2. REQUIREMENTS AND GOALS FOR COMMERCIAL AND DEMONSTRATION FUSION POWER PLANTS

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2. REQUIREMENTS AND GOALS FOR COMMERCIAL AND DEMONSTRATION FUSION POWER PLANTS

2.1. INTRODUCTION

The demand for substantial increases in electrical power requirements has been forecast for decades. Conservation and use of relatively inexpensive fuel have reduced the need to develop new electrical energy sources, affording more time for the development of new sources of energy. At the same time, environmental concerns have severely curtailed many of the previously viable electrical sources. Improved power plants using existing energy sources are meeting with increasingly difficult regulations to continually improve both local and global environmental impacts. Fusion offers the promise of an abundant energy source that is not tied to national resources and will have only a minimal impact on the environment. As such, there exists a window of opportunity to become a substantial provider of electric power.

During the past decade, enormous progress has been made toward demonstrating the necessary physics and engineering goals in experiments such as DIII-D, TFTR, JET, and JT-60. The proposed ITER device will continue to advance the state of knowledge toward a clearer understanding of the creation, control, and use of large-size tokamak plasmas. The last step in the development of fusion is a demonstration power plant which is built and operated to assure the user community that fusion is ready to enter the commercial arena of electrical power generation.

Paramount to a project such as the U.S. Fusion Demo is understanding the customer needs. From that, one can derive a qualitative mission statement which describes the intent and purpose of the project and how it addresses customer needs, and the requirements which translate the customer needs into quantitative measures. Based on experience and the existing data base, conceptual designs are then developed and used to refine the requirements, as well as to identify critical issues and R&D needs. An R&D implementation plan is then produced and implemented. This concept development phase may be repeated as further conceptual designs are developed, based on the new data and new R&D, until sufficient confidence is achieved to proceed with the preliminary design phase of the project.

In this context, the Starlite project was commissioned to initiate the process by investigating the mission, requirements and goals, features, and key R&D requirements of an electricity-generating, fusion demonstration power plant. The project includes broad participation from several organizations in the U.S. engaged in fusion research, including universities, national laboratories and industrial partners. A fully integrated approach to power plant analysis and design was adopted. A set of criteria for fusion power has been derived based on interaction and advice from the utilities and industry. These criteria were then used to develop a mission statement as well as top-level system requirements for the commercial and demonstration fusion power plants. This work is reported in this section. Several candidate options for the physics operating regime as well as the engineering design of various components (*e.g.,* choice of structural material, coolant, breeder) have been developed and assessed against the top-level system requirements and reported in the remaining sections of this report.

2.2. REQUIREMENTS & GOALS FOR FUSION POWER

A demonstration power plant will be built and operated in order to assure the user community (the general public, utilities, and industry) that fusion is ready to enter the commercial arena of electrical power generation. Thus, the requirements and goals for acceptance of fusion power must first be defined.

Power producers (utilities and independent power producers) and the industries that manufacture the power plants demand that any source of energy will be a commercial success (*i.e.,* affordable, profitable, and meeting public acceptance). The general public and government agencies ask for an energy source which is safer, generates little or no waste, does not deplete limited natural resources, and has minimal effect on the environment. These are common goals shared by all other existing and alternative energy sources. Fusion power, therefore, should meet these goals.

Fusion power in its present embodiments will result in a large, central-station power plant. At present, the investor-owned, public electric utilities best represent the customers for this type of power plant. To better understand the needs of this class of customer, the Starlite Project solicited several large public utilities and support industries to help define the requirements and goals for fusion power. Several utilities and industries agreed to help establish and participate in a Power Plant Studies Utility Advisory Committee. This committee provided advice to help formulate the mission and goals for fusion in general, and for a fusion demonstration power plant in particular. The case for an attractive fusion power was developed, as shown in Table 2.2-I and discussed below (A similar set of criteria has been developed by the EPRI fusion working group [1]):

Cost advantage over other available central station options. Because fusion is a new technology in the energy marketplace, it must have a cost advantage to offset the inherent technical risk of a new technology; otherwise, it will never be widely endorsed. It should be noted that this cost reflects a complete life-cycle cost; that is, it includes costs associated with decommissioning, waste-disposal, costs due to delays in licensing and/or public opposition to an evacuation plan, *etc.* Fusion should achieve its full safety and environmental potential for it to have a cost advantage over other sources of electricity.

Eased licensing process. To circumvent the difficulties experienced by fission, fusion should be easy to license by the national and local regulating agencies. Only through the use of low-activation materials and failure-tolerant design will fusion power plants be designed such that the consequences of an accident are minimal.

Table 2.2-I.
Elements of the Case for an Attractive Fusion Electric Power Source

1.	Cost advantage over other available central station options
2.	Eased licensing process
3.	No evacuation plan needed
4.	No high-level waste produced
5.	Reliable, available, and stable electrical power production
6.	No local or global atmospheric impact
7.	Closed on-site fuel cycle
8.	High fuel availability
9.	Plant capability of load-following
10.	Availability in a range of unit sizes

No evacuation plan needed. In order to gain public acceptance and support, fusion should demonstrate that it does not disturb the day-to-day life of the public. Fusion must be perceived by the public to be inherently safe. To support this criterion, fusion power plants should not require a site evacuation plan.

No high-level waste produced. An important public demand is that new technologies not provide a burden for future generations; that is, waste generated should be either recyclable or disposable in a time frame which is within a human life span. Therefore, to gain public acceptance, fusion should not produce long-lived high-level waste.

Reliable, available, and stable electrical power production. Because fusion is a new technology, it must demonstrate that it can achieve the necessary degree of reliability. This criterion should be addressed early in the development path of fusion power. Todays experiments are, by their charter, experimental devices and are not intended to provide detailed engineering data to support the design, construction, and operation of a power plant. Experiments with burning plasmas will provide some data, but the design and construction cycle of these devices are so long that data can be obsolete by the time they are obtained. This set of requirements is perceived as the most difficult to achieve in a time-constrained development program.

The remaining criteria are foreseen as reasonably easy for fusion to achieve but are significant attributes for an electrical power source. The desire for no atmospheric impact is a powerful requirement in light of the difficulties of competing energy sources. No scrubbers, containment buildings, or special active safety systems will be needed in fusion plants. The self-contained fuel located on site is a powerful advantage that circumvents strikes, natural calamities, and adverse supplier actions. This helps the utility better control their self destiny. Fuel availability is similar in that all elements in the fuel cycle are in abundant supply with no critical resource shortages. The last two criteria deal with how well the fusion plant will function in conjunction with the power network and the time-varying energy demand. There appears to be no difficulty in designing a fusion plant to load-follow (*i.e.,* operate at a fraction of their full power rating). Availability in a range of sizes is limited only by the fact that smaller sizes would tend to be more costly on a COE basis.

If there were reasonable assurances that this set of high level criteria could be met by a demonstration power plant, then the decision to purchase a commercial fusion electrical power plant would likely be positive. Thus the intent for the Demo power plant is to use these criteria as guiding features to help structure its mission and goals.

2.3. MISSION & REQUIREMENTS FOR THE FUSION DEMO

The prior section discussed the goals needed for the commercial plant to be accepted and to succeed. On the other hand, the Demo must "demonstrate" those attributes that would convince the utility or their investors and the public that this new technology, for long periods of time, is safe, economical, and does not harm the environment. The Demo need not meet 100% of all commercial power plant goal objectives, but the risk in eventually meeting those goals in a power plant must be acceptable. The public is very concerned about safety and environmental impact; thus this goal must be demonstrated to a high level of confidence, *i.e.,* low risk. The economics goal (for the Demo) would be difficult to meet without significant government or investor subsidies to artificially lower the capital and operating cost. Thus the owner/operator of this demonstration power plant must be able to operate the plant on the power grid for long periods of time and gain both operational experience and profit for the sale of electricity. The public perception of the interaction of the first fusion power plant with the environment will be a highly visible public issue. This is another area where the Demo plant must convincingly demonstrate over long time periods that fusion is a "good neighbor." There will have to be high visibility of all safety and environmental issues to comfort and sustain the public.

Based on the above arguments, the Starlite project has adopted the following mission statement for the U.S. Fusion Demo Power Plant:

The Fusion Demo demonstrates that fusion power is a secure, safe, licensable, and environmentally attractive power source that is ready for commercialization at an economically superior total cost.

This mission statement is supported by the demonstration of a set of qualitative attributes. These attributes include:

1. **Technology and Performance Demonstration:** Demo should use the same technologies as planned for commercial power plants. Introduction of a new technology (*e.g.,* different plasma operating regime, coolant, or structural material) would be inappropriate, as this would require that a new development path be initiated.

2. **Integration and Scalability Demonstration:** Demo should demonstrate all systems working as an integrated unit. The Demo should be large enough so that the step to the first commercial power plant is small.

3. **Economics Demonstration:** Initiation of the Demo construction requires clear demonstration that the successful operation of the Demo will lead to a economically superior power plant. Operation of the Demo should demonstrate that construction, operation, maintenance, and decommissioning costs are in the forecasted range, and that the power plant would have a competitive life-cycle cost of energy.

4. **Safety and Licensing Demonstration:** Demo should demonstrate that fusion power is safe. Demo should conduct demonstration testing, as an element of certification by regulatory agencies, which enhances public acceptance and will support timely licensing. Demo should provide the data base necessary to obtain certification by the regulatory agency of the standard plant in order to ensure timely licensing for commercial plants and instill investor confidence.

5. **Waste-Disposal Demonstration:** Demo should demonstrate that fusion generates only low-level waste and all waste can be recycled and/or disposed of at an acceptable cost.

6. **Decommissioning Demonstration:** Demo should demonstrate that decommissioning can be performed at an acceptable cost.

7. **Reliability Demonstration:** Demo should demonstrate that fusion power plants can operate within the prescribed performance envelope (load following, start-up and shutdowns, load ramp rates, endurance operation) with unscheduled internal events not exceeding the designed and prescribed values.

8. **Maintainability Demonstration:** Demo should demonstrate that fusion power plants can be maintained (both scheduled and unscheduled maintenance) within the prescribed cost/schedule envelope. This is necessary to both achieve the desired availability and eliminate the risk of a plant write-off because of a severe internal accident.

9. **Availability Demonstration:** Demo should demonstrate that fusion power plants meet or exceed availability targets that are competitive with other sources of electric energy.

10. **Operability Demonstration:** Demo should demonstrate ease of operation. Demo should demonstrate that routine emissions from the plant are all below allowable values.

11. **Industrial Supplier Demonstration:** Demo should stimulate an industrial infrastructure which is prepared to supply fusion power plants on order. Demo should

yield the industrial commitment to deploy the first series of commercial power plants.

12. **Power-Producer Interface Demonstration:** Demo should stimulate establishment of a power producer (user) interface which is prepared to provide operational support programs and support generic regulatory interactions in order to ensure timely penetration of fusion power plants into the market.

2.4. TOP-LEVEL REQUIREMENTS

The list of attributes, discussed in previous sections, must be quantified in order to formulate a Demo program and eventually define a credible conceptual Demo design which would lead to a commercially acceptable, electric generation plant. To quantify the goals or attributes supporting the Demo Mission Statement, the Starlite project defined a set of top level requirements for both the Demo and the commercial power plant, shown in Table 2.4-I. Each of these requirements will be discussed as to background and implications for meeting the requirements.

Commercially-relevant technologies. The U.S. Demo must use and demonstrate the same technologies that will be incorporated in a fully-commercial power plant. This requirement is fundamental in determining the features of the Demo and may or may not be adopted by other countries in their definition of a "Demo." If the basic technologies are changed following the Demo, then another Demo must be built before the design and construction of the commercial plant. A private investor will not accept risk of failure or reduced performance due to unproven and undemonstrated technologies. Additionally, it may be impossible to insure and/or license such a plant.

This requirement allows for the performance levels to be reduced from a fully commercial plant as specified in the remaining Demo requirements. For example, a reduced level of thermal efficiency, availability and component lifetime in the Demo (owing to less competitive cost of electricity) allows the components to be designed slightly different and operate at lower temperatures and stresses. There is no requirement that specifies the component operating conditions must be exactly prototypical.

However, through operation of the Demo, a high level of confidence must be gained so that the first commercial plant is assured to meet the more stringent commercial power plant requirements. If performance levels are reduced from that of a full commercial

Table 2.4-I.
Top-Level Requirements and Goals
for Commercial and Demonstration Fusion Power Plants

Element	Demo	Commercial
Must use technologies to be employed in commercial power plant	Yes	Yes
Net electric output must be greater than	75% commercial	N/A
Cost of electricity (COE) must be competitive (in 1992 mill/kWh)	80 (Goal)	65 (Goal)
	90 (Reqmt)	80 (Reqmt)
No evacuation plan required for any credible accident:		
Total dose at site boundary	< 1 rem	< 1 rem
Generate no rad-waste greater than	Class C	Class C
Must demonstrate public day-to-day activity is not disturbed	Yes	Yes
Must not expose workers to a higher risk than other power plants	Yes	Yes
Must demonstrate robotic maintenance of power core	Yes	Yes
Must demonstrate routine operation with less than		
(x) unscheduled shutdowns per year including disruptions	1	1/10
Demonstrate a closed tritium fuel cycle	Yes	Yes
Must demonstrate operation at partial load conditions at	50%	50%

plant, then the ability to extrapolate must be clearly demonstrated. The method to demonstrate this extrapolation has not been specified.

No evacuation plan. One of the most powerful advantages that fusion may possess is that the risk to the public may be low enough so as to not require an evacuation plan for the surrounding population. In discussions with the utilities, much time and effort are devoted to prepare for and obtain acceptance of the evacuation plans. If there were no need for an evacuation plan, the siting of the plant would be much eased and the licensing could be expedited.

Careful control of vulnerable tritium inventories should allow attainment of this goal of 1 rem total dose at the site boundary. Choice of power core materials and coolants will be tailored to eliminate or limit generation or transport of hazardous material to the site boundary. This will minimize the accident potential or consequence.

No radioactive waste greater than Class C. The requirement to generate no radioactive waste greater than Class C was levied on the Demo plant because there is a general public aversion to creating hazards that need protection for long periods of time. The governmental regulators are responding to the public concern by increasingly stiffening applicable legislation. Fusion power plants could be constructed and operated with a number of materials that could meet the physical design properties. However, it was anticipated that plants that generate high-level radioactive waste, even at small amounts, might result in an adverse public reaction. Power plants, both public and private, are highly visible by the general public and environmental groups. Thus to be prudent, Starlite adopted the requirement that all generated waste must meet the requirement to be Class C or better.

This stringent requirement requires that the in-vessel materials generally be made of low-activation materials. This would suggest vanadium, ferritic steel, or silicon carbide as the structural material. The composition of these materials would be tailored to eliminate or reduce offending trace elements that would contribute to high level radioactivity. There are still open questions as to the use of mixed waste, the degree of isotopic tailoring required, and the cost of meeting these requirements.

Public day-to-day activities not disturbed. The requirement to demonstrate the public day-to-day activities should not be disturbed arose from the desire to have public acceptance of fusion. Utilities spend a great deal of time and money assuring the public that they will not be disturbed. There are many public hearings discussing the intrusion of electrical generating plants into their communities. Fusion has long professed that it was a safe energy option and now it must demonstrate that indeed it is.

This requirement is foreseen to be a combination of many factors to assure the public that the fusion power plant will not intrude into their lives (except through the wall outlet). The requirement for no evacuation plan is an integral part of the plan. They can be assured that regardless of what happens at the plant, they will never have to be evacuated from their homes. The requirement for no high level radioactive waste assures that they will never worry about transportation of that waste through their highways, rivers, or rail lines. The on-site, closed fuel cycle minimizes the traffic of fuel suppliers.

Not expose workers to a higher risk than other power plants. Protection of the plant worker is also a strong incentive to provide safeguards. All work environments entail additional risks over and above that for non-work environments. Fission plants have adopted design approaches and strong requirements to safeguard their employees from nuclear materials. Other forms of electrical power generation plants provide stringent worker safety related programs.

From the start, fusion should be mindful of the plant worker safety. It is a nuclear process with radioactive components. In all activities involving radioactive components or dangerous situations, robotic or remote maintenance should be incorporated. Particular attention is required for tritium handling and containment. High pressure or liquid metal coolants will require special hardware and procedures.

Closed fuel cycle. Tritium is not available naturally, therefore an important Demo requirement is to demonstrate that a power plant will never be at risk of running out of fuel. Since there are no secure external sources of tritium, loss of the on-site tritium inventory could lead to a serious crisis for the utility, making it impossible to operate the plant. During long down-times, on-site tritium will decay (12.4 y half-life). Thus, maintenance of adequate reserves to survive extended down-times is mandatory. In an economy with multiple fusion plants on-line, the guarantee for reserves is reduced somewhat, since an operating plant could provide start-up inventory for a plant coming on line.

The power level and availability goals of Demo are such that Demo itself could not operate without a closed fuel cycle. At 3000 MWe and 80% availability, 250 g of tritium would be consumed daily. The expected supply of tritium from external sources (such as

CANDU reactors) for Demo will be only a few kilograms, and even this may be absorbed by test facilities such as ITER. In that case, the demonstration of a closed fuel cycle is mandatory if Demo itself meets its other requirements.

The utilities have not specified any requirements on Demo to over-produce tritium, although this may be an important goal in order to provide the initial start-up inventory needed for the first generation of commercial plants. In any case, even small excess tritium production rates in Demo will provide more than adequate start-up inventories (estimated at a few kilograms), such that this is not expected to create any additional design considerations.

Aside from the uniqueness of tritium, it is a powerful advantage for a utility to have the autonomy of possessing all the fuel on-site for the lifetime of the plant. There can be no pressure from suppliers or natural disasters to impede the availability of the fuel supply. This feature also allows the utility to determine up front the fuel cycle costs and not be subject to the whims of the external marketplace.

Net electric output greater than 75% of commercial. The requirement for the demonstration plant to generate electricity at a capacity near to that anticipated for the commercial plant is determined by economics and the perceived risk to scale to a full-sized plant. The premise is that Demo is to be built and operated by a utility. This plant is to be designed to be fully integrated into a power grid for the purpose of power generation. Thus it must of a size sufficient to contribute to the grid demands and be profitable. The present understanding of tokamak fusion power plants is that below a net capacity of several hundred megawatts, the plants have very unfavorable economics. Even with a moderate size and other less optimal performance parameters such as reduced availability, substantial financial subsidies will be required for a nominal rate of return for the Demo.

The second factor is technical risk to scale to a full-sized plant from a much smaller demonstration plant. If the demo is too small, it entails too high a risk for the investor. On the other hand, building the Demo too large puts a larger burden of risk on Demo, extrapolating from the database of the then existing experimental devices. ITER may have the proper size plasma, but other subsystems may not be of an adequate size to serve as the design basis for Demo.

Within the fusion community and the Utility Advisory Committee, the debate continues regarding the proper size for a commercial plant. One faction would prefer a small plant that could be sited anywhere there is a demand, basically in a distributed network.

Another view is that large power parks should be used as bigger is better. The latter view is better suited to the nature of tokamak power plants, but it is not a convincing argument. In formulating its Demo requirements, we chose that the Demo be roughly 75% of the size of the commercial plant. This would provide adequate size for the economics to be viable and also have acceptable risk in scaling the relevant technologies. Ultimately the Demo size will be chosen based on market economics at the time of the Demo project.

Operation at partial load conditions. The operation of a power plant at partial load condition is a reasonable expectation for any plant that is to be integrated into a power grid with a minimum of difficulties. The only question is the lower level of operation at which it is expected to operate continuously. The Utility Advisory Group thought that 50% would be a reasonable value for a base-loaded plant. If it were to be load-following, which it is not, then it would have to operate at a much lower capacity. It is not foreseen that tokamak reactors would have any inherent problems with operation at reduced capacity. As with any base-loaded plant, the economics are not favorable at reduced capacity operation.

Maintainability. It is not foreseen that a fusion power plant will allow hand-on maintenance following operation with DT fuel. Therefore, the ability to remotely remove and replace any component which can fail must be demonstrated, even if the component does not actually fail during operation. It is anticipated that the majority of fusion power plant maintenance will be done by robots, such that all robotic systems must be demonstrated during Demo operations. Further, robotic maintenance is meant to be predominantly computer controlled maintenance with minimal human intervention except for key actions or unique situations. This will allow faster and more reliable maintenance operations for known and repetitive operations.

It is likely that these maintenance demonstrations would be performed prior to the start of DT operation, such that any flaws or failures may be corrected prior to activation. A high degree of confidence in the repair time is necessary in order to meet the very high availability goal of Demo. The availability goal of Demo is stated in such a way that initial operations need not meet the full availability goal. This allows for some tolerance for extended down-times due to maintenance. However, given that Demo is expected to be constructed with some fraction of private investment, there will be very strong economic incentives to minimize downtime during any phase of operation.

Demonstration of maintenance actions encompassing plant operations to the end-of-life of in-vessel components also will be essential. Changes in material properties, permanent deformations, and chemical and physical interactions may complicate maintenance procedures. End-of-life maintenance demonstration will occur naturally because the total operating life of Demo is expected to exceed the lifetime of a set of in-vessel components. A utility will demand positive results from the demonstration and replacement of components prior to committing to the construction of the first commercial plant.

Unscheduled shutdowns. Unscheduled shutdowns are very undesirable for a power plant operator. Besides the obvious impact on availability resulting from down-time, a power plant cannot be brought back on-line immediately following an unplanned outage until the source of the problem is identified, any damage is repaired, and corrective actions are taken to prevent future occurrences.

A major plasma disruption is one such intolerable event. The requirement to avoid disruptions is difficult to achieve and may require performance trade-offs in order to operate the plasma far enough from any stability boundaries that the frequency of disruptions is reduced below one per year [4]. Note that the unscheduled shutdown requirement is one per year total for all systems and should include in-vessel component premature failure, power conversion systems, fueling systems, *etc.* Surprisingly, the consequences to the surrounding structures may become a secondary concern since these can be repaired and replaced relatively quickly, while the ability to determine the source of a disruption and correct the flaw may require substantially more time.

Cost of Electricity. The final requirement is that the cost of electricity (COE) for the Demo must establish the economic competitiveness of fusion. An actual value for this requirement was difficult to quantify but the Starlite project felt the general fusion community needed guidance in this area. In response to that need, both a goal and an upper limit requirement were established for the Demo and the commercial power plant. While long-range electrical demand projections are uncertain and the target for a competitive COE is elusive, costs are an important design consideration. It was felt that if the COE of 65 mills/kWh were obtained, fusion energy would likely be seen as a formidable competitor. Realists sought some relief from the seemingly difficult demand to reach such a value. Thus the commercial goal was provisionally set at 65 mill/kWh and the upper limit requirement was established at 80 mill/kWh. Rollback to the Demo requirements resulted in adoption of a COE goal of 80 mill/kWh and a requirement of 90 mill/kWh.

To achieve the bottom line COE values, all the elements in the cost of electricity must be determined and controlled. Resolved into capital and operating cost components, the COE projection is driven by decisions regarding plant size (noting economies of scale), materials choices [6], thermal cycle efficiency, availability, and maintenance scheme as well as a host of other factors. There is a strong incentive to expedite the construction time to lower the finance costs. Plant availability is determined by the interplay between design margins and redundancy, which affect the forced outage rate. Access and modularization of the power core influence the mean time to repair, scheduled outage durations, and capital cost. These sub-tier requirements will be initially allocated to arrive at an overall acceptable COE. As the design evolves, trade studies will continue to determine the best mix of risk, performance, and cost.

Since the Demo will still be on a steep part of the performance and cost learning curve, it will not represent an optimal design for a commercial plant. Moreover, it would still have to carry the burden of some development costs, increased costs associated with first-of-a-kind production components, and higher contingency allowances. Thus Demo would not be expected to achieve the desired COE values without significant government or investor subsidy to artificially lower the capital and operating costs. Thus the owner/operator of this demonstration power plant must be able to operate this demo plant on the power grid for long periods of time and gain both operational experience and profit for the sale of electricity.

2.5. SUMARY AND CONCLUSIONS

This set of requirements constitutes the Starlite project guiding principles to arrive at a commercially acceptable electric-generating power plant. This is the “market pull” portion of the equation. On the other side of the coin is the “technology push.” The size and power level of tokamak plasmas are reaching the size necessary for commercial applications. The control and stability of the plasmas are sufficient for experiments, but need to be demonstrated for commercial usage. The current drive systems for long duration, steady-state plasma need to be applied to large tokamak plasmas. Low-activation materials for the power core structure and shielding need to be developed, validated, and applied in components operating in representative high heat and radiation environments. Much work remains to establish the solid technology and engineering foundations upon which the Demo can be designed, built, and operated. Hopefully, these top level requirements will provide insight for the program to help achieve a successful commercial venture.

REFERENCES

[1] J. Kaslow *et al.*, "Criteria for Practical Fusion Power Systems - Report from the EPRI Fusion Panel," EPRI report BR-104469 (1994).