shop buildings (2,18, and 21) have railroad spur access for all three reactors. The turbine building (6) is also provided with a railroad spur access.

The process support systems buildings (3,17, and 22) are closely coupled to the reactor buildings they serve, to minimize piping and control cable runs.

The facilities for general service: magnet fabrication building (25), mock-up building (26), administration and engineering building (27), laboratories and maintenance shops (28), warehouse (29), gate houses (38), and parking area (39) are functionally located.

Adequate road access is provided to each facility by a paved plant road system.

The fenced-in plant area, including the substation/switchyard complex, is approximately 328,000 square meters.

### 4.1.10 Conceptual Simplified Electrical Single Line Diagram

A preliminary, simplified electrical single line diagram was developed to conceptualize the electrical systems required for the committed site. The diagram, shown in Figure 4-2, depicts the electrical systems required for the fully developed committed site, with a demonstration/prototype phase generic tokamak device,,, an EPR phase tandem mirror device and a demonstration/prototype phase EBT device operating simultaneously. Any less ambitious operating scenario would, of course, reduce the electrical requirements.

Power is carried to the site through two 230 kV transmission lines, which supply energy to a 230 kV ring bus, located at the utility's 230 kV substation. 230 kV, 2000 A oil circuit breakers are provided for protection of this ring bus and outgoing 230 kV feeders.

The 230 kV power is stepped down by three 200/238 MVA, 230 kV-34.5 kV power transformers. One of these transformers is a stand-by unit. The secondaries of these transformers is connected through 4000 A oil circuit breakers to a 34.5 kV

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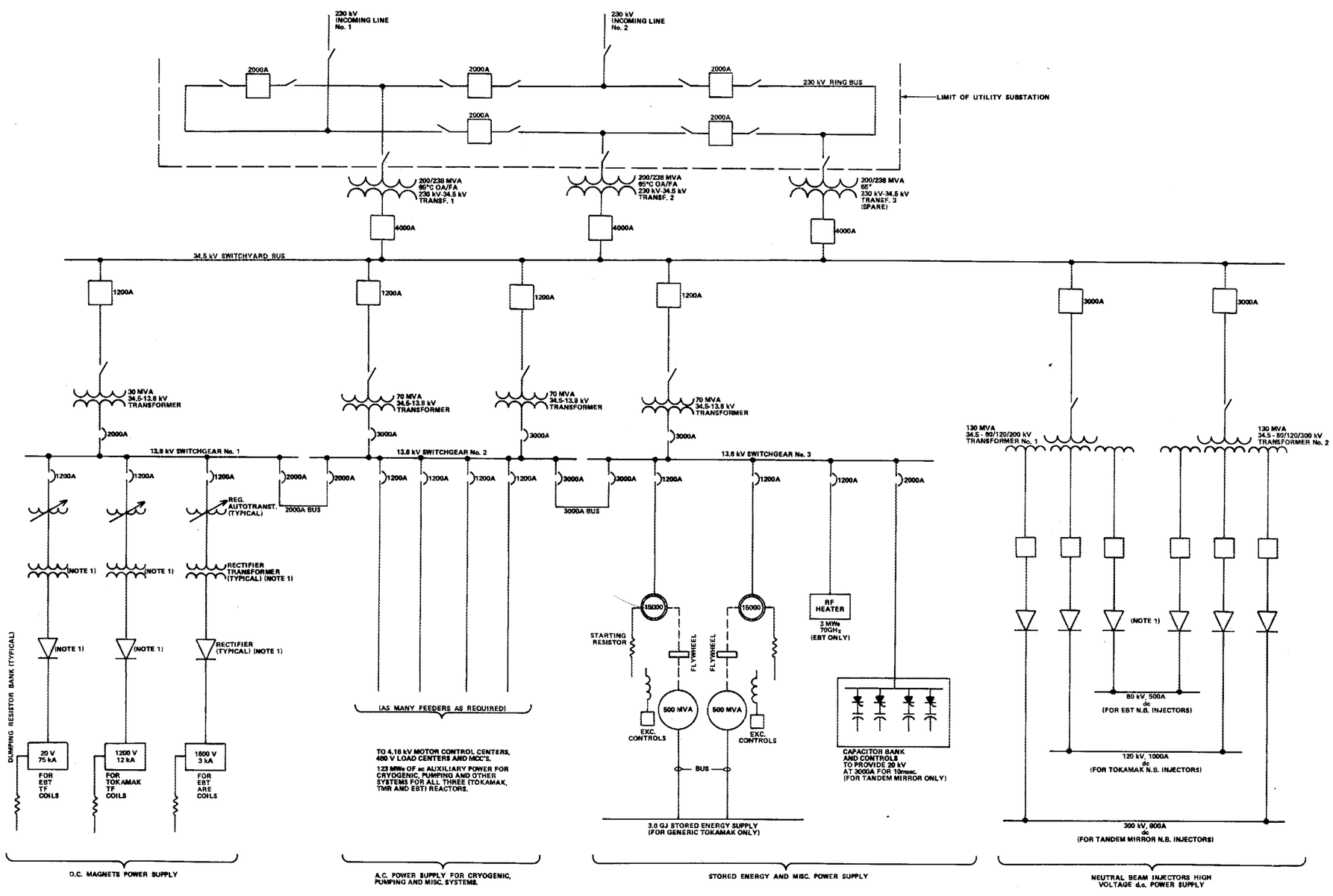


LEGEND

- POWER TRANSFORMER
- REGULATING AUTOTRANSFORMER
- OIL CIRCUIT BREAKER
- AIR CIRCUIT BREAKER
- SILICON DIODE RECTIFIER
- SILICON CONTROLLED RECTIFIER
- WOUND ROTOR MOTOR NUMBER INDICATES HORSEPOWER

NOTES:
1. ONLY ONE TRANSFORMER / RECTIFIER SHOWN ON THIS SINGLE LINE DIAGRAM ALTHOUGH SEVERAL UNITS WILL BE REQUIRED IN PARALLEL TO DELIVER THE NECESSARY AMOUNT OF POWER.
2. THIS IS A VERY SIMPLIFIED SINGLE LINE DIAGRAM PREPARED TO SHOW ONLY THE RATINGS OF THE MAJOR TRANSFORMERS AND THE OVERALL POWER FLOW.

| No. | DATE | REVISIONS | BY | CHKD | DESIGN ECPV | ENGR | PROJ ENGR | APPR |
|---|---|---|---|---|---|---|---|---|
| A | | ISSUED FOR REPORT | | | | | | |

SCALE NONE | DESIGNED J.G. RIVAS | DRAWN S. LOUIE | CHIEF ENGR

BECHTEL
SAN FRANCISCO

COMMITTED FUSION SITE STUDY

CONCEPTUAL SIMPLIFIED ELECTRICAL SINGLE LINE DIAGRAM, FOR SIMULTANEOUS OPERATION OF TOKAMAK, TMR & EBT DEVICES

| JOB No. | DRAWING No. | REV. |
|---|---|---|
| 12890 | Figure 4-2 | A |

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switchyard bus. Power from this bus is stepped down by additional transformers as follows. A 30 MVA, 34.5-13.8 kV transformer reduces the voltage to 13.8 kV, for distribution to the banks of regulating auto transformers, rectifier transformers and rectifiers required to provide the necessary dc power for the steady state magnets used in the tokamak and EBT reactors.

A bank of two 70 MVA, 34.5-13.8 kv transformers provide all the 13.8 kV power to be distributed throughout the site for all the ac plant auxiliary loads. This power is distributed also at levels of 4.16 kV and 480 volts, through additional transformers, depending on the size and voltage requirements of the auxiliary plant loads. The 13.8 kV bus, supplied by these two 70 MVA transformers, also serves as a source of backup power for the 13.8 kV bus described above and is used for the dc magnet power supply system. The power required for the stored energy system could also be drawn from this bus.

A third 70 MVA, 34.5-13.8 kV transformer provides the power for the two 15,000 HP wound rotor motors to drive the three GJ stored energy supply system generators. This system is required for the tokamak reactor only. The same transformer will also supply the power for the 3 MWe, 70 GHz RF heating system needed for the EBT reactor, and a capacitor bank required to provide 20 kV, 3000 A 10 msec pulses for the tandem mirror reactor.

Two other transformers, rated at 130 MVA, step-up the 34.5 kV power to a level of 80 kV, 120 kV, and 300 kV through three

separate secondary windings. This high voltage ac power is rectified and shaped by special circuits and is then used to supply power for the EBT, tokamak, and tandem mirror neutral beam injectors.

## 4.2 SCHEDULE EFFECTS OF COMMITTED SITE ON FUSION DEVELOPMENT

The establishment of a committed fusion development site will undoubtedly have a significant effect on the development and commercialization of power producing fusion reactors. This effect, as it can be visualized at this early development stage of fusion, appears to be mostly beneficial from both the economic and schedule points of view. It is conceivable, however, that if the availability of funds is unlimited, development phases taken sequentially on the committed site may be entered simultaneously for several devices at separate, individual sites. This is unlikely to occur, for the following two reasons:

- Common sense dictates that whatever funds are made available for fusion development, the largest possible portion of the funds should be spent on the technical advancement of the fusion concepts and not on duplicating expenses for site selection and certification, necessary site improvements on several sites, and duplicating service systems, which are common for most devices.
- The development of some concepts, primarily tokamaks and mirrors, is more advanced than other fusion concepts. The idea of simultaneous development of several concepts would, therefore, not only be costly but not realistic. The other concepts require considerable development and proof-of-concept time, before they can be considered for major engineering experiments.

The schedule effects of the committed site on the fusion development program can be summarized as follows:

- The time involved and the cost incurred in the site selection/certification process will only occur once.
- The bulk of the cost involved in the general site improvement process (see Appendix A, Task 100 Interim Letter Report, Subsection 5.0, Base Line Site Requirements, Subsections 5.1 through 5.4.5) needs to be expended only once, at the front end of the establishment of the committed site.
- The shareable service facilities (main plant substation, switchyard, control building, administrative, engineering maintenance and shop facilities, magnet winding facilities, mock-up building, circulating water system, cooling towers, turbine generators, etc.) will serve all devices and development phases, with probably minor extensions or modifications.

The description of the procedure involved in site selection presented here is greatly simplified. Even so, it can be easily seen that it is lengthy and costly. The establishment of the committed site would greatly reduce the cost and compress the time required for this procedure. The overall fusion development program would benefit from the savings resulting from the concentration of the efforts and limitation of the expenditures to a single site, rather than repeating them for each fusion device at different locations.

The site selection process, assuming a grass root site, has to be done in several successive steps:

- Preliminary screening; factors used in the preliminary screening process include hydrology,

geology, demography/land use, meteorology, ecological sensitivity, geography/topography and general acceptability. The preliminary screening highlights the potential areas for siting.

- Identification of, candidate regions; Screening of candidate regions will be based on factors involving geology, demography/land use, accessibility, ecological sensitivity, and geography/topography.

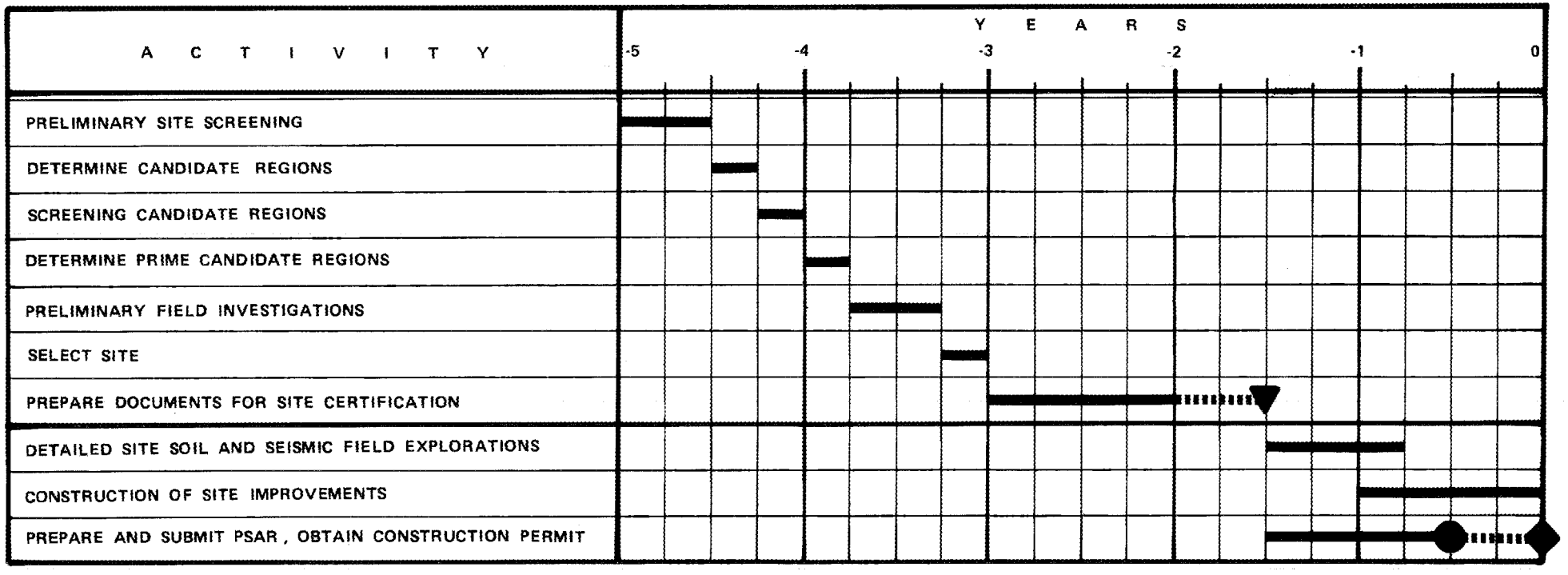
- Selection of prime candidate regions.

Once the prime candidate regions are determined, preliminary site investigations will be carried out, involving soil borings and seismic investigations. The results of these more specific preliminary investigations will help in the identification of the candidate site within the primary candidate region.

### 4.2.1 Schedule For Site Selection/Certification

The probable schedule for the activities involved in site selection is shown in Figure 4-3.

Recent experience shows that the time required to obtain a construction permit for a grass-root light water reactor power plant is four to six years. For a grass-root coal-fired fossil power plant, it is two to four years. Based on this experience, a time span of five years has been assumed for the activities required to obtain the construction permit for a fusion reactor from the Nuclear Regulatory Commission. It is further assumed that a temporary construction permit will be issued after submittal and approval of all the applicable documents required for the issuance of such a temporary construction permit by




LEGEND:

- ▼ RECEIVE TEMPORARY CONSTRUCTION PERMIT
- ● SUBMIT PRELIMINARY SAFETY ANALYSIS REPORT
- ● RECEIVE CONSTRUCTION PERMIT

Figure 4-3

SCHEDULE FOR SITE SELECTION/CERTIFICATION AND SITE IMPROVEMENTS

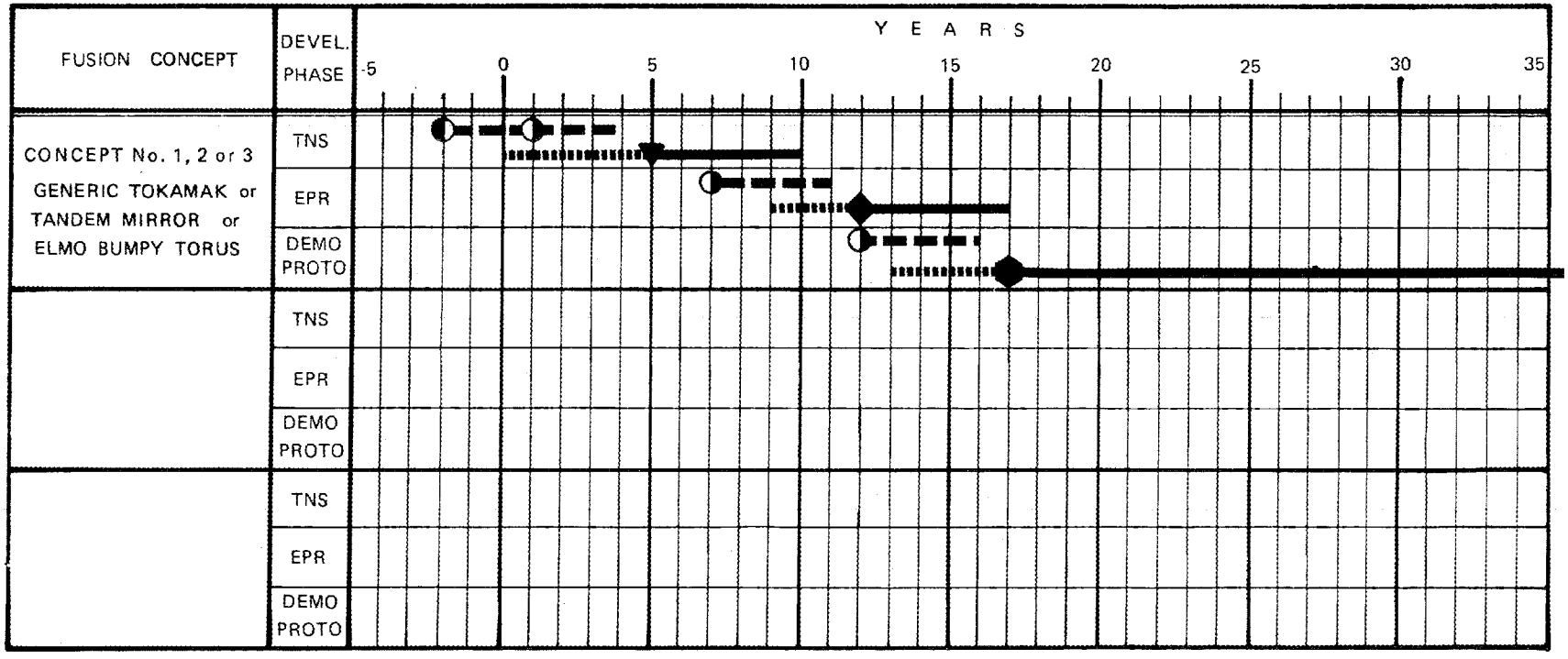
federal and state agencies, as listed in Appendix B, Task 200 Interim Letter Report, Subsection 6.1, Table 6-1.

### 4.2.2 Construction/Upgrading and Operation Schedule for Scenarios I through IIc-1

Construction/upgrading and operation schedules have been developed for Scenarios Ia through Ic, covering the cases where single concepts are developed in TNS, EPR and demonstration/prototype phases, and for Scenarios IIa through IIc-1, which assume the construction and operation of up to three concepts at the committed site.

Figure 4-4 shows the schedule for developing a single concept on a committed site.

Year 0 is assumed to be the beginning of construction of the structures at the site. The activities which must precede this activity are shown in Figure 4-3. Note on Figure 4-4 that the engineering which supports the commencement of construction activities must also begin approximately two years prior to starting construction, therefore the technical information needed to start engineering of the structures must be available for the architect-engineer, who is responsible for the design of the structures. The technical information must contain preliminary building arrangement drawings, piping and instrumentation diagrams, and equipment drawings. The flow of technical information from the reactor designer to the architect-engineer




LEGEND

- ENGINEERING: STRUCTURES, PROCESS SYSTEMS
- CONSTRUCTION/UPGRADING
- OPERATION
- TECHNICAL INFORMATION REQUIRED TO SUPPORT BUILDING STRUCTURAL DESIGN
- TECHNICAL INFORMATION REQUIRED TO SUPPORT PROCESS SYSTEM DESIGN
- TNS PHASE OPERATION COMMENCES (NO POWER CONVERSION SYSTEM REQUIRED)
- EPR PHASE OPERATION COMMENCES (STEAM GENERATION SYSTEM AND TURBINE GENERATOR REQUIRED)
- DEMONSTRATION/PROTOTYPE PHASE OPERATION COMMENCES (UPGRADING OF STEAM GENERATION SYSTEM AND SECOND TURBINE GENERATOR REQUIRED.)

**Figure 4-4**

**ENGINEERING, CONSTRUCTION/UPGRADING AND OPERATING SCHEDULE FOR SCENARIOS Ia, Ib AND Ic**

must be such that it will not disrupt the development of drawings, specifications, and purchase documents needed for the orderly construction of the structures at the site.

At approximately year +1, the technical information needed for the design of process systems must be ready for the architect-engineer. The flow of this information again must be continuous and uninterrupted in accordance with the detailed engineering-construction schedule.

The construction period is assumed to be five years. During this period, the construction of all structures, yard facilities, and installation of all nuclear and mechanical equipment, piping, conduits, and wiring is assumed to be completed, tested, and made ready for TNS operation at year 5.

At year 7, the technical information needed for upgrading the TNS device for EPR operation must start to flow to the architect-engineer. Engineering of the upgrading modification is assumed to last four years.

At year 9, the construction of energy conversion facilities and systems starts, and when the TNS operations are terminated, the upgrading of the reactor (installation of blanket) commences. The upgrading construction, including the installation of steam generating system and turbine generator, is assumed to be complete and the device made ready for EPR operation at year 12. The EPR operation is assumed to last for five years. Just about

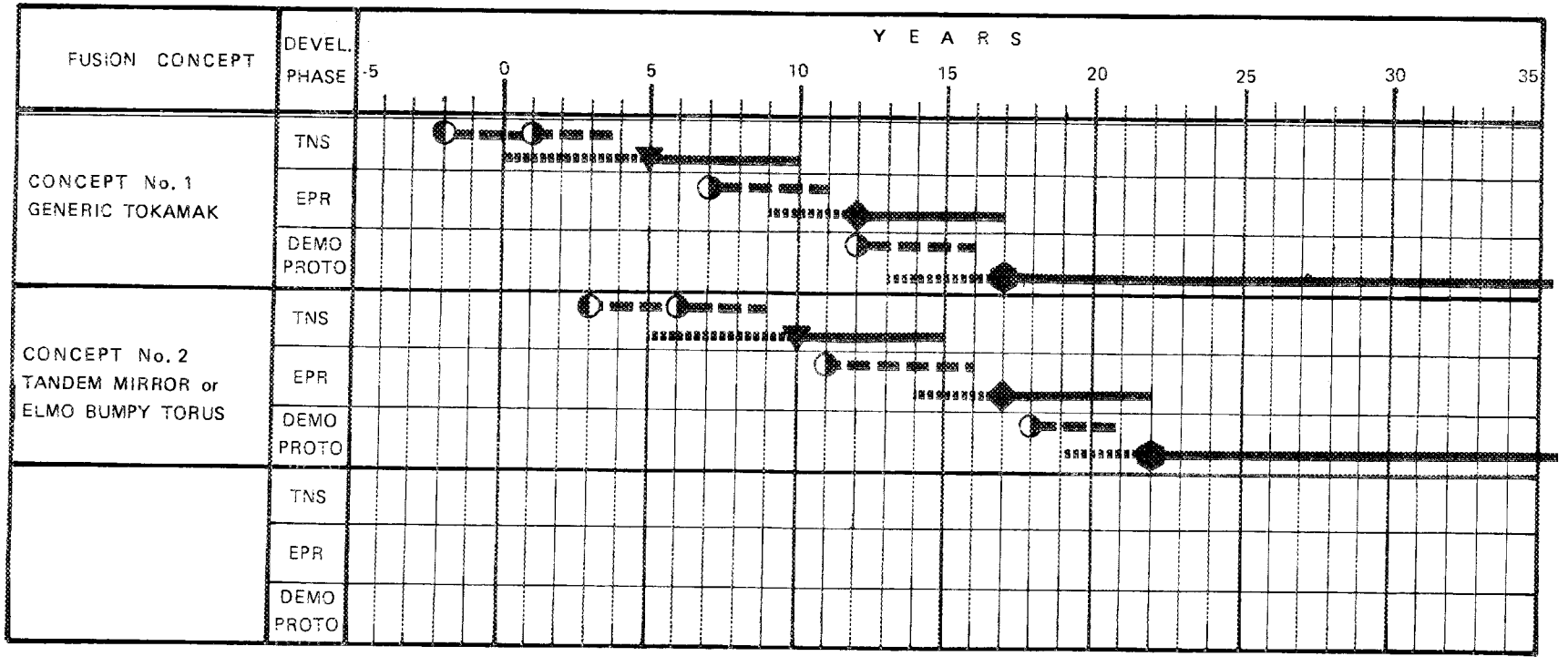
the time the EPR operation commences, the flow of technical information supporting the upgrading engineering activities for demonstration/prototype operation must start. This engineering is assumed to last for four years, ending at year 17.

The construction of demonstration/prototype facilities (second reactor building for the tokamak, second steam generation system, upgrading of process support system facilities, second turbine generator) is assumed to start at year 13, and be completed at year 17. The demonstration/prototype operation starts at year 17, and is assumed to last for twenty years.

The schedule shown in Figure 4-4 is based on tokamak installation, but is not expected to vary greatly for the tandem mirror and EBT devices. These devices are not developed far enough to warrant exploration of differences in engineering, construction/upgrading, and operation schedule at this time.

Figure 4-5 shows the engineering, construction/upgrading, and operating schedule for Scenarios IIa and IIb which combines the tokamak and either the tandem mirror or the EBT at the committed site.

The schedule for the tokamak device is identical to that shown in Figure 4-4, and the schedule for the second concept is phased in such a way that when the EPR operation of the first concept (tokamak) is complete, the EPR phase operation of the second concept (tandem mirror or EBT) can commence.




LEGEND

- ENGINEERING: STRUCTURES, PROCESS SYSTEMS
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- DEMONSTRATION/PROTOTYPE PHASE OPERATION COMMENCES (UPGRADING OF STEAM GENERATION SYSTEM AND SECOND TURBINE GENERATOR REQUIRED)

**Figure 4-5**

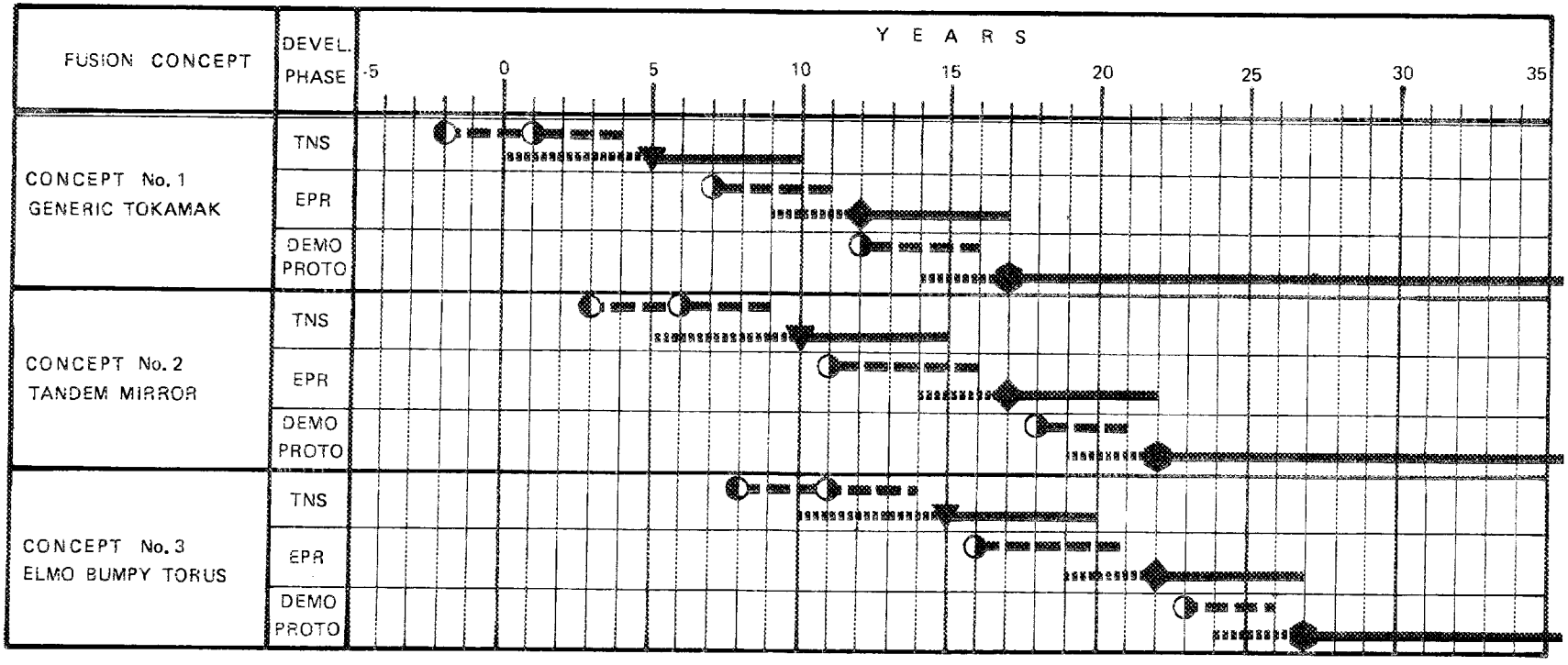
**ENGINEERING, CONSTRUCTION/UPGRADING AND OPERATING SCHEDULE FOR SCENARIOS IIa AND IIb**

The general logic of this schedule is basically the same as for the one shown in Figure 4-4; therefore, the explanations given for the operations there, are also applicable here. It is noteworthy, that from year 22, four 300 MWe turbine generators are required for the demonstration/prototype operation for two devices.

Figure 4-6 shows the engineering, construction/upgrading, and operating schedule for Scenario IIc; the sequential construction and simultaneous operation of three concepts at the committed site.

The logic for this schedule is basically the same as for Scenarios Ia through Ic, therefore the explanations given for those are applicable here also.

It is noteworthy, that the EPR phase operation for all three concepts can be completed by year 27. If demonstration/prototype phase operation of all three concepts is required, they can be operated in this phase independently and for a long period of time. The price of this type of operation, however, is the installation of six turbine generators, having a generating capacity of 300 MWe each. However, the probability of three devices proceeding to this phase on this schedule is judged fairly remote.




LEGEND

- ENGINEERING: STRUCTURES, PROCESS SYSTEMS
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- DEMONSTRATION/PROTOTYPE PHASE OPERATION COMMENCES (UPGRADING OF STEAM GENERATION SYSTEM AND SECOND 300 $MW_e$ TURBINE GENERATOR REQUIRED.)

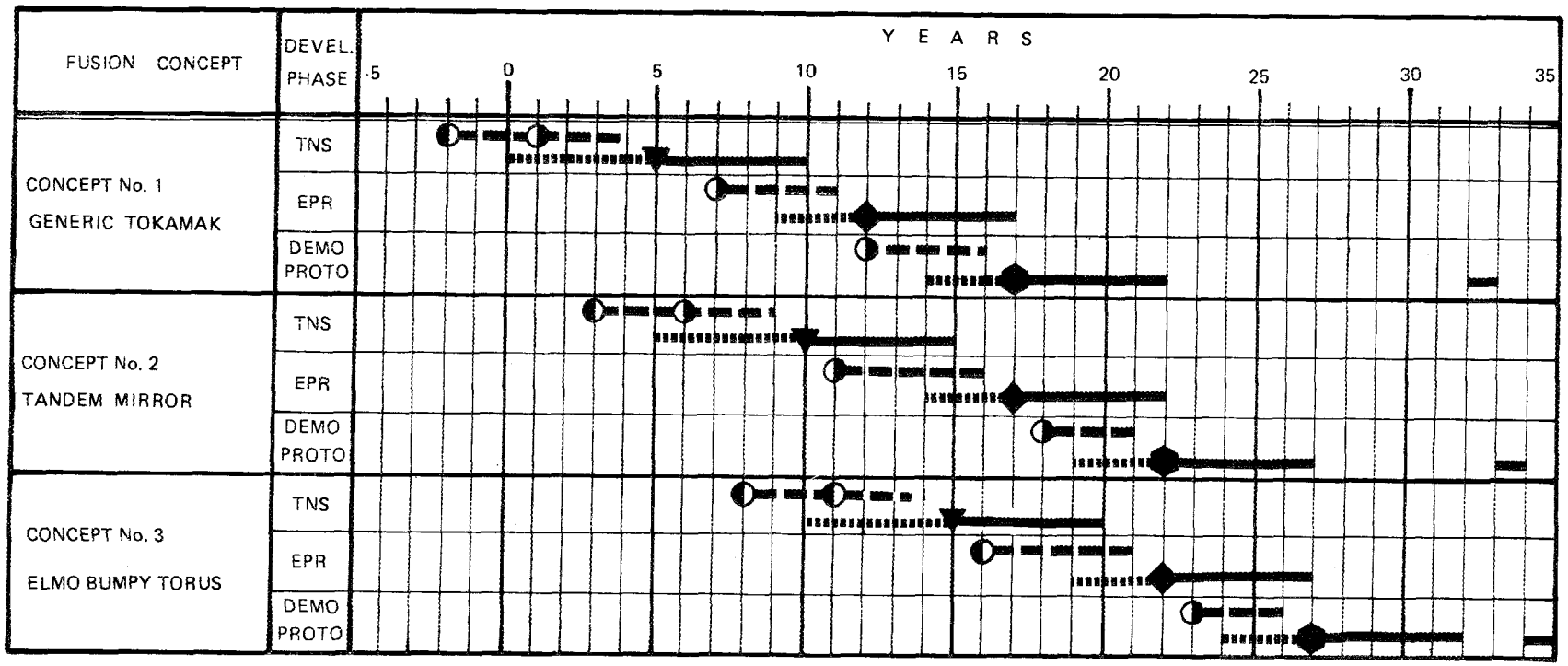
**Figure 4-6**
**ENGINEERING, CONSTRUCTION/UPGRADING AND OPERATING SCHEDULE FOR SCENARIO IIc**

Figure 4-7 shows a schedule for a more likely scenario (Scenario IIc-1) for the engineering, construction/upgrading, and operation of three devices on the committed site.

This schedule is basically the same as the one shown in Figure 4-6, with the exception of the need and utilization of turbine generators. It would require one 300 MWe turbine generator to support the uninterrupted EPR operation of all three concepts for five years each. At year 17, a second turbine generator, having 600 MWe generating capacity, would be installed. This larger unit would insure the uninterrupted, independent operation of all three concepts in the demonstration/prototype phase, but only for five years for each device. After that, some phasing in the operation of the devices would be required if more than one device is to be operated beyond the allocated five-year demonstration period.

It is also postulated that around year 25 or so, enough operating experience will be available to make a decision as to which concept has the optimum performance, and the 600 MWe capacity turbine generator may be allocated for the demonstration/prototype phase operation of that concept for a longer period of time than the originally allocated five years.

In conclusion, it can be said that the committed site has definite schedule advantages over the individual siting of each concept. The elimination of the site selection/certification phase for the second and third concept may save up to five years




LEGEND

- ENGINEERING: STRUCTURES, PROCESS SYSTEMS
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**Figure 4-7**

**ENGINEERING, CONSTRUCTION/UPGRADING AND OPERATING SCHEDULE FOR SCENARIO IIc-1**

in schedule time and up to fifteen million dollars per device. The sharing of certain multiple-use buildings, process service facilities, and systems and the availability of skilled technicians and operators for all devices increase the schedule and economic benefits of the committed site.

The schedules shown in this section are based on the assumption that the construction of the first device of the second fusion concept can commence at year 5, and that the first device for the third concept can start at year 10. It is postulated that the five year time lag between start construction for the first devices of the second and third concepts is sufficient to bring their state of development to an acceptable level, so that they will be ready for construction. Based on this assumption, the TNS and EPR phases of operation of all three concepts can be completed at the end of year 27.

## 5.0 EFFECTS OF PLACING FUSION-FISSION HYBRID DEVICES ON THE COMMITTED SITE

A preliminary qualitative assessment was made to determine the likely effects of using the committed site to test fusion-fission hybrid concepts. The testing of hybrids at the committed site might take one or both of the following forms:

- Testing in loops or small modules to determine performance and answer more basic technology questions
- Testing of large segments or complete blankets to determine blanket and integrated system performance, technology, and engineering data (i.e. prototypical)

In either case, significant quantities of new and irradiated fission fuel would be located at the site and have to be handled.

There are several major aspects of the committed site that might be expected to be affected by hybrid testing. These are:

- Site selection
- Licensing and permits
- Security
- Special nuclear material accountability
- Transport and handling of fission fuels
- Radioactive waste

A brief discussion of some of the major considerations involved with each of these aspects follows.

## 5.1 SITE SELECTION

The presence of fission fuel and fission products at the site will impose requirements for a more sparsely populated location as well as additional analysis to show the suitability of the site. It is likely, however, that any location selected for the committed site could accommodate hybrids with suitable engineered safety features. Thus, it is judged unlikely that hybrids will impose any severe constraints on site selection. However, the process may take somewhat longer because of the additional items that must be considered. There is also a greater risk of public opposition to the site if hybrids are to be tested.

## 5.2 LICENSING AND PERMITS

Unless located at an existing site already qualified for fission reactors, the licensing, environmental impact assessments, and permits will certainly be more extensive and time consuming. At least through the EPR stage and probably including the demonstration/prototype plant, the facilities will be government-owned and be classed as experimental.

Demonstration/prototype facilities would be subject to the full nuclear fission regulatory and licensing process. Although experimental facilities would not be subject to the full process

including public hearings, it is likely that major experimental facilities would require extensive safety and environmental review, such as the Fast Flux Test Facility was subjected to. This would probably add to the time required to obtain site approval and device licenses and permits.

## 5.3 SECURITY

Security requirements for nuclear power plants have become very strict. The presence of hybrids at the site will require special physical barriers, survailance systems, and a large, well-trained guard force. The security requirements for protection of tritium and tritium extraction facilities are not known; they may turn out to be as restrictive as for fissionable material.

## 5.4 SPECIAL NUCLEAR MATERIAL ACCOUNTABILITY

Very strict accountability is required for fission fuels. No physical additions to the committed site are expected other than those which will be required for normal handling and storage. Additional staff may be required to perform the accountability functions, however.

## 5.5 TRANSPORT AND HANDLING OF FISSION FUELS

New fuel unloading, inspection, spent fuel loading, and fuel cleaning facilities will be required. If consideration is given these requirements in the site and device design stage, it is probable that many of these facilities can be designed to be shared by several experiments. Additional provisions such as larger cranes, special fuel handling machines, and building structures designed for the heavier loads imposed by fuel handling will be required for the device buildings.

## 5.6 RADIOACTIVE WASTE

Larger quantities of radioactive waste can be expected with hybrids. Leaking fuel will result in the release of fission products to the coolant. Coolant cleanup systems will be used to remove these and other radioactive contaminates; these wastes will be processed by the radioactive waste system. Irradiated fuel cleaning, disassembly operations required before shipping, packaging for shipping, and shipping cask maintenance and cleanup will generate radioactive waste. Washing operations can generate significant quantities of waste. If fuel examination facilities are provided on the site, large amounts of high-level gaseous and solid waste will be generated.

# 6.0 CONCLUSIONS AND RECOMMENDATIONS

Although the information this report is based on is by no means complete, it was possible to determine with a fair amount of certainty that the committed site concept is definitely feasible. It appears to offer significant economic and schedule advantages over the case when the candidate fusion concepts and their development phases are constructed on separate, individual sites.

## 6.1 ADVANTAGES OF THE COMMITTED SITE

Based on a partial cost evaluation of the postulated scenarios, the saving the committed site approach would result in varies between $40 million and $1,375 million. (Refer to Tables 2-1 and 2-2 in the Summary Section.)

The major cost advantage of the committed site lies in its implementation in the development of a single fusion device as opposed to the development of multiple fusion devices on the same site. As an example, from Table 2-1, the cost saving for tokamak development on a committed site is $610 million (TNS-EPR-Demo/Proto), and the cost saving for EBT on a committed site is $576 million. These savings represent a reduction in cost of about 50 percent compared to three separate sites for tokamak and three separate sites for EBT. However, combining all three development phases of the tokamak and EBT on a single site results in the much lower cost advantage of $80 million (see Table 2-2) compared to the combined cost of the development of

each concept on separate committed sites. Grouping the tokamak with the tandem mirror reactor leads to the same conclusion.

The cost advantage of the committed site for single fusion concept development over that for multiple concept development results because there is not much equipment which can be shared among upgrades of the different fusion reactor devices. The tokamak needs large quantities of pulsed electrical power for current initiation and heating. Power supplies which are needed on a tokamak TNS can be used on the EPR upgrade and shared between multiple tokamak units in a demonstration phase. However, EBT and tandem mirror reactors are steady-state machines and do not need the large banks of stored electrical energy required for pulsed operation. The mirror needs large amounts of high energy neutral beams to drive the reactor, but this power is drawn off the utility grid in a continous fashion.

The primary cost elements which can be shared among different fusion concepts at a committed site are the costs associated with site selection and development and the cost advantage of higher capacity process equipment, such as heat rejection systems, tritium handling systems, etc., sized to meet the combined needs of the candidate fusion reactors.

The schedule advantage is harder to evaluate. Based on judgement rather than quantitative analysis, it is estimated that the development of three fusion concepts, up to their EPR development

phase, can be accomplished in five to ten years less time than if the devices are constructed on separate, individual sites.

The lengthy and costly procedure of site selection and improvements, which are required only once if the committed site concept is adopted, is an area affecting both cost and schedule. It requires five years to ready a site for the construction of fusion devices; the associated expenditures are in the order of $25 million for a grassroot site.

The Alternate Concepts Section of the ETF Mission Statement (to be published by ORNL) raises the possibility of a second or third load assembly on the ETF site. If the first core fusion device at the ETF site is a tokamak, then the saving in cost which could be derived by placing a tandem mirror and EBT on the ETF site, as opposed to locating them on two new sites, would be approximately $80 million (15% reduction) as shown in Table 2-2. Equally important, five to ten years could be saved in time required for additional site preparation and licensing.

There are several intangible advantages to a committed site. These include, but are not necessarily limited to the following:

The concentration of a highly trained technical and scientific staff at one location may result in cross fertilization of ideas concerning solutions to the many technical problems which, no doubt, will surface during the technical development of the fusion concepts.

Highly skilled technicians and craftsmen will be required for the development of the first and one of a kind fusion devices. The concentration of these specially trained people in one location will result in better utilization of their talent for the benefit of the whole fusion development program. Technical training programs for the development of new talents can benefit from the presence of the experienced technicians and utilize their experience and expertise.

The operating experience gained by operating one device would be readily available for all subsequent devices.

The concentration of the fusion development program at one geographic location would require almost continuous construction activities for twenty years or so. The contractors involved in these activities will be accustomed and aware of the quality control methods and requirements for highly sophisticated devices, thus making their operation more efficient. The construction labor force would find long, continuous employment at one location. This should help to minimize the problem of possible labor shortages.

## 6.2 DISADVANTAGES OF THE COMMITTED SITE

The advantages of the committed site, as presented in the preceeding section, seem to be very definite despite the fact that the information they are based on is less than definite. There may be some areas, where the future development work on the

fusion devices may highlight presently unknown facts, which may cast some doubt on the advantages which appear so clear today. Even discounting this possibility, there are some areas, where some disadvantages of a centralized fusion development site can be identified.

- Diverse development requirements.
  Comparing concept characteristics as they are conceived today, a great diversity is observed. It has been assumed that the majority of these diverse requirements can be eliminated or at least greatly reduced by standardization or managerial action. As development progresses, it may be apparent that such a standardization would require major performace compromises for some devices. If, on the other hand, at the time the committed site is established, flexibility is demanded in site facilities and service systems which are capable of accommodating a great diversity in device requirements, the cost of this flexibility may significantly lessen the cost advantage of the committed site.

- Obsolesence.
  At the time the committed site is going to be established, the site facilities and device support systems will be provided based on the state of the art of the technology available. The development of the fusion concepts may create new technologies involving facilities and systems quite different from those installed at the site. Systems, which were contemplated to serve several devices for a long time, may become obsolete and have to be upgraded or even replaced way before the end of their useful life.

- Limitation on the pursuit of new concepts.
  The committed site, established for the operation of selected fusion concepts, would set the path of fusion reactor development. Dedicated to the testing and operation of devices in relatively advanced development phases, it may not be suited for laboratory scale, proof of principle type experiments. These probably can be best performed at the facilities of the developing laboratories. TNS and larger versions of alternate concepts, however, must take into consideration what facilities and support systems are available at the committed site, and what changes or modifications

are necessary in site facilities to accommodate the requirements of the new concepts.

## 6.3 RECOMMENDATIONS

The advantages of the committed site seem to overshadow the possible limitations and disadvantages it may have. In order to explore both the advantages and disadvantages in more detail and have a more definitive and quantitative answer to the merits of the concepts, the following recommendations are made.

- Development of Integrated Plant Designs for the Candidate Concepts.
  Support systems for most, if not all fusion concepts, are undefined. These facilities and systems represent a great portion (upward of 70 percent) of the overall plant costs and may not be adequately represented in present plant cost estimates. Their design may affect the development of the fusion devices, therefore a parallel effort for the development of BOP system design is highly recommended. A coordinated effort for producing integrated fusion reactor plant conceptual designs will result in compromises in both reactor and BOP designs which are beneficial for the economy, safety, and operating ease of the complete facility.

- Location of the Committed Site.
  The present effort assummed grassroot location for the committed site. Considerable time and investment can be saved if it is located on a government reservation or another equally well-characterized site. Field exploration (geologic, seismic, hydrologic, meteorologic, etc.) costs, associated with the selection of the site could be greatly reduced since this information is readily available at most government reservations. At a government reservation then, licensing time could be shortened considerably, and the licensing procedure could be concentrated on real safety issues rather than issues with extremely low hypothetical risks which tend to be emphasized in the public licensing arena. A thorough survey of the available government reservations could quantify the trade-offs needed for an intelligent

decision in locating the committed fusion development site.

- Urgency of Siting Activities.
  The siting activities must be closely coordinated with the other facets of the fusion development program. As pointed out earlier, it may take five years to ready a site for the construction of the first fusion device. This time should be integrated into the overall fusion program schedule if the danger of placing the siting question on the critical path is to be avoided. The site improvement costs should also be developed and included in the fusion program's budget.

# APPENDICES

APPENDIX A

TASK 100

INTERIM LETTER REPORT

# EVALUATION OF A COMMITTED FUSION SITE

OCTOBER, 1978

BY

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P.O. BOX 3965
San Francisco, California 94119

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# 1.0 INTRODUCTION

The Committed Fusion Site approach emerged from studies conducted in Government Fiscal years (GFY) 1976 and 1977 by the Advanced Systems Program of the Fusion Energy Division of Oak Ridge National Laboratory. The Committed Fusion Site Project for GFY78/79 is being conducted by Bechtel under subcontract with the Oak Ridge National Laboratory, operated by the Union Carbide Corporation, who are providing technical direction. The objective of this study is to evaluate the technical and economical merits of a committed fusion development site, dedicated to major engineering experiments, not proof-of-principle for magnetic confinement fusion concepts.

The project kick-off meeting was held at Oak Ridge National Laboratory on June 20, 1978.

The technical effort is divided into five major tasks as follows:

100 Definition of Baseline Site Requirements

200 Development of Site Characteristics

300 Technical Implications of Site Development

400 Evaluation of Committed Site Development

500 Evaluation of the Feasibility of a Committed Site

At the completion of Tasks 100 through 400, an interim letter report will be prepared. These reports will summarize the work performed and conclusions reached in each of the tasks. In Task

500, an overall evaluation will be performed and these interim letter reports will be integrated into a comprehensive final report on the feasibility of a committed fusion development site.

This is the first interim letter report on the project and it describes the work performed in Task 100, Definition of Baseline Site Requirements.

The depth of this interim report is limited by budgetary and schedule constraints as well as by the relatively early stage of the evolution of most, if not all, fusion concepts. As the fusion concepts are developed further, a reevalution of the conclusions of the present effort may become necessary.

## 2.0 CRITICAL ISSUES

On the surface, the committed site approach for major fusion engineering, demonstration, and prototype facilities appears to offer some significant technical and programmatic advantages. However, there are several critical issues that must be evaluated before even a tentative conclusion can be drawn regarding this approach.

These critical issues and the key considerations associated with them are discussed in the following paragraphs.

### 2.1 DIVERSE DEVELOPMENT REQUIREMENTS

The committed site and the facilities established on it must satisfy not only the requirements for testing and/or operation of different experimental and demonstration devices at various stages of their development, but the same provisions must be made for different fusion concepts. It is important, therefore, to consider each development phase and every candidate magnetic fusion concept in establishing site requirements. Such flexibility, associated with scheduling considerations in phasing the requirements and/or experimental operation of the devices, may result in severe economic penalties and incompatible site development.

## 2.2 COMMONALITY OF FACILITIES AND SERVICE EQUIPMENT

There are two key considerations involved in this issue. The first is whether different concepts and development phases have enough common requirements for services to show decisive economic and schedule advantage for a committed site. Power and water supplies, major structures, vacuum and refrigeration systems, magnet and first wall fabrication facilities, maintenance hot cells, diagnostic equipment, data acquisition and processing equipment, tritium processing, and storage facilities are typical examples of the facilities and services which can be shared by the different development phases and/or different concepts, if partial or full compatibility can be established.

The second consideration is obsolescence. Fusion concepts, systems, and technology are in their infancy. Rapid changes, improvements, and advances in all areas are certain to occur. Therefore, the useful life span of components, systems, and technologies may be relatively short. As the evolution of fusion concepts from engineering experiments to power plants may span decades, it is probable that some or much of the equipment used and technologies applied at the early stages of the development program will become obsolete before the evolution process has progressed to power producing demonstration plants or prototypes. The probable useful life span of equipment and systems must be assessed to establish what systems are likely to survive the evolutionary process and what provisions for future use or

upgrading to satisfy anticipated future requirements must be included.

## 2.3 RADIOLOGICAL, ENVIRONMENTAL, AND LICENSING REQUIREMENTS

Presently, there are no established safety regulations and licensing requirements for fusion facilities. The probable regulations and licensing criteria for the committed fusion development site must, therefore, be forecast. Extreme precaution should be exercised in predicting safety regulations and licensing criteria for fusion installations; careful consideration must be given to specific radiological characteristics. Any attempt to extrapolate existing light water reactor safety regulations and licensing requirements to fusion reactor licensing seemingly would have the inherent danger of being overly conservative and thus unduly penalize the design and economics of fusion reactors. The requirements for controlling radioactive releases are likely to be the most restrictive and the most difficult to forecast, therefore they require the most careful attention.

## 2.4 REACTOR DEVELOPMENT SCENARIOS

The path(s) of fusion development and commercialization may affect the benefits that can be realized from the committed site concept. Several scenarios can be postulated involving the development tests and the various candidate fusion reactor

concepts. At the beginning of this study, a scenario progressing from TNS through EPR, demonstration, and commercial prototype was adopted. The current DOE policy involves a slightly different set of devices; however, the differences are not significant relative to the committed site approach. A full investigation involving all combinations of all scenarios cannot fit into the frame of this study, but combinations of some of the scenarios, believed to be representative, will be examined in search of the sensitivity of benefits of the committed site concept to fusion reactor development scenarios.

## 2.5 LIMITATIONS ON THE PURSUIT OF NEW CONCEPTS

The establishment of a committed fusion development site, based on the requirements of selected fusion concepts and development stages, would influence the path of fusion reactor development. A committed fusion development site, dedicated to the testing of relatively advanced development stages (starting with Ignition Test or High Energy Gain), would certainly not preclude the near term exploration of the feasibility of new, alternate fusion concepts. The initial laboratory scale experimentation with these alternate concepts, however, could probably be carried out most effectively in the facilities of the present fusion research laboratories. When these experiments prove the merits of further development, the design of the TNS-scale device either must take into consideration what site facilities are available at the committed site or contemplate the changes and/or modifications

necessary in site facilities to accommodate the testing of the new concept.

## 2.6 AVAILABILITY OF TECHNICAL INFORMATION

Selection and development of a site for a power generating station or a test facility requires the knowledge of detailed technical information and input on safety and environmental requirements. This information is normally available from detailed design studies and past experience on similar facilities. In case of fusion, this information is not presently available; therefore, even the questions to be raised to obtain the required input have to be formulated.

Considering the early stages of development of fusion concepts, most of the parameters determining required site characteristics would be based on best estimates and judgments rather than factual knowledge. One main objective of the present study is to define the questions that must be raised to obtain the information needed for site selection and development. Conversely, the responses to the questions that already have been developed will serve as the basis for the tentative determination of site characteristics of a committed fusion site. The reliability of these site characteristics is largely dependent upon the accuracy of the information they are based on. The largely judgmental plant requirements the fusion research laboratories were able to provide at this stage of fusion device

development would allow the establishment of only tentative site characteristics for the committed fusion site.

## 2.7 FLEXIBILITY OF FACILITIES AND SYSTEMS

The requirements for the first devices to be tested will likely be reasonably well defined at the time site development commences. This probably will not be the case for subsequent devices, since the requirements for those may be affected not only by design development, but also by the results of earlier experiments. To accommodate these possibilities, as well as for possible changes in the development scenario, overall flexibility and extra performance margins can be incorporated into the design of the site facilities. Generally, there is an economic penalty associated with the provision of flexibility and a misjudgment in required performance margins which may dictate compromises in the technical performance of future devices.

## 2.8 ECONOMICS

There are several important economic questions that must be considered in evaluating the merits of a committed site. Some of these are:

- Are there enough supporting facilities and systems that can be shared so that savings can be realized?
- What are the extra costs of flexibility to accommodate a variety of devices and development scenarios?

- Initial cost of site development will be high, and realization of potential savings may not come for years. Will cash flow requirements be a problem?

## 3.0 TECHNICAL APPROACH

The technical approach adopted in achieving the objective of this task was to collect and evaluate responses on the available site-related information for representative magnetic fusion concepts which might be constructed, tested, and operated at the committed fusion development site. The fusion research laboratories developing the concepts were the source for this information.

Oak Ridge National Laboratory established the contact personnel at the laboratories. The candidate fusion concepts, and the laboratories working on these concepts, were identified as follows:

| | |
|---|---|
| Elmo Bumpy Torus (EBT) | Oak Ridge National Laboratory (ORNL) |
| Reversed Field Pinch (RFP) | Los Alamos Scientific Laboratory (LASL) |
| Tandem Mirror Reactor (TMR) | Lawrence Livermore Laboratory (LLL) |
| Tokamaks | Argonne National Laboratory (ANL)<br>General Atomic Company (GA)<br>Massachusetts Institute of Technology (MIT)<br>Oak Ridge National Laboratory<br>Princeton Plasma Physics Lab. (PPPL) |
| Torsatron | Massachusetts Institute of Technology |

The method used to collect the required information was:

- Preparation of a "Concept Design Information Questionnaire."
- Personal visit to the fusion research laboratories by Bechtel project team members to review the answers to the questionnaire and to obtain any additional insight the labortories might have regarding the committed site.

The questionnaire was prepared with Oak Ridge National Laboratory's cooperation and covers the following topics:

- General Questions
- Reactor Data
- Heat Balance Data
- Electrical
- Plasma Heating
- Magnets
- Vacuum System
- Cryogenic System
- Radiological Data
- Chemistry/Fuel
- Direct Converter

Copies of the questionnaire were mailed to the laboratories on July 27, 1978. The cover letter requested that the addressees fill in the response to as many questions as possible, based on the available design information, or on best-judgment estimates

if the design has not progressed far enough to develop definitive answers.

The questionnaire was followed by telephone calls to all laboratories, and a schedule for the visit of the Bechtel project team was established. Between August 8 and August 23, 1978, all laboratories were visited. During these visits, many questions which were unanswered by the laboratories were verbally discussed, clarified, and additional information recorded.

## 4.0 EVALUATION OF RESPONSES TO "CONCEPT DESIGN INFORMATION QUESTIONNAIRE"

This section gives an overall evaluation of the responses given to the "Concept Design Information Questionnaire" by the fusion research laboratories.

Examination of the responses to site-requirement questions reveals that laboratories working on the development of TNS devices were able to supply the most information, while site requirements for prototype devices are the least definitive at this time. Table 4-1 shows the percentages of site-requirement questions answered by each laboratory for each concept and development phase. The completeness, or incompleteness, of the laboratory responses reflects the amount of work that has been done by each laboratory on each development phase; as would be expected, the best characterized are the tokamaks.

TABLE 4-1

QUESTIONNAIRE RESPONSE PROFILE
RELATIVE RESPONSE VALUES FOR EACH PHASE OF THE CONCEPTS

NUMBERS ARE PERCENTAGES OF QUESTIONS ANSWERED

| LAB | CONCEPT | DEVELOPMENT PHASES | | | | AVERAGE OF ALL DEVELOPMENT PHASES |
|---|---|---|---|---|---|---|
| | | TNS | EPR | DEMO | PROTO | |
| ANL | Tokamak | 0 | 70 | 46 | 0 | 29.0 |
| GA | Tokamak | 96 | 96 | 78 | 0 | 67.5 |
| LASL | RFP | 0 | 0 | 78 | 0 | 19.5 |
| LLL | TMR | 56 | 0 | 0 | 46 | 25.5 |
| MIT | Tokamak | 50 | 0 | 0 | 62 | 28.0 |
| | Torsatron | 46 | 0 | 0 | 36 | 20.5 |
| ORNL | Tokamak | 86 | 86 | 86 | 0 | 64.5 |
| | EBT | 72 | 66 | 70 | 0 | 52.0 |
| PPPL | Tokamak | 76 | 76 | 76 | 76 | 76.0 |
| AVERAGE ALL CONCEPTS | | 53.6 | 43.8 | 48.2 | 24.4 | 42.5 |

Percentages of responses received, grouped by concepts, are shown in Table 4-2.

TABLE 4-2

PERCENTAGE OF RESPONSES RECEIVED

| Concepts | Percentages of Questions Answered |
|---|---|
| Tokamaks* | 53.0 |
| Elmo Bumpy Torus | 52.0 |
| Tandem Mirror | 25.5 |
| Torsatron | 20.5 |
| Reversed Field Pinch | 19.5 |

*Percentage indicated is the average for five Tokamak concepts.

Tables 4-1 and 4-2 highlight the concepts that have not yet had an evaluation across the full spectrum of expected development phases. The "0" in Table 4-1 show those development phases that have not received any engineering consideration as yet. These may be areas that should receive programmatic attention. The major characteristics of the fusion devices in all development phases are compiled in Tables 4-3 through 4-6. Although not all the characteristics listed are site-requirement-related, these additional characteristics are provided to give an overview of the devices which are candidates for the committed site.

TABLE 4-3

# MAJOR DEVICE CHARACTERISTICS

TNS

| LAB | CONCEPT | Peak Thermal power generated ($MW_t$) | Burn time sec | Total cycle time sec | Primary coolant type | Pri. coolant temp. in/out °C | Interm. loop used | Thermal flywheel (GJ) | Steam conditions | Gross elect. output ($MW_e$) |
|---|---|---|---|---|---|---|---|---|---|---|
| ANL | Tokamak | | | | | | | | | |
| GA | Tokamak | 750 | 30 | 60 | Water | 243/316 | No | | Sat. | 15 |
| LASL | RFP | | | | | | | | | |
| LLL | TMR | 100 | S.S.* | | Water or He | 80/100 | | | | |
| MIT | Tokamak | 80 | 15 | | | | | | | |
| | Torsatron | | S.S.* | | | | | | | |
| ORNL | Tokamak | 1775 | 1200 | | Water | 40/150 | | | | |
| | EBT | 500 | S.S.* | | Water | 40/150 | | | | |
| PPPL | Tokamak | 200 | 100 | | Water or He | | | | | |

*Steady State

TABLE 4-4

# MAJOR DEVICE CHARACTERISTICS

EPR

| LAB | CONCEPT | Thermal power generated ($MW_t$) | Burn time sec | Total cycle time sec | Primary coolant type | Pri. coolant temp. in/out °C | Interm loop used | Thermal flywheel (GJ) | Steam conditions | Gross elect output ($MW_e$) |
|---|---|---|---|---|---|---|---|---|---|---|
| ANL | Tokamak | 600 | 300 | 320 | Press. water | 238/340 | no | no | super-heat | 120 |
| LASL | RFP | | | | | | | | | |
| LLL | TMR | | | | | | | | | |
| MIT | Tokamak | | | | | | | | | |
| | Torsatron | | | | | | | | | |
| ORNL | Tokamak | 2260 | 1200 | 1260 | He | 200/500 | yes | 129 | super-heat | 750 |
| | EBT | 2000 | S.S.* | S.S.* | water | 40/150 | no | no | | |
| PPPL | Tokamak | 500 | 600 | 700 | He | | | 450 | super-heat | |

*Steady State

TABLE 4-5

# MAJOR DEVICE CHARACTERISTICS

DEMO

| LAB | CONCEPT | Thermal power generated ($MW_t$) | Burn time sec | Total cycle time sec | Primary coolant type | Pri. coolant temp. in/out °C | Interm. loop used | Thermal flywheel (GJ) | Steam conditions | Gross elect. output ($MW_e$) |
|---|---|---|---|---|---|---|---|---|---|---|
| ANL | Tokamak | 1500 | | | | | | | | 500 |
| GA | Tokamak | 1441 | 106 | 125 | He | 285/585 | no | | super-heat | 374 |
| LASL | RFP | | | | | | | | | |
| LLL | TMR | | | | | | | | | |
| MIT | Tokamak | | | | | | | | | |
| | Torsatron | | | | | | | | | |
| ORNL | Tokamak | 6780* | 1200 | 1260 | He | 200/500 | yes | 129 | super-heat | 2250 |
| | EBT | 2500 | S.S.** | S.S.** | He | 200/500 | yes | no | super-heat | 875 |
| PPPL | Tokamak | 1500 | 1000 | 1100 | He | 360/638 | no | no | super-heat | 500 |

* 3-units at 2260 $MW_t$ per unit

** Steady State

TABLE 4-6

# MAJOR DEVICE CHARACTERISTICS

PROTOTYPE

| LAB | CONCEPT | Thermal power generated ($MW_t$) | Burn time sec | Total cycle time sec | Primary coolant type | Pri. coolant temp. in/out °C | Interm. loop used | Thermal flywheel (GJ) | Steam conditions | Gross elect. output ($MW_e$) |
|---|---|---|---|---|---|---|---|---|---|---|
| ANL | Tokamak | | | | | | | | | |
| GA | Tokamak | | | | | | | | | |
| LASL | RFP | 2980 | 21.6 | 26.6 | water | 150/427 | no | no | super-heat | 1190 |
| LLL | TMR | 2780 | S.S. | S.S. | He | 350/550 | no | no | super-heat | 1000 |
| MIT | Tokamak | 2470 | 425 | 500 | Flibe | 544/580 | | | | 870 |
| | Torsatron | 4860 | S.S.* | S.S.* | | | | | | 1520 |
| ORNL | Tokamak | | | | | | | | | |
| | EBT | | | | | | | | | |
| PPPL | Tokamak | 3000 | 1000 | 1100 | He | 360/638 | no | no | super-heat | 1100 |

*Steady State

The responses given to selected, site-requirement-related questions in the questionnaire by the fusion research laboratories are compiled in matrix form in Tables 4-7 to 4-14. A narrative description of the purpose of each question, summary of the responses, and a brief evaluation is provided.

## 4.1 GENERAL QUESTIONS

The purpose of the questions in this group was to explore:

- *Schedule considerations of the various fusion concepts and development phases
- The reusability of major components in successive experiments
- The method of decommissioning the devices no longer in use
- Siting preferences of the laboratories
- Computer needs
- Manning requirements at the committed site
- *Requirements for removal, disassembly, and maintenance of radioactive components
- The need for diverter in plasma purity control
- *The need for onsite fabrication of magnets and first wall components.

The list above represents all the major headings in the questionnaire, under "General Questions." In the "Concept Characteristics Summary Sheets" (Table 4-7) only selected concept characteristics, marked with asterisks, are tabulated. The following narrative section, however, discusses responses received to all questions.

TABLE 4-7

COMMITTED FUSION SITE STUDY

CONCEPT CHARACTERISTICS SUMMARY SHEET

SYSTEM 1.0 General

SHEET 1 OF 1

| DESCRIPTION OF SYSTEM CHARACTERISTICS | DEV'T PHASE | TOKAMAK | TANDEM MIRROR | EBT | TORSATRON | REVERSED FIELD PINCH |
|---|---|---|---|---|---|---|
| Schedules for Device Construction and Operations<br><br>For Tokamaks the Labs are listed and then year construction commences, year operation begins, and the year the device operation is terminated. | TNS | PPPL - 1983 1986 1991<br>MIT - 1980 1985 1988<br>ORNL - 1985 1990 2000<br>GA - 1983 1989 1999 | 1985 1990 1995 | 1988 1993 2003 | 1983 1986 N.A. | |
| | EPR | ANL - 1980 1985 2005<br>ORNL - 1989 1996 2016<br>PPPL - 1988 1992 2002 | | | | |
| | DEMO | ANL - 1990 1997 2027<br>GA - 1993 2001 N.A.<br>ORNL - 1992 1999 2029<br>PPPL - 1993 1997 2027 | | | | |
| | PROTO | MIT - 2010 2017 2037<br><br>PPPL - 1998 2003 2033 | | | 2015 N.A. N.A. | 1995 2000 N.A. |
| Hot Cell Usage<br><br>Labs state if a hot cell will be used for reactor repairs. These responses are not phase related. | | ANL - NO | NO | YES | YES | YES |
| | | GA - YES | | | | |
| | | MIT - YES<br><br>ORNL - NO | | | | |
| | | PPPL - YES | | | | |
| On Site Magnet Fabrication<br><br>Labs stated if they thought that magnet fabrication would be performed on site. These responses are not phase related. | | ANL - YES | YES | No for all phases | | YES |
| | | GA - YES<br><br>MIT - NO | | No for all phases | | |
| | | ORNL - NO for all phases | | No for all phases | | |
| | | PPPL - YES for all phases | | No for all phases | | |

TABLE 4-8

COMMITTED FUSION SITE STUDY

CONCEPT CHARACTERISTICS SUMMARY SHEET

SYSTEM 2.0 & 3.0 Major Device Characteristics

SHEET 1 OF 1

| DESCRIPTION OF SYSTEM CHARACTERISTICS | DEV'T PHASE | TOKAMAK | TANDEM MIRROR | EBT | TORSATRON | REVERSED FIELD PINCH |
|---|---|---|---|---|---|---|
| Peak Thermal Power (MW)<br>Ranges are given for the Tokamaks<br>Primary Coolant<br>Type - Temp in °C / Temp out °C<br>Ranges are given for the Tokamaks | TNS | 80 - 1775<br>Water 40/150 | 100<br>Water or He 80/150 | 500<br>Water 40/150 | | |
| | EPR | 600 - 2260<br>Water or He 200/500 | | 2000<br>Water 40/150 | | |
| | DEMO | 1441-6780<br>He 200-360/500-638 | | 2500<br>He 200/500 | | |
| | PROTO | 2470-3000<br>He or Flibe 344-360/580-638 | 2780<br>He 350/550 | | 4860 | 2980<br>Water 150/427 |
| Intermediate Loop<br>Is one used?<br>The number in parenthesis is the number of labs responding.<br>Thermal Flywheel<br>Required capacity (CJ) | TNS | | | | | |
| | EPR | Yes (1) No (3)<br>129 | | YES<br>NONE | | |
| | DEMO | Yes (1) No (2)<br>136-387 | | YES<br>NONE | | |
| | PROTO | NO (2)<br>273 | NO<br>NONE | | | NO<br>NONE |
| Steam Conditions<br>Superheat?<br>(YES or NO)<br>Number is parenthesis is the number of labs responding.<br>Gross Electrical Output<br>(MWe) Ranges are given<br>Gross Minus Net Electrical Output<br>(MWe) Ranges are given | TNS | | | | | |
| | EPR | Yes (3) No (1)<br>15-750<br>75-90 | | | | |
| | DEMO | Yes (4) No (0)<br>374-2250<br>67-225 | | NO<br>875<br>45 | | |
| | PROTO | Yes (1)<br>870-1100<br>95-200 | YES<br>1000 | | 1520<br>152 | YES<br>1190<br>190 |

TABLE 4-9

COMMITTED FUSION SITE STUDY

CONCEPT CHARACTERISTICS SUMMARY SHEET

SYSTEM 4.0 Electrical

SHEET 1 OF 1

| DESCRIPTION OF SYSTEM CHARACTERISTICS | DEV'T PHASE | TOKAMAK | TANDEM MIRROR | EBT | TORSATRON | REVERSED FIELD PINCH |
|---|---|---|---|---|---|---|
| Power Distribution System<br><br>The entries are summaries of the material available in this category. | | ANL - No distribution data given except for 180kV-DC for the NBI.<br>GA - Submitted a one line | LLL - No distribution data available. 100kV-DC needed for NBI. | ORNL - No distribution data available. 460V for NBI and 60V for TF coils. | MIT - No distribution data available. | LASL - No distribution data available. |
| | | diagram for the TNS Pump, magnet and NBI requirements were defined.<br>MIT - No distribution data | | | | |
| | | available.<br>ORNL - No Distribution data available.<br>PPPL - Only requirements | | | | |
| | | defined were 120kV and 10kV for the NBI and R.F. heaters. | | | | |
| Type and Capacity of Electrical Energy Storage<br><br>The capacity is given in Gigajoules (GJ). | TNS | MIT - Inductive - 0.5GJ<br>ORNL - MG flywheel - 3.7GJ<br>PPPL - MG flywheel - 10.0GJ<br>GA - Inductive - 0.5GJ | LLL - Stated that MFTF uses 0.01 GJ of storage | No storage required | No storage required | LASL - Homopolar |
| | EPR | ORNL - MG flywheel - 3.7GJ<br>PPPL - MG flywheel - 10.0GJ | | | | |
| | DEMO | ORNL - MG flywheel - 3.7GJ<br>PPPL - MG flywheel - 10.0GJ | | | | |
| | PROTO | ANL - Inductive - 12.0GJ<br>PPPL - MG flywheel - 10.0GJ | | | | LASL - Homopolar - 11.7GJ |
| Rate of Charging and Discharging the Electrical Energy Storage<br><br>Charge (GJ/sec)<br>Discharge (GJ/sec) | TNS | MIT - /0.001<br>GA - 0.5/0.16<br>PPPL - 0.009/0.5 | | | | |
| | EPR | PPPL - 0.009/0.5 | | | | |
| | DEMO | PPPL - 0.009/0.5 | | | | |
| | PROTO | ANL - 1.3/1.3<br><br>PPPL - 0.009/0.5 | | | | LASL - 0.117/0.117 |

# TABLE 4-10

## COMMITTED FUSION SITE STUDY
## CONCEPT CHARACTERISTICS SUMMARY SHEET

SYSTEM 5.0 Plasma Heating

SHEET 1 OF 1

| DESCRIPTION OF SYSTEM CHARACTERISTICS | DEV'T PHASE | TOKAMAK | TANDEM MIRROR | EBT | TORSATRON | REVERSED FIELD PINCH |
|---|---|---|---|---|---|---|
| NBI Operating Characteristics<br><br>NBI requirements listed across the block are for different Tokamak devices. The parameters listed are Particle Energy - P.E. (keV)<br>Power/Unit - Pwr (MW)<br>Accelerated Ion Charge - AIC (positive or negative) | TNS | MIT ORNL PPPL GA<br>P.E. - 120 120 120 300<br>Pwr - 2 13 2-5 4<br>AIC - Pos Pos Pos Neg | LLL<br>P.E. - 200<br>Pwr - 2<br>AIC - Neg | ORNL<br>P.E. - 80<br>Pwr - 10<br>AIC - Pos | MIT<br>P.E. - 120<br>Pwr -<br>AIC Pos | Not Required |
| | EPR | ANL ORNL PPPL<br>P.E. - 180 120 120<br>Pwr - 2.5 13 2-5<br>AIC - Pos Pos Pos | | ORNL<br>P.E. - 120<br>Pwr - 10<br>AIC - Pos | | Not Required |
| | DEMO | GA ORNL PPPL<br>P.E. - 130 120 7.5<br>Pwr - 5 13 7.5<br>AIC - Pos Pos Pos | | ORNL<br>P.E. - 120<br>Pwr - 10<br>AIC - Pos | MIT<br>P.E. - 120<br>Pwr - -<br>AIC - Pos | Not Required |
| | PROTO | MIT PPPL<br>P.E. - 120 7.5<br>Pwr - 12.5 7.5<br>AIC Pos Pos | LLL<br>P.E. - 1200<br>Pwr - -<br>AIC - Neg | | | Not Required |
| R. F. Heaters Operating Characteristics<br><br>R.F. heater requirements listed across the block are for different Tokamak devices. The parameters listed are Frequency - Freq (GHz)<br>Power - Pwr (MW)<br><br>LH is Lower Hybrid Heating frequency which is approximately 3GHz<br><br>* Frequency has not been decided. | TNS | PPPL GA<br>Freq - * LH<br>Pwr - 5-10 4 | | Freq - 70<br>Pwr - 3 | | Not Required |
| | EPR | ANL PPPL<br>Freq - LH *<br>Pwr - 2.5 10-50 | | Freq - 70<br>Pwr - 3 | | Not Required |
| | DEMO | GA PPPL<br>Freq - LH *<br>Pwr - 4 10-100 | | Freq - 70<br>Pwr - 3 | | Not Required |
| | PROTO | PPPL<br>Freq - *<br>Pwr - 10-100 | | Freq - 70<br>Pwr - 3 | | Not Required |
| | TNS | | | | | |
| | EPR | | | | | |
| | DEMO | | | | | |
| | PROTO | | | | | |

TABLE 4-11

COMMITTED FUSION SITE STUDY

CONCEPT CHARACTERISTICS SUMMARY SHEET

SYSTEM 6.0 Magnets

SHEET 1 OF 1

| DESCRIPTION OF SYSTEM CHARACTERISTICS | DEV'T PHASE | TOKAMAK | TANDEM MIRROR | EBT | TORSATRON | REVERSED FIELD PINCH |
|---|---|---|---|---|---|---|
| Steady State Magnet Data<br>Information listed is:<br>Name of magnet<br>Superconducting (S/C) or Normal (N)<br>Voltage and Amperage required | TNS | Toroidal Field<br>PPPL, ORNL, GA, 100V<br>MIT - 100V, 200kA 10kA | Plug Coils and Solenoid Coils both S/C | Toroidal Field<br>S/C | Helical and Helmholz<br>Both are N | No Steady State Magnets |
| | EPR | | | Toroidal Field<br>S/C<br>60V, 25kA | | No Steady State Magnets |
| | DEMO | Toroidal Field<br>GA - S/C<br>GA - 50kA | | Toroidal Field S/C,<br>60V, 25kA | | No Steady State Magnets |
| | PROTO | | | | Helical and Helmholz both are S/C | No Steady State Magnets |
| Steady State Magnet Energy Storage and Dissipation<br>Information listed is the amount of energy stored in the steady state magnets and system is used for energy dissipation. | TNS | ORNL - 10GJ<br>PPPL - 10GJ<br>Both use resistor bank<br>GA - 500MJ | | 1.4GJ | | Not Needed |
| | EPR | 50GJ<br>Resistor bank | | 1.4GJ | | Not Needed |
| | DEMO | 100GJ<br>Resistor bank | | 1.4GJ | | Not Needed |
| | PROTO | 200GJ<br>Resistor bank | | | | Not Needed |
| Pulsed Magnet Data<br>Information listed are:<br>Name of magnet<br>Superconducting (S/C) or Normal (N). | TNS | EF GA<br>Normal S/C | | | | |
| | EPR | | | | | |
| | DEMO | F and S E<br>Normal S/C | | | | |
| | PROTO | | | | | PFC TFC<br>S/C S/C |

TABLE 4-12

COMMITTED FUSION SITE STUDY

CONCEPT CHARACTERISTICS SUMMARY SHEET

SYSTEM 7.0 Vacuum System / 8.0 Cryogenic System

SHEET 1 OF 1

| DESCRIPTION OF SYSTEM CHARACTERISTICS | DEV'T PHASE | TOKAMAK | TANDEM MIRROR | EBT | TORSATRON | REVERSED FIELD PINCH |
|---|---|---|---|---|---|---|
| Vacuum System Requirements<br>Volume to be evacuated ($m^3$)<br>Reactor nominal operating pressure (Torr) | TNS | MIT - 30 $10^{-8}$<br>ORNL - 425 $10^{-8}$<br>PPPL - 450 $10^{-6}$<br>GA - 300 $10^{-8}$ | 500 $10^{-6}$ | 180 $10^{-7}$ | | |
| | EPR | ANL - 400 $10^{-6}$ $10^{-3}$<br>ORNL - 425 $10^{-8}$<br>PPPL - 1000 $10^{-6}$ | | 710 $10^{-7}$ | | |
| | DEMO | ANL - 400 $10^{-6}$ $10^{-3}$<br>GA - 748 $10^{-8}$<br>PPPL - 2000 $10^{-6}$ | | 710 $10^{-7}$ | | |
| | PROTO | MIT - 320 $10^{-8}$<br>PPPL - 3600 $10^{-6}$ | | | | 570 $10^{-3}$ |
| Liquid Helium Refrigeration Requirements<br>1. Refrigeration Power<br>2. LHe Temp. °K<br>3. Flow requirements l/sec<br>4. System used:<br>Forced Flow (F.F.)<br>Pool Boiling (P.B.) | TNS | GA - 48kW 4.5<br>16 P.B.<br>ORNL - 100kW 4.0 F.F. | 4.2 P.B. | 7kW 4.2 P.B. | | |
| | EPR | ANL - 15MW 4.2 P.B.<br>ORNL - 100kW 4.0 F.F.<br>PPPL - 125kW 6.0 F.F. | | 7kW 4.2 P.B. | | |
| | DEMO | GA - 4.7MW 4.2<br>390 P.B.<br>ORNL - 300kW 4.0 F.F.<br>PPPL - 250kW 8.0 | | 7kW 4.2 P.B. | | |
| | PROTO | PPPL - 360kW 8.0 | | | | |
| Liquid Nitrogen Refrigeration Requirements<br>1. Refrigeration Power<br>2. LN temperature<br>3. Flow requirements | TNS | 0.3kW 77.0<br>60 l/sec | | | | |
| | EPR | ORNL - 250kW N.A. N.A. | | | | |
| | DEMO | | | | | |
| | PROTO | | | | | |

TABLE 4-13

COMMITTED FUSION SITE STUDY

CONCEPT CHARACTERISTICS SUMMARY SHEET

SYSTEM 9.0 Radiological Data

SHEET 1 OF 1

| DESCRIPTION OF SYSTEM CHARACTERISTICS | DEV'T PHASE | TOKAMAK | TANDEM MIRROR | EBT | TORSATRON | REVERSED FIELD PINCH |
|---|---|---|---|---|---|---|
| Low Activation Materials<br>Will they be used? | TNS | GA - No<br>ORNL - No<br>PPPL - No | | | | |
| | EPR | ORNL - No<br>PPPL - No | | | | |
| | DEMO | GA - No<br>ORNL - No<br>PPPL - No | | | | |
| | PROTO | PPPL - No | | | | |
| Solid Radioactive Waste<br>How much is generated annually? (kg)<br>Liquid Radioactive Waste<br>How much is generated annually? ($m^3$) | TNS | GA - 100kg<br>GA - 4 $m^3$ | | | | |
| | EPR | ANL - 63,000kg<br>ANL - 8 $m^3$ | | | | |
| | DEMO | ANL - 63,000kg<br>ANL - 8 $m^3$ | | | | |
| | PROTO | | | | | |
| Tritium Inventory<br>Listings of Tritium on site storage. | TNS | ORNL - 10.0kg<br>PPPL - 0.020kg<br>GA - 0.5kg | 1kg | 2kg | | |
| | EPR | ANL - 1.2kg<br>ORNL - 20.0kg<br>PPPL - 0.5kg | | 10kg | | |
| | DEMO | ANL - 1.5kg<br>GA - 2-3kg<br>ORNL - 60.0kg<br>PPPL - 1.2kg | | 20kg | | |
| | PROTO | PPPL - 2.0kg | | | | 12kg |

TABLE 4-14

COMMITTED FUSION SITE STUDY
CONCEPT CHARACTERISTICS SUMMARY SHEET

SYSTEM 10.0 Chemistry/Fuel

SHEET 1 OF 1

| DESCRIPTION OF SYSTEM CHARACTERISTICS | DEV'T PHASE | TOKAMAK | TANDEM MIRROR | EBT | TORSATRON | REVERSED FIELD PINCH |
|---|---|---|---|---|---|---|
| Tritium Breeding and Processing | TNS | | | | | |
| | EPR | ANL - No breeding | Encapsulated Li batch processed | | | |
| | DEMO | ANL - Encapsulated Li batch processed<br>GA - Encapsulated continually processed | | Encapsulated Li batch processed | | |
| | PROTO | MIT - Flowing Li Continually processed<br>ORNL - Encapsulated Li batch processed | | | Encapsulated Li continually processed | $Li_2O$ - Continually processed |
| Fuel Injection Method | TNS | PPPL - Li encapsulated or continuous flow<br>PPPL - Pellet Injection and NBI | NBI and Pellet Injection | | Pellet Injection or Gas Puffing | |
| | EPR | GA - Pellet injection or gas puffing<br>PPPL - Pellet injection and NBJ<br>GA - Pellet injection or gas puffing | | | | |
| | DEMO | PPPL - Pellet injection | | Pellet Injection | | |
| | PROTO | MIT - Gas puffing or pellet injection<br>ORNL - Pellet injection<br>PPPL - Pellet injection | | | Pellet Injection or Gas Puffing | Gas Puffing |
| Fusion-Fission Hybrid<br>Is one planned for the development scenario? | TNS | | | | | |
| | EPR | ANL - Possible<br>GA - Possible<br>MIT - NO | YES | NO | NO | NO |
| | DEMO | ORNL - NO<br>PPPL - YES | | | | |
| | PROTO | | | | | |

The responses given to these questions help evaluate the feasibility of a committed fusion site with respect to scheduling the experiments, exploring the potential savings by reusing some components in successive development phases, potential savings in security systems safeguarding decommissioned devices, clarifying computer needs, accommodating of scientific, engineering, operating and maintenance personnel, and identifying the need for magnet and first wall component fabrication facilities at the committed site.

The response to the question regarding commencement and completion of construction of the devices, assuming funding availability, was as follows:

| | Start Construction | Complete Construction |
|---|---|---|
| Tokamak TNS devices | 1980 to 1985 | 1985 to 1990 |
| Takamak EPR devices | 1980 to 1989 | 1985 to 1996 |
| Tokamak Demo/Prototype devices | 1990 to 1999 | 1997 to 2001 |
| Torsatron TNS device | 1983 | 1986 |
| Reversed Field Mirror Demo device | 1995 | 2000 |
| Tandem mirror TNS device | 1985 | 1990 |
| Elmo Bumpy Torus TNS device | 1988 | 1993 |

The construction and operating schedule of all candidate fusion devices and development stages are indicated in bar-chart form in Figure 4-1.

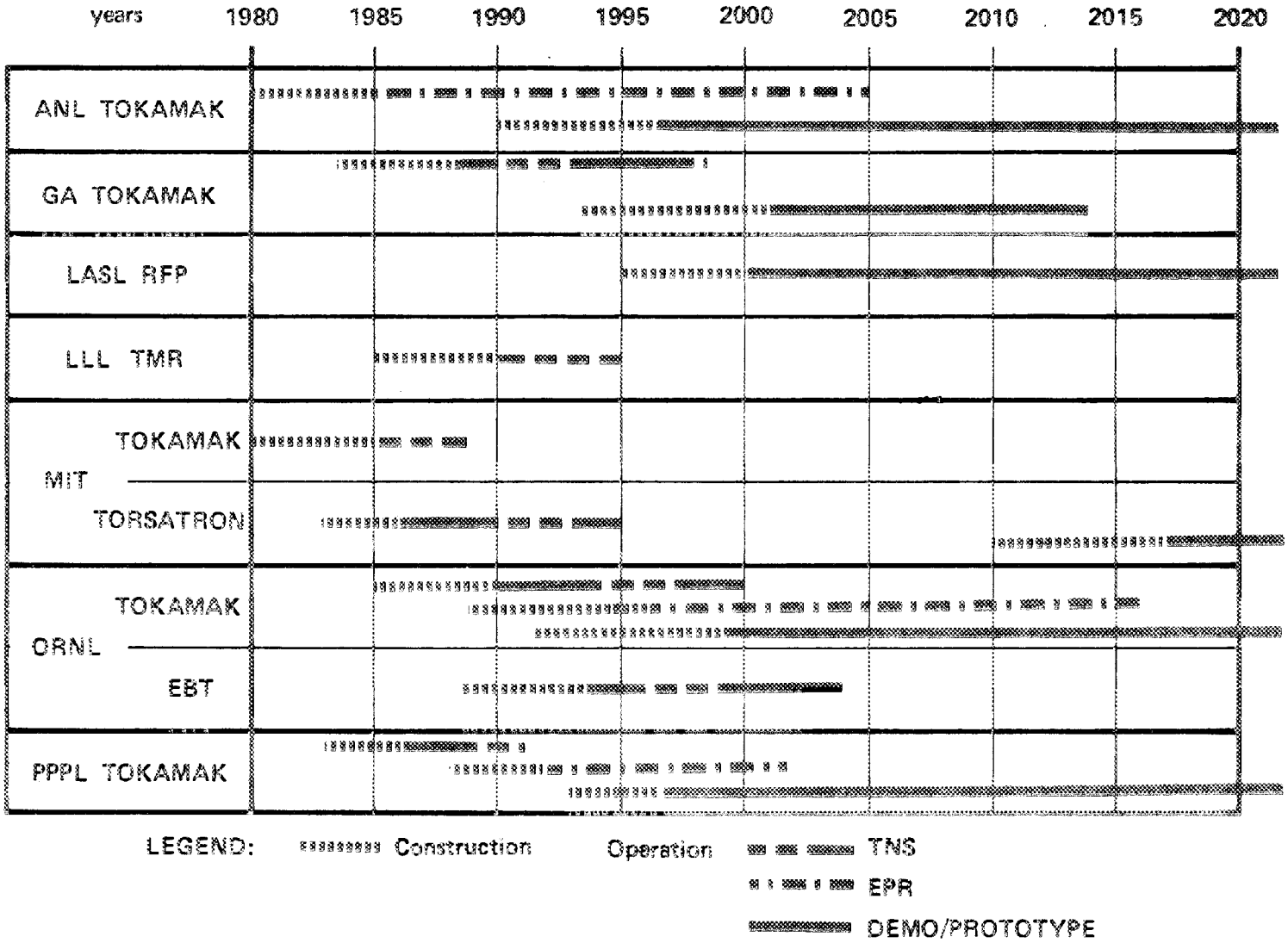


Figure 4-1

CONSTRUCTION AND OPERATING SCHEDULE FOR FUSION DEVICES

Commonalities can be clearly identified in the following areas:

- Most laboratories agree that onsite magnet fabrication facilities are desirable because of the potential transportation problems associated with the shipping of bulky, heavy, magnet components over long distances, and the special equipment and skills needed in winding large, superconducting magnets. A centralized magnet fabrication shop would eliminate the need for duplicating specialized equipment, and would enhance the development of expert operators for this equipment, thus increasing the quality and reliability of the fabricated products.

- All respondents identified the need for real time computer systems for reactor control. Data processing probably can be best handled with onsite computer units also. The onsite full-time computer maintenance technician and programmer staff can increase the reliability of the computer system.

Partial commonality was found in the responses given to questions regarding radioactive component removal and handling. Some concepts employ specially designed, remotely-operated equipment to rebuild the first wall and/or blanket in place, while others utilize hot cells for maintenance operations. In the latter case, the hot cell could be equipped with current state-of-the-art remotely-controlled manipulators, which could serve several types of activated components used in different fusion concepts.

Partial commonality could also be established in the requirement for field fabrication of first wall/blanket components. The opinion of the laboratories was evenly divided, some of them prefering field fabrication, some feeling that these components can be fabricated in offsite shops and shipped in small enough components, thus not creating any transportation problems.

The responses given to the question regarding reuse of components in successive experiments could also be regarded as having partial commonality. All respondents agree on the possibility of reusing neutral beam injectors, radio frequency heaters, power supplies and, perhaps, magnets and shielding components. The multiple use of these components is greatly influenced, however, by the scheduling of the construction and operation of successive, more advanced devices. Most laboratories envision the start of construction of the successive phase devices before the experiments with the preceding device are terminated. If this philosophy is to be adhered to, some duplication of device components seems unavoidable, unless relatively low duty factors in TNS and EPR experiments would permit sharing of power supplies or power supply components. In case of the possibility of substantial improvements in the performance of these components, based on the experience gained during the operation of the preceding phase, the duplication may be justified. Otherwise, the question of duplicating equipment used in the preceding phase in order to gain time, versus adjusting the commencement of operation for the successive phase and reusing components from the preceding phase, deserves a serious economic evaluation.

Responses to the questions regarding siting preferences of the laboratories for the committed fusion site revealed that two of the laboratories (MIT and PPPL) probably cannot accommodate even smaller TNS or EPR devices. The rest of the laboratories are capable of siting TNS and EPR size devices at their existing

facilities. The general feeling of the respondents was that demonstration and prototype size fusion devices would most likely be best operated by utilities.

The method of decommissioning devices which are no longer in use, is not clear at this time. Most respondents indicated that they are planning to disassemble the obsolete devices, some indicated the possibility of entombment. In the latter case, the committed site could offer some economic advantages in reduced security system costs associated with the control of the area where the decommissioned units are located. The method of decommissioning does not appear to have a great significance on the feasibility of the committed site, however.

Essentially no planning has been done by the laboratories regarding the number of scientists, engineers, technicians, maintenance personnel, and administrators required at the committed site for the operation of the fusion devices. Few laboratories responded to the question. The estimates were in the order of 500 or more people.

The responses given to the questions of a general nature are adequate for the evaluation of the feasibility of a committed fusion development site. As the study progresses, it may be necessary to contact the laboratories again or search other available sources for specific information not covered in

sufficient detail during the Task 100 activities; or else to answer new questions that may arise during subsequent tasks.

## 4.2 REACTOR DATA

The purpose of this group of questions was to gain an insight of the basic operating parameters of the candidate fusion concepts and development phases.

The questions covered the following reactor characteristics:

- Main dimensions
- List of components interchangeable with other fusion devices
- *Peak thermal power generated
- Burn time
- Total cycle time
- Use of direct converter
- Gross electrical output
- Net electrical output

The list above represents all the major headings in the questionnaire, under "Reactor Data." In the "Concept Characteristics Summary Sheet" (Table 4-8), only the selected concept characteristic, marked with asterisk, is tabulated. The following narrative section, however, discusses responses received to all questions.

Responses to this group of questions help define whether a single confinement structure would be practical to accommodate several devices in subsequent development phases, or whether separate structures would have to be built for each candidate concept. The responses also provide information helpful in examining the interchangeability of components of common functions between devices. Examination of other device characteristics help to identify common features which could possibly be served by shareable service systems or facilities.

### 4.2.1 Buildings

Analysis of the responses shows commonality in confinement size for tokamak EPR size devices, requiring an approximately 50 meter square, or 55 meter diameter circular building, 35 meter high. This size building will accommodate the reactor and neutral beam injectors or RF heaters. Auxiliary equipment could be placed at the lower levels, between the reactor and the outside wall. Although no information was received on building size requirements for TNS size tokamak devices, it seems reasonable to assume that the confinement designed for EPR size requirements will accommodate the TNS size devices also. The power supply most likely will be located in an adjacent, but separate, building.

The TNS and EPR devices for other concepts would require separate buildings, mainly because of the differences in overall geometry. The tandem mirror device, due to its linear, rather than circular shape, and the Torsatron and EBT devices due to their doughnut shape geometry would most likely impose building shape and service requirements which cannot easily be accommodated in a structure designed to satisfy tokamak specifications.

### 4.2.2 Confinement Structure

The confinement structure would have to be accompanied by other auxiliary structures, like control building, maintenance and storage facilities, tritium handling and storage, cryogenics and helium storage facilities, maintenance hot cells, power supply facilities, vacuum system facilities, and others required for the testing and operation of fusion devices in the power generating stage. Some of the service systems located in these auxiliary structures may be shareable, operation schedule and duty factor permitting.

Several respondents gave dimensions for a demonstration/prototype size plant. Princeton's demonstration size tokamak would probably require a 65-meter diameter, 50-meter high space for the reactor and either neutral beam injectors or RF heaters alone.

The Los Alamos reversed field pinch prototype plant would require a 90-meter diameter, 50-meter high structure to house the reactor and all the auxiliary equipment.

The Lawrence Livermore's tandem mirror prototype plant would require a structure 130 meters long, 100 meters wide, and approximately 30 meters high to house the reactor, all its auxiliaries, excluding the building space required for the direct converters and turbine generators.

The Elmo-Bumpy Torus prototype plant would require a 75-meter O.D., 45-meter I.D., 35-meter high doughnut-shape ring structure to house the reactor alone. Auxiliaries are placed in separate buildings, partially inside, partially outside of the reactor ring.

MIT's Torsatron prototype would also be housed in a doughnut shape containment structure with an outside diameter. approximately 160 meter.

Responses given to other questions in this group enhance the understanding of the operation of the candidate fusion devices. They are not essential for the evaluation of the feasibility of a committed fusion site, but helpful in comparing operating parameters of the various fusion concepts. Generally, the responses received to this group

of questions are considered adequate for the preliminary establishment of characteristics of a committed fusion site.

## 4.3 HEAT BALANCE DATA

The purpose of the questions in this group was to establish requirements for power generating and heat rejection equipment. Heat rejection will be required in all development phases. Power generation is an objective in the EPR, Demonstration, and Prototype devices.

The information requested was:

- Heat balance diagram for each phase, where applicable
- Number of heat transport loops
- *Type of cooling
- List of heat loads
- *Necessity of intermediate heat transfer loop
- *Thermal flywheel requirement
- *Steam cycle conditions

The list above represents all the major headings in the questionnaire, under "Heat Balance Data." In the "Concept Characteristics Summary Sheet" (Table 4-8), only selected concept characteristics, marked with asterisks, are tabulated. The following narrative section, however, discusses responses received to all questions.

Responses to the questions in this group provide an indication of the possibility of sharing power generating and heat rejection systems and equipment. Any sharing would have to be between different concepts in the same development phase.

Most of the respondent laboratories have not defined the heat balance, power generating, and heat rejection requirements to any detail. Some commonality of the stated requirements could be developed, however.

Most respondents stated that they are planning to use superheated steam; most employed helium as primary coolant and most were not planning to utilize an intermediate heat transport loop.

Responses, giving gross electrical output for EPR devices vary from 15 MWe to 750 MWe, two using saturated and one superheated steam cycles. Demonstration size devices have a gross electrical output ranging from 374 MWe to 2,250[1] MWe, and most use superheated steam.

The range of electrical output for prototype devices vary from 870 MWe to 1520 MWe. All respondents stated that their prototype will use a superheated steam cycle.

The responses given to this group of questions clearly point out the need for coordination in device electrical output capacity

[1] 3-units at 750 MWe per unit.

and in the steam cycle area. Provided that such coordination through managerial action is practical, a single heat rejection system can be shared by all TNS devices and single power generating and heat rejection system constructed on the committed site should be able to serve all candidate fusion devices in the EPR phase, operating schedule and duty factors permitting. The Prototypes and probably the demonstration plants would operate too long to share these systems.

## 4.4 ELECTRICAL SYSTEM

The purpose of this group of questions was to define the electrical power distribution system. The information requested was arranged such that if an electrical distribution system has not been developed, then a summation of partial listing of major load requirements could establish the basic electrical system characteristics.

The information requested was:

- Single line diagram of the electrical power distribution system for major loads and criteria for design
- *Electrical requirements for major electrical equipment
- *Type and capacity of electrical energy storage system
- Load profile diagram for pulsed loads

The list above represents all the major headings in the questionaire under "Electrical." In the Concept Characteristics

Summary Sheet (Table 4-9), only selected concept characteristics marked with asterisks are tabulated. The following narrative section discusses responses received to all questions.

Responses to this group of questions will be utilized to assess the feasibility of using a central electrical distribution system or reusing all or part of the electrical system components for subsequent experiments. They will also be helpful to consider the practicality of a fully or partially centralized electrical distribution system at the committed fusion development site.

There are three electrical distribution subsystems which are common to any fusion device;

- ac distribution
- dc distribution
- Pulsed energy distribution

The following paragraphs discuss these subsystems and any requirements identified by the laboratories. AC distribution systems needed for EPR's and demonstration and prototype plants are essentially the same as for any nuclear power generating plants of equivalant generating capacity. The ac system required for the TNS devices is generally smaller and less extensive since fewer and smaller motors, and other electrical equipment are used. The ac system will also supply a large dc system for any concept or development phase. This is a major difference between fusion devices and existing fission nuclear plants.

The dc system will supply the power for steady state magnets, and in some designs, the NBI's. NBI's which operate in a steady state mode such as the tandem mirror reactor, will operate directly on the dc system. NBI's which are cycled on and off will probably be supplied by the pulsed electrical energy system. The dc superconducting magnets require low voltage (<100V charging, 50GJ; <1V steady state) and high current (25-200kA). The NBI's use very high voltage (100-280kV) and low current (few hundred Amps). All concepts have a heavy requirement for dc and as generating capacity increases, the dc requirements increase proportionally.

The pulsed electrical energy storage system supplies power to cyclic loads, e.g. pulsed magnets, NBI's, and R.F. heaters. This system consists of an electrical energy storage device and a pulse forming network. Motor-generator flywheel and inductive storage units are the two energy storage devices most often listed by the Laboratories. Homopolar generator and capacitive storage systems are also being considered, but to a lesser extent.

The EBT, tandem mirror, and the Torsatron have little or no requirement for an electrical energy storage system since they are steady state machines. The tokamak and Reversed Field Pinch have large electrical energy storage requirements. The capacity requirements for the tokamaks range from 0.1 to 12 GJ. The capacity requirements increases with the size of the device.

LASL listed 11.7 GJ for their prototype which is the same magnitude as the tokamak. The charge and discharge rate requirements for storage devices vary widely with the particular concept.

The power supply for the electrical energy storage system will be from either the ac or dc systems depending on the storage unit. The prime mover for either the flywheel or homopolar generator will probably be an induction motor which requires ac power. The inductive or capacitive storage will be on the dc system. The electrical specifications for inductive storage devices which are superconducting will not be the same as for the superconducting steady state magnets used in the fusion devices. High voltages (< 50kV) will be needed and hysteresis losses must be minimized.

No details were given for ac distribution system, but assuming there will be very few differences between any fusion device and a comparable size existing fission nuclear power plant, then all the ac systems will be basically the same. It remains to be studied to what extent an ac system can be centralized or shared and what economic advantages can be derived. Several scenarios and tradeoffs have to be examined.

The dc systems are also about the same for all the devices. Here again, it is likely that the systems could be centralized and reused. Large line losses occur when transmitting low voltage, high current dc. Rectifying systems may not be large expense

items and could be located close to the magnet. Advantages and disadvantages as they apply to the various scenarios have to be investigated. The storage devices are similar and could possibly be centralized.

Some of the laboratories integrated the electrical energy storage system into the pulse forming network of the pulsed loads. Using this arrangement, a centralized storage unit is not possible. ANL has developed another approach wherein one storage unit can supply several different loads. They use a superconducting coil for electrical energy storage, which serves several pulse forming networks to produce the required wave form for their associated load.

Since this method seems to be suitable for providing the electrical power needs for more than a single unit, or device, it will be further investigated in subsequent tasks of this study.

To further evaluate the possibility of centralizing the ac system, some assumptions have to be made regarding the requirements at a committed fusion site. These assumptions will be made based on past experience in nuclear power plant design adjusted to the identifiable specific needs of fusion devices. Relative costs of large, centralized systems will be compared with smaller, local systems. The possibility of designing a flexible system which can grow with increased demand will also be evaluated.

The same approach will be used for the dc system. With the dc requirements of the magnets and NBI's partially identified, more concrete data will be available and fewer assumptions will have to be made.

The possibility of centralizing a pulsed storage system will require more research and discussion with laboratories.

All assumptions will be discussed with the laboratories to determine if they are compatible with their fusion plant as they conceive it now.

The emergency power supply system will be reviewed to determine if centralizing is possible and if it has economic advantages. It will be determined if one diesel generator set for each device or one large common diesel generator plant will be more practical and economical.

## 4.5 PLASMA HEATING

The purpose of this group of questions is to determine the methods of plasma heating that the laboratories are planning to use in their candidate fusion concepts. This information will allow evaluation of how the selected plasma-heating methods might influence site requirements and if sharing or transfer of equipment between projects is possible.

The questions in this group covered the following topics:

- *Neutral Beam Injectors
- Possibility of modularization of neutral beam injector components
- *Radio frequency heaters
- Possible interchangeability of RF heater components between units

The list above represents all the major headings in the questionnaire, under "Plasma Heating." In the "Concept Characteristics Summary Sheet" (Table 4-10), only selected concept characteristics, marked with asterisks, are tabulated. The following narrative section, however, discusses responses received to all questions.

The method of plasma heating influences the feasibility of a committed fusion site only if it can be established that one kind of plasma-heating system can serve several devices in practically all development phases.

Based on the responses, it is believed that, when planned for, neutral beam injectors can be transferred from device to device, either as a complete unit or as components (power pack, beam source, accelerator grids).

Partial commonality was found in particle energy and ion acceleration used. Most of the laboratories require 120 keV particle energy and positive ion acceleration. Only Princeton's

tokamak and Lawrence Livermore's tandem mirror concepts indicated need for higher particle energy level and negative ion acceleration. Neutral beam technology development is just getting underway. There is a great divergence of opinion as to just what requirements are desired or can be achieved.

It is conceivable that after some coordinating activity and managerial action, a standardized neutral beam injector could be developed. This unit most likely would be able to serve all concepts which are contemplating using neutral beam injection for plasma heating.

Fewer concepts are planning to use radio-frequency heaters for plasma heating. Again, this is a new concept scarcely out of the preliminary laboratory stage. There is significant difference in operating frequency between devices. The remark about the desirability of standardization in the preceeding paragraph is applicable for the RF heaters also.

The method of plasma heating has only indirect effect on site characteristics. On that basis, the responses received to this group of questions, are considered adequate.

## 4.6 MAGNETS

The purpose of this group of questions was to explore what special services and systems are required for the operation of

the magnets in the fusion devices.

The questions in this group covered the following topics:

- *Magnet types (superconducting, normal)
- *Stored energy in magnets
- *Energy dissipation methods
- Cooling of magnets

The list above represents all the major headings in the questionnaire under "Magnets." In the "Concept Characteristics Summary" (Table 4-11), only selected concept characteristics, marked with asterisks, are tabulated. The following narrative section, however, discusses responses received to all questions.

Commonality was found in that most devices use magnets that are superconducting, and require extensive cryogenic systems. The shape of the magnets show a great variation from concept to concept, excluding the possibility of interchanging them between the various concepts. All concepts use steady state magnets for plasma confinement; the tokamaks and Reversed Field Pinch concepts utilize pulsed magnets for plasma heating. Power supplies for the steady state magnets may be identical for several concepts; the pulsed ones require unique power supplies, designed for their specific needs.

Each magnet system requires an energy dissipation device to dump the energy stored in the magnets in case of an emergency. The

amount of energy stored in the magnets is in the gigajoule range. Resistor banks were mentioned by the respondents as a means of energy dissipation. It is conceivable that a single, appropriately sized energy dissipation system could serve several devices.

A common cooling system could be shared by several devices, which use normal, nonsuperconducting magnets.

The responses given to the questions in this group are considered to be adequate for the evaluation of the feasibility of a committed fusion development site.

## 4.7 VACUUM SYSTEM

The purpose of this group of questions was to establish vacuum system requirements.

The questions in this group covered the following topics:

- *Volume of space to be evacuated and nominal operating pressures
- Type and rating of mechanical vacuum pumps
- Type and rating of other vacuum pumping systems

The list above represents all the major headings in the questionnaire, under "Vacuum System." In the "Concept Characteristics Summary Sheet" (Table 4-12), only the selected concept characteristic, marked with a asterisk, is tabulated. The following narrative section, however, discusses responses received to all questions.

The responses indicated that design of the vacuum systems has not progressed far enough to provide definitive requirements. The few responses received show the volume to be evacuated is in the 300 to 500 cubic meter range. Vacuum requirements vary from $10^{-6}$ torr to $10^{-8}$ torr. As to pumping equipment, roots blowers, diffusion pumps, and cryo pumps were mentioned by the respondents.

The possibility of sharing vacuum systems among the various concepts and development phases is most likely to be limited to the roughing pumps. GA feels that sharing vacuum systems may be questionable due to the problems arising from radioactive contamination.

Since the vacuum systems used by various fusion concepts have no great influence on site requirements, the responses received - no matter how sketchy - are considered adequate for the evaluation of the merits of a committed fusion site.

## 4.8 CRYOGENIC SYSTEMS

The purpose of this group of questions was to establish cryogenic system requirements for the candidate fusion concepts and development phases.

The questions in this group covered the following topics:

- Liquid helium demand
- Liquid helium loads, temperature, pressure, and flow rates
- Liquid nitrogen, refrigeration, power, and temperature
- Liquid nitrogen loads and flow rates

The answers to the questionnaire are tabulated in Table 4-12. Engineering work on which refrigeration requirements are based was very preliminary and there were no details. This is true for almost all concepts and development phases. Responses to the questionnaire were limited to approximate temperature requirements for the liquid helium and nitrogen. In some instances refrigeration power requirements were given and a preliminary decision made on whether pool boiling or forced flow will be used in cooling the magnets.

Based on these very preliminary parameters and discussions with the laboratiories, it appears that a central refrigeration plant at a committed site could be used to supply a bank of dewars

located at the devices. The dewars in turn would supply the refrigerant to the magnets. An engineering/economic evaluation should determine if a large central refrigeration plant can be installed and operated more economically than smaller, individual units. The refrigeration load will be very large in all concepts and economics may require that integrated on-line refrigerator systems be used rather than batch liquid transfer.

The responses are considered adequate for the purpose of evaluating merits of a committed site.

## 4.9 RADIOLOGICAL DATA

The purpose of this group of questions was to determine the amount of radioactive waste produced by the candidate fusion concepts and development phases, and the method of handling and disposal of these wastes.

The questions in this group covered the following topics:

- *Use of low activation materials in reactor design
- *Amount of radioactive liquid wastes generated annually
- *Amount of radioactive solid wastes produced annually

- Onsite storage of radioactive waste
- Radiation level inside containment
- *Amount of tritium stored on-site

The list above represents all the major headings in the questionnaire under "Radiological Data." In the "Concept Characteristics Summary Sheets" (Table 4-13), only selected concept characteristics, marked with asterisks, are tabulated. The following narrative section, however, discusses responses received to all questions.

These questions have received little or no attention in preliminary fusion reactor design work to date.

The only meaningful response to this group of questions was that few of the respondents are planning to use low activation materials in their reactor design. GA indicated that low activation materials will be used where their use is justified. Consequently, radiation level during maintenance shutdowns will be high and remote maintenance will be required. Radioactive first wall/blanket components, which have to be replaced at relatively short intervals (3 to 5 years) represent a large amount of highly radioactive solid waste which require special handling equipment and storage facilities.

Onsite tritium storage does not seem to represent any problem and will not significantly effect the feasibility of a committed site.

The radiological aspects of the fusion devices, and their effect on the feasibility of a committed site, will be further investigated in subsequent tasks of this study.

## 4.10 CHEMISTRY/FUEL

The purpose of this group of questions was to determine the method, equipment, and facilities needed for fuel breeding, device fueling, and exhaust gas handling.

The questions in this group covered the following topics:

- *Fuel breeding and processing
- *Method of device fueling
- Exhaust gas handling
- *Fusion-fission hybrid reactor option

The list above represents all the major headings in the questionnaire under "Chemistry/Fuel." In the "Concept Characteristics Summary Sheets" (Table 4-14) only selected concept characteristics, marked with asterisks, are tabulated. The following narrative section, however, discusses responses received to all questions.

The responses to these questions provide the basis for conceptualization of a central fuel and exhaust gas processing facility capable of serving the devices for several fusion concepts and/or development stages.

Almost all EPR, demonstration, or prototype devices have the capability of breeding tritium. TNS devices do not have the capability of breeding tritium. As to processing the bred tritium, half of the respondents visualize batch processing of encapsulated tritium, while the other half contemplate continuous flow processing. Batch processing particularly lends itself to being performed in a central processing facility, which could be shared by several fusion devices in all development phases.

A centralized facility does not seem to be practical for continuous flow processing, since the piping carrying the radioactive lithium would have to leave the confinement building. Each device using this method will have its own processing plant, located inside the confinement structure.

A question regarding the fueling method of the devices was raised to determine whether fueling equipment, or components of it, can be made sharable. The respondents indicated three types of fueling:

- Gas puffing
- Pellet injection
- Neutral beam injection

Of these, pellet injectors and neutral beam injectors could be made in such a way that they can be used in several devices interchangeably, or, have interchangeable components.

Some tokamak devices (MIT's for example) would have to handle some 50 grams of exhaust gas every 500 seconds. This gas must be handled at a high rate to limit cycle downtime. Radioactive exhaust-gas handling equipment should be located inside the confinement building despite the fact that some respondents felt that exhaust gas handling equipment could be placed in a separate structure and shared. GA feels that this sharing is objectionable.

Two respondents indicated interest in a fusion-fission hybrid reactor as part of their reactor development scenario. There are special site requirements associated with this concept. A limited assessment of these requirements will be made during subsequent phases of the present study.

# 5.0 BASELINE SITE REQUIREMENTS

The responses received to the "Concept Design Information Questionnaire" and their review performed during Task 100, enables us to assess the activities and the sequence necessary to establish a committed fusion development site.

The list of these activities, which follows, is based on the assumption that the selection of the committed site could be heavily influenced by the criteria, rules, and regulations currently in force for granting construction permits for fission reactors. It is further assummed that the design of structures and service systems will be governed by codes, industrial standards, and government regulations generally applicable for the design of fission reactor plants. Special safety and licensing issues unique to fusion reactors, however, will be addressed in subsequent tasks of this study.

The list is believed to be general enough to cover the requirements for any candidate fusion concept and all postulated development phases. The listed activities will result in the establishment of a self-sufficient, complete fusion development site, including scientific, engineering, administrative, and maintenance support. Requirements for other scenarios will be investigated in subsequent tasks of this study.

The necessary activities to be performed in order to establish the committed fusion development site shall include, but are not limited to, the following:

5.1 ACQUISITION OF LAND, SELECTED AND CERTIFIED FOR THE CONSTRUCTION AND OPERATION OF A NUCLEAR FACILITY

5.2 PROVISION FOR ACCESS TO THE SELECTED LAND, BY:

5.2.1 Plant access road, connecting the selected site to the nearest State Highway

5.2.2 Railroad spur, connecting the site with the nearest major railroad line

5.2.3 Barge unloading facility, built on the nearest navigable waterway

5.3 PROVISION FOR AREA SECURITY STSTEM CONSISTING OF:

5.3.1 Fencing

5.3.2 Vehicular and personal access gates

5.3.3 Guard houses

5.4 PROVISION FOR SITE IMPROVEMENTS:

5.4.1 Rough grading and drainage including clearing undesirable vegetation, demolition of existing, nonuseable structures, cutting and filling to the designed plant grade, and providing flood protection by establishing major area drainage

5.4.2 Establish preliminary plant road system suitable for the construction period

5.4.3 Provision for temporary electric powerline and transformer suitable for needs during the construction period

5.4.4 Provision for potable water supply system, sized for the demands during construction

5.4.5 Establish sanitary sewer collection and treatment system, sized for needs during construction

5.5 CONSTRUCTION OF STRUCTURES:

5.5.1 Nuclear Island Structures:

5.5.1.1 Reactor Confinement Structure, Including:

- o Reactor chamber
- o Radwaste cells
- o Vacuum pumps (finishing)
- o Neutral beam injector, or RF heater cells
- o Liquid helium dewar cells
- o Hot cells with remote controlled equipment
- o Material handling equipment (cranes, manipulators, etc.)
- o D-T reprocessing area

5.5.1.2 Control building, housing reactor control, and data processing equipment

5.5.1.3 Magnet power supply building

5.5.1.4 Tritium processing and storage building

5.5.1.5 Cryogenic refrigeration building, including helium storage facilities

5.5.1.6 Vacuum building

5.5.1.7 Lithium storage and handling building

5.5.1.8 Energy dissipation building, housing equipment required for dissipation of energy stored in the magnets

5.5.2 Balance of plant structures:

5.5.2.1 Administration and engineering building: including change house, health physics, reproduction facilities, meeting rooms, educational facilities, and security facilities

5.5.2.2 Fire house

5.5.2.3 Laboratories including chemical, physics, materials testing, photo, and miscellaneous laboratory facilities

5.5.2.4 Shops, including mechanical, electrical, instrumentation, carpentry, painting, and miscellaneous shop facilities

5.5.2.5 Mock-up building

5.5.2.6 Magnet fabrication, assembly, and testing building

5.5.2.7 Warehouse

5.5.2.8 Steam generating building

5.5.2.9 Turbine building

5.5.2.10 Main switchgear building

5.5.2.11 Circulating water inlet structure and pumphouse

5.5.2.12 Cooling towers

5.5.2.13 Evaporation pond (if applicable)

5.6 ESTABLISHMENT OF PROCESS SERVICE SYSTEMS

5.6.1 Electrical

5.6.1.1 Main substation, providing electrical interface between the utility grid and the fusion site

5.6.1.2 Plant switchyard

5.6.1.3 Plant electrical distribution system

5.6.1.4 Uninterruptable plant emergency electrical system

5.6.1.5 Magnet power supply system

5.6.1.6 Neutral beam or RF heater power supply system

5.6.1.7 Energy dissipation system

5.6.2 Water supply

5.6.2.1 Circulating water system

5.6.2.2 Other plant process water system

5.6.2.3 Fire water system

5.6.2.4 Plant domestic water system

5.6.3 Vacuum system

5.6.3.1 Roughing vacuum system

5.6.3.2 Finishing vacuum system

5.6.4 Cryogenic system

5.6.4.1 Liquid helium receiving and storage system

5.6.4.2 Cryogenic plant system

5.6.4.3 Liquid helium distribution system

5.6.4.4 Dewar system

5.6.4.5 Liquid nitorgen system

5.6.5 Radwaste handling system

5.6.5.1 Gaseous radwaste processing and storage system

5.6.5.2 Liquid radwaste processing and storage system

5.6.5.3 Solid radwaste processing and storage system

5.6.6 Plasma purity control system

5.6.6.1 Diverters

5.6.6.2 D-T reprocessing system

5.6.7 Lithium system

5.6.7.1 Lithium receiving and storage system

5.6.7.2 Lithium distribution system

5.6.7.3 Lithium sampling and purity control system

5.6.8 Tritium system

5.6.8.1 Tritium process system

5.6.8.2 Tritium storage system

5.6.9 Plant atmosphere control system

5.6.9.1 Plant space heating system

5.6.9.2 Plant ventilation system

5.6.9.3 Plant air conditioning system

5.6.9.4 Plant air born contamination clean-up system

5.6.10 Plant control system

5.6.10.1 Plant control computer system

5.6.10.2 Data processing system

5.6.10.3 Plant security control system

5.6.11 Steam generation system

5.6.11.1 Primary heat transport system including intermediate heat exchangers and primary heat transport pumps, if applicable

5.6.11.2 Intermediate heat transport system, if applicable

5.6.11.3 Steam generation equipment

5.6.11.4 Intermediate heat transport media circulating pumps, if applicable

5.6.12 Power generation system

5.6.12.1 Turbine generator, including all piping, pumps, condensing, and auxiliary power generation equipment

5.6.12.2 Main switch gear equipment

5.6.13 Plant maintenance system

5.6.13.1 Reactor maintenance system

5.6.13.2 Remotely controlled maintenance equipment in hot cells

5.6.13.3 Shop equipment for:

- Magnet fabrication shop
- Mechanical shop
- Electrical shop
- Instrumentation shop
- Carpentry shop
- Paint shop

5.6.13.4 Mobile maintenance equipment:

- Trucks
- Forklifts
- Mobile cranes

5.6.14 Laboratories

5.6.14.1 Laboratory equipment for:

- Tritium laboratory
- General chemical laboratory
- Materials testing laboratory

# 6.0 CONCLUSIONS

Task 100 was the information gathering phase of the Committed Fusion Site Study.

The design information the fusion research laboratories were able to supply was generally in line with the depth of the development effort it was based on; some areas were covered in substantial detail, while others were based on best estimates only. Considering the early stages of development for all fusion concepts, the information received could be regarded as the best available at this time. In general it can be concluded that the information gathered during Task 100 is adequate for the assessment of the feasibility of a committed fusion development site. However, there may be some specific areas identified during later phases of the project that will require additional assessment or technical information beyond that obtained in this task.

## 6.1 FURTHER WORK

There are several areas where further work is necessary for the demonstration of the potential benefits of a committed fusion development site which can already be identified. These are:

- Construction and operation of the candidate fusion devices must be carefully planned. It must be decided whether one or more tokamaks will be built, what kind and how many other devices will

be built, and in what sequence the various devices are to be constructed and operated at the committed site. A timely decision regarding these questions would keep the flexibility requirements for the service systems within reasonable limits, and set the boundaries for the design margins which must be incorporated into the design of the site facilities.

- Benefits which the committed site concept may offer can be increased if the design of devices and device components is performed with the committed site in mind. Some areas where this is expected to be particularly beneficial, are:

  - Site electrical distribution system
  - Device power supply system
  - Electrical energy storage system
  - Magnetic energy dissipation system
  - Heat rejection system
  - Radioactive waste handling and storage system
  - Process and cooling water system
  - Maintenance facilities

- Further benefits can be achieved by standardizing systems or components common to several devices. Some candidates for standardization are:

  - Neutral beam injectors or neutral beam injector system components
  - Refrigeration system
  - Vacuum system
  - Fluid system equipment: valves, pumps, etc.

Aside from the direct benefits of using standardized systems and components in several devices, the requirement for maintaining fewer spare parts and simplifying maintenance are supplemental advantages of standardization.

## 6.2 POTENTIAL PROBELMS AREAS

The economic advantages of the committed site are greatly influenced by the scheduling of construction and operation of the fusion devices. If maximum economic benefits from the reuse of equipment and facilities are to be achieved, the experiments and/or operations at the committed site must be carefully sequenced. While construction of the subsequent device may proceed during the operation of the preceeding device, the operation of it must follow completion of the experimental program of the preceeding device. This sequencing offers the optimum utilization of the service systems and shareable equipment, but it may not be satisfactory from the overall scheduling viewpoint of fusion development. If, on the other hand, the simultaneous operation of two or more devices is a mandatory requirement, the capacity of the service systems must be designed to satisfy the increased demand, and the economic advantage of utilizing single components and systems in more than one device, is at least partially lost.

Another potential problem area is the danger of obsolescence of the service systems at the committed site. Since the development of the fusion concepts is in its early stage, setting the requirements for the service systems based on present or near term fusion technology may require the upgrading or even complete replacement of some service systems as the evolution of fusion concepts progresses.

Subsequent tasks in the present effort will provide the basis for the evaluation of the merits of a committed fusion site and highlight areas of uncertainty, need for more detailed future analysis, and problem areas, if any, which may influence the preliminary conclusions of the Task 100 effort.

APPENDIX B

TASK 200

INTERIM LETTER REPORT

# EVALUATION OF A COMMITTED FUSION SITE

MARCH, 1979

BY

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# 1.0 INTRODUCTION

Task 100 was the information gathering phase of the "Evaluation of a Committed Fusion Site" study.

During Task 200, the responses received to the "Concept Design Information Questionnaire" were analyzed in greater detail in order to develop the requirements and characteristics for a committed site.

In this second Interim Letter Report, the requirements for the committed site imposed by the different fusion concepts and their phases of development are defined.

Budget and schedule constraints set the depth of the investigation. The availability of technical information it is based on places some limitations on the conclusions. Therefore, as the development of fusion concepts progresses, the conclusions of the present effort should be reviewed, reevaluated, and modified, as appropriate.

Where the available information was not adequate for the establishment of site requirements, assumptions were made. Wherever this was the case, the assumption was clearly identified as such.

The objective of Task 200 is to develop the site requirements for a committed fusion development site. In achieving this

objective, the information gathered during Task 100 was analyzed in greater depth. Special emphasis was given to determining the common requirements of the different fusion concepts and their development phases. The shareability of site facilities and common service systems were explored in light of the likely site development scenarios. The number of possible site development scenarios, considering that the fusion development laboratories reported development work on five tokamak devices and four alternate fusion concepts, could be quite large. From all possible combinations of the site development scenarios, several believed to be representative and most likely to form an envelope of requirements, are discussed.

Licensing requirements and issues were addressed to the extent the available technical information warranted.

The technical information that the conclusions of this report are based on is by no means complete nor does this report represent the final word. The collected information is augmented by assumptions based on previous experience in light water reactor or liquid metal fast breeder reactor plant design. Ongoing or future advancements in fusion reactors may, in places, alter the information used in this report. When this happens, the reevaluation of the conclusions reached herein is in order. It is felt, however, that future progress in fusion reactor technology will not significantly affect the viability or practicality of the development of a committed fusion site.

## 2.0 TECHNICAL APPROACH

The technical approach adopted to achieve the objectives of Task 200 was to review and evaluate the responses to the "Concept Design Information Questionnaires" in Task 100 and augment them with assumed requirements based on available technical literature and previous experience, when appropriate. Then, on these bases, develop the site requirements for each fusion concept andment phase will be developed.

Site facility interface requirements were determined mainly based on assumptions, since little or no information was available in this area from the fusion research laboratories.

Site development scenarios discussed in this Letter Report were selected to represent scenarios that might reasonably be expected. They were considered to be typical of scenarios that might offer economic and/or technical advantages for the overall development program of commercial-size, power-producing fusion reactors.

Postulated licensing requirements and issues were identified based on Bechtel's extensive experience in licensing light water reactor plants with due consideration of the known special licensing issues of fusion devices. Since safety regulations and licensing requirements for fusion facilities have not yet been established, special attention has been given to assessing the most likely impact of safety and licensing on the committed site.

# 3.0 SITE REQUIREMENTS

The committed fusion development site has three basic requirements:

- Land
- Electric power
- Water

These requirements are common for all fusion concepts and development phases; only the quantities vary.

Since the recommendation of any specific area of the Continental United States for the committed fusion development site is outside of the scope of this study, only general qualitative preferences for the basic site requirements will be discussed.

## 3.1 LAND

Present light water reactor siting practices were used to estimate the general order of magnitude of the site size. Based on this, the test facilities should be located at the center of a plot having an exclusion area of 250 hectares. This area requirement, in most cases, will satisfy the criteria that the radiation dose at the boundary of the plot will not exceed five millirem per year during normal operation. Since no such criteria exists for fusion reactor plants, it is assumed that the

requirements for fusion facility siting will be no more stringent.

Considering that the committed fusion development site may have more than one fusion device operating at any one time, it is suggested that its area to be around 400 hectares, or have a diameter of approximately 2,200 meters.

Aside of the area requirements, the land of the committed fusion development site preferably should have the following characteristics.

### 3.1.1 Soil Conditions

Soil conditions should be such that the foundation of heavy structures and equipment can be provided without undue economic disadvantage. It is suggested, therefore, that the shear wave velocity of the soil should be above 750 meters per second (2,500 feet per second), and the allowable bearing capacity be 57,500 pascal (12,000 pounds per square foot), at the selected site. These requirements can normally be met by sedimentary rock formations of moderate density.

### 3.1.2 Seismicity

Although structures and equipment can be designed to withstand practically any seismic force postulated within the conterminous United States, the economic penalty for accommodating severe

seismic conditions could be quite substantial. It is suggested, therefore, that the committed site be located in areas of low to moderate seismic activity. These areas are designated as seismic risk zones 0, 1, and 2 in the Uniform Building Code. (See Figure 3-1.)

The free field ground acceleration for the Safe Shutdown Earthquake (SSE) can be limited to 0.25 g's, and for the Operational Basis Earthquake (OBE), to 0.125 g's in these risk zones. These free field ground acceleration values appear reasonable and do not represent major restriction in selecting the actual location for the committed fusion development site. For example, a large percentage (80 percent to 90 percent) of all prospective sites for nuclear facilities will satisfy this seismic criteria.

### 3.1.3 Topography

There are no particular requirements regarding the topography of the committed fusion site. A few restrictions, normally applicable for the siting of any major industrial installation, should be kept in mind, however.

Areas with large rock outcrops and ragged surface formations should be avoided.

Areas within the floodplains of major natural bodies of water (rivers, lakes) are not suitable for siting.

The selected site should not have any major surface drainage channels on it, or, if it has, the flow of surface drainage should be divertable toward the boundary lines of the plot, utilizing a system of intercepting and diversion ditches.

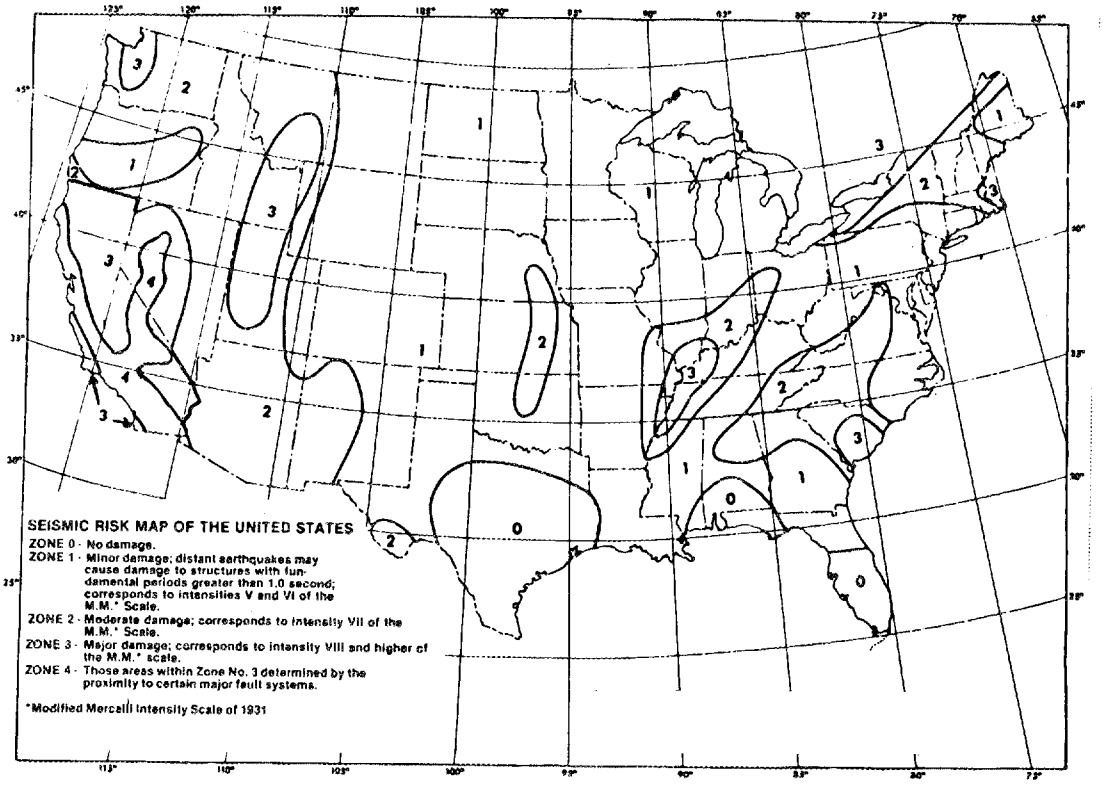


**Figure 3-1**
**SEISMIC RISK - MAP OF THE UNITED STATES**

### 3.1.4 Geographic Location

Preferences for a specific geographic location may be influenced by a number of sometimes contradictory factors, such as:

- Proximity. Reasonable proximity to a major population center, so that the heavy demand for a large labor force during construction can be met and the housing, social, and cultural needs of the operators can be satisfied. The population center distance, (the distance from the reactor to the nearest boundary of a densely populated center of more than about 25,000 residents, by the definition of 10 CFR Part 100) must be determined by calculations involving the postulated radio-active releases from the nuclear facility, local meterological conditions, and dose limits set by regulatory requirements. 10CFR Part 100 also states that in case the site is expected to contain multiple reactor facilities which are interconnected to the extent that an accident in one reactor could affect the safety of operations of any other, the size of the exclusions area, low population zone, and population center distance shall be based upon the assumption that all interconnected reactors emit these postulated radioactive products simultaneously. Regulatory requirements can best be met if the site is located in a remote area. Other requirements would favor a relatively short distance from a major population center.

- Site Accessibility. The committed fusion site has to have land accessibility by road and railroad. It is desirable, therefore, that it be located reasonably close to a major highway and major railroad line so that the connecting access road and railroad spur can be constructed at reasonable cost.

  Since the weight and size of some of the equipment used in fusion reactor plants is beyond the capacity and clearance limits of highway and railroad transportation, it is desirable that a barge unloading facility on a navigable waterway be available near the selected site.

- Meteorology. There are no specific requirements for the meterological characteristics of the committed site. Structures and facilities can be designed to suit any meteorological conditions within the conterminous U.S.

## 3.2 ELECTRICAL REQUIREMENTS

The electrical power supply and distribution system for experimental fusion devices must be designed to supply reliable electrical power continuously for the device and all its electrical auxiliaries, including the ac, dc and stored energy systems, during all types of operating conditions.

For the TNS devices, all electrical power will be obtained from the electric utility through conventional high voltage transmission lines. The EPR devices will also depend on power obtained from the utility, but will be able to use their own generated power to supply some of their electrical energy needs. The Demonstration and Prototype devices will operate in a manner similar to a conventional power plant.

The different electrical energy needs have been tabulated in the Electrical Power Requirements Chart, Table 3-1 located at the end of this section. In addition, the Reactor Coil Designation Chart, Table 3-2 shows the various types of coils and magnets used in the major reactors. The number of transformers and rectifiers for the different reactors has been assumed on the basis of one reactor per site. For a committed site, where more than one reactor is installed, changes in the ac voltage ratings and numbers of transformers/rectifiers will have to be made to take advantage of the possibility of combining power supplies.

# TABLE 3-1

## ELECTRICAL POWER REQUIREMENTS

| REACTOR TYPE | STEADY STATE MAGNET POWER SUPPLY | | | | | NBI DC POWER SUPPLY (DIRECT ac-dc CONVERSION, NO ENERGY STORAGE REQUIRED) | | | | | PULSED POWER SUPPLY | | | CONVERSION EQUIPMENT AREA AND REDUNDANCY REQUIREMENTS | | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | STEADY STATE DC POWER REQUIREMENTS | DC CONVERSION EQUIPMENT COST (NOTE 1) MILLION $ | ALUMINUM BUS CROSS SECTION $cm^2$ cm X cm | COST OF ENERGY LOSS IN BUS $/m/hr | ALUMINUM BUS INSTALLED COST $/m | DC POWER SOURCE REQUIREMENTS | DC CONVERSION EQUIPMENT COST MILLION $ | BUS SIZE (INSULATED CABLE BUS) CABLE SIZE (MCM) | COST OF ENERGY LOSS IN BUS $/m/hr | CABLE BUS INSTALLED COST $/m | STORED ENERGY MJ | PEAK POWER RATING MVA | SYSTEM COMPONENT COST MILLION $ | AREA REQUIRED ALL AC-DC CONVERSION EQUIP. m X m | CONVERSION EQUIPMENT REDUNDANCY | |
| G.A. TOKAMAK TNS/EPR | T.F. COILS (12 IN SERIES) 100 V dc, 10 kA PEAK | $0.81 | 160 16 X 10 | $0.004 | $108 | 60 MW, 150 kV dc, 400 A FOR 5 SECONDS | $ 4.[illegible] | 2-500 MCM (NOTE 2) | NEGLIGIBLE | $ 197 | 550 | 1,500 | 40.2 | 100 X 80 (NOTE 3) | TF: 1 OF 3 NBI: 1 OF 5 | HOMOPOLAR GENERATOR IS USED FOR ENERGY STORAGE |
| ORNL TOKAMAK TNS/EPR | T.F. COILS (12 IN SERIES) 1300 V dc, 15 kA PEAK | $1.88 | 232 16 X 14.5 | $0.006[illegible] | $157 | 6 UNITS IN PARALLEL, 120 kV, 1300 A TOTAL FOR 5-6 SECONDS/ EACH CYCLE | $ 7.2 | 6-500 MCM (NOTE 2) | NEGLIGIBLE | $ 590 | 4,300 | 1,200 | 51.5 | 140 X 100 (NOTE 3) | TF: 1 OF 4 NBI: 1 OF 5 | MOTOR GENERATOR–FLYWHEEL IS USED FOR ENERGY STORAGE |
| ANL TOKAMAK EPR | T.F. COILS (12 IN SERIES) 72 V dc, 60 kA PEAK | $2.48 | 920 20 X 46 | $0.025 | $621 | 12 UNITS IN PARALLEL, 180 kV, 672 A TOTAL | $ 7.9 | 3-500 MCM (NOTE 2) | NEGLIGIBLE | $ 270 | 3,000 | 500 | 27.5 | 120 X 120 (NOTE 3) | TF: 1 OF 4 NBI: 1 OF 5 | MOTOR GENERATOR–FLYWHEEL IS USED FOR ENERGY STORAGE |
| PPPL TOKAMAK PROTO | T.F. COILS (48 IN SERIES) – 60 MWe PEAK 48 kV (MAX) AT LOW CURRENT AND 10,000 A (MAX) AT LOW VOLTAGE | $8.7 | 160 16 X 10 | $0.004 | $108 | 20 MW dc POWER (10 MW INJECTION AND 50% EFF) 20 UNITS, 5 kV, 4 kA TOTAL | $ 1.85 | 5 kV, 4 kA BUS TAPPED AT EACH UNIT | NEGLIGIBLE | $ 328 | 10,000 | 510 | 62.8 | 170 X 140 (NOTE 3) | TF: 1 OF 5 NBI: 1 OF 5 | MOTOR GENERATOR–FLYWHEEL IS USED FOR ENERGY STORAGE |
| MIT TOKAMAK HFCTR PROTO | 8 COILS WITH INDEPENDENT POWER SUPPLIES EACH RATED 212 V dc, 11 kA PEAK | $4.05 | 170 17 X 10 | $0.0046 | $114 | 8 UNITS TOTAL POWER REQUIRED: 80 kV AT 1664 A | $ 9.73 | 6-500 MCM (NOTE 2) | NEGLIGIBLE | $ 590 | 1,100 | 4,000 | 105.5 | 160 X 160 (NOTE 3) | TF: 1 OF 9 NBI: 1 OF 7 | MOTOR GENERATOR–FLYWHEEL IS USED FOR ENERGY STORAGE |
| ORNL EBT TNS | 24 T.F. COILS (3 SETS OF 8): 20 V, 75 kA 48 ARE COILS (3 SETS OF 16): 1600 V, 3 kA | $1.11 (TF) $0.96 (ARE) | 1,155 30 X 38.5 (TF) 95 10 X 9.5 (ARE) | $0.032 (TF) $0.002 (ARE) | $780 (TF) $ 63 (ARE) | 2 UNITS TOTAL POWER REQUIRED: 80 kV AT 500 A | $ 5.2 | 2-500 MCM (NOTE 2) | NEGLIGIBLE | $ 197 | | N O N E | | 160 X 120 (NOTE 3) | TF: 1 OF 3 ARE: 1 OF 3 NBI: 1 OF 5 | NBI SYSTEM IS AUGMENTED BY 3.0 $MW_e$ of MICROWAVE HEATING AT 70 GHz. MICROWAVE HEATING SYSTEM COST: $ 25.0 MILLION |
| ORNL EBT EPR/DEMO | 24 T.F. COILS (3 SETS OF 8): 20 V, 75 kA. 48 ARE COILS (3 SETS OF 16): 1600 V, 3 kA | $1.11 (TF) $0.96 (ARE) | 1,155 30 X 38.5 (TF) 95 10 X 9.5 (ARE) | $0.032 (TF) $0.002 (ARE) | $780 (TF) $ 63 (ARE) | 6 UNITS TOTAL POWER REQUIRED: 120 kV AT 1,000 A | $13.0 | 2-500 MCM (NOTE 2) | NEGLIGIBLE | $ 197 | | N O N E | | 160 X 120 (NOTE 3) | TF: 1 OF 3 ARE: 1 OF 3 NBI: 1 OF 9 | NBI SYSTEM IS AUGMENTED BY 3.0 $MW_e$ of MICROWAVE HEATING AT 70 GHz. MICROWAVE HEATING SYSTEM COST: $ 25.0 MILLION |
| TANDEM MIRROR | UNDEFINED | $ 1.0 ALLOWANCE FOR TRANSITION COIL POWER SUPPLY | N/A | N/A | N/A | 240 MWe 300 kV, 800 A dc 30 SECONDS | $11.61 | 4-500 MCM (NOTE 2) | NEGLIGIBLE | $ 394 | | N O N E | | 170 X 100 (NOTE 3) | NBI: 1 OF 9 | |
| TORSATRON | HELICAL WINDINGS AND COMP LOOPS: 1 kV, 500 kA | $21.3 | 7700 100 X 77 | $0.21 (DURING CHARGING PERIOD ONLY) | $5201 | 500 MWe 120 kV, 4166 A | $24.54 | 20-500 MCM (NOTE 2) | NEGLIGIBLE | $1970 | | N O N E | | 150 X 230 (NOTE 3) | H.W. AND COMP. LOOPS : 1 OF 11 NBI : 1 OF 11 | |
| REVERSED FIELD PINCH | NO INFO ON dc SUPPLY. LASL SUGGESTS A 4.7 GJ HOMOPOLAR GEN | $47 (INSTALLED) | —— | —— | INCLUDED | NO NBI'S ARE REQUIRED | N/A | N/A | N/A | N/A | 11,300 | 500 | 69.9 | SPACE REQUIRED FOR HOMOPOLAR EQUIPMENT NOT DEFINED | —— | HOMOPOLAR GENERATOR IS USED FOR ENERGY STORAGE THIS REACTOR ALSO REQUIRES AN ADDITIONAL HOMOPOLAR GENERATOR POWER SUPPLY FOR THE POLOIDAL FIELD COILS, WITH A CAPACITY OF 6.6 GJ |

NOTES:

1. The dc conversion equipment costs include only the rectifier transformers with the associated oil circuit breakers and the rectifiers. It does not cover the cost of the ac step down transformers to reduce the power line voltage, or the cost of any regulating autotransformers required for variable ac voltage control. These costs do not include equipment installation either, except for the reverse field pinch homopolar equipment price.
2. Number of cables are for each dc bus. For both positive and negative buses, the number of cables must be doubled.
3. Space shown is for the oil circuit breakers, rectifier transformers and rectifiers only. It does not include the ac step down transformers, high voltage ac buses or stored energy systems space requirements.
4. System component costs are based on $0.005 per Joule and $25.00 per kVA.

TABLE 3 - 2

MAGNET TYPE - SUPERCONDUCTING (SC) NORMAL (N)

## REACTOR COIL DESIGNATION CHART

OPERATING MODE - PULSED (P) STEADY STATE (SS)

| NAME OF COIL | TOKAMAK | | | | | TANDEM MIRROR | ELMO BUMPY TORUS | TORSATRON | REVERSED FIELD PINCH |
|---|---|---|---|---|---|---|---|---|---|
| | ANL | GA | MIT | ORNL | PPPL | | | | |
| TOROIDAL FIELD COILS | SC - SS | SC - SS | SC - SS | SC - SS | SC - SS | | SC - SS | | SC – P |
| POLOIDAL FIELD COILS | | | | SC - P | SC - P | | | | SC - P |
| OHMIC HEATING COIL (OH) | SC - P | | SC - P | | | | | | |
| EQUILIBRIUM FIELD COILS (EF) | SC - P | | | | | | | | |
| F COILS | | N - P | | | | | | | |
| S COILS | | N - SS | | | | | | | |
| E COILS | | N - P | | | | | | | |
| DIPOLE COILS (DC) | | | SC - SS | | | | | | |
| NULLING FIELD COILS (NF) | | | N - P | | | | | | |
| QUADRUPOLE COILS | | | N - P | | | | | | |
| HEXAPOLE | | | SC - P | | | | | | |
| RIPPLE FIELD COILS | | | SC - SS | | | | | | |
| VERTICAL FIELD COILS | | | | | SC - P | | | | |
| SOLENOID COILS | | | | | | SC - SS | | | |
| BASEBALL COILS | | | | | | SC - SS | | | |
| TRANSITION COILS | | | | | | SC - SS | | | |
| ASPECT RATIO ENHANCEMENT COILS (ARE) | | | | | | | SC - SS | | |
| HELICAL | | | | | | | | SC - SS | |
| HELMHOLTZ | | | | | | | | SC - SS | |
| FEED BACK COILS | | | | | | | | | N - P |

There are four basic types of power requirements in all the experimental fusion devices as described below:

### 3.2.1 Steady State Magnet dc Requirements

The supply of energy to the toroidal field coils requires generally a source of low voltage (hundreds of volts) and high current (thousands of amps) for periods of at least several seconds. The most economical way to supply this power is with silicon diode type rectifiers together with their associated step-down rectifier transformers. If variable voltage is required, SCR-type rectifiers can be used. After the initial large amount of power required to excite these superconducting coils, the power requirements are diminished during the steady state operation of the device. If the operation of the device is interrupted, the energy contained in the coils is discharged in liquid-type resistor banks.

The following are the requirements of typical reactors:

G.A. Tokamak TNS/EPR. This reactor has 12 toroidal field coils connected in series requiring 100 volts dc (maximum) at 10,000 A. Three rectifier-transformer units will be used, one being a full spare, each one rated 13.8 kV, 3 phase, ac input and 100 V, 5000 A, dc output.

ORNL Tokamak TNS/EPR. This reactor has 12 toroidal field coils connected in series requiring 1300 volts dc (maximum) at 15,000 A. Four rectifier-transformer units will be used, one as a full spare, each one rated 13.8 kV, 3 phase ac input and 1300 V, 5,000 A dc output.

ANL Tokamak EPR. This reactor also has 12 toroidal field coils connected in series and requiring a total of 72 volts dc (maximum) at 60,000 A. Four rectifier-transformer units will be used, one as a spare, each one rated 13.8 kV, 3 phase, ac input and 72 V dc, 20,000 A output.

PPPL Tokamak Prototype. This reactor has a total of 48 coils requiring variable voltage and current. Initially, these series-connected coils will be charged at 1000 volts (each), at a reduced current value. As they are charged, the voltage requirements will decrease until reaching a steady state value of 25 volts. The current will have reached a value of 10,000 A. According to PPPL, the total peak power required will be 60 MWe and the total average power will be 28.8 MWe.

The very high voltage required initially (48,000 volts for all 48 coils) can be supplied by capacitors during a short period of time. SCR-type rectifiers with voltage control (through regulating autotransformers) and current control will be used to supply these coils during the rest of the charging period. Five rectifier-transformer units will be required, one being a

full spare, with a capacity of 15 MWe each and a maximum current of 10,000 A.

MIT Tokamak HFCTR Prototype. This reactor has eight toroidal field coils, each requiring a separate power supply capable of developing 212 V dc at 11,000 A. Nine rectifier-transformer units will be provided, one of them as a spare capable of being switched over to any of the toroidal field coils.

ORNL EBT TNS. The ORNL EBT TNS reactor requires two different magnet power supplies. It has 24 toroidal field coils arranged in three parallel groups of eight series-connected coils. The total power required is 20 volts dc (maximum) at 75,000 A. This can be obtained from 3 rectifier transformers with one being a spare, rated 13.8 kV, 3 phase input and 20 V, 37,500 A dc output. The reactor also requires dc power for 48 ARE coils connected in 3 sets of 16 coils. The 3 parallel connected sets require a total power of 1600 volts at 6,000 A. The power supply will consist of three rectifier-transformer units, one as a spare, rated 13.8 kV, 3 phase ac input and 1600 V, 3,000 A dc output.

ORNL EBT EPR/Demonstration. This reactor has exactly the same number and type of coils and power requirements as the ORNL EBT TNS reactor described above.

Tandem Mirror. This reactor will require a 1 MWe power supply for transition coils. The start up of this reactor requires a total of 3000 A at 20,000 V dc during 10 milliseconds. Capacitors can be used to provide this power.

Torsatron. This reactor does not have toroidal field coils. However, a 1,000 volt dc 500,000 A power supply is required for the superconducting helical windings and compensation loops during the charging period.

To provide this power, a total of 11 rectifier-transformer units will be required, one of them being a spare unit. Each unit will be rated 13.8 kV, 3 phase ac input and 1000 V, 55,000 A dc output.

### 3.2.2 Power Requirements for Neutral Beam Injectors

The neutral beam injectors require a dc power supply capable of providing (in each injection cycle) a very high voltage (hundreds of thousands of volts) and relatively low current (hundreds of amperes) during several seconds.

Our study has assumed that this power will be obtained by stepping up the ac voltage source through transformation and then rectifying it through silicon controlled rectifiers with their gate firing circuits electronically controlled to provide the necessary step function voltage required for ion

acceleration. This approach would allow the use, at a committed fusion site, of only one power supply to serve more than one fusion device.

Another alternative to provide this dc power is supplying ac power to each neutral beam injector and have a small, independent, power supply in each unit to step up the voltage and rectify it as required. This approach has the advantage that there is no need to supply large blocks of dc power at very high voltage from a central power supply located at some distance from NBI units. The disadvantages are, in part, that if one power supply fails, the corresponding unit is shut down, and that this system may be less economical at a site where more than one reactor is installed.

The following are the requirements of typical reactors:

G.A. Tokamak TNS/EPR. This reactor has twelve units that require a total of 400 Amps at 150 kV for periods of up to 5 seconds in each injection cycle. The common power supply concept will use five rectifier/transformer units, each one rated 13.8 kV, 3 phase ac input and 150 kV, 100 A dc output.

ORNL - Tokamak TNS/EPR. Six NBI units are used in this reactor, requiring a total of 120 kV at 1300 A. The power will be supplied by 5 rectifier/transformers, one of them

spare, and each one rated 13.8 kV, 3 phase ac input and 120 kV, 325 A dc output.

ANL Tokamak EPR. This reactor will have 24 neutral beam injectors, requiring a total power of 180 kV at 672 A dc (120 MWe). This power will be obtained from 5 rectifier/-transformer units, with one of them used as a spare and each one rated 13.8 kV, 3 phase, ac input and 180 kV, 168 A dc output. ANL stated that they could feed the NBI's from a 3 GJ stored-energy system, allowing 2 GJ for other coils.

PPPL Tokamak Proto. This reactor requires 20 NBI units, each one of them rated 5 kV, 200 A. The total power requirements will be 5 kV at 4000 A. Three rectifier/transformer units, one of them a spare, will be provided. Each unit will be rated 13.8 kV, 3 phase ac input and 5 kV, 2000 A dc output.

MIT Tokamak HFCTR. This reactor will use 8 NBI units requiring a total power of 120 kV at 166 A. To provide this power, seven rectifier/transformer units will be used, one of them a spare, and each one rated 13.8 kV, 3 phase, ac input and 120 kV, 280 A, dc output.

ORNL EBT TNS. Only 2 NBI units, requiring 80 kV, 500 A dc total power, will be used in this reactor. This power will be obtained from five rectifier/transformers, one of them a

spare, and each one rated 13.8 kV, 3 phase, ac input and 80 kV, 125 A dc output.

ORNL EBT EPR/Demonstration. The neutral beam injector and their power requirements for this reactor are 120 kV, 1000A dc total power.

Tandem Mirror. This reactor requires a total power for the neutral beam injectors of 300 kV at 800 A (240 MWe input for 120 MWe injection power). This power will be obtained from nine rectifier/transformer units one of them used as a spare, and each one rated 13.8 kV, 3 phase, ac input and 300 kV, 100 A dc output.

Torsatron. The information obtained about this reactor indicates that its neutral beam injectors require about 120 kV at a power level of from 400 to 600 MWe. Assuming 500 MWe as a basis, this power will be obtained from eleven rectifier/transformer units, using one of them as a spare. Each one of them will be rated 13.8 kV, 3 phase, ac input and 120 kV, 420 A dc output.

Reverse Field Pinch. This reactor will not use neutral beam injectors.

### 3.2.3 Stored Energy Power Requirements

Very high power levels of dc energy have to be delivered to the EF and Ohmic heating coils of the reactors during short periods of time. At certain points during the starting period these coils also regenerate power which must be absorbed by the system or dissipated in some way. Other types of coils in certain reactors, such as the transition coils in the Tandem Mirror reactor also require this type of power.

There are three basic ways to supply these energy requirements, which are discussed briefly in the following paragraphs:

- Superconducting Induction Storage System. This system consists of one (or several) large superconducting magnet similar to the toroidal field magnets. This magnet will receive power from the steady-state dc power supply used for the TF magnets, which will maintain its energy at a flotating level. The system has a solid state, SCR-type conversion unit to control the output to obtain the required pulse shape and duration. This conversion system will also switch polarities automatically.

- Homopolar Generator. The homopolar generators act as very large capacitors capable of storing and delivering high current levels with a very fast rise time. In most cases these generators require a prime mover which normally consists of an ac wound-rotor type induction motor. However, these machines are not yet being widely considered for stored energy systems because they are still in a primitive stage of development.

- M-G Sets with Flywheels. These units consist of a very large ac wound rotor type induction motor driving a fly-wheel which weighs several hundred tons (depending on the Megajoule rating required) and an ac generator (alternator). The alternator output,

due to the flywheel effect when coasting (delivering energy) or accelerating (absorbing energy), will have a varying frequency which can be corrected through the use of a cycloconverter (a solid-state, ac to ac frequency converter). The output of the cycloconverter can then be rectified and applied to the magnets.

Stored energy devices can also be used, through proper wave shaping, to supply power to the Neutral Beam Injectors described in the preceding paragraph, although for the purposes of this description, we have considered that the NBI will be supplied from more conventional conversion equipment.

The stored energy requirements of the different fusion reactor concepts are as follows:

G.A. Tokamak TNS/EPR. G. A. suggests the use of homopolar generators to supply the following stored-energy requirements.

- "F" Coils: 90 MWe peak, 45 MWe average for 30 seconds on and 30 seconds off at 100 volts. 10,000 V required during start up for 20 milliseconds.
- "S" Coils: 10 MWe peak, 1 MWe average, 50 V at 100 kA, with maximum voltage of 1000 V dc required for less than one second.
- "E" Coils: 800 MWe peak at 1000 V dc for a period of less than 5 seconds.

ORNL - Tokamak TNS/EPR. This reactor has six sets of "EF" coils and Ohmic heating system requiring a total stored capacity of 3.7 GJ. ORNL suggests the use of MG sets with flywheels.

ANL Tokamak EPR. This reactor requires a 2 GJ stored-energy system for pulsed coils. ANL feels that system could be increased to 3 GJ and also supply the NBI's. 15 MWe of ac power required for the 3 GJ MG set.

PPPL Tokamak Prototype. PPPL advises that the start up power requirements for this reactor are 510 MWe peak during a 6000-second cycle. Average power is negligible.

MIT Tokamak HFCTR. The following information was obtained from MIT about this reactor:

- At t=0.03 sec after start up, the coils regenerate 3,114 MWe.
- At t=2.0 sec after start up, the coils regenerate 87 MWe.
- At t=4.0 sec after start up, the coils absorb 468 MWe.

ORNL EBT TNS. No stored-energy type power requirements.

ORNL EBT EPR/Demonstration. No stored-energy type power requirements.

Tandem Mirror. Start up requires pulses of 3000 A at 20 kV dc during 10 milliseconds, which can be supplied by capacitors. A 1 MWe power supply will be required for the transition coils.

Torsatron. No stored-energy power requirements. The 1 kV, 500 kA power supply required during the charging period is described in Subsection 3.2.1.

Reversed Field Pinch. LASL suggests the use of a 4.7 GJ homopolar generator system to supply the toroidal field coils.

Another homopolar generator power supply system, rated 6.6 GJ, will be required to supply the poloidal field coils.

### 3.2.4 Auxiliary Power Requirements

These include all the power required by the cryogenic and water pumping systems, and miscellaneous ac electrical loads. The ac power input requirements for the dc rectifiers and stored-energy systems are not included.

G.A. Tokamak TNS/EPR. The auxiliary power requirements are:

| | |
|---|---|
| Liquid Helium system: | 24 MWe |
| Liquid Nitrogen system: | 3 MWe |
| Pumps: | 10 MWe |
| Miscellaneous power: | 7 MWe |
| Total auxiliary power: | 44 MWe |

ORNL - Tokamak TNS/EPR. The auxiliary power requrements are:

| | |
|---|---|
| Cryogenic system: | 50 MWe |
| Pumps: | 27 MWe |

| | |
|---|---|
| Miscellaneous power: | 10 MWe |
| Total auxiliary power: | 87 MWe |

ANL Tokamak EPR. The auxiliary power requirements are:

| | |
|---|---|
| Cryogenic system: | 10 MWe |
| Pumps: | 6 MWe |
| Miscellaneous power: | 18 MWe |
| Total auxiliary power: | 34 MWe |

PPPL Tokamak Prototype. The auxiliary power requirements are:

| | |
|---|---|
| Cryogenic system: | 100 MWe |
| Pumps: | 20 MWe |
| Miscellaneous power: | 24 MWe |
| Total auxiliary power: | 144 MWe |

MIT Tokamak HFCTR/Prototype. The auxiliary power requirements are:

| | |
|---|---|
| Cryogenic system: | 152 MWe |
| Pumps: | 20 MWe |
| Miscellaneous power: | 20 MWe |
| | 192 MWe |

ORNL EBT - TNS. The auxiliary power requirements are:

| | |
|---|---|
| Cryogenic system: | 4 MWe |
| Pumps: | 7.5 MWe |
| Miscellaneous power: | 12 MWe |
| | 23.5 MWe |

ORNL EBT/Demonstration. The auxiliary power requirements are:

| | |
|---|---|
| Cryogenic system: | 4 MWe |
| Pumps: | 25 MWe |
| Miscellaneous power: | 18 MWe |
| Total auxiliary power: | 47 MWe |

Tandem Mirror. The auxiliary power requirements are:

| | |
|---|---|
| Liquid He system: | 25 MWe |
| Pumps: | 4 MWe |
| Miscellaneous power: | 25 MWe |
| Total auxiliary power: | 54 MWe |

Torsatron. The auxiliary power requirements are:

| | |
|---|---|
| Refrigeration system: | 15 MWe |
| Pumps: | 36 MWe |
| Miscellaneous power: | 10 MWe |
| Total auxiliary power: | 61 MWe |

Reversed Field Pinch. The auxiliary power requirements are:

| | |
|---|---|
| Refrigeration system: | 33 MWe |
| Vacuum system: | 4 MWE |
| Pumps: | 24 MWe |
| Miscellaneous power: | 12 MWe |
| Total auxiliary power: | 73 MWe |

## 3.3 WATER REQUIREMENTS

Water requirements are determined by the process water needs of the devices located at the site, the fire water needs for the facility fire protection system, and the domestic water needs of the operators and other facility personnel.

The process water requirements are device-related, while the fire and domestic water needs are determined by the applicable codes and industrial standards.

### 3.3.1 Process Water Requirements

Since once-through cooling does not seem to be environmentally acceptable, recirculating cooling systems with forced draft cooling towers have been assumed. The process water requirements are determined primarily by the make-up water needs in the cooling water system to replace the evaporation losses and drift, and, to a lesser degree, by the demineralized water needs of the devices.

Based on power/plant design experience, it has been assumed that the make-up water requirement is 3 percent of the circulating water (cooling water) flow and the demineralized water requirement is 10 percent of the make-up water supply.

Circulating water flow for the water-cooled TNS and EPR devices was calculated based on the total amount of waste heat to be

rejected by the cooling tower and the difference between the inlet and outlet temperatures across the cooling tower. The total amount of waste heat was assumed to be the peak thermal output of the fusion reactor for the non-power-producing TNS devices. The waste heat to be rejected by the cooling tower for power generating devices was calculated on the basis of the difference of peak thermal output of the reactor and the electric output of the system. The temperature difference across the cooling tower, if not given by the laboratories, was assumed to be 14°C.

No consideration was given to duty factors of the various devices in their development phases. The circulating water flow was determined based on the peak thermal output of the devices as if they were operating continuously at their rated thermal output. It was judged that optimizing the relatively low cost circulating water system and possibly imposing operating limitations on the devices would be false economy in the early stages of engineering experimentation with the fusion devices.

Process water requirements of the various candidate fusion devices in their development phases are tabulated in Table 3-3.

The parameters shown in Table 3-3 are:

- Peak thermal output of the reactor (MWt)
- Circulating (cooling) water flow (liters/sec)
- Circulating water pump rating based on 50 meters of total dynamic head in all cases (horsepower)

# TABLE 3-3

## SITE CHARACTERISTICS

SYSTEM PROCESS WATER

| SYSTEM PARAMETERS | DEV'T PHASE | TOKAMAK | | | | TANDEM MIRROR | EBT | TORSATRON | REVERSED FIELD PINCH |
|---|---|---|---|---|---|---|---|---|---|
| PROCESS WATER REQUIREMENTS: | TNS | G.A. | | ORNL | | LLL | ORNL | | |
| 1. Peak Thermal Output of Reactor: R ($MW_t$) | R | 750 | | 1,775 | | 300 | 500 | | |
| 2. Circ. Water Flow: Q(lit/sec) | Q | 14,700 | | 38,220 | | 5,160 | 10,780 | | |
| 3. Circ. Water Pump Rating N(HP) | M | 11,500 | | 30,000 | | 4,050 | 8,450 | | |
| 4. Circ. Water Pumping Power Required: (Based on 50m pumping head) P (MWe) | P | 10 | | 27 | | 3.6 | 7.50 | | |
| 5. Number of Circ. Water Pipes n (each) | n | 1 | | 2 | | 1 | 1 | | |
| 6. Diameter of Circ. Water Pipes D (m) | D | 2.50 | | 2.85 | | 1.50 | 2.15 | | |
| 7. Circ. Water Make-up Requirement: q1 (lit/sec) | q1 | 440 | | 1,150 | | 155 | 320 | | |
| 8. Demineralized Water Requirement: q2 (lit/sec) | q2 | 40 | | 120 | | 15 | 30 | | |
| 9. Total Process Water Requirement q3 (lit/sec) | q3 | 480 | | 1,270 | | 170 | 350 | | |
| | EPR | ANL | G.A. | ORNL | | | ORNL | | |
| | R | 600 | | 2,260 | | | 2,000 | | |
| | Q | 8,540 | | 34,100 | | | 28,800 | | |
| | N | 6,700 | | 26,800 | | | 22,600 | | |
| | P | 6 | | 24 | | | 20 | | |
| | n | 1 | | 2 | | | 2 | | |
| | D | 1.90 | | 2.70 | | | 2.50 | | |
| | q1 | 260 | | 1,020 | | | 870 | | |
| | q2 | 30 | | 100 | | | 90 | | |
| | q3 | 290 | | 1,120 | | | 960 | | |
| | DEMO | ANL | G.A. | ORNL | PPPL | | ORNL | | |
| | R | 1,500 | 1,441 | 6,780 | 2,650 | | 2,500 | | |
| | Q | 17,100 | 19,400 | 102,400 | 27,960 | | 35,960 | | |
| | N | 13,400 | 15,200 | 80,300 | 21,920 | | 28,200 | | |
| | P | 12 | 13.6 | 72 | 20 | | 25 | | |
| | n | 2 | 2 | 4 | 2 | | 2 | | |
| | D | 1.90 | 2.00 | 3.30 | 2.50 | | 2.80 | | |
| | q1 | 510 | 580 | 3,060 | 840 | | 1,080 | | |
| | q2 | 50 | 60 | 300 | 80 | | 120 | | |
| | q3 | 560 | 640 | 3,360 | 920 | | 1,200 | | |
| | PROTO | MIT | | PPPL | | LLL | | MIT | LASL |
| | R | 2,470 | | 5,305 | | 2,560 | | 4,340 | 2,980 |
| | Q | 28,940 | | 55,910 | | 32,000 | | 50,700 | 33,840 |
| | N | 22,700 | | 43,800 | | 25,100 | | 39,750 | 26,500 |
| | P | 20 | | 40 | | 22.4 | | 36 | 24.0 |
| | n | 2 | | 3 | | 2 | | 2 | 2 |
| | D | 2.50 | | 2.80 | | 2.60 | | 3.30 | 2.80 |
| | q1 | 870 | | 1,680 | | 960 | | 1,520 | 1,015 |
| | q2 | 90 | | 170 | | 100 | | 180 | 105 |
| | q3 | 960 | | 1,850 | | 1,060 | | 1,700 | 1,120 |

- Circulating water pump drive power required (MWe)
- Number of circulating water pipes (each)
- Diameter of circulating water pipes, based on 3 m/sec velocity (m)
- Circulating water make-up requirement (liters/sec)
- Demineralized water requirement (liters/sec)
- Total process water requirements (liters/sec)

It is assumed that the water-cooled TNS and EPR devices will have a closed-loop cooling system and a water-to-water heat exchanger to cope with the relatively large difference between the inlet and outlet temperature at the device and limit the temperature gradient through the cooling tower to 14°C maximum. Another purpose of the closed-loop cooling system and heat exchanger is to prevent tritium release through the cooling tower.

### 3.3.2 Fire Water Requirements

The design characteristics of the fire protection systems at the committed site will be based on the National Fire Protection Association (NFPA) codes. The following are the principal NFPA codes which will influence the design of the fire protection systems:

NFPA-13 Sprinkler Systems, Installation

NFPA-14 Standpipe and Hose Systems

NFPA-15 Water Spray Fixed Systems

NFPA-20 Centrifugal Fire Pumps

NFPA-24 Outside Protection

Based on the above codes and design experience with fossil and light water reactor power plants, the following requirements are established for the fire water system:

Water System Fire Pumps and Water Sources. Three fire pumps, 100 liters per second capacity at 0.9 mega pascal pressure each will be required to supply the main fire water loop surrounding the plant. These pumps will be located over the suction sump of the cooling water basin, draw water directly from the sump, and discharge into the fire main. Individual fire protection systems that use water for extinguishing fires will be supplied from this fire main.

Alternative source for fire water will be the 1,200 $m^3$ capacity fire water tank. The standby water pump, identical in capacity and pressure to the main fire water pumps, will draw water from this tank.

The main fire pumps will be electric-motor-driven with adequate capacity to provide the flow demand of the largest fixed automatic water extinguishing system plus 65 liters per second for hose streams. These pumps will maintain enough pressure in the fire loop to provide a minimum residual pressure of 0.4 MPa at the highest hose station with a flow rate of 6 liters per second from that station.

The standby fire pump will provide backup to the main fire pumps and will be diesel-engine-driven. This unit will start

automatically when the pressure in the main fire loop drops 0.07 MPa below the setting at which the main fire pumps start.

A jockey pump will maintain system pressure at approximately 0.9 MPa in the main fire loop. The jockey pump will be sized to make up leaks at a rate of 2 liters per hour per 100 joints in the main fire loop, but not more than 2 liters per second.

### 3.3.3 Domestic Water Requirements

The domestic water requirements for the committed site will be determined by the number of operators, maintenance and support personnel occupying the site. The few respondents to the questionnaire sent out during Task 100 estimated the total number of plant personnel at around 100.

Domestic water requirements on that basis will be 47,500 liters per day supplied at a maximum flow rate of 6 liters per sec.

The domestic water system will consist of disinfectant injection equipment, a hydropneumatic tank of 20.0 $m^3$ capacity, and associated electric motor driven pumps and compressors. This system will feed the domestic water distribution piping at a pressure required by the local plumbing code.

## 4.0 COMMON FUSION SITE CHARACTERISTICS

Common fusion site characteristics vary somewhat for TNS (The Next Step, Ignition Test Reactors) devices, which have the primary purpose of achieving plasma ignition only, and EPR, demonstration and prototype fusion reactors, all of which produce electric power.

The thermal power generated by the TNS devices will be rejected through cooling towers; therefore, steam generation and power generation facilities will not be required for the TNS devices. Few of the TNS devices are equipped with blankets, and even the ones which are planned to be utilized as combination TNS/EPR devices, and have blanket sections, will not breed tritium when operated in the TNS mode. Therefore, TNS devices will not have facilities to handle tritium separation from lithium, and tritium purification.

Since most of the TNS devices will use water to cool the first wall, lithium storage, handling, and purification facilities will not be required. Based on the differences in characteristics between the TNS and more advanced EPR, demonstration and prototype fusion devices, the following lists describe the characteristics of the two groups.

### 4.1 COMMON CHARACTERISTICS OF TNS FUSION DEVICES

All TNS fusion devices must have a site satisfying the listed requirements and have the characteristics described below.

### 4.1.1 Land

Land, selected and certified for the construction and operation of a nuclear facility. It must have highway and railroad access and, preferably, a barge unloading facility nearby.

### 4.1.2 Land Improvements

- Fencing, with personnel and vehicular access gates, and gate houses
- Grading and drainage
- Plant road system
- Plant railroad spur

### 4.1.3 Structures

4.1.3.1 Reactor block structures, including:

- Reactor building
- Control building
- Magnet power supply building
- Cryogenics building
- Vacuum building (located in the reactor building)
- Energy dissipation building

4.1.3.2 Balance of Plant Structures.

- Administration and engineering building
- Pump houses (for fire and domestic water)
- Fire house
- Laboratories
- Shops
- Mock-up building
- Magnet fabrication, assembly, and testing building
- Warehouse
- Cooling towers
- Circulating water pump house

4.1.4 <u>Process Service Systems</u>

4.1.4.1 Electrical.

- Main substation
- Plant switchyard
- Plant ac distribution system
- Uninterruptable plant emergency electrical system
- Plant dc system
- Energy dissipation system

4.1.4.2 Water Supply.

- Circulating water system
- Other plant process water system
- Fire water system
- Plant domestic water system

4.1.4.3 Vacuum System.

- Roughing vacuum system
- Finishing vacuum system

4.1.4.4 Cryogenic System.

- Liquid helium system
- Liquid nitrogen system

4.1.4.5 Radwaste Handling System.

- Gaseous radwaste processing and storage system
- Liquid radwaste processing and storage system
- Solid radwaste processing and storage system

4.1.4.6 Plasma Purity Control System.

4.1.4.7 Plant Atomosphere Control System (HVAC).

4.1.4.8 Plant Control System.

- Plant operation and safety control and monitoring system
- Data processing system
- Plant security control system

4.1.4.9 Plant Maintenance System.

- Reactor maintenance system (hot cells)
- General plant maintenance system, including maintenance shops
- Mobile maintenance equipment

4.1.4.10 Laboratories.

- General chemical laboratory
- Materials testing laboratory

## 4.2 COMMON CHARACTERISTICS OF EPR, DEMONSTRATION, AND PROTOTYPE FUSION DEVICES

In addition to the requirements and/or characteristics listed in Subsection 4.1 for TNS devices, the power generating EPR, demonstration, and prototype devices have the following common characteristics.

### 4.2.1 Structures

The structures listed below will be required for the operation of power generating devices in addition to the structures listed in Subsection 4.1.3.1:

- Tritium processing and storage building
- Lithium storage and handling building
- Steam generating building
- Main switchgear building
- Turbine generator building

### 4.2.2 Process Service Systems

The process service systems listed below will be required for the operation of power generating devices in addition to the process service systems listed in Subsection 4.1.4:

- Diverters (as required)
- D-T reprocessing system
- Blanket breeding material (lithium or other) receiving and storage system
- Blanket breeding material (lithium or other) distribution system
- Blanket breeding material (lithium or other) sampling and purity control system
- Tritium process system
- Tritium storage system
- Steam generation system
- Primary heat transport system
- Intermediate heat transport system, if applicable
- Power generation system

Of the process service systems, the electrical requirements are relatively well defined. These requirements are described in Section 3.2, and are shown in Table 3-1.

The process, fire, and domestic water requirements were calculated from the total rejected heat by each fusion reactor concept, fire code requirements, and past power plant design experience. These requirements are described in Subsection 3.3 and the results are tabulated in Table 3-3.

Two additional process service systems: the cryogenic system and the vacuum system were defined to a lesser depth than the electrical and water systems. The requirements for these two systems, as well as the responding laboratories could define them, are shown in Tables 4-1 and 4-2, respectively.

Requirements for the rest of the process service systems are not defined in enough detail; therefore, the requirements cannot be established nor quantified at this time.

## 4.3 OTHER, NONCOMMON FUSION CHARACTERISTICS

There are a few fusion site characteristics which are not common. These are primarily site-sensitive or site-related characterics, unique to a specific location of the committed fusion site. These include, but are not necessarily limited to, the following:

- Geographic location

# TABLE 4-1

## SITE CHARACTERISTICS

SYSTEM CRYOGENICS

| SYSTEM PARAMETERS | DEV'T PHASE | TOKAMAK | | TANDEM MIRROR | EBT | TORSATRON | REVERSED FIELD PINCH |
|---|---|---|---|---|---|---|---|
| LIQUID HELIUM:<br>Largest refrigeration system data available is from CTI - Cryogenics:<br>Refrigeration Capacity-8KW<br>Input Power - 4 MW<br>Dimensions - Cold Box 2.5m diameter x 6m high<br>Compressor-4mx8mx2m high<br>Cost - $3.7x10^6$/system<br>R - refrigeration capacity required (KW)<br>N - number of systems (Redundant systems not included)<br>A - area required for systems (mxm)<br>C - cost of total system ($x10^6$) | TNS | ORNL<br>R - 100<br>N - 13<br>A - 18x48<br>C - 48.1 | GA<br>R 48<br>N 6<br>A 48x120<br>C 22.2*<br>*9.7 by G.A. | | R 7<br>N 1<br>A 8m x 8m<br>C 3.7 | | |
| | EPR | | PPPL<br>125<br>16<br>18x112<br>59.2 | | Same as TNS | | |
| NOTE:<br>Liquid helium distribution system and liquid nitrogen storage and distribution system are not included, because of insufficient information. | DEMO | ORNL<br>R 300<br>N 38<br>A 48x140<br>C 140.6 | PPPL<br>140<br>18<br>48x112<br>66.6 | | Same as TNS | | LASL<br>R = 72<br>N = 9<br>A = 10x35<br>C = 33 |
| | PROTO | PPPL<br>R 280<br>N 35<br>A 48 x 164<br>C 129.5 | | | | | |

# TABLE 4-2

## SITE CHARACTERISTICS

SYSTEM VACUUM

ROUGHING VACUUM PUMP:

$V(M^3)$ - Volume of Vacuum Chamber

D (liters/sec) - Pumping rate required calculated from

$$D = \frac{\text{Volume} \times F_A}{\text{time}}$$

$F_A$ = System factor derived from Kinney Vacuum Company System factor curves = 15

Time (sec) - Time to pump down from 760 torr to 0.1 torr

F value is rounded up to rating of next size pump offered by Kinney Vacuum Company

S - Pump Dimensions height(cm) x length(cm) x width(cm)

C - Approximate cost

*ORNL needs same pumping requirements for both TNS and EPR and requires 3 identical systems for EPR since there are three reactors.

| DEV'T PHASE | TOKAMAK | | | TANDEM MIRROR | EBT | TORSATRON | REVERSED FIELD PINCH |
|---|---|---|---|---|---|---|---|
| TNS | MIT<br>V 30<br>D 95<br>S 117x 107x 86<br>C 8,000 | ORNL*<br>425<br>945<br>170x221 x122<br>27,000 | PPPL<br>450<br>945<br>170x221 x122<br>27,000 | V - 500<br>D - 1275<br>S - 170x236x122<br>C - 30,000 | V - 180<br>D - 85<br>S - 127x147x97<br>C - 14,000 | | |
| EPR | ANL<br>V 400<br>D 945<br>S 170x 221x 122<br>C 27,000 | GA<br>300<br>755<br>155x200 x102<br>21,000 | PPPL<br>1000<br>3020<br>190x239 x196<br>42,000 | | V - 710<br>D - 1890<br>S - 191x216x173<br>C - 35,500 | | |
| DEMO | GA<br>V 750<br>D 1890<br>S 191x216x 173<br>C 35,500 | PPPL<br>2000<br>4530<br>191x239x226<br>50,000 | | | Same as EPR | | |
| PROTO | MIT<br>V 320<br>D 755<br>S 155x200x 102<br>C 21,000 | PPPL<br>3600<br>7550 (2 - 3775 Units)<br>191x239x226/ Unit<br>45,500/Unit | | | | | V - 570<br>D - 1275<br>S - 170x236x122<br>C - 30,000 |

- Site accessibility
- Site topography
- Site geology (soil conditions)
- Site seismicity
- Site hydrology
- Site meteorology

Some of these characteristics may have a heavy bearing on the development cost of a committed fusion site, but will not influence the feasibility of concentrating all fusion development work at one committed site.

## 5.0 SITE-FACILITY INTERFACE REQUIREMENTS

The attractiveness of the committed fusion development site approach stems from the possibility of sharing structures, facilities, and service systems by subsequent development phases of the same fusion concept or even by different fusion concepts. It is a preconceived conclusion, therefore, that the committed site will have the structures, facilities, and service systems constructed and installed at the time the fusion reactor components arrive at the site and are ready for installation.

The interface between the fusion device and the site facilities and process service systems available at the site will be inside the reactor building structure.

Just what service systems will be provided at the site for a particular device, as a permanently installed system, largly depends on how the requirements for these service systems are established. Design criteria for the site-installed service systems must be carefully coordinated with the requirements of the candidate fusion concepts. The economic advantage of the committed fusion site will obviously be maximum if the facilities and process service systems provided can serve nearly all candidate fusion concepts with minimum amount of alterations and modifications. What this means is that the shared process facilities and service systems are most cost effective if the flexibility requirements and design margins can be kept at minimum level.

The success of the optimum utilization of the site-installed facilities and service systems also depends heavily on how effectively a standardization effort can be enforced in the design of the candidate fusion reactor devices. Common components, such as neutral beam injectors, dc power supplies for the magnets, pulsed power supplies, energy storage systems, and energy dissipation systems can be standardized to serve several fusion concepts. The requirements for electrical, cryogenic, vacuum service cooling water, and heat rejection systems for these components can be satisfied by common, site-installed service facilities. The interface between the fusion reactor and these services can be established inside the reactor building in the form of bus couplings, headers, supply, and discharge lines.

Plant operation and safety surveillance control devices for process systems of similar function are also good candidates for multipurpose installations in the control building. Quantification of these interface requirements may be possible after a tentative selection has been made of the fusion devices scheduled to be installed at the committed site.

In summary, the site-installed facilities and service systems which may have interfaces with the TNS fusion devices, are listed below:

- Structures
- Plant auxiliary ac electric power
- dc power supply, steady state

- dc power supply, pulsed
- Electric energy storage system
- Energy dissipation system
- Process, fire and domestic water supply, and distribution system
- Vacuum system (roughing)
- Cryogenic system
- Reactor fuel systems
- Reactor maintenance and service systems
- Plant operation and safety surveillance control system
- Data processing system
- Heat rejection system
- General plant maintenance system
- Administration, scientific and engineering support, including chemical, materials testing, and tritium laboratories

For power generating EPR demonstration and prototype devices, the above list must be expanded to include the following facilities and process service system over and above those listed for the TNS devices:

- Tritium handling, process, and storage system
- Lithium process and storage system
- Steam generating system
- Power generation system

# 6.0 LICENSING AND ENVIRONMENTAL REQUIREMENTS AND ISSUES

This section addresses the licensing, safety, and environmental aspects of a committed site for fusion development. Subsection 6.1 generally describes the current licensing requirements which might be applied to a committed site. Subsection 6.2 describes the generic environmental issues which must be considered.

## 6.1 LICENSING

Licensing requirements and issues applicable to a committed fusion development site may be divided into two groups.

- Group 1 - Regulatory requirements which address possible external environmental effects which are generally independent of the internal power plant design. (These requirements are presently known.)
- Group 2 - Regulatory requirements which address nuclear safety issues which are related to the internal fusion power plant design or concept. (These requirements are largely unknown or uncertain at the present.)

An evaluation of fusion plant sites with regard to the first group of requirements above would be relatively straightforward. These regulations basically address external environmental effects and do not place restrictions on internal plant designs or concepts. The requirements and permits associated with the first group of regulations can be evaluated now, and are limited only by one's ability to quantify the environmental effects of a fusion plant. A comprehensive list of permits and approvals has

been developed based on current power plant licensing procedures. These permits and approvals represent valid environmental concerns which will probably continue to be pertinent whenever fusion plant sites are evaluated.

The possible federal, state, and regional permits are presented in Table 6-1. Since county and municipal permits for building codes, easement along county roads, and other local ordinances are site specific and cannot be identified at this time, they are not included in this initial list. The applicability of many of the listed permits will depend on the particular state, region, land use and/or environmental characteristics of the site. To produce a final list, permits must be added or deleted from the initial possibilities in the context of the final site and its characteristics.

The U.S. environmental regulatory requirements are constantly being modified. Eventually, the permits currently administered by the U.S. Environmental Protection Agency will all be delegated to state agencies. This delegation of authority is part of an ongoing effort to streamline the permit process. As a result of this effort, permits and responsible agencies will likely be defined and consolidated over the next decade. At the present time, about half of the states are authorized to issue the National Pollutant Discharge Elimination System (NPDES) permit.

TABLE 6-1

POSSIBLE PERMITS AND APPROVALS FOR A FUSION POWER PLANT



| PERMIT | ADMINISTERING AGENCY |
|---|---|
| Federal | |
| Construction Permit | Nuclear Regulatory Commission (NRC) |
| Operating License | NRC |
| Materials License | NRC |
| Permit for Dredge and Fill; Section 404 of Clean Water Act | Army Corps of Engineers |
| Permit to Build in or Cross a Navigable Waterway; Section 10 of Rivers and Harbors Act | Army Corps of Engineers |
| National Pollutant Discharge Elimination System (NPDES) Permit (1) | Environmental Protection Agency (EPA) |
| Prevention of Significant Air Deterioration (PSD); Permit to Construct | EPA |
| Hazardous Waste Permit (for disposal of hazardous construction/operation wastes, excluding radioactive wastes) | EPA |
| Toxic Substances Definition and Control (for disposal of toxic construction/operation wastes, excluding radioactive wastes) | EPA |
| Permit to Construct Structures Greater than 200 feet Tall | Federal Aviation Administration |
| Building Permit for Structure in Floodplains of Major Streams (2) | Floodplain Management Agencies |
| Right-of-Way Permit (for transmission lines to cross or occupy railroad land) (2) | Railroad Companies |

TABLE 6-1 (Continued)



| PERMIT | ADMINISTERING AGENCY |
|---|---|
| Federal (Cont'd) | |
| Special Land Use Permits (for burning, disposal, surveying, soil sampling, construction, etc.)(2) | Forest Service |
| Right-of-Way Permit or Lease (for temporary or permanent facilities on respective lands as applicable) (2) | Bureau of Land Management; Forest Service; Bureau of Indian Affairs National Park Service |
| Navigation Lights Permit (for intake and other structures if posing possible threat to watercraft | U.S. Coast Guard |
| State and Regional (3) | |
| (Approval or) Permit to Construct Plant | State Siting Commission or Board |
| (Approval or) Permit to Construct Transmission Lines | State Siting Commission or Board |
| Certification of Convenience and Necessity (for plant and possibly 2nd permit for transmission lines) | State Public Service Commission/ Utilities |
| Water Quality Permit (may be included in NPDES permit if state authorized to administer NPDES) | State Environmental Control Agency; Water Quality |
| Permit to Construct (for auxillary boiler and emergency diesel air emissions and construction impacts) | State Environmental Control Agency; Air Quality |
| Certification of Section 404 Permit (necessary for Corps of Engineers' approval) | State Environmental Control Agency; Water Quality |
| Waste Disposal Permit (for dredged spoils and construction/operation wastes | State Environmental Control Agency or Department of Natural Resources or State Health Department |
| Right-of-Way or Lease for State Lands | Department of Natural Resources |

TABLE 6-1 (Continued)



| PERMIT | ADMINISTERING AGENCY |
|---|---|
| State and Regional (Cont'd) | |
| Surface Water Appropriation Permit (for potable water supply on site, wells) | Department of Natural Resources |
| State Permit for Construction in Navigable Waters | Department of Natural Resources or State Engineer's Office |
| State Permit for Dredging in Navigable Waters | Department of Natural Resources or State Engineer's Office |
| Potable Water Supply or Safe Drinking Water Permit | State Environmental Protection Agency or State Health Department |
| Sanitary Waste Treatment and Disposal Permit | State Health Department |
| Plant Plumbing Approval | State Health Department |
| Approval of Construction of Transmission Lines | State Division of Aeronautics |
| Permit to Cross and/or Share State Highway Right-of-Way with Transmission Lines | State Department of Transportation |
| Construction Permit/Building Plan Approval | Union/State Department of Industry and Labor |
| Approval of Relocation Assistance Plan for Displaced Former Occupants | Local Affairs and Development Department or State Planning Commission |
| Project Review and Approval | State Historical Commission or State Archaeologist |
| Building Fire Safety Approval | State Fire Marshall |
| Zoning Permit | State or Regional Coastal Zoning Commission |
| Project Approval/Building Permit | State and/or Regional Planning and Development Commission |
| Project Approval/Building Permit | Regional Water Quality Control Boards and/or Regional Air Quality Control Boards |

(1) The NPDES Permit for a nuclear facility requires an extensive aquatic biological study (one year) to obtain a waiver from 316(a) and allow any heat discharge in the plume.

(2) These permits are site specific. Their applicability can only be determined after the construction site is designated.

(3) These permits will vary from state to state. Applicability can be determined after site is designated.

The total number of permits and approvals required for each site and the cost and time involved in obtaining them provide incentives to concentrate fusion development at one site. Provided generic fusion plant external effects can be quantified, then these permits and approvals would be required only once for the site. If additional requirements are generated, the established site records of testing, geology, meterology, ecology, etc., would provide a good basis for expeditious evaluation of new requirements.

In contrast to Group 1 requirements which are generally known, the regulations addressing the internal design requirements for a fusion plant, classified as Group 2, are largely unknown. There are currently no established regulations addressing the nuclear safety aspects of a fusion plant. Although many of the basic concepts of nuclear safety applicable to light water fission power plants are also applicable to fusion plants, it may not be possible to extrapolate current fission-plant-oriented regulations to fusion reactors. There are significant safety and environmental advantages for fusion power plants over fission plants. It is anticipated that a fresh approach to fusion plant licensing will result in more consistant and effective regulation and a shorter licensing schedule.

The majority of Group 2 regulations, when developed, will address adequate plant designs for protection of the public and plant operations. For the most part, these requirements will address design features which will minimize risk of release of

radioactive material. Both routine and accidental releases, and exposures, must be quantified. The objective of regulations will be to ensure that plant designs minimize the risk and size of large accidental releases and maintain routine releases and exposure at a low level. The safety analysis of a fusion plant and the perceived risk of accidents could influence siting near urban areas.

Future regulations may also address hazards unique to fusion reactors such as the release of liquid metal coolants (lithium), the effects of strong magnetic fields, or the possibility of magnetic interference with local electronic and communication systems.

Most current evaluations of siting and licensing have shown fusion to have safety advantages over fission power plants. It appears that siting close to urban centers may be possible.

Although there does not appear to be any specific fusion regulatory consideration related to the siting of a facility of this nature, the licensing process has become progressively more subject to public opinion, and environmental litigations could delay or complicate licensing of a particular site.

For this reason it would be prudent to select a site at which potential delays can be minimized. Consideration might be given to use of a government reservation for siting the first fusion

demonstration plants. This would minimize the potential for delays based on non-safety or non-technical issues.

In summary, the known regulatory requirements and approvals described in Group 1 and listed in Table 6-1 are examples of typical permits which may be required for fusion sites. These requirements will cover the routine environmental effects. The unknown licensing requirements which are yet to be developed were catagorized as Group 2. These address plant internal design for safety and, although not presently quantified, should not significantly affect selection of a reactor site, except from the standpoint of proximity to populated areas.

## 6.2 GENERIC ENVIRONMENTAL ISSUES

While no safety regulations or licensing requirements have yet been established for fusion facilities, it may be assumed that such requirements will be based upon the same type of concerns affecting the present generation, industrial, and nuclear facilities. Generic environmental issues identified for the fusion site at this time are the potential effects on terrestrial and aquatic ecology, water and atmospheric effects, transportation and corridor effects, land use, socioeconomics and agricultural productivity, noise and aesthetic effects, the potential for radioactive releases, and electromagnetic effects.

The value of the terrestrial and aquatic ecological resources must be determined for a potential facility site. The presence of rare or endangered species may be expected to adversely affect site suitability. Factors to be included in the assessment of these resources are the stability of the ecosystems, the degree of prior disruption, and the degree of predicted disturbance. The potential disturbance or loss of any unique or rare resources during construction could constrain licensing of a fusion facility. Also, effects on terrestrial and aquatic habitats may not be limited to the site. The effects of construction, operation, and transportation on these resources in outlying areas must also be determined. Care in siting, revegetation, and establishment of wildlife habitats for use by the scientific community or interested laymen are examples of preventative and mitigating measures often implemented for these impacts.

The potential for contamination of groundwater,, surface water and the atmosphere are important environmental concerns. Existing groundwater resources must be evaluated with respect to water quality and aquifer characteristics. The possibility of chemical or nuclear contamination of groundwater must be examined and measures taken to insure that wastewater streams do not degrade the groundwater by percolation through the soils.

Surface water impacts are another concern. In addition to the chemical and nuclear contamination potential, thermal pollution is also a significant environmental issue. Surface water may be a key environmental issue since it can affect human and wildlife

habitat, plant life, and groundwater systems at considerable distances from the facility.

In addition, consumption of water supplies for cooling water, process make-up, or other uses may affect downstream uses by present or future residents and industries. Low flow in surface waters, recharge rates in groundwater, and fusion facility consumption should be considered in siting the facility.

Atmospheric effects from cooling towers and from fugitive dust (particularly during construction) are of considerable concern. Cooling towers have the potential for creating a visible plume, spreading salt on nearby vegetation, and forming ice on adjacent roads. Of more serious concern, however, is the potential for leaks of radioactive material into the atmosphere.

Noise and aesthetics are also significant environmental factors arising from construction and operation of a proposed facility. These annoyance factors do much to affect community attitudes. It is important that these factors be evaluated with respect to the preconstruction noise and aesthetic environments to ensure that intrinsic values are not unduly degraded.

While a primary advantage of fusion technology is the lack of radioactive wastes from the fusion reaction, significant amounts of radioactive waste will be generated by neutron activation of components near the reactor such as the first wall and blanket. Additionally, a fission reactor, which does produce radioactive

wastes, may be involved in some concepts (fusion-fission hybrids). Of course, the present uncertainty concerning nuclear waste disposal is invariably an environmental concern.

Certain factors peculiar to fusion technology may become significant environmental concerns. Among these may be the large amount of tritium, and the electromagnetic effects of the large electromagnetic field required. In addition to equipment distrubances from a large magnetic field, such as to the navigation of aircraft in the site vicinity, biological effects may be of considerable public concern.

Transportation effects include delays, potential increase in hazards, and rerouting of road and rail systems. These effects are most evident during facility construction when the change in volume of transportation is most pronounced. Transportation effects tend to demonstrate the presence of the facility to the surrounding community.

Potential sites for the proposed fusion facility should be compatible with existing land uses and proposed or zoned land uses. Areas designated as residential, recreational, critical environmental areas, historic areas, or archaeological sites should be avoided. In addition, areas now being utilized by other industries which could pose a hazard to the fusion facility (i.e., explosives, chemicals, etc.) should also be avoided. Regional, federal, state, and local agencies should be consulted about the proposed facility.

Introduction of a facility into certain rural areas may change the area's character from agricultural to an industrial economy. Both direct and indirect loss of agricultural productivity could be possible from facility construction in this case.

In addition to the effect on land use, introduction of a large facility into a rural area may change local lifestyles considerably. Socioeconomic effects, first noticeable during the construction phase, include population increases and economic shifts. Population increase without adequate planning may result in housing shortages and inadequate public services, such as utilities and roads. Economic effects typically include the use of the local labor force, sometimes resulting in insufficient support of traditional services. Changes in the property tax base due to increased contributors and an increased demand for community services may be offset by the taxes paid by the facility, and wages paid to local and imported labor forces.

Environmental effects could result from the construction of corridors required to support the project such as roads, railways, pipelines, and power transmission routes.

# 7.0 SITE DEVELOPMENT SCENARIOS[1]

During this study, data was gathered on five tokamak designs, and four other fusion concepts: the Tandem Mirror, Elmo Bumpy Torus, Torsatron, and Reversed Field Pinch.

For the purposes of this study, it is assumed that one tokamak design approach will be selected. Even so, the number of possible combination of a tokamak and the other four alternative concepts is rather large. Considering that the state of development for the tokamak is more advanced than for any of the other concepts, it is further assumed that the selected scenarios will include the tokamak.

To keep the number of scenarios within a manageable limit, two basic scenarios were considered in Task 200:

- Scenario I. One fusion concept, for the reason mentioned earlier. The tokamak will be constructed and operated in the TNS, EPR and demonstration/prototype phase at the committed site.

- Scenario II. Two fusion concepts (the tokamak and the tandem mirror, or any alternative fusion concept, which is ready) will be constructed consecutively and operated in a phased sequence, so that the utilization of the turbine generator in the EPR and demonstration/prototype mode, can be optimized.

  Scenario II could impose a restriction on the operation of the devices, especially in the demonstration/prototype phase. The degree of this

[1]This section discusses a preliminary assessment of the postulated scenarios for the development of the committed fusion site. A detailed discussion of the finally adopted scenarios is presented in Section 4.0 of the Final Report.

restriction depends on how soon the second concept can be made ready for construction and operation.

## 7.1 SCENARIO I - TOKAMAK DEVELOPMENT

The sequence of construction and operation of the different phases is shown in Figure 7-1.

This scenario assumes the construction and operation of tokamak devices only. The construction of the TNS device is followed by the operating period of the same device. Construction of the EPR device can be started even before the operation of the TNS device commences. This is possible mainly because the reuse of components which were activated during the operation of the TNS device is highly unlikely. Upgrading the TNS device by adding blanket segments to the reactor after an operating period may not be cost effective, since most of the upgrading modification would have to be done by remotely-operated manipulators, and thus would be time-consuming and costly. The upgrading of a TNS tokamak device to EPR stage would further be complicated by the fact that the structural support system for the TNS device would also have to be modified to clear the blanket section, or the blanket sections would have to be designed to suit the structural support system of the in-place TNS device.

A practical solution to this problem would be the construction of a combination TNS-EPR tokamak device, which has the blanket sections already built in. To what extent the blanket section

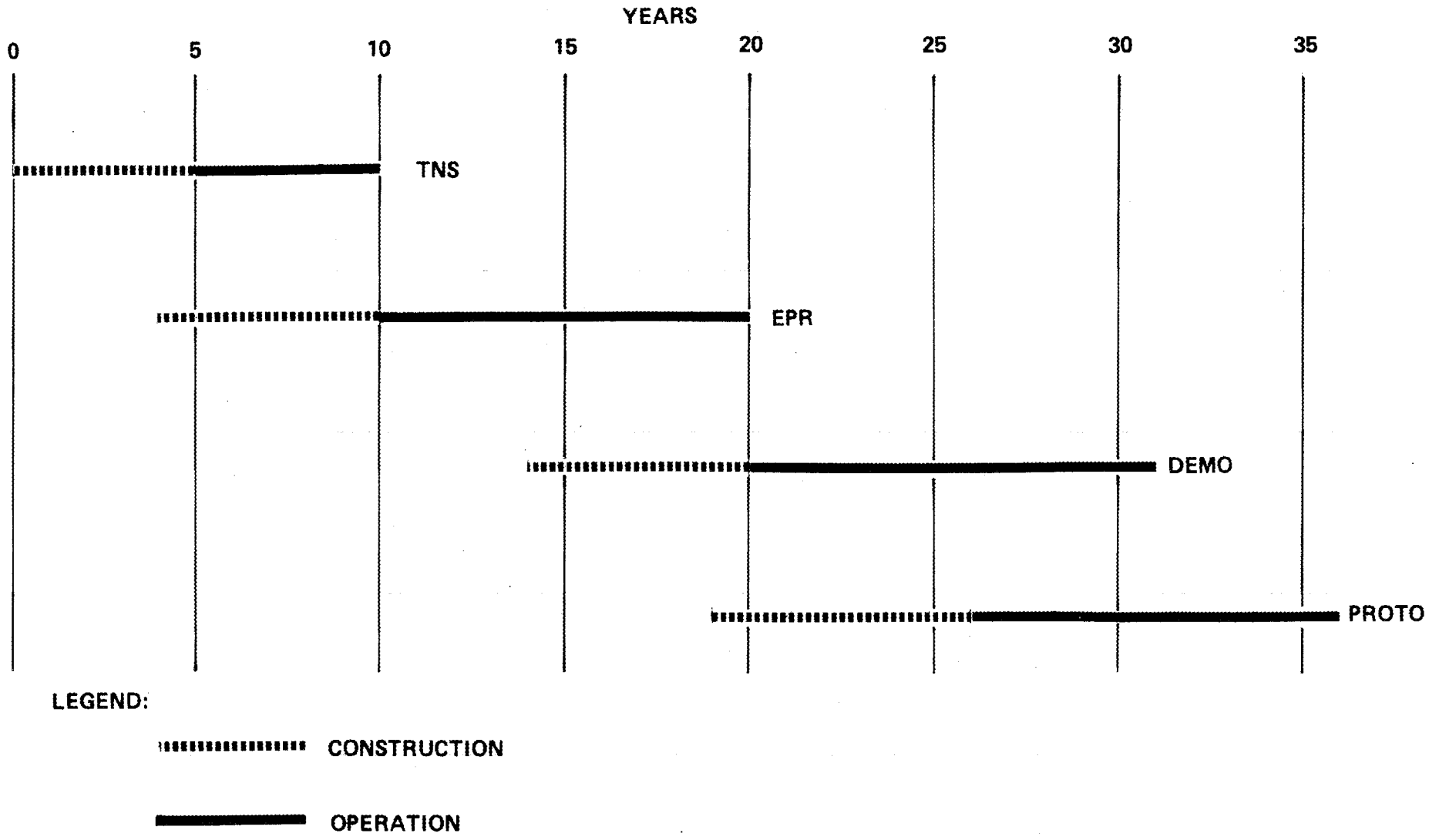


Figure 7-1

SCENARIO I
DEVELOPMENT OF ONE CONCEPT (TOKAMAK) IN ALL DEVELOPMENT PHASES
HYPOTHETICAL CONSTRUCTION AND OPERATING SCHEDULE

would be utilized during the TNS operation would be dependent on the design of the blanket, the cooling media used, etc.

The question of how the blanket design could influence the practicality of building multiple-use devices should be investigated in further detail since utilization of such devices would not only offer significant economic advantages, but could have definite schedule advantages.

The construction and operation of the TNS and EPR devices at the committed site is easily visualized and predictable based on our present knowledge of the candidate fusion concepts. Whether the construction and operation of the demonstration and prototype size devices are practical and advisable at the committed fusion development site is not clear. The involvement of the electric power generating utilities may have a decisive influence over where these larger devices are going to be built and how they will be operated. Just what political, organizational, and financial arrangements have to be made to obtain utility participation in the final design and construction management for these larger devices is not predictable at this time.

## 7.2 SCENARIO II - PARALLEL BUT SEQUENCED DEVELOPMENT OF TOKAMAK AND TANDEM MIRROR DEVICES

This scenario assumes parallel but slightly phased construction and sequential operation of tokamak and tandem mirror devices. This scenario requires the simultaneous operability of two devices in each development phase except the electrical (the dc system). It also assumes that the dc requirements of the two devices are compatible, so a single, centrally located dc system can service either by merely switching the dc power from one to the other. This scenario is shown in Figure 7-2.

The relatively low duty cycle of the TNS and EPR devices may make the multiple use of the expensive dc power supply system possible. While this system is serving the experimental operation of one device, the evaluation of the data collected during the previous experiments of the other device can be performed. Any modification which may be required in one device can also be performed while the other one is operating.

The proper sequencing of the experiments and/or operation of two devices utilizing a single dc power supply system would not only result in substantial economic advantages, but also offer schedule gains. Considering the relatively short operating time and long downtime required for evaluation of the results of the operation, it appears feasible to conduct experimental programs on the two devices, concurrently. However, there will almost

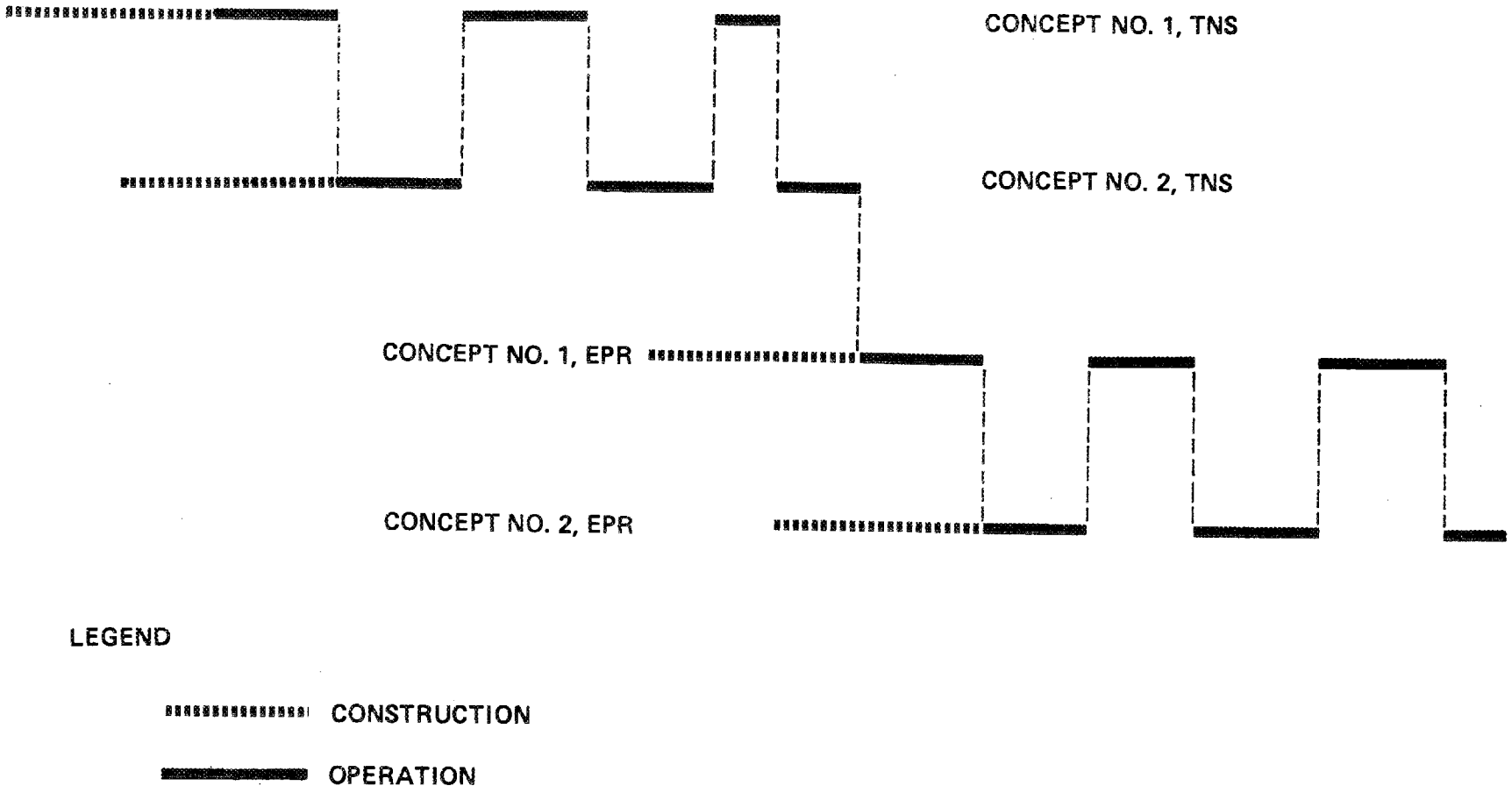


Figure 7-2

SCENARIO II
PARALLEL, BUT PHASED DEVELOPMENT OF TWO ALTERNATE FUSION CONCEPTS
IN TNS AND EPR PHASES.
HYPOTHETICAL CONSTRUCTION AND OPERATING SCHEDULE

certainly be conflicts from time to time and the feasibility of this mode of operation should be further evaluated.

If the EPR devices turn out to be used general fusion test facilities for technology similiar to the EBR II in the Liquid Metal Fast Breeder Reactor development program, it is conceiveable that the EPR devices will operate for a long time. In that case, it must be determined which of the two fusion concepts is the more useful from the overall fusion technology development point of view, and concentrate on the continuous operation of that one. The other device can be either abandoned or replaced with another fusion device. During construction of this second device, the operation of the preferred one still can go on uninterrupted until the new one is ready for testing and/or operation. So the versatility of Scenario II is quite favorable as long as the dc and other process system requirements of the two devices can be maintained compatible.

The construction and operating schedule for Scenario II, shown in Figure 7-2, covers the TNS and EPR development phases only. Theoretically, this schedule can be extended to cover the demonstration and prototype phases also. Assuming, however, that these more advanced development phase devices will operate for a long time with medium- to occasionally heavy-duty cycle, the advantages of shareable service systems and facilities are not nearly as pronounced as for the earlier development phases. Uncertainties associated with utility involvement in the final design, construction management, and operation of these large

devices make it even harder to predict whether they should be located at the committed site.

It is suggested that the question of locating demonstration and prototype devices be reevaluated when plans for them are definitive.