REPORT TO THE CONGRESS

Efforts To Develop Two Nuclear Concepts That Could Greatly Improve This Country's Future Energy Situation

Energy Research and Development Administration

BY THE COMPTROLLER GENERAL OF THE UNITED STATES

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

This report discusses the efforts to develop two nuclear concepts that could greatly improve this country's future energy situation.

We made our review pursuant to the Budget and Accounting Act, 1921 (31 U.S.C. 53), and the Accounting and Auditing Act of 1950 (31 U.S.C. 67).

We are sending copies of this report to the Director, Office of Management and Budget, and to the Administrator, Energy Research and Development Administration.

James B. Staats

Comptroller General
of the United States

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ABBREVIATIONS

AEC	Atomic Energy Commission
DCTR	Division of Controlled Thermonuclear Research
DMA	Division of Military Application
ERDA	Energy Research and Development Administration
GAO	General Accounting Office
KMSF	KMS Fusion, Incorporated
LIS	laser isotope separation

COMPTROLLER GENERAL'S REPORT TO THE CONGRESS

EFFORTS TO DEVELOP TWO NUCLEAR CONCEPTS THAT COULD GREATLY IMPROVE THIS COUNTRY'S FUTURE ENERGY SITUATION
Energy Research and Development Administration

D I G E S T

WHY THE REVIEW WAS MADE

Within the last year, the Atomic Energy Commission has described, and many articles have been published on, the extraordinary promise that two nuclear concepts being developed--fusion power and laser isotope separation--hold for greatly improving the energy situation in this country.

If these concepts are developed successfully, they could

--produce electricity with a fuel that is virtually inexhaustible and

--enrich uranium fuel needed for current nuclear electric power-generating plants more cheaply and with much less energy than at present.

GAO reviewed efforts in this country to develop these two concepts. The Atomic Energy Commission, the predecessor agency to the recently established Energy Research and Development Administration, predicted that fusion power could be developed by the end of this century and that laser isotope separation could be developed by the early 1980s.

FINDINGS AND CONCLUSIONS

Fusion power

Fusion--the joining of light atoms to form a heavier one--could lead to the ultimate nuclear power plant because it

--would use a virtually inexhaustible fuel found in ordinary water and

--could reduce by over 90 percent the hazardous radioactive waste problem associated with current reactors. (See p. 2.)

A fusion powerplant is projected to have other important environmental advantages over current powerplants, such as

--inherent safety against potential nuclear accidents,

--reduced danger of nuclear material diversion for clandestine purposes, and

--lower biological hazards in the event of sabotage or

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natural disaster. (See p. 2.)

Energy Research is developing two fusion methods: magnetic confinement and inertial confinement. Its officials consider the magnetic confinement method to be more mature. The Energy Research plans for each method call for building a demonstration plant in the 1990s.

Magnetic confinement involves holding a sufficiently hot, dense plasma--a special type of gas--with the forces created by powerful electromagnets, so that fusion reactions can occur over a suitably long time. (See p. 2.)

From 1951 to 1974 the Commission spent about $544 million on magnetic confinement research and development. It carried out this effort at its national laboratories, at universities, and at private industrial laboratories. Energy Research plans to spend an estimated $1.5 billion on magnetic confinement research and development in fiscal years 1975-80, including $92.7 million in fiscal year 1975. (See p. 3.)

Inertial confinement involves hitting a very small pellet of fuel for a fraction of a second with powerful beams which heat and compress the fuel until fusion occurs. These beams can be produced with either laser or electron beam generators. (See p. 4.)

The Commission carried out most of its laser fusion effort at Government laboratories.

Also, three private firms are involved in the research and development of laser fusion in the United States. In total, these three organizations have invested about $25 million in laser fusion research and development. (See pp. 12 and 16.) One Energy Research laboratory is developing electron beam fusion. (See p. 16.)

The Commission spent about $116 million on inertial confinement research and development through fiscal year 1974. Energy Research plans to spend an estimated $550 million in fiscal years 1975-80, including $54 million in fiscal year 1975. Most of this money was and will be spent on developing laser fusion at its three weapons laboratories. (See pp. 4 and 16.)

The Commission's laser fusion activities originated in its weapons research and development program which was primarily for military applications. Because of the potential of laser fusion as a possible future energy source, additional funds were provided for this program in 1975 and a long-range energy development plan was established. Energy Research officials emphasize that, at this stage of development, the program is aimed at understanding laser fusion phenomenology which is necessary to either military application or civilian energy development. (See p. 12.)

In addition to their long-range goal of generating electricity for commercial use, the inertial confinement methods have shorter range goals in the military applications area. Although this report deals with the energy aspects of fusion, its military applications are also important. (See p. 5.)

Early private involvement in national laser fusion program is desirable

All three private organizations developing laser fusion believe that the first important milestone of laser fusion can be demonstrated by much less powerful lasers than those which the Energy Research laboratories consider necessary. (See p. 16.)

One of these private organizations achieved an important step in May 1974 that has not yet been duplicated by any Energy Research laboratory. In February 1975 Energy Research awarded a $350,000 contract to this organization for certain laser fusion experiments. Energy Research is also reviewing other funding proposals from these firms.

Energy Research recognizes the need for increased industrial participation in its laser fusion program. It recently established a panel to review and recommend the appropriate level of Federal support it should give directly to industry for laser fusion development. (See p. 21.)

In GAO's view, early involvement of the private sector in developing and demonstrating the economic feasibility of laser fusion could expedite the accomplishment of this Nation's laser fusion goals. (See p. 22.)

Energy Research and Development Administration's efforts to improve management under various fusion approaches

Although both fusion efforts have the same long-range goal, they are managed by two separate divisions each having different management philosophies.

GAO believes that some method should be established which would identify the priorities for all the fusion approaches--lasers, electron beams, and various magnetic confinement systems. This would permit Energy Research's top management to be in a better position to determine (1) the content, pace, and budget for the total fusion program and (2) how scientific breakthroughs and achievement of milestones will affect future decisions and choices among the fusion approaches.

The Commission set up a three-member fusion overview panel chaired by its Deputy General Manager. The panel is developing key considerations for assessing the relative priorities and goals of the two methods. The panel should serve to identify any management changes that are needed in Energy Research's management of fusion. (See p. 27.)

GAO endorses the panel's mission and plans to closely monitor Energy Research's actions on the panel's determinations.

Laser isotope separation

In addition to using lasers to develop fusion power, Energy Research and at least one private firm are experimenting with passing laser beams through uranium to separate its various forms, or isotopes. This process is called laser isotope separation. (See pp. 5 and 29.)

Natural uranium must be enriched before it can be used as fuel for most nuclear powerplants. This country is now using a process called gaseous diffusion to enrich uranium ore. About 10 new enrichment plants would have to be built by the year 2000 to keep up with demand for nuclear fuel. (See p. 29.)

Gaseous diffusion plants are expensive to build and operate. The capital cost for the Government to build a gaseous diffusion plant, as of 1974, was about $1.4 billion. Also, each plant requires as much electricity as two average-sized nuclear powerplants can generate. (See pp. 5 and 33.)

If the laser isotope separation process is developed commercially, it could offer tremendous economic advantages over the gaseous diffusion process. The two Energy Research laboratories working on this process estimated the capital cost of a laser isotope separation plant could be less than $90 million.

Energy Research estimates that the electrical power needed to operate such a plant would be less than 5 percent of the amount required for an existing gaseous diffusion plant. The total savings to the country by the year 2000 are estimated to be as high as $80 billion. According to Energy Research officials, these are preliminary estimates. (See p. 33.)

Additional savings may result from laser isotope separation's greater enrichment potential. If successfully developed, this process is expected to be able to enrich uranium more efficiently than the gaseous diffusion process. More efficient processing will considerably reduce the uranium ore requirement and extend the existing ore reserves. Energy Research laboratory officials estimated that this aspect alone could result in estimated savings of $33 billion by the end of the century. (See p. 34.)

In view of the potential savings, the emphasis and priority Energy Research gives to the process is very important.

Funding for the program was less than $1 million in fiscal year 1973 but is projected at $14.6 million for fiscal year 1975. Despite this sharp increase, there are technical problems in the process which are not now being addressed because of the lack of funds. (See p. 31.)

In an August 1974 report, a committee the Congress established to advise the Commission on technical matters said considerable effort should be made to speed up the development of the laser isotope separation process because of its great importance. The committee recommended

--increasing funding for laser development and

--beginning a development effort, with the assistance of personnel experienced in enrichment technology, leading to a pilot plant design in the late 1970s. (See p. 34.)

The committee also noted that the overall technical management and staffing of the program needed to be increased. (See p. 35.)

Because the laser isotope separation process holds great promise in its potential to efficiently and economically enrich uranium and to extend the existing uranium ore reserves, it is important that Energy Research make every effort to carry out these recommendations promptly.

In September 1974, the Commission responded to the committee by stating that it would

--accelerate development of the process if resources could be made available in the face of competing priorities and

--obtain, as quickly as possible, a principal program manager with a good technical understanding of the program and a belief in the program's importance.

On February 20, 1975, Energy Research requested the Congress to approve $5 million of additional funds for fiscal year 1975. In April 1975 the Congress approved this request for additional funds for developing the process. For fiscal year 1976 and the 3-month transition period, Energy Research requested funds of $31.5 million. The

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C2 Joint Committee on Atomic Energy has authorized this amount. In addition, Energy Research officials said that, since September 1974, they had hired a principal program manager and had strengthened the management staff.

RECOMMENDATIONS AND SUGGESTIONS

This report contains no recommendations or suggestions.

AGENCY ACTIONS AND UNRESOLVED ISSUES

GAO discussed this report with Energy Research officials and included their comments where appropriate.

MATTERS FOR CONSIDERATION BY THE CONGRESS

The report should provide the Congress with useful information on the progress and expectations relating to the development of certain nuclear energy concepts which--with adequate research effort and funding--could greatly improve the energy situation in this country.

CHAPTER 1

INTRODUCTION

The growing shortage of fossil fuels is spurring the search for alternative energy sources. Nuclear power reactors, using enriched uranium as a fuel, are an alternative to fossil fuel. The Energy Research and Development Administration (ERDA), 1/ the successor agency to the Atomic Energy Commission (AEC), predicts that U.S. electrical energy demand will double between 1970 and 1985 and will double again by the year 2000. At present, nuclear power accounts for about 6 percent of the total U.S. electrical capacity. ERDA expects that, by the year 2000, it will amount to about 60 percent.

All presently operating nuclear reactors are fission-type reactors. Fission involves splitting an atom, which releases energy. Because U.S. reserves of economically usable nuclear fuel, uranium, needed for such reactors are limited, ERDA is developing an alternative to current fission plants; namely, breeder reactors. Since breeder reactors are to produce more nuclear fuel than they consume while generating electricity, they will help extend our uranium reserves. However, the supply of natural uranium which breeders need to make nuclear fuel will eventually run out. Moreover, breeders, like all fission reactors, produce radioactive waste which remains hazardous for thousands of years.

Within the last year, many published articles and AEC have described the extraordinary promise that two nuclear concepts being developed--fusion power and laser isotope separation (LIS)--hold for greatly improving the energy situation in this country. If these concepts are developed successfully, they could (1) produce electricity with a fuel that is virtually inexhaustible and (2) enrich uranium fuel needed for current nuclear electric power-generating plants more cheaply and with less energy than at present.

1/The Energy Reorganization Act of 1974 (Public Law 93-438) abolished AEC and established ERDA and the Nuclear Regulatory Commission on January 19, 1975. All the AEC programs and activities discussed are now carried out by ERDA. Consequently, all actions that occurred after January 19, 1975, and all future actions should be considered ERDA's.

FUSION POWER

Fusion is the joining of two light atoms to form a heavier one. It occurs constantly in the sun and results in the release of tremendous quantities of energy.

The main fuel supply for fusion is a form of hydrogen, called heavy hydrogen or deuterium, found in all water. AEC's calculations show that the energy that would be produced by the deuterium in 1 gallon of water would equal that obtained from the combustion of 300 gallons of gasoline.

ERDA projects the safety and environmental features of fusion, in addition to its potential to provide an inexhaustible fuel supply, to be much more acceptable than with the fission process. ERDA has reported that fusion's most important advantages are

--reduction of radioactive waste problems by over 90 percent,

--inherent safety against potential nuclear accidents,

--reduced danger of nuclear material diversion for clandestine purposes,

--lower biological hazards in the event of sabotage or natural disaster, and

--the eventual possibility of urban siting.

ERDA is developing two fusion methods: magnetic confinement and inertial confinement. ERDA officials consider the magnetic confinement method to be more mature. ERDA plans for each method call for building a demonstration plant in the 1990s.

Magnetic confinement

In magnetic confinement a gas is heated to such a point that its atoms hit each other hard enough to break into electrons, which have a negative charge, and nuclei, which have a positive charge. This hot gas of charged particles, called a plasma, is contained by the magnetic forces created by an electromagnet. At sufficiently high temperatures (above 50 million degrees Centigrade) the nuclei can collide with each other with enough energy to overcome the natural repulsive force between like charged particles and can have a chance to fuse and emit highly energetic particles. These particles would be captured to either (1) produce steam to generate electricity or (2) be converted directly into electricity. ERDA is developing three approaches using magnetic confinement to achieve fusion. These approaches are discussed in chapter 2.

The magnetic confinement effort is directed by the Division of Controlled Thermonuclear Research (DCTR) at ERDA headquarters. In fiscal year 1974, 80 percent of the reseach and development effort was carried out at four ERDA laboratories: Lawrence Livermore Laboratory, Livermore, California; Los Alamos Scientific Laboratory, Los Alamos, New Mexico; Oak Ridge National Laboratory, Oak Ridge, Tennessee; and the Princeton Plasma Physics Laboratory, Princeton, New Jersey. The remainder of ERDA's program is centered at a number of private firms and universities. The funding for fiscal years 1951-74, as well as the projected funding for fiscal years 1975-80, is shown below.

Funding for the Magnetic Confinement Fusion Program

Fiscal year	Total (millions)	Fiscal year	Total (millions)
	Funding for FY 1951-74		
1951-53	$ 1.1	1964	$ 22.6
1954	1.8	1965	23.1
1955	6.1	1966	23.1
1956	7.4	1967	23.9
1957	11.6	1968	26.6
1958	29.2	1969	29.7
1959	28.9	1970	34.3
1960	33.7	1971	32.2
1961	30.0	1972	33.3
1962	24.8	1973	39.1
1963	25.5	1974	56.4
			544.4
	Estimated funding through FY 1975-80 (note a)		
1975	92.7	1978	314.0
1976	184.0	1979	344.0
1977	227.0	1980	392.0
			1,553.7
Total			$2,098.1

a/Estimates obtained from 5-year plan for magnetic confinement.

Inertial confinement

Inertial confinement involves hitting a very small pellet of special fuel for a fraction of a second with powerful beams. The beams can be produced with either laser or electron beam generators. The energy from the beams is focused on the pellet, which causes an implosion, a bursting inward. This implosion causes fusion.

Since March 1974, the inertial confinement research and development effort has been directed by the Office of Laser and Isotope Separation Technology in the Division of Military Application (DMA). The Office was established to increase management attention on laser fusion and LIS efforts. Previously, the programs were under the Assistant Director for Research and Development, DMA, responsible for developing nuclear weapons.

Three ERDA laboratories, Los Alamos; Livermore; and Sandia Laboratory, Albuquerque, New Mexico, develop nuclear weapons, and also conduct research work on inertial confinement. The following table shows the past and estimated future funding for this program.

Inertial confinement funding FY 1963-74

Fiscal year	Total (millions)	Fiscal year	Total (millions)
1963	$ 0.2	1969	$ 2.1
1964	1.1	1970	3.2
1965	1.3	1971	9.4
1966	1.2	1972	17.9
1967	1.4	1973	34.2
1968	1.3	1974	42.6
			115.9
Estimates of funding FY 1975-80 (note a)			
1975	53.9	1978	92.0
1976	90.0	1979	107.0
1977	85.3	1980	122.0
			550.2
Total			$666.1

a/Taken from the fiscal year 1976 budget estimate and fiscal years 1977-80 projections.

OTHER APPLICATIONS OF FUSION

Although both fusion methods are aimed at eventually being used to generate electricity for commercial use, fusion also has other civilian applications, and the inertial confinement approach has military applications.

Military applications

Laser- and electron-beam-initiated fusion are expected to be able to simulate aspects of the design and effects of nuclear weapons. This would allow laboratory investigation of the effects of nuclear weapons.

Other potential military applications include using fusion for electrical power at military installations for propulsion. Although this report deals with the energy aspects of fusion power, the importance of fusion for military applications should not be overlooked.

Civilian applications

A private company is developing a process which will use laser fusion to produce hydrogen. The company claims that such hydrogen could be converted to methane which could be used as a substitute for natural gas at a competitive price as early as 1983. ERDA is studying the possible use of magnetic confinement reactors for hydrogen generation capabilities.

Some ERDA officials believe that a fusion reactor could also be used for transmutation--that is, to change material from one substance to another. In this way, fusion could convert natural uranium into nuclear fuel, minimize the radioactive levels of fission waste, or recycle garbage. ERDA officials told us that these applications were in the conceptual stage and that ERDA was funding only conceptual design studies. According to ERDA laboratory officials, transmutation requires proof of the fusion principle, and until proof of principle occurs, efforts beyond paper studies are premature. The University of Rochester is also pursuing research in this area.

LASER ISOTOPE SEPARATION

All current commercial nuclear power reactors in the United States use enriched uranium as a fuel. Natural uranium must be processed or enriched before it can be used as fuel. Our country is now using a process called gaseous diffusion to enrich uranium ore. Gaseous diffusion plants are expensive to build and operate. AEC estimates showed, as of 1974, the capital costs of a Government-built gaseous diffusion plant was about $1.4 billion. Also, each plant requires as much electricity as two average-sized nuclear powerplants can generate.

Livermore and Los Alamos laboratories are now experimenting with uranium enrichment by passing laser beams through uranium to separate its various forms, or isotopes. LIS, if developed successfully, could have major economic advantages over the gaseous diffusion process. This process--which, except for using lasers, has no similarity to laser fusion--is more fully discussed in chapter 4.

CHAPTER 2

THIS COUNTRY'S MAJOR EFFORTS TO ACHIEVE FUSION

The two fusion methods include five major approaches to developing a fusion reactor. The magnetic confinement method includes the tokamak, theta-pinch, and mirror approaches; and the inertial confinement method includes the laser and electron beam approaches. The major efforts in all of these approaches are carried out in ERDA laboratories.

MAGNETIC CONFINEMENT

Three approaches to developing a fusion reactor

ERDA is funding the development of three magnetic confinement approaches. Even though other approaches exist, ERDA has determined that these three approaches have more potential for successful development. None of the approaches, however, has yet proven to be technically or economically feasible. ERDA projects that technical feasibility will be demonstrated in the next 5 years.

Development of the magnetic confinement approaches began in the early 1950s. These approaches, their basic distinctions, and the laboratories responsible are as follows:

--The tokamak, a Princeton, Oak Ridge, and General Atomic project, is a doughnut-shaped device with low-density plasma that will operate through repetitive, long (100 minutes) energy pulses or through continuous operation.1/

--The theta-pinch, a Los Alamos project, is a bicycle-tire-shaped device with high-density plasma that will be pulsed repetitively with each pulse lasting one-tenth of 1 second.

--The mirror approach, a Livermore project, is an open-ended device (the plasma containment device allows some plasma particles to escape out the ends) which will operate continuously after the initial pulse.

1/ The frequency at which electrical energy is put into the magnetic confinement device to begin fusion reaction.

Proponents of all three magnetic confinement approaches intend to use a fuel of deuterium and tritium--two forms of hydrogen--in initial reactors. In later reactors, pure deuterium--found in ordinary water--and other mixtures of fuels might be preferable because they offer potential for lower radioactivity and greater efficiency.

Future milestones and current efforts

The future milestones for the magnetic confinement approaches and the dates when ERDA expects them to be achieved are:

--Scientific feasibility, the point where all the conditions for a fusion reactor are met using hydrogen plasma (late 1970s).

--Break-even power production, the point where as much fusion energy is produced as was used to create and heat the plasma (about 1980).

--Net energy gain, a step where usable electrical energy is produced for the first time (about 1985).

--Demonstration plant, a refined device which is large enough to demonstrate the economics of fusion power (late 1990s).

To achieve these milestones each magnetic confinement approach must reach a desired plasma temperature, density, and confinement time (the time plasma is held in a state of fusion). Each approach has already reached the density needed to demonstrate scientific feasibility. The theta-pinch and mirror approaches have produced the desired temperatures. ERDA says that none of the approaches has reached the desired confinement time because the requisite large experimental devices are only now being built. The problems which must be overcome to achieve and improve these plasma conditions are unique to each approach. Thus if one approach reaches the desired temperature, density, or confinement time, this will not necessarily help solve the problems of other approaches.

The best measurement of the technical progress of each of the three approaches is the product obtained by multiplying density (number of atoms per cubic centimeter of plasma) by confinement time. The following table indicates products already achieved and products desired for a power reactor.

Approach	Product of density times confinement time: Obtained to date	Desired for a reactor
	(000,000 omitted)	
Tokamak	1,000	100,000
Theta-pinch	1,000	100,000
Mirror	10	100,000

Each magetic confinement approach is being researched to solve problems hindering the achievement of the desired increases in temperature, density, and confinement time.

--The organizations developing tokamak (Oak Ridge, Princeton, and General Atomic) are trying to (1) eliminate impurities in the plasma that affect plasma confinement and (2) optimize a means of increasing temperature.

--Los Alamos is working to increase confinement time for theta-pinch.

--Livermore's mirror researchers are working to increase confinement time to make mirrors economical by converting into electrical power plasma particles lost out of its open ends. This will require major technical breakthroughs.

As shown below each major laboratory is working with devices aimed at accomplishing goals necessary to develop fusion reactors.

Approach	Device	Laboratory	Cost (note a) (millions)	Objectives
Tokamak	Princeton large torus (under construction)	Princeton	$13	Experiment intended to produce a reactor-like hydrogen plasma.
Tokamak	Poloidal diverter (under construction)	Princeton	17	Experiment with impurities in plasma that affect confinement time.
Tokamak	Fusion test reactor (construction to begin in 1977)	Princeton	159	Experiment with fuel to eventually be used in a reactor.
Tokamak	ORMAK (in operation)	Oak Ridge	4	Experiment with impurities in plasma that affect confinement time and temperature scaling.
Tokamak	Princeton adiabatic toroidal compressor (in operation)	Princeton	1.5	Experiment to test new methods of plasma heating.
Tokamak	Doublet IIa (in operation)	General Atomic	2	Experiment to study the characteristics of noncircular tokamak plasmas.
Tokamak	Doublet III (under construction)	General Atomic	26	Experiment to produce reactor grade plasma with a noncircular cross section.
Theta-pinch	Syllac (in operation)	Los Alamos	11	Experiment to increase confinement time.
Theta-pinch	Staged theta-pinch (in operation)	Los Alamos	1.5 to 2	Experiment to increase the plasma radius and temperature.
Mirror	BBIIT (in operation)	Livermore	2.8	Experiment with building plasma density.
Mirror	2xIIB (in operation)	Livermore	3.1	Experiment with high temperatures.

a/ Costs of project when constructed, when converted from an earlier project, or projected construction costs in 1975 dollars.

ERDA has decided to build a fusion test reactor based on the tokamak approach. In addition, Los Alamos and Livermore have tentative long-range plans to develop the theta-pinch and mirror approaches to the fusion test reactor stage. The Los Alamos, Livermore, and Oak Ridge laboratories plan to build demonstration plants on all three approaches. Fulfillment of these plans will depend largely on the DCTR which manages the magnetic confinement program--decisions on future funding for the three approaches.

DCTR officials advised us, however, that only two of the magnetic confinement approaches would be scaled up for fusion test reactors. The first one will be a tokamak, and its goal will be to demonstrate break-even power production conditions. Initial funding for the tokamak fusion test reactor has been requested for fiscal year 1976. Construction of the tokamak fusion test reactor is scheduled to begin in 1977. According to DCTR officials, the decision on whether the theta-pinch or mirror approach will be used in the second test reactor will likely be made in 1977 or 1978.

Involvement of private industry

DCTR has taken the position, although ERDA laboratories will bear principal responsibility for near-term magnetic confinement research, that private industry must begin to develop fusion reactor technology at an early date. According to the Division, the best time and way to phase this into private industry has not yet been established. It is clear, however, that private industry's participation must increase markedly during the 1980s. Private firms now account for about 10 percent of all the Federal and private research and development funds spent on developing the magnetic confinement process. DCTR officials believe that private funding in the 1980s will increase and hope it will grow to about 30 to 40 percent of total private and Federal funding in the mid- to late 1990s.

About 82 percent of ERDA's fiscal year 1975 magnetic confinement funding supports its programs at Livermore, Los Alamos, Oak Ridge, and Princeton laboratories. All the magnetic confinement work at these four major laboratories is funded by ERDA.

Also, ERDA is partially funding the magnetic confinement programs at General Atomic, the University of Texas, and United Aircraft Research Laboratory. Private industry is funding the remainder. The ultimate goal of these three programs is to develop commercial fusion reactors. Moreover, ERDA is funding magnetic confinement work at various industrial, university, and other Government laboratories. During fiscal year 1975, ERDA will spend about $17.3 million on magnetic confinement efforts at places other than its four major laboratories.

INERTIAL CONFINEMENT

Laser approaches to a fusion reactor

AEC's laser fusion activities originated in its weapons research and development program which was primarily for military applications. Because of the potential of laser fusion as a possible future energy source, additional funds were provided for this program in 1975 and a long-range energy development plan was established. ERDA officials emphasize that, at this stage of development, the program is aimed at understanding laser fusion phenomenology which is necessary to either military application or civilian energy development.

Regarding the civilian energy aspects, both private industry and ERDA have laser fusion programs aimed at developing commercial reactors. The University of Rochester, Battelle Memorial Institute, and KMS Fusion, Incorporated (KMSF), have privately funded laser fusion programs. Livermore, Los Alamos, and Sandia--the three ERDA weapons laboratories--conduct laser fusion programs directed by DMA. The Sandia laser fusion program is limited primarily to developing the new lasers, while the Livermore and Los Alamos programs e compass a full range of activities associated with developing laser fusion. At the time of our review, ERDA plans projected Sandia's role as a developer of new lasers and not as a major participant in the program's pellet compression facets.

The laser fusion method is relatively new compared with the magnetic confinement method. Small-scale laser fusion work began at Livermore in 1963 and at Los Alamos in 1970. The private laser fusion programs in the United States started about 3 or 4 years ago. Total funding for AEC programs almost doubled in fiscal year 1973, and funding projections show continued growth. (See p. 4.)

Four characteristics distinguish lasers from one another: wavelength, pulse length, efficiency, and lasing medium. They are defined as follows.

--Laser beams are made up of light waves, and the wavelength is the distance between two corresponding points on the waves. The wavelength and laser energy determine the details of the material interaction process when the laser beam strikes a pellet.

--Pulse length is the period of time consumed by one laser burst.

--Efficiency is the percentage of light energy that a laser produces in relation to the energy it consumes during its operation.

--Lasing medium is the material within the laser which gives off light energy when properly stimulated.

At present all public and private laser fusion programs primarily depend on short wavelength, low efficiency, and glass-medium lasers of varying pulse lengths. The ERDA laboratories are also pursuing longer wavelength, high efficiency, carbon dioxide, and other gas-medium lasers. Although ERDA has not yet made a long-range commitment, officials of DMA's Office of Laser and Isotope Separation Technology advised us that a short wavelength, repetitively pulsed, approximately 10-percent efficient, gas-medium laser probably will be needed for a commercial power laser reactor system.

Only a limited number of fuel pellets have been hit with lasers at ERDA's laboratories. Before the scientific feasibility of laser fusion can be proven, numerous experimental goals must be met and the results analyzed. Los Alamos and Livermore are each developing a different type of large laser. Los Alamos has a carbon dioxide, 1,000-joule (a unit of energy) laser on line, but it is not up to full power. Also, a 1,000-joule glass laser is scheduled to be on line at Livermore before the end of fiscal year 1975. Both laboratories are also developing different types of 10,000-joule lasers which they believe will be needed to demonstrate the scientific feasibility of laser fusion. The laboratories are also developing several other types of lasers.

Future milestones and current efforts

ERDA's 5-year plan for inertial confinement has four future milestones leading toward military applications and the development of a commercial laser fusion reactor. These milestones are:

1. Significant thermonuclear burn--to burn a pellet with laser beams until it releases a considerable number of energy-producing neutrons.

2. Scientific break-even point--the point at which the fusion energy released through pellet burning equals the laser energy deposited.

3. Net energy gain--the point at which more fusion energy is produced through pellet burning than the total of the energy used to operate the laser.

4. Demonstration plant--a plant that will demonstrate the economics of electrical power generation for private consumers.

Officials of each of the ERDA and private laser fusion laboratories discussed their programs with us in terms of these four milestones. Los Alamos, Livermore, and KMSF have predicted the achievement for these milestones, but Battelle and the University of Rochester were not as specific in their plans for reaching milestones beyond significant thermonuclear burn. KMSF's dates are more optimistic than those of Los Alamos and Livermore. The table on page 15 shows each laboratory's predictions concerning the four milestones, including the dates when it expects to achieve the milestones and the lasers it believes will be needed.

Development of the larger Los Alamos and Livermore lasers will require large capital expenditures. Projected costs of the lasers that ERDA laboratory officials believe will achieve the scientific break-even point and net energy gain are as follows:

Laboratory	Status	Laser	Capital expenditures
		(joules)	(000,000 omitted)
Los Alamos	Under development	10,000	$ 4
Los Alamos	FY 1975-79 project	100,000	23
Livermore	Under development	10,000	25
Livermore	FY 1978-81 project	100,000	35

Most problems of the laser fusion method involve the characteristics that distinguish lasers from one another. Current efforts are directed toward reducing the pulse length, increasing laser efficiency, and developing a suitable laser

Milestones, Achievement Dates, and Required Lasers

Laboratory	Significant thermonuclear burn--date and laser	Scientific break-even point--date and laser	Net energy gain--date and laser	Demonstration plant--date and laser
Los Alamos (note a)	FY 1977-78; 10,000 joules	FY 1979-81; either 10,000 joules or 100,000 joules	FY 1981-83; 100.000 joules	FY 1995; to be determined
Livermore (note a)	FY 1977-78; 10,000 joules	FY 1979-81; either 10,000 joules or 100,000 joules	FY 1981-83; 100,000 joules	FY 1995; 100,000 to 1,000,000 joules
KMSF	Undetermined date; 200 to 300 joules (note b)	Feb. 1975; 1,000 joules	July 1976; 1,000 to 2,000 joules	1979; 10,000 to 30,000 joules
University of Rochester	Undetermined date; 1,400 joules (note b)	(c)	(c)	(c)
Battelle	Undetermined date; 1,200 to 1,500 joules	5,000 to 10,000 joules	(c)	(c)

a/ Milestones are based on DMA's estimates of program-funding requirements which are higher than the fiscal year 1976 budget estimates and fiscal years 1977-80 projections recently submitted to the Congress. DMA believes that the funding reductions are important enough to cause major slippages in the milestones identified above.

b/ Existing lasers.

c/ Program does not currently project accomplishment of these milestones.

medium. In addition, laser size is being increased and the capability to repetitively deliver laser shots is being developed.

According to laboratory officials, neither of the large lasers now under construction at Livermore and Los Alamos will resolve all the problems confronting successful development of laser fusion. The lasers will be used primarily to prove the scientific feasibility of laser fusion. Researchers believe that, after the laboratories prove scientific feasibility, larger lasers will be needed to resolve problems which may arise in developing a commercial power laser reactor system.

Approaches taken by private firms

Private laser fusion programs in the United States are at lower funding levels than ERDA's programs at Los Alamos and Livermore. Total cumulative private expenditures on laser fusion amount to about $25 million.

The lasers that Battelle, the University of Rochester, and KMSF use in their programs cost $1.5 million, $1 to $1.5 million, and $1.75 million, respectively. Annual program operating costs have averaged $200,000 at Battelle, $1.2 to $1.3 million at the University of Rochester, and $3 million at KMSF.

Officials at all the private laser fusion laboratories said they intended to demonstrate significant thermonuclear burn with their existing lasers. These lasers are much smaller than those Los Alamos and Livermore are proposing for the same type of demonstration. Los Alamos and Livermore propose using 10,000-joule lasers to demonstrate significant thermonuclear burn, but the private laboratories propose using from 200- to 1,500-joule lasers.

Electron beam approach to a fusion reactor

Electron beam fusion, which involves the hitting of a special fuel pellet with an electron beam and the resulting interaction, became a formal approach in AEC's overall fusion power effort during fiscal year 1974. In the past, the primary functions served by electron beam machines were military oriented.

The electron beam fusion process is similar to the laser fusion process, i.e., an electron beam is focused on a pellet, causing it to implode and release energy. Only one laboratory in the United States, Sandia, has carried out electron beam fusion experiments.

Electron beam fusion had not been seriously considered as a fusion method in the past because beam-focusing problems made it impracticable as a means of imploding a pellet. In mid-1972, Sandia made a breakthrough in electron beam focusing and proposed electron beam fusion as a method to achieve commercial fusion reactors. This work was funded largely by DMA with some support by DCTR.

Future milestones and current efforts

Sandia's electron beam fusion program has the same four milestones as the laser fusion program. The dates Sandia expects to accomplish these milestones and the types of electron beam machines Sandia expects to use are presented in the following table.

Milestone (note a)	Projected fiscal year of accomplishment	Electron beam machine needed
Significant thermonuclear burn	1978-79	20,000-joule machine
Scientific break-even point	1979-81	200,000-joule machine, scaled up to 1,000,000 joules
Net energy gain	1981-82	200,000-joule machine, scaled up to 1,000,000 joules
Demonstration plant	1995	Undetermined

a/ Milestones are based on DMA's estimates of program-funding requirements which are higher than the fiscal year 1976 budget estimates and fiscal years 1977-80 projections recently submitted to the Congress. DMA believes that the funding reductions are important enough to cause major slippage in the milestones.

The problems of the electron beam approach relate to improving the focusing capability of electron beams and reducing the pulse length. Sandia now uses 2 electron beam machines of 5,000 and 50,000 joules in its program, which ERDA says do not have the desired focusing and pulse length characteristics necessary for achieving significant thermonuclear burn. Current efforts are directed at these problems. They must be solved in order to demonstrate the scientific feasibility of electron beam fusion.

EARLY PRIVATE INVOLVEMENT IN NATIONAL LASER FUSION PROGRAM IS DESIRABLE

In fiscal year 1975, ERDA expects to spend about $3 million of its $53.9 million budget for laser fusion development at about 40 universities and private firms. Nearly all of this estimated $3 million will be used for support work in the laser fusion programs at the three ERDA weapons laboratories.

DMA officials told us that private industry should participate in developing laser fusion technology. They said, however, that the limited funds for ERDA's laser and electron beam fusion efforts and the limited DMA staff directing the efforts have precluded direct funding of large laser fusion programs at universities and private laboratories.

Officials of the three private laser fusion laboratories expressed concern that the ERDA laser fusion program was being conducted in weapons laboratories which undertook weapons projects that were based on national needs, like defense, rather than on the need for an economical product. They believed that the ERDA laser fusion program needed people with expertise in developing programs which judge a project's feasibility primarily on economic grounds. In their opinion, this meant involving private industry.

ERDA officials disagreed and pointed out that the weapon laboratories were successfully engaged in research and development for a variety of civilian energy and other applications, e.g., Departments of Transportation and Agriculture, in which economic considerations are important. However, ERDA agreed that private involvement was necessary.

KMSF, Battelle, and University of Rochester officials believe that, although some ERDA laboratories are expert in developing economically justified projects, Los Alamos and Livermore weapons designers are not. Many of the Livermore and Los Alamos personnel working on laser fusion are or were weapons designers. These industry officials also said that industry was prevented from becoming heavily involved in laser fusion because much of the critical information was classified. ERDA officials stated they were aware of the classification problem and were attempting to alleviate this problem by declassifying some information and making it available to the private organizations. ERDA, however, cannot declassify direct weapons expertise and information relevant to laser fusion because of weapons proliferation and national security considerations.

In August 1974 AEC declassified a considerable portion of the weapons-related information from its laser fusion program. In addition, during September 1974 AEC invited representatives from this country's industrial and academic laser fusion community to a meeting at Sandia at which AEC laboratory officials briefed them on the status of AEC's program. This briefing included recently declassified information on laser fusion.

ERDA's laser fusion plan calls for developing larger and larger lasers. This is because ERDA believes that a laser fusion powerplant will require extremely powerful lasers. Because ERDA expects such large lasers to cost from about $4 million to $35 million each and to take several years to design and fabricate, ERDA is devoting more than half of its laser fusion efforts to laser development.

All three private organizations developing laser fusion believe that significant thermonuclear burn can be demonstrated by much less powerful lasers than those the ERDA laboratories consider necessary. Officials of KMSF told us that, since lasers one-tenth to one-third as powerful were sufficient for commercial laser reactor systems, they believed that ERDA's program could move faster and cost less with less powerful lasers. Although Battelle and the University of Rochester are not predicting the size of the lasers needed for a laser reactor system, the managers of their programs believe that lasers approximately one-tenth as large as those ERDA is projecting for significant thermonuclear burn can achieve the same milestone.

ERDA laboratory officials say their belief that large lasers are necessary is supported by their experience in the nuclear weapons development field and their large computer calculation capability which permits them, among other things, to simulate fusion experiments. However, there is not enough experimental data for either the ERDA laboratories or the private laboratories to prove which approach is correct.

KMSF thinks that its accomplishments support its belief. The most significant of these accomplishments was in May 1974 when, according to KMSF, it produced a considerable number of fusion-created neutrons by compressing pellets of special fuel with a laser. Neither the ERDA laboratories nor the other two private organizations claim to have reached this point. ERDA does not see the production of these neutrons as bearing greatly on the ultimate goal of economical laser fusion. Although creating these neutrons is a notable achievement, ERDA says, it should not be misconstrued as resolving the technical uncertainties of laser fusion.

AEC representatives and consultants from the laser fusion programs at the AEC laboratories visited the KMSF laboratories on May 23, 1974, to review KMSF's research program and to analyze the data supporting its claim. In its report on this visit, AEC concluded that

> "The achievement of laser-initiated compression is an impressive accomplishment demonstrating both the validity of the concept and the ability of the KMSF staff. The magnitude of the achievement is consistent with the laser system and target designs being used at KMSF and is consistent with the expectations of qualified observers of the KMSF program even though it falls short of laser-fusion breakeven by nine orders of magnitude. For the overall laser-fusion effort in this country, the goals remain the demonstration of significant thermonuclear burn, scientific breakeven, and net energy gain. In order to reach these more significant goals, major advances in optics, laser design diagnostics, and perhaps even pellet design will be needed. The compression experiments of KMSF provide encouragement for the ultimate success of laser-fusion."

KMSF has made two proposals to AEC for financial support of its laser fusion program. AEC turned down the first proposal--dated June 6, 1974--because:

> "* * * judged in the context of all AEC-supported laser fusion work, the KMSF proposal does not

appear to us to add a sufficient increment of technical benefit to justify the $7 million requested."

In August 1974 KMSF offered three alternative proposals for varied time frames and amounts ranging from 4 months and $1.5 million to 1 year and $3.5 million. KMSF officials said they had little hope that AEC would provide funding for KMSF's laser fusion program.

On February 5, 1975, ERDA awarded a $350,000 contract to KMSF, for KMSF to use its facilities to run a series of selected laser target interaction experiments.

In addition to KMSF's proposal, ERDA has also received proposals from Battelle, the University of Rochester, and ...rs. ERDA planned to award contracts totaling about ...illion to one or more of these organizations in fiscal ... 1975. However, as part of the Federal effort to curb ...ation, ERDA deferred spending this $2 million until fis... year 1976.

A Senate member of the Joint Committee on Atomic Energy recently stated, regarding ERDA's laser fusion program, that:

"There has been scant encouragement to industry to pursue laser fusion research and development. Any Government program that rapidly builds up expenditures towards a quarter-billion-dollar figure should have room for complementary or parallel programs in private industry."

ERDA's decisions on funding the private organizations are partially dependent upon recommendations solicited from a special panel which was set up on September 15, 1974. This panel is to review and report to ERDA the potential payoffs and the technical status of laser fusion efforts in Government and non-Government areas. In addition, the panel is to recommend:

--Appropriate roles for the Government and the private sector in a national laser fusion program.

--Appropriate interaction between the public and the private sectors.

--Research and development strategy and appropriate support, if any, by ERDA and private firms.

As of January 31, 1975, the panel's final report was completed and was being administratively reviewed. ERDA expects to release the report soon.

CONCLUSION

Improving the U.S. energy situation is a national goal. Fusion power, if successfully developed, would play an important role in helping to alleviate our energy problems.

In keeping with national policy, it has been the role of the Government to (1) take the lead in developing complex, potentially viable, and expensive technologies beyond the reach of private industry and (2) encourage the private sector to assume an increasing share of the development costs for such technologies. This policy was used in connection with commercializing the currently operating fission reactors. Commercial fusion power will largely depend on whether its economic advantages can be demonstrated to the private sector.

ERDA has directly funded several private magnetic confinement programs aimed at developing commercial fusion reactors. It plans to spend about 18 percent of its fiscal year 1975 magnetic confinement budget at places other than the four major ERDA laboratories. About 6 percent of ERDA's fiscal year 1975 laser fusion budget will be spent at private organizations. Nearly all of these funds are for work that will support the three ERDA weapons laboratories' programs.

ERDA recognizes the need for increased industrial participation in its laser fusion program. As previously pointed out, it recently established a panel to review and recommend the appropriate level of Federal support it should directly give to industry for laser fusion development.

Early involvement of the private sector in developing and demonstrating the economic feasibility of laser fusion could help this Nation reach its laser fusion goals more quickly.

CHAPTER 3

ERDA'S MANAGEMENT OF VARIOUS FUSION APPROACHES AND HOW IT COULD BE IMPROVED

The large commitment of funds for fusion research and development and the complexity of the various approaches being investigated require sound, coordinated management. This will be especially important if development progresses into advanced stages and if experimental power reactors costing billions of dollars are built. Overall management control and coordination of fusion production will be needed to avoid unnecessary duplication and prolongation of less viable fusion approaches and to insure that development efforts on the best approach or approaches proceed as rapidly as possible.

MANAGEMENT APPROACH AND ORGANIZATIONAL STRUCTURE FOR DEVELOPING MAGNETIC CONFINEMENT

The Director, DCTR, administers and manages ERDA's magnetic confinement program. The DCTR is divided into three offices which are responsible for

--confinement systems,
--development and technology, and
--research.

DCTR also has 28 professional and technical staff members.

DCTR operates under a centralized management philosophy and exercises fairly tight control over the various laboratories participating in the magnetic confinement program. These controls seem most evident in the planning, project review, and device review areas.

Management tools

One of the primary management tools DCTR uses is its 5-year magnetic confinement fusion plan. DCTR prepared the plan from a collection of research publications, ad hoc panel studies of specialized areas, previous program plans, and its experience. The plan is periodically reviewed and modified in accordance with new scientific understanding and budget changes.

The latest plan, dated February 1974, lays out a program leading to the operation of a demonstration fusion powerplant in the late 1990s. Between now and the late

1990s, DCTR will use this plan as a guide for administering the magnetic confinement research program.

This plan indicates that the tokamak approach is more promising for achieving fusion than the theta-pinch and mirror approaches. DCTR has already decided that the first fusion test reactor will be based on a tokamak device and wants the second one to be based on either a theta-pinch or a mirror device. Since DCTR has no responsibility for inertial confinement research and development, neither laser nor electron beam fusion is considered in the division's 5-year plan.

DCTR also uses its annual detailed budget review of major laboratory projects as a control mechanism. Under this review, a laboratory, when it wants to begin a major project in one of the three program categories--confinement systems, development and technology, and research--must describe the project in detail in its budget submission to DCTR. DCTR reviews the project description and decides whether the project should be funded. If a multiyear project is funded, the laboratory must furnish DCTR with detailed information on the project's progress for each year it is underway.

DCTR officials told us that, although they could keep abreast of a laboratory's major projects through detailed budget reviews, expensive, experimental, magnetic confinement devices proposed by a laboratory required special attention. For this reason, DCTR has formal review procedures governing the fabrication of experimental devices estimated to cost over $250,000.

Under these procedures, DCTR reviews, in detail, a laboratory's experimental device proposals, to determine whether they are technically sound and programmatically relevant. For some proposals, DCTR sets up ad hoc review panels. The panel's membership can vary from only DCTR staff to a combination of DCTR staff and outside magnetic confinement experts. The Director of DCTR considers the recommendations of the ad hoc review panel and those of his staff before making the final decision on the proposal.

On June 4, 1974, the Director of DCTR formed the Fusion Power Coordinating Committee, which consists of the following voting members: himself (as chairman); his three technical assistant directors; the project directors of the magnetic confinement programs at Oak Ridge, Princeton, Livermore, and Los Alamos laboratories; and the DMA assistant director responsible for the laser fusion effort. The committee was formed to review technical projects in ERDA's magnetic confinement program, assess progress within specific areas of research and development, and promote communication and coordination.

MANAGEMENT APPROACH AND ORGANIZATIONAL STRUCTURE FOR INERTIAL CONFINEMENT

DMA's Office of Laser and Isotope Separation Technology is responsible for planning, directing, and managing ERDA's inertial confinement and laser isotope separation programs. (The laser isotope separation program is discussed in chapter 4.) The office has two technical branches--laser fusion and laser isotope separation development. In January 1975 it had eight professional staff members. The laser fusion branch is responsible for electron beam fusion development.

Management tools

DMA follows a decentralized management philosophy and does not exercise as tight a control over the laboratories in technical matters as DCTR does. For example, where operating funds are used, DMA does not approve or disapprove all experimental laser and electron beam machines estimated to cost as low as $250,000, as does DCTR for its experimental devices. DMA uses 5-year plans and reviews of laboratories' programs as management tools and exercises a combination of control and coordination to manage the laboratories. ERDA officials have described DMA's philosophy as "buying management" from the laboratories.

DMA provides programmatic direction to the laboratories through plans and budgets. The laboratories, in turn, develop detailed technical management on a day-to-day basis. The function of the DMA staff is to establish controlling guidelines, to plan long-range programs, and to insure coordination of the laboratory efforts toward meeting goals within available resources.

In January 1972 AEC organized the Laser Fusion Coordinating Committee to provide overall coordination of laser and electron beam fusion efforts. It consists of five members: one each from Los Alamos, Livermore, Sandia, DMA, and DCTR. The committee prepared a 5-year plan for inertial confinement development, which is updated at least annually.

The plan lays out a program leading to a demonstration laser fusion powerplant in about 1995. The plan identified technical milestones which ERDA expects to reach between

1975 and 1980. Since DMA has no responsibility for magnetic confinement development, the inertial confinement 5-year plan does not consider the magnetic confinement approaches.

DMA reviews the Livermore, Los Alamos, and Sandia annual budgets for inertial confinement efforts and requires the laboratories to furnish detailed descriptions of proposed programs within the inertial confinement area.

The fabrication of most of the lower energy, and hence lower cost, laser and electron beam machines is approved at the laboratories, although DMA is made aware of these actions. The estimated cost of one such machine--Los Alamos' 1,000-joule carbon dioxide laser--exceeded $1 million. The committee reviews proposals for high-energy laser and electron beam machines, as well as overall laboratory programs, and makes technical recommendations to DMA. After reviewing the committee's recommendation, the LIS technology staff makes a recommendation to the Director of DMA.

MANAGEMENT NEEDS A WAY TO MAKE CONSISTENT EVALUATIONS OF ALL FUSION APPROACHES

DCTR manages the magnetic confinement approach to fusion, and DMA manages the inertial confinement approach.1/ DCTR exercises centralized control management, but DMA believes in less centralized control and in buying management from the laboratories.

Both divisions have control mechanisms for the fusion efforts they manage. ERDA, however, has no overall mechanisms to assist it in making decisions on its fusion efforts as a whole in assessing the effect of scientific breakthroughs and the achievement of milestones. The two divisions independently propose and justify commitments of dollars, manpower, and facilities for their programs.

1/Under the ERDA organization, the magnetic confinement programs are the responsibility of the Assistant Administrator for Solar, Geothermal, and Advanced Energy Systems and the inertial confinement programs are the responsibility of the Assistant Administrator for National Security.

We believe that ERDA headquarters management needs a mechanism to assess the technical merits and promise of all fusion efforts in comparison with each other. The following example, we believe, illustrates this need.

Eliminating the least promising fusion approach

DCTR plans to select two of its three magnetic confinement approaches for further development in 1977-78. DCTR plans to consider only the three magnetic confinement approaches in making its decision. Such a decisionmaking process may result in eliminating a more promising approach than laser fusion, electron beam fusion, or both. Unless all five approaches are consistently and systematically reviewed and evaluated, ERDA cannot be certain that the least promising approach to long-term commercial fusion power is eliminated.

ALTERNATIVE FOR IMPROVING FUSION MANAGEMENT

One alternative for improving the management of ERDA's fusion effort is to centralize all responsibility for fusion research in one division. DMA officials, however, believe that consolidating magnetic confinement efforts with the civilian portion of inertial confinement efforts should come only when the technology has advanced far enough to separate civilian and military applications. They believe that an effective separation could be made only after achievement of net energy gain. At this point, they expect there will be a basis for assessing the potential of military and commercial applications more confidently. Their schedule calls for achieving net energy gain in the early 1980s.

During our review, AEC appointed a three-member fusion overview panel to study how to approach determining priorities and goals for fusion technologies in a broader context. The panel's work was to relate to

--obtaining fusion as an energy resource in the nearest practicable time frame,

--including industrial participation in the fusion development effort,

--the role of laser and electron beam fusion technologies in the area of national security, and

--the factors affecting relative emphasis among fusion technologies in both the near-term budget process and the long-range program planning.

The panel's findings and recommendations were not available at the time we prepared this report.

CONCLUSION

Management of the fusion programs could be improved. Centralizing management responsibility is one possible alternative for improvement. Others, such as an overview group, which would periodically review and technically evaluate fusion approaches, could also serve this purpose.

Some method should be established which would permit ERDA to (1) evaluate and compare the relative merits of the approaches and (2) identify priorities for all the fusion approaches--lasers, electron beam, and magnetic confinement systems. This would permit ERDA's top management to be in a better position to determine the content, pace, and budget for the fusion program and how scientific breakthroughs and the achievement of milestones will affect future decisions and choices among the three fusion approaches. The recently established panel should serve to identify any management changes that are needed in ERDA's management of the fusion effort. We endorse the panel's mission and plan to closely monitor ERDA's actions on the panel's determinations.

CHAPTER 4

DEVELOPMENT OF LASER ISOTOPE SEPARATION

Officials at ERDA's Los Alamos laboratory estimate that it will cost less than $500 million to fully develop a new way of enriching uranium using the LIS process. This could save the country as much as about $80 billion by the year 2000. In view of this potential saving, the emphasis and priority that ERDA gives to the process is important.

DEMAND FOR ENRICHED URANIUM

Natural uranium ore contains essentially two forms, or isotopes. One isotope, uranium 235 (U-235), is used as a fuel in fission power reactors. The U-235 content of natural uranium ore is 0.7 percent. Since the fuel for fission reactors requires about 3 percent U-235, the percentage of U-235 in uranium must be increased from 0.7 to 3 percent. This is called enrichment.

The present method of enriching uranium--gaseous diffusion--is expensive and requires large amounts of capital and energy. Our country has three gaseous diffusion plants located at Oak Ridge, Tennessee; Portsmouth, Ohio; and Paducah, Kentucky.

ERDA expects that nuclear capacity--which is now about 6 percent of the total U.S. electrical capacity--will be about 60 percent by the year 2000. Consequently, the projected demand for enriched uranium will exceed the projected U.S. enrichment capacity by the mid-1980s. Because of the time (about 8 years) required to plan and build a gaseous diffusion plant, a commitment to increase enrichment capacity must be made soon. Since 1972 AEC, now ERDA, has been trying to get private industry to build the next enrichment plant. Private industry, however, has not yet made a commitment to do so. ERDA has projected that a new enrichment plant must be completed every 18 months beyond the mid-1980s, to keep pace with demand for enriched uranium.

Because gaseous diffusion plants are expensive to build and operate, the United States and foreign nations are developing other processes to meet the projected future demand for nuclear fuel.

NEW ENRICHMENT TECHNOLOGY

ERDA is investigating several new processes for enriching uranium. The two most promising are laser isotope separation (LIS) and gas centrifuge. LIS is still in the research stage and it is too early to determine its commercial feasibility, but LIS has the potential to considerably improve the economics of uranium enrichment. Although other major scientific and technological problems exist, LIS is critically dependent on the development of high-powered lasers.

ERDA says the gas centrifuge process has advanced beyond the development stage to the point where there is no question that an operable enrichment plant using the centrifuge process can be built. The main question remaining is one of economics: that is, whether the centrifuge process can do the job at a cost as low as or lower than the gaseous diffusion process.

Laser isotope separation

Los Alamos and Livermore are doing research and development work on LIS. The technical details and status of the Los Alamos process are classified and therefore are not presented in this report. Los Alamos started work on LIS in 1970 and now has a method it feels can be scaled up to a pilot plant. Although there are many uncertainties in establishing a time frame for developing the process, Los Alamos believes that the earliest that a pilot plant would be built would be 1979. A technical review group, set up by AEC to review proposals and progress in LIS development, stated in its December 1973 report that the Los Alamos approach had potential advantages for combining separation efficiency with high throughput of feed material. These advantages, according to its report, are a desirable combination which is not found in the gaseous diffusion process. The review group warned, however, that:

> "* * * it is too early to tell whether the process can be made economically competitive with gaseous diffusion or the gas centrifuge. However, there is such a great margin between the Los Alamos estimate of the cost of separating 235U by the laser process and the cost by gaseous diffusion that the process must be given serious attention."

The review group recommended that a major effort be started, if scientific feasibility can be demonstrated, to develop the Los Alamos process. This demonstration would involve actual production of enriched U-235 on a small scale. Los Alamos is focusing nearly all of its work on this one project.

Livermore is devoting about half of its LIS program resources to the evaluation of a number of new processes involving lasers. The other half is devoted to scaling up one process, which uses atoms of vaporized uranium as a feed material. Uranium vapor is extremely corrosive and will destroy almost anything it touches.

Livermore officials told us, however, that they had solved many of the uranium corrosion problems. Livermore is the only ERDA laboratory that has experimentally demonstrated LIS of uranium, although only in microscopic quantities.

The following table gives past and projected funding for LIS. The projected funding shown below was taken from the Laser Fusion Coordinating Committee's 5-year plan.

Fiscal year	Total
	(millions)
1973	$ 0.8
1974	3.5
1975 (estimated)	14.6
1976 (estimated)	35.5
1977 (estimated)	63.0
1978 (estimated)	72.8
1979 (estimated)	58.9
1980 (estimated)	56.9
	306.0
Capital costs (estimated)	47.0
	$353.0

Despite the sharp increases in funding, there are technical problems in the process which are not now being studied. For example, laser development is an important item for the Los Alamos process. Highly specialized lasers have to be developed before a pilot plant can be built. According to Los Alamos officials, they do not now have enough funds or manpower to develop these lasers.

Gas centrifuge

The gas centrifuge process for isotope separation has been under development since about 1919, but mechanical problems prevented any measurable progress until 1934. Since then, a great deal of work around the world has been done to study and improve the centrifuge process. It was used in the United States and Germany during World War II for separation of uranium isotopes on a laboratory scale.

There are many problems associated with putting the centrifuge theory into practical operation. Despite these problems, many nations are interested in the process because it has certain advantages over gaseous diffusion. For example, gas centrifuge is expected to require only 10 percent of the electrical power necessary to operate a diffusion plant. Another advantage is the centrifuge process' ability to begin enriching uranium at an earlier time than a diffusion plant even if construction of both plants was started at the same time.

The following tabl- -aken from recent ERDA estimates, compares the cost of eq--!-sized gaseous diffusion and gas centrifuge plants.

	Gaseous diffusion	Gas centrifuge (note a)
Capital cost	$1,400,000,000	$1,400,000,000
Annual operating cost (excluding power)	$ 16,000,000	$ 90,000,000
Annual power cost (at 10 mills per kilowatt-hour)	$ 210,000,000	$ 21,000,000
Power requirement	2,400 megawatts	240 megawatts

a/Preliminary estimates subject to continuous refinement.

The capital cost of either a gaseous diffusion plant or a gas centrifuge plant is expected to be about the same. A gas centrifuge plant requires about 10 times less power than a gaseous diffusion plant but requires more labor to construct. Also material costs are higher due to the shorter service life of centrifuge equipment. Ultimately, the economics of a gas centrifuge plant versus a gaseous diffusion plant will depend on the future costs of power versus the future costs of labor and materials.

IMPACT OF SUCCESSFUL LIS PROCESS

If successfully developed, LIS could impact considerably on the economics of enriching uranium and on international security.

Economics

The most important advantage of a successful LIS program is expected to be economic. Livermore officials estimate the total savings from using the LIS process from 1985 to 2000 could amount to as much a $80 billion. They point out that the cost estimates for LIS are speculative, but the differences between gaseous diffusion, gas centrifuge, and LIS are so great that, even with a tenfold error in the LIS estimates, the savings would still have a profound effect on the U.S. economy. According to ERDA officials these are preliminary estimates.

If, as ERDA has projected, a new enrichment facility will be needed every 18 months beginning in the mid-1980s, about 10 new enrichment plants will be required by the year 2000. If these plants are the gaseous diffusion or centrifuge type, the capital costs will be about $14 billion. If these plants are LIS plants, the capital costs, according to the laboratories' estimates, will be less than $90 million, a saving of about $13 billion.

Additional savings could be realized in the cost of electricity to operate enrichment plants. A gaseous diffusion plant 1/ that produces enough fuel to run 100 average-sized powerplants requires about 2,400 megawatts of electricity annually. The average nuclear electric powerplant is designed to produce about 1,200 megawatts and to cost about $500 to $600 million to construct. Therefore, it would take two nuclear electric powerplants to operate one gaseous diffusion plant. Estimates of the annual electric power required for a comparable-sized LIS plant range from 8 to 100 megawatts, or less than 5 percent of the amount required for a gaseous diffusion plant. Consequently, LIS plants would probably not require dedicated 2/ powerplants.

Additional savings may result from LIS's greater enrichment potential. If successfully developed, the LIS process is expected to be able to enrich uranium more efficiently than the gaseous diffusion and gas centrifuge

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1/Gaseous diffusion plants can operate at various levels of efficiency or waste assay. In this instance, the waste assay is assumed to be 0.3 percent.

2/A plant used to furnish power exclusively to one user.

processes. More efficient processing will considerably reduce the uranium ore requirement and extend the existing ore reserves. The laboratories' officials estimate that this aspect alone would result in savings of $33 billion by the end of the century.

Because of its higher separation efficiency, LIS could also be used to enrich the tails, or waste, from gaseous diffusion plants. This would result in even more savings.

An August 1974 report by the General Advisory Committee--a committee established by the Congress to advise AEC on technical and scientific matters--stated that considerable effort should be made to speed up development of LIS because of its great importance. Among other things, the committee recommended

--increasing funding for laser development and

--beginning a development effort with the assistance of personnel experienced in enrichment technology leading to a pilot plant design in the late 1970s.

In responding to this recommendation, the AEC Chairman said that AEC would accelerate LIS development if it were determined that resources could be made available in the face of competing priorities. On February 20, 1975, ERDA asked the Joint Committee on Atomic Energy to approve $5 million in additional fiscal year 1975 funding to accelerate efforts in the LIS program. In April 1975 the Congress approved this request for additional funds for developing the process. For fiscal year 1976 and the 3-month transition period, ERDA requested funds of $31.5 million. The Joint Committee on Atomic Energy has authorized this amount.

International security

There is a growing concern about the prospects of foreign nations' acquiring the capability to develop nuclear weapons. The high cost of building and operating gaseous diffusion plants--which are necessary to enrich uranium to a weapons grade level--has prevented many nations from acquiring this capability. If it is successfully developed, the LIS process could also enrich uranium to a weapons grade level. Also the LIS process might not present the financial burden to some nations that gaseous diffusion does.

ERDA officials told us that the Israeli Government was developing an LIS process and speculation is that several other countries are also developing it. According to ERDA, the Israeli process is similar to the Livermore process in that it uses uranium vapor.

PROGRAM MANAGEMENT

The organizational structure for program management indicates ERDA's lack of adequate attention. For example, LIS is under the Office of Laser and Isotope Separation Technology, which is part of DMA. As of January 1975 there were only two persons working full time to manage the research effort of the two ERDA laboratories.

The General Advisory Committee, in its August 1974 report, recommended giving the LIS program a:

> "* * * principal program manager with a good technical understanding, a belief in the high importance of the program, and a flexibility that will assure the most rapid development of one or more forms of laser separation capability. Such a position and such a person is not now a part of the system of management."

The AEC Chairman responded in September 1974 by saying that AEC would shortly staff a position similar to the one which the General Advisory Committee recommended. ERDA officials have advised us that, since September 1974, they have required a principal program manager and have been able to strengthen the management staff.

Also, development progress on LIS was delayed because of limited participation in the development of LIS by ERDA's Division of Production and Material Management and Union Carbide--a contractor that operates the Oak Ridge gaseous diffusion plant for ERDA. The Division of Production and Material Management and Union Carbide have expertise in the commercialization of promising uranium enrichment concepts. Because the Los Alamos scientists did not fully inform the enrichment experts from Union Carbide about the details of the process, for 9 months Los Alamos unknowingly used incorrect material which the Union Carbide experts would have known was a mistake. Los Alamos personnel became aware of their mistake during a meeting with Union Carbide experts.

In commenting on this situation, ERDA officials gave us the following statement.

> "The interaction between Union Carbide Nuclear Corporation (UCNC) at Oak Ridge and Los Alamos

personnel has been extremely fruitful and has clearly accelerated LIS developments. Early in the program, in the absence of a close working relationship, Los Alamos used and experienced unfavorable results with material which UCNC experts would have known to be unsuitable. A very close working relationship has since developed, and we foresee no further problems of this kind."

LIS program funds have since been given to Union Carbide for engineering-support work on the process. ERDA's plans call for this funding to continue. This arrangement could help expedite development of the process and could minimize avoidable mistakes, such as the one cited above.

PRIVATE INVOLVEMENT

The LIS process is considered feasible by a private company developing a LIS process reportedly similar to the Livermore and Israeli Government process. The company has invested almost $15 million and estimates that it may need $150 million more to develop the process. It estimates a production-scale enrichment plant could be built by 1985 or 1986. We cannot discuss additional information on this company's development efforts because the company considers that information proprietary. ERDA officials told us that other private companies were also developing LIS processes.

CONCLUSION

Insufficient funding appears to be hampering the solution of technical LIS problems, such as laser development. Moreover, ERDA's management of this program should be strengthened by increasing staffing and coordination between ERDA's laboratories and Union Carbide's enrichment experts.

The General Advisory Committee has made recommendations aimed at resolving these problem areas. Because the LIS process holds great promise for this country in its potential to more efficiently and economically enrich uranium and extend existing uranium resources, it is important that ERDA make every effort to carry out these recommendations promptly. ERDA has said it will act soon on the Committee's recommendations. We plan to monitor ERDA's actions closely.

CHAPTER 5

SCOPE OF REVIEW

We reviewed efforts in this country--primarily Federal effort--to develop fusion power and LIS and obtained the information used in this report by reviewing planning documents, reports, correspondence, and other records and by interviewing officials at the following locations:

--AEC Headquarters, Germantown, Maryland

--Los Alamos Scientific Laboratory, Los Alamos, New Mexico

--Sandia Laboratory, Albuquerque, New Mexico

--Lawrence Livermore Laboratory, Livermore, California

--Oak Ridge National Laboratory, Oak Ridge, Tennessee

--Union Carbide Nuclear Division, Oak Ridge, Tennessee

--University of Rochester, Rochester, New York

--Princeton Plasma Physics Laboratory, Princeton, New Jersey

--Battelle Memorial Institute, Columbus, Ohio

--KMS Fusion, Incorporated, Ann Arbor, Michigan

We obtained additional information through correspondence with Exxon Nuclear Company, Incorporated, Bellevue, Washington.

We made no attempt to make technical assessments.

PRINCIPAL OFFICIALS OF THE ATOMIC ENERGY COMMISSION AND THE ENERCY RESEARCH AND DEVELOPMENT ADMINISTRATION RESPONSIBLE FOR ADMINISTERING THE ACTIVITIES DISCUSSED IN THIS REPORT

	Tenure of office From	To
ATOMIC ENERGY COMMISSION		
CHAIRMAN:		
Dixy Lee Ray	Feb. 1973	Jan. 1975
James R. Schlesinger	Aug. 1971	Feb. 1973
Glenn T. Seaborg	Mar. 1961	Aug. 1971
GENERAL MANAGER:		
Robert D. Thorne (acting)	Jan. 1975	Jan. 1975
John A. Erlewine	Jan. 1974	Dec. 1974
Robert E. Hollingsworth	Aug. 1964	Jan. 1974
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION		
ADMINISTRATOR:		
Robert C. Seamans, Jr.	Jan. 1975	Present
ASSISTANT ADMINISTRATOR FOR NATIONAL SECURITY:		
Edward B. Giller (acting Deputy)	Jan. 1975	Present
ASSISTANT ADMINISTRATOR FOR SOLAR, GEOTHERMAL AND ADVANCED ENERGY SYSTEMS:		
John M. Teem (acting Deputy)	Jan. 1975	Present