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The Department of Energy's Tritium Production Program

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Summary

Tritium is a radioactive isotope of hydrogen used to enhance the explosive yield of every thermonuclear weapon. Tritium has a radioactive decay rate of 5.5% per year and has not been produced in this country for weapons purposes since 1988. To compensate for decay losses, tritium levels in the existing stockpile are being maintained by recycling and reprocessing it from dismantled nuclear weapons. To maintain the nuclear weapons stockpile at the level called for in the Strategic Arms Reduction Treaty (START) II (not yet in force), however, a new tritium source would be needed by the year 2011. If the START I stockpile levels remain the target, as is now the case, tritium production would be needed by 2005.

On December 6, 1995, the Department of Energy (DOE) issued a Record of Decision to pursue a dual-track approach to develop the two options it considered most promising. The first was to investigate the purchase of the services of an existing commercial reactor or the reactor itself to supply radiation for transforming lithium into tritium (CLWR). The second was to design, build, and test a particle accelerator at Savannah River to drive tritium-producing nuclear reactions (APT). Both options could meet the 2011 deadline but only the CLWR option could be ready by 2005. If tritium is needed sooner, an interim source may be necessary. One possible source, the Fast Flux Test Facility (FFTF) in Hanford, WA, is no longer an option because of nuclear proliferation concerns.

The DOE selected the purchase of radiation services from existing reactors owned by the Tennessee Valley Authority. Further, DOE will reimburse TVA for actual costs under terms of the Economy Act, which TVA agreed to. DOE estimates total costs for this option to range from $1.2 to $2.9 billion over a 40-year period. The TVA Board recently approved the contract with DOE, which should be signed soon. Work was to continue on the accelerator option for a period of time as a backup. The 106th Congress ratified this decision through the FY2000 defense authorization act (P.L. 106-65). This act also requires DOE to continue work on the APT option as a backup.

Even though the decision has been made, several issues exist that are not totally resolved and that might arise again as the time for tritium production approaches. These issues include the target date when production is needed, the costs of the various options, environmental and safety concerns, regulatory concerns, and possible nuclear nonproliferation concerns. At present, none of these issues appears to be serious enough to halt use of the TVA reactors for tritium production, although a license amendment by the Nuclear Regulatory Commission to allow such production has yet to be issued.

For FY2002, DOE requested $124.5 million. DOE also proposes to closeout the APT project. Congress appropriated $123.5 million and directed that no funds be provided for the APT project. In the defense authorization bill, the House (H.R. 2586) authorized an additional $15 million to complete APT efforts while the Senate authorized the requested amount and made no comment on the APT project.

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Role of Tritium

Why It Is Needed

Tritium is a crucial component of thermonuclear weapons. Tritium gas is used in every U.S. nuclear warhead to enhance its explosive yield. A typical thermonuclear device consists of two stages, a primary where the explosion is initiated, and a secondary where the main thermonuclear explosion takes place. The yield of the primary stage, and its effectiveness in driving the secondary to explode, is increased (boosted) by tritium gas which undergoes a nuclear fusion reaction with deuterium, and generates a large amount of neutrons to 'boost' the nuclear burn up of the plutonium or highly enriched uranium.[1]

Tritium is radioactive and has a relatively short half-life of a little over 12 years. As a result, the supply of tritium in a newly manufactured weapon would decay by 5.5% per year to less than 1% of its original amount in seven half-lives or 87 years without replenishment. In the past, tritium for replenishment in existing weapons was produced in a nuclear reactor, called the K reactor, at the U.S. Department of Energy's (DOE) Savannah River Site (SRS) in South Carolina.[2] In 1988, the reactor was shut down for safety reasons, and no additional tritium has been produced in the United States for weapons purposes. Replenishment of tritium in the stockpile has continued, however, by recycling tritium from existing nuclear weapons as they are dismantled. In 1991, President George Bush signed the Strategic Arms Reduction Treaty II (START II) which committed the major nuclear powers to a large reduction in their nuclear weapons stockpiles. As a result of this reduction, the stockpile's tritium levels have been maintained primarily by recycling the tritium from deactivated warheads without new tritium production.

By 1993, based on the annually updated Nuclear Weapons Stockpile Plan (NWSP), DOE and DOD determined that tritium production would need to be resumed by 2011 if the United States were to maintain its weapons stockpile at the levels set by START II.[3] The NWSP is the blueprint by which DOE proposes to manage the nation's nuclear weapon's stockpile in the absence of testing. Because

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[1] U.S. Department of Energy, *Final Environmental Impact Statement for the Production of Tritium in a Commercial Light Water Reactor,* DOE/EIS-0288 (March 1999), S-6.

[2] U.S. Department of Energy, *Final Environmental Impact Statement,* S-7.

[3] U.S. Department of Energy, *Final Programmatic Environmental Impact Statement for Tritium Supply and Recycling; Executive Summary,* DOE/EIS-0161 (October 1995), ES-7.

of the long lead time required to set up a tritium production facility, it was advisable that development of preferred production options begin immediately. In the 1996-2001 NWSP, the President directed DOE to fully support the higher START I nuclear weapons level until START II is ratified by all parties and implemented. The United States Senate gave its advice and consent to ratify the treaty in January 1996 and the Russian Duma ratified the treaty in April 2000. The instruments of ratification, however, have not been exchanged and amendments attached by the Duma may preclude U.S. acceptance of the Russian ratification.[4] The START I level requires that new tritium production begin in 2005.[5]

What Is Tritium and How Is It Made?

Tritium is a radioactive form — an isotope — of hydrogen. Tritium atoms have a half-life of 12.43 years. When tritium undergoes radioactive decay, it converts to a stable, non-radioactive form (isotope) of helium, helium-3. The half-life is the time it takes for half of a given number of radioactive nuclei to be converted to helium-3.

Although tritium occurs naturally in the environment, the amount is too small for practical recovery. Therefore tritium for nuclear weapons must be produced artificially. There are two ways of producing tritium, both involving nuclear reactions using neutrons. In the first way, neutrons are made to strike a target consisting of a lithium/aluminum material. The neutrons react with the lithium, producing tritium and other byproducts. This technology has been used to produce small quantities of tritium for several decades at the Savannah River Site (SRS) in South Carolina. In the second method, neutrons react with helium-3 to produce tritium and normal hydrogen as byproducts. Although this process has been demonstrated, the helium-3 method has not yet been used in any tritium production system.

Tritium Production Technologies

The production of tritium requires the generation of energetic neutrons. There are two suitable ways of producing such neutrons: nuclear reactors and accelerators. In an accelerator, neutrons are produced by a process called spallation. Protons, accelerated in a particle accelerator to very high energies, strike a target made of tungsten. The energetic protons then knock neutrons and more protons off the tungsten atoms like billiard balls. These neutrons and protons then knock off more neutrons in a cascade fashion. In a nuclear reactor, energy is produced by nuclear fission, or splitting, of uranium and plutonium atoms. Neutrons are used to produce the fission in the first place, and a byproduct of this reaction is more neutrons. Most of these neutrons are used to create more fission reactions — a chain reaction — but some neutrons leave the reaction region — the reactor core — without initiating a

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[4]For further information about START II, see, Congressional Research Service, *Nuclear Arms Control: The U.S.-Russian Agenda*, by Amy Wolf, CRS Issue Brief IB98030.

[5] U.S. Department of Energy, *Final Environmental Impact Statement,* S-7. For Start I, about 3 kilograms (kg) of tritium would be needed each year. For START II, about 1.5 kg per year would be needed.

fission reaction. These neutrons are available for other nuclear reactions including those that produce tritium. In either case, the quantity of neutrons produced can be controlled by adjusting parameters inherent to the accelerator or nuclear reactor.

Congressional Considerations

Introduction

In this section, a review is presented of DOE activities from the demise of tritium production in 1988 to the present time. Following that is a discussion of the FY2000, FY2001, and FY2002 budget actions on the DOE tritium program. The section concludes with an description and analysis of the various issues that arose during the period DOE was considering options for the long-term production source. These issues include the target date when production is needed, the costs of the various options, environmental and safety concerns, regulatory concerns, and possible nuclear nonproliferation concerns.

DOE Activities

The responsibility of maintaining the country's nuclear weapons stockpile is assigned to the Department of Energy (DOE). The signing of the Comprehensive Test Ban Treaty (CTBT) by President Clinton on September 24, 1996, banning further testing of nuclear weapons, contemplates that the U.S. nuclear weapon stockpile is to be maintained primarily with a science based approach using laboratory experiments and computer simulations. Weapons activities fall within DOE's Office of Defense Programs[6] and consist of two major components: stockpile stewardship and stockpile management.[7] The first of these is charged with research and development on ways to ensure the safety and reliability of the existing stockpile, and to preserve a core of weapons-related technical and scientific expertise. The stockpile management component is responsible for stockpile surveillance activities — those activities designed to ensure the safety, reliability and performance of the existing stockpile, including remanufacture of existing weapons, and for all tasks related to the production of nuclear weapons. Tritium activities lie within the stockpile management program.

Historically tritium was produced at the K Reactor and other reactors at the Savannah River Site. As noted, tritium production declined and halted altogether in 1988 when the K Reactor was shut down for safety upgrades. In the same year, DOE started the New Production Reactor (NPR) project to develop a long-term source of tritium to replace the aging K Reactor. In September 1992, the Bush Administration, under pressure from 102nd Congress and citing reduced tritium demands, decided to

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[6]The nuclear weapons activities of the Office of Defense Programs were recently transferred to the National Nuclear Security Agency (NNSA) created by the FY2000 Defense Authorization Act, P.l.106-65.

[7] U.S. Department of Energy, *Stockpile Stewardship Program: 30-Day Review*, November 23, 1999, 2-1, [http://www.dp.doe.gov/dp_web/public_f.htm].

defer any further work on the NPR until 1995 and stopped all the reactor design efforts. With the signing of START II by President Bush in 1993, the number of active nuclear warheads and the need for tritium were dramatically reduced.[8] At that time, the Department of Defense (DOD) and DOE concluded that recycling the existing tritium from the deactivated warheads could supply the needed tritium until a new source was ready.

During the FY1993 budget process, the 102nd Congress directed DOE to prepare and submit a report on tritium supplies and the necessary schedule to resume tritium production.[9] Again in the FY1994 Defense Authorization Act (P.L. 103-160), the 103rd Congress directed DOE to study tritium production and identify the selected technology by March 1995.[10] In October 1995, DOE released its final Programmatic Environmental Impact Statement (PEIS) on tritium production although it did not, at that time, make a decision on the selected technology.[11]

Based on the analysis of the PEIS and other considerations, on December 5, 1995, the DOE issued the Record of Decision, Tritium Supply and Recycling Facilities, which committed DOE to pursue a dual track strategy to ensure an adequate tritium production capability.[12] The dual-track approach (1) initiated the purchase of an existing commercial reactor or the lease of irradiation services from an existing reactor with an option to purchase the reactor and convert it to a defense facility; and (2) initiated design, construction and testing of critical components of an accelerator system for tritium production (called Accelerator Production of Tritium or APT).

According to DOE, the reactor approach would be available by 2005 while the accelerator would be operational by 2007. The Savannah River Site is to be the location for an accelerator, should one be built. Furthermore, the tritium recycling facility at SRS will be upgraded and consolidated to support both options. On September 5, 1996, the Secretary of Energy selected Burns and Roe Enterprises, Inc., to demonstrate the APT concept at Los Alamos National Laboratory, and to design the accelerator at the SRS site.

On February 7, 1997, DOE selected the Watts Bar Nuclear Plant of the Tennessee Valley Authority, on a sole-source contract, for the commercial reactor test. This plant has been operating since 1996. The purpose of the test was to demonstrate that tritium can be produced in the plant's fuel assembly without

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[8]Congressional Research Service, *Nuclear Arms Control.*

[9]Conference Report, *National Defense Authorization Act for Fiscal Years 1992 and 1993,* 102nd Congress, 1st Session, H.Rept. 102-311, 302.

[10]Conference Report, *National Defense Authorization Act for Fiscal Year 1994,* 103rd Congress, 1st Session, H.Rept. 103-357, 410-11.

[11]U.S. Department of Energy, *Final Programmatic Environmental Impact Statement (PEIS) for Tritium Supply and Recycling,* DOE/EIS-0161 (October 1995).

[12]U.S. Department of Energy, "Record of Decision: Tritium Supply and Recycling Programmatic Environmental Impact Statement," *Federal Register* 60, no. 238 (December 12, 1995): 63878.

affecting the plant's ability to produce electricity. On September 15, 1997, the Nuclear Regulatory Commission (NRC) granted its approval to the project. During a refueling that was completed on October 16, 1997, 32 of the neutron absorber rods were replaced by rods containing lithium. When the 18-month fuel cycle was completed early in the summer of 1999, those rods were removed. They were sent to Argonne National Laboratory for testing and removal of the tritium formed by the reaction of the reactor's neutrons with the lithium. Some of the rods were sent to DOE's Pacific Northwest Laboratory (PNL) for destructive testing. A final report on the test is due in FY2002. About one ounce (29 grams) of tritium was produced. None of that tritium will be used in a nuclear weapon.

On June 4, 1997, DOE issued a request for proposals for a fixed-price contract to provide a commercial reactor for sale or lease for production of tritium. Only pressurized water reactors with a thermal rating of 2400 megawatts or more and which will be operating at full power by 2003 were to be considered. The only responsive bid received was from the Tennessee Valley Authority (TVA), and it originally included two options. One was to use the existing Watts Bar and Sequoyah plants and the other was to use its uncompleted Bellefonte plant plus the existing plants as needed. In the original bid, the latter option would have required government assistance for completion of the Bellefonte plant for its use as a tritium source at an estimated cost to DOE of about $2 billion. Operation costs for tritium production from that plant were estimated at $28 million per year. If the Bellefonte plant were to be selected, DOE would also have received revenue from the sale of electricity. DOE estimated that such payments could amount to a significant portion of the $2 billion. Under the bid, the Watts Bar/Sequoyah option would have cost DOE about $12 million per year for irradiation services those two reactors (basically to use neutrons produced by the reactor during their normal operations to irradiate lithium supplied by DOE to produce tritium). TVA allowed that bid to expire when it was not acted upon, keeping only the Bellefonte option on the table.

In November 1998, TVA modified its Bellefonte offer by reducing the cost to DOE to $1.35 billion. At the same time, DOE would no longer have received any revenues from the sale of any electricity from a completed plant. TVA also offered Watts Bar as a backup in the event Bellefonte could not be completed. The existence of this backup would have effectively capped the cost to DOE for this option at $1.35 billion plus whatever operating costs were necessary to process the tritium produced in the reactor. TVA also submitted a variant on the Bellefonte proposal by stating that it would accept shipments of uranium fuel from DOE in lieu of payments totaling up to $474 million.

Then DOE Secretary Bill Richardson also asked TVA to resubmit a Watts Bar irradiation services bid. The new bid, received early December, 1998, provided such services from both the Watts Bar and Sequoyah plants for $85 million per year. According to the TVA proposal, however, tritium production from this option would have been only about 54% of the completed Bellefonte option and would have lasted for 25 years compared to 40 years for Bellefonte.

On December 22, 1998, DOE announced its decision to contract with the TVA for the Watts Bar and Sequoyah plant option. DOE stated that this would be the least costly option for providing U.S. tritium needs, and would offer the most flexibility for changes in tritium demand that may result from new weapons treaties. On May 7, 1999, DOE released its Consolidated Record of Decision (ROD) for the Tritium Supply Program.[13] In that document, DOE affirmed its December 22, 1998, selection of Watts Bar Unit 1, and Sequoyah Units 1 and 2 as the Department's long-term source of tritium production, announced that the tritium extraction facility will be constructed at the Savannah River Site (SRS), and that the APT option will serve as a backup tritium supply technology, and, should construction be required, be located at the SRS site. In the ROD, DOE announced that the life-cycle cost of the CLWR selection would range from $1.2 billion to $2.9 billion over the 40-year life of the contract with TVA. The range depends on the arrangements to be made for the increased uranium enrichment required for reactor fuel to produce the tritium.

In December, 1999, the TVA Board of Directors voted 3-0 to accept the DOE contract. The contract was signed by TVA on December 14, 1999 and by DOE on December 21, 1999. The effective date of the contract is January 1, 2000.

In November 1999, DOE issued a request for proposal (RFP) for fabrication and production of the TPBARs that would be used in the Watts Bar and Sequoyah power plants. According to the RFP, the selected contractor would assemble, fabricate, and ship up to 6000 TPBARs for Phase I of the contract and develop the capacity to manufacture up to 4000 TPBARs per year for Phase II.[14] The RFP stated that a firm delivery date for the delivery of the Phase I TPBARs would be set after the contract was awarded, but that the contractor should be capable of delivering the TPBARs by March 1, 2003. At the present time, DOE expects to have the production capability and operations systems needed to produce tritium in the two plants in place by FY2003. In order to meet the 2005 deadline for having tritium available for the weapons stockpile, the rods must be in the reactor 18 months prior to that date. In the summer of 2000, WesDyne International, a subsidiary of BNFL, was selected to perform the contract.

Construction of the tritium extraction facility began in the first quarter of FY2000. According to the FY2002 DOE budget justification, the facility is to be completed in the fourth quarter of FY2004 at a total project cost of $401 million. Integrated system testing with tritium is scheduled to begin in FY2005 with project completion and start of facility operations scheduled for FY2006.

In February 2000, DOE held a vendor's forum for transportation services to ship irradiated TPBARs from the Watts Bar and Sequoyah power plants to the tritium extraction site at the Savannah River Site. According to DOE, 14 to 20 shipments a year of no more than 300 TPBARs per shipment will be required. The proposed contract calls for shipments to begin in 2006 for an initial ten-year period.

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[13]U.S. Department of Energy, "Consolidated Record of Decision for Tritium Supply and Recycling," *Federal Register* 64, no. 93 (May 14, 1999):26369.

[14]U.S. Department of Energy, "Tritium Producing Burnable Absorber Rod (TPBAR) Fabrication Solicitation: Commercial Light Water Reactor (CLWR) Production of Tritium Solicitation No. DE-PR02-99DP00229," November 17, 1999, [http://www.dp.doe.gov/dp-62/default.htm].

Tritium Program Budget Actions

FY2001. For FY2001, DOE requested $152.0 million, a reduction of 10.3% from FY2000. The reduction resulted from a decline in engineering development and demonstration for the APT and a suspension of design work on the APT plant. Both actions reduced funding by a total of $68.7 million from FY2000. DOE is asked for increases of $9.2 million for procurement of TBBARs and $42.1 million to begin construction of the tritium extraction facility.

The FY2001 defense authorization act (P.L. 107-398; H.R. 106-945) authorizes $177 million for tritium readiness. The increase, $25 million, is for continuation of preliminary design and engineering activities associated with the APT project. DOE has not requested any funds for that effort. The authorization also includes $75 million for the tritium extraction facility being built at Savannah River. In the conference report, the 106th Congress expressed its belief that the APT project should be managed and funded by the National Nuclear Security Administration and not the Office of Nuclear Energy, Science and Technology as proposed by DOE in the budget request.

The FY2001 Energy and Water Development appropriations act provides $167 million for tritium readiness. The additional $15 million is for the APT project. The latter funds are to be used only for design activities.

FY2002. The DOE budget justification shows a request of $124.47 million for the tritium readiness program for FY2002. Included is $42.35 million for the CLWR activity, $1 million for the APT activity, and $81.125 million for construction of the tritium extraction facility. No construction funds are being requested for APT construction activities. In the narrative, DOE states that the APT project will be closed out, having completed its engineering development and demonstration and preliminary design. Funding for FY2002 will be used to document and archive the results of that design effort and to complete closeout.

The funding requested for the CLWR activity will be used to begin assembly of the TPBARs being produced by WesDyne International and complete documentation of the extraction tests and destructive testing of the TPBARs irradiated in the Watts Bar experiment. In addition, funds will be used for modifying the reactor sites for handling the TPBARs, and for the process to amend the reactor's operating licenses.

On June 28, 2001, the House approved its version of the Energy and Water Development Appropriations Bill, 2002 (H.R. 2311, H.Rept. 107-112), which provides the requested amount for tritium readiness. Included in the appropriation are $42.35 million for tritium readiness, $1.0 million for APT efforts, and $81.12 million for construction of the tritium extraction facility. On July 19, 2001, the Senate approved its version of the bill (S.1171, S.Rept. 107-39) which provides $138.47 million, $14.0 million or 11.2% above the request. In addition to funding the tritium readiness and construction activities as requested, the Senate version provides a total $15.0 million to close out the APT activities. The Senate also directed that those activities be transferred to the Advanced Accelerator Applications (AAA) program which it directed should be located in DOE's Nuclear Energy. While directing that DOE close down its APT program in FY2002, the Senate also stated that DOE should continue research on tritium production using accelerator technology in the new AAA program. It specifically suggested that the LANSCE facility at Los Alamos could be used for such research.

On November 1, 2001, Congress approved the conference report (H.Rept.107-258) of the Energy and Water Development Act, 2002. The act provides $123.5 million for tritium readiness for FY2002, $1 million below the request. No language appeared in the report about the reduction. Congress did, however, specify that no funds were to be provided for the accelerator production of tritium project.

On September 25, 2001, the House passed its version of the National Defense Authorization Act for FY2002 (H.R.2586, H.Rept. 107-194). That bill recommends authorization of appropriations of $139.8 million, $15.0 million above the request. The additional funds are to complete preliminary design and engineering development and demonstration work on the backup APT technology. The House urged DOE to complete this work as soon as it could so that the resources could be used for other needs. The House also noted that the current tritium production schedule calls for irradiation to begin in 2003 and first extraction to begin in 2006. It there are no further reductions in the nuclear weapons stockpile, this schedule would require a one-year draw down of the five-year tritium reserve. The House believes that this draw down could be made up in subsequent years.

On October 2, 2001, the Senate passed its version of the defense authorization bill (S.1438, S.Rept.107-62). The bill authorizes $124.5 million for tritium readiness, the requested amount. The Senate did not comment further about the authorization, and made no mention of the APT project.

Program Issues

The principal controversy about the DOE tritium production program has been the choice of long-term production technology. For the few years leading up to the December 22, 1998, decision, the choices had narrowed to the purchase of radiation services from an existing commercial light water reactor (CLWR), or the construction of a linear accelerator dedicated to the production of tritium (APT). DOE has now decided to proceed with the CLWR option and the 106th Congress ratified that decision. Nevertheless, some of the issues that formed the debate have not been completely resolved, and may come up again in the 107th Congress as actual implementation of the production process nears. In addition, there may be questions about the decision by DOE to end work on the APT backup option.

Target Date. Although current policy is set to meet the 2005 target for a new tritium production source, there are those who believe that completion of that source can be extended well beyond that deadline. If START II enters into force, the need for new tritium production would be delayed to 2011 because the number of strategic warheads allowed in the stockpile would be much lower than the START I limits defining the 2005 target. START II calls for a stockpile of 3,500 nuclear strategic warheads compared to 6,000 warheads under START I.[15]

Many argue that further nuclear weapons reduction beyond the START II limits is possible with the result that additional years would be available to recycle tritium from dismantled warheads because the tritium production schedule included an additional 5-year reserve. Some nuclear arms control advocates have argued for further reductions to around 1,000 deployed warheads. In that case, the need for new tritium production could be pushed back to 2035 by the recycling of the tritium from the deactivated warheads. The Clinton Administration, however, rejected further unilateral cuts in U.S. nuclear weapons until the START II entered into force, and there was no official proposals, either from the 106th Congress or the Clinton Administration, for additional nuclear weapons stockpile reductions. It is unclear at this time what the policy of the Bush administration will be on further reductions in strategic nuclear weapons. Considerations about the ABM treaty and missile defense systems may complicate further attempts at arms reduction.

Technology Issues. Commercial light water reactors contain burnable absorber rods (BAR) in the reactor core which control the production and distribution of heat in the core by absorbing excess neutrons that would otherwise produce fission reactions. To produce tritium in the reactor, the normal absorbing material, boron, would be replaced by an isotope of lithium, requiring a redesign of the rods. That isotope of lithium is an absorber like boron, but the nuclear reaction it undergoes during the absorption process also produces tritium. Such rods are called tritium-producing burnable absorber rods (TPBARs).

Unlike the boron BARs, however, the TPBARs lose little of their ability to absorb neutrons during their stay in the reactor core. Therefore, there is a limit on the number of such TPBARs that can be inserted in the core if the 18-month refueling cycle is to be maintained. Too many TPBARs would result in shutting down the reactor before refueling could take place because there would be an insufficient number of neutrons to sustain the chain reaction. For the Watts Bar reactor, that upper limit is 3,400 TPBARs.[16] Furthermore, even within that TPBAR limit, the fuel that is loaded must have a higher concentration of enriched uranium than if boron BARs are used. And, if the number of TPBARs exceeds a certain number — 2,000 for the Watts Bar reactor — a higher number of fuel assemblies must be replaced during refueling. All of this is necessary to ensure enough of the uranium isotope required for the fission reaction (U-235) is available to sustain a chain reaction for the 18-month life of the fuel cycle. One potential consequence of these changes is that

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[15]Congressional Research Service, *Nuclear Arms Control.*

[16] United States Department of Energy, *Final Environmental Impact Statement for the Production of Tritium in a Commercial Light Water Reactor*, DOE/EIS-0288, Summary, March 1999, S-24. In its November 1998 revised proposal to DOE, TVA stated that it was prepared to operate Watts Bar with any number of TPBARs up to a maximum of 2,496, and would continue to operate the plant with an 18-month refueling cycle. TVA also stated that it would be prepared to operate Bellefonte up to a maximum of 3,000 TPBARs and with a 12-month refueling cycle.

the amount of spent fuel to be stored on site would increase because of the larger number of fuel assemblies replaced during each refueling.

This TPBAR-number limitation constrains the amount of tritium that can be produced in any one reactor operating with an 18-month refueling cycle. To produce 3 kilograms (kg) per year, the amount needed to maintain a START I stockpile, 4,000 TPBARs per year (6,000 over 18 months or 76.5% more than the 3400 limit) would be required. To produce tritium to maintain a START II stockpile, 1.5 kg per year, would require 2,000 TPBARs per year or 3,000 over 18 months.

If DOE should decide it needs to produce enough tritium to meet START I levels, it could place more TPBARs in the reactor, or it could use a second (or third) reactor. Although the Watts Bar reactor is capable of holding more than 3,400 TPBARs, it would not be possible to sustain a chain reaction over 18 months under those conditions. Therefore, a shorter refueling cycle would be required. If a 12-month cycle is selected, 4,000 TPBARs would be required. Watts Bar is capable of holding that number of TPBARs, and, under those conditions, could sustain power output over that period. That 33% shorter cycle, however, would require more frequent refueling outages that would significantly reduce the plant's average annual energy output, forcing an adjustment by TVA in order to ensure an adequate power supply to meet its load.

It is not likely that DOE will ask TVA to change the refueling cycle for Watts Bar. In the August 1998 draft environmental impact statement for the CLWR option, DOE stated that it did not foresee the need to change the fuel cycle period, and no mention was made of this possibility in the December 22, 1998 announcement.[17] Presumably, if DOE needed to produce 3 kg per year of tritium, the START I levels, it would use one or both of the Sequoyah units as well and live with the 18-month refueling cycle in both plants. If DOE also wanted to ensure that no additional spent fuel were produced, the Watts Bar unit and both of the Sequoyah units would need to be used to meet START I levels, while START II levels could be met with Watts Bar and one Sequoyah unit. DOE is now planning for the full complement of 3 kg or 6000 TPBARs to meet the 2005 target for tritium. The contract for fabrication of the TPBARs, however, gives DOE the flexibility to lower the number to be produced if a smaller quantity of tritium is needed. TVA expects a binding commitment from DOE by the fall of 2001 as to how much tritium it will need TVA to produce.[18]

As noted above, DOE placed 32 TPBARs in the Watts Bar reactor in July 1997 to test the assemblies under actual operating conditions. The design of the test assemblies was overseen by the Nuclear Regulatory Commission, which issued a license to Watts Bar permitting the test. The purpose of the test was to develop and install a TPBAR assembly and to examine its tritium production capabilities and durability. Because the number of TPBARs used in the test was very small compared to the number that would have to be used for significant tritium production, the test could not examine the effect of such production on reactor operations. According to

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[17] United States Department of Energy, *Final Environmental Impact Statement for the Production of Tritium in a Commercial Light Water Reactor*, S-24.

[18] Private communication, Jeanette M. Pablo, TVA, January 12, 2001.

DOE officials, examination of the test assembly to date shows that it operated as expected and there were "no surprises." [19] Final results on the test, however, will not be available until sometime in FY2002.

The second option in DOE's dual-track approach, accelerator production of tritium (APT), would be a significant departure from previous approaches. Existing DOE particle accelerators are capable of producing only a small amount of tritium. The research accelerators were designed for pulsed, and not continuous, operation at low power levels (about 800 KW). A production accelerator would be required to deliver a high power proton beam at 170 MW, or more than 200 times greater.[20] While the APT process has yet to be demonstrated on anything approaching the scale required for the stockpile, research and development is being conducted at Los Alamos National Laboratory (LANL) to demonstrate its feasibility. Several subsystems including a prototype of the superconducting radiofrequency (RF) cavity that will provide the proton acceleration are under construction. Early results in the development of the initial stages of the accelerator have been promising. Also, prototypes of the RF power supplies that will drive the cavities have been operating continuously for an extended period, building confidence in the ability of the accelerator to run steady state (continuously). Cavities of this type are now operating at the DOE Thomas Jefferson National Accelerator Facility in Newport News, VA. The accelerator facility which is part of the Los Alamos Neutron Science Center, is being used for this R&D.

There are several potential advantages of APT. It does not create high-level nuclear waste, and safety concerns are not a major problem since it does not use fissionable material. The quantity of tritium to be produced can be adjusted by the schedule of operation. In addition, the accelerator could be available for scientific experiments and possibly production of medical isotopes, because tritium production is not likely to demand all of its continuous output. A major disadvantage is that the APT would require a substantial amount of electrical power to produce the high energy proton beam. A machine to reach tritium production required by START I levels will require 450 MW while an accelerator designed for START II levels (see below) will require 385 MW.

Costs. One of the most contentious issues between the two options concerned their costs. Supporters of the CLWR option argued that it would be significantly less costly than the APT option. Supporters of the APT, however, claimed the cost estimates made to date grossly overstated the cost of the APT option.

According to DOE, TVA has agreed to supply irradiation services under the terms of the Economy Act, which states that services supplied by one federal agency to another would be reimbursed at actual cost. In its May 7, 1999 ROD, DOE announced its estimates of the life-cycle costs for the irradiation services from TVA

[19]Private communication, Lewis Steinhoff, DOE, April 11, 2001.

[20] The proposed accelerator at Savannah River is approximately 0.7 mile long, and would be part of an APT complex covering approximately 173 acres of land.

to be $1.2 billion to $2.9 billion over a 40-year period.[21] The costs include a capital cost of $580 million to establish tritium production capabilities at the TVA reactors and to complete the tritium extraction facility to be built at Savannah River. The annual operating costs would range from $20 million to $60 million depending on how DOE supplied the enriched uranium for the reactor fuel needed for tritium production in the TPBAR assemblies. At the lower cost, DOE would supply the uranium from blended-down highly enriched uranium from its stockpiles, while at the higher cost, DOE would pay for the additional enrichment.

The Congressional Budget Office (CBO) had estimated CLWR irradiation service costs in a report issued in 1998.[22] The CBO estimate for operating costs was $1.32 billion over 40 years in 1999 dollars. In addition, CBO estimated $460 million for design and construction costs, also in 1999 dollars, that would be borne by DOE. The funds include manufacture and irradiation of the first array of absorber rods producing tritium, construction and startup of the tritium extraction facility, and delivery of the first unit of tritium gas. Including those costs gives a CBO estimate for total costs of the CLWR irradiation services option of $1.78 billion for 40 years, falling within the DOE cost estimate range for the TVA contract.

The DOE cost estimate for the APT option, also provided in the May 7, 1999, ROD, is $3.4 billion to complete, in constant 1999 dollars, with $135 million in annual operating costs over 40 years for a START I-level machine. The 40-year life-cycle cost estimate for this option was given by DOE to be $9.2 billion.[23] A recent effort led by Los Alamos National Laboratory reported a plan to reduce the cost of the APT facility by using a modular design. DOE stated in the ROD that this option would have an investment cost of $2.8 billion. The DOE ROD reported that the life-cycle cost of the START II-capable APT option would be $7.5 billion. For a comparable CLWR option, it reported a life-cycle cost of $2.2 billion or less. The APT estimates do not include any allowance for offsetting revenues that might accrue from the sale of medical isotopes produced by the APT facility.

Researchers at LANL believe they can reduce the cost of the APT options to $3.0 billion for a START I machine and $2.6 billion for a START II machine, again in constant 1999 dollars.[24] Lower construction costs and reduced contingency funds were the major sources of the lower costs. They also suggest a lower operating cost for the START I machine of $114 million per year. Using those figures gives total cost estimates, in constant 1999 dollars, of $7.6 billion and $6.1 billion respectively for the two production levels. Again, no potential offsetting revenues have been included.

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[21] *Federal Register*, 60, no.93, 26373.

[22] Congressional Budget Office, *Estimated Budgetary Effects of Alternatives for Producing Tritium*, Letter Report, August, 1998, 2.

[23] *Federal Register*, 60, no.93, 26373.

[24] Letter from Paul Lisowski, APT National Project Director, Los Alamos National Laboratory, to Ray Hall, Congressional Budget Office, August 31, 1998.

Those recent APT estimates, however, may be low. DOE has a recent history of cost overruns on major projects, although there are some notable exceptions. Indeed, the facility that comes closest to the APT in technology terms, the Thomas Jefferson National Laboratory, was constructed under budget and on schedule. The existence of other overruns, however, has forced DOE to be extra cautious about making project cost estimates. It included a 20% contingency factor which is typical of the overruns experienced by DOE on some other accelerator projects. Nevertheless, an accelerator with all of the requirements of the APT has never been built before, and even though much of the technology has been used elsewhere, the risk of cost escalation remains.

The other reactor option, completion of the Bellefonte plant, was originally estimated to cost DOE $1.8 to $2 billion in capital costs plus about $28 million per year in operating costs over the 40-year life of the plant.[25] In that proposal, DOE would also have received a portion of the revenues from the sale of electricity. TVA estimated that those revenues flowing to DOE would eventually offset a significant portion of DOE's outlay to finish plant construction. The CBO analysis estimated those offsetting receipts would be somewhat more than total DOE operating costs over the 40-year life.

One concern that was raised about this proposal was the possibility of cost overruns in completing the plant. The Bellefonte plant consists of two units, one 60% complete and the other 90% complete according to TVA, and no work has been done on these plants for several years. While those percentages suggest that most of the plant cost has been spent, that might not be the case. The history of nuclear power construction in the United States has been replete with large cost overruns, much of which have occurred when a plant was near completion. Furthermore, in 1994, Southern Company estimated completion costs for Bellefonte at $2.5 to $4.5 billion, although TVA disputes those estimates.

The revised Bellefonte option delivered in November 1998, however, would have put a cap on those costs for DOE regardless of the total cost of completing the reactor. TVA stated that it would be responsible for costs above the $1.35 billion it is asking of DOE.[26] In its May 7, 1999 ROD, DOE announced that if it were necessary to use Bellefonte for tritium production, the investment cost would range from $1.2 to $1.8 billion.[27] The total cost of completing Bellefonte would remain about $2 billion, and could go higher, but the ratepayers of the TVA system would be paying any difference. Indeed, they are now paying for the approximately $4.3 billion that has already gone into the Bellefonte plant. Of course, if the plant is completed, it would produce electricity for use by those ratepayers.

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[25] Letter proposal from Craven Crowell, Chairman, Board of Directors, Tennessee Valley Authority to the Honorable Bill Richardson, Secretary, U.S. Department of Energy, December 8, 1998.

[26] Letter proposal from Craven Crowell.

[27] *Federal Register*, 60, no.93, 26373.

There is reason to believe that the APT option might have been comparable in capital cost terms to the original Bellefonte proposal, but probably not to the revised proposal. In any event, it appears that Bellefonte would have had a significant operating costs advantage because of the high electricity costs of the accelerator. Compared to the Watts Bar/Sequoyah option selected by DOE, the APT option appears to be at a decided cost disadvantage.

There are, however, some uncertainties that might affect this conclusion. First, TVA stated in its Watts Bar/Sequoyah proposal that tritium production capability would end 25 years after its start in 2004. Further, it stated that the Sequoyah backup would not be available after 2021, 17 years after tritium production startup. Those periods were determined by the expiration dates of the two plants' licenses. While Watts Bar, alone, could supply the amount of tritium needed for START II levels, the availability of a backup in case something happened to Watts Bar could be important. Those ending dates, however, are likely to be excessively conservative. The plants themselves may be capable of operating far longer than their existing license duration. Most nuclear utilities expect that license extension should be possible. Indeed, DOE assumes in its May 7, 1999 ROD that nuclear power plants will be available for the entire 40 years of the TVA contract, either through license extension or from other plants. Even with an extension, however, there may be added costs for DOE if significant plant modifications are required as a condition for license extension. There has been no experience with license extension to date, so it is difficult to tell what it would entail for either Sequoyah or Watts Bar. If such extension does not happen, DOE could be facing added costs in securing a replacement tritium source.

The possibility of producing medical isotopes in the APT accelerator has raised the possibility of generating offsetting revenues for that option from the sale of such isotopes.[28] A group of medical researchers held a workshop in May about using the ATP for the production of radionuclides for medical purposes. The workshop participants concluded that the APT facility could be a major source of such radionuclides resulting in substantial biomedical research opportunities. The large target volume and high beam power of the facility would be major reasons for the large medical isotope production potential. Additional costs would be incurred, if this capability is added, to modify the target area and build the infrastructure needed to extract and process the medical isotopes. Officials from LANL state that using the APT for this purpose would reduce tritium output by about 1%.

The amount of revenues from this option would depend heavily on the success of many of the radionuclide therapies and diagnostic techniques, now in the research stage, that were reported on at the May workshop. For the purposes of its analysis, the CBO assumed a revenue stream of about $15 million per year. In a cost analysis by LANL, a market of $150 million per year was assumed. That level would

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[28] U.S. Department of Energy, Pacific Northwest National Laboratory, *Medical Isotope Production at the Fast Flux Test Facility - A Technical and Economic Assessment,* PNNL-SA-29502 (November 1997) 7.1. See also Congressional Research Service, *Tritium Production for the U.S. Nuclear Weapons Program: An Analysis of Key Issues,* Richard Rowberg, et al., RL30129, April 12, 1999, 15.

completely compensate for APT facility operating costs. The market is highly uncertain, however, and could be much greater if a significant portion of the research reported on is successful. DOE appears interested in this option, but has not put any funds into developing it further. While discussions have taken place with the National Institutes of Health (NIH) about this possibility, NIH has been noncommittal about providing any support at this point.

Schedule and Flexibility. Currently, U.S. policy is to have tritium production capacity in place by 2005 in order to meet the requirements of a START I stockpile level. If the START II is put into force, the need for new tritium production would be delayed to 2011 because the number of strategic warheads allowed in the stockpile would be much lower than the START I limits.

Under the DOE selection, tritium production could begin at the start of the next refueling cycle — in October 2003 — assuming construction of the necessary TPBAR assemblies. It could also be delayed for an indefinite period without incurring additional cost. Therefore, if START II were put into force, DOE would not have to begin use of the Watts Bar plant until 2011 and would not incur any production costs until then. If greater reductions in nuclear arms were agreed to, production startup and costs could be postponed even further.

The APT option appears to have less flexibility. The facility could not be completed in time to meet START I requirements, and an interim source would be needed. This fact was clear about the APT from the beginning. It could be ready, however, by 2007, well in advance of the 2011 START II requirement date. The modular approach would give the APT some flexibility in that DOE would not have to commit to a START I level machine at the beginning of construction. Nevertheless, some level of commitment would be needed leading to construction expenditures from now until the machine is completed regardless of the level of tritium production eventually required.

Environmental and Safety Concerns. Important factors that might have influenced the decision about tritium production technology are the potential impact of the candidate technologies on the environment, and the safety level of the production facility. Common to all the reactor options are concerns about reactor safety and the generation and management of radioactive waste. Since the early 1970s, no new commercial nuclear reactor has been ordered in the United States. The major reasons have been the high cost of nuclear power compared to other electric power generation technologies and the slowdown in the growth of electric power demand which left substantial excess generation capacity. In addition, there have been concerns about reactor safety. While the U.S. nuclear power industry has a generally excellent safety record and there is evidence of a substantial improvement in power plant safety in the last several years, the memory of Three Mile Island and foreign accidents has contributed to public resistance toward more nuclear power plants.

Some of the environmental impacts of the CLWR option selected by DOE would not be significantly greater than those already experienced due to the operation of the reactor alone.[29] There could be some additional air and water releases of radioactivity, primarily tritium, and some additional waste generation at the reactor site because of the existence of the TPBARs. Radiation exposure for the population in the vicinity of Watts Bar due to those emissions increases would still be well within regulatory limits. In addition, a significant increase in spent fuel would result if tritium production is confined to one (in the START II case) or two (in the START I case) reactors, and more on-site storage capacity might be needed.

The APT is not a reactor and would not generate any spent fuel nor would there be any significant safety concerns. A DOE environmental impact statement on the project states that the impact would be "minor and consistent with what might be expected for any industrial facility."[30] Because nuclear reactions would take place in the APT facility, some radioactive waste material would result. It would be a small amount, however, and all of it would be low level waste (waste whose radioactive byproducts are low energy and far less dangerous than byproducts from nuclear reactors). The principal environmental consequence of an APT facility would likely be the large amount of electric power which would be required. This power would very likely be generated by the burning of fossil fuels which contribute to air quality concerns and produce carbon dioxide. At this point, however, DOE believes that existing electric power capacity in the region where the accelerator would be located is capable of supplying all of the APT needs.

Regulatory Concerns. Regulation is also an issue for the choice of production technology since any reactor option would be subjected to the current nuclear power plant regulatory process. Presently commercial reactors are licensed and regulated by the Nuclear Regulatory Commission (NRC). DOE assumes that Watts Bar and Sequoyah, if used to make tritium for the department, would remain licensed by the NRC, with license amendments for insertion of tritium target absorber rods. TVA intends to submit request to NRC in February 2001 to amend the licenses of these two plants to permit production of tritium.[31] It expects NRC to act on the amendment in advance of October 2003, the date now planned to begin irradiation.[32]

For the Watts Bar test described above, the NRC permitted an amendment of the operation license in September 1997, a few months after the request. NRC approval to insert the lithium rods was necessary because that constituted a modification of the original reactor license.

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[29] United States Department of Energy, *Final Environmental Impact Statement for the Production of Tritium in a Commercial Light Water Reactor,* S-34.

[30]U.S. Department of Energy, *Environmental Impact Statement: Accelerator Production of Tritium at the Savannah River Site,* DOE/EIS-0270 (March 1999), S-13.

[31]Private communication, Jeanette M. Pablo, TVA, January 12, 2001.

[32]*Federal Register*, 60, no.93, 26372.

The APT option would not be subject to NRC licensing under current law. The accelerator would be solely a DOE defense production facility, which would be regulated for health and safety by Defense Nuclear Facilities Safety Board.[33]

Nonproliferation Concerns. Another issue is the possible nuclear proliferation consequences of using civilian facilities for weapons tritium production. U.S. commercial nuclear power production has traditionally been independent of the nation's weapons program, and some nuclear nonproliferation interests have cited the separation as important to U.S. nonproliferation efforts. The policy has developed over time, however, and the separation has not always been complete. Perhaps the most notable merging of the two was the N-Reactor at Hanford, WA, which produced weapons-grade plutonium and sold by-product steam to the Washington Public Power Supply System, which used the steam to generate electricity for the commercial market. That situation ended in the late 1980s when the N-Reactor was shut down.

In the conference report for the FY1998 National Defense Authorization Act, the 105th Congress requested that DOE lead an interagency review of the nuclear nonproliferation issues associated with tritium production.[34] That report was released on July 14, 1998.[35] The review concluded that the nonproliferation policy issues connected with the CLWR option were "manageable." It also concluded that the APT option "raised no significant nonproliferation policy issues." In that review, DOE concluded that existing law does not prohibit the use of commercial facilities to produce tritium for use in nuclear weapons. In particular it stated that the provision in the Atomic Energy Act that prohibits the production of special nuclear materials (fissile materials, mainly uranium-235 and plutonium-239) in commercial facilities for "nuclear explosive purposes" is not applicable in this case because tritium is not a special nuclear material but rather a byproduct material as defined by the Act. DOE also argued that the practice of separating civil and defense nuclear facilities has not been absolute. It cited the Hanford N–Reactor example described above. Finally, the review concluded that no international treaty prohibits tritium production in a nuclear reactor. The inspections provision, to which the United States voluntarily adheres, of the Nonproliferation Treaty has only been applied to materials that can be used directly in nuclear weapons or transformed into such materials. It has not been applied to tritium and the International Atomic Energy Agency, which administers the inspections, has stated that it will not include tritium in the future.

The review also concluded that a number of mitigating factors existed to reduce any proliferation danger from producing tritium in commercial reactors. Among these are that TVA, which is the sole organization interested in supplying the CLWR option, is an instrumentality of the U.S. government, and use of TVA reactors would be extending a long practice of using government-owned facilities for both civilian and

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[33] *Federal Register*, 60, no.93, 26372.

[34] Conference Report, *National Defense Authorization Act for Fiscal Year 1998,* 105th Congress, 1st Session, H.Rept. 105-340, .

[35] U.S. Department of Energy. *Interagency Review of the Nonproliferation Implications of Alternative Tritium Production Technologies under Consideration by the Department of Energy.* A Report to the Congress (July 1998), p. 5.

defense purposes. Also, any reactor used for tritium production would be fueled with uranium fuel having an uranium-235 enrichment level of less than 5%.[36] Nuclear weapons require uranium enriched to significantly higher levels.

Although the DOE review does not consider the production of tritium in a commercial reactor a proliferation issue, controversy remains.[37] A principal concern of nonproliferation proponents, which was not addressed in the review, is that the use of U.S. civilian nuclear reactors for the production of weapons material may set a bad precedent. While there are no legal prohibitions against producing tritium for weapons use in a commercial facility, doing so might make other nations believe that the United States was not serious about nuclear nonproliferation and take steps to use their own commercial facilities for weapons purposes.

Separation of commercial and weapons programs in other countries has been a factor in U.S. nonproliferation policy. In the recently concluded agreement for peaceful nuclear cooperation with China, for example, one of the most important issues was assurance that nuclear technology and facilities supplied by the United States would not be used or mixed with China's nuclear weapons program. In addition, U.S. aid to Russia to improve the safety of nuclear power reactors there has been made difficult by the fact that plutonium produced in those reactors has been involved in the weapons program. Further, U.S. objections to the Russian project to build a power reactor at Bushehr in Iran are based on evidence that Iran is using the civilian project as a cover to develop weapons. Nonproliferation proponents argue that U.S. criticism of other weapons states' failure to keep civilian and weapons programs separate will lose force in the future if the United States does not follow the same separation policy.

Proliferation concerns received attention at the NRC public meeting on the Watts Bar test. Opponents argued that once Watts Bar is operating with the lithium rods and is producing tritium for later extraction, it becomes a "bomb plant." Although DOE officials pointed out that tritium has other purposes besides its use in nuclear weapons, is not a special nuclear material, and is not covered by the Atomic Energy Act, opponents pointed out that the sole purpose of the test is to demonstrate the feasibility of producing tritium for nuclear weapons. They noted that Egyptian officials had cited the Watts Bar experiment in justifying that country's decision to proceed with construction of a nuclear power plant. Therefore, while the letter of the law is met, the spirit of the law is not according to these opponents.

The DOE proliferation review concluded that the APT option would not pose any proliferation risks. It has been noted, however, that because the accelerator

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[36]Naturally occurring uranium consists of about 0.7% U-235, the rest being U-238. Because the latter does not produce a self-sustaining fission reaction while the former can, uranium in the reactor fuel must be enriched by adding U-235. For commercial light water reactors, an enrichment of about 2-4% — the fuel contains 2-4% U-235 — is sufficient to sustain the reaction. Nuclear weapons require a much higher concentration of U-235 and reactor fuel would not be useable for weapons without additional enrichment.

[37]For a more extended discussion of this issue, see, Congressional Research Service, *Tritium Production for the U.S. Nuclear Weapons Program,* 28.

would involve technology capable of producing special nuclear materials, export of any of those technologies would be controlled under relevant federal regulations. There should be no concern about a civilian/weapons separation for the APT facility because it would be a dedicated defense facility when operating in its tritium production mode. If it were also used for scientific research, however, it is possible that such concerns would be raised, particularly to the degree there was international access to the technology used in the accelerator. Similarly, concerns could arise if the facility were to be used for medical isotope production.

A concern has recently emerged that is indirectly related to the nonproliferation issue.[38] When attempting to purchase a new steam generator for its Sequoyah power plant, the TVA was told by Mitsubishi in Japan that it would not sell anything to TVA to be used on that plant because it was to be involved in producing tritium for the U.S. nuclear weapons program. While TVA believes that it will eventually be able to purchase a steam generator, the fact that foreign suppliers might be unwilling to sell TVA nuclear power plant equipment because of the tritium production connection is troubling. Over 90% of the replacement equipment for a nuclear power plant must be obtained from foreign suppliers because there are no domestic suppliers. If a significant fraction of those suppliers will not sell parts to TVA for either Sequoyah or Watts Bar, then TVA could be forced to pay substantially higher prices for those parts than if the reactors were not part of the tritium production program. Such an occurrence might result in higher payments by DOE to TVA.

[38] Jeanette M. Pablo, Tennessee Valley Authority, private communication, October 1999.