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The U.S. Program to Produce Tritium Using Commercial Power Reactors: 2019 Update

Status as of February 2018

Tritium is an essential component of every U.S. nuclear weapon. Tritium only exists in trace amounts in nature and the U.S. has had to create its entire tritium stockpile by exposing lithium to neutrons in nuclear reactors. Due to its radioactivity, 5.5% of tritium decays away every year. Therefore maintaining a tritium stockpile requires continuing production.

I have previously written about the U.S. tritium production program.[2] Between 1948 and 1988 the U.S. produced tritium in military plutonium production reactors at Hanford and Savannah River.[3] U.S. tritium production ended in 1988 when the K reactor at Savannah River was shut down for safety reasons. Due to the decline of the U.S. nuclear stockpile with the end of the Cold War, which significantly reduced tritium requirements, tritium was not produced during the 1990s.

As its tritium stockpile continued to decay away, the U.S. restarted production using Watts Bar 1, a commercial light water nuclear power plant located in Tennessee. Watts Bar 1 is operated by the Tennessee Valley Authority (TVA). The reactor started producing tritium in 2003.

To allow higher fuel enrichments and thereby longer fuel cycles, Watts Bar 1 (like most light water power reactors), used boron containing burnable absorber rods to suppress excess reactivity at the start of a fuel cycle. To produce tritium the boron is replaced by lithium (in the form of lithium aluminate) to create tritium-producing burnable absorber rods (TPBARs). The TPBARs are irradiated for one reactor fuel cycle (18 months). They are then removed and are sent to Savannah River in South Carolina where the tritium is extracted.

The tritium production at Watts Bar 1 has been less than expected. Production was hampered by higher than expected tritium leakage from the TPBARs. The radiation exposure to plant workers and the public resulting from these enhanced tritium releases was not very large but the releases

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[1] This paper is the product of the author's personal research and the analysis and views contained in it are solely his responsibility. Though the author is also a part-time adjunct staff member at the RAND Corporation, this paper is not related to any RAND project and therefore RAND should not be mentioned in relation to this paper. I can be reached at GregJones@proliferationmatters.com

[2] Gregory S. Jones, "U.S. Increased Tritium Production Driven by Plan to Increase The Quantity of Tritium per Nuclear Weapon," June 2, 2016 https://nebula.wsimg.com/08a60104185a91e6db9008fb929a0873?AccessKeyId=40C80D0B51471CD86975&disposition=0&alloworigin=1 and Gregory S. Jones, "The U.S. Program to Produce Tritium Using Commercial Light Water Power Reactors, An Update," February 7, 2018. https://nebula.wsimg.com/77dab2caba65efc5954687e3461d9304?AccessKeyId=40C80D0B51471CD86975&disposition=0&alloworigin=1

[3] Gregory S. Jones, "History of U.S. Tritium Production 1948-1988," June 12, 2017. https://nebula.wsimg.com/a4bccfe8ef76f715d91ec4c4f3123259?AccessKeyId=40C80D0B51471CD86975&disposition=0&alloworigin=1

exceeded the amount that was used in the environmental impact statement (EIS) submitted to approve tritium production at Watts Bar 1. Though the initial plan called for Watts Bar 1 to irradiate up to 2,304 TPBARs per 18 month fuel cycle, Watts Bar 1's operating license was initially limited to just 204 TPBARs per fuel cycle. To slow the rate of decline of the tritium stockpile, in May 2009 the operating license was amended to allow the irradiation of 704 TPBARs per fuel cycle.

Efforts to redesign the TPBARs to reduce the tritium leakage failed. Instead, a supplemental EIS was issued in February 2016 which took into account the increased tritium leakage from the TPBARs.[4] In August 2016 the operating license of Watts Bar 1 was amended to permit the irradiation of 1,792 TPBARs per fuel cycle.[5] For its fuel cycle fifteen (spring 2017 to fall 2018), Watts Bar 1 was loaded with 1,104 TPBARs.

Until 2015 the goal for the production rate of tritium was 1,700 grams per 18 month period (1,133 grams per year) which would imply an equilibrium stockpile of around 20 kilograms of tritium.[6] However, to allow the nuclear weapons in the U.S. stockpile to be serviced less frequently and to provide greater assurance of weapon reliability given the lack of full yield nuclear weapon testing, the amount of tritium per weapon is going to be significantly increased. The goal for the production rate is now 2,800 grams per 18 month period (1,867 grams per year). This production rate implies an equilibrium stockpile of about 33 kilograms of tritium. The U.S. Department of Energy has suggested that the current rate goal is somewhat higher than is needed for equilibrium production to allow for some catching up and that in the long-run the required production rate might be reduced somewhat.[7] Therefore the equilibrium stockpile is probably intended to be around 30 kilograms of tritium which is a 50% increase over the planned pre-2015 stockpile.

The current production rate goal requires the use of two commercial power reactors. The supplemental EIS allows for this second reactor to be either Watts Bar 2 or one of the two reactors that the TVA operates at its Sequoyah site. It was generally expected that the second reactor would be at the Sequoyah site but in June 2016, the National Nuclear Security Administration asked the TVA to consider using Watts Bar 2. This was a somewhat surprising decision, in part, since at that time Watts Bar 2 had not yet started commercial operation.[8] It was expected the Watts Bar 2 would start tritium production in its fuel cycle four (fall 2020 to spring 2022).

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[4] "Final Supplemental Environmental Impact Statement for the Production of Tritium in a Commercial Light Water Reactor," U.S. Department of Energy and National Nuclear Security Administration, DOE/EIS-0288-S1, February 2016. https://www.energy.gov/sites/prod/files/2016/02/f29/EIS-00288-S1_F%20Tritium%20SEIS%20For%20Web%202016-01-19.pdf

[5] Nuclear Regulatory Commission, Tennessee Valley Authority; Watts Bar Nuclear Plant, Unit 1; Maximum Number of Tritium Producing Burnable Absorber Rods, *Federal Register*, Vol. 81, No. 153, August 9, 2016, pp. 52716-52717. https://www.govinfo.gov/content/pkg/FR-2016-08-09/pdf/2016-18841.pdf

[6] The equilibrium stockpile of tritium (where the amount of tritium produced each year is counterbalanced by the amount that decays away) is found by multiplying the annual production of tritium by its mean-life of 17.78 years. The mean-life is the half-life divided by the ln 2.

[7] "Tritium and Enriched Uranium Management Plan Through 2060, Report to Congress," October 2015, U.S. Department of Energy, p. 11. http://fissilematerials.org/library/doe15b.pdf

[8] Watts Bar 2 started commercial operation in October 2016.

The tritium production program at Watts Bar 1 also continued to experience unspecified problems that was reducing the amount of tritium being produced.[9] Love et al. reported that the TPBAR irradiation during cycle fourteen (fall 2015 to spring 2017) produced almost 10% less tritium than expected due to "programmatic and operational issues." For these same reasons, it was "likely" that the tritium production during cycle fifteen (spring 2017 to fall 2018) would be "less than desired." For cycle sixteen (fall 2018 to spring 2020) it was expected that "operational issues will limit tritium production."

The February 2018 Nuclear Posture Review confirmed tritium production shortfalls and expressed concerns about the adequacy of U.S. tritium production. "U.S. production of tritium…is now insufficient to meet the forthcoming U.S. nuclear force sustainment demands…"[10] Underlining the importance of increasing tritium production, the report stated that unless there is "a marked increase in the planned production of tritium in the next few years, our nuclear capabilities will inevitably atrophy and degrade below requirements."

Developments Since February 2018

The U.S. program to produce tritium appears to be turning the corner and is coming closer to meeting the required tritium production rate. Watts Bar 1 completed its fuel cycle fifteen in the fall of 2018. In this fuel cycle 1,104 TPBARs were irradiated (see Table 1). At one time it had been hoped that about 1 gram of tritium would be produced in each TPBAR but some irradiation cycles have fallen short of this goal (see Table 2).[11] A shortfall occurred in fuel cycle fifteen where only 0.916 grams of tritium were produced per TPBAR. Still, in this fuel cycle Watts Bar 1 produced just over 1 kilogram of tritium which is the highest amount that has been produced by this program thus far.

Steps continue to be taken to increase tritium production. At one time it was expected that 1,408 TPBARs would be irradiated in fuel cycle sixteen of Watts Bar 1[12] but the actual number was increased to 1,584 TPBARs.[13] These TPBARs are being irradiated now and will be discharged in spring 2020. Even if only 0.884 grams of tritium are produced per TPBAR in fuel cycle sixteen, 1.4 kilograms of tritium will be produced which is the required per reactor production rate needed to meet the goal of 2.8 kilograms per 18 month period. For fuel cycle seventeen, in

[9] EF Love, ML Stewart, BD Reid and KA Burns, "Tritium Production Assurance," Pacific Northwest National Laboratory, June 5, 2017, p. 11. https://www.energy.gov/sites/prod/files/2017/06/f34/May%2011%20-%20Stewart%20-%20Tritium%20Production%20Assurance.pdf

[10] "Nuclear Posture Review," Office of the Secretary of Defense, February 2018, p. 62. https://media.defense.gov/2018/Feb/02/2001872886/-1/-1/1/2018-NUCLEAR-POSTURE-REVIEW-FINAL-REPORT.PDF

[11] DJ Senor, "Science and Technology Supporting the Tritium Sustainment Program," Pacific Northwest National Laboratory, October 23, 2018, p. 3. https://www.energy.gov/sites/prod/files/2019/06/f63/Science-and-Technology-Supporting-the-Tritium-Sustainment-Program.pdf

[12] EF Love, ML Stewart, BD Reid and KA Burns, "Tritium Production Assurance," Pacific Northwest National Laboratory, June 5, 2017, p. 4. https://www.energy.gov/sites/prod/files/2017/06/f34/May%2011%20-%20Stewart%20-%20Tritium%20Production%20Assurance.pdf

[13] *Stockpile Stewardship and Management Plan, FY 2020*, National Nuclear Security Administration, United States Department of Energy, July 2019, p. 2-29. https://www.energy.gov/sites/prod/files/2019/08/f65/FY2020__SSMP.pdf

the spring of 2020, 1,792 TPBARs are planned to be loaded, which is the maximum number permitted by the current license.[14]

Preparations continue for the start of tritium production in Watts Bar 2. A request has been submitted to the Nuclear Regulatory Commission to amend the license of Watts Bar 2 to permit the irradiation of up to 1,792 TPBARs per fuel cycle.[15] Approximately 1,000 TPBARs are going to be fabricated and delivered to Watts Bar 2 for irradiation in its fuel cycle four, which is to begin in fall of 2020.[16]

It is anticipated that Watts Bar 2 will demonstrate the capability to irradiate the maximum 1,792 TPBARs in a later fuel cycle. Once that has been accomplished, the NNSA has stated: "Planned reactor production can be adjusted…"[17] Presumably this adjustment would depend on just how much tritium is being produced in each TPBAR and on the exact tritium production requirement at the time. To meet the goal of producing 2.8 kilograms of tritium per 18 month period, each reactor will probably irradiate between about 1,500 and the maximum 1,792 TPBARs per fuel cycle.

In sum, the U.S. program to produce tritium appears to be turning the corner. With the discharge of 1,584 TPBARs in the spring of 2020, Watts Bar 1 will likely demonstrate the necessary per reactor production rate of 1.4 kilograms of tritium in an 18 month period to meet the production goal of 2.8 kilograms of tritium in an 18 month period. Still, until tritium production begins at Watts Bar 2, the U.S. tritium stockpile will continue to decline. The earliest that tritium production at Watts Bar 2 will be sufficient to meet the production goal of 2.8 kilograms of tritium in an 18 month period is its fuel cycle five. Tritium produced in this fuel cycle will not be discharged until fall of 2023.

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[14] *Ibid.*

[15] "Tennessee Valley Authority; Watts Bar Nuclear Plant, Units 1 and 2," *Federal Register*, Vol. 84, No. 28, February 11, 2019, pp. 3259-3263. https://www.govinfo.gov/content/pkg/FR-2019-02-11/pdf/2019-01859.pdf

[16] *Stockpile Stewardship and Management Plan, FY 2020*, National Nuclear Security Administration, United States Department of Energy, July 2019, p. 2-29.

[17] *Ibid.*

Table 1

Actual and Projected TPBAR Irradiation

Approximate fuel cycle dates	Reactor	Number of TPBARs irradiated
Fall 2003 to Spring 2005*	Watts Bar 1	204
Spring 2005 to Fall 2006	Watts Bar 1	204
Fall 2006 to Spring 2008	Watts Bar 1	204
Spring 2008 to Fall 2009	Watts Bar 1	368
Fall 2009 to Spring 2011	Watts Bar 1	204
Spring 2011 to Fall 2012	Watts Bar 1	544
Fall 2012 to Spring 2014	Watts Bar 1	544
Spring 2014 to Fall 2015	Watts Bar 1	704
Fall 2015 to Spring 2017	Watts Bar 1	704
Spring 2017 to Fall 2018	Watts Bar 1	1,104
Fall 2018 to Spring 2020	Watts Bar 1	1,584
Spring 2020 to Fall 2021	Watts Bar 1	1,792
Fall 2020 to Spring 2022**	Watts Bar 2	~1,000

*This was the sixth fuel cycle for Watts Bar 1. The current fuel cycle (fall 2018 to spring 2020) is the sixteenth fuel cycle.
**Watts Bar 2 fuel cycle four.

Table 2

Watts Bar 1
Number of TPBARS Irradiated per Fuel Cycle, Average Tritium Produced per TPBAR and Total Tritium Produced per Fuel Cycle

Fuel Cycle	Number of TPBARs	Average Tritium Produced per TPBAR (grams)	Total Tritium Produced in Fuel Cycle (grams)
6	240	0.974	234
7	240	0.972	233
8	240	0.911	219
9	368	0.949	349
10	240	1.000	240
11	544	0.893	486
12	544	0.996	542
13	704	0.980	690
14	704	0.867	610
15	1,104	0.916	1,011