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Consideration of Accelerator Production of Tritium Requires R&D

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Resources, Community, and
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The Honorable Mike Synar
Chairman, Environment, Energy, and
Natural Resources Subcommittee
Committee on Government Operations
House of Representatives

The Honorable Brock Adams
United States Senate

This letter responds to your request for updated information on a concept to produce tritium with a particle accelerator and on the Department of Energy's (DOE) intentions concerning accelerator development. DOE is responsible for producing tritium, a crucial nuclear weapons material that gradually decays and must be replenished to maintain weapon readiness. DOE has traditionally produced tritium in its nuclear reactors, but the reactors are aging and the extent of their useful life is unknown. An accelerator, which would use a high-energy beam to produce tritium, has been proposed as an alternative to building new reactors because the accelerator offers potential safety and environmental advantages. As agreed with your offices, we are providing information on (1) the current status of the accelerator concept and (2) the extent to which DOE has considered the accelerator concept.

Results in Brief

Since its proposal in 1989, by scientists at Los Alamos and Brookhaven National Laboratories, as an alternative for new tritium production capability, the accelerator production of tritium concept has received relatively little funding from DOE. As a result, the full extent of the accelerator's capability remains unknown. Studies in 1990, by both GAO [1] and the Energy Research Advisory Board (ERAB),[2] found that the accelerator concept offered potential safety and environmental advantages and was technically feasible, but it required further development because of the immaturity of the technology. However, DOE did not establish an accelerator development program. Funding for the accelerator concept was limited to less than $1 million in Los Alamos discretionary funds.

[1] Nuclear Science: The Feasibility of Using a Particle Accelerator to Produce Tritium (GAO/RCED-90-73BR, Feb. 2, 1990).

[2] Accelerator Production of Tritium (APT) (DOE/S-0074, Feb. 27, 1990). The Energy Research Advisory Board was an independent review board appointed by the Secretary of Energy to advise DOE on technical issues.

DOE did not pursue development of the accelerator concept because it did not believe sufficient time existed to develop the concept, given the immaturity of the technology and the urgency with which DOE believed new tritium production capacity would be needed. However, reductions in the nuclear weapons stockpile have lessened the urgency for new tritium production capacity and provided DOE more time to study the accelerator. DOE recently sponsored a re-evaluation of the accelerator concept by the JASON Group.[3] The Group's January 1992 report recommended that the accelerator concept be considered as an alternative to reactors in the decision on new tritium production capacity scheduled for August 1993. In addition, the Group's report recognized that further consideration of the accelerator will require a funded research and development program.

Background

DOE is responsible for researching, developing, producing, and testing nuclear weapons for the Department of Defense. These responsibilities include producing tritium—a crucial nuclear material used to enhance the explosive power of nuclear warheads. Because tritium decays at a rate of 5.5 percent each year, existing weapons must be resupplied with tritium in order to maintain their readiness. The three production reactors at DOE's Savannah River site in South Carolina are the nation's tritium production source for defense purposes. However, these reactors were shut down in 1988 for extensive upgrades and repairs. DOE has been relying on existing tritium supplies, supplemented by tritium recovered from retired weapons. Currently, DOE is seeking to restart only one of the reactors—the K reactor. In December 1991 DOE began restart tests of the K reactor at Savannah River but then stopped the tests to address problems with tritium-contaminated water leaking from its heat exchangers. DOE plans to continue tests this year and then shut down the reactor for connection to a new cooling tower. Although DOE officials do not believe there are any life-limiting conditions related to the K reactor, the reactor is already over 35 years old and the extent of its useful life is uncertain.

Faced with concerns about the existing reactors' reliability, the Congress, in 1987, directed DOE to develop an acquisition strategy for new production reactors. In 1988 DOE, on the basis of an Energy Research Advisory Board assessment, developed a preferred strategy of constructing two new production reactors—a Heavy Water Reactor with the capacity to provide 1988 goal amounts of tritium and a Modular High-Temperature Gas-Cooled

[3] The JASON Group, a collection of eminent U.S. scientists, was established in the late 1950s to provide assistance to the government on national policy involving technical or scientific issues.

Reactor to provide half that capacity.[4] DOE planned to build these reactors by the year 2000 on an urgent schedule. However, in February 1991 DOE amended its strategy because of budget constraints and sought to build just one full-sized reactor. DOE planned to decide which reactor would be built in December 1991 after completion of an environmental impact statement.

In September 1991 the President announced significant reductions in the nation's nuclear weapons arsenal. In November 1991, in view of the announced cutbacks, the Secretary of Energy announced a delay in the decision, scheduled for December 1991, to build a new production reactor. In addition, on December 16, 1991, the Secretary announced plans to re-evaluate the feasibility of using an accelerator to produce tritium. The Secretary plans to incorporate the decision on new tritium production capacity into a broader programmatic environmental impact statement (PEIS) on the reconfiguration of the entire nuclear weapons complex, which is scheduled to be completed by August 1993.[5] The Secretary believes this change will ensure a more deliberative decision that reflects the newly defined defense needs and environmental concerns. These needs continue to change as the President announced further nuclear weapons reductions in his January 1992 State of the Union address. The bulk of these reductions are contingent on whether the nations that formerly comprised the Soviet Union make similar reductions; however, the reductions have the potential to further decrease drastically the size of our nuclear stockpile and the need for tritium.

Accelerator Production of Tritium Concept Remains Undeveloped

Accelerators have been used for various scientific experiments for more than 50 years, and proposals for producing tritium with an accelerator were first made over 30 years ago. While using an accelerator to produce tritium has been thought to have safety and environmental advantages over reactors, the concept has not been developed primarily because DOE relied on proven reactor technology for tritium production and because a number of technological questions had not been explored and resolved. Although recent advances in accelerator technology have renewed the interest in accelerator production of tritium, the concept has remained undeveloped.

[4]The goal amount is the quantity of tritium needed to meet all national defense needs.

[5]In January 1991 DOE's Nuclear Weapons Complex Reconfiguration Study outlined the development of a modernization plan for the complex. The complex consists of 13 government-owned, contractor-operated facilities that support the nuclear deterrent policy of the United States. DOE is currently developing the accompanying environmental study, a programmatic environmental impact statement that will provide more detail on plans for the future complex.

First developed in the 1930s for research purposes, a particle accelerator is a device that uses basic laws of electromagnetism to increase the energy of charged particles, such as protons. Accelerator designs vary, but all employ certain principal components: a source of particles to be accelerated, a series of metal structures that establish electromagnetic fields to accelerate the particles, one or more beams of the accelerated particles, and a collision or target chamber.

The use of an accelerator to produce tritium offers potential safety and environmental advantages over reactors. Traditional reactor production of tritium employs uranium fuel elements interspersed with aluminum tubes containing lithium. In the reactors, neutrons are generated by the fission, or splitting, of the uranium fuel. Some of these neutrons are then absorbed by the lithium, thus forming tritium. In general, the accelerator and a neutron-generating target would replace the reactor as the source of free neutrons for tritium production. The accelerator would bombard a target with accelerated particles to generate free neutrons for tritium production. In comparison to a reactor, the absence of fission in the accelerator would result in lower amounts of radioactive waste and substantially reduce the possibility of a loss-of-coolant accident resulting in the escape of radioactive materials.

Although proposals to use an accelerator for tritium production have been made since the 1950s, the feasibility of using nuclear reactors for producing tritium became established, and no facility was constructed to test the feasibility of an accelerator production system. However, in a March 1989 report, scientists at DOE's Los Alamos and Brookhaven National Laboratories noted that accelerator research advances for the Strategic Defense Initiative in the 1980s were applicable to the type of accelerator needed for tritium production. In our February 1990 report (see footnote 1), we noted that the concept presented fewer safety and environmental concerns than reactors and was technically feasible but that it had uncertainties that would require engineering development. Also, in February 1990 ERAB reported that an accelerator was an attractive alternative to reactors because it offered significant environmental and safety advantages. ERAB concluded that the accelerator concept was technically sound but that a strong development program was needed, especially on the target system.

Because of the conceptual nature of an accelerator-based system for tritium production, the full extent of the system's capabilities was unknown. For example, ERAB was concerned that the target was the least-developed component of the accelerator system. ERAB noted that the highest safety and environmental risk was associated with processing the target to remove the tritium. In addition, DOE had specific concerns that the power needed to produce 1988 goal amounts of tritium—about 900 megawatts—would require an expensive commitment of electric power either through a long-term contract with a utility or a new power plant. Meeting this power requirement could offset the accelerator's advantages over reactors—especially if a new power plant was required. Finally, although the scope of a new production reactor has been limited to tritium production, DOE believes it may be required to produce other nuclear material, such as isotopes for National Aeronautics and Space Administration (NASA) programs. DOE questioned the ability of an accelerator to produce other materials without losing its safety and environmental advantages because fissionable material and radioactive waste would be involved.

Accelerator proponents sought to address concerns raised about the accelerator production of tritium concept. For example, scientists at Los Alamos proposed a new target concept that uses the decay product of tritium, helium-3, as the neutron absorber (instead of lithium) and converts it back into tritium. The target system proponents claim that the new target concept offers additional safety and environmental advantages through continuous processing and fewer waste disposal problems. In addition, DOE has been separating and storing helium-3 from its nuclear weapons and has built up a substantial inventory.[6] (See app. I for a description of the accelerator production of tritium concept.) In producing other nuclear materials, the proponents claim that an accelerator is flexible in producing different materials. Specifically, proponents claim the accelerator can produce isotopes for NASA without losing safety and environmental advantages. Although fissile material would be present, the accelerator will have the advantages of a low inventory and smaller waste amounts, according to Los Alamos proponents.

A vehicle to develop the accelerator concept and address the various uncertainties associated with it was not created. DOE did not create a program to develop the helium-3 target or any other aspect of the accelerator concept. Los Alamos officials estimated that funding for the original accelerator concept proposal was limited to about $800,000 in Los Alamos internal research funds, with only an additional $60,000 spent on the helium-3 target concept. We reported in October 1991 that many

[6]The use of the helium-3 inventory for other purposes, such as fusion research, may also have to be considered.

questions still remained about the proposal to produce tritium in an accelerator.[7] The report pointed out that the concept lacked any detailed designs upon which meaningful cost estimates could be made. As a result, without a research and development program, the proposal remains undeveloped, and questions about its capabilities persist.

Further Consideration of the Accelerator Option Will Require Research and Development

DOE did not pursue accelerator development because it did not consider an accelerator to be a viable alternative to reactors. Because of the unknown reliability of existing reactors, DOE believed it needed new capacity to produce 1988 goal amounts of tritium on an urgent schedule (in or about the year 2000). DOE did not believe an accelerator to produce tritium could be developed and built by the year 2000. In 1990 ERAB estimated that an accelerator could possibly be developed and built in 10 years after program start. As a result, DOE's efforts have focused on using new production reactors to meet future tritium needs. DOE has spent hundreds of millions of dollars in planning for new production reactors. These expenditures include a major environmental impact study of the strengths and weaknesses of various reactor options.

The President's recent announcement of reductions in the nuclear weapons stockpile led to an almost 2-year delay in the new production reactor decision and reduced the schedule urgency that contributed to DOE's decision of not considering the accelerator as an alternative. In addition, the cutbacks further reduced tritium demand while providing additional supplies through recovery from retired weapons. These cutbacks could reduce the required capacity of a new tritium production facility. Lower tritium requirements enhance the attractiveness of an accelerator because less power is needed to produce lower levels of tritium. On the basis of these developments, the Secretary announced on December 16, 1991, that he had asked the DOE Science and Technology Advisor to re-evaluate the feasibility and practicality of using an accelerator to produce reduced quantities of tritium to meet future weapons demands.

In response to the Secretary's request, DOE sponsored an independent assessment that the JASON Group completed in January 1992. The assessment concluded that the accelerator approach was feasible and practical and recommended its inclusion in the PEIS as an alternative in DOE's decision process on new tritium production capacity. In addition,

[7] Nuclear Science: Accelerator Technology for Tritium Production Needs Further Study (GAO/RCED-92-1, Oct. 31, 1991).

our October 1991 report noted that further consideration of the accelerator will require a funded research and development program. The report does not recommend a research and development program, but the Chairman of the JASON panel estimated that a $70 million, 18-month research and development program would be required to provide enough data for the PEIS to consider the concept of an accelerator as an alternative. However, no funding is provided for accelerator research and development in DOE's fiscal year 1993 budget request, and the Secretary is due to make a decision on new tritium production capacity in August 1993. Without funding a research and development program, it will be difficult to fully consider the accelerator as an option for new tritium production capacity.

Conclusions

The recently announced nuclear weapons cutbacks provide an opportunity to fully assess an accelerator for comparison with reactor options. However, a complete assessment of the accelerator for consideration with reactors may be difficult because, in the past, no program was created to develop the accelerator concept. DOE has not conducted a research and development program because the agency did not consider it possible to develop and build an accelerator on an urgent schedule, given the immaturity of the technology. However, decreases in tritium requirements have eliminated the need for an urgent schedule and allowed more time to develop the technology. To sufficiently develop the technology for an accelerator so that it can be compared with reactors for tritium production would require a research and development program.

Recommendation

We recommend that the Secretary of Energy ensure that the accelerator concept is given full consideration when the advantages and disadvantages of possible tritium production options are compared. This concept would require research and development funding to better understand the feasibility and practicality of using an accelerator to produce tritium. Any program should be structured to provide timely and sufficient information for assessing the accelerator as an option in the decision on new tritium production capacity, which DOE currently has scheduled for August 1993. Now that the urgency for new tritium production capacity has been reduced, DOE should ensure that sufficient time is allowed to study and consider the technology options and their potential benefits before a final decision is made.

Agency Comments

We discussed the facts contained in this report with DOE officials representing the DOE Science and Technology Advisor, officials from the Office of New Production Reactors, and national laboratory officials. The officials generally agreed with the facts presented. In their comments, DOE officials noted that the Secretary of Energy is committed to developing the accelerator concept as an option for new tritium production. These officials pointed out that DOE has recently committed $3 million in contingency funds to begin planning a program for developing information on the accelerator concept. In addition, DOE plans to submit a request to the Congress for reprogramming $27 million from DOE's Office of Defense Programs for consideration of the accelerator concept. A detailed research and development program plan is currently being developed. Finally, DOE headquarters and laboratory officials wanted to emphasize that both of the accelerator target concepts offer potential safety and environmental advantages over reactor production of tritium. As agreed with your offices, we did not obtain written agency comments on a draft of this report.

Scope and Methodology

The information in this report is based on a review of proposals to produce tritium with a particle accelerator and DOE's efforts to consider the accelerator as an option for new tritium production. To determine the current status of the accelerator concept, we examined all relevant documentation associated with accelerator production of tritium and DOE's plans for providing new tritium production capacity for the nuclear weapons complex. We also examined independent evaluations of the proposal by ERAB and the JASON Group. We discussed the concept with Los Alamos and Brookhaven National Laboratory officials responsible for the accelerator concept. To determine DOE's consideration of the concept, we discussed it with responsible DOE officials at headquarters. Our work was performed between August 1991 and May 1992 in accordance with generally accepted government auditing standards.

As agreed with your offices, unless you publicly announce its contents earlier, we plan no further distribution of this report until 30 days from the date of this letter. At that time, we will send copies to appropriate congressional committees; the Secretary of Energy; and the Director, Office of Management and Budget. We will also make copies available to others upon request.

This work was done under the direction of Victor S. Rezendes, Director, Energy Issues, who can be reached at (202) 275-1441. Other major contributors to this report are listed in appendix II.

J. Dexter Peach
Assistant Comptroller General

Current Accelerator Production of Tritium Concept

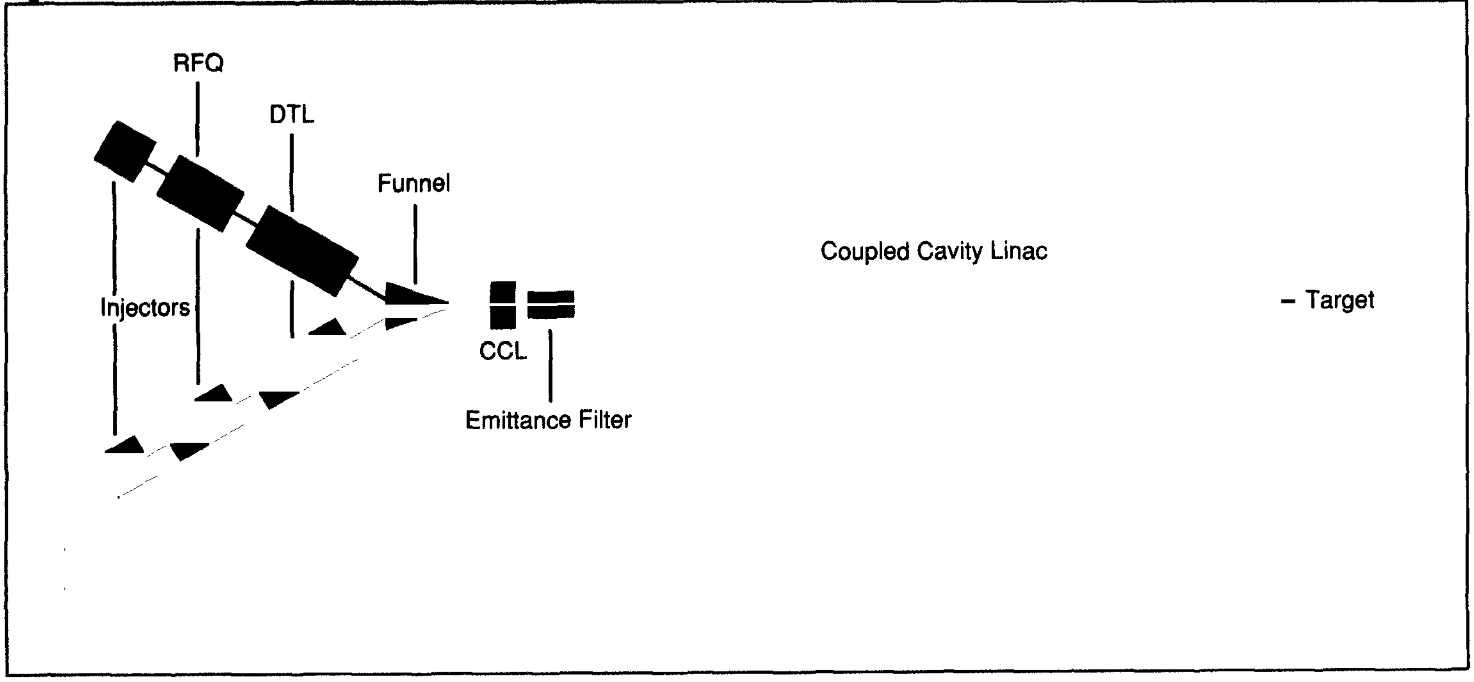
The accelerator production of tritium concept is broken down into two major components: (1) a particle accelerator to create a high-energy proton beam and (2) a target that the beam hits and that generates neutrons for tritium production. The particle accelerator under consideration is largely based on current technology. That technology provides confidence that an adequate facility can be built, although some design work is still needed. However, the two target concepts under consideration are considered less developed. The original lithium/aluminum target is based on existing reactor target technology for tritium production at Savannah River. The newly proposed helium-3 target offers potential safety and environmental advantages over the original target concept but is at an earlier stage of development.

Accelerator Proposed for Tritium Production Is Based on Established Technology

For the most part, the accelerator under consideration today is the same that Energy Research Advisory Board (ERAB) reviewed in 1990 except that it operates at a lower average current. In agreeing with the ERAB report, the JASON Group concluded that an adequate base of experience and technology exists to give confidence that an accelerator can be built and operated with adequate reliability. However, design development is needed to consider and resolve all design trade-offs and operational issues.

The particle accelerator currently under consideration for production of tritium is a radio-frequency linear accelerator based on the Los Alamos Meson Production Facility (LAMPF) at Los Alamos National Laboratory and more recently developed high-current technology funded by the Strategic Defense Initiative. The accelerator would be used to generate a high-energy proton beam—essentially a stream of protons that strikes a target assembly. As currently conceptualized by Los Alamos scientists, the accelerator would consist of five principal components—injectors, radio frequency quadrupoles (RFQ), drift tube linear accelerators (DTL), a funneling device, and a coupled cavity linear (CCL) accelerator—arranged as in figure I.1.

Figure I.1: Accelerator Proposed for Tritium Production



Source: Los Alamos National Laboratory.

The injectors provide a stream of low-energy protons that are propelled into the radio frequency quadrupoles where they are arranged into bunches and accelerated to form beams. The drift tube linear accelerators further accelerate the protons and add power to the beams. The two beams created are merged in the funnel using magnetic elements to combine them. The number of proton bunches, and thus the current in the combined beam, is twice that of each beam entering the funnel. The combined beam then enters the last component of the accelerator—the coupled cavity linear accelerator—where electron tubes called klystrons are used to provide power to accelerate the beam to a high-energy level.

Target Proposals Are Less Developed

A design for the target system for accelerator production of tritium is less developed than the accelerator itself. The original target concept reviewed by ERAB in 1990 was a lithium/aluminum structure much like the targets used in reactor production of tritium. This target was proposed by a joint

Los Alamos and Brookhaven National Laboratory team. While scientists at Brookhaven have continued to advocate and develop the lithium/aluminum target, scientists at Los Alamos have proposed a new concept that would recycle the decay product of tritium, helium-3, back into tritium. The JASON Group report notes that the original lithium/aluminum target system is an adaption of the technology used for 35 years with the Savannah River tritium production reactors. In comparison, the helium-3 target concept is more innovative and offers potential operational, safety, and environmental advantages, but its earlier stage of development implies a greater technical uncertainty, according to the JASON Group. The Group recommends support for continuing design activities on both concepts to further explore their merits.

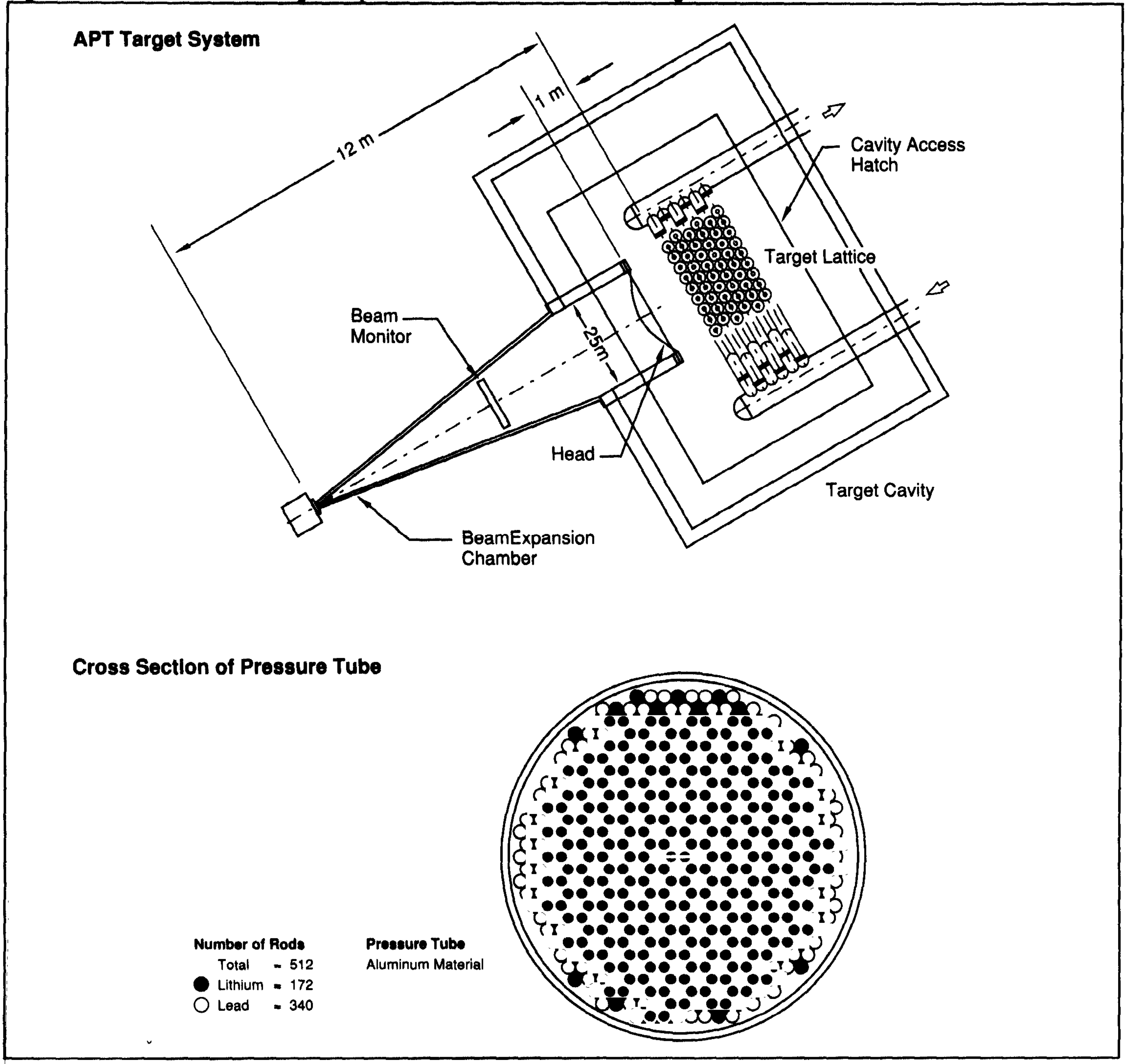
Lithium/Aluminum Target

The lithium/aluminum target concept has not been changed significantly since it was proposed by the Los Alamos/Brookhaven team in 1989. The current design, promoted by Brookhaven, would use arrays of lead and lithium/aluminum rods clad with aluminum, each about 1 centimeter in diameter and 130 centimeters long. The rods would be manufactured by methods similar to those used for many years in the manufacturing of reactor targets for tritium production at Savannah River. About 500 rods would be contained in each of the aluminum pressure tube housings, arranged in rows perpendicular to and along the length of the proton beam to form a target lattice. A target cavity, with a beam window about 2 meters in diameter, would contain the target lattice. Water would be pumped through each target housing to moderate the neutrons produced and remove heat generated in the lead and lithium/aluminum rods. (See fig. I.2.)

The accelerator's proton beam would enter the target cavity, collide with the lead rods, and produce neutrons and other high-energy particles. These particles would interact with other lead atoms to produce still more neutrons in a multiplier effect, so that ultimately many neutrons would be generated from a single proton and lead collision. Many of the neutrons generated would eventually be captured by the lithium, which would then be converted to tritium. The entire inventory of tritium produced is held in the targets until it is ready for an extraction process.

The extraction process would be very similar to that used at Savannah River for reactor targets. After the tubes were removed from the target, the tritium would be extracted. However, ERAB noted that the highest safety and environmental risk was associated with the processing of the target to remove the tritium. The entire inventory of tritium produced is held in the target until it is extracted. This process can present a safety and environmental risk because of the total amount of tritium present should an accident occur. In addition, the irradiated lead contains hazardous and radioactive waste, and means for its safe disposal or reprocessing must be addressed, according to the JASON Group.

Figure I.2: Lithium/Aluminum Target Proposal for Use With Tritium Producing Accelerator



Source: Brookhaven National Laboratory.

Helium-3 Target Concept

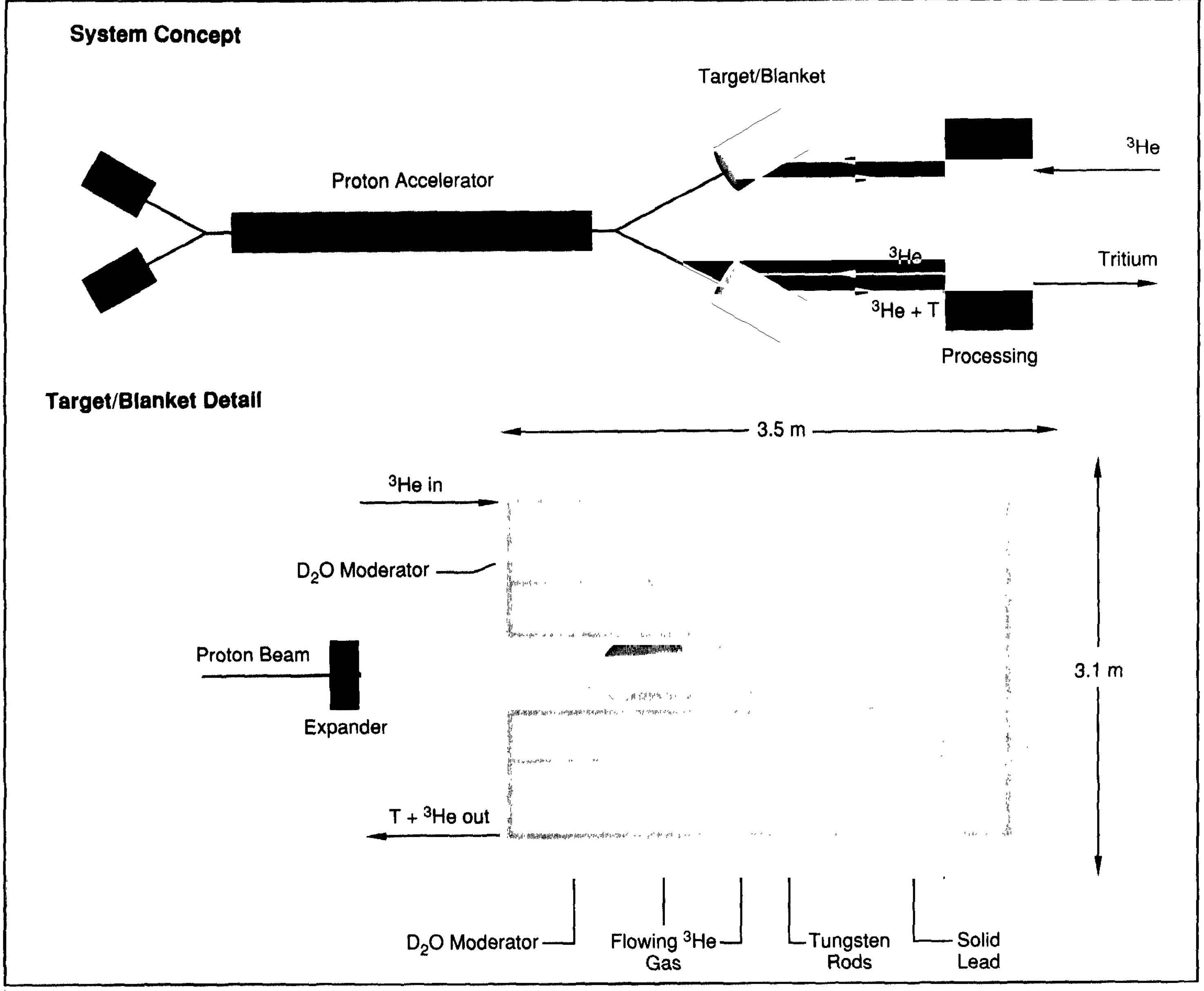
In an attempt to further improve upon the original target proposal, scientists at Los Alamos proposed a new target concept in 1990. The new Los Alamos target concept would use the decay product of tritium, helium-3, as the neutron absorber (in place of lithium), and convert it back to tritium. In this proposed concept, the accelerator's high-energy proton beam would strike tungsten (a heavy metal) rods and generate free neutrons from the impact. The neutrons would stream out of the tungsten target and into a surrounding tank of heavy water[1] known as the "blanket." The blanket would contain tubes filled with helium-3 gas. The helium-3 gas would circulate continuously through these tubes, absorb neutrons, and be converted to tritium. As the helium-3 gas is joined by newly created tritium in the circulation system, a small sidestream would be continuously processed for tritium extraction. (See fig. I.3.)

The helium-3 target concept attempts to improve upon the tritium extraction process. After the sidestream of helium-3 gas and newly created tritium are removed from the blanket region, the tritium would be separated from the helium-3. The separation processes would be similar to those in use at the Los Alamos Tritium Systems Test Assembly, which has developed tritium processing and handling methods for the U.S. fusion-energy program. The remaining helium-3 would then be re-injected into the circulation system. Pure tritium would be extracted and no separate target processing involving highly radioactive materials would be needed. In addition, the continuous tritium extraction ensures that only a small amount of tritium is present in the target/blanket system at any one time—a considerable advantage should a serious accident occur. Finally, the use of tungsten instead of lead as the neutron source would present less of a waste disposal problem.[2] Although the helium-3 target offers potential advantages, the JASON Group notes that it is at an earlier stage of development and presents greater technical uncertainty.

[1]Heavy water contains a greater concentration of deuterium—a hydrogen isotope that has an extra neutron and is twice as heavy as normal hydrogen.

[2]The solid lead surrounding the tungsten target in the helium-3 concept would not be subjected to the direct impact of the proton beam. Thus, it would present less of a waste disposal problem compared with the lithium/aluminum target, which contains lead that is directly affected by the proton beam.

Figure I.3: Detail of the Helium-3 Target/Blanket Proposal for Use With Tritium Producing Accelerator



Key
m = meter
^{3}He = helium-3
D^{2}0 = heavy water
T = tritium

Source: Los Alamos National Laboratory.

Major Contributors to This Report

Resources, Community, and Economic Development Division, Washington, D.C.

James E. Wells, Jr., Associate Director
William F. Fenzel, Assistant Director
Kenneth E. Lightner, Jr., Assignment Manager
Mark E. Gaffigan, Evaluator-in-Charge

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