Starpower: the quest for fusion energy today

The Reagan administration in seven years has cut the magnetic fusion budget in half, crippling the program. Part I of a series from the OTA's report.

In time for the seventh anniversary of the passage and signing of the Magnetic Fusion Energy Engineering Act of 1980 (Public Law 96-386), the Congressional Office of Technology Assessment issued a 248-page report, *Starpower,* which reviews the status and prospects for harnessing magnetic fusion energy. The Office of Technology (OTA) is no friend of the fusion program—or any high technology, for that matter. But, because of a peculiar set of political exigencies, the OTA in this case has carried out a reasonably competent job, at least in terms of the "technical" material that is developed in depth.

The OTA report demonstrates in some detail that "great progress" has been and continues to be made in the magnetic fusion research program, but that over the past seven years the effort has been put into a "holding pattern" due to budget cutbacks by the Reagan administration. Construction of major next-generation fusion experiments have been deferred despite the fact that researchers have continued to make major scientific advances with existing machines—significantly beyond what was originally projected for those devices. At the same time, the scope of the program has been narrowed as many experiments have been slowed and mothballed.

OTA shows that if this policy is continued much longer, the U. S. effort will no longer be viable. With the passage and signing of the Magnetic Fusion Energy Engineering Act of 1980, the government of the United States of America determined: "The United States is now ready to embark on the next step toward the goal of achieving economic fusion power: Exploration of the engineering feasibility of fusion." But instead of doubling the magnetic fusion budget over seven years as mandated by this Law, the Reagan administration has cut the program by half in real dollars.

The OTA report proves that there was no technical or scientific basis for this action, only the "politics of perception"—the perception that neither the United States, nor the world needs the virtually limitless potential for cheap, clean fusion energy, or, that the United States must maintain its scientific and technological preeminence.

A decade of stagnation

In 1973 the U.S. Atomic Energy Commission (AEC), the agency then responsible for directing fusion energy research, mapped out a crash program to realize a working magnetic fusion electric power plant by 1980. At that time such a program would have had a significant risk of failing to meet this goal. But a comparison of the data made available in the OTA report to the projections made in this 1973 AEC study, demonstrates that that crash program would have succeeded, well beyond the expectations of the original planners.

The magnetic fusion program did embark on the essential elements of such a crash effort. In 1974 it was determined that the next major experimental facility would be designed to reach fusion breakeven. This was the Princeton Tokamak Fusion Test Reactor (TFTR).

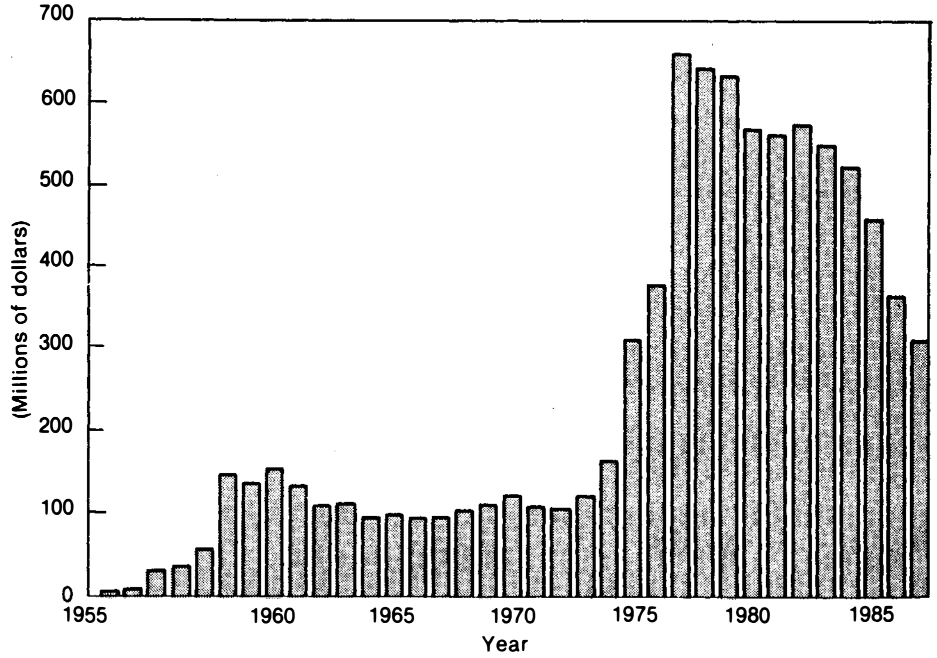
Due to budget cutbacks and other actions to slow the fusion program during the Carter administration, this facility is only now approaching its full potential. The fact remains that this machine, first conceived in 1974, is the last major magnetic fusion facility to be initiated by the United States, more than 13 years ago!

Now, after more than a decade of stagnation, as the OTA documents, both the Western Europeans and Japanese have overtaken the U.S. magnetic fusion effort.

FIGURE 1

Historic magnetic fusion R&D funding, 1951-87

(in 1986 dollars)



Source: U.S. Department of Energy, Office of Energy Research, letter to OTA project staff, Aug. 15, 1986.

The OTA further documents, that despite the general stagnation of the program, the fusion effort has in the past trained the essential pool of scientific manpower needed for manning crucial defense projects and much of the science and technology that is currently being developed by the Strategic Defense Initiative (SDI) missile defense program. And if funding for fusion continues to erode, OTA concludes that this source for the pool of most advanced scientists and engineers will completely dry up. Already, the number of staff with doctorates has declined 20% since 1983. And more than half of the 40 universities with fusion programs could withdraw by 1989.

The OTA report concludes, as all fusion reviews have similarly concluded since 1974, that the next essential step is to construct a tokamak fusion ignition experiment. Such a device would sustain long pulses of burning fusion plasmas. This would provide the actual conditions to demonstrate the full scientific aspects of operating magnetic fusion reactor plasmas and many of the physical conditions needed to experimentally develop the materials and technology for economic fusion power plants. The latest paper design for such a machine is the Compact Ignition Tokamak (CIT), which is currently projected to cost $357 million.

Among the reasons for the OTA carrying out this reasonably competent technical review of the U.S. magnetic fusion research program is that OTA has lost much of its "technical" credibility because of the incompetent diatribes it has authored against the Strategic Defense Initiative (SDI) missile defense program. OTA reports on the SDI have been demonstrated to have major technical flaws in their analysis and description of technologies. From a partisan political standpoint, the fusion program offers a subject upon which the OTA can regain some of its technical credibility, while simultaneously exposing the Reagan administration's undermining of U.S. fusion energy development capabilities.

The following are extensive excerpts from the OTA's *Starpower* report on the U.S. magnetic fusion research program. These excerpts do not present the full conclusions reached by the OTA—most of which are not demonstrated from a technical standpoint within the body of the report. The excerpts do present a clear and self-contained picture of technical progress in the program. And while the report does have a brief appendix on inertial confinement fusion—laser pellet fusion—it is not intended as a serious review of this second major approach to nuclear fusion. Therefore, only excerpts concerning magnetic fusion research are presented.

Copies of the full OTA *Starpower* report can be obtained from the Superintendent of Documents, Government Printing Office, Washington, D.C. 20402-9325. $10.00, 052-003-01079-8.

Overview

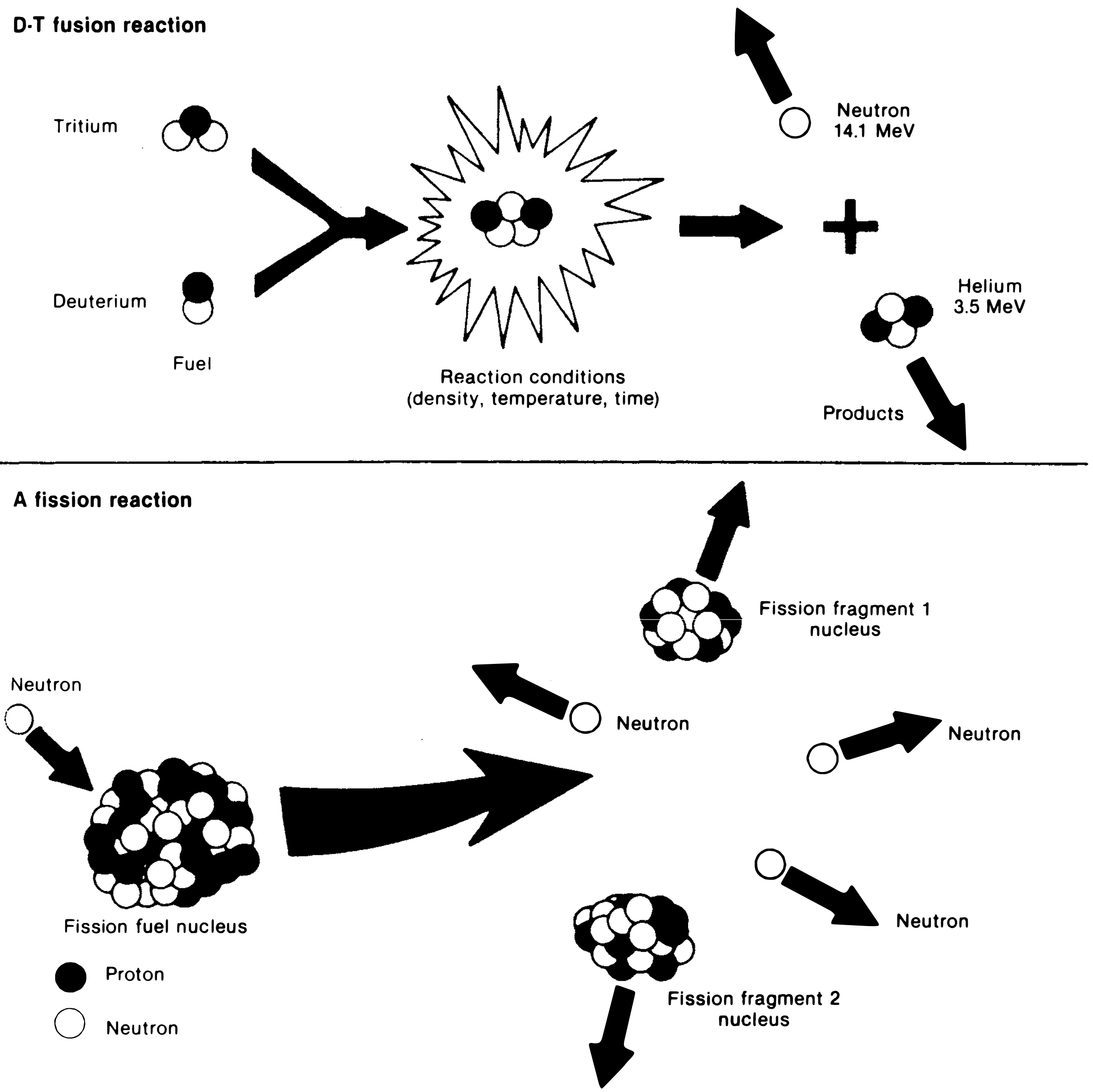
If successfully developed, nuclear fusion could provide humanity with an effectively unlimited source of electricity that has environmental and safety advantages over other electric energy technologies. . . .

The budget for fusion research increased more than tenfold in the 1970s, due largely to growing public concern about environmental protection and uncertainty in long-range energy supply. However, a much-reduced sense of public urgency in the 1980s, coupled with the mounting Federal budget deficit, halted and then reversed the growth of the fusion budget. Today, the fusion program is being funded (in 1986 dollars) at about half of its peak level of a decade ago (see **Figure 1**).

The change in the fusion program's status over the past

FIGURE 2

The D-T fusion reaction and a fission reaction



Source: Adapted from Princeton Plasma Physics Laboratory, Information Bulletin NT-1: Fusion Power, 1984, p. 2; Office of Technology Assessment (fission), 1987.

10 years has not resulted from poor technical performance or a more pessimistic evaluation of fusion's prospects. On the contrary, the program has made substantial progress. However, the disappearance of a perceived need for near-term commercialization has reduced the impetus to develop commercial fusion energy and has tightened pressure on fusion research budgets. Over the past decade, the fusion program has been unable to maintain a constant funding level, much less command the substantial funding increases required for next-generation facilities. In fact, due to funding constraints, the program has been unable to complete and operate some of its existing facilities.

The Department of Energy (DOE) manages the U.S. fusion program, and its goal is to evaluate fusion's technological feasibility—to determine whether or not a fusion reactor can be designed and built—early in the 21st century. A positive evaluation would enable a decision to be made at that time to construct a prototype commercial reactor. However, this schedule cannot be met under existing U.S. fusion budgets. The DOE plan requires either that U.S. budgets be increased substantially or that the world fusion programs collaborate much more closely on fusion research.

Choices made over the next several years can place the U.S. fusion program on one of four fundamentally different paths. . . .

1) With substantial funding increases, the fusion program could complete its currently mapped-out research effort domestically, permitting decisions to be made early in the next century concerning fusion's potential for commercialization.

2) At only moderate increases in U.S. funding levels, the same results as above might be attainable—although, possibly somewhat delayed—if the United States can work with some or all of the world's other major fusion programs (Western Europe, Japan, and the Soviet Union) at an unprecedented level of collaboration.

3) Decreased funding levels, or current funding levels in the absence of extensive collaboration, would require modification of the program's overall goals. At these constrained funding levels, U.S. evaluation of fusion as an energy technology would be delayed.

4) If fusion research ceased in the United States, the possibility of domestically developing fusion as an energy technology would be foreclosed unless and until funding were restored. Work would probably continue abroad, although possibly at a reduced pace; resumption of research at a later time in the United States would be possible but difficult. . . .

A quick fusion primer

The fusion reaction

In a fusion reaction, the nuclei—or central cores—of light atoms combine or fuse together; when they do, energy is released. In a sense, fusion is the opposite of fission, the process utilized in existing nuclear power plants (see **Figure 2**), in which energy is released when a heavy nucleus splits into smaller pieces.

The lightest atom, hydrogen, is the easiest one to use for fusion. Hydrogen has three forms, or isotopes; two of them—deuterium (D) and tritium (T)—in combination work the best in fusion reactions. The kinetic energy released in the D-T reaction can be converted to heat, which in turn can be used to make steam to drive a turbine to generate electricity.

But a fusion reaction cannot happen unless certain conditions are met. To fuse hydrogen nuclei together, the nuclei must be heated to approximately 100 million degrees Celsius (C). At these temperatures, matter exists as plasma, a state in which atoms are broken down into electrons and nuclei. Keeping a plasma hot enough for a long enough period of time, and effectively confining it, are crucial for generating fusion power.

While no solid container can withstand the heat of a plasma, magnetic fields may be able to confine a plasma successfully. This assessment discusses magnetic confinement research and the various magnetic field configurations that look promising for producing fusion power. . . .

The feasibility of fusion

Before fusion power plants can generate electricity, fusion must be proven technologically and commercially feasible.

Technological feasibility will require that both scientific feasibility and engineering feasibility be shown. Scientists must bring fusion reactions to breakeven, the point at which at least as much energy is produced as must be input to maintain the reaction. Existing experiments are expected to reach this long-elusive milestone by 1990. Beyond breakeven, scientists have an even harder but more important task of creating high energy gain—energy output that is many times higher than the energy input. Only when high-gain reactions are produced will the scientific feasibility of the fusion process be demonstrated. If a high-gain reaction reaches ignition, it will sustain itself even when the external heat is turned off.

Once scientific feasibility of fusion as a potential energy source is established, the engineering development necessary to develop fusion reactors must be completed. Engineering feasibility denotes the successful development of reliable components, systems, and subsystems for operating fusion reactors.

Scientific and engineering feasibility, although involving different issues, are interdependent. Demonstrating either one will require advances to be made in basic scientific understanding as well as in technological capability.

The goal of fusion research is to prove fusion's technological feasibility so that its commercial feasibility is likely. To be marketable, fusion power must be socially and environmentally acceptable and economically attractive compared to its competitors, and it must meet regulatory and licensing requirements.

Probability of success

Experiments now existing or proposed to be built should be sufficient, within the next few years, to demonstrate fusion's scientific feasibility. If these experiments do not uncover unfavorable surprises, it appears likely—although not certain—that fusion's engineering feasibility can be subsequently established. Most of the technological and engineering challenges to designing and building a reactor have been identified. However, it cannot yet be determined whether or not a fusion reactor will be commercially attractive.

History of magnetic confinement fusion research

1950s and 1960s

From 1951 until 1958, fusion research was conducted by the U. S. Atomic Energy Commission (AEC) in a secret program code-named "Project Sherwood." Many different magnetic confinement concepts were explored during the early 1950s. Although researchers were careful to note that practical applications lay at least 10 to 20 years in the future, the devices being studied were thought to be capable of leading directly to a commercial reactor.

In reality, however, very little was known about the behavior of plasma in experiments and even less about how it would act under the conditions required for fusion reactors. Experimental results were often ambiguous or misinterpreted, and the theoretical understanding underlying the research was not well established. By 1958—as people realized that harnessing magnetic fusion was going to be difficult and that national security considerations were less immediate—the research was declassified. This action made widespread international cooperation in fusion research possible, particularly since the countries involved realized that the state of their research programs was more or less equivalent.

With the optimism of the 1950s tempered, fusion researchers in the United States proceeded at a steady pace throughout the 1960s. In 1968, Soviet scientists announced a major breakthrough in plasma confinement in a device called a "tokamak." After verifying Soviet results, the other world fusion programs redirected their efforts toward development of the tokamak.

1970s and 1980s

With the identification of the tokamak as a confinement concept likely to reach reactor-level conditions, the U.S. fusion program grew rapidly. Between 1972 and 1979, the fusion program's budget increased more than tenfold. This growth was due in part to uncertainty in the early 1970s concerning long-range energy supply; fusion energy, with its potentially inexhaustible fuel supply, appeared to be an attractive alternative to exhaustible resources such as oil and gas. In addition, the growth of the environmental movement and increasing opposition to nuclear fission technology drew public support to fusion as an energy technology that might prove more environmentally acceptable than other energy technologies.

The fusion program capitalized on this public support; program leadership place a high priority on developing a research plan that could lead to a demonstration reactor. Planning began for the Tokamak Fusion Test Reactor, a new experiment using D-T fuel that would reach breakeven. By 1974, the funding increases necessary to pursue accelerated development of fusion were appropriated.

Program organization changed twice during the 1970s. In 1974, Congress abolished the AEC and transferred its energy research programs to the newly created Energy Research and Development Administration (ERDA). . . . Three years later, President Carter incorporated the functions of ERDA into a new agency, the Department of Energy (DOE).

Under DOE, the fusion program did not have the same sense of urgency. Fusion could not mitigate the short-term oil and gas crisis facing the United States. . . .

The fusion program has continued to make substantial technical progress during the 1980s. Several world machines have the potential to achieve breakeven, or breakeven-equivalent conditions, within the decade; in addition, significant advances in plasma physics and fusion technology continue.

ERAB review of the fusion program, 1980

In 1980, the Energy Research Advisory Board (ERAB), a standing committee that advises the Secretary of Energy, established a committee to review DOE's fusion program. The commitee's report evaluated technical progress in the fusion program over the previous few years and found many accomplishments that justified the panel's confidence that breakeven was near. The panel concluded that

> . . . the United States is now ready to embark on the next step toward the goal of achieving economic fusion power: exploration of the engineering feasibility of fusion.

The panel proposed that the program begin planning a Fusion Engineering Device (FED), which would provide a focus for development of reactor-relevant technologies and components, enable researchers to evaluate safety issues associated with fusion power, and facilitate investigation of additional plasma physics issues. This device would be built and operated as part of a broad program of engineering experimentation and analysis to be conducted by a new fusion engineering center. The ERAB panel recognized that planning and constructing FED would require a doubling of the fusion budget over the next five to seven years, and it recommended this budget increase.

The Magnetic Fusion Energy Engineering Act, 1980

Many of the recommendations of the ERAB panel were incorporated into the Magnetic Fusion Energy Engineering Act (MFEE Act), passed by Congress in September 1980. Passage of the MFEE Act was largely a result of Representative Mike McCormack's (D-Washington) efforts. It urged acceleration of the national effort in magnetic fusion research, development, and demonstration activities. Like the ERAB report, the act recommended creation of a Magnetic Fusion Engineering Center to coordinate major magnetic fusion engineering devices.

The Magnetic Fusion Energy Engineering Act recommended that funding levels for magnetic fusion be doubled (in constant dollars) within seven years. . . . Actual appropriations in the 1980s did not grow at the level specified in the act and in fact continued the drop in constant dollar funding that began in 1977. . . .

. . . Despite constrained funding, the U.S. fusion program has made significant advances in plasma physics and fusion technology throughout the 1980s. . . .

Fusion as a research program

The ultimate objective of fusion research is to produce a commercially viable energy source. Yet, because the research program is exploring new realms of science and technology, it also provides near-term, non-energy benefits. These benefits fall in four major categories.

Near-term benefits

1. Development of plasma physics. Plasma physics as a branch of science began in the 1950s, driven by the needs of scientists working on controlled thermonuclear fusion, and later, by the needs of space science and exploration. The field of plasma physics has developed rapidly and has synthesized many areas of physics previously considered distinct disciplines. Magnetic fusion research funding is crucial to the continuation of plasma physics research; over half of all Federal plasma physics research is funded by the magnetic fusion program.

2. Educating scientists. Educating scientists and engineers is one of the most widely acknowledged benefits of the fusion program. Over the last decade, DOE's magnetic fusion energy program has financed the education of most of the plasma physicists produced in the United States. DOE, through its magnetic fusion program, directly supports university fusion programs and provides 37 fusion fellowships annually to qualified doctoral students. Training in plasma physics enables these scientists to contribute to defense applications, space and astrophysical plasma physics, materials science, applied mathematics, computer science, and other fields.

3. Advancing science and technology. Many high-technology research and development (R&D) programs produce secondary benefits or "spin-offs." Over the years, the magnetic fusion energy program has contributed to a variety of spin-off technologies with wide-ranging applications in other fields. Among them are superconducting magnet technology, high-quality vacuums, high-temperature materials, high-frequency and high-power radiofrequency waves, electronics, diagnostics and tools for scientific analysis, high-speed mainframe computers, and particle beams. . . .

Contributions to industry

Certain phenomena associated with fusion research have proven particularly applicable to the development of electronic systems and industrial manufacturing processes. *Plasma etching* is an important process in the semiconductor industry. Fusion research has provided information necessary to characterize and understand the process more completely and also has contributed plasma diagnostics that can be used to monitor the etching process.

Microwave electronics is another fusion contribution that has both civilian and military applications. Microwave tubes and plasmas share certain physical principles of operation, and advances in the understanding of basic plasma physics have contributed to improvements in microwave technology. The fusion program has also fostered development of the microwave industry through its requirements for high-frequency, high-power microwave sources, such as the gyrotron. Typical applications of microwave technology include high-power radar stations, television broadcasting, satellite communications, and microwave ovens. . . .

. . . [T]he fusion program has contributed to the national defense. The most valuable contributions are in the background plasma physics research conducted by the fusion program and the education of scientists that later are hired by defense programs. In addition, many scientific ideas and technological developments being investigated under the Strategic Defense Initiative (SDI) grew out of research in the fusion program. For example, contributions made by the magnetic fusion program in the development of neutral beams and accelerators for free electron lasers have been instrumental to the development of directed-energy weapons necessary for SDI applications. . . .

4. Stature. The stature of the United States abroad benefits from conducting high-technology research. The United States has been at the forefront of fusion R&D since the program began in the 1950s. Maintaining a first-rate fusion program has placed the United States in a strong bargaining position when arranging international projects, has attracted top scientists from other fusion programs to the United States in scientific and technical programs other than magnetic fusion.