H570

BY THE COMPTROLLER GENERAL 110496

Report To The Congress

OF THE UNITED STATES

Fusion--A Possible Option For Solving Long-Term Energy Problems

The fusion reactor may someday be the dependable, virtually inexhaustible source of energy that the Nation is seeking Officials of the Department of Energy are optimistic that fusion energy will become a commercially feasible power source in the 21st century However, in the past, similar predictions have proven to be overly optimistic

Although fusion is considered as being in the applied research phase, portions of fusion research remain in the basic research phase It is therefore premature to assume that all of the problems to be encountered have been identified Fusion is a long-term energy option, and its potential for becoming a viable commercial energy source is unknown While continued funding of fusion research is needed to keep this energy option open, the Congress, in considering the adequacy of requested funding levels for fusion, should be mindful that fusion energy should not be looked to as a means for solving the Nation's near or mid-term energy problems

UNITED STATES GENERAL ACCOUNTING OFFICE

EMD 79 27
SEPTEMBER 28, 1979

COMPTROLLER GENERAL OF THE UNITED STATES
WASHINGTON D C 20548

B-164105

To the President of the Senate and the
Speaker of the House of Representatives

CW000001

This report provides an overview of the Department of Energy's magnetic confinement and inertial confinement fusion programs. Included is an analysis of the status of fusion research, impediments to the development of fusion energy, and prospects for realizing fusion as an energy source.

AGC00912

Copies of this report are being sent to the Director, Office of Management of Budget; the Director, Office of Science and Technology Policy; the Secretary of Energy; and interested Members and Committees of the Congress.

Comptroller General
of the United States

HSE00608

COMPTROLLER GENERAL'S
REPORT TO THE CONGRESS

FUSION--A POSSIBLE OPTION FOR SOLVING LONG-TERM ENERGY PROBLEMS

D I G E S T

For almost 30 years, the Federal Government has been sponsoring fusion research for the purpose of developing a virtually inexhaustible source of energy.

Department of Energy officials are optimistic that significant amounts of energy from commercial fusion reactors will become available in the period 2025 to 2050, but many problems remain to be solved.

Before a fusion reactor--the ultimate goal--can produce usable energy, scientific and engineering feasibility must be proven and commercial practicality demonstrated. Commercial practicality will be proven when an economically competitive design has been met in a safe, environmentally acceptable manner. Department of Energy officials estimate that it will cost about $18 billion to reach that goal. (For a description of the fusion process, see pp. 1 and 2).

Based on recent experimental results, scientists are currently stating that scientific breakeven will be achieved in the mid-1980s. Breakeven means energy generated from a fusion reaction equals the amount of energy spent to start up a reaction. In the past, predictions for achieving breakeven have proven to be overly optimistic. Problems encountered with certain fusion concepts resulted in shifting emphasis to other approaches or concepts, accompanied by slippage of milestone dates.

If breakeven and scientific feasibility are achieved, engineering feasibility will have to be demonstrated to show that fusion reactors can be scaled to sizes sufficient to generate vast amounts of energy. Although, from a research classification standpoint, fusion is in the applied research phase of development, portions of both the magnetic and inertial confinement fusion efforts are still in the basic or fundamental research phase.

Thus, it is premature to assume that all of the problems that may be encountered have been identified. Experimental data so far have indicated that some formidable physics and engineering problems remain. Only after such problems are resolved and scientific and engineering feasibility demonstrated can the commercial potential of fusion as an energy source be determined.

The commercialization phase is to include the development and operation of commercial demonstration reactors and the widespread deployment of fusion technology in the economy. The minimum time from the beginning of the commercialization phase until fusion can contribute significantly to the Nation's energy supply is estimated to be about two decades. The decision whether to ultimately develop fusion for widespread commercial power will be made in the context of other energy sources available at that time. (For a discussion of U.S. and foreign fusion efforts, see pp. 7 through 22).

In both magnetic and inertial confinement fusion, the front-running concepts--tokamak and glass lasers, respectively--are being emphasized for development as quickly as possible toward achieving scientific breakeven, while vigorous backup efforts are being maintained to develop alternative candidates which may ultimately prove to be better suited for economic commercialization. (See pp. 23 through 37.)

During its consideration of the fiscal year 1979 budget, the Congress addressed the issue of establishing separate funding for civilian uses of inertial confinement fusion The Congress chose not to segregate such funding at that time, but to continue efforts in inertial confinement fusion principally for weapons purposes--at least until scientific feasibility is proven. GAO agrees that a separately funded civilian use program is not yet needed. Only after breakeven and scientific feasibility are proven, and the chances of eventually achieving a commercial inertial confinement fusion powerplant are better known, can a decision to separate civilian uses of inertial confinement fusion be made with reasonable confidence. (See pp. 37 and 38.)

MATTERS FOR CONSIDERATION BY THE CONGRESS

The 96th Congress will be faced with many difficult decisions concerning the adequacy of the administration's requested funding levels in fiscal years 1980 and 1981, particularly for energy. The administration's budget request for fiscal year 1980, which includes more than $10 billion for the Department of Energy's various programs, has been described as austere because of an effort to hold down recently spiraling inflation. The annual funding level for fusion programs has increased in the wake of the Arab oil embargo of 1973-74. The funding for these programs during the 6-year period, fiscal years 1974 to 1979, totals nearly one and a half times as much as the total cumulative funding for these programs during the preceding 23 years. These funding increases can be attributed, in part, to a general belief that fusion will help solve the Nation's energy problems.

There are also indications that such a belief has been somewhat reinforced by a number of public statements of optimism by Government officials concerning the prospects for fusion power. Even the Department of Energy's annual budget reflects optimistic views of fusion as an energy source, without effective balancing statements that (1) characterize fusion as a long-term energy option with unknown potential for becoming a viable commercial energy source and (2) describe the program in terms of its present status and near-term goals.

GAO cautions, however, that disappointments are possible in the fusion effort because a number of elements or questions affecting the fusion program require basic or fundamental research. Thus, at this time fusion's commercial potential for becoming a viable energy source is unknown.

While continued funding of fusion research is needed to keep this possible energy option open, such funding must be made with the knowledge that fusion will not supply energy in the near- or the mid-term. Even if current predictions of achieving scientific breakeven by the mid-1980s are achieved and the milestones for achieving scientific, engineering, and commercial feasibility are met, it will still be sometime during the second quarter of the next century before fusion can become a significant energy source.

Thus, the Congress, in considering the adequacy of requested annual funding levels for fusion should not look upon fusion as a means for solving the Nation's near- or mid-term energy problems. In carrying out its legislative and oversight functions, therefore, the Congress should instead view fusion as a possible option for solving long-term energy problems.

In this connection, the Secretary of Energy should take steps to make sure that the Department's budget justifications for the fusion program and its public announcements relating to program accomplishments do not overstate the prospects for commercial fusion power. This is especially important to ensure that, during congressional deliberations on the administration's budget request for energy, fusion is viewed as a long-term energy option with unknown potential for becoming a viable commercial energy source. The appropriateness of the requested funding levels should be considered in light of the levels requested for other comparable or similar energy research and development programs.

RECOMMENDATION TO THE SECRETARY OF ENERGY

The Congress, as part of its authorization and appropriation process, should have access to accurate information relating to the current status and actual potential of federally supported energy technologies.

Therefore, the Secretary of Energy should ensure that, in future budget submissions, fusion is clearly described as a long-term energy option with unknown potential for becoming a viable commercial energy source.

Future public statements concerning the activities and accomplishments of the fusion programs should avoid language which may lead to the belief that fusion energy may become commercially viable in the near- or mid-term, unless evidence clearly indicates otherwise.

AGENCY COMMENTS

Drafts of this report were reviewed by officials at the Department of Energy, Office of Management and Budget (OMB), and the Office of Science and Technology Policy. OMB declined to provide formal comments. The Department of Energy and the Office of Science and Technology Policy both agreed that fusion is a long-term energy option. However, they added that any such characterization should be balanced by mentioning fusion's high potential payoff as an energy source.

A draft of this report was also reviewed by a group of distinguished experts knowledgeable about fusion issues.

Where appropriate, changes were made to this report to reflect the comments received.

Contents

ABBREVIATIONS

AEC	Atomic Energy Commission
DOE	Department of Energy
ERDA	Energy Research and Development Administration
EURATOM	European Atomic Energy Community
GAO	General Accounting Office
INTOR	International Tokamak Reactor
OSTP	Office of Science and Technology Policy
R&D	Research and development

CHAPTER 1

INTRODUCTION

Nuclear fusion is the process whereby atoms, subatomic particles, or isotopes 1/ of sufficient temperature collide, fuse, and consequently form heavier matter. The sun and other stars naturally generate energy via fusion; on earth, the process is being studied for possible future electrical power production.

If and when developed, fusion is expected to be safe and environmentally attractive. Various elements or isotopes theoretically could be used as a fuel; however, researchers presently envision using deuterium and tritium--two isotopes of hydrogen--as fuel because this combination requires the lowest temperatures to achieve a fusion reaction. However, in later fusion reactors, researchers believe pure deuterium or other mixtures of fuels might be preferable because they offer the potential for lower radioactivity.

Large quantities of deuterium exist in ordinary water. If the deuterium found in the Pacific Ocean could be used to fuel fusion reactors, it could provide enough energy to generate electricity for the entire world for billions of years. Tritium can be produced in a fusion reactor from lithium, an element found in granitic rocks and underground salt water.

The sun consists of a very hot gas--so hot that the atoms contained in it have become ionized. This means that electrons (negatively charged particles which circle the nucleus) have become separated from the positively charged nucleus (called an ion) of the atom. This gas of electrons and ions is called a plasma and has some very special properties. One of these properties is that the ions frequently collide with each other. The hotter the plasma, the harder they collide. If the plasma is hot enough, the ions will collide with enough force to overcome their natural tendency to repel each other due to their positive electric charges. When this happens, these ions or nuclei combine, or fuse together to form new nuclei (new elements), thereby releasing energy in the process.

Researchers throughout the world are exploring ways to generate a suitably hot plasma and contain it long enough at

---

1/Isotopes are atoms of the same element which have the same number of protons but a different number of neutrons.

a sufficient density so that many fusion reactions take place and release vast amounts of energy. The major problem facing researchers is how to hold and heat the plasma in a suitable container so that the ions, which are moving more than a million miles per hour, will not strike the container's walls and dissipate their energy before they have a chance to fuse.

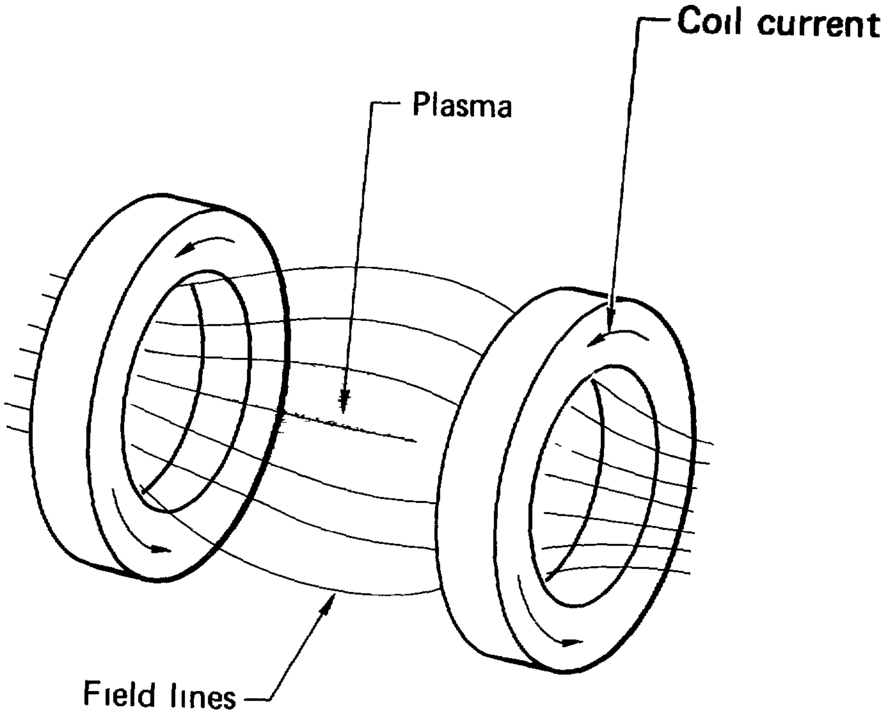
The Department of Energy (DOE) is pursuing two major approaches to achieving fusion--magnetic confinement fusion and inertial confinement fusion. Magnetic confinement fusion is a process whereby the fuel is heated until its atoms collide with sufficient force to separate into individual electrons and nuclei. What results is a plasma confined to a certain shape by magnetic fields. Theoretically, at temperatures in excess of 100 million degrees Celsius (over 180 million degrees Fahrenheit), the fuel nuclei collide and fuse. About 80 percent of the energy created by the reaction is carried by neutrons which, because they have no electrical charge, are not confined by the magnetic field and enter a surrounding blanket, which will probably contain lithium. The neutrons bombard the lithium and convert some of the atoms to tritium--a component of the fuel--and also heat the blanket. If this process is developed to produce a lot of heat, a heat exchanger could use the blanket heat for producing steam to drive a turbine and produce electricity. DOE diagrams of the two basic magnetic field shapes (open and closed) currently being researched, are shown on page 3.

In inertial confinement fusion, tiny fuel pellets--also called targets--are struck by intense energy beams. These beams could be laser beams, electron beams, or ion beams, which heat and vaporize the pellets' surface material. This vaporization produces a force in the opposite direction--much like a jet or rocket engine--which forces the remainder of a pellet inward and compresses the fuel to densities exceeding 100 times that of ordinary solids. It is hoped that this rapid compression will heat the fuel to the temperatures required for fusion and that electricity could be produced from this reaction in a manner similar to that envisioned for magnetic fusion. A DOE diagram of this approach is illustrated on page 4.

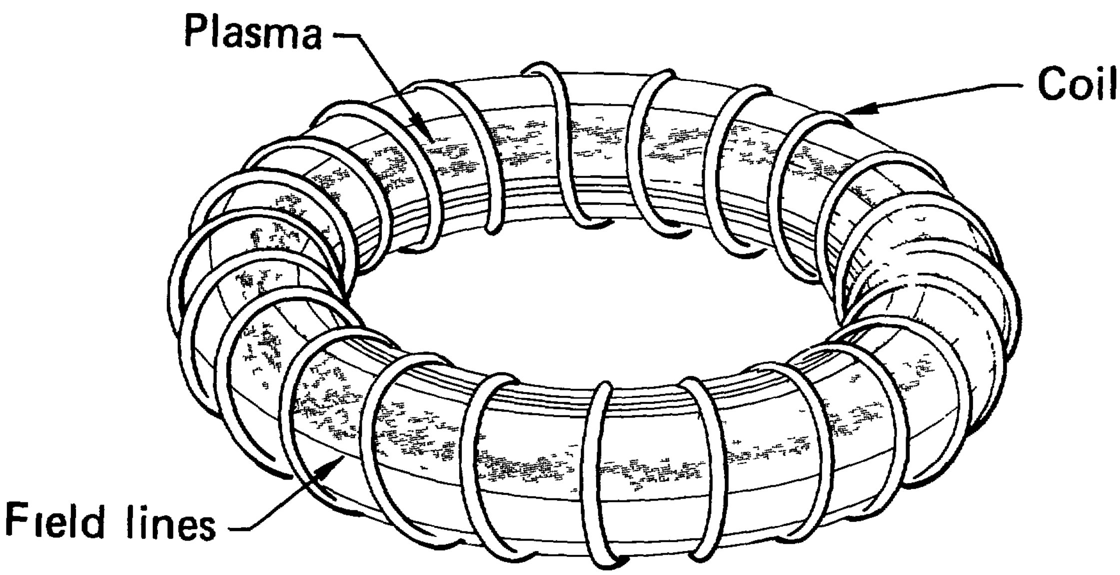
The possibility of generating energy from controlled fusion reactions was discussed by researchers in the United States as early as 1944, and a federally funded fusion research program was initiated in 1951. Federal funding of fusion research and development increased from slightly over $1 million for the period 1951 through 1953, to about $75 million in 1973. Following the advent of the 1973 Arab oil

OPEN AND CLOSED MAGNETIC FIELD SHAPES

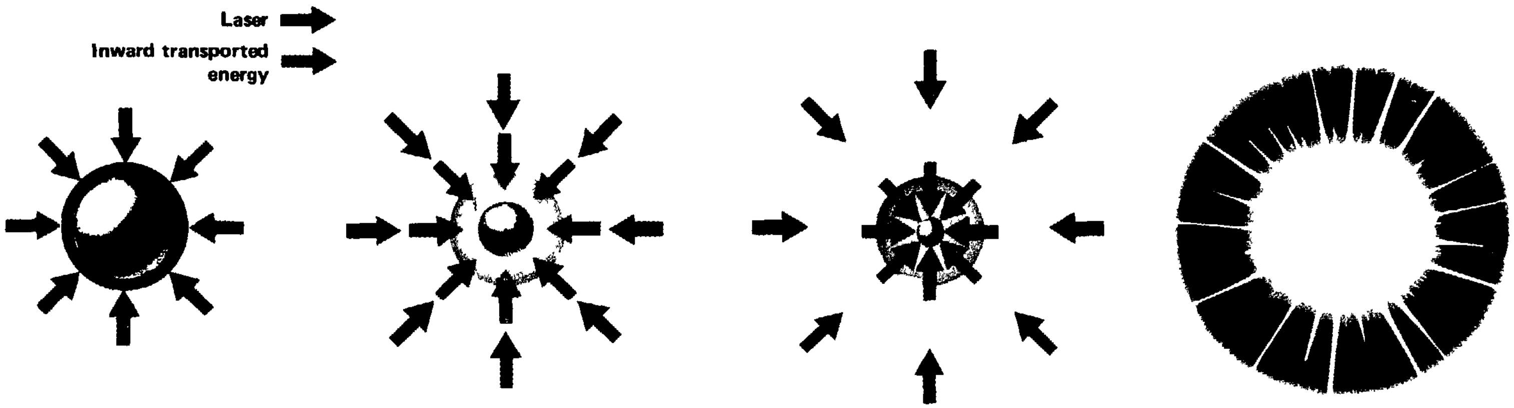
OPEN FIELD



CLOSED FIELD



Inertial confinement fusion concept



Atmosphere Formation

Laser or particle beams rapidly heat the surface of the fusion target forming a surrounding plasma envelope

Compression

Fuel is compressed by rocket-like blowoff of the surface material

Ignition

With the final driver pulse, the full core reaches 1000 – 10,000 times liquid density and ignites at 100 000 000°C

Burn

Thermonuclear burn spreads rapidly through the compressed fuel, yielding many times the driver input energy

embargo, funding increased rapidly to an estimated $500 million in fiscal year 1979. Much of the recent increases have been spurred by an increasing awareness that energy which might be derived from controlled fusion reactions will be needed as fossil energy resources dwindle or are depleted. However, the increases can also be attributed, in part, to a number of announcements of possible breakthroughs in the field.

Magnetic and inertial confinement fusion programs are managed separately. Upon its formation in October 1977, DOE assigned responsibility for magnetic fusion research and development efforts to the Office of Fusion Energy, under the Assistant Secretary for Energy Technology, and responsibility for inertial confinement fusion efforts to the Office of Inertial Fusion, under the Assistant Secretary for Defense Programs.

Magnetic confinement fusion is being developed solely for civilian uses. Inertial confinement fusion is being developed for both civilian and military uses. An estimated 85 percent of the research being performed in inertial confinement fusion is considered common to the development for both uses. However, inertial confinement fusion research is considered to be primarily for near-term military use.

SCOPE OF REVIEW

This report discusses the results of our review of the history and status of fusion energy research, and describes the physics and engineering problems which remain to be solved if fusion is ever to become a practical energy source. This report is not intended to evaluate the technical propriety of the fusion technologies nor the processes used by the researchers to overcome the obstacles to fusion power.

We made our review principally at DOE headquarters, Washington, D.C.; and at DOE's contractor-operated laboratories, namely, the Princeton Plasma Physics Laboratory, Princeton, New Jersey; Lawrence Livermore Laboratory, Livermore, California; Los Alamos Scientific Laboratory, Los Alamos, New Mexico; and Sandia Laboratories, Albuquerque, New Mexico. We also contacted private researchers, nuclear industry representatives, environmental groups, foreign embassy representatives, and scientists from various universities to obtain their views on federally funded fusion efforts.

Drafts of this report were reviewed by DOE, Office of Management and Budget, and Office of Science and Technology Policy officials. In addition, drafts of this report were reviewed by a group of distinguished experts knowledgeable about fusion energy and DOE's fusion programs. Where appropriate, changes based on the reviewers' comments were made to this report. Copies of DOE's and the Office of Science and Technology Policy's comments appear as appendices I and II to this report. The Office of Management and Budget declined to submit formal comments.

CHAPTER 2

HISTORY AND STATUS OF FUSION RESEARCH AND DEVELOPMENT

Federally funded fusion research since 1951 has demonstrated that monumental problems remain to be solved before energy from commercial fusion reactors can be realized. The minimum criteria for sustained fusion reactions has not yet been attained, but DOE officials are optimistic that it can be done through magnetic confinement via the Tokamak Fusion Test Reactor currently under construction in Princeton, New Jersey, and through inertial confinement via the Nova glass laser system, planned for construction in Livermore, California, by the mid- or late-1980s. A number of other countries are also sponsoring fusion research and development (R&D) efforts, are emphasizing the same approaches as the United States, and are encountering similar types of physics and engineering problems. These countries exchange information both formally and informally on magnetic confinement fusion, but they are reluctant to share information on inertial confinement fusion R&D because it can contribute to an understanding of nuclear weapons physics.

EARLY RESEARCH EFFORTS AND PROGRAM EVOLUTION

Federal funding for magnetic confinement fusion R&D, apart from weapons research, began in 1951 under the Atomic Energy Commission's (AEC's) sponsorship. Federal funding for inertial confinement fusion began in 1963 (although it was not identified in the budget as such until 1970). Although a number of fusion research concepts have been funded, none have yet met the basic requirements to achieve scientific breakeven. Scientific breakeven is the point where sufficient temperature, density, and confinement time for fusion are achieved so that the total amount of energy from the fusion reaction equals the amount of energy used to create the fusion conditions. Scientific feasibility, on the other hand, is defined by DOE officials as when the total amount of energy from the fusion reactions exceeds the amount used to create the fusion conditions.

The period from 1951 to about 1958 was one of great expectations because it was believed that achieving the density, confinement, and temperature for fusion was relatively simple. Predictions were made that a demonstration reactor would be in operation within 10 years. The fusion concepts funded at the time were magnetic mirrors 1/ at the Lawrence Livermore Laboratory, the Z-pinch 2/ at the Los Alamos Scientific Laboratory, and the stellarator 3/ at the Princeton Plasma Physics Laboratory. In 1953, researchers achieved a plasma density sufficient for fusion to occur. However, adequate temperature and confinement time were not achieved to attain scientific breakeven.

From 1959 through about 1968, primarily because of difficulties encountered in confining the plasma, interest in magnetic confinement fusion waned, and pessimism engulfed the program. Even so, in 1962, sufficient temperature was attained for fusion to occur, but not with adequate density or confinement time to achieve breakeven. Research on the Z-pinch concept was phased out in the early 1970s because the plasma could not be controlled in a stable configuration.

Meanwhile, in the early 1960s, scientists realized that laser beams offered a medium for delivering large amounts of energy in very short periods of time. This realization prompted AEC in 1963 to fund laser fusion research. Initial calculations showed the need for a high-energy laser, so emphasis was placed on developing a glass laser at Lawrence Livermore Laboratory and a carbon dioxide (gas) laser at the Los Alamos Scientific Laboratory.

In 1969, the Soviet Union announced it had achieved spectacular results in confining plasma with a tokamak 4/ magnetic confinement fusion device. Using this device, the Soviets

---

1/Magnetic mirrors involve the use of a magnetic field to shape the plasma into a long tube. A strong magnetic force at each end of the tube reflects the plasma particles back into the tube to help delay and control their escape.

2/The Z-pinch concept involved a toroidal (or doughnut shaped) device in which the plasma was to be confined by "pinching" with an internal magnetic field.

3/The stellarator concept involves a toroidal device in which the plasma is confined by two external magnetic fields, one spiraling around the device and the other encircling it.

4/A tokamak is a hollow, doughnut-shaped device which confines the plasma with a spiraling magnetic field and an internal magnetic field.

achieved an unusually high plasma confinement time, but not with adequate temperature or density to achieve scientific breakeven. The United States quickly converted its stellarator program to tokamaks, and the experimental results announced by the Soviets were verified. International interest in magnetic confinement fusion, specifically in the tokamak, soared.

In 1968, the Soviet Union announced the first observation of neutrons from laser fusion systems. In 1974, a private company, KMS Fusion, Inc., produced the first laser fusion neutrons in the United States. In 1973, Sandia Laboratories began research with an inertial confinement system different from the laser system--the particle beam system. Research with still another type of non-laser inertial confinement fusion energy system began in 1976 when Sandia Laboratories began developing an ion beam system. However, work on laser concepts has continued and in May 1978, the latest Livermore glass system called "Shiva" produced 27 billion thermonuclear neutrons. However, a yield of over 100,000 times as much is needed to achieve scientific breakeven.

Although cumulative AEC, Energy Research and Development Administration (ERDA), and DOE funding of fusion research through fiscal year 1978 totals nearly $2 billion, scientific breakeven has not yet been achieved. In 1970 congressional hearings, AEC officials stated that the scientific feasibility of magnetic confinement fusion would be proven by 1980. In 1973, AEC officials stated that the program was slightly ahead of schedule and that scientific breakeven would be proven in the late 1970s.

In a prior report on fusion research ("Efforts to Develop Two Nuclear Concepts that Could Greatly Improve this Country's Future Energy Situation," RED-75-356, May 22, 1975) we reported that scientific breakeven for magnetic confinement fusion was still expected to be achieved by the late 1970s. Through the 1970s to the present, AEC, ERDA, and DOE have announced substantial advancements in nearly all areas of the program, especially in plasma heating and confinement and in verification of theory. During this period, however, scientific breakeven eluded the researchers.

In August 1978, DOE announced another major advancement. After about 5 years of work, researchers at the Princeton Plasma Physics Laboratory successfully operated neutral beam injectors to produce plasma temperatures of 60 million degrees Celsius in a tokamak device. This accomplishment was not achieved in conjunction with the other criteria for fusion, but according to DOE officials, it assures that temperature, density, and confinement conditions could be scaled to larger devices and that scientific breakeven was achievable. More recently, temperatures of over 70 million degrees Celsius were achieved on the same device and improvements in plasma stability, density, and confinement time were achieved on a number of other devices.

Milestones for inertial confinement fusion have similarly not been met In 1975 congressional hearings, AEC officials stated that scientific breakeven would be achieved during fiscal year 1978. Latest estimates are that breakeven will not be achieved until 1984 to 1988

Optimistic statements concerning the prospects for fusion energy have also surfaced in DOE's budget submissions. For the past few years, the magnetic confinement fusion budget justification contained phrases such as "commercial fusion power reactors," "technical and economic feasibility," and reactors which "might be operational in the first decade of the next century." While such phrases and statements may be indicative of staff optimism or long-range goals, they are not effectively balanced by descriptions of actual status and near-term plans. For example, fusion represents, at best, a possible long-term energy option and current emphasis is on demonstrating scientific breakeven.

CURRENT U.S EFFORTS

DOE is continuing its efforts to achieve scientific breakeven in both the magnetic confinement and inertial confinement concepts and has a small effort in studying alternative fusion energy applications. In addition, relatively small, related efforts are being made by the National Aeronautics and Space Administration, the Department of Defense, private industry, and universities.

Magnetic confinement fusion

About $356 million is expected to be devoted to magnetic confinement fusion research during fiscal year 1979. The fiscal year 1980 budget sent to the Congress requests $364 million for magnetic confinement fusion. The ultimate goal of DOE's magnetic confinement fusion program is to develop a fusion reactor capable of producing electrical power safely, reliably, and economically. Most of the current magnetic confinement fusion program is focused on two concepts--the tokamak, which has the highest programmatic priority, and the magnetic mirror, which is the principal backup to the tokamak concept In addition, DOE is conducting a proof-of-principle experiment with the Elmo Bumpy Torus. (See pages 11 and 13 for a description of these concepts.)

Tokamak

About 65 percent of DOE's funding for magnetic confinement fusion is channeled into the tokamak concept because DOE officials believe, based on recent experimental results, that the tokamak is the most scientifically advanced and the most promising magnetic confinement concept for achieving scientific breakeven. Currently, three major tokamak devices are in operation--the "Alcator," operated by the Massachusetts Institute of Technology; the "Doublet," operated by the General Atomic Corporation; and the "Princeton Large Torus," operated by the Princeton Plasma Physics Laboratory. However, none of these devices is capable of using deuterium-tritium fuel; instead, they each use hydrogen. These devices are designed for researching specific problem areas such as high magnetic fields, neutral beam and radio frequency heating, size scaling, and pellet injection fueling. The "Tokamak Fusion Test Reactor"--currently being constructed and scheduled to operate in March 1982--is planned to be the first major facility in the United States capable of using deuterium-tritium fuel, and it is expected to achieve scientific breakeven for magnetic confinement fusion. A DOE diagram of this tokamak device is illustrated on page 12

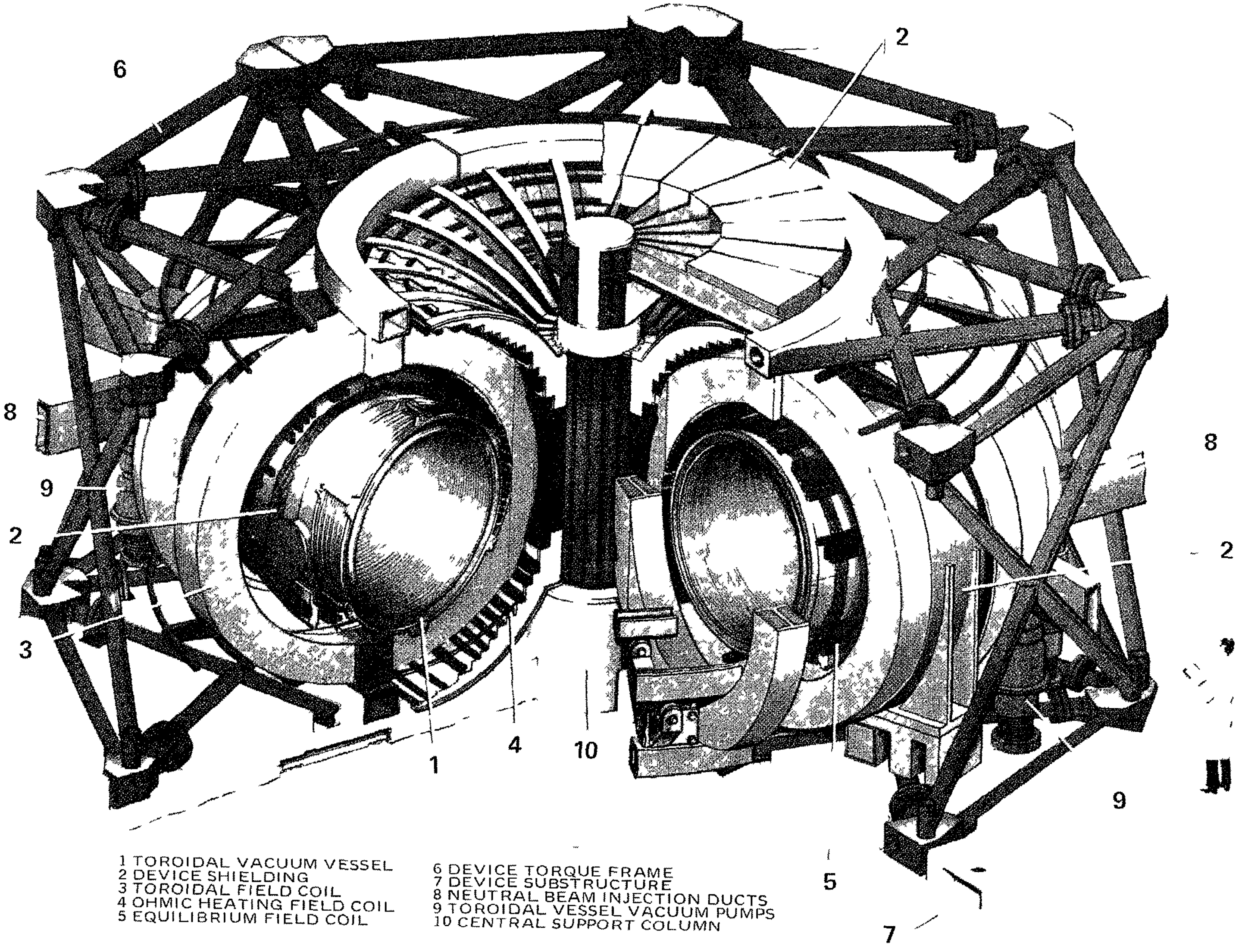
Magnetic mirror

Magnetic mirrors are being researched as the principal backup concept to the tokamak. The magnetic mirror concept, in its simplest form, involves a device in which a magnetic field shapes the plasma into a tubelike configuration A magnetic force at each end of the tube reflects the plasma back into the tube to help delay and control the plasma's escape. Magnetic mirror research is primarily conducted at the Lawrence Livermore Laboratory The major mirror device currently in operation is the Tandem Mirror Experiment at Livermore This is a device for studying confinement scaling, increasing power input-output ratios, and studying plasma heating.

By 1982, DOE program officials expect the "Mirror Fusion Test Facility," now under construction at Livermore, to be in operation. This experimental test facility will employ superconducting magnets and is expected to be capable of extending physics investigations to reactor grade plasmas

DOE's efforts on the mirror concept consumes about 15 percent of the magnetic confinement program's funds.

TOKAMAK FUSION TEST REACTOR



Other exploratory efforts

DOE is currently considering eight concept areas as eventual alternatives to the tokamak or mirror as a power reactor. These concepts have been divided into three categories. The first, a proof-of-principle test using a hydrogen fuel with most of the relevant physics parameters at near reactor levels, includes only the Elmo Bumpy Torus. 1/ The second category includes concepts in a less developed research phase which may eventually be selected for accelerated development. Concepts in the second category are the Reversed Field Pinch, Linear Magnetic Fusion, Advanced Fuels/Multipoles, and Stellarator/Torsatron. The third category consists of concepts at the earliest stage of development where a small experimental device could be used to provide early tests of the concept. Three concepts are in the third category: Compact Toroid, Linus, and Tormac.

Inertial confinement fusion

About $144 million is expected to be spent on inertial confinement fusion efforts by the Federal Government during fiscal year 1979; the budget sent to the Congress for fiscal year 1980 requested $146 million. DOE's inertial confinement fusion research efforts are designed to demonstrate the feasibility of achieving large releases of energy from laser-driven, inertially confined microexplosions and apply this technology in the near term to weapons technology applications, and in the longer term, to produce commercial fusion power.

DOE's current inertial confinement fusion research efforts are concentrated on different types of energy beams or drivers, on different sizes and materials for targets or pellets, and on understanding how different types of beams and pellets interact. Generally, glass laser beams are used for basic physics research, and gas laser beams and particle beams of either electrons or ions are being developed for possible future powerplant applications.

Glass lasers

Glass laser systems, primarily being developed at the Lawrence Livermore Laboratory, are systems in which a light beam--a laser beam--is given high energy by passing the beam

---

1/The Elmo Bumpy Torus is a closed or toroidal mirror, thus combining some feature of tokamaks with some mirror features.

through glass amplifiers. The glass amplifiers contain an element, usually neodymium, which is charged to a high energy level by an outside energy source. The beam, passing through the glass amplifiers, picks up additional energy and exits the amplifiers at a higher power level. After passing through a number of amplifiers, one or more beams enter a target chamber and strike the fuel pellet or target. Major glass laser devices used by Lawrence Livermore include "Janus," a $2-million, two-beam system, first operated in 1974; "Cyclops," a $5-million, single-beam system, first operated in 1975; "Argus," a $3-million, two-beam system, first operated during 1976; and "Shiva," a $25-million, 20-beam system first operated in 1978. DOE plans to incorporate the Shiva device into a larger system called "Nova." The first phase of Nova is expected to be operational in 1983. If experimental results warrant, a second phase will be completed between 1984 and 1988. DOE officials believe that the completed system will be capable of achieving scientific breakeven.

In addition to Lawrence Livermore's glass laser efforts, the University of Rochester is constructing a medium-powered glass laser to be operated as a user research facility. This project is being jointly funded by the University of Rochester, DOE, the State of New York, and private industry.

Gas lasers

Gas laser systems, primarily being developed at the Los Alamos Scientific Laboratory, are somewhat similar to glass laser systems. However, in gas systems the light beam passes through an energized gas, usually carbon dioxide, and is amplified to a higher energy level in the same manner as the glass laser systems. The major carbon dioxide laser system presently operating is HELIOS (formerly known as the "Eight Beam System"). DOE is currently constructing "Antares," a 72-beam laser system that is expected to operate in 1984. Antares, which will cost about $62 5 million, will be about as powerful as the first phase of Nova and is being designed to achieve scientific breakeven.

Particle beam systems

DOE is examining particle beams of electrons, light ions, and more recently, heavy ions as an alternative to using laser beams. Accelerators are used to impart substantial velocity, and thus, energy to these particles. R&D efforts are directed toward forming such particles into intense, concentrated, and focused beams that can be used as inertial confinement fusion drivers, much as laser beams are currently used

Pulse power accelerators are used to generate electrons and light ion particle beams. Simply stated, a pulse power accelerator takes ordinary electrical power and transforms it into very high-power, short pulses of electrical energy. These pulses of electrical energy are then used to form high-power, focused beams of electrons or light ions. Conventional accelerators normally used for basic high-energy physics research, like those at the Fermi National Accelerator Laboratory in Illinois and Stanford Linear Accelerator Center in California, may be adapted to generate heavy ion beams.

Advanced laser development

DOE has plans to develop an advanced laser capable of replacing the carbon dioxide gas laser if the latter proves unsuccessful or unsuitable for powerplant use. Four generic classes of lasers are being evaluated by Sandia and Livermore laboratories and a number of private companies. At least one will be selected for further development. In 1979, DOE plans to build a device incorporating the selected laser concept(s) at a size sufficient to provide information on whether it can be used as a driver in a powerplant. Two concepts will be selected if sufficient funding is available. Depending on the progress made in the carbon dioxide and particle beam concepts, DOE may eventually build an even larger advanced laser device before selecting the driver for an experimental power reactor.

Development of targets or fuel pellets

Regardless of which type of driver is ultimately selected, it will have to irradiate fuel pellets to achieve energy gains. Fuel pellets, or fusion targets as they are often called, consist of tiny spheres containing deuterium-tritium fuel. Several layers of an additional material may be structured on top of the sphere to enhance the driver/target interaction process.

At present, sophisticated target fabrication techniques and target designs are necessary to create fusion targets which will properly implode. For example, a target surface having irregularities greater than about 10 to 100 nanometers (billionths of a meter) may be unacceptable.

DOE is using electron and ion beam drivers to help gain a better understanding of the physics in the reactions between different pellets and drivers. In addition, KMS Fusion, Inc., a DOE contractor, is working with various types of targets and is developing target fabrication techniques. However, according to DOE officials, as more powerful drivers become available, some target fabrication and design requirements might be relaxed, and powerplant fuel pellets may be comparatively simple.

Other efforts

The Lawrence Livermore, Los Alamos, and Sandia laboratories carry out DOE's weapons research and development efforts, so it is logical that inertial confinement fusion, which also may have military applications, is carried out by these laboratories. In addition, the Department of Defense's Naval Research Laboratory carries out research in glass laser development, laser/target interactions, inertial confinement fusion theory, electron beams, and advanced gas laser concepts.

Alternative fusion applications

In addition to researching fusion to develop a process for producing electricity, DOE is studying whether fusion reactions can be applied to produce energy in other forms. Two alternative applications being studied are (1) the production of synthetic fuels and (2) development of a fusion-fission hybrid reactor.

In studying the production of synthetic fuels, researchers are exploring the feasibility of using the intense heat and/or neutrons expected to be generated from fusion reactions for producing hydrogen, alcohol, and synthetic natural gas. If feasible, researchers believe that such fuels could be produced from water and gases found in the air.

DOE is studying the possibility of combining the fusion and fission processes in a fusion-fission hybrid reactor. By adding natural or depleted uranium to the lithium blanket, researchers expect 10 times as much energy per fusion reaction to be produced along with fissile material which could be used to fuel a nuclear fission reactor A hybrid reactor of this type has less stringent physical demands then a pure fusion reactor and researchers believe it could be developed in the near term.

However, fusion-fission hybrid reactors are surrounded by much controversy. Proponents believe such reactors can significantly contribute to near-term energy requirements. They envision that the hybrid reactors could be used to produce electricity, breed fission fuels, and/or convert long-lived, highly radioactive fission wastes into less hazardous wastes.

On the other hand, critics claim that fusion-fission hybrid reactors represent the worst aspects of fusion and fission. Although such reactors might be useful as power producers, they believe that hybrid reactors could be environmentally dangerous. One of the dangers cited is the breeding of fissile material. The Electric Power Research Institute estimates that a typical fusion-fission hybrid powerplant, producing 1,000 megawatts (thermal), could annually produce in excess of 2,000 kilograms of plutonium. In view of the opposition that fission breeder reactors have faced because of nuclear weapons proliferation issues, it is doubtful that fusion-fission hybrid reactors can be made a near-term energy source.

FOREIGN EFFORTS

The possibility of harnessing fusion as a future energy source has inspired worldwide interest and a wide variety of research efforts. At least 20 nations are sponsoring research programs ranging from theoretical studies to the construction of large experimental devices. Nearly all countries with large-scale fusion energy research programs are emphasizing the same approaches, with research on the tokamak concept being the most heavily funded Similar types of physics and engineering problems are being encountered and addressed in all programs.

The Soviet Union, the European Atomic Energy Community (EURATOM), and Japan have significant programs in magnetic confinement fusion research, and the Soviet Union has a large inertial confinement fusion research program. In addition, a number of other countries are conducting theoretical studies or small experimental programs. Countries are generally cooperating, coordinating, and exchanging magnetic confinement fusion information. According to DOE officials, few impediments to international magnetic confinement fusion information exchange and cooperation exist, and the current level of coordination is effective. However, countries are reluctant to share information on inertial confinement fusion because inertial confinement fusion research and experiments can contribute to an understanding of nuclear weapons physics.

Soviet Union

According to Soviet embassy officials, DOE officials, and published fusion articles and papers, the Soviet Union's fusion program appears to be a broad-based effort conducted on tokamaks, stellerators, mirrors, pulsed systems, and lasers and electron beam devices at seven major Soviet research centers. Currently, emphasis is placed equally on magnetic confinement fusion (principally the tokamak) and inertial confinement fusion. DOE officials believe the overall level of effort in the Soviet Union is about equal to that in the United States.

The Soviets began fusion research about the same time as the United States. The tokamak concept was first tested in the Soviet Union in 1969. The Soviet Union currently has many tokamaks in operation. Their major operating tokamak is about the size of the Princeton Large Torus. A major new tokamak is being constructed and is expected to operate in 1983.

The Soviets are currently operating two stellerators and constructing two more. According to published articles, the Soviets believe the stellerator is potentially more attractive as a reactor because theoretically it is a less complex device and would result in a more economic reactor. As previously noted, DOE does not currently carry out any significant efforts on the stellerator.

The mirror concept was first tested by Soviet scientists in 1961. DOE officials informed us that the Soviet magnetic mirror program is, in part, similar to U.S. tandem mirror efforts and that the Soviets similarly consider this concept to be a backup to the tokamak. The Soviets are also exploring several other mirror concepts such as those employing rotating and multiple mirrors.

The Soviets are also attempting to develop the fusion-fission hybrid reactor and are carrying out research in pulsed systems. The pulsed system work is aimed at improving the magnetic confinement systems so they may better withstand the neutrons produced by fusion reactions. The Soviets are also reported to be working on several other magnetic confinement concepts in an attempt to resolve plasma containment problems.

In inertial confinement fusion, DOE officials told us that the Soviets are not as advanced as the United States in the use of lasers, but are probably ahead in using electron beam drivers. The Soviet program, according to DOE officials, is closely related to military applications. These officials contend that the Soviet Union's laser efforts have been adversely affected by an inferior optical industry (good optics are needed to focus beams for good laser performance) and inadequate analytical computer capabilities. In electron beams, the Soviets have at least three major devices in operation, are currently designing another, and expect to achieve scientific feasibility in the early 1980s.

EURATOM

EURATOM, the nuclear research and development arm of the European Common Market Community, was created in 1957 to promote peaceful uses of nuclear power. It has nine member nations--Belgium, West Germany, France, Italy, Luxembourg, the Netherlands, Denmark, Ireland, and the United Kingdom. Sweden, a nonmember nation, signed a cooperative agreement in 1976 to be associated with EURATOM's fusion research.

EURATOM's fusion research funding for the period 1971 through 1975 totaled about $86 million, but has been increasing rapidly. For the period 1976 through 1980, funding is expected to total about $633 million.

EURATOM's fusion research efforts are implemented through contracts with member countries' research organizations. Each participating country operates its own laboratories, but EURATOM attempts to integrate the European efforts into a single unified program. EURATOM contributes funds for about 25 percent of the operating expenses and 45 percent of the investment capital required for building large experimental devices of interest to the member nations. The individual participating countries pay the remainder. EURATOM also sponsors meetings and symposiums on fusion.

EURATOM's major project is the "Joint European Torus," a large tokamak device being built in Culham, England, for studying plasma under reactor-like conditions. Construction is underway, and the device is expected to be ready for operation by 1982.

Other fusion activities that EURATOM supports are:

--Experiments on existing tokamaks and the possible construction of medium-sized devices

--Research on high beta systems.

--Research with stellarators

--Research on heating plasma to the high temperatures needed for fusion.

--Research on supporting technologies such as power supply control, vacuum techniques, materials, and fusion power reactor design.

EURATOM considers inertial confinement fusion to be an alternative to magnetic confinement fusion, but only plans to keep abreast of worldwide progress without undertaking any major research effort.

Japan

Japan's goal is to develop fusion energy for use in the 21st century. Funding for the period 1975 to 1979 is estimated at $500 million, with research being performed at five major laboratories and several universities. DOE officials believe that Japan's fusion program is not as advanced as the U.S. program, but because of its aggressive efforts, Japan is expected to reach scientific feasibility about the same time as other countries with large-scale programs.

Japan has two operating tokamaks and another planned for operation in 1982 to study plasma in near reactor conditions. Japan is also exploring mirror concepts similar to the United States' Tandem Mirror Experiment at Livermore and the Elmo Bumpy Torus at Oak Ridge.

Japan has a small inertial confinement fusion effort which generally follows the path of the U.S. program; that is, a primary effort using glass lasers and secondary projects involving carbon dioxide lasers and electron beams. The Japanese have predicted they will achieve scientific feasibility with a glass laser system, but have not announced a target date for it.

Other foreign efforts

Some EURATOM member nations and other countries carry out magnetic fusion research at their national laboratories. The French emphasize tokamaks and plasma heating. Italy's program includes a tokamak device and supporting basic fusion research. The Netherland's program emphasizes plasma research and toroidal systems. West Germany is conducting research on tokamaks, stellarators, and pulsed systems. Other countries independently performing magnetic confinement fusion research include Denmark, South Africa, China, Switzerland, and Sweden.

Some countries have small inertial confinement fusion efforts. Canada is carrying out work using carbon dioxide lasers, Belgium is doing theoretical work, West Germany is performing research using iodine lasers, France is working on target designs, and the United Kingdom is working on the glass laser exclusively for military applications. Other countries with small inertial confinement fusion efforts include Poland, Israel, and Rumania.

International cooperative efforts

In magnetic confinement fusion research, there has been formal and informal cooperation through bilateral and unilateral arrangements for exchanging information and manpower. In addition to EURATOM, there are two major international organizations which, in part, promote the development of magnetic confinement fusion. Under the auspices of the United Nations, the International Atomic Energy Agency (whose membership is open to all nations) encourages cooperation in international nuclear energy research.

In addition, the International Atomic Energy Agency is sanctioning INTOR (International Tokamak Reactor). Under this project, the United States, the Soviet Union, the European Community, and Japan are developing the technical objectives and nature of the next large tokamak.

The other agency is the International Energy Agency, a part of the Organization of Economic Cooperation and Development, whose membership consists of 18 European and North American countries (including the United States), plus Japan. This agency provides member nations with a united front for (1) cooperating with the oil-producing countries and companies for mutual benefit, (2) lessening the oil dependence of its members, and (3) providing an oil-sharing plan for emergencies. As one means of reducing future dependence on oil, the agency sponsors cooperative R&D programs on various technologies, including magnetic confinement fusion concepts. Two major cooperative agreements related to fusion have been signed under the agency's auspices: one for developing a large superconducting coil, and another for researching container wall damage. The United States has the lead role for developing facilities for use under the superconducting coil agreement, and West Germany has the lead role for developing a tokamak device for researching container wall damage. The United States is also participating in the wall damage project and will have access to conduct experiments on the West German device. Similarly, other participating countries will have access to conduct experiments at the facility that the United States is developing under the coil agreement. An agreement on fusion materials is currently being negotiated.

In addition to participating in the efforts of these international agencies, since about 1958 the United States and the Soviet Union have been exchanging magnetic confinement fusion information. Initially this was done on an informal basis, but in February 1974 information exchanges between the two countries were formalized with a written agreement to exchange information on magnetic confinement fusion. Under the agreement, the United States and the Soviet Union have exchanged information on experimental results and made reciprocating site visits. There also have been personnel exchanges and jointly sponsored seminars and conferences on a variety of magnetic confinement fusion concepts.

The United States and Japan have recently signed an Agreement for Cooperation in Energy Research and Development One of the areas for cooperation is fusion. Tentatively, the agreement will (1) establish a Joint Institute for Plasma Physics, (2) allow for coordinated fusion planning, and (3) provide for information exchanges and facility visits. In addition, the Japanese may provide $60 million to upgrade the United States' Doublet III device.

CHAPTER 3

PROBLEMS IMPEDING THE DEVELOPMENT OF FUSION AS AN ENERGY SOURCE

DOE officials are optimistic that energy from fusion reactors will be commercialized in the next century. It appears that fusion, if developed, will be a virtually inexhaustible source of energy because deuterium is abundant and tritium can be derived from a readily available substance. But many problems remain to be solved. Before a commercial reactor can produce usable energy, scientists must achieve scientific breakeven, prove scientific and engineering feasibility, and demonstrate a commercial reactor. Until these items are proven, the practical potential of fusion cannot be determined.

Engineering feasibility will be achieved when the physical and engineering requirements for a potentially economically competitive design have been met. Commercial feasibility will be demonstrated when net usable energy is produced from a fusion reactor in an economically competitive, safe, and environmentally acceptable manner. DOE's research efforts have been emphasizing the achievement of scientific breakeven. To help ensure the success of ultimately achieving commercial fusion power, its efforts are also directed toward developing backup concepts and engineering designs, and addressing environmental and safety issues.

PROBLEMS IMPEDING THE DEVELOPMENT OF MAGNETIC CONFINEMENT FUSION

In magnetic confinement fusion, DOE is emphasizing the development of the tokamak concept because it believes this concept has the highest potential to achieve scientific breakeven. However, even after scientific breakeven is achieved, many physics and engineering problems will remain to be solved.

Breakeven and scientific feasibility

To achieve breakeven and scientific feasibility, tokamak researchers have identified four major physics problems which impede achievement of the temperature, density, and confinement criteria.

--Transport and scaling. Transport and scaling refers to understanding the physical laws which describe plasma behavior in present experiments and predict plasma behavior in larger devices. Information on scaling is being obtained by experimentation with successively larger devices. One of the key elements necessary to determine the economics of fusion reactors is understanding scaling laws so that the requirements for a larger reactor can be accurately estimated. According to DOE officials, recent experiments at the Princeton Plasma Physics Laboratory have done much toward solving the scaling questions, and they expect that experiments at the Tokamak Fusion Test Reactor, currently being constructed, will resolve the problem.

--Heating. Plasma temperatures currently are too low to overcome the repulsion of like-charged particles; overcoming such repulsion is needed so fusion can occur. The plasma temperature required for magnetic confinement fusion reactors is expected to be about 100 million degrees Celsius. Recent experiments involving neutral beams on tokamaks have produced temperatures of about 70 million degrees Celsius. Research is being carried out to develop new heating methods.

--Controlling plasma impurity. Foreign particles, or impurities, in the plasma can cool the plasma or cause the plasma to shrink and become unstable. Hence, controlling impurities is essential for long periods of operation. A major source of this contamination is expected to be the inner reactor wall from which impurities can be dislodged by neutron bombardment during a fusion reaction. Efforts are underway to develop materials which can withstand neutron bombardment. In the event that materials presently being developed and tested prove to be insufficient, other methods are being studied to prevent plasma ions from hitting the wall. Two such methods are (1) the magnetic divertor which is to "divert" the plasma impurities into a special auxiliary chamber and (2) gas blankets which are to help reduce the number of ions that bombard the inner wall.

--Stabilizing plasma. Plasma stability is affected by the shape of the plasma. Researchers have predicted that plasma confined in a noncircular shape is theoretically capable of being confined by lower strength magnetic fields than plasma in a circular shape. If the required strength of the magnetic field can be reduced, smaller reactors will be needed, and powerplant costs can be reduced. Efforts are underway to determine the optimal plasma configuration.

As a principal backup to the development of the tokamak concept, DOE is also developing the magnetic mirror concept.

The magnetic mirror concept enjoys an advantage over the tokamak because such devices have a natural tendency to reduce inner wall impurities; the plasma is self-purifying since particles escape before reaching the inner wall of the container. Magnetic mirrors have potential to operate continuously rather then in the pulsed mode used by tokamaks. However, the magnetic mirror concept, in its present form, has the major disadvantage of low efficiency in terms of power-input to power-output. Simple mirrors have an estimated power-output to power-input ratio of slightly more than one compared to a very large ratio for tokamaks, where the plasma may require little or no additional energy to be self-sustaining.

Engineering feasibility

Assuming scientific breakeven is achieved using a tokamak device by the mid-1980s as predicted by DOE, other physics and engineering problems will have to be solved before a commercial reactor is feasible. Although the tokamak is the most scientifically advanced magnetic confinement concept, utility industry experts are concerned that it may not be practical for use in a commercial powerplant. They point out that, of the alternative approaches to fusion currently being considered, the tokamak is the most complex approach from the standpoint of the engineering required to scale up for energy production. They also point out that the complexity of the tokamak's design would tend to make a commercial powerplant uneconomical. Hence, researchers are seeking to find ways to simplify the engineering required and reduce the size of tokamak reactors, which in turn would help reduce costs. Recent experimental results relative to these objectives have been encouraging.

Some potential problems that researchers have identified to date are currently being worked on.

--Magnetic power deficiencies. Conventional magnets have excessive heat losses and require large amounts of electrical power. Conventional magnets are also very large, thereby necessitating large reactor configurations. Thus, efforts are underway to develop small superconducting magnets which would permit full magnetic power while inputing significantly smaller amounts of electricity.

--Temperature Fusion researchers have long recognized that neutral beams of greater efficiency must be developed for injecting high-energy atoms into plasma to raise its temperature Efforts are underway to achieve more powerful neutral beam currents.

--Refueling. Many uncertainties remain in refueling fusion reactors. Fusion research on refueling fusion reactors has only recently begun because refueling has not been required for present short-pulse experiments. Experiments are underway on using pellet injectors for fueling experiments on future tokamaks, and several other techniques are also being pursued, including rotating centrifuges, and electrostatic accelerators. In addition, DOE is studying other possibilities such as gas blankets, plasma guns, and low neutral beam injection

--Materials. Current state-of-the-art in materials technology would limit the first wall life of fusion reactors to 10 years or less due to radiation damage. Efforts are underway to explore using other materials which would help resolve the problem In addition, DOE is studying modular construction designs which would allow periodic change-outs of inner walls or other damaged structures.

--Radiation. Tritium, if not properly handled and contained, could pose a radiological hazard. DOE has recognized this potential problem and has a major effort underway in tritium containment and control. Analyses performed to date indicate that current cleanup system technologies would adequately control anticipated tritium releases from fusion reactors.

--Wastes. Radioactive waste associated with fusion powerplants may pose handling and disposal problems. DOE does not believe radioactive wastes from fusion plants will prove to be a major problem because such wastes will be produced only by activation of structural material, and not as a direct product of the fusion reaction itself. Hence, when compared to fission reactions, the magnitude of the problem is relatively small, with fusion expected to produce only a tenth as much waste as the fission process. However, DOE is making efforts to minimize the quantities of radioactive waste and to ensure that the waste is in a form which could be easily handled and disposed

Commercial feasibility

To successfully commercialize fusion, not only does its breakeven, and scientific and engineering feasibility need to be proven, but it must be (1) economically competitive with other energy sources and (2) acceptable to the general public as a safe and environmentally compatible technology. Because portions of magnetic confinement fusion are still in the basic research phase of development, it is premature to expect that all the economic, safety, and environmental issues have been identified, let alone resolved. For example, the state-of-the-art has not yet advanced to a point where reliable cost estimates can be made for constructing and operating a commercial fusion reactor. Hence, a multitude of problems remain to be solved before magnetic confinement fusion becomes a commercial energy source.

PROBLEMS IMPEDING THE DEVELOPMENT OF INERTIAL CONFINEMENT FUSION

Much as with magnetic confinement fusion, researchers seeking to develop inertial confinement fusion as an energy source face a multitude of problems. Scientific breakeven has not yet been achieved, and much of the work on this concept is in the basic research phase. DOE is continuing its efforts to achieve scientific breakeven and hopes to reach that point during the period 1984 through 1988.

Currently, DOE is concentrating its inertial confinement fusion efforts in three major problem areas:

--Developing more powerful and efficient drivers.

--Gaining a complete understanding of the highly complex physical process of interacting drivers and fuel pellets or targets.

--Developing a process to mass produce sufficient usable targets.

Driver development

A major problem facing researchers is developing a driver which deposits sufficiently large amounts of energy on targets to sustain a large number of fusion reactions so that energy can be produced. To achieve an energy gain sufficient to produce electricity, the driver must efficiently deliver energy to the target. The ratio of the energy yielded from a target to the energy input by the driver is called pellet gain. To generate electricity in a commercial inertial confinement reactor, researchers estimate that the pellet gain ratio needs to be in excess of 20 to 1. To date, the highest ratio achieved in an inertial confinement fusion experiment has been about 1 to 100, a net loss of energy. Hence, it is obvious that much work remains to be done to improve the power of drivers if commercial power is to be generated from an inertial confinement fusion reactor.

DOE is exploring several types of drivers because each has different characteristics and can serve different purposes. Currently, glass lasers are being used in efforts to achieve scientific breakeven, carbon dioxide gas and other advanced lasers are being evaluated for potential use in powerplants; and particle, electron, and ion beams are being used in experiments designed to gain a better understanding of the physics in the reactions between different pellets and drivers. Although glass lasers are being developed to achieve scientific breakeven, most fusion researchers do not consider such lasers acceptable as drivers in a future commercial powerplant. The reason is that heat builds up in the glass, which prevents the laser from being repeatedly fired at the rates believed to be necessary in a commercial power system. Glass lasers can be fired only about once an hour, whereas a commercial driver is expected to be fired about 10 times per second. Consequently, DOE does not currently plan to develop glass lasers beyond scientific breakeven and other drivers are being developed for possible use in a commercial reactor.

Carbon dioxide gas laser beams are being developed for potential powerplant use because they have relatively high efficiency, are considered adaptable for scaling up to larger sizes, and can be fired repeatedly. However, the long wavelength associated with gas laser beams requires special optical equipment. The lenses currently available are either not completely satisfactory or difficult to make. In addition, the long wavelength may adversely affect implosion physics phenomena and reduce the potential for achieving high pellet or energy gains.

In comparison to laser driver systems, experiments have indicated that light ions and electron beam drivers may be relatively simple, inexpensive, and efficient. Efficiencies have been estimated up to 50 percent, whereas an extremely efficient laser driver only may attain a 15-percent efficiency. However, research in such particle beams is in its infancy, and much development work must still be performed before the potential of particle beams as drivers of inertial confinement fusion systems is known. For example, scientists at Sandia Laboratories are concerned that certain physical and technical constraints could limit the maximum amount of power that can flow from an accelerator and cause serious difficulties in scaling to higher power levels. Techniques for overcoming these problems are to be explored with an "Electron Beam Fusion Accelerator," now being built at Sandia Laboratories in New Mexico. Another potential problem is undesirable blast and radiation damage. This matter is under study at Sandia Laboratories, and theoretical and experimental results to date indicate that the problem can be overcome.

Driver/target interaction

The interaction, or energy coupling, of the driver and the target and the subsequent compression and heating of the fuel involve highly complex physical processes. While much has been learned about these processes, existing laser and particle beam systems cannot focus enough energy and power on targets to resolve the remaining uncertainties. DOE is seeking to successfully complete and operate experiments with more powerful driver systems in the next few years so that scientists can resolve the uncertainties.

To implode a target, the energy from the driver must be efficiently coupled with the target, and the energy deposited must effectively compress and heat the target. Counteracting physical processes inherent in both the driver and target contribute to the existing uncertainties. For example, turbulence in the fuel could either enhance its energy-absorbing efficiency or impede it. The turbulence might also pre-heat the fuel in the core of the pellet, making compression more difficult.

Uncertainties also exist about the physical processes that affect stability of pellet compression. Microscopically irregular ridges and depressions on the surface of the fuel pellet or between layers of pellet materials can adversely affect the stability and uniformity of the compression. Some physical processes enhance the growth of these instabilities, while others tend to dampen growth. A better understanding of the conditions under which these physical processes occur is needed.

These and other uncertainties, some of which are classified, exist because the theoretical predictions of which physical processes will prevail when targets are irradiated by more powerful laser and/or particle beam pulses have not been experimentally confirmed. It is possible that some of the problems may not exist at higher energy levels or that other problems may surface.

Target fabrication

The ability to fabricate targets to required specifications is as important to the program as the development of high-powered driver systems. Each target must meet microscopic design specifications to be suitable for fusion research. As drivers become more powerful, larger targets will be required, and fabrication may be less difficult. However, new target designs may require development of new fabrication techniques or may pose other unforeseen problems.

Target fabrication is a complex process requiring batch processing of billions of prefabricated hollow glass microspheres ranging in diameter from 40 to 600 micrometers. Until recently, only 1 in 100 million microspheres produced was suitable; however, with new production methods, about 1 in 100 is suitable. Further improvements are expected

Target fabrication requires filling selected targets with fuel; advanced targets may require the solidification of this fuel as a frozen film on the inside surface of the microsphere. Because the fuel freezes at minus 253 degrees Celsius--20 degrees above absolute zero--cryogenic fabricating and handling techniques will have to be developed. Developing mass production processes will require analyzing a wide variety of materials so that those with physical properties that are experimentally useful, machineable, and compatible with other materials can be selected.

After fabrication, a highly sophisticated examination procedure is needed. Each pellet and layer within a pellet must be examined for thickness and irregularities. Since an enormous number of microscopic pellets will be required, unique electronic scanning procedures must be developed and employed

Target design and fabrication activities to date have centered on producing single, high-cost fusion targets for experimental purposes. An inertial confinement fusion reaction may require from 100,000 to 1 million fuel pellets a day. Thus, economical mass production techniques for producing reliable, high-quality pellets must be developed to enable this fusion process to be economically feasible

<u>Classification requirements are potential impediments</u>

Much of the inertial confinement fusion target fabrication and design criteria, many of the related theoretical studies and computer modeling programs, and experimental results are classified because inertial confinement fusion research and experiments can contribute to an understanding of nuclear weapons physics. The classification of information results in a lack of freedom to fully exchange ideas about driver/target interaction and target implosion physics with scientists who do not have the required security clearance. The remaining unclassified information cannot always fully describe the knowledge that has been accumulated from research. DOE program managers are concerned that this restriction may adversely affect the program. Consequently, program officials have recently taken action to increase university and industry involvement in inertial confinement fusion research efforts.

Six private firms and university groups have been selected to perform classified research. Program officials plan to annually determine the need for additional participation.

Other areas of concern

If scientific breakeven is achieved, scientific feasibility is demonstrated, and research emphasis is shifted to demonstrating engineering feasibility, industry involvement is expected to rapidly increase. DOE hopes these efforts will culminate with an experimental power reactor capable of generating limited electrical power before the year 2000. About 2005, DOE plans to demonstrate commercial feasibility by having utility companies construct and operate a prototype power reactor in a safe, reliable, economic, and environmentally acceptable manner.

As with a magnetic confinement fusion system, a significant portion of the inertial confinement fusion program is still in the basic research phase, and it is premature to assume that all the economic, safety, and environmental problems have been identified or solved. Hence, as research continues, it is inevitable that additional physics, engineering, economic, safety, and environmental problems will need to be resolved.

MANAGEMENT APPROACH TO OVERCOME PROBLEMS AND DEMONSTRATE COMMERCIAL FEASIBILITY

Both the Offices of Fusion Energy and Inertial Fusion centrally manage their respective programs. Each office provides program direction, establishes priorities and milestones, monitors work progress, evaluates results, and generally decides what and when work should be done. In managing the program, Fusion Energy obtains advice from advisory panels and Inertial Fusion from the DOE laboratories. Although inertial confinement fusion efforts are directed in the near-term toward weapons development rather than energy, their research and demonstration strategies are also similar. Each office's management strategy has been to prioritize the concepts, based on potential for near-term achievement of scientific breakeven, and emphasize work on the highest priority concept. Recognizing that concepts used to achieve scientific feasibility may not be suitable as commercial reactors, however, lower keyed efforts are being continued on other concepts.

Strategy for magnetic confinement fusion

The Office of Fusion Energy's planned strategy to demonstrate commercial magnetic confinement fusion centers around three major milestones. The first is breakeven (and generally within the same time frame, scientific feasibility); the second, engineering feasibility; and the third, commercial feasibility. This strategy has been criticized by some experts for inadequately mitigating the risks involved. Although program officials recognize these risks, they believe it is important to achieve scientific breakeven as soon as possible so that the physics involved in fusion reactions of that magnitude can be studied.

The Office of Fusion Energy has been emphasizing work on the tokamak concept because it is the most scientifically advanced and is currently the most promising for achieving scientific breakeven. However because scientific feasibility has not yet been achieved and other problems must be overcome before ultimately producing commercial power, the Office of Fusion Energy is also proceeding with work on other concepts which it believes show some promise.

Engineering feasibility would demonstrate all the physics and engineering required for a complete energy system on a small and relatively inefficient scale. Fusion Energy has been carrying out some limited efforts designed to identify and solve engineering problems, so that excessive delays toward fusion's development will not occur after scientific breakeven is achieved. After breakeven is achieved, a device tentatively titled the "Fusion Test Facility" is planned to be constructed to prove engineering feasibility.

To demonstrate commercial feasibility, a device will have to generate reliable electric power using a magnetic confinement fusion reactor in an economic, safe, and environmentally acceptable manner. It is planned that a device called the "Demonstration Fusion Power Reactor" will be built to provide the technical and economic groundwork necessary for introducing commercial fusion power reactors into the Nation's electric grid

This strategy recently has been reviewed by two separate groups. In June 1978, an ad hoc advisory group, established by DOE to provide a concise assessment of the content and balance of DOE's fusion programs, reported that the research efforts in the magnetic fusion program should be broadened. The group recommended that greater basic research efforts should be carried out among more concepts and that greater efforts should be directed toward engineering problems. The group explained its rationale by stating, in part:

> "In our judgment it is too risky at this stage to select and provide specific emphasis on one of the several major concepts. Also, it is too risky at "this time to concentrate just on the physics experiments and delay to a later time considerations of downstream engineering problems. Rather, with diligence and good luck we would hope to find one or more acceptable combinations of physics and engineering concepts which would seem to provide viable paths to fusion energy."

Also in June 1978, the Working Group on Basic Research, established by the Office of Science and Technology Policy, reported on the results of its study of the scope and quality of basic research by DOE. A portion of that report addressed fusion energy. The working group cited both the magnetic and inertial confinement fusion programs for "attempts to move ahead too rapidly without adequate theoretical, experimental and engineering assessment of existing results." The group further noted that:

> "The highly competitive nature of the two programs has accentuated the tendency of trying to leapfrog the normal states of evolution of a difficult and not-yet-well-understood technology."

The group recommended a broadly based fusion research program in which (1) basic research is supported; (2) universities play an expanded role; and (3) the pace of large-scale, expensive experiments is set to extract maximum value from investments in facilities.

In regard to the expansion of university roles, the vehicle for universities to become involved in fusion research is unsolicited proposals, which DOE generally reviews and funds annually. In a separate letter report to the Secretary of Energy, we pointed out that improvements were needed in DOE's evaluation system for unsolicited fusion research proposals. 1/

With respect to the broadening of the fusion research efforts, we agree that expanded efforts on more concepts would help mitigate the uncertainties involved in seeking to

---

1/(EMD-78-63, Apr. 26, 1978).

eventually commercialize fusion as an energy source. Some broadening of these research efforts has occurred since these reports were issued and it appears that DOE's present program is appropriately balanced. We agree with DOE's approach of placing greatest research emphasis on those concepts which, based on the latest experimental and scientific data and technical judgements, have the greatest potential for achieving scientific breakeven.

Fusion, along with fission (with some type of breeder) and solar power, is one of the few essentially inexhaustible energy technologies that can help solve the Nation's long-range energy problems. Expanded research in each concept, regardless of currently expected potential of success, may improve the chances of eventual success, but fund limitations would result in a decreased potential of success and extend the time frame for reaching scientific breakeven. Hence, research in fusion, in our view, should continue to be directed toward achieving scientific breakeven.

To some extent, fund limitations have already adversely affected the magnetic confinement fusion program In July 1976, program officials devised a plan (currently being revised) which set out five different logics or scenarios for magnetic confinement fusion development.

--Logic I. Program at a maintenance level under which a demonstration reactor will be built far in the future, if at all. No major facilities would be built.

--Logic II. A moderately expanding, sequential program limited by the availability of funds.

--Logic III An aggressive program effort with adequate funding, but reasonably limited.

--Logic IV. An accelerated program effort. Funds are not unlimited, but reasonably limited.

--Logic V. A maximum effort with facilities and funds available on a priority basis.

The following table shows the operation dates estimated in 1976 for major magnetic confinement fusion tokamak devices under the various logics.

Milestones	Logics and Target Dates				
	I	II	III	IV	V
Scientific feasibility	Indeterminate	1981	1981	1981	1981
Engineering feasibility	Indeterminate	1997	1991	1985	1985
Commercial feasibility	Indeterminate	2005	1998	1993	1990

Even after commercial feasibility is demonstrated, DOE officials believe it would take another 20 years before fusion can be a widespread commercial energy source. Milestone dates for mirror devices, if needed, would be scheduled further in the future because the mirror is not as far advanced as the tokamak.

According to Fusion Energy officials, until recently the magnetic confinement fusion program was operating under Logic III. These officials informed us that the program has not received the funding levels they requested in the last few years, and Logic III milestones will not be met. In fiscal year 1977, funding was $12 million or 7 percent less than requested and, in fiscal year 1978, funding was $59 million or 28 percent less than requested by the Office of Fusion Energy.

To mitigate the effects of limited funding, program officials decided to concentrate resources in theory and physics research. The most significant reduction was made in long-range efforts to develop the engineering and technology base for a fusion reactor. For example, in fiscal year 1977, the reactor engineering budget was decreased by $13 million, or 22 percent; in fiscal year 1978 it was decreased by $25 million, or 33 percent. In light of budget stringencies this change in emphasis seemed appropriate to us because, should efforts to achieve scientific breakeven with the Tokamak Fusion Test Reactor fail, the increased effort on engineering experiments could provide only marginal benefit. Hence, it seemed more prudent to use limited resources to emphasize work on the theoretical and physical problems which will first have to be resolved

Fusion Energy and laboratory officials told us that funding limitations have already delayed some other program aspects and will have additional effects. They noted that the final cost of the Tokamak Fusion Test Reactor will increase, and the completion date will slip from June 1980 to March 1982. Limited funding is also expected to have a negative impact on plasma-heating work at Lawrence Livermore and Lawrence Berkeley Laboratories.

Because it is not certain whether the tokamak--or for that matter, any of the magnetic confinement fusion concepts--will achieve commercial fusion, Fusion Energy has scheduled decision points to determine which concepts should be pursued. Program officials will decide for each concept whether to proceed, accelerate, or terminate work. To facilitate these decisions, program officials plan to conduct critical assessments of the physics and engineering for tokamaks in 1979, for mirrors in 1982, and for alternate concepts during the period 1980 through 1986. If either the physics, engineering, or commercialization prospects are rated poor for a given concept, DOE plans a reassessment followed by an appropriate shift in program emphasis.

Strategy for inertial confinement fusion

The Office of Inertial Fusion's inertial confinement fusion program goal is to develop the technology for

--near-term applications to nuclear weapons development and testing and

--long-term applications as an inexhaustible energy source.

To accomplish this goal, Inertial Fusion believes it is essential to achieve scientific breakeven and demonstrate scientific and engineering feasibility as soon as possible. In line with this strategy, funding priorities were established as follows:

--Achieve scientific breakeven using glass lasers.

--Conduct experiments using drivers other than glass lasers.

--Develop and evaluate advanced driver technologies.

--Develop mass production techniques for targets

--Develop reactor technology.

In the mid-1980s, if breakeven and scientific feasibility are achieved, efforts will focus on demonstrating engineering and commercial feasibility At that time, Inertial Fusion plans to transfer much of the program's development effort from DOE's weapons laboratories to private industry. Inertial

Fusion officials believe that the current state-of-the-art precludes setting definitive mid-term goals, but they have outlined a number of hoped-for achievements:

--Build two experimental power reactors before proceeding to a prototype power reactor.

--Resolve materials problems common to inertial and magnetic confinement fusion.

--Build a materials test facility to resolve materials problems peculiar to inertial confinement fusion.

--Develop pellet design and fabrication technology fast enough so that pellet availability problems do not delay reactor development.

The objective of the two experimental power reactors would be to demonstrate engineering feasibility in smaller, less costly reactors by verifying the physics and engineering principles required for a prototype power reactor. A prototype power reactor, currently planned for about the year 2005, is to demonstrate commercial feasibility and produce electrical power in a safe, reliable, and environmentally acceptable manner.

Inertial Fusion has given first priority to achieving scientific breakeven using glass lasers largely because such lasers are the most scientifically advanced inertial confinement driver. However, experimental data has shown that glass lasers have limited potential for use in commercial powerplants.

Inertial Fusion program officials told us they are emphasizing the achievement of scientific breakeven with glass lasers--even though glass lasers are not expected to be used in a commercial powerplant--because it is important to tackle the high risk-task of achieving energy gain as soon as it is feasible in order to keep total program costs low in the event high-energy gain is found to be either impossible to attain or uneconomical, compared to other available energy supply options. They added that glass laser experiments can be used as a surrogate for most fuel pellet or target experiments that otherwise would be needed for advanced lasers or particle beams. (Inertial Fusion officials informed us that the strategy described above is still in effect; however, a new strategy is currently being developed and will be announced during the summer of 1979).

There has been some congressional concern that the pursuit of military goals in inertial confinement fusion may retard its development for civilian-oriented energy use. In its consideration of DOE's fiscal year 1979 budget, the House Committee on Science and Technology recommended that $8.8 million be authorized for initiating an inertial confinement fusion civilian applications program in DOE to develop, demonstrate, and use inertial confinement fusion for domestic energy. The House Committee on Appropriations similarly provided $8.8 million for inertial confinement civilian energy applications. However, the Senate Committee on Appropriations did not approve funds for this purpose. Instead, the committee stated that the primary focus of the inertial confinement program is related to national security objectives. The committee further noted that at an appropriate time, after scientific feasibility has been demonstrated, the program goals will be redirected to include civilian energy applications. In commenting on the issue of separate funding for civilian inertial confinement fusion applications, the Committee of Conference reported that it is appropriate for work related to civilian applications to be funded along with that related to military applications.

We generally agree that a separately funded civilian use program is not yet needed. Such a program would undoubtedly devote additional resources toward addressing the potential engineering, economic, safety, and environmental problems associated with developing inertial confinement fusion for use in a commercial powerplant. We believe that research efforts should continue to emphasize the resolution of the fundamental theoretical and physical problems so that the scientific feasibility of inertial confinement fusion is known as early as possible. In view of the uncertainty involved in proving that energy gains can be produced from inertial confinement fusion reactions and the commonality of the research (85 to 90 percent is estimated to be common to both military and civilian applications), we believe that the prudent course of action is to achieve scientific breakeven before committing significant additional resources to a separate civilian use program. Only after scientific breakeven is achieved and the chances of ultimately achieving a commercial inertial confinement powerplant better known, can a decision to establish a separate civilian use program be made with reasonable confidence.

PRACTICAL POTENTIAL NOT YET DETERMINED

Theoretically, energy from the fusion process would be virtually inexhaustible. However, the practical potential of fusion can only be determined after it is known that scientists can generate energy using this process. Thus, the achievement of scientific breakeven and feasibility, and demonstration of engineering feasibility must be accomplished before an educated estimate can be made of the potential energy that can be produced.

DOE officials are optimistic that scientific breakeven can be proven with the Tokamak Fusion Test Reactor currently under construction. However, this reactor is only a start toward developing a commercial reactor; there will still be major engineering problems to be faced. Even the most optimistic estimates predict that a magnetic confinement fusion demonstration reactor cannot be built until about the year 2000. Similarly, the most advanced inertial confinement fusion system uses a glass laser as the driver for transporting and focusing energy on the fuel pellet or target. This system is expected to achieve scientific breakeven in the mid-1980s. However, glass lasers are not expected to be suitable for a commercial powerplant, and other lasers or drivers must be developed. Even if scientific breakeven is achieved, inertial confinement fusion will require research well into the next century to develop into a significant commercial power source. Consequently, it will be well into the next century, if at all, before fusion can become a commercially viable energy source. DOE estimates that it will cost $18 billion to reach that goal.

If fusion power can be developed to expectations, it could replace most other forms of electric power in the United States by the middle of the 21st century. This would free the Nation from the need to use precious and dwindling supplies of fossil fuels in powerplants. Coal, oil, and gas would not be needed for electric power, and power would flow from the virtually inexhaustible fuel reserves of deuterium extracted from oceans. Studies made in recent years indicate that fusion systems also could be used directly or indirectly for the manufacture of combustible fuels, such as hydrogen, synthetic natural gas, and alcohol from water and gases found in the air. However, based on the state-of-the-art to date, it is uncertain whether fusion will ever be an economic source of commercial power; at best it is only a possible option for solving long-term energy problems.

CHAPTER 4

CONCLUSIONS, MATTERS FOR CONSIDERATION

BY THE CONGRESS, AND RECOMMENDATION

TO THE SECRETARY OF ENERGY

CONCLUSIONS

Since 1951, the Federal Government has been sponsoring fusion research for the purpose of developing a new source of energy. When developed, fusion is expected to be a virtually inexhaustible energy source. However, scientists have not yet been able to reach the point where energy generated from a fusion reaction equals the amount of energy spent to initiate the reaction (scientific breakeven).

Although researchers are optimistic that fusion will be proven to be scientifically feasible in the mid-1980s, in the past, similar optimism has proven to be unfounded. For example, it was originally thought that scientific breakeven could be achieved in the 1960s. But problems encountered with pursued concepts caused shifts of emphasis to other concepts; and, consequently, milestone dates slipped.

Once breakeven is achieved and fusion is proven to be scientifically feasible, engineering feasibility will have to be demonstrated to show that fusion reactions can be scaled up to sizes large enough to generate vast amounts of energy. Although fusion research is considered as being in the applied research phase, portions of this research remain in the basic research phase. It is, therefore, premature to assume that all of the problems that may be encountered have been identified. Experimental data have indicated that some formidable physics and engineering problems remain. Only after such problems are resolved and engineering feasibility is demonstrated can fusion's practical potential as an energy source be determined.

The commercialization phase is to include the development and operation of commercial demonstration reactors and the widespread deployment of fusion technology in the economy. The minimum time from the beginning of the commercialization stage until fusion can contribute significantly to the Nation's energy supply is estimated to be about two decades. The decision whether to ultimately use fusion for commercial power will be made in the context of the promise of other energy options available at that time.

In both magnetic and inertial confinement fusion, the most scientifically advanced concepts are being emphasized for achieving scientific breakeven, while vigorous backup efforts are being maintained to develop alternative candidates which may ultimately prove to be better suited for economic commercialization.

During its consideration of the fiscal year 1979 budget, the Congress addressed the issue of establishing a separate inertial confinement fusion program for civilian uses. It chose not to establish such a program at that time, but to continue efforts in inertial confinement fusion principally for weapons purposes--at least until scientific feasibility is proven. We agree that only after scientific feasibility is proven, and the chances of eventually achieving a commercial inertial confinement powerplant are better known, can a decision to establish a separate civilian use program be made with reasonable confidence.

MATTERS FOR CONSIDERATION BY THE CONGRESS

The annual funding level for fusion programs has increased in the wake of the Arab oil embargo of 1973-74. The funding for these programs during the 6-year period, fiscal years 1974 to 1979, totals nearly one and a half times as much as the total cumulative funding for these programs during the preceding 23 years. These funding increases can be attributed, in part, to a general belief that fusion will help solve the Nation's energy problems. There are also indications that such a belief has been somewhat reinforced by a number of public statements of optimism by Government officials concerning the prospects for fusion power. Even DOE's annual budget reflects optimistic views of fusion as an energy source, without effective balancing statements which (1) characterize fusion as a long-term energy option with unknown potential for becoming a viable energy source and (2) describe the program in terms of its present status and near-term goals.

We caution, however, that disappointments are possible in the fusion effort because a number of elements or questions affecting the fusion program require basic or fundamental research. Thus, at this time fusion's commercial potential for becoming a viable energy source is unknown. While continued funding of fusion research is needed to keep this possible energy option open, such funding must be made with the knowledge that fusion will not supply energy in the near- or mid-term. Even if current predictions of achieving scientific breakeven by the mid-1980s are achieved and the milestones for achieving scientific, engineering, and commercial feasibility are met, it will still be sometime during the second quarter of the next century before fusion can become a significant energy source. Thus, the Congress, in considering the adequacy of requested annual funding levels for fusion, should not look upon fusion as a means for solving the Nation's near- or mid-term energy problems. In carrying out its legislative and oversight functions, therefore, the Congress should instead view fusion as a possible option for solving long-term energy problems.

In this connection, we recommend that the Secretary of Energy take steps to ensure that the Department's budget justifications for the fusion programs and its public announcements relating to program accomplishments do not overstate the prospects for commercial fusion power. This is especially important to ensure that during congressional deliberations on the administration's budget request for energy, fusion is viewed as a energy option with unknown potential for becoming a viable commercial energy source. The appropriateness of the requested funding levels should be considered in light of the levels requested for other comparable or similar energy research and development programs.

RECOMMENDATION TO THE SECRETARY OF ENERGY

The Congress, as part of its authorization and appropriation process, should have access to accurate information relating to the current status and actual potential of federally supported energy technologies. Therefore, we are recommending that the Secretary of Energy ensure that, in future budget submissions, fusion is clearly described as a long-term energy option with unknown potential for becoming a viable commercial energy source. We are also recommending that future public statements concerning the activities and accomplishments of the fusion programs avoid language which may lead to the belief that fusion energy may become commercially viable in the near- or mid-term, unless evidence clearly indicates otherwise.

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
WASHINGTON D C 20500

May 9, 1979

Mr. Harry S Havens
Director, Program Analysis
Division
U S General Accounting Office
Washington, D C 20548

Dear Mr Havens

Dr Press asked me to respond to your letter of April 24, which requested our comments on a draft of your report to the Congress entitled "Fusion -- A High Risk Option for Solving Long-Term Energy Problems " [See GAO note 1, p 44]

As the report indicates, fusion power is very unlikely to contribute to the Nation's near- or mid-term energy supply OSTP is thus in agreement with the report's main thrust -- fusion's contribution will arise only in the long-term However, the specific recommendations do give me some pause

The report recommends that the Secretary of Energy coordinate with OSTP to determine the fusion programs' future funding level and program emphasis I do not feel it is necessary at this time for OSTP to assume so central a role in the development of the Department's program First, the Secretary has had the benefit of a careful and very complete review of the fusion program by an advisory committee chaired by John Foster This group is technically competent and it has made, or is making, carefully considered recommendations as to both funding and emphasis Thus, the Department is open to advice from outside experts and accordingly, the need for OSTP surveillance is reduced Second, OSTP has the opportunity to review funding levels and program emphasis in the normal budget process We thus do not feel that any additional intrusion is necessary at this time

The report also alleges that the Department has made "misleading inferences on the justification of the programs," and has improperly failed to characterize the program as basic research In the absence of documentation, the claim of "misleading inferences" seems somewhat harsh And your recommendation that the program be called basic research may place undue emphasis on labels Indeed, the argument for purity in labeling seems somewhat incongruous in light of the earlier characterization of magnetic confinement fusion as one in the "basic applied research phase of development " /p 37/

We appreciate the opportunity to comment on the draft

Sincerely,

Richard A Meserve
Senior Policy Analyst

GAO note 1 Title of draft report was changed to "Fusion--A Possible Option for Solving Long-Term Energy Problems."

GAO note 2 The recommendation which appeared on page 37 of the draft report has been deleted from this final report.

Department of Energy
Washington, D C 20545

May 9, 1979

Mr J Dexter Peach, Director
Energy and Mineral Division
U S General Accounting Office
Washington, D C   20548

Dear Mr Peach

We appreciate the opportunity to review and comment on the GAO draft report entitled "Fusion -- A High Risk Option For Solving Long-Term Energy Problems " Our views with respect to the text of the report and recommendations contained therein are discussed below (See GAO note 1 p 46)

The draft report points out that one cannot, at this time, be overly confident about the favorable economics of fusion energy when scientific feasibility remains to be demonstrated and, even after that occurs, a very difficult engineering development and multi-decade commercialization phase remains to be accomplished   DOE recognizes the present strategy for developing fusion energy as being of high risk and that the minimum time from the commercialization phase until fusion can contribute significantly to the Nation's energy supply is estimated to be about two decades

The report characterizes fusion research and development as "basic research " DOE's basic research is defined as the "Systematic, fundamental study directed toward fuller scientific knowledge or understanding of subjects bearing on national energy needs -- efforts to increase knowledge and quantitative understanding of natural phenomena and environment " Applied research is defined as the "Systematic study directed toward fuller scientific knowledge or understanding for direct use in fulfilling specific requirements -- those efforts directed toward the solution of problems in the physical, biological, behavioral, social, and engineering sciences which have no clear-cut applicability to specific projects   This includes the technical means of obtaining the knowledge, understanding, and solution " Both fusion programs are recognized as being in the Technology Base portion (which includes basic research, applied research, and exploratory development) of DOE's R & D However, we do not characterize fusion programs as "basic research" in the conventional sense of only increasing knowledge about some phenomenon   Because the activities in the fusion program are focused on steps

2

Mr J Dexter Peach, Director

to reach a highly desirable national goal, the major part of the effort is more appropriately termed applied research and the funding priorities appropriately consider the potential very high payoff of a successful development process, while recognizing the high risks along the way A good statement of the potential payoff appears in the last paragraph on page/38/of the report For balance, this payoff statement should be included in the Digest section

DOE works closely with the Office of Science and Technology Policy (OSTP) in many matters and we believe that fusion should be coordinated with OSTP in the same manner as other basic research programs The organizational placement of the fusion programs within DOE has had little to do with either program emphasis or budget It exists largely for historical reasons, in Energy Technology in the case of magnetic fusion and for security reasons in Defense Programs in the case of inertial fusion Organizational relocation would not necessarily directly affect the program strategy

We agree that policy statements by DOE should not be misleading or inappropriately optimistic

Comments of an editorial nature have been provided to members of your staff

We appreciate your consideration of these comments in the preparation of the final report and will be pleased to provide any additional comments you may desire

Sincerely,

Don C Gestiehr

Donald C Gestiehr
Director
GAO Liaison

GAO note 1: Title of draft report was changed to "Fusion--A Possible Option for Solving Long-Term Energy Problems."

GAO note 2 The recommendation which appeared on page 37 of the draft report has been deleted from this final report.

REPORT CHANGES RESULTING FROM AGENCY COMMENTS

COORDINATION WITH THE OFFICE OF SCIENCE AND TECHNOLOGY POLICY

A draft of this report included a proposal that the Secretary of Energy coordinate with the Office of Science and Technology Policy to determine the fusion program's future funding levels and program emphasis. The Office of Science and Technology Policy responded to that recommendation stating that they

> "* * * do not feel it is necessary at this time for OSTP to assume so central a role in the development of the Department's program. First, the Secretary has had the benefit of a careful and very complete review of the fusion program by an advisory committee chaired by John Foster. This group is technically competent and it has made, or is making, carefully considered recommendations as to both funding and emphasis. Thus, the Department is open to advice from outside experts and accordingly, the need for OSTP surveillance is reduced. Second, OSTP has the opportunity to review funding levels and program emphasis in the normal budget process. We thus do not feel that any additional intrusion is necessary at this time."

In view of these comments, we reexamined certain aspects of DOE's budgetary process for fusion programs and held discussions with Office of Management and Budget officials. We believe that the function of this proposal is essentially being served through various informal mechanisms during the normal budget process, at least for the time being. For that reason, the recommendation has been deleted from this report.

FUSION PROGRAMS--APPLIED OR BASIC RESEARCH

Both DOE and the Office of Science and Technology Policy commented on the characterization of fusion research as being in the "basic research phase." DOE commented that:

> "The report characterizes fusion research and development as 'basic research.' DOE's basic research is defined as the 'Systematic, fundamental study directed toward fuller scientific knowledge or

"understanding of subjects bearing on national energy needs--efforts to increase knowledge and quantitative understanding of natural phenomena and environment.' Applied research is defined as the 'Systematic study directed toward fuller scientific knowledge or understanding for direct use in fulfilling specific requirements--those efforts directed toward the solution of problems in the physical, biological, behavioral, social, and engineering sciences which have no clear-cut applicability to specific projects. This includes the technical means of obtaining the knowledge, understanding, and solution.' Both fusion programs are recognized as being in the Technology Base portion (which includes basic research, applied research, and exploratory development) of DOE's R&D. However, we do not characterize fusion programs as 'basic research' in the conventional sense of only increasing knowledge about some phenomenon. Because the activities in the fusion program are focused on steps to reach a highly desirable national goal, the major part of the effort is more appropriately termed applied research and the funding priorities appropriately consider the potential very high payoff of a successful development process, while recognizing the high risks along the way. A good statement of the potential payoff appears in the last paragraph on page 54 of the report [which is on p. 38 of this report]. For balance, this payoff statement should be included in the Digest section."

After detailed discussions with DOE officials, we have deleted references in the report which characterize fusion as being entirely basic research. The report now points out that the fusion programs are categorized as applied research with portions of the related work still in the basic research phase. Related to this topic was a proposal that the fusion programs' budgets should not be included with other energy development programs, due to the basic research nature of fusion. Accordingly, this proposal was deleted from this report.

Perhaps the most appropriate comment on this subject was a statement by the Office of Science and Technology Policy which indicated that we may be placing too much emphasis on labels, whether predominatly basic or applied research.

We believe the most important characterization of the fusion program is that of a long-term energy option with an unknown potential for becoming a viable commercial energy source.

(307030)

☆U S GOVERNMENT PRINTING OFFICE 1979 - 620-167/319

Single copies of GAO reports are available free of charge Requests (except by Members of Congress) for additional quantities should be accompanied by payment of $1 00 per copy

Requests for single copies (without charge) should be sent to

U S General Accounting Office
Distribution Section, Room 1518
441 G Street, NW
Washington, DC 20548

Requests for multiple copies should be sent with checks or money orders to

U S General Accounting Office
Distribution Section
P O Box 1020
Washington, DC 20013

Checks or money orders should be made payable to the U S General Accounting Office NOTE Stamps or Superintendent of Documents coupons will not be accepted

PLEASE DO NOT SEND CASH

To expedite filling your order, use the report number and date in the lower right corner of the front cover

GAO reports are now available on microfiche If such copies will meet your needs, be sure to specify that you want microfiche copies

AN EQUAL OPPORTUNITY EMPLOYER

UNITED STATES
GENERAL ACCOUNTING OFFICE
WASHINGTON, D C 20548

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE,$300

POSTAGE AND FEES PAID
U S GENERAL ACCOUNTING OFFICE

US MAIL

THIRD CLASS