United States General Accounting Office

GAO

Report to the Honorable
Vic Fazio, House of Representatives

September 1989

NUCLEAR SCIENCE

Better Information Needed for Selection of New Production Reactor

GAO/RCED-89-206

GAO

United States
General Accounting Office
Washington, D.C. 20548

Resources, Community, and
Economic Development Division

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September 21, 1989

The Honorable Vic Fazio
House of Representatives

Dear Mr. Fazio:

On June 29, 1988, you requested that we provide information on the adequacy of the process used by the Department of Energy (DOE) to select a new production reactor for nuclear weapons materials. The new reactor will be used primarily to produce tritium, an important ingredient in nuclear weapons, and one that has to be replenished periodically. Since your request, the need for a new production reactor has become more acute because of increased uncertainty concerning the ability of DOE's tritium-producing reactors to operate until a new reactor can supply tritium.

While DOE has not made a final selection of the reactor technology for the new production reactor, it has recommended a preferred strategy to the Congress—a heavy-water reactor at its Savannah River Site in Aiken, South Carolina, and a modular high-temperature, gas-cooled reactor at its Idaho National Engineering Laboratory near Idaho Falls, Idaho. The recommended strategy and the supporting information used by DOE to select this strategy are contained in DOE's August 8, 1988, report to the Congress entitled Acquisition Strategy for New Production Reactor Capacity.

In your request, you also asked us to answer specific questions pertaining to various aspects of DOE's selection process, including schedule, cost, technology transfer benefits, costs and benefits of one versus two new reactors, and remaining research and development. Information on many of these issues was presented to the Congress as part of DOE's August 8, 1988, report. Therefore, as agreed with your office, this letter addresses the adequacy and completeness of the information DOE provided to the Congress. Appendixes I through V address your specific questions.

Results in Brief

We found that following DOE's August 8, 1988, report, events have occurred that affect the basis on which the DOE strategy was developed. In addition, the information in the DOE report does not provide a complete and accurate picture of all the ramifications of implementing the two-reactor strategy. Specifically,

- Conditions have changed with respect to the reliability of the tritium-producing reactors located at DOE's Savannah River Site. DOE assumed that these reactors would continue to be a reliable source of tritium for at least 10 years. The reactors are presently shut down, and it is uncertain when they will be restarted and what actions will be required to ensure their reliability for several more years.
- DOE's report to the Congress does not provide clear information concerning the total time frame necessary to construct the two recommended reactors and obtain tritium from them. In addition, the DOE schedule does not provide any contingency for uncertainties in the areas of safety, environmental challenges, and construction delays.
- Some cost estimates are inaccurate because DOE used unrealistic assumptions in their development.
- The benefits of demonstrating an inherently safe modular high-temperature, gas-cooled reactor for commercial application may be achieved more quickly under another DOE program.

Background

DOE is responsible for producing nuclear materials for national defense purposes. To support this effort, DOE has built a nuclear weapons complex consisting of 15 major facilities in 12 different states. One of the primary components of this complex is the production reactors that can produce tritium and plutonium for use in nuclear weapons. The only reactors in the United States capable of producing tritium in sufficient quantities are located at DOE's Savannah River Site. However, these reactors have been shut down since August 1988 because of safety problems. As early as 1982, DOE recognized the need for new production reactors to provide a continuing supply of tritium for nuclear weapons. In addition, the Congress has recognized the need and as a result in December 1987 requested that the Secretary of Energy prepare a report on acquiring replacement reactors. In January 1988, the Secretary asked the Energy Research Advisory Board,[1] an independent peer review board, to assess four candidate technologies for new production reactor capacity. The four reactor technologies were: (1) heavy-water, (2) modular high-temperature, gas-cooled, (3) light-water, and (4) liquid-metal.

On August 8, 1988, the Secretary of Energy issued a report to the Congress recommending that DOE proceed on an urgent schedule to construct

[1] The Energy Research Advisory Board is an independent review board appointed by the Secretary of Energy to provide input to DOE on issues such as candidate technologies for a new production reactor. A panel of 19 experts formed subpanels to concentrate on each technology. Various reports were drawn together from DOE and its subcontractors to form the background for the study. References to the Energy Research Advisory Board or studies by them refer to the entire base of reports.

a heavy-water reactor at the Savannah River Site and a modular high-temperature, gas-cooled reactor at the Idaho National Engineering Laboratory. The estimated cost of the two reactors is $6.8 billion.[2] In addition, as a contingency, the report stated that work should continue on the development of a light-water reactor tritium target[3] and on solving the institutional issues associated with acquisition of the Washington Nuclear Plant, Unit 1, a 63-percent complete light-water reactor located on DOE's Hanford Reservation near Richland, Washington. This plant is owned by the Washington Public Power Supply System.

Reliability of Tritium Production Has Changed

The reliability of the tritium-producing reactors at the Savannah River Site has changed since DOE made its August 8, 1988, recommendation to the Congress, and this change has a direct effect on the selection process.

In making its August 1988 recommendation, DOE assumed the tritium-producing reactors operating at Savannah River would maintain their operational reliability during the period necessary to provide new production capacity, which is about 10 years, according to DOE. However, the day before the Secretary of Energy announced his recommendations, the reactor operators experienced problems while restarting one of the reactors at Savannah River. Although the reactor was shut down safely, the event cast some doubt on the ability of the operators to properly operate the reactors. In addition, technical problems—cracked pipes, vessel integrity, and the performance of the emergency core cooling system under accident conditions—have been identified.

Plans for the future operation of the reactors depend on resolving numerous technical and resource problems. For example, restart dates depend on which safety improvements must be completed prior to restart and whether additional resources will be needed to complete these improvements. The dates of restart, attainable power levels, and maintenance outage times for all three Savannah River reactors is yet to be determined. In addition, analysis of the condition and the remaining useful lives of each reactor must be completed.

[2]The $6.8 billion includes $3.2 billion for the heavy-water reactor and $3.6 billion for the modular high-temperature, gas-cooled. These are capital and pre-operational costs in 1988 dollars.

[3]Tritium targets are tubes containing a lithium compound that are placed in a reactor and irradiated by neutrons, thus producing tritium.

Given these problems, the need for a new production reactor is more acute than it was when DOE made its recommendation to the Congress. Thus, while a new reactor will not provide a solution to the present problems, such a reactor will be needed soon if a long-term source of tritium is to be provided. (See app. I.)

Inadequate Schedule Information and Schedule Uncertainties

DOE's August 8, 1988, report to the Congress does not provide a clear schedule for completion of the new production reactors or indicate when tritium will actually be realized. The report states that approximately 10 years would be needed to provide new production capacity.

We found, however, that the 10-year estimate does not include the time needed for testing or the time needed to produce and extract tritium. In the case of the heavy-water reactor, the schedule would thus have to be increased from 10 to 12-1/2 years because 1 year is needed for testing and 1-1/2 years is needed for the production and extraction of a full load of tritium.

The modular high-temperature, gas-cooled reactor is somewhat different since it will be built in phases, but it will be a total of 16 years, instead of 10 years, before DOE will obtain the first full load of tritium, or 50 percent of its goal, from this reactor.

During the selection process, DOE considered two additional reactor technologies—the liquid-metal reactor and the light-water/Washington Nuclear Plant, Unit 1, reactor. While DOE did not recommend either of these reactor technologies, DOE did present schedules showing that the liquid-metal reactor would take about 12 years and the Washington Nuclear Plant, Unit 1, which is partially completed, would take about 7 years to complete, including full tritium production and extraction. While the Washington Nuclear Plant, Unit 1, presents the shortest schedule of the four technologies assessed, there are unresolved technical and institutional issues associated with its completion that could extend the schedule. In September 1988, GAO issued a report[4] that addresses technical issues related to target development and institutional issues related to acquisition, and public and political acceptance.

In addition to the known schedule increases, there is clearly potential for each reactor's schedule to increase even further. In this respect, we

[4] Nuclear Science: Issues Associated With Completing WNP-1 as a Defense Materials Production Reactor (GAO/RCED-88-222, Sept. 21, 1988).

noted several uncertainties, which DOE is aware of but has not factored into its schedule. These include the safety review process, environmental challenges, and construction delays.

First, the safety review process facing DOE is basically unknown. September 1988 legislation (P.L. 100-456) set up a DOE Defense Nuclear Facilities Safety Board. However, the members were not appointed until July 1989, and the Board's specific requirements are unknown.

Second, DOE's schedule shows an orderly transition from issuance of a final environmental impact statement to the beginning of detailed design. However, environmental challenges, similar to ones faced in the commercial nuclear power industry, are likely to occur and could cause schedule problems.

And last, construction delays may have the greatest potential of all uncertainties to increase the schedules for new production reactors. DOE's schedule shows 5-1/2 years from the start of construction to fuel loading for the heavy-water reactor and a similar schedule for the modular high-temperature, gas-cooled reactor. However, we noted that new commercial reactors, completed between 1977 and 1980 and for which the technology is well known, took about 9 years for the same basic construction period, i.e., from start of construction to fuel loading.[5]

For a further comparison, the scheduled construction time to complete the Washington Nuclear Plant, Unit 1, reactor, which is presently 63-percent complete, is 4 years. DOE estimates, on the other hand, that it will be able to construct a new reactor from scratch in only 5-1/2 years. In other words, DOE's schedule anticipates taking 1-1/2 years longer to construct an entire plant than to complete one that is 63-percent complete.

In addition, there is some uncertainty associated with the ability of any of the reactor technologies to produce the quantities of tritium needed. While all technologies can eventually meet DOE's goal, there are outstanding technical questions that have to be resolved for each technology, and these might delay reactor development. These questions involve design, fuel and target technology, and other technical problems. For instance, the heavy-water reactor will employ a new design that may require some research and development to ensure its success. The

[5]This period was selected because it is prior to the Three Mile Island reactor accident, and is thus more conservative than recent years in which the time frame increased substantially.

modular high-temperature, gas-cooled reactor is a new technology and many technical problems may have to be resolved. If the schedule for resolving these problems is not met, then the overall schedule may increase. (See app. II.)

Cost Information Is Unclear

When the Congress requested DOE to prepare a report on acquiring new production reactors, it also directed DOE to provide a comprehensive comparative financial analysis and cost estimate of alternatives considered. To do this, DOE contracted with Martin Marietta, the operations contractor at its Oak Ridge National Laboratory in Tennessee, to perform the cost study. At DOE's direction, the contractor developed cost estimates for each of the four technologies, assuming each type of reactor would produce 100-percent goal quantity of tritium and take 10 years to construct.

DOE prepared 18 different options for a new production reactor strategy that were submitted to the Congress as part of the August 8, 1988, report. The options consisted of one or more reactor technologies, located at one or more of the three sites being considered. In formulating the options, DOE scaled down the reactor technologies according to the percent of the goal amount of tritium set forth in the options. For example, a full-sized reactor would produce 100 percent of the tritium goal and a half-size would produce 50 percent of the goal.

In developing cost estimates for the 18 options, DOE used Martin Marietta's cost information for full-sized reactors and scaled them down to develop costs for less than full-sized reactors. In our judgment, DOE's scaling assumptions were not realistic and resulted in improper and unrealistic cost estimates for the various options. Martin Marietta provided scaling factors for each cost category, but DOE applied them only to capital costs. Operations costs remained the same except for small adjustments in fuel costs. This methodology resulted in inaccurate operations cost estimates. We applied the Martin Marietta scaling factors to the operations cost and found that net life-cycle costs for DOE's dual reactor options changed by several billion dollars from DOE cost estimates.

In addition, after calculating the cost of a half-sized, modular high-temperature, gas-cooled reactor to be built on a 10-year schedule, DOE decided to increase the schedule to 16 years. DOE, however, did not change the estimated cost to allow for the stretched-out schedule, nor did it perform a timely and consistent cost analysis to determine whether the estimated cost would increase or decrease.

In this connection, it should be recognized that DOE's costs figures for the two-reactor strategy are only initial estimates. However, recently the average final cost of constructing commercial reactors in the United States has exceeded initial cost estimates by a factor of seven, including inflation. Also, DOE's proposed two-reactor strategy has the added uncertainty of not yet having detailed reactor designs, without which it becomes very difficult to develop a firm estimate.

As previously noted, the estimated cost for the recommended two-reactor strategy is $6.8 billion. DOE also provided estimates for the two technologies not selected—the liquid-metal reactor and the Washington Nuclear Plant, Unit 1, completion. The DOE estimated costs for these technologies are $4.4 billion and $2.2 billion, respectively.[6] (See app. III.)

Two Separate DOE Programs Are Developing Similar Reactor Technologies

One major benefit associated with selecting the modular high-temperature, gas-cooled reactor technology is the possibility of demonstrating an inherently safe reactor for our commercial nuclear power industry. DOE's selection criteria and its statements to the Congress, standing alone, leave the impression that this benefit is only achievable through the new production reactor program. In this respect, the August 1988 report to the Congress did not provide information that (1) for several years DOE has been funding research and development on an advanced commercial modular high-temperature, gas-cooled reactor; (2) the commercial modular high-temperature, gas-cooled reactor will provide the same major benefit as that expected from the new production reactor; and (3) the commercial version will receive certification by the Nuclear Regulatory Commission.

The Advanced Reactor Program Office under the Assistant Secretary for Nuclear Energy has initiated design work on such a reactor, and is working closely with the Nuclear Regulatory Commission on licensing and certification matters. Presently, the DOE commercial modular high-temperature, gas-cooled reactor program is ahead of its production reactor counterpart. In addition, owing to the involvement of the Nuclear Regulatory Commission and the commercial program's close ties to the commercial power industry, DOE's commercial program is likely to be better

[6]These are capital and pre-operational costs in 1988 dollars. The $2.2 billion estimate for the WNP-1 does not include the cost to acquire the partially completed reactor.

suited to transfer the technology to the commercial sector. However, the DOE commercial modular high-temperature, gas-cooled reactor program is for development, and as such, stops short of actual construction.

DOE has recognized that the two modular high-temperature, gas-cooled reactor programs are duplicative and in March 1989 issued a document coordinating the two efforts. The document identifies common design and development activities and also notes differences in the programs. However, the fact still remains that DOE is spending money in two different programs to develop a similar reactor technology. (See app. IV.)

Conclusions

DOE has recommended a two-reactor strategy that, at best, will provide tritium for national defense purposes in 12-1/2 years. The same strategy will produce a back-up reactor after 16 years that will provide 50 percent of the tritium necessary to meet national defense needs. Schedule uncertainties may further increase the time required to realize tritium from the recommended strategy.

Given the importance of tritium to our national defense and the need for a new production reactor or reactors, it is important that DOE thoroughly assess all available options for tritium production and provide clear and accurate information to the Congress concerning the options. DOE has not yet provided an in-depth or realistic analysis of schedule, costs, and benefits associated with an acquisition strategy.

On May 24, 1989, with your permission we testified on DOE's selection process for a new production reactor before the DOE Defense Nuclear Facilities Panel of the House Committee on Armed Services.[7] We recommended that DOE provide the Congress with an in-depth analysis of schedule, costs, and benefits of each option before reaching a final decision on the new production reactors—now scheduled for late 1991. We continue to support that recommendation.

Objective, Scope, and Methodology

The objective of this review was to assess the process used by DOE for selecting a new production reactor acquisition strategy. The major emphasis of the review focused on the accuracy and completeness of the information used by DOE in its decision process. In addition, we

[7] GAO's Views on DOE's New Production Reactor Selection Process (GAO/T-RCED-89-46, May 24, 1989).

addressed several specific questions relating to the new production reactor program. These included (1) the schedule risk of the various reactor technologies, (2) the accuracy and completeness of cost information, (3) technology transfer benefits, and (4) the remaining research and development associated with each technology.

We reviewed in detail the four candidate reactor technologies evaluated by DOE during its selection process. We also reviewed the cost information used to formulate estimates for the various options. We did not perform an in-depth review of all light-water reactor technologies for tritium production. However, we did include the Washington Nuclear Plant, Unit-1, in our review. This is a light-water reactor, and as such, has features similar to other light-water reactors.

In addition, we reviewed the work performed by the Energy Research Advisory Board and its various technical committees that addressed key technical issues related to each of the reactor technologies. We inter viewed the proponents of each reactor technology to determine the status and advantages and disadvantages associated with the technologies. The proponents included General Atomic Technologies (modular high-temperature, gas-cooled reactor), Westinghouse Corporation (heavy-water reactor and light-water react· ·/Washington Nuclear Plant, Unit-1), General Electric (liquid-metal reactor), and Rockwell International (liquid-metal reactor). In addition, we obtained some cost information from the proponent organizations. However, the majority of the cost information was obtained from DOE headquarter's officials and Martin Marietta officials at Oak Ridge, Tennessee. We also interviewed officials in DOE's New Production Reactor Project Office, and DOE officials at the Richland and Savannah River Operations offices.

Our review was performed between August 1988 and May 1989 in accordance with generally accepted governmental auditing standards.

Unless you publicly announce its contents earlier, we plan no further distribution of this report until 30 days after the date of this letter. At that time, we will send copies to the appropriate congressional committees and the Secretary of Energy. We will also make copies available to others upon request.

This work was performed under the direction of Keith O. Fultz, Director. He can be reached on (202) 275-1441. Other major contributors are listed in appendix VI.

Sincerely yours,

J. Dexter Peach
Assistant Comptroller General

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Abbreviations

DOE	Department of Energy
ERAB	Energy Research Advisory Board
HWR	heavy-water reactor
LMR	liquid-metal reactor
LWR	light-water reactor
MHTGR	modular high-temperature, gas-cooled reactor
NEPA	National Environmental Policy Act
NRC	Nuclear Regulatory Commission
WNP-1	Washington Nuclear Plant, Unit 1

Background on DOE's Efforts to Construct a New Production Reactor

The Department of Energy (DOE) is responsible for producing nuclear materials for U.S. weapons. To support this effort, DOE has built a nuclear weapons complex consisting of 15 major facilities in 12 different states. One of the primary components of this complex is the production reactors that can produce tritium and plutonium—two important ingredients used in nuclear weapons.

According to a DOE official, tritium represents a special case because it undergoes relatively rapid radioactive decay compared with other nuclear weapons components. Tritium's half-life—the amount of time necessary for one-half of the material to decay—is about 12-1/2 years. Other nuclear materials—such as plutonium—have half-lives of thousands of years. For this reason, tritium needs to be replenished frequently in weapons components.

At present, the only operable reactors capable of producing tritium in sufficient quantities are at DOE's Savannah River Site, Aiken, South Carolina. These reactors are referred to as heavy-water reactors (HWR) and produce tritium using target elements made partially of lithium-6.[1] The tritium target elements are placed beside reactor fuel elements containing fissionable uranium that is permitted to reach nuclear criticality—the phenomenon of nuclear fission. In this "irradiation" process, the lithium-6 in the target elements absorbs a neutron and becomes tritium. After irradiation, the tritium target elements must be left for several months in a cooling water pond. The tritium targets are then processed—tritium is extracted from the targets, purified, and prepared for national defense purposes. This process takes about 18 months under normal circumstances; however, according to the former Acting Director, Office of New Production Reactors, smaller quantities of tritium can be produced in as little as 6 months.

During 1988, the three production reactors at DOE's Savannah River Site were shut down because of safety-related problems. The reactors are over 30 years old and are experiencing aging effects that have reduced their operational reliability. According to the Secretary of Energy, the reliability of the reactors will continue to degrade during the 10 years DOE estimates it will take to construct new tritium production facilities.

DOE has recognized the need for a new production reactor to provide a continuing supply of tritium for nuclear weapons. It conducted several

[1]Tritium targets in the HWR are aluminum tubes containing lithium that are placed in a reactor and irradiated by neutrons, thus producing tritium.

studies, and in 1982 it unsuccessfully sought funding for a new production reactor. However, in December 1987 the Congress recognized the need for a new production reactor and requested that DOE prepare an acquisition strategy report for replacement production reactors.

To fulfill the congressional mandate, in January 1988 the Secretary of Energy asked the Energy Research Advisory Board (ERAB)[2] to assess four reactor technologies using criteria established by DOE and accepted by ERAB. The four technologies assessed were the (1) HWR, (2) modular high-temperature, gas-cooled reactor (MHTGR), (3) light-water reactor (LWR)—including the conversion of the Washington Nuclear Plant, Unit 1 (WNP-1) into a production reactor,[3] and (4) the liquid-metal reactor (LMR).

In addition to the ERAB study, a site evaluation team of DOE personnel performed an in-depth evaluation of three candidate sites. The sites evaluated were DOE's Savannah River Site; its Hanford Reservation near Richland, Washington; and its Idaho National Engineering Laboratory, near Idaho Falls, Idaho.

In August 1988, the Secretary of Energy sent the Congress a report entitled Acquisition Strategy for New Production Reactor Capacity. The report was based in part on the ERAB assessment and the site evaluation team's work. The report recommended

- building an HWR at the Savannah River Site capable of supplying 100 percent of the needed amount of tritium;
- building a MHTGR at the Idaho National Engineering Laboratory near Idaho Falls, Idaho, capable of supplying 50 percent of the needed amount of tritium;
- continue working on developing a new high-yield tritium target element for the LWR; and

[2]ERAB is an independent review board appointed by the Secretary of Energy to provide input to DOE on issues such as candidate technologies for new production reactors. A panel of 19 experts formed subpanels to concentrate on each technology. Various reports were drawn together from DOE and its subcontractors to form the background for the study. References to the Advisory Board or studies by the Advisory Board refer to all these reports.

[3]WNP-1 is a partially completed commercial light-water power reactor that was started by the Washington Public Power Supply System in 1973. Construction was halted in April 1982 because of a decrease in the demand for power and financial difficulties.

- continue working to resolve the institutional issues that could hamper DOE's ability to acquire WNP-1 and convert it to a reactor capable of producing both electricity and tritium.[4]

According to the report, the estimated cost of the recommended strategy was \$6.8 billion (\$3.2 billion for the HWR and \$3.6 for the MHTGR).[5] The HWR is expected to take about 10 years to construct and start operating. The MHTGR is scheduled to start operation, on a partial basis, 1 year later.

[4]On May 24, 1989, the former Acting Director of DOE's Office of New Production Reactors, told the DOE Defense Nuclear Facilities Panel of the House Committee on Armed Services that the issues that could hamper DOE in acquiring and converting WNP-1, located on DOE's Hanford Reservation in Washington State, were potential legal challenges resulting from local political opposition and concerns over the policy question of using a defense reactor to generate commercial power. Additionally, there are questions related to valuation of the facility, which could range from \$30 million (salvage value) to \$2.1 billion (total amount of outstanding bonds).

[5]These are capital and pre-operational costs in 1988 dollars.

Uncertainties Associated With DOE's New Production Reactor Schedule

This appendix discusses the schedule risk of each reactor technology, given the deteriorating condition of the tritium production reactors at the Savannah River Site.

DOE's New Production Reactor Schedule

To build new production reactors or to convert WNP-1 to a production reactor, DOE must first address the requirements of the National Environmental Policy Act (NEPA) of 1969 (P.L. 91-190),[1] according to DOE's Director, Office of NEPA Assistance. As required by NEPA, DOE must issue a formal Notice of Intent of its planned actions. The Director added that although a final decision has not been made, DOE put the NEPA process in motion in September 1988 by issuing a formal Notice of Intent to Prepare Environmental Impact Statements and to build the recommended new reactors and/or convert WNP-1 to a production reactor.

According to the Director, the next step under NEPA will be to prepare environmental impact statements. She added that the final environmental impact statement is scheduled to be issued in late 1991. Shortly thereafter, DOE will have to issue a formal Record of Decision, also required by NEPA, announcing DOE's final decision on which reactor(s) will be built and the location(s). Until the formal Record of Decision is issued, she said that all schedules and plans are termed "predecisional" and are subject to modification.

Also, according to the Director, after the Record of Decision is announced, DOE will begin the detailed plant design and submit requests to procure items that take a long time to acquire. Once these tasks are completed, reactor construction can commence. After construction is completed, fuel loading and testing would occur; and once testing is finished, the tritium production process could begin.

Heavy-Water Reactor

In April 1987, DOE's Deputy Assistant Secretary for Nuclear Materials told the Subcommittee on Energy and Water Development, Senate Committee on Appropriations, that a new production reactor could be built in 8 to 10 years. However, the schedule that DOE presented to the Congress in its August 1988 report shows that it would take about 11 years from the formal Notice of Intent to complete construction, fuel loading, and testing of the HWR. At that point—in late 1999—production of tritium could begin. However, since normal operations require about 18

[1]Numerous other statutes, amendments, and executive orders also apply, but, according to DOE's Director, Office of NEPA Assistance, NEPA provides the basic legislative guidance.

months to irradiate and process the tritium targets, the first full load of tritium from the new LWR would not be available until about mid-2001—about 12-1/2 years after the formal Notice of Intent.

Modular High-Temperature, Gas-Cooled Reactor

The MHTGR that DOE proposes to build near Idaho Falls, Idaho, will consist of four modules. Construction of the first module of the MHTGR is scheduled to begin in mid-1994. Also, according to the former Acting Director, Office of New Production Reactors, construction is due to end (with fuel loading) in mid-1998 with reliability testing to continue until mid-2000 when tritium production would begin. According to a proponent of the MHTGR and the Deputy Manager, Idaho National Engineering Laboratory, it would take about 6 months to irradiate and process the tritium targets; therefore, the first tritium would be available by the end of 2000, about 12 years after DOE issued the formal Notice of Intent. However, the first module of the MHTGR would produce only 12-1/2 percent of the needed amount of tritium.

If the first module of the MHTGR is successful, according to the former Acting Director, construction on the three remaining modules would begin in mid-2000. Tritium production from the three additional modules would begin in mid-2004—about 16 years after the formal Notice of Intent. At that point, the four modules would be capable of producing 50 percent of the needed amount of tritium. However, the schedule for producing tritium from the MHTGR is contingent on the availability of support facilities to fabricate fuel and tritium target elements and to extract the tritium from the targets after they are irradiated. The Savannah River Site has the only existing facilities for fabricating or processing tritium targets, but the deputy manager of the DOE Savannah River Operations Office told us that these facilities are not capable of extracting tritium produced in the MHTGR. Under DOE's present plans, construction of the new support facilities needed for operation of the MHTGR are not scheduled to begin until early 2001 and would not be in operation until mid-2005. Thus, unless other means are found, the MHTGR would not be able to begin operations until about mid-2005.

Light-Water Reactor/WNP-1

The Secretary's recommended strategy, as previously stated, also included the continuation of research and development on a new high-yield tritium target for the LWR. According to DOE's acquisition strategy report, the research and development work on the new target would be completed in early 1992. The strategy also included resolving the acquisition issues for the WNP-1 in early 1990.

However, the WNP-1 is already 63-percent complete as a commercial light-water power reactor, and according to the former Acting Director of DOE's Office of New Production Reactors, WNP-1 could be converted to a completed production reactor by about mid-1994.[2] Also, according to the former Acting Director, like the HWR, the LWR requires about 1-1/2 years to irradiate and process tritium targets. Thus, the first full load of tritium from WNP-1—which he said would be about 80 percent of goal quantity—would be available by early 1996. According to the Savannah River Operations Office's deputy manager, if WNP-1 was completed as a production reactor, the Savannah River Site would be capable of fabricating and processing LWR tritium targets and fuel, and depending on the target technology selected, could do so for WNP-1 until support facilities could be built at the Hanford Reservation.

Factors Raising Uncertainties in Schedules for Building New Reactors and Producing Tritium

As a part of ERAB's new production reactor study, a committee examined information supplied by the proponents of each reactor technology to determine whether the requirement of producing goal quantities of tritium on an urgent schedule at low risk could be met. ERAB concluded that two technical elements presented the primary risks that the acquisition schedule for any new reactor might face. Those two technical elements were

- stage of development in reactor design and tritium target technology, and
- the time required to complete the reactor safety review process.

Furthermore, our review of pertinent literature and discussions with our technical consultant indicate there are at least two other factors that raise questions concerning DOE's ability to build the reactors within the currently proposed schedules. Those factors are

- the impact of legal suits that intervenors may file challenging the reactors' compliance with NEPA requirements, and
- the actual time required to build nuclear reactors in the commercial private sector has been significantly greater than the time DOE has allowed in its schedule.

[2] This schedule assumes that the acquisition issues are resolved on time in early 1990, as reported in the acquisition strategy report.

Uncertainties Related to Reactor Design and Target Development

ERAB assessed schedule risks to determine potential delays in the 10-year schedule for each type of reactor, except for WNP-1, which was based on a 6-year schedule. The 10-year schedule for new reactors included design, construction, and testing of the reactor. It also included time to complete necessary research and development for MHTGR and LWR target development, as well as time to meet safety and environmental regulatory requirements.

ERAB evaluated the current stage of technology development for each reactor's design and tritium target to assess the risk that DOE would not be able to attain production of tritium on schedule. ERAB's assessments are shown in table II.1.

Table II.1: ERAB's Assessment of Reactor Design and Tritium Target Schedule Risk

	Degree of schedule risk	
Type of reactor	Reactor design verification risk	Tritium target development risk
Heavy-water	Medium	Low
Gas-cooled	High	High
Light-water	Medium	High
WNP-1	Medium	High
Liquid-metal	High	High

Heavy-Water Reactor

As shown in table II.1, the HWR's schedule was rated as facing a medium risk because of the need to verify the reactor design and a low risk in tritium target development. An ERAB subpanel stated that tritium production is the most challenging and least understood isotope production technology, and that the HWR is the recommended choice for tritium production. ERAB added that HWR technology is the most mature U. S. tritium production technology. The existing HWRS at the Savannah River Site have demonstrated their capability over many years of providing weapons material reliably and predictably, and their targets have proven reliable over time, although their age and condition have caused recent reliability questions.

ERAB stated that although a HWR design phase and safety review are needed, the reactor would be based on existing technology and, therefore, would be built with high confidence in meeting cost and schedule estimates, and performance specifications. According to DOE's HWR project manager, the new HWR would no doubt look different than existing Savannah River Site reactors because of an external containment dome, cooling towers, and other updated systems lacking in the existing reactors, but these are basically engineering refinements that do not affect the fundamental technology.

Modular High-Temperature, Gas-Cooled Reactor

ERAB stated that the MHTGR conceptual design has been completed and a preliminary design is underway. However, the concept must be further developed into a detailed design, including design of support facilities. Thus ERAB, as shown in table II.1, rated the MHTGR's stage of design as posing a high risk to the schedule. The MHTGR tritium target technology—also rated as a high risk—has been demonstrated, but unlike the target for the HWR it must be fully qualified through testing.

Light-Water Reactor/WNP-1

According to ERAB, as shown in table II.1, the schedule for a LWR, such as WNP-1, would face a medium design risk. It has the most mature technology base for commercial power production, considering the extensive industrial structure derived from support of both commercial electric power plants and naval reactors. However, the LWR lacks a proven tritium target technology, which ERAB rated as a high schedule risk. DOE's former Acting Director, Office of New Production Reactors, informed us that an existing target concept, which has been well-tested in the laboratory setting, is believed to be capable of producing about 80 percent of the needed quantity of tritium, and a new target concept currently under development could possibly provide as much as 110 percent of the needed quantity. However, he added that questions concerning whether these targets will work satisfactorily cannot be fully resolved until full-scale manufacturing and irradiation testing of the targets have been completed.

Liquid-Metal Reactor

According to ERAB as shown in table II.1, the LMR tritium production concept constitutes high schedule risks and would require evaluation and the selection of a specific approach for a production reactor. For example, the target technology requires conceptual design, evaluation, and testing.

Safety Review Process Uncertainty

Another factor that could delay the schedule of the reactors is the uncertainty surrounding the safety review process. Unlike DOE's reactors, commercial power reactors have been subject to the licensing requirements of the Nuclear Regulatory Commission (NRC). Although DOE's reactors are not subject to the NRC's regulation and review, the fiscal year 1989 National Defense Authorization Act (P.L. 100-456) requires the President to appoint a DOE Defense Nuclear Facilities Safety Board (Safety Board). According to DOE's former Acting Director, Office of New Production Reactors, the Safety Board, which was appointed in July 1989, will have responsibility for reviewing the safety of the new production reactor(s).

ERAB recognized in its report to the Secretary of Energy that the safety review process will pose a risk of schedule delays in building any new production reactor. ERAB said that the time required to complete the safety review process is uncertain because actual experience is limited, the process that will be used has not yet been determined, and such a process is inherently subjective. ERAB's assessments are shown in table II.2.

Table II.2: ERAB's Assessment of Safety Review Schedule Risk

Type of reactor	Safety review process risk
Heavy-water	Medium
Gas-cooled	High
Light-water	Low
WNP-1	Low
Liquid-metal	High

DOE is recommending proceeding with its new production reactor acquisition on an urgent schedule. It is making this recommendation even though the new Safety Board required by Public Law 100-456 is in its infancy, and the Safety Board's specific safety requirements have not been established for the new production reactors. DOE's former Acting Director, Office of New Production Reactors, stated, however, that the new production reactors shall "meet or exceed" standards set for the commercial nuclear industry. He also stated that, despite the future uncertainties in the review process, DOE made a reasonable schedule—one that should accommodate any external review.

According to the former Chairman of the NRC, prior to Public Law 100-456, there was no provision for formal, external, regulatory-type reviews of DOE's reactors, such as the NRC's reviews of private sector nuclear plants. Some external advisory studies of DOE's existing reactors have been conducted, such as a 1987 production reactor study by the National Research Council for the National Academies of Science and Engineering, and reviews by DOE's Advisory Committee on Nuclear Facility Safety. According to DOE's HWR project manager, these studies made an impact: they forced DOE to acknowledge problems at the facilities. However, these groups were advisory in nature and were not granted oversight or regulatory responsibility.

Heavy-Water Reactor

ERAB, as shown in table II.2, rated the safety review process as posing a medium risk to the schedule for the HWR. According to ERAB, no HWR has been subjected to a regulatory safety review. However, according to DOE's former Acting Director, Office of New Production Reactors, the HWR generally fits into the NRC's safety rules and regulations for LWR reactors because the physical plants are quite similar. Further, claims are made that the HWR is inherently safer than the LWR because it operates at lower pressures and lower temperatures than the LWR. Finally, the HWR may be viewed as safer because it will not produce steam to generate electricity and therefore will have fewer critical parts, such as pumps and heat exchangers.

However, one key issue that the new Safety Board will have to review for the HWR is nuclear fuel "recriticality." Recriticality is a safety question because the fuel for existing HWRs is composed of highly enriched uranium. According to the former Acting Director, Office of New Production Reactors, highly enriched uranium fuel is desirable for reactor efficiency; however, in a severe accident, the highly enriched fuel could melt, and the molten material could form a mass that could again become critical, resulting in uncontrolled nuclear fission, potentially leading to radiation releases to the environment.

One potential solution to the recriticality concern for the HWR is to use low enriched uranium fuel. In this respect, recriticality has not been a major problem in commercial LWRs because they use low enrichment fuel, which even in a meltdown is unlikely to result in recriticality.

As of March 1, 1989, DOE had not completed studies of the potential for recriticality and other serious accidents, according to the New Production Reactor Project Manager at Los Alamos National Laboratory in New Mexico. Those studies will be conducted by DOE's safety review team, headquartered at Los Alamos. According to the Los Alamos manager, the DOE team currently is reviewing the computer safety codes for the existing Savannah River Site reactors,[3] and this review will form the foundation for similar studies of safety for the new production reactor.

Modular High-Temperature, Gas-Cooled Reactor

ERAB, as shown in table II.2, rated the safety review process as posing a high risk to the schedule for the MHTGR. The MHTGR is considered an advanced reactor designed to be passively safe when normal cooling is lost. Five high-temperature, gas-cooled reactors—two in the United

[3]Computer safety codes are mathematical expressions used to evaluate a reactor's ability to deal with abnormal events.

States—have been licensed worldwide as commercial power reactors; however, none has been licensed either in the modular design or as a production reactor.

In July 1988—according to the Los Alamos Safety Review Chief—NRC staff concluded that the commercial version of the MHTGR is sufficiently safe that it does not need any emergency evacuation plan. Nonetheless, the NRC Advisory Committee on Reactor Safeguards has reported numerous safety issues that should be resolved concerning the commercial MHTGR. The Safety Review Chief added that computer safety codes have been developed for the commercial version but not for the production reactor version. Scientists at Los Alamos National Laboratory are studying safety codes for the production reactor version.

Light-Water Reactor/WNP-1

ERAB, as shown in table II.2, rated the safety review process as posing a low risk to the schedule for LWRs such as WNP-1. LWRs have been subjected to many years of extensive actual licensing reviews by NRC, and a variety of computer safety codes already exist for different types of LWRs, according to the Los Alamos Safety Review Chief. He added that the fact that reactor systems have been exposed to stringent reviews by NRC and the nuclear industry, would probably assist any new light-water production reactor in a review by the new Safety Board.

However, according to DOE's former Acting Director, Office of New Production Reactors, the LWR is not free from the risk of schedule delays resulting from the safety review process because no LWR has ever been constructed or licensed as a production reactor in this country, and safety codes would have to be developed for the selected fuel and targets.

Liquid-Metal Reactor

ERAB, as shown in table II.2, rated the safety review process as posing a high risk to the schedule for the LMR. This type of reactor is considered an advanced concept, offering inherent safety features, according to our technical consultant. Contractors have been working with NRC staff since 1984 to establish licensing features for the commercial version of the LMR. DOE has sponsored a program to facilitate design and construction of the LMR so that licensing will cause no delays for the prototype commercial version. Our technical consultant added that few safety analyses have been conducted to date on the production reactor version.

Uncertainties Related to Potential Environmental Challenges

Another uncertainty is the potential impact of lawsuits challenging the new production reactors' compliance with the requirements of NEPA and other environmental statutes. In January 1989, DOE submitted a report to the Congress entitled Actions To Shorten New Production Reactor Schedules, a requirement of Public Law 100-456 (National Defense Authorization Act, Fiscal Year 1989). In the report DOE recommended that the Congress formally recognize the national security need to replace the aged existing production reactors with new production capacity on an urgent schedule and that the Congress legislatively endorse DOE'S NEPA process for new production reactors.

The former Acting Director, Office of New Production Reactors, acknowledged in May 1989 congressional hearings that legal challenges could be a major schedule concern and that legislation could be required to assist DOE in overcoming such challenges. With the issuance of its formal Notice of Intent in September 1988, DOE began the process of developing the environmental impact statement for the candidate sites.

According to DOE's Director, Office of NEPA Assistance, scoping hearings for the environmental impact statement for each site were conducted between November 10, 1988, and December 8, 1988. The draft environmental impact statements are scheduled to be completed in late 1990, almost 2 years after the process began. According to DOE's former Acting Director, Office of New Production Reactors, the final statements are to be issued in late 1991, with the Record of Decision issued shortly thereafter. According to our technical consultant, although 2 years appears to be a realistic allowance, it should be noted that actions involving DOE's existing production reactors—have been challenged in court. As DOE acknowledged in congressional hearings, the threat of court challenges is a major schedule concern for the new production reactor.

According to a former Chairman of the NRC, DOE is likely to receive unprecedented environmental challenges not only from special interest groups, but governmental bodies as well. He noted, for example, that recently the governor of one state would not permit a trainload of nuclear waste from another state to cross his state's border. He added that this type of antinuclear attitude may be seen more in the future.

Private Sector Experience Raises Schedule Uncertainties

ERAB assessed the risk that the industrial base might be inadequate to meet the scheduled completion dates of the reactors. In assessing the capability of the industrial base, ERAB evaluated the extent to which the nuclear industry and its infrastructure can mobilize personnel, material, resources, and facilities to design, develop, manufacture, construct, and operate the new production reactor complex.[4] The ERAB's assessments are shown in table II.3. The industrial base was rated as a medium risk to the schedule of the HWR and as a high risk for the MHTGR.

Table II.3: ERAB's Assessment of Industrial Base Schedule Risk

Type of reactor	Industrial base risk
Heavy-water	Medium
Gas-cooled	High
Light-water	Low
WNP-1	Low
Liquid-metal	High

In our view, DOE's current construction schedule may be unduly optimistic when compared with construction periods for recently completed commercial power reactors in the United States, which have also depended upon the industrial base. New commercial nuclear power reactors completed in the United States between 1977 and 1980 took about 9 years from the start of construction to fuel loading. However, DOE expects to start fuel loading in the heavy-water reactor about 5-1/2 years after construction begins. Therefore, DOE is planning to build a reactor in about two-thirds the average time taken to build a commercial reactor.

[4] ERAB's assessment of industrial base schedule risk included the risk associated with construction of support facilities.

Completeness and Accuracy of Cost Information

This appendix discusses the accuracy and completeness of DOE's cost information and the extent to which cost was considered in the strategy DOE recommended for the new production reactors.

In December 1987, the Congress directed the Secretary of Energy to prepare an acquisition strategy report for new production reactors. The Secretary's report was to include a comprehensive comparative financial analysis and cost estimate for each of the reactor technologies considered. In addition, the report was to provide an overall cost analysis of the use of different reactor technologies at one or more sites.

DOE used a two-pronged approach to address this congressional directive. First, DOE contracted with Martin Marietta Energy Systems, Inc. (Martin Marietta), its operations contractor at the Oak Ridge National Laboratory in Oak Ridge, Tennessee, to perform a cost evaluation of the four reactor technologies being considered. Second, Martin Marietta, under DOE's close direction, formulated and determined the cost of 18 different options using various combinations of reactor technologies and sites.

The results of these two efforts represent the basic cost information and analysis provided to the Congress as part of the August 8, 1988, DOE acquisition strategy report. The following sections briefly discuss the Martin Marietta cost evaluation, the 18 options, and the extent to which cost was considered in the recommended strategy.

Martin Marietta Cost Evaluation

Martin Marietta prepared line item cost estimates for the four technologies (HWR, MHTGR, LWR, and LMR) under consideration and the WNP-1 completion. The estimates included both capital and life-cycle costs of each technology. In addition, each reactor technology was assumed to be full-size, or capable of producing 100 percent of the tritium needed, and would take 10 years to complete.

Because some of the technologies being considered did not have detailed design, it was not possible to make a typical engineering cost estimate based on design quantities of special items such as cable and pipe. Therefore, Martin Marietta used information provided by (1) the proponents of the technologies, (2) a 1985 cost study prepared for DOE by the Bechtel National Corporation, and (3) DOE officials located at the three proposed sites (Hanford, Idaho, and Savannah River). In addition, in early March 1988, Martin Marietta received briefings on cost and schedule from the proponents of each technology.

After formulating initial cost information, Martin Marietta began a process of "normalizing" or assuring that the cost for each technology would reflect a true comparison of differences in technologies, design, and sites. Martin Marietta updated the cost estimates several times, in response to revisions suggested by the proponents. Beginning in mid-March 1988, each proponent was provided opportunities to suggest revisions of its own and of others' estimates to Martin Marietta. DOE officials at the three proposed sites also provided expertise in estimating costs, especially for required support facilities at their respective sites.

Martin Marietta's efforts resulted in line item cost estimates, such as reactor design, construction, and fuel fabrication, for each proposed technology at each site considered, as well as summaries of capital and life-cycle cost estimates of all technologies. The final cost evaluation report, entitled NPR Capacity Cost Evaluation, was published in July 1988. Table III.1 shows the results of the Martin Marietta cost evaluation.

Table III.1: Martin Marietta Estimated Cost by Technology and Site (Constant 1988 Dollars in Billions)

Reactor technology	Capital	Preoperations	Operations[a]	Net life-cycle cost[b]
Heavy-water reactor				
Hanford	$4.4	$.2	$17.0	$21.6
Idaho	4.0	.2	16.3	20.5
Savannah River	3.0	.2	16.5	19.7
Modular high-temperature, gas-cooled reactor				
Hanford	4.9	.5	20.2	18.8
Idaho	4.3	.5	19.1	17.0
Savannah River	4.3	.5	19.4	15.2
Light-water reactor				
Hanford	4.6	.5	17.1	16.0
Idaho	3.9	.5	16.6	14.7
Savannah River	3.8	.5	17.1	12.4
Liquid-metal reactor				
Hanford	3.8	.7	17.6	18.2
Idaho	3.7	.7	17.5	18.0
Savannah River	3.7	.7	17.5	16.7
WNP-1				
Hanford	1.7	.5	16.7	12.1

[a]Includes maintenance and operations costs for 40-year life.

[b]Total of all costs (capital, preoperations, and operation) less revenues from the sale of steam for electric generation.

Preparing Cost Estimates for the 18 DOE Reactor Options

Public Law 100-202 required that DOE analyze the use of alternative reactor technologies at one or more sites using the most current information, including overall costs and capital and life-cycle costs, when considering the sale of steam for electric generation. Between early July 1988 (publication of the Martin Marietta evaluation) and August 8, 1988 (the Secretary of Energy's report to the Congress), DOE formulated 18 different options for a new production reactor strategy. The 18 options and their estimated costs are shown in table III.2.

Table III.2: Cost Summary of 18 Reactor Options Submitted to the Congress by DOE (Constant 1988 Dollars in Billions)

Option number	Reactor	Percent of goal	Site	Capital	Preoperations	Operations[a]	Net life-cycle cost[b]
1	HWR	100	Savannah River	$3.0	$.2	$16.5	$19.7
2	HWR	100	Savannah River	3.0	.2	16.5	19.7
	WNP-1	50	Hanford	1.7	.5	16.7	12.1
3	HWR	75	Savannah River	2.6	.2	16.5	19.3
	LWR	75	Hanford	3.9	.5	17.1	16.9
4	HWR	50	Savannah River	2.1	.2	16.5	18.8
	LWR	50	Hanford	3.3	.5	17.1	17.8
5	HWR	75	Savannah River	2.2	.2	8.9	11.3
	HWR	75	Savannah River	2.2	.1	8.9	11.2
6	HWR	50	Savannah River	1.7	.2	8.9	10.8
	HWR	50	Savannah River	1.7	.1	8.9	10.7
7	HWR	75	Savannah River	2.6	.2	16.5	19.3
	MHTGR	75	Idaho	3.7	.5	18.8	17.9
8	HWR	50	Savannah River	2.1	.2	16.5	18.8
	MHTGR	50	Idaho	3.1	.5	18.4	18.6
9	HWR	75	Savannah River	2.6	.2	16.5	19.3
	WNP-1 or	50	Hanford	1.7	.4	16.7	12.0
	MHTGR	25	Idaho	1.3	.5	12.0	12.1
10[c]	HWR	100	Savannah River	3.0	.2	16.5	19.7
	WNP-1 or	50	Hanford	1.7	.4	16.7	12.0
	MHTGR	25	Idaho	1.3	.5	12.0	12.1
11[c]	HWR	100	Savannah River	3.0	.2	16.5	19.7
	WNP-1	50	Hanford	1.7	.4	16.7	12.0
12[c]	HWR	100	Savannah River	3.0	.2	16.5	19.7
	MHTGR	25	Idaho	1.3	.4	12.0	12.0
13[c]	HWR	100	Savannah River	3.0	.2	16.5	19.7
14	HWR	50	Savannah River	2.1	.2	15.5	18.8
	LMR	50	Idaho	2.6	.7	16.8	18.1
15	MHTGR	100	Idaho	4.3	.5	19.1	17.0
16	WNP-1	100	Hanford	1.7	.5	16.7	12.1
17	HWR	100	Savannah River	3.0	.2	16.5	19.7
	MHTGR	50	Idaho	3.1	.5	18.4	18.6
18[c]	HWR	100	Savannah River	3.0	.2	16.5	19.7
	MHTGR	50	Idaho	3.1	.5	18.4	18.6

[a]Includes maintenance and operations costs for 40-year life.

[b]Total of all costs less revenues from the sale of steam for electric generation.

[c]These options appear identical because we omitted DOE target research and development funding, totaling less than $150 million, for the MHTGR and LWR (WNP-1).

As shown in table III.2, most of the options consisted of two reactor technologies, with each located at a different site. However, some options show one reactor at one site, and two of the options show two reactors of the same technology located at one site. In addition, almost all the options show "scaled down" or less than full-size (100 percent) versions of the various technologies.

To provide cost estimates for the options, DOE used the cost information provided by Martin Marietta for the full-size reactor technologies at the various sites and applied a scaling formula to those costs, using scaling factors provided by Martin Marietta. DOE, however, did not apply the scaling factors to all cost categories. DOE applied scaling factors only to the capital cost and did not make any adjustments to the other costs, except for small adjustments in the cost of fuel for the scaled-down reactors.[1] In other words, the operating costs, which make up about 80 percent of total cost, basically remain the same whether the reactor is full- or half-size.

During our review we applied the Martin Marietta scaling factors to the operations cost and found that the net life-cycle cost for 12 of the options showed decreases ranging from $500 million to $7 billion. Four of the options remained the same, and four showed increases ranging from $1 billion to $6 billion.[2]

The method DOE used in scaling the 100-percent sizes down to smaller sizes to create the various options produced some unexpected results. In addition, there appear to be discrepancies scattered throughout the table or summary presented to the Congress. For example, in the case of option 5, DOE assumed two scaled-down reactors (75 percent) could be operated for nearly the cost of one full-size reactor. In addition, several arithmetical errors were contained in the information sent to the Congress. However, we have made the corrections to the information presented in table III.2.

In a related matter, after calculating the cost of a half-sized MHTGR to be built on a 10-year schedule, DOE decided to increase the schedule to 16 years. Before announcing its August 1988 recommendation to construct

[1]For example, when going from a 100-percent to a 50-percent WNP-1, only one-half the fuel would be needed on an annual basis over a 40-year period. In this particular case that is a lower cost of about $1 million per year, or $40 million over the life of the reactor.

[2]The total number of options cited equals 20 rather than 18, because options 9 and 10 contain 2 dual reactor combinations. (See table III.2.)

a half-sized MHTGR, DOE did not perform a detailed cost analysis to determine whether the estimated cost would increase or decrease. In early 1989 Martin Marietta conducted such an analysis for DOE to measure the effects of the MHTGR schedule extension on cost in terms of both constant dollars and dollars discounted to determine present value.[3] However, DOE did not allow Martin Marietta to use reasonable and consistent assumptions in its calculations. Therefore, we feel the question of whether estimated cost would increase or decrease is still unanswered.

Cost as a Basis for Selection

DOE did not use its cost estimates as a meaningful criterion in recommending an acquisition strategy to the Congress. DOE officials testified at July 1988 hearings before the Senate Energy and Water Development Subcommittee that cost estimates were not a "discriminator"[4] in reaching its preliminary recommendation. DOE officials stated that a major "discriminator" was the assurance of long-term tritium production capacity. It appears that at each step DOE directed that costs be calculated for options it chose based on "discriminators" other than cost, rather than using true cost-benefit analysis to recommend cost-effective options that would meet production concerns. In this respect, DOE's recommended option has the highest total net life-cycle cost among all options it considered.

In its July 1988 report comparing feasibility of reactor technologies, ERAB noted that it reviewed reactor proponents cost estimates. However, ERAB stated that widely differing cost bases and lack of a reactor project definition made cost estimates too uncertain to use except for general qualitative comparisons. Therefore, ERAB did not give significant weight to cost factors in its comparative assessment of the technologies.

[3]Costs incurred or recovered in the future should be discounted by an appropriate rate of interest to determine the amount of money, if invested today at a selected interest rate, sufficient to meet expected future funding needs.

[4]The term discriminator, as used here, is the same as criterion. DOE established specific evaluation criteria—safety and environment, ability of technology to produce tritium, cost, and several others.

Nuclear Production Reactors' Technology Transfer Capability

This appendix discusses the potential civilian technology transfer benefits to be gained from the various new production reactor technologies. In this respect, DOE reported that all of the reactor technologies offer varying degrees of technology transfer benefits. In addition, one of the two technologies recommended—the MHTGR—was presented to the Congress as having the potential to significantly advance nuclear technology for power production. The other reactor selected, the HWR, was cited as having the most mature technology for tritium production and demonstrated target technology. We noted, however, that another DOE program—not associated with the new production reactor program—has been and continues to be directed at providing the same kind of benefits to the private sector, and in the case of the MHTGR may do so sooner than the production reactor program.

Technology Transfer as a Selection Criterion

One of the selection criteria for the new production reactor was contributions to the advancement of nuclear technology. The ERAB report stated, "The board believes that a combination of technologies, including advanced technologies, offers a unique opportunity that should be carefully considered, even at increased costs, for a step increase in reactor safety and a substantial improvement in commercial reactor technology." Although any of the four technologies will provide a "state-of-the-art" plant, according to DOE officials, the two advanced reactor technologies, the MHTGR and the LMR, will provide additional features, such as passive decay heat removal and inherent safety and modularity.

Further evidence regarding the apparent significance of technology transfer is in a document DOE provided to congressional committees to support the Secretary's recommendation for a new production reactor. In the August 1988 report to the Congress, DOE indicated the design and construction of the MHTGR offer the potential to significantly advance nuclear technology for power production. The document also points out that the reactor technology will take advantage of new features such as robotics, instrumentation control, fiber optics, and safety procedures.

Congress Not Fully Informed on DOE Technology Transfer Program

DOE's selection criteria and its statements to the Congress, when considered alone, leave the impression that technology transfer benefits are only achievable through pursuit of a new production reactor, particularly the MHTGR. The August 1988 report to the Congress did not provide information that (1) DOE is funding research and development on two advanced commercial reactors, including a MHTGR, (2) the commercial MHTGR will provide the same advanced nuclear technology as that expected from the new production reactor program's MHTGR, and (3) the commercial MHTGR will receive NRC certification.

In addition, DOE's new production reactor program does not include technology transfer as part of its mission. According to DOE's new production reactor program officials, the commercial side of DOE will be the conduit to make any technology transfer information available to the private sector. DOE commercial research and development officials stated that the commercial MHTGR, which has been in development since the 1950s, will advance technology transfer more than a production MHTGR version because the commercial version will be a licensed, NRC-certified plant.

DOE's Program for Civilian Technology Transfer

Since the late 1950s, DOE has been funding civilian reactor development for light-water and advanced reactors under its Advanced Reactor Research and Development program. In August 1985, the Secretary of Energy asked ERAB to establish an ad hoc panel to review DOE's "Strategic National Plan for Civilian Nuclear Reactor Development." The ERAB report issued in October 1986 proposed changes in the following areas: (1) improve existing light-water electric generating reactors; (2) develop two advanced nuclear reactors (MHTGR and LMR) that would be more efficient, affordable, and economically competitive than the LWR; and (3) fund state-of-the-art engineering at DOE national laboratories and universities. The report specifically recommended committing at least $200 million annually to programs for development of advanced reactors for civilian use.

The improvements recommended by ERAB for the LWRS included programs to improve plant operating efficiencies by reducing plant outages, increasing electric plant operating times, reducing radiation exposure to plant operators, reducing the volume of waste produced, and reducing fuel cycle costs.

The goal of DOE's Advanced Reactor Research and Development program is to develop and demonstrate LMR and MHTGR systems. DOE's program seeks to verify that these alternative systems do, in fact, provide the promised breakthroughs, that modular plants can overcome the economies of scale enjoyed by large plants, and that these designs are at least as, if not more, licensable by NRC than competing LWR designs.

Over the last 5 years DOE has been appropriating the amounts shown in table IV.1 for its civilian reactor development.

Table IV.1: Civilian Reactor Appropriations (1985-89)

Dollars in millions

Fiscal year	MHTGR	LMR	Facilities	Total
1985	$31.8	$126.9	$133.9	$292.6
1986	30.2	96.6	131.2	258.0
1987	19.9	55.2	126.9	202.0
1988	22.7	68.8	117.0	208.5
1989	20.0	60.5	118.2	198.7

DOE awarded four 5-year contracts between September and December 1988 for one commercial MHTGR and one contract for a commercial LMR. The four MHTGR contracts, totaling about $411 million, are for design activities. Three contracts are to move from conceptual design through preliminary and final design in support of NRC design review and approval of the MHTGR concept. The fourth contract is for architect and engineering design studies in support of the MHTGR balance of plant engineering. A prospectus has been prepared to find one utility company to pay for construction and operation of the plant. As of July 1989, a utility company has agreed to do a feasibility study for a lead MHTGR plant. The vice president of the utility company advised the House Subcommittee on Energy, Research and Development in March 1989 that the company was undertaking a MHTGR lead project study during 1989 to determine the feasibility of using utility personnel to operate the plant as well as consideration of several ownership arrangements, power use options, and siting locations. However, the utility's plans to construct the MHTGR are contingent on considerable financial support from the federal government.

The LMR program includes a 3-year contract for research and development, and advanced conceptual design for $46.7 million. If extended, the contract allows a final 2-year, $44.4-million option for preliminary design of an LMR power plant.

In addition to the development of the commercial MHTGR and LMR technology, DOE has a technology transfer program that encompasses state-of-the-art reactor design and operation. This program includes such advanced nuclear concepts as

- an advanced controls program incorporating advances in artificial intelligence, man-machine interface, and information management;
- advanced instrumentation for reactor systems;
- advanced shielding materials and methods;

- high-temperature materials and structural design; and
- robotics for reactor systems.

DOE's Future Plans for Advanced Commercial and Production Reactors

DOE has been funding the development of one MHTGR for the commercial electric utility market and one for the production of tritium. The work on the commercial MHTGR will lead to the development of final plant designs in support of NRC design review and approval of the MHTGR concept. The work on the production MHTGR will lead to an advanced nuclear reactor that will provide tritium and generate electricity. Under the MHTGR master schedule of April 18, 1989, assuming a buyer is found by late 1990 or early 1991 and federal funding is forthcoming, completion of the first module of the commercial MHTGR plus a year of testing is expected about March 2000, whereas the first module and a year of testing for the production MHTGR is expected in October 2000. The complete four-module commercial MHTGR is scheduled for completion by March 2002 and the production MHTGR by January 2005. According to DOE officials, one of the main differences between the two nuclear plants causing the time disparity is that DOE requires the production MHTGR to have a radiation containment facility.

On March 2, 1989, in order to assure coordination of research and development work, DOE officials of the commercial MHTGR and of the production MHTGR programs issued a document integrating the two programs. The DOE plan details common design/development activities of the two programs and also shows differences.

DOE has also been funding research and development on an advanced nuclear LMR for the production of electricity. The LMR technology is capable of providing burn-up of long-lived waste materials and is a "breeder" of fuel. That is, it can produce more nuclear fuel material than it consumes.

Even if neither of these two advanced technologies is selected for the new production reactor, they will not necessarily be lost, because DOE in recent years has continued to allocate about $80 million of its $200 million annual research and development budget for MHTGR and LMR work.

Specific Technology Transfer Benefits of Production Reactor Technologies

Specific benefits expected from each of the four technologies are presented below.

HWR

The HWR was cited by the ERAB report as a technology that can contribute to nuclear advancements primarily through development and testing in specific areas such as robotics, refueling automation, in-core instrumentation, and redundancy in safety systems. The ERAB report, however, said, "Major contributions to overall commercial reactor system development are not expected."

LWR

The special water reactor and the small advanced special water reactor are advanced versions of LWRs. Contractor officials believe both plants will improve on nuclear technology. The special water reactor will employ new technology in refueling activities, component inspection, and tritium recovery. It would also utilize an advanced instrumentation and control system. In addition to the "state-of-the-art" plant achievements, the special water reactor design includes some advanced safety systems, such as hydrogen igniters, to prevent build-up of hydrogen, and some passive cooling features.

The small advanced special water reactor will demonstrate a partially modular small reactor (600 megawatts electric) with full passive safety systems. In addition, it would utilize the same state-of-the-art instrumentation and control systems as the special water reactor or other nuclear technologies.

LWR/WNP-1

DOE has under development a light-water tritium target technology. If converted to tritium production, the WNP-1 reactor, which is presently 63-percent complete, will use this new target technology. In addition a converted WNP-1 would be a state-of-the-art nuclear plant for robotics, control, and other new technological concepts.

MHTGR

The MHTGR is a second-generation nuclear power system. Based on technology developed and demonstrated in the United States and the Federal Republic of Germany, the system makes use of refractory-coated nuclear fuel, helium gas as an inert coolant, and graphite as a stable core structural material. The safety and protection of the plant investment is provided by inherent and passive features and does not depend upon operator actions or the activation of engineered systems. The design of the MHTGR is being developed jointly by private companies and DOE.

LMR

The LMR is a next-generation, sodium-cooled, modular nuclear power reactor. The LMR offers the following unique technological advantages over competing reactor concepts:

- Enhanced safety by use of passive safety features, metal fuel, and elimination of more complex, less reliable engineered safety systems.
- Improved nuclear waste disposal. The LMR will burn up its own long-life radioactive wastes. This burn-up will reduce the effective lifetime of nuclear waste storage from thousands of years to a few hundred years.
- Production or breeding of substantially more nuclear fuel material than it consumes, according to experts.

Benefits Associated With Constructing Two Reactors as Opposed to One

The primary objective of the new production reactor program is to provide tritium for national defense purposes. Thus, although electric power generation is attractive because it provides lower life-cycle costs and benefits beyond tritium production, these are not criteria that have to be met. In this respect, the HWR, which is the most proven tritium-producing technology, does not produce electric power because it is low-temperature and low-pressure. All the other reactor technologies evaluated are capable of producing electric power and would thus present a benefit beyond tritium production. In addition, life-cycle costs for these reactors would be decreased.

As previously noted in appendix III, cost information is not clear. However, it is certain that the construction and operation of two production reactors will cost more than one. In this connection, revenues from the sale of steam or electricity could be used to lower the cost of a power-producing reactor technology.

In summary, if two reactors are deemed necessary, it would seem prudent and cost-beneficial to select at least one technology that would produce electric power. However, if only one reactor is needed, the ability of the technology to provide an assured supply of tritium should be a primary consideration.

Research and Development Remaining on the Candidate Reactor Technologies

This appendix describes the remaining research and development activities necessary for each of the candidate reactor technologies and their estimated associated costs.

In its August 1988 report to the Congress, DOE estimated the remaining research and development costs for each of the reactor technologies as shown in table V.1.

Table V.1: DOE's Estimated Research and Development Costs for Technologies Evaluated

Dollars in millions

Technology	Cost
Heavy-water	$60
Gas-cooled	172
Light-water	140
WNP-1	141
Liquid-metal	305

With the exception of WNP-1, all candidate technologies either were not designed or were in preliminary design stages at the time of our review. The estimates will be revised as designs are refined. Presented below is a description of the research and development activities remaining on each of the technologies.

Heavy-Water Reactor

Since its August 1988 report to the Congress, DOE revised its $60-million estimate to $72.6 million through fiscal year 1990, an increase of about $12 million. The plan provides for early work on assessing safety and design technology and includes work to (1) build a wider knowledge base regarding HWR production reactor technology and (2) determine the remaining research and development needed. The research and development needed after fiscal year 1990 is to be determined on a year-by-year basis as the results of preliminary design, analysis, testing, and development of major reactor components progress.

Modular High-Temperature, Gas-Cooled Reactor

The research and development activities remaining in early 1987 were fuel particle development; validating strength and corrosion characteristics of the graphite base; metal performance testing; development and testing of control materials and system component technology; and target development and demonstration. In March 1989, DOE officials told us that they would further refine the $172-million related costs for the

MHTGR. DOE plans to revise the cost and amount of research and development needed by the end of fiscal year 1989.

Light-Water Reactor, Including WNP-1

The remaining research and development activities are building and testing the tritium target technology, and verifying the tritium extraction process. This work includes performing tests of the targets in a reactor. The WNP-1 estimated cost of $141 million may be revised because a recriticality study no longer needed was eliminated.

Liquid-Metal Reactor

The principal remaining research and development activities planned for the estimated $305 million include (1) reactor refueling systems, (2) thermal/hydraulic behavior of primary sodium system, (3) steam generators, (4) shutdown heat removal systems, (5) containment system, (6) sodium coolant cleanup systems, (7) target assembly mechanical design, (8) seismic design, and (9) fuel cycle.

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