This ORNL Study has resulted in an evaluated Reference Design that does satisfy the technical objectives set out for a tokamak Experimental Power Reactor. Because of the large size and cost and poor extrapolation of this design to a demonstration reactor, a reconsideration of the basic physics and range of technical objectives has been undertaken. This has led to an intermediate step and new design, TNS-The Next Step after TFTR, having a higher benefit/cost than EPR. The TNS experiment, now in the early design phases, is based on a smaller size and considerably higher power output than the EPR design, and extrapolates to an economically viable fusion reactor.

1. Summary of EPR Study
1.1 INTRODUCTION
In terms of the overall fusion design process, the FY1975-76 EPR study represents the most extensive effort to date in advanced studies of early power reactors though it is still only the present point on the evolutionary scale of design for the first fusion 'reactor'. The results of this study, discussed herein, have been twofold. On the detailed technical level many issues have been investigated and more clearly appreciated; work is now underway to address the problems identified. On the broader programmatic level, the need for an achievable, high power density fusion plasma device, extrapolatable to an economically viable reactor has been keenly made clear. The present EPR design does not satisfy the economic viability criterion although it does satisfy the technical requirements. The recognition of the
This ORNL Study has resulted in an evaluated Reference Design that does satisfy the technical objectives set out for a tokamak Experimental Power Reactor. Because of the large size and cost and poor extrapolation of this design to a demonstration reactor, a reconsideration of the basic physics and range of technical objectives has been undertaken. This has led to an intermediate step and new design, TNS-The Next Step after TFTR, having a higher benefit/cost than EPR. The TNS experiment, now in the early design phases, is based on a smaller size and considerably higher power output than the EPR design, and extrapolates to an economically viable fusion reactor.

1. Summary of EPR Study

1.1 INTRODUCTION

In terms of the overall fusion design process, the FY1975-76 EPR study represents the most extensive effort to date in advanced studies of early power reactors though it is still only the present point on the evolutionary scale of design for the first fusion 'reactor'. The results of this study, discussed herein, have been twofold. On the detailed technical level many issues have been investigated and more clearly appreciated; work is now underway to address the problems identified. On the broader programmatic level, the need for an achievable, high power density fusion plasma device, extrapolatable to an economically viable reactor has been keenly made clear. The present EPR design does not satisfy the economic viability criterion although it does satisfy the technical requirements. The recognition of the pressing need for higher power density operation has led to the development of the TNS program; The Next Step after TFTR is being pursued as an ignition device whose characteristics do extrapolate to an economically viable fusion reactor.

1.2 Principal Considerations at the Outset of the EPR study

1. EPR is a major step in the U. S. fusion program.

As such, it is necessary for rational fusion program planning that a clear picture of the EPR's nature, magnitude, requirements, and options be generated as input to the overall plan.

2. This study is a forcing function for science and technology.

In the iterative process of defining objectives, projecting current scientific and technological understanding to reactor application, undertaking engineering design, and then comparing costs and schedules with objectives, two critical benefits emerge:

*Research sponsored by the Energy Research and Development Administration under contract with Union Carbide Corporation.*
• the technical issues are better addressed, because the implications that emerge from the extrapolation of current ideas are made clear to the community, and
• the key research, development, and demonstration needs become better defined and the ongoing programs more able to contribute effectively.

3. The effort is conceptual in nature and not intended to result in a project proposal.
At this early stage, the emphasis is placed on defining what is technically necessary and feasible and not on preparing to build the device. The study aims at the identification of problem areas and the development of possible solutions using an engineering-oriented reference design.

With the resources available, the study has been further limited to the examination and technical evaluation of the key reactor systems (plasma, magnets, blanket, beams). A secondary emphasis has been placed on the balance of the plant systems.

4. This study was conducted using a project orientation.
Given the manifold problems so closely linked to ongoing research and development, and the perhaps surprisingly tight schedule for the execution of a major project even ten to fifteen years in the future, the study was organized into a project environment. This approach was used to couple effectively the systems-oriented technical personnel with the research and development specialists and with the engineering design team. This permits technical judgments to be made on the basis of available information in time to meet project requirements.

1.3 Relationship to Other Studies*
The EPR is envisaged as a step leading to the Demonstration Reactor Plant (Demo) and the succeeding Commercial Power Plants (CPP). In view of this role, the EPR study has been conducted in parallel with a Demonstration Plant study where the principal concepts for EPR were extrapolated to the Demo and CPP and designs acceptable for all three applications were sought.
The nature of EPR as an early fusion reactor requires that the study be closely connected to all other relevant fusion work. This is the case at ORNL. Through the work of the plasma engineering personnel the best information available from the experimental and theoretical plasma effort here and elsewhere is included in the EPR study. In the technology areas, the ongoing development work in large superconducting tokamak magnets, in high-power, long-pulse neutral beams, and in nuclear technology areas is reflected in the EPR study.

1.4 Objectives of the EPR
A clear view of the EPR is essential to the effective performance of the EPR study. The EPR objectives were outlined by ERDA-DHFE+, they are summarized here from the results of the first task in the ORNL study and form the base for the remainder of this paper.
The EPR itself is viewed as the first facility to generate significant amounts of high temperature fusion-derived energy with continuous high duty cycle operation.


†Tokamak Study 1975 ERDA-DCTR Washington, D. C.
The objective of the EPR program is to advance the science and technology required for commercial fusion power by providing on a timely basis:

- system operating experience and testing of components and subsystems for a larger demonstration plant,
- a focal point for research and development programs, and
- large-scale testing of plasma physics scaling including the effects of an ignited deuterium-tritium plasma.

This general objective requires that the EPR program qualify for subsequent demonstration (in the Demo) all essential features of a safe, reliable, working fusion power plant.

As a critical control, the EPR must:

- be able to accomplish the technical objectives in a timely and economical manner.

"Timely" means that design, construction, and operation of the EPR fit smoothly with the preceding experiments and expedite successful Demo operation. "Economical" means that the actual total program costs be a reasonable step up from the preceding experiment and, as importantly, that the extrapolation of the EPR costs both to larger power output and to the economics associated with scale be reasonable.

1.5 Summary of Activities

The principal activities in the EPR Program thus far fall into three major phases: a scoping study,(1) development of a reference design,(2) and evaluation of the reference design.(3)

Based upon the findings of the broad scoping study which identified problem areas and potential solutions, a reference design was established as the design focus for the EPR studies in FY 76. Choices in the reference design were based on the following considerations:

- high probability of providing a successful scientific experiment based on extrapolation of current plasma physics, and
- high probability of technological and engineering feasibility in the 1980's, derived from research, development, and demonstration programs in the late 1970's.

1.5.1 Description of the September 1975 Reference Design

A set of basic machine parameters for the EPR Reference Design were chosen which would produce a reactor-grade plasma with significant neutron flux. These parameters included the following: minor radius of 2.25 m, major radius of 6.75 m, magnetic field on axis of 4.8 T (requiring use of Nb,Sn conductor with 11 T at the winding), and plasma current of 7.2 MA.

Despite uncertainties in plasma scaling, it was possible to predict that the neutron flux will be produced under both beam-driven and ignition conditions. The neutral beam power needed was 100 MW, with an accelerating voltage of 200 keV. The safety factor of(α) was 2.5. Burn time was 100 sec, with a duty cycle equal to 50%. The overall diameter was 22 m. The output power for a driven system was ~ 400 MW(t) and for a system under ignition conditions was ~ 200 MW(t), for the specific operating modes examined.

1.5.2 Improvement of the Reference Design

The bases upon which the Reference Design was established varied widely from explicit calculations to management judgments. Consequently, the major thrust of the work in FY 76 was to perform a technical evaluation of the Reference Design and to upgrade it where necessary. A number of technical issues were addressed, and where possible "solutions" were developed. That is to say, those ideas concerning
outstanding problems which upon serious consideration appeared to be feasible design concepts have been proposed and examined in a number of key areas. In the current reference design, for example, the following have been added to the original reference design:

- A fuller description of an ignited plasma.
- A new modular, maintainable, workable blanket design.
- A new TF magnet design more credible in terms of fabrication. Additional analytic tools have been developed and used to define more closely the stability margin and the ac losses.
- In-depth study of the enhanced heating and electromagnetic shielding systems driving the plasma current, protecting the TF coils, and reducing the energy requirements. Critical questions have been identified.
- Establishment of the basis for the overall structural system.
- A first pass at the balance of plant.

1.5.3 Evaluation of the Design

In addition to re-emphasizing the importance of resolving the key technical issues, the conceptual development of some of the technical problems has identified some very difficult judgmental problems.

- The mechanical system is extremely complex. Even though a case can be made for the successful execution of any one of the successive execution of all them simultaneously seems doubtful.
- Of the required extrapolations in plasma physics parameters, it is the extrapolation with pulse time that is the greatest and hence the most uncertain.
- Each of the component technologies is being pushed and extended significantly beyond present capabilities.

1.5.4 Principal Scientific and Technological Considerations

The fusion power produced in a magnetic confinement system varies as the square of beta; therefore, the attainment of high beta has been emphasized in the EPR studies. In the ORNL EPR studies, $\beta_p$ has been limited to $\sim A$. As a result, the total attainable $\beta$ in the EPR designs is $< 3\%$. Elongation of the plasma may permit an increase in the attainable value of $\beta$, but uncertainties exist in the equilibrium and stability behavior to be expected in such cases, and economic and engineering difficulties are associated with producing a high degree of elongation. The incentive for elongated plasmas is clear, but the actual advantage remains to be determined.

Although the fusion power varies as the fourth power of the magnetic field, the importance of achieving the highest possible value of $\beta$ follows from the difficulty of obtaining high magnetic fields. The strength of the magnetic field, $B$, which can be utilized in a magnetic confinement device is constrained by technology: there is a limit on magnetic field for the two types of superconductor, NbTi and Nb$_3$Sn, which are available in commercial quantities. In addition, practical engineering considerations and economic constraints may prevent the use of fields much in excess of 12 T at the surface of the superconducting coil.

The EPR design is of a low aspect ratio machine. Once an aspect ratio has been chosen, the magnetic field in the plasma is determined by the maximum allowable field at the conductor. There is thus strong motivation to utilize the more expensive high-field superconductors. However, the use of high-field superconducting magnets in a low aspect ratio torus results in extreme asymmetric forces on the coils; these forces must be minimized by the fabrication of
asymmetric coils. Unfortunately, the fabrication of such asymmetric coils is complicated by the fact that they must be of large size, in accord with the EPR designs.

The size of the EPR plasma and its blanket and shield determines the size of the superconducting coil. The plasma size is determined by the scaling laws used to specify the energy containment of the plasma. All of the EPR designs have used the so-called trapped-ion mode scaling to specify the energy containment time. This has led to large plasma sizes, which are necessary in order to attain an $n_t$ near the ignition condition. This large plasma size, combined with the necessity for a blanket and shield between the plasma and the superconducting coils, has resulted in EPR superconducting coil sizes of roughly $7 \times 10^2$ m (horizontal and vertical dimension) weighing several hundred tons apiece.

Finally, analysis of thermal cycling effects and techniques of remote maintenance and assembly of the toroidal blanket and shield structure in a low aspect ratio EPR has revealed great practical difficulties, which could be alleviated by increasing the aspect ratio.

The following is a general listing of the problems encountered in the EPR designs produced to date:

1. inherently unmanageable shape (low aspect ratio)
2. pulsed operation
3. exacting tolerances on very large components
4. radiation damage requiring replacement of internal components by totally remote means
5. very low inherent power density
6. very large electric power demands
7. excessively complex auxiliaries
8. questionable breeding potential.

Many of these difficulties result from the plasma physics scaling laws and $\beta$ relationships discussed above. If the power density and the aspect ratio could be increased, many of these problems would be less severe.

1.6 Conclusions

- EPR should produce a significant amount of power.

The step in the fusion program that encompasses thermonuclear power production at a high duty cycle will be large, difficult, and costly. Since this step appears to be inherently very expensive, it should be accompanied or characterized by production of an amount of power that represents a significant fraction of the output of a commercial power plant.

- The assumption and requirements used in the EPR study have resulted in a large device and the need for major technology extrapolations.

The inherent difficulty and associated cost follow directly from the need for a large device. The size is dictated by the plasma scaling assumptions used in the study and by the blanket/shield needs to satisfy the requirement of continuous, high duty cycle operation at hundreds of thermal megawatts. The toroidal field magnet size compatible with this system is of itself very large and is a major extrapolation from present experience. Similarly, the neutral beam power requirements and ohmic heating system characteristics far exceed those of present devices.

- The current EPR device is uncomfortably large and the power output is uncomfortably small.

For a device of the size and complexity of the current EPR design, the cost appears to be in the range of $1-2$ billion. The fusion power density depends on a number of variables and can potentially be improved by technical advances. Therefore, effort...
must first be directed toward developing improved performance in a device of reduced size.

- EPR, as presently conceived, is not the next logical step.

Since the magnitude of the EPR task is such a large increment beyond the present state of the art and since the benefit is uncertain, the EPR is not the next logical step to take in the fusion program. Following the line of argument above, efforts are needed to conceive, develop, and demonstrate means of improving the fusion power density before an EPR is undertaken. These efforts are discussed in Section 3 below.

2. THE UPDATED EPR REFERENCE DESIGN

2.1 Description

As a result of intensive evaluation of the blanket and magnet systems of the September 1975 Reference Design, along with a continuing examination of the plasma engineering basis, an updated Reference Design has been generated. Although significant improvements have been made in the key systems, this updated design does not represent a full iteration of the design, in particular, there is no change in plasma shape or impurity control, both of which would be changed in a new Reference Design. A full and summary descriptions of the Reference Design are contained in Reference ORNL/TM-5576 and ORNL-EPR study - Results and Implications, D. G. McAlees to be presented at the ASME Winter Annual Meeting Transactions, New York, New York - Dec 5-10, 1976.

The EPR is an ignited, D-T burning, power-producing, air core tokamak with superconducting toroidal field (TF) and, in large measure, superconducting poloidal field coils. The duty cycle is 87%, with a burn time of 100 sec. The machine has a major radius of 6.75 m, and \( \varepsilon \) circular plasma radius of 2.25 m (aspect ratio of 3.0). A blanket is provided to transfer a nominal 410 MW (t) from the burning plasma to a steam power cycle. For design purposes, the nuclear aspects of the EPR are based on a neutron wall loading of \( \sim 1 \text{ MW/m}^2 \), which is equivalent to a power output of 800 MW (t). Operation at this power level is considered an optimistic upper limit. A neutral beam system is provided to inject 50 MW of power into the plasma to achieve ignition. Figure 1 illustrates the elevation view. Figure 2 presents a composite chart of each of the key preparatory steps before operation and the key events during an operating cycle.

A tabulation of overall system parameters and their values for the EPR is shown in Table 1.

2.2 Evaluation

As an example of the system oriented work performed in this part of the study, the various aspects of the poloidal field system design will be highlighted here. Table 2 defines the research, development and demonstration needs of the PFS.

2.2.1 Purpose

The poloidal field system and magnetic shielding is consistent with a long-pulse, high-\( \beta \) tokamak with superconducting TF coils. It is nearly an optimal system, in the sense that it minimizes the volt-seconds required to set up the plasma current and permits an increase in pulse length and duty cycle. The EPR system minimizes the pulsed field at the superconducting TF coils (reduces \( \Delta \) by a factor of 6) in order to permit the highest toroidal field to be attained with the least risk of superconduction quenching. It has equilibrium field coils coupled closely to the plasma so that they will respond rapidly to large increases in plasma \( \beta \). An intrinsic advantage of such a system is a substantial reduction of power supplies (by 41%) and stored energies (by 34%) as compared to the designs without
magnetic shielding. In view of the uncertainties in the development of large, superconducting, high-field coils (TF) and pulsed high-field coils (OH-primary), the fact that the magnetic field shielding system makes available the options of using simpler superconductor coil designs makes it a likely candidate for future tokamak reactors.

2.2.2 Plasma Input Considerations

The plasma start-up problem has been considered on the basis of several effects. For very low pre-ionization, the breakdown of the plasma proceeds as an exponential increase in plasma density, and is described in terms of the gas discharge parameters $E/p$, $\alpha/p$, $V_p$, and $T_e$. The volt-second consumption depends critically upon the pre-ionization level. At 50 V and $p = 4.4 \times 10^{-4}$ torr in EPR, a density increase by a factor of $10^{12}$ requires 10.5 V·sec, whereas an increase by a factor of $i_c^2$ only requires 1.75 V·Sec. Such uncertainties have a strong impact on the PFS criteria. Similarly, since small radius or low-density start-up procedures may be required in the EPR and future power devices, additional time dependent control may well have to be incorporated in the PFS.

2.2.3 Design Considerations for the PF System

The function of the PF coil system is to create, pre-heat, and develop the plasma current, and to maintain and stabilize the plasma column. Usually the system consists of two different sets of coils: the ohmic heating (OH) coils, which provide the necessary flux swing, and the equilibrium vertical field (VF) coils, which serve a stabilizing function (although the latter usually also supply significant volt-seconds).

An important design consideration is the position of the VF coils: inside or outside of the TF coils. Placing the VF coils outside the TF coils is the engineer's choice, as it makes assembly and maintenance jobs simpler. On the other hand, placing the VF coils inside could lower the ampere-turn and energy storage requirements of the PF coil system; by a proper design, this alternative could also reduce pulse fields on the TF coils and provide an option of shaping the plasma. The physics advantages were judged to be strong enough to take the latter approach. With this scheme, a set of shield-vertical field (S-VF) coils is placed inside the TF coils, a counterwrap winding of decoupling coils is placed at the same locations as the OH winding, and a set of trim-vertical field (T-VF) coils is used for the fine-tuning of the vertical fields. Figure 1 shows the locations of the different sets of PF coils. Because of the engineering difficulties anticipated in the construction, the S-VF coils are room-temperature, normal conductor windings. The rest of the vertical field coils and the OH coils are superconducting coils, as the power and refrigeration requirements for these coils are found to be prohibitively high if they are non-superconducting.

2.2.4 Remote Maintenance Implications

Key assembly questions have been examined for feasibility of the design concepts. The basic approach to the Reference Design has been to assume that the center compression hub and the large TF coils would be semi-permanent installations, and that all other components could be removed and replaced without moving them. Modular construction of the vacuum vessel, blanket, and shield units has been proposed to facilitate the design and development of remote handling equipment.

The design of the connecting joints of the shield-vertical field windings must therefore be meshed in with the overall design. Sixteen conductors recessed into
the inner shield surface form this coil, which lies in a toroidal direction around the plasma. These coil segments are made up 2\(\times\)2-in. copper extrusions, and they have a 1/4-in. hole in the center of water-cooling. Nine of these conductors are potted in a square to make up the conductors of the coil segments. These segments are bolted into the shield segments before the shield segments are installed in the reactor. When the shield segments are put in place, each of the 16 coil segments extends beyond the edge of the shield on each side. The coil segments in one shield match the corresponding coil segments in the adjacent shield. A square bus with a special terminal fixture is situated on each end of the segments, and a special clamping clevis engages adjacent coil terminals, completing a mechanical and electrical joint between coil segments. This detailed study was conducted because the reference OH system forms a fundamental constraint on machine assembly, which in turn dictates strongly the overall cost effectiveness of EPR.

2.2.5 Summary

Running across the various areas of plasma phenomena is the set of electromagnetic effects linking the plasma to the outside environment. This areas, most aptly described as plasma magnetics, has been the scene of much innovation and progress, which has resulted in large part from focus on EPR. Careful, detailed distributions of ampere-turns providing and matching appropriate plasma conditions have been calculated. Conception and development of the TF coil shielding idea finds its basis in an understanding of plasma magnetics. Investigation of this scheme leads to a comprehensive calculation of volt-second demands, but even here experimental evidence is sorely needed to verify or to guide choices in volt-second requirements in the transient states. A remaining undetermined factor is the actual magnitude of the changing magnetic fields at the TF coils which may lead to significant hardware demands on both refrigeration and ohmic heating supplies.

On the technological side, three issues stand out, namely, conductor design, structure and energy storage and transfer.

3. THE NEXT STEP

As the EPR study progressed and the findings at each of the EPR study laboratories became more definite, while remaining similar, attention was focused on the assessment of the implications of the findings of the study. These final sections discuss the Oak Ridge judgments concerning this assessment, and the actions to be taken.

The outcome of the EPR study indicates that intermediate steps will be required to support development of an EPR.\(^{(4,5)}\) 3.1 Clarification of the EPR Objectives

Examination of the set of EPR objectives indicates that many of the objectives subordinate to the ultimate EPR goal of net electric power can be achieved in earlier, lesser facilities. Those objectives that can only be achieved in an EPR are related to the high duty cycle and availability of the plant and to the full energy conversion and tritium breeding in the blanket. With the renewed assignment of these most advanced goals to the EPR, satisfaction of the subordinate objectives can be achieved at a benefit/cost ratio and cost level seen to be acceptable.

3.2 Re-thinking the Basic Physics

Extrapolation

In the assessment of the EPR situation it is quite clear that the basic plasma engineering assumptions concerning minimum size and field for ignition play a dominant role in setting the overall size and difficulty of EPR. Recent advances, both experimental
and conceptual, have led to a re-thinking of these basic assumptions. These advances indicate (1) that it may be possible to achieve higher β values than had previously been supposed, and (2) that operation at high density should provide improved performance. In setting up the basis for the next tokamak step, use will be made of the benefits of high-density plasma operation, and close attention will be given to a better understanding of its achievement. More data on the scientific basis for the postulated high-density, high-β operation will be forthcoming from the next generation of large experiments now under construction.

3.3 Plans for The Next Step

The Next Step Program (TNS) at ORNL has been initiated to develop the basis for a major experiment in the mid 1980's having two principal objectives, 1) achievement of a fusion reactor core, i.e. D-T ignition, and 2) forcing function for reactor technology. The ORNL-TNS program is based upon the operation of high density, hot plasma using technologies being developed in the DMFE plan. Long pulse length operation permitting burn dynamics to be studied is planned whereas continuous, high duty cycle operation is deferred until EPR. Preliminary calculations indicate thermal power output greater than 1500 MW in an \( n = 2 \times 10^{11} \) cm\(^{-3} \) plasma whose minor cross section is 1.25 m by 2.0 m high. From these preliminary indications, TNS will have a benefit/cost considerably greater than the EPR design discussed here and, furthermore, the extrapolation from TNS is to an economically viable fusion reactor.

REFERENCES

### A. General Characteristics

#### 1. Requirements

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Device lifetime</td>
<td>$t_L$</td>
<td>10 years</td>
</tr>
<tr>
<td>Duty cycle</td>
<td>$d_c$</td>
<td>87%</td>
</tr>
<tr>
<td>Availability - normal</td>
<td>--</td>
<td>80%</td>
</tr>
<tr>
<td>Thermonuclear power (ignition)</td>
<td>$P_0(\text{th})$</td>
<td>410 MW</td>
</tr>
<tr>
<td>Net Electric power</td>
<td>$P_0(\text{e})$</td>
<td>30 MW</td>
</tr>
</tbody>
</table>

#### 2. Other Features

<table>
<thead>
<tr>
<th>Parameter</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Plasma radius</td>
<td>$a$</td>
<td>2.25 m</td>
</tr>
<tr>
<td>Major radius</td>
<td>$R_0$</td>
<td>6.75 m</td>
</tr>
<tr>
<td>Aspect ratio</td>
<td>$A$</td>
<td>3.0</td>
</tr>
<tr>
<td>Plasma edge to winding distance</td>
<td>$\Delta$</td>
<td>1.40 m</td>
</tr>
<tr>
<td>Plasma volume</td>
<td>$V$</td>
<td>675 m$^3$</td>
</tr>
<tr>
<td>Overall height</td>
<td>$H$</td>
<td>15 m</td>
</tr>
<tr>
<td>Overall diameter</td>
<td>$D$</td>
<td>23.3 m</td>
</tr>
</tbody>
</table>

### B. Plasma Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Burn time</td>
<td>$t_B$</td>
<td>100 sec</td>
</tr>
<tr>
<td>Current</td>
<td>$I_p$</td>
<td>7.2 MA</td>
</tr>
<tr>
<td>Confinement measure</td>
<td>$N_{e-E}$</td>
<td>2.7 x 10$^{13}$ sec cm$^{-3}$</td>
</tr>
<tr>
<td>Plasma temperature</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ion temperature</td>
<td>$T_{\text{ion}}$</td>
<td>12.2 keV</td>
</tr>
<tr>
<td>Electron temperature</td>
<td>$T_e$</td>
<td>13 keV</td>
</tr>
<tr>
<td>Beta poloidal</td>
<td>$\beta_p$</td>
<td>1.9</td>
</tr>
<tr>
<td>Beta (total)</td>
<td>$\beta$</td>
<td>0.03</td>
</tr>
<tr>
<td>Safety factor</td>
<td>$q$</td>
<td>2.5</td>
</tr>
<tr>
<td>Electron density</td>
<td>$N_e$</td>
<td>7.4 x 10$^{13}$ cm$^{-3}$</td>
</tr>
<tr>
<td>Fuel ion density</td>
<td>$N_i$</td>
<td>7.0 x 10$^{13}$ cm$^{-3}$</td>
</tr>
<tr>
<td>Impurity level</td>
<td>$Z_{\text{eff}}$</td>
<td>1.34</td>
</tr>
<tr>
<td>Injection deuteron energy</td>
<td>$P_b$</td>
<td>50 MW</td>
</tr>
<tr>
<td>Injected deuteron energy</td>
<td>$E_b$</td>
<td>200 keV</td>
</tr>
<tr>
<td>Particle confinement time</td>
<td>$\tau_p$</td>
<td>9.6 sec</td>
</tr>
<tr>
<td>Energy confinement time</td>
<td>$\tau_E$</td>
<td>3.7 sec</td>
</tr>
</tbody>
</table>

### C. Electromagnetic Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum toroidal field</td>
<td>$B_{\text{max}}$</td>
<td>11 T</td>
</tr>
<tr>
<td>Toroidal field on axis</td>
<td>$B_T$</td>
<td>4.8 T</td>
</tr>
<tr>
<td>Number of toroidal coils</td>
<td>$N_c$</td>
<td>20</td>
</tr>
<tr>
<td>Magnetic field ripple at plasma edge</td>
<td>$\Delta B$</td>
<td>2.2%</td>
</tr>
<tr>
<td>Conductor configuration</td>
<td>--</td>
<td>composite cable in a square aluminum conduit</td>
</tr>
<tr>
<td>Superconductor</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 1. (CONTINUED)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Superconductor</strong></td>
<td></td>
</tr>
<tr>
<td>in the high field region</td>
<td>--</td>
</tr>
<tr>
<td>in the moderate and low field region</td>
<td>--</td>
</tr>
<tr>
<td>Average poloidal field at plasma edge</td>
<td>$B_p$</td>
</tr>
<tr>
<td>Poloidal field coil core type</td>
<td>--</td>
</tr>
<tr>
<td>Poloidal coil volt-seconds</td>
<td>VS</td>
</tr>
</tbody>
</table>

**D. Thermal**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum power rating of blanket</td>
<td>$P_R$</td>
</tr>
<tr>
<td>Blanket coolant</td>
<td>--</td>
</tr>
<tr>
<td>Outlet temperature of blanket coolant</td>
<td>$T_{out}$</td>
</tr>
<tr>
<td>Blanket coolant pressure</td>
<td>$P_{He}$</td>
</tr>
<tr>
<td>Shield coolant</td>
<td>--</td>
</tr>
<tr>
<td>Coil coolant (superconducting)</td>
<td>--</td>
</tr>
</tbody>
</table>

**E. Nuclear Parameters**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutron flux on first wall (operating point)</td>
<td>$P_W$</td>
</tr>
<tr>
<td>Neutron wall loading (design point)</td>
<td>$P_W$</td>
</tr>
<tr>
<td>Neutron flux on first wall (operating point)</td>
<td>$\phi_W$</td>
</tr>
<tr>
<td>Neutron flux on first wall (design point)</td>
<td>$\phi_W$</td>
</tr>
<tr>
<td>Tritium breeding ratio (in one experimental module)</td>
<td>BR</td>
</tr>
</tbody>
</table>
OAK RIDGE EPR DESIGN
ORNL-DWG 76-11696

INITIAL START UP

10 DAYS

OPERATING CYCLE (113 sec. period)

6 HOURS

INJECT

PULSE ON

FUEL

ON

COIL

BEAM ON

INJECTORS

BURN

PULSE CHARGE ON

COIL AND

EVACUATE

TORUS

COOL

6 HOURS

100 sec.

1 sec.

25 sec.

3 sec.

100 seconds

TIME INTERVAL

OHMIC HEATING COIL CURRENT

BEAM CURRENT ABSORBED BY PLASMA

CURRENT EXTINGUISHED

PLASMA CURRENT

TOROIDAL FIELD, Bmax

TORSUS VACUUM

EVACUATE

TORSUS

COOL DOWN

BEAM ON

COIL CHARGED

ROUGHING PUMPS

OPERATING

COOL DOWN

CRYO PANELS

INJECT

FUEL

TORSUS

MEGAMOTOR

HELIUM FLOW

POWER REQUIRED, MAX

HELIUM FLOW

Fig. 5

EPR OPERATING CHART.