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Magnetic Fusion Program Plan

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The fusion program strategy takes into account the key science and technology issues, available resources, and the nation's need for future energy sources.

PREFACE

During the past few years, there have been some substantial changes in the energy and economic circumstances in the United States and elsewhere. This has resulted in the need to make some changes in the priorities of certain programs within the Department.

During the early period (1973-1976) of National concern over the then looming energy crisis, the Magnetic Fusion Energy Program laid out a plan that was dedicated to the goal of a working fusion energy reactor system by the year 2000. This goal and the Plan based on it were used to guide the Program's activities and to determine the support levels until the past few years. Although the need for and desirability of an energy supply system based on the nuclear fusion principle have not diminished, there is less urgency to develop such a system by the year 2000.

The United States and several other Nations have made substantial investments in the equipment and in the training of scientists and engineers needed to make progress in this complex field of research. Although some of the problems have proven to be more difficult to solve than originally anticipated, excellent and sustained progress has been made in solving them. It is generally agreed that the remaining problems can be solved and that practical fusion reactor systems can be developed.

What is needed now is a revised Magnetic Fusion Program Plan that takes into account the present economic conditions, the energy situation now and in the future, the role of technical progress in fusion research, the role of the Program in training scientists and engineers, the contributions to basic research in the fields of plasma physics and atomic physics, and technology transfer.

This Plan reflects the present conditions of the energy situation and is consistent with National priorities for the support of basic and applied research. It is realistic in taking advantage of the technical position that the United States has already established in fusion research to make cost-effective progress toward the development of fusion power as a future energy option.

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EXECUTIVE SUMMARY

Goal

The goal of the National Energy Policy Plan is to foster an adequate supply of energy at reasonable costs. As an element in this Plan, the goal of the magnetic fusion program is to establish the scientific and technological base required for fusion energy.

Technical Issues

Although magnetic fusion research and development is addressing a wide spectrum of detailed scientific and technological problems, the remaining work to reach the program goal can be summarized by four key issues. These are magnetic confinement systems, properties of burning plasmas, materials for fusion systems and nuclear technology of fusion systems.

Objectives

Given the nature of the key technical issues, three strategic objectives in the areas of science, technology and technology transfer are necessary to reach the program goal. The science objective is to be able to predict, control and optimize the behavior of plasma confined in fusion relevant magnetic configurations. The technology objective is to show that it is possible to create the unique fusion components and subsystems under conditions relevant to fusion energy sources. The technology transfer objective is to provide a range of options for private sector investment and commercial development of fusion.

Schedule

The schedule for completing magnetic fusion development is directly related to the technical, economic and political uncertainties associated with the energy supply, which are likely to exist for several decades. The Magnetic Fusion Program Plan is a strategy for solving fusion's technical problems within a time frame keyed to resolution of problems in other areas of energy development.

Assuming that the strategic objectives for fusion research and development are achieved, a sufficient scientific and technological base will exist to assess the technical and economic potential of fusion as an energy resource.

Strategy

The strategy adopted to reach the program goal must take into account the key technical issues of fusion, the schedule for program completion and the available resources.

The essence of the program strategy is to maintain a broad domestic research and development program with emphasis on establishing the basic elements (components or subsystems) of the science and engineering technology required for fusion. The focus on the practical energy goal of the program will be provided by fusion system studies. Technology transfer will be pursued by seeking industrial and utility participation in these system studies, as well as in appropriate research and development.

Resources

The resources necessary to pursue a successful fusion program consist of technical personnel, annual budgets and international collaboration.

Technical Personnel. Skilled technical personnel are a major element of the program's resources. In spite of strong competition for fusion trained graduates by defense and industrial activities, the program expects to continue to attract the high quality professionals needed over the coming decade. This will be accomplished by continuing to support a central research activity in the universities and maintaining a vital, creative research element within the overall program.

Budgets. The estimate for budget needs is based on two major factors. The first is the need to maintain a balance between our domestic science and technology program and those abroad to allow for effective international collaboration. The second is the need to support appropriate experimental investigations. Facilities that are large enough to explore high temperature regimes of plasma physics are required, as well as smaller facilities for investigating key technological problems or scientific issues at more modest plasma temperatures.

International Collaboration. The United States purpose in collaborating internationally is to establish an adequate fusion science and technology base in a timely fashion.

During the next five years, a concentrated effort will be made to identify cost-effective component and system test facilities for resolving the key technical issues. A key element in this effort will be the attempt to establish an international consensus on the nature of these facilities. If the result is that more integrated and expensive facilities are needed than can be accommodated by the budgets of individual national fusion programs, then the degree of international collaboration achieved will dominate the schedule for achievement of our goal.

Technical Milestones and Decisions

The major technical milestones and necessary decisions for achieving the program goal and objectives are summarized in the Plan. The subprogram elements are highly interrelated and are all necessary for an assessment of the potential technical, economic and environmental merits of fusion. The milestones should be interpreted as goals that can be achieved with steady domestic support and significant international cooperation and collaboration. They form the framework for detailed annual program planning and for international negotiations.

Upon completion of the milestones, sufficient information will be available to achieve the program goal and objectives. At that point, it would be possible to proceed with the design of an integrated magnetic fusion system based upon the results of all of the scientific and technological test programs of the 1990's. On this basis, it should be possible to proceed into the subsequent stages of process development and commercialization.

I

MAGNETIC FUSION'S ROLE IN NATIONAL ENERGY POLICY

The goal of the National Energy Policy Plan is to foster an adequate supply of energy at reasonable costs. The principal strategy adopted to achieve this goal is to promote a balanced and mixed energy resource system with minimum federal control and involvement. One appropriate federal function is sponsorship of research and development programs for alternate energy sources where cost or duration of the program prohibits private investment. The magnetic fusion program is one of the clearest examples of appropriate energy research in the federal research and development portfolio.

The schedule for completion of magnetic fusion development is directly related to the technical, economic and political uncertainties of energy supply, which are likely to exist for several decades.

With appropriate support, the magnetic fusion program can provide the scientific and technological base for a major new energy option. The Magnetic Fusion Program Plan is a strategy for solving fusion's technical problems within a time frame keyed to resolution of problems in other areas of energy development. The Plan discusses the program goal, key technical issues, objectives, schedule and strategy, required resources and major technical milestones.

This Plan is the strategic framework within which implementation plans to achieve the program goal will be formulated. The implementation plans will be updated on a continuing basis, taking into account funding, scientific and technological progress, and future international agreements to collaborate on specific technical tasks.

II

PROGRAM GOAL AND MOTIVATION

The goal of the magnetic fusion program is to establish the scientific and technological base required for fusion energy. Achievement of this goal, along with a successful technology transfer effort, will enable decisions on whether fusion deserves further development as part of the national response to the energy realities of the next century.

The development of magnetic fusion could lead to economic energy sources that possess a secure fuel reserve as well as attractive environmental and safety features. The fuel, deuterium, is readily available at low cost, and the supply is essentially unlimited. Potential end use applications are electricity generation and production of synthetic fuels, nuclear fuels and high grade heat for industrial applications.

Nearer term benefits of fusion development include an increase in the understanding of plasma physics and related scientific fields, as well as the attraction and training of outstanding scientists and engineers. Fusion related science combines plasma physics, atomic physics, nuclear physics, surface and solid state physics, and advanced computational techniques. Fusion related technology involves superconducting systems, large magnetic systems, high power radio frequency heating systems, tritium processing, high heat flux energy recovery systems, advanced materials development, nuclear technology, real-time computer control, novel scientific instrumentation, unique vacuum systems and particle beam heating systems. The technology developed in support of fusion research has many applications in science, industry and defense.

Magnetic fusion research also has an important international dimension. The fusion programs of the world have a history of successful cooperation and collaboration. Scientific and technological progress within the fusion field has benefited greatly as a result. Recently, the Versailles Summit Working Group on Technology, Growth and Employment recognized that international collaboration in science and technology, specifically including fusion, can play an important role in improving general economic growth and employment and in stimulating culture and education.

III

KEY TECHNICAL ISSUES FOR MAGNETIC FUSION

Although magnetic fusion research and development is addressing a wide spectrum of detailed scientific and technological problems, the remaining work that must be accomplished to reach the program goal can be summarized by four key issues.

The first of these issues is magnetic confinement systems. Development of a variety of magnetic confinement systems is essential to achieving the program's goal. Although significant technical progress continues to be made, at this time it is not possible to design a fusion reactor. It is quite possible that further development of the tokamak concept will lead to an economic fusion system. However, it is likely that the most desirable fusion reactor systems, in the next century, will require features from other types of magnetic confinement systems. Furthermore, the history of fusion development has shown that progress in all systems will be more rapid because of the cross fertilization possible between related concepts. Therefore, it is essential to explore an appropriate range of possibilities for magnetic confinement.

The second key technical issue is properties of burning plasmas. Achievement of the program goal requires that at least one burning plasma be produced and studied to complete the scientific base. Furthermore, since a burning plasma will require much of the technology required for a fusion reactor, such an experiment offers the additional benefit of advancing the technological portion of the goal.

The third key technical issue is materials for fusion systems. Since materials play a central role in determining the environmental characteristics of a fusion reactor, they are the key to realizing the benefits of fusion. Achievement of the program goal requires the development of new materials with properties that enhance the economic and environmental potential of fusion.

The fourth key issue is nuclear technology of fusion systems. While the three key technical issues mentioned above blend the fruitful basic and applied research that have characterized the fusion program to date, this last issue requires advances in the basic engineering sciences, as well as the application of the results of basic fusion materials research. Fusion blankets have a generic function in all fusion systems. However, to achieve the program goal, a certain breadth of technology must be maintained in order to be able to optimize the economic, safety and environmental performance of fusion reactors. This research program will be completed only when integrated blankets are tested in a nuclear environment.

A more detailed description of the four key issues for magnetic fusion is provided on the following page.

KEY TECHNICAL ISSUES FOR MAGNETIC FUSION

Magnetic Confinement Systems

A variety of magnetic fields can be used to confine and insulate a fusion plasma. However, the confined plasma interacts with different confining magnetic fields in ways that affect the heating and confinement efficiency of the system. The unique nature of this interaction creates the scientific richness of fusion plasma physics. The nature of the fusion reactor will also be profoundly affected by the particular magnetic configuration. The size of the reactor, the ease of operation, and the cost of construction all depend on understanding the scientific principles of the interactions of the fusion plasma with the magnetic confinement configuration.

There are only two basic magnetic structures which have been shown to confine plasmas of fusion interest: the magnetic mirror and the magnetic torus. However, each of these magnetic confinement systems has several variations. These confinement systems differ in practice by emphasizing particular principles of fusion science to improve plasma confinement or to simplify the technical requirements for producing the magnetic fields. Historically, the tokamak, a toroidal confinement concept, embodied a set of principles which was comparatively easy to implement in the laboratory. As a result, most of the scientific progress has been made with this concept. Today tokamaks are unique in the ability to produce the most fusion reactor-like plasmas for scientific study.

The rapid scientific and technological development of the fusion program in the last decade, resulting in large part from successful tokamak experiments, has contributed to overcoming many of the technical difficulties of other magnetic confinement concepts. We are fortunate to have a number of concepts which are now beginning to catch up with the tokamak. In addition, the tokamak concept itself has begun to evolve rapidly because of discoveries in tokamak research and ideas generated by research in these other concepts.

Properties of Burning Plasmas

Resolution of the confinement issue depends on a fundamental scientific understanding of several magnetic confinement principles. All of these principles are now under investigation, with the exception of those associated with a burning plasma. The new physical phenomena in the burning state will also require study. A fusion plasma is said to burn when the heat released within the plasma by the fusion reaction is sufficient to maintain the plasma temperature in face of heat loss from the system. In order to attain this state, one must solve scientific problems of magnetic confinement which are prerequisites to achieving the necessary insulation. Only the tokamak confinement system is approaching the point at which this condition might be achieved. Identification of the conditions required for ignition is expected to occur in the United States experiment, Tokamak Fusion Test Reactor, within two years. Initial experiments with significant fusion reactions are planned for following years. At the same time, studies are proceeding to specify a cost-effective experiment to investigate the physics of burning plasmas.

Fusion Materials

The ultimate economics of fusion energy, like most other energy systems, will depend on the materials required for the system. Fusion materials research separates naturally into two classes of problems: those associated with interaction of plasma with the materials and those associated with the interaction of fusion neutrons with the materials. Both involve basic and applied research. However, the former are near-term problems which must be solved to advance plasma confinement research. The latter problems are more fundamental to the ultimate success of fusion as an energy source.

The last decade of research, using available nuclear test facilities, has revealed that there are materials which could withstand the nuclear environment of a fusion reactor with reasonable system economics and relatively modest waste disposal requirements. However, studies have also shown that it is important to improve the economics of these systems and to reduce the need for long-term waste disposal of fusion materials even further through the development of specialized materials. The future fusion materials program must include both the basic research on fundamental new materials and the development of the new technology required for testing those materials.

Fusion Nuclear Technology

In a fusion reactor, most of the energy is recovered from a structure surrounding the fusion plasma. This structure is known as a fusion blanket and must perform several functions besides converting the energy released by the fusion plasma into useful heat. The blanket must also use the energetic neutrons emitted from the plasma to create part of the fuel for the fusion reactor and allow recovery of this fuel. It is even possible that the blanket might be used to produce nuclear fuel for use in fission reactors. The blanket also shields the outside world from radiation, but in doing so becomes radioactive. It is clear that as the major radioactive component of a fusion system, the blanket is the main focus of interest for safety and environmental concerns.

There are several technical options, based on combinations of different materials and technologies, to perform the various blanket functions. Moreover, different confinement concepts may impose different limitations on these technologies and on overall blanket design. These individual technologies can be evaluated on their ability to satisfy the blanket function in the most acceptable way. However, each of the blanket functions is so interrelated in practice that an integrated research and development approach is required.

IV

PROGRAM OBJECTIVES

Given the nature of the key technical issues, there are three strategic objectives in the areas of science, technology and technology transfer, which must be achieved in order to reach the program goal.

Science Objective

The science objective is to be able to predict the behavior of plasma confined in fusion relevant magnetic configurations. There are several magnetic confinement systems that could develop into reactors. Each has special features that could make the difference between an acceptable and a non-acceptable reactor. Furthermore, new variations and improvements will likely emerge as our understanding of plasma physics matures. Since budget constraints preclude parallel development of all possible ideas to the same level of performance, a predictive scientific understanding is essential to make an informed choice of the best direction for fusion development.

Technology Objective

The technology objective is to develop unique fusion components that can operate under conditions relevant to fusion energy sources. Practical fusion power will depend on a host of technological components. Many of these are within the purview of industry. There are, however, certain technological components of fusion systems which are unique, either because they are beyond the industrial state-of-the-art or because of new requirements imposed by the special conditions of a fusion system. Such unique components exist in the areas of magnetics, plasma heating, energy removal, fuel production and materials. These components must be developed and tested by the program to be able to forecast the economic and environmental characteristics of fusion reactors.

Technology Transfer Objective

The technology transfer objective is to provide a range of options for private sector investment and commercial development of fusion. The establishment of the scientific and technological base for fusion requires industrial participants both to provide expertise in conventional components and to gain experience with the unique aspects of fusion science and technology. The necessary degree of industrial experience is best gained through the technical participation of industrial personnel in the state-of-the-art developments produced by the fusion program. A noteworthy aspect of this objective is that through it, the fusion program will also serve as a stimulus to United States technological growth and the further training of scientists and engineers in industry.

V

PROGRAM SCHEDULE AND STRATEGY

Program Schedule

The schedule for completion of the fusion program objectives is determined by one of the key aspects of the National Energy Policy Plan strategy; namely, to promote a balanced and mixed energy resource system. At the present time, there is a great deal of uncertainty in the United States energy future associated with the present mix of energy resources. This uncertainty will persist for some time because of political and economic influences on international and domestic fuel supply, as well as the long time needed for assessments of the environmental impacts of current energy sources.

Assuming that the strategic objectives for fusion research and development are achieved during the 1990's, a sufficient scientific and technological base will exist to assess the technical and economic potential of fusion as an energy resource. This information, coupled with knowledge of factors that affect the economic future of fossil, nuclear and alternate energy sources other than fusion, will provide a basis for decisions on future directions for fusion development.

The essential aim of the magnetic fusion program is to develop the scientific and technical information needed to reach the point where fusion can be considered as an option in the future mix of energy resources available in the United States.

Program Strategy

In the past the centerpiece of United States fusion program planning has been envisioned as an integrated fusion test facility which served to develop fusion science and, simultaneously, to test both the plasma-related and the nuclear-related technologies required for fusion. This was considered to be a cost-effective route to achieving the program goal especially when national need gave a sense of urgency to the deployment of new energy technology. However, because of improvements in the present energy situation, this approach should be revised.

Although the fusion program must plan for decade-long efforts to resolve key scientific and technological problems, it operates on year-to-year appropriations. A key feature of a durable program strategy is, therefore, its ability to accommodate deviations from planned annual budgets. When construction of centerpiece projects dominates program expenditures, budget perturbations are particularly difficult to accommodate without endangering essential program balance. Our present strategy, therefore, is to take a complementary approach which emphasizes development of the scientific and technological components or subsystems of the integrated fusion system, to the maximum extent that is technically feasible.

This approach is most appropriate for our program goal, as well as for the technical uncertainties which exist about the exact nature of a suitable fusion reactor. In addition, there appears to be no premium on early deployment of fusion in our present energy circumstances, and time is available to perfect the necessary fusion energy source. Finally, the utilization of the United States portion of the world's fusion development resources can be enhanced by this approach since it provides the flexibility to collaborate internationally.

The essence of the program strategy is to maintain a broad domestic research and development program with emphasis on establishing the basic elements (components or subsystems) of the science and engineering technology required for fusion. The focus on the practical energy goal of the program will be provided by fusion system studies. Technology transfer will be pursued by seeking industrial and utility participation in these system studies, as well as in appropriate research and development activities.

To make best use of United States scientific strength in the area of fusion plasma research, a number of magnetic confinement systems, which offer promise of superior reactor performance, will be investigated. However, recognizing constraints on available resources, this investigation will emphasize increasing scientific understanding of the unique features of the most promising concepts, rather than attempting to develop each as a separate reactor system. To achieve a complete scientific base, we will address the scientific issues of fusion in depth through the generation and study of high temperature plasmas in facilities of appropriate size and scope, including a burning plasma experiment. In the latter experiment, the lowest cost magnetic confinement system which can meet the scientific objective will be sought. This approach is intended to provide the broadest understanding at minimum cost and is most appropriate for the present stage of fusion development.

VI

RESOURCES

The resources necessary to pursue a successful fusion program consist of technical personnel, annual budgets and international collaboration. The difficulty and timescale of fusion development are such that significant quantities of each will be required.

Technical Personnel

Skilled technical personnel are a major element of the program's resources. For more than thirty years, the magnetic fusion program has attracted some of the best scientific and engineering talent throughout the United States. Over that period of time, the scientific discipline of plasma physics has matured into one of the largest and most active fields of science in the United States. In addition, the program has fostered the development of a valuable group of interdisciplinary engineering scientists who can combine standard engineering disciplines with the systems integration of the many different technologies required for fusion.

American universities have played a key role in educating the generation of talent responsible for the success of the magnetic fusion program in the last decade. These universities have accomplished this through their central involvement in the most challenging research and development problems of the fusion program. This involvement has attracted the high quality of personnel required for this difficult field and helped maintain quality engineering graduate programs. In spite of strong competition for fusion trained graduates by defense and industrial activities, the program expects to continue to attract the high quality professionals needed over the coming decades. This will be accomplished by continuing to support a central research activity in the universities and maintaining a vital, creative research element within the overall program.

Annual Budget

The estimated budget level is based on two major factors. The first is the need to maintain a balance between our domestic science and technology program and those abroad in order to allow effective international collaboration. The second is the need to support appropriate experimental investigations. Facilities that are large enough to explore high temperature regimes of plasma physics are required, as well as a number of smaller facilities for investigating key problems or scientific issues which can be addressed at more modest plasma temperatures.

The funding required through the 1990's will be determined by the facilities and program schedule needed to reach the program objectives in a timely fashion. The determination of the magnitude and complexity of the facilities will be based on technical results of the program over the next five years. However, the schedule will depend on scientific progress, the perceived need for the program to pursue its goal at the specified rate, and the extent of international collaboration.

During the next five years, a concentrated effort will be made to identify cost-effective component and system test facilities to resolve the key technical issues by the turn of the century. A key element in this effort will be the attempt to establish an international consensus on the nature of these facilities. If the result is that more integrated and more expensive facilities are required than can be accommodated by the budgets of the individual national fusion programs, the degree of international collaboration achieved will dominate the schedule for achievement of our goal.

International Collaboration

The purpose of the United States in cooperating internationally is to advance the prospects for establishing a sufficient fusion science and technology base in a timely fashion. The magnetic fusion programs of the world currently have a vigorous program of international cooperation and collaboration that includes scientific and technological exchanges, joint experiments and joint planning activities. These activities will be strengthened to emphasize international involvement, at an early stage, in planning for major new activities and facilities. This should enable us to identify mutually advantageous opportunities for collaboration and, on a case by case basis, to negotiate agreements which will minimize duplication and accelerate the achievement of our common goals.

A similar approach will be used to achieve our technology objective. Plasma-related technologies will be developed as appropriate to support the advance of the experimental program. Since this program must include a burning plasma facility, this should ensure sufficient development of most plasma-related and some nuclear-related technologies that are necessary to achieve the program goal. The remaining technological components will be developed with specialized test facilities. A considerable effort will be devoted to the development of cost-effective facilities in the materials and nuclear technology areas.

Finally, in the area of technology transfer, in addition to seeking industrial and utility involvement in systems studies, we will concentrate on maximizing the interaction of laboratory, university and private sector technical personnel within the fusion program. This will be done through appropriate R&D contracts, personnel exchanges and joint programs.

VII

MAJOR TECHNICAL MILESTONES AND DECISIONS

The major technical milestones and decisions for achieving the program goal and objectives are identified below and summarized in the following Figure. As shown in the Figure, the program elements are highly interrelated and lead to an assessment of the potential technical, economic and environmental merits of fusion. The milestones should be interpreted as goals that can be achieved with steady domestic support and appropriate international cooperation and collaboration. They form the framework for detailed annual program planning and for international negotiations.

Milestones for around the year 1990 follow.

1. Establish a sufficient theoretical and experimental understanding of magnetic confinement of a hydrogen plasma to begin experiments to establish the characteristics required for a fusion reactor.
2. Establish a sufficient theoretical and experimental understanding of tokamak plasma behavior to allow a cost-effective burning plasma experiment.
3. Establish the nonnuclear fusion technology required for all of the above experiments.
4. Complete small-scale screening tests and analytical studies of candidate blanket features and plan a generic blanket test program, including an appropriate blanket test facility.
5. Complete fusion materials screening studies and evaluations necessary to proceed with a materials testing program in an appropriate neutron source that is capable of testing materials on an accelerated basis.

The above five milestones are based upon full utilization of existing fusion facilities for about the next five years and provide the basis for the following decisions around the year 1990. At the time the decisions are made, full consideration will be given to accomplishing more than one activity in one facility in order to reduce costs.

1. For the most promising confinement concepts, proceed with hydrogen experiments with plasma characteristics close to the reactor level.
2. Proceed with an ignited, long-pulse, burning plasma experiment.
3. Proceed with a generic blanket test program, including an appropriate nuclear source facility.
4. Proceed with a materials test program, including an appropriate neutron source facility.

Assuming that decisions are made to proceed as indicated above either within the United States fusion program, within a foreign program or through international collaboration, the following milestones are established for around the year 2000.

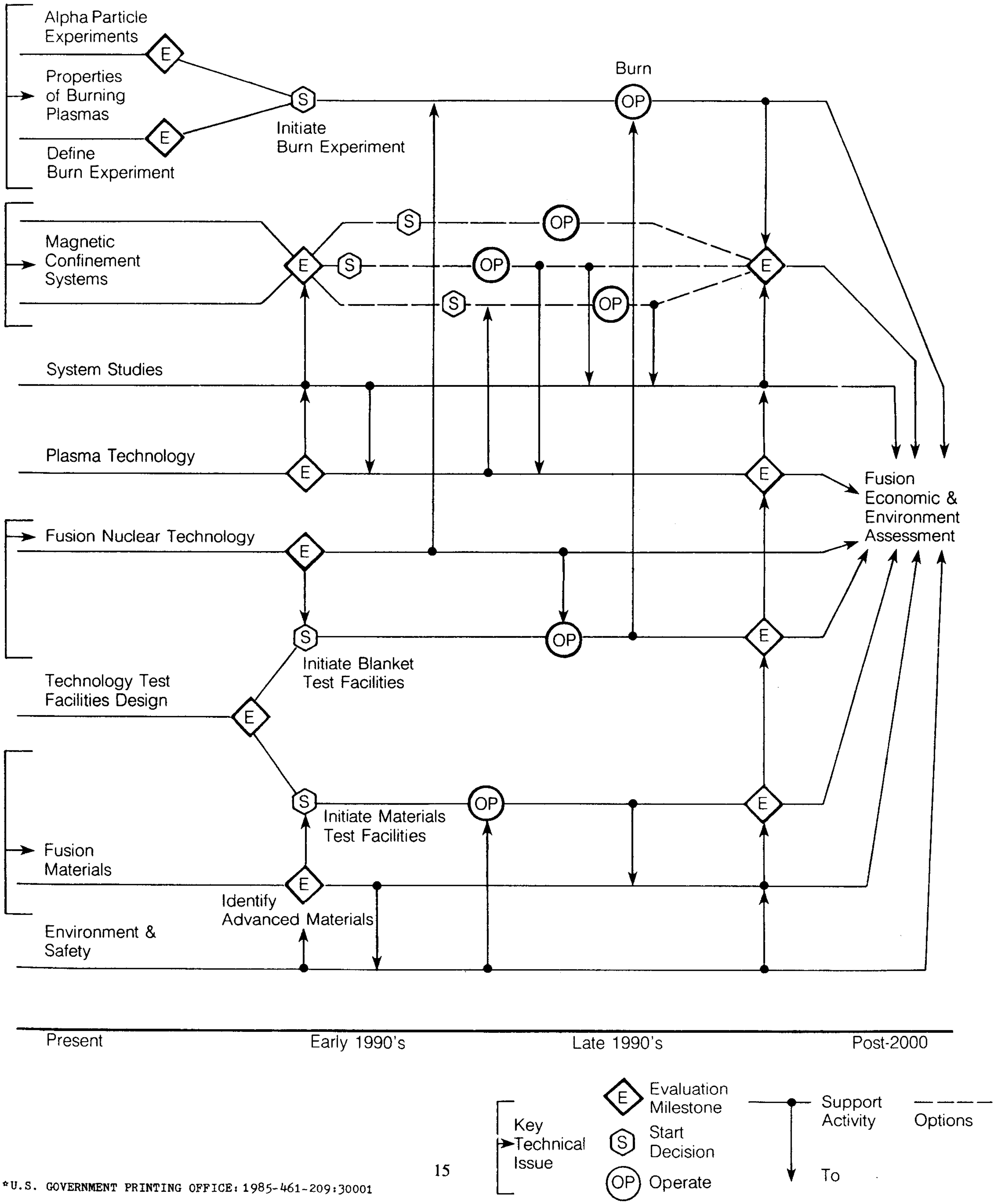
1. Define optimized magnetic confinement configurations based upon results from the burning plasma experiment and the promising confinement concepts coupled with improved theoretical understanding of plasma behavior.
2. Confirm the adequacy of the nonnuclear fusion technologies.
3. Define a blanket configuration that would be compatible with the optimized magnet configuration defined in item 1 above based upon results from the generic blanket test program.
4. Establish the acceptabililty of materials that could be used in the optimized magnet confinement configuration and blanket defined in items 1 and 3 above based upon end-of-life materials testing information.
5. Establish sufficient industrial participation to allow effective private sector synthesis of program results.

In addition, environmental and safety activities will be required on a continuing basis in support of all the above milestones. Finally, throughout this period, systems studies will be required in order to guide the above decisions and to identify economical and environmentally acceptable directions for an integrated magnetic fusion system.

Upon completion of the above milestones, sufficient information will be available to achieve the program goal and objectives. At that point, it would be possible to proceed with the design of an integrated magnetic fusion system based upon the results of all of the scientific and technological test programs of the 1990's. In addition, it should be possible to proceed into the subsequent stages of process development and commercialization.

THE FOLLOWING FIGURE ILLUSTRATES THE MILESTONES AND DECISIONS OF A PLAN TO REACH THE FUSION PROGRAM GOAL. THE SUBPROGRAMS ARE INTERRELATED AS SHOWN. THIS INTERRELATIONSHIP WILL BE PRESERVED ALTHOUGH THE SPECIFIC FACILITIES AND TIMING SHOWN WILL VARY TO ACCOMMODATE TECHNICAL RESULTS, ANNUAL BUDGETS, AND THE DEGREE OF INTERNATIONAL COLLABORATION ACHIEVED.

Magnetic Fusion Program Plan
Major Technical Milestones and Decisions



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