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June 12, 2017

History of U.S. Production of Tritium 1948-1988

Introduction

Tritium is a vital component of every U.S. nuclear weapon. Tritium makes it possible to produce boosted primaries in thermonuclear weapons. According to the British, such primaries are not subject to predetonation, which helps ensure that the weapon will produce the desired yield.[2]

Due to tritium's radioactive decay, continued production is required to maintain the U.S. nuclear weapon stockpile. The U.S. has always produced tritium by irradiating lithium in nuclear reactors. When irradiated by neutrons the isotope lithium 6 produces tritium by the reaction: lithium 6 + neutron = tritium + helium 4. Natural lithium consists of two isotopes, lithium 6 and lithium 7. Lithium 6 comprises 7.5% of natural lithium and lithium 7 the other 92.5%. It is possible to produce lithium which is enriched in the isotope lithium 6.

Between 1948 and 1988 the U.S. produced tritium in plutonium production reactors at Hanford and Savannah River by irradiating a lithium aluminum alloy. 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, the U.S. did not resume tritium production until 2003. Currently tritium is being produced at the commercial power reactor Watts Bar 1 located in Tennessee and operated by the Tennessee Valley Authority. I have previously written about the tritium production program at Watts Bar 1.[3]

In this paper I will provide a history of U.S. tritium production between 1948 and 1988. Three interesting conclusions result from this history.

First, though the U.S. tested its first boosted nuclear weapon in 1951, it did not quickly decide to deploy such weapons. The U.S. twice ended tritium production (in 1952 and 1954) and at one time appeared to prefer the use of U-233 instead of boosting. It was not until the latter part of 1955 that the decision was finally made to use boosted nuclear weapons with the first weapons being produced in 1957.

Second, until about 1960 the U.S. used natural lithium to produce tritium. In the 1960s the U.S. used 38.5% enriched lithium for tritium production. When tritium production ended at Savannah River in 1988, 50% enriched lithium was being used. When using a lithium aluminum alloy,

[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 and a faculty member of the Pardee RAND Graduate School, this paper is not related to any RAND project or the Pardee RAND Graduate School and therefore these organizations should not be mentioned in relation to this paper. I can be reached at GregJones@proliferationmatters.com
[2] Lorna Arnold, *Britain and the H-Bomb*, UK Ministry of Defense, Palgrave, 2001.
[3] Gregory S. Jones, "U.S. Increased Tritium Production Driven by Plan to Increase The Quantity of Tritium per Nuclear Weapon," June 2, 2016. Link

50% enrichment is the highest enrichment that can be used due to the need to retain the tritium within the target element.

Third, at the peak of the U.S. nuclear stockpile in the 1960s, the U.S. tritium stockpile was roughly 100 kilograms.

Tritium Production and the Development of Boosted Nuclear Weapons

In 1948 Hanford was tasked with producing tritium. In 1949 Hanford began to irradiate lithium fluoride target elements, though it soon shifted to using a lithium aluminum alloy which was 3.5 weight percent lithium. This low concentration of lithium ensures that the lithium is contained as a single phase as a solid solution in the aluminum, which provides the alloy with good corrosion characteristics. The irradiation was carried out in the H reactor which used highly enriched uranium/aluminum alloy as fuel. The alloy was 7.5 weight percent uranium (so-called J slugs). Facilities were built at Hanford to separate the tritium and the first tritium deliveries occurred in mid-1950.[4] Working with the tritium gave Hanford various problems as the tritium was hard to contain and resulted in significant worker exposure.

The histories of operations at Hanford and Savannah River do not give explicate reasons for the production of tritium. However, it appears that the initial purpose for tritium in the late 1940s was to produce a large yield device now known as the "classical super." The "super" was the initial design attempt to produce a hydrogen bomb. It envisioned using an atomic device to cause a fusion reaction in an external deuterium/tritium capsule which would in turn cause a large deuterium capsule to undergo fusion and thereby produce a large yield nuclear explosion. Apparently large quantities of tritium would be required and the construction of five heavy water moderated reactors was started at Savannah River. These five reactors would be dedicated to producing tritium by irradiating lithium.

However, in 1951 the U.S. discovered the correct design to produce a hydrogen bomb (the so-called Teller-Ulam device) which was successfully tested in November 1952 as the Mike test in the Ivy test series. This design apparently did not require any tritium. As a result, tritium production at Hanford was abruptly ended in early 1952.[5]

In 1953 there was renewed interest in tritium and the DR reactor began irradiating 3.5 weight percent lithium aluminum alloy targets (known as N slugs) using J slugs as fuel.[6] The reason for this renewed interest is unknown. Hanford began separating tritium in December 1953[7] but by May 1954 production of new J and N slugs ended.[8] In August 1954 Hanford ceased to separate tritium[9] even though the DR reactor continued to irradiate J and N slugs until March 1955.[10] It

[4] "Four Years at Hanford," General Electric, HW-22201, Richland, Washington, p. 35.
[5] "1952 at Hanford Works," General Electric, HW-26705, Richland, Washington, p. 11.
[6] "Monthly Report, Hanford Atomic Products Operation for April 1953, HW-27932, General Electric, May 20, 1953.
[7] "Monthly Report, Hanford Atomic Products Operation for December 1953, HW-30423, General Electric, January 22, 1954.
[8] "Monthly Report, Hanford Atomic Products Operation for May 1954, HW-31964, General Electric, June 22, 1954.
[9] "Monthly Report, Hanford Atomic Products Operation for August 1954, HW-32889, General Electric, September 17, 1954.

has been estimated that between 1949 and 1954 about 1.2 kilograms of tritium was separated at Hanford.[11]

Also in 1953 at Savannah River, a reactor loading was developed known as "LM" which was to irradiate lithium aluminum alloy targets to produce tritium.[12] However, in 1954, before any lithium aluminum alloy had been irradiated, the loading was changed to thorium in order to produce U-233. As late as May 1955 development research focused on U-233 with virtually no funds for tritium production.[13] Only experimental quantities of thorium were irradiated before the focus on producing U-233 ended, sometime later in 1955.

At the same time, the decision was made to shift back to tritium production at Savannah River. The first reactor began irradiating lithium in 1956. Apparently the need for speed was so great that the fuel used a design that could be implemented quickly even though it was known that it would produce tritium inefficiently.[14] By 1957 the L, C and K reactors at Savannah River were producing tritium. These three reactors would be the main tritium producers for the U.S. into the 1960s.

A history of Savannah River has reproduced a portion of a 1955 de Pont report on these gyrations:[15]

> The original purpose [of the Savannah River facilities] was the production of plutonium, together with the maximum tritium producible with natural uranium as the fuel. Almost immediately, emphasis shifted to maximum plutonium production. Soon interest in tritium revived and about two years ago, it appeared that the plant would be primarily a tritium producer. Again, as a result of new information, tritium dropped out of the picture. Instead, it was believed that U-233 producible from thorium, might be a major product. This interest waned and although some U-233 has been produced, it is no longer in the production forecast. Instead, interest in tritium has revived more bullishly than ever before…

The U.S. tested its first boosted weapon in May 1951 as the Item test in the Greenhouse test series. Yet clearly the U.S. did not quickly decide to deploy boosted weapons since it stopped tritium production in 1952 and again in 1954. The temporary emphasis on U-233 is interesting. The Soviet Union used U-233 in its first two-stage thermonuclear test in 1955.[16] It is possible

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[10] "Monthly Report, Hanford Atomic Products Operation for March 1955, HW-35891, General Electric, April 20, 1955.

[11] C. T. Kincaid *et al.*, "Inventory Data Package for Hanford Assessments," PNNL-15829, Rev. 0, Pacific Northwest National Laboratory, June 2006, p. D.2.

[12] "Savannah River Plant Engineering and Design History," Volume II, #100-R,P,L,K & C Areas, DPE-971, E. I. du Pont de Nemours & Co. (Inc.), January 1957.

[13] L. C. Evans, "Process Development Review," DPW-55-261, E. I. du Pont de Nemours & Company, May 17, 1955.

[14] D. F. Babcock and R. L. Menegus, "Hazards Summary Memorandum-Savannah River Reactors, The Production of Tritium Using Tubular Fuel Elements," DPW-56-353, E. I. du Pont de Nemours & Co., Wilmington, Delaware, September 1956.

[15] Mary Beth Reed *et al.*, "Savannah River Site at Fifty," U.S. Department of Energy, 2003, p. 385.

[16] David Holloway, "Research Note: Soviet Thermonuclear Development," *International Security*, Winter 1979/80, Vol. 4, No. 3, p. 195.

that the U.S. planned to use U-233 as a plutonium substitute in order to try to avoid predetonation problems in thermonuclear primaries. The U.S. decided ultimately to use boosted primaries for thermonuclear weapons and from the latter part of 1955 on this would be the main reason for U.S. tritium production. In 1956, facilities at Savannah River began to extract large amounts of tritium from lithium targets and in 1957 the facilities began to fill the gas reservoirs of boosted weapons.[17]

Lithium Enrichment Used for Tritium Production

Throughout the 1950s natural lithium was used to produce tritium. In 1953 the U.S. began small-scale production of lithium enriched in lithium 6 for thermonuclear weapon secondaries. In 1955 the U.S. began large-scale production of enriched lithium using a monothermal lithium amalgam/lithium hydroxide chemical exchange process. Between 1953 and 1963 when production ended, the U.S. had produced approximately 400 metric tons of enriched lithium.[18] The lithium so produced had three enrichment levels, 95.5%, 60% and 40%.

In 1960 Hanford was developing the "E-N load" as a possible means of producing tritium. This was a combination of 0.95% enriched uranium fuel elements (E slugs) and lithium aluminum alloy target elements (N slugs) that would efficiently produce plutonium and tritium. At this time 38.5% enriched lithium was available and Hanford's analysis showed that somewhat more plutonium and tritium could be produced using this material compared with using natural lithium.[19] As a result, when three E-N test loads were irradiated in the H reactor from 1961 to 1963, 38.5% enriched lithium was used. Though these tests were successful, large-scale tritium production was not undertaken at Hanford. Later in the 1960s, Hanford continued to explore options for the production of tritium using 44% enriched lithium in a lithium aluminum alloy that was 3.2% weight percent lithium.[20] These options remained theoretical, as instead almost all of the Hanford reactors were shut down.

Less information is available for the reactors at Savannah River though it is known that when tritium production began in the 1950s, natural lithium was used. Savannah River stopped producing tritium in 1988 when the K reactor was shut down for safety reasons. At that time Savannah River was irradiating 50% enriched lithium in a lithium aluminum alloy that was 3.2 weight percent lithium.[21] For lithium aluminum alloy targets, 50% enriched lithium is the maximum that can be used since the tritium is retained in the target element by binding with the residual lithium.[22]

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[17] N. Stetson et al., *Savannah River Production Reactor History*, CIV-685-2A, September 1963.
[18] "Declassification of the Quantity of Enriched Lithium Produced at the Y-12 Plant in Oak Ridge, Tennessee," U.S. Department of Energy
[19] R. Nilson, "Conversion Ratio Incentive for Using Black Mint in an E-N Load," HW-63668, General Electric, Richland, Washington, January 28, 1960.
[20] R. L. Miller, "Hanford Isotope Production Capabilities for Single Pass Reactors," DUN-4979, Douglas United Nuclear Inc., Richland, Washington, December 12, 1968.
[21] W. R. McDonell, "Aluminum-Lithium Target Behavior," WSRC-RP-89-970, Westinghouse Savannah River Company, October 1989.
[22] M. R. Louthan Jr., "Aluminum-Lithium Technology and Savannah River's Contribution to Understanding Hydrogen Effects in Metals," WSRC-MS-2000-00061.

Approximate Tritium Stockpile Size in the Mid-1960s

Little information is available on the total size of the U.S. tritium stockpile but an inference can be drawn from the annual capacity of a proposed tritium extraction facility. In 1965 Hanford examined the possibility of building a tritium extraction facility that would replace the facility at Savannah River.[23] It would have an annual capacity of either 5 kilograms or 7 kilograms per year. These capacities would imply a steady-state tritium stockpile of 89 kilograms and 125 kilograms respectively.[24] This facility was never built but the capacity range implies that the maximum size of the U.S. tritium stockpile near the time of the peak of the U.S. nuclear weapon stockpile was somewhere around 100 kilograms.[25]

The main source of tritium production before 2003 was Savannah River. Since 1956 the tritium extraction facilities have been and still are at Savannah River. As I have written elsewhere, the current U.S. tritium stockpile is about 20 kilograms and may be expanded to about 30 kilograms.[26]

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[23] G. P. Kesel and D. D. Wodrich, "Tritium Extraction Facility Study – 1965," RL-SEP-676, General Electric, Richland, Washington, August 20, 1965.

[24] The steady-state stockpile of tritium is one where the annual decay of tritium is counter-balanced by the production of new tritium. The steady-state stockpile of tritium is found by multiplying the annual rate of tritium production by the mean-life of tritium which is 17.8 years. The mean-life is found by dividing the half-life by ln 2.

[25] Before the 1965 Hanford report was declassified in the 1990s, the National Resources Defense Council estimated the tritium inventory in the mid-1960s to be about 74 kilograms. See: Thomas B. Cochran, William M. Arkin, Robert S. Norris and Milton M. Hoenig, "Nuclear Weapons Databook: Volume II, U.S. Nuclear Warhead Production," Ballinger Publishing Company, Cambridge, Massachusetts, 1987, p. 180.

[26] Gregory S. Jones, "U.S. Increased Tritium Production Driven by Plan to Increase The Quantity of Tritium per Nuclear Weapon," June 2, 2016. Link