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Tritium production

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Summary

Tritium is an important material used in most, if not all, nuclear weapons. It is therefore also of importance in the field of export control. This report discusses production methods and availability of this hydrogen isotope.

Tritium is radioactive, and about 5.5 percent of existing stocks undergo radioactive decay to helium-3 every year. Tritium is produced in nuclear reactors by neutron capture on lithium-6, and remaining stocks are processed regularly to remove (and capture) the accumulated helium-3.

The infrastructure required to produce tritium is complex and expensive. It spans from the mining of lithium through enrichment in lithium-6 and shaping of this for use as target material in nuclear reactors to extraction and purification of tritium and handling of tritium reservoirs. These processes are illustrated using the United States as an example.

Despite the complexity, no serious, potentially show-stopping bottlenecks to a nuclear-weapon programme were identified.

Sammendrag

Tritium er et viktig materiale som benyttes i de fleste, om ikke alle, kjernevåpen. Av den grunn er det også viktig i en eksportkontrollsammenheng. Rapporten tar for seg produksjon og tilgjengelighet av denne hydrogenisotopen.

Tritium er radioaktivt, og ca. 5,5 prosent av beholdningen omdannes årlig til helium-3. Tritium produseres i kjernereaktorer ved nøytronbestråling av litium-6. Eksisterende beholdninger må behandles med jevne mellomrom for å fjerne (og samle opp) helium-3.

Nødvendig infrastruktur for produksjon av tritium er omfattende og kostbar. Den spenner fra utvinning av litium fra gruver, via anrikning av litium-6 og klargjøring av dette for bestråling, til utvinning og rens av produsert tritium og håndtering av tritiumbeholdere for kjernevåpnene.
I rapporten blir disse prosessene illustrert med USA som eksempel.

Prosessene er komplekse, men det er likevel ikke funnet noen alvorlige flaskehalser som i sin tur kunne påvirke utviklingen av kjernevåpen.

Contents

1 Introduction

Tritium is an important material in nuclear weapons where it is used in neutron generators, which initiate the nuclear chain reaction, as well as in boosting the chain reaction. Because of this, it is also of importance in the field of export controls. After a brief introduction about tritium and its applications, this report discusses production methods and availability of this hydrogen isotope.

1.1 Tritium

As illustrated in Figure 1.1, tritium is an isotope of hydrogen also referred to as hydrogen-3, H-3, ^{3}H or T. It is radioactive with a half-life of 12.32 years, decaying by beta emission:

$$^3\mathrm{H} \rightarrow {}^3\mathrm{He} + \mathrm{e}^- + \bar{\nu}_\mathrm{e} \qquad (1.1)$$

That is, it decays into a helium-3 nucleus, an electron and an electron antineutrino. The average energy of the decay electron (or β-particle) is only 5.7 keV, implying that this radiation penetrates less than 1 cm of air, and that it cannot penetrate the outermost dead layer of human skin.

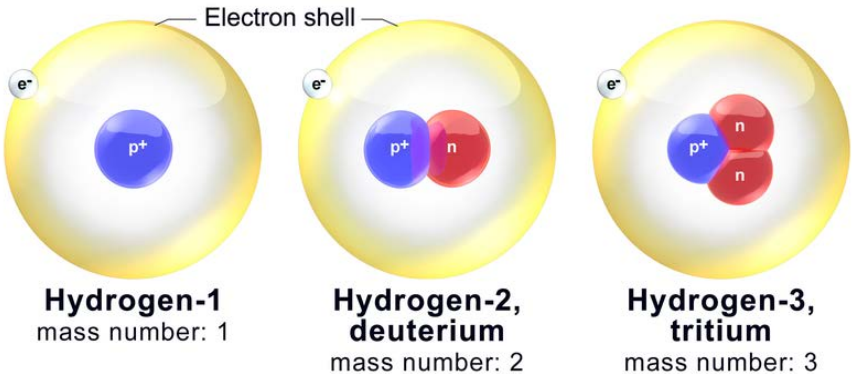

*Figure 1.1 Hydrogen isotopes. All hydrogen atoms contain one positively charged proton (labelled p^+) in a nucleus "surrounded by" one negatively charged electron (labelled e^-). In addition, deuterium (*H-2 *or* D*) has one neutron (labelled n) in its core, and tritium (*H-3 *or* T*) has two neutrons. (Illustration by "BruceBlaus", from wikimedia.org under Creative Commons Attribution 3.0 Unported license.)*

Tritium has commercial uses as an energy source in closed capsules surrounded by a fluorescing compound. It can then provide illumination independently of any external power sources, and this is made use of in, for example, exit signs, runway lights and light wands. Tritium is also used as a radioactive tracer in biological studies in the form of tritiated water (HTO or T_2O). If and when the world gets commercial fusion power plants, tritium will become a much sought after commodity. (1)

1.2 Tritium and nuclear weapons

Tritium is relevant to nuclear weapons because it can fuse with deuterium (shown in Figure 1.1) in a process that generates a free, high-energy neutron (cf. Figure 1.2):

$$D + T \rightarrow {}^4He\ (3.5\ MeV) + n\ (14.1\ MeV) \qquad (1.2)$$

The neutrons generated by DT fusion may in turn be used to initiate the nuclear chain reaction in a fission weapon or to boost the yield of such a weapon. These applications most likely require a few grams of tritium for each weapon, most of it used for boosting. Tritium is an essential component of *all* current United States nuclear weapons (2).

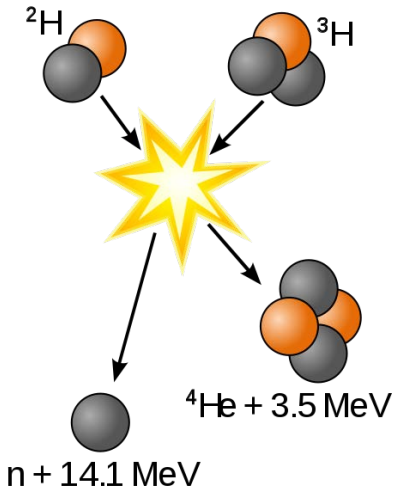

Figure 1.2 DT fusion. A deuterium nucleus (^2H) (also known as a deuteron) fuses with a tritium nucleus (^3H) (also known as a triton). The fusion process, which is only possible if the relative speed of the two nuclei is sufficiently high to overcome the electrostatic repulsion between them, results in an ordinary helium nucleus (^4He) moving with a kinetic energy of 3.5 MeV as well as a high-energy neutron moving with 14.1 MeV. The light brown particles in the sketch are protons, and the grey are neutrons. (Illustration from wikimedia.org, public domain.)

The DT fusion used to initiate the chain reaction takes place in a neutron generator, a small accelerator inside a tube. Here, ionised deuterium atoms, that is, deuterium nuclei, are accelerated towards a cathode covered in a metal tritide, or vice versa, tritium nuclei may be

accelerated towards a metal deuteride. In any case, the accelerator provides the necessary energy to overcome the electrostatic repulsion between the two nuclei. The overall result will be a short pulse containing millions of neutrons, sufficient to initiate the nuclear chain reaction at the optimal point in time (3). The neutrons are emitted in all directions, and the neutron generator may be placed outside the "physics package" (that is, outside the nuclear explosive assembly in the warhead). Neutron generators are made for a number of commercial purposes, but few details are available about neutron generators for use in nuclear weapons.

The main concern when it comes to tritium supply, regards tritium used for boosting of fission charges. Both applications are crucially important, but fusion boosting appears to require significantly larger quantities of tritium. Tritium and deuterium for boosting are supplied to the weapon from an external reservoir (gas bottle) as part of the arming process of the weapon.[1]

Since about 5.5% of existing tritium decays every year, the tritium assigned to each weapon must be regularly replenished. This is done by removing the weapon's tritium reservoir and exchanging it with a newly refilled reservoir (5). Figure 1.3 shows what may be such a reservoir. Neutron generators must also be periodically replaced (7). Even though tritium is expensive and elaborate to produce, extract and handle, the supply of tritium does not so far seem to have limited the nuclear-weapon programmes in the nuclear-weapon states.

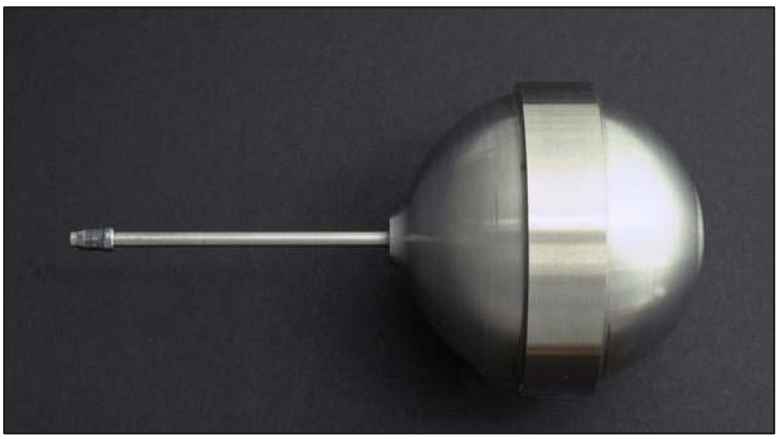

Figure 1.3 A device claimed to be a tritium reservoir most likely manufactured at the Department of Energy Kansas City Plant (6).

Information about the situation in the United States is publicly available and is provided as an example here. The United States closed its aging Department of Energy (DOE) tritium production facility at the Savannah River Site in South Carolina in 1988. Total tritium production in the United States until then is estimated at 225 kg, of which about 150 kg has been lost to decay. Existing supplies in addition to excess tritium from dismantled weapons would be sufficient to run the nuclear-weapon programme for many years thereafter. Exactly how many years, would of course depend on the number of warheads in future stockpiles. Some estimates made in the 1990s are presented in Ref. (8). With an arsenal of 3500 nuclear

[1] There are many references to "tritium bottles" or "tritium reservoirs" in open literature. Ref. (4) states that the tritium gas (T_2) is mixed with deuterium gas (D_2) in the reservoirs.

warheads, the United States would have run out of tritium already in 2015; with 1000 warheads, the supplies would last until 2032, and with 100 warheads until 2073. It was assumed that each warhead contains 4 g of tritium, and that the tritium pipeline (tritium tied up in various facilities and processes) in 2026 could be reduced from about 7 kg to about 2 kg. The 2073 estimate further assumes that the DOE stops its commercial sales of tritium of about 0.15 kg per year. (8)

2 Tritium production

Hydrogen in nature is a mix of 99.9885% “ordinary hydrogen” (H-1) and 0.0115% deuterium (9). Trace amounts of tritium are also present. This tritium has been produced by cosmic radiation interacting with atoms in the upper atmosphere and has subsequently fallen to earth as rain. The concentration of tritium in nature is too low to permit extraction for commercial or nuclear weapons use, however. (1)

2.1 Possible processes

Several nuclear reactions lead to the generation of tritium. They generally imply neutron bombardment of light nuclei, but few of them are relevant for large-scale tritium production. The most important reaction is

$$^{6}\mathrm{Li} + \mathrm{n} \rightarrow {}^{4}\mathrm{He}\ (2.05\ \mathrm{MeV}) + \mathrm{T}\ (2.75\ \mathrm{MeV}) \qquad (2.1)$$

Note that reaction (2.1) is exothermic and therefore may be initiated by neutrons of any energy. To make use of this reaction, one would irradiate lithiuim-6 in a nuclear reactor, preferably one designed for the purpose.

The fact that natural lithium contains 7.59% lithium-6 mixed with 92.41% lithium-7 (9) constitutes a practical obstacle to tritium production. It is possible to produce tritium from lithium-7 according to

$$^{7}\mathrm{Li} + \mathrm{n} \rightarrow {}^{4}\mathrm{He} + \mathrm{T} + \mathrm{n}' \qquad (2.2)$$

However, this is an endothermic reaction requiring that the incident neutron has an energy of at least about 2.5 MeV, an energy that is rare among neutrons in a nuclear reactor. The preferred choice among nuclear-weapon states appears to be to separate the isotopes before irradiation. The separation is a complicated process. It is discussed further in Section 2.3.

An alternative that has been considered in the United States, is to use a high-energy, high-current particle accelerator to generate the necessary neutrons (referred to as *Accelerator*

Production of Tritium or APT). In such an accelerator, a proton beam would hit a tungsten target knocking out neutrons and protons, which in turn will knock out even more neutrons and protons. A thorough conceptual design study that was carried out in the 1990s, recommended building a 1700 MeV linear proton accelerator with a 100 mA beam current for this purpose (10). The knocked-out neutrons would then be used to produce tritium. The conceptual design included a comprehensive "target/blanket assembly" containing heavy-water cooled tungsten rods, as well as lead and (ordinary) cooling water providing both shielding and moderation of the neutrons. Inside this assembly, tritium would be produced by (exothermic) neutron capture on helium-3:

$$^{3}\mathrm{He} + \mathrm{n} \rightarrow {}^{1}\mathrm{H} + \mathrm{T} \tag{2.3}$$

The helium-3 would be pumped through the target/blanket assembly in a closed system in which the tritium production would take place. In a separate unit outside the assembly, tritium would subsequently be separated from helium by cryogenic distillation. It is estimated that each incident proton would lead to the creation of about 40 tritium atoms. This method has the obvious advantage of avoiding a nuclear reactor and therefore not generating any spent nuclear fuel. On the other hand, it requires forefront accelerator technology as well as an estimated 500 MW of electricity to operate the accelerator. (10)(11)

A third option is to use tritium generated in heavy-water moderated reactors. Deuterium nuclei in the heavy water may capture reactor neutrons and become tritium nuclei. The likelihood of this happening is not very high, however, so this is not a very efficient way of producing large quantities of tritium. Wikipedia reports that Canada, which has a number of heavy-water moderated nuclear power plants, separates out about 2.5 kg of tritium a year from the processing of about 2.5 million kilograms of heavy water (12). This very significant quantity of tritium is commercially available, but is prohibited from use in nuclear weapons (11).

2.2 Tritium production in the United States – the CLWR approach

As was done in Section 1.2, the situation in the United States is used as an example to illustrate the challenges faced by all nuclear-weapon states. This section presents an overview of tritium production in the United States from the beginning in 1949 until today.

Between 1944 and 1949, four nuclear reactors were built at Hanford in Washington to produce plutonium for nuclear weapons as well as other isotopes of military interest. Two reactors, the B Reactor (Figure 2.1) and the most recently built H Reactor were modified for irradiation of targets containing lithium-6. Tritium production at this site took place from 1949 until 1954. After irradiation, the target material was taken to a nearby facility where it was melted in a vacuum furnace, and the tritium was then drawn off in the vacuum line. The tritium processing facility at Hanford was shut down in 1955. In total, about 1.2 kg of tritium was extracted at this facility during its lifetime. When the first thermonuclear device was detonated in the Ivy Mike test at the Enewetak Atoll in the Pacific Ocean on 1 November 1952, it used tritium produced at Hanford. (6)(13)(14)

The Savannah River Plant (SRP) in South Carolina, since 1989 known as the Savannah River Site (SRS), was designed in 1950 to produce not only tritium, but also weapons grade plutonium and other special nuclear materials such as plutonium-238. Five dedicated reactors, known as the R, P, L, K and C Reactors, were built, and by March 1955, they were all operational. Lithium was enriched in lithium-6 at the Oak Ridge Y-12 Plant in Tennessee (see more about lithium isotope separation in Section 2.3). At SRP, lithium-6 was alloyed with aluminium and shaped into use in control rods or in driver fuel assemblies. The first tritium extraction and purification facility at SRP became operational in 1955, and since then all tritium extraction in the United States has taken place at SRP/SRS. The prototype reactor, the R Reactor, shut down already in 1964 due to lack of demand. The L Reactor was shut down for upgrades in 1968 and not started again until 1985, the same year that the C Reactor was shut down due to cracks in its primary system. Tritium production at SRP ended with the shutdown of the remaining P, L and K Reactors in 1988. The total amount of tritium produced is not available from official sources. Based on an analysis in *Nuclear Weapons Databook* (16) for the years up to 1984 in combination with comments in the published history of SRP/SRS (16), an estimated total of about 190 kg (±30 kg) of tritium was produced at SRP. (6)(17)

Figure 2.1 The B Reactor at Hanford. The reactor is inside the tall building at the centre of the picture. The tritium extraction facility is in the building to the far right (6). (Picture from wikimedia.org, public domain.)

In the years from the wartime Manhattan Project to 1963, a total of nine reactors was built at the Hanford site to produce weapons grade plutonium Pu-239 and other isotopes such as tritium and polonium-210 for nuclear weapons. The Hanford N Reactor Coproduct Program for tritium

production produced significant amounts of tritium between 1965 and 1967. The N Reactor, which first achieved criticality in 1963, was a unique, dual-use, 4000 MW_t reactor that could supply electric power to the civilian power grid while producing isotopes for nuclear weapons. The main purpose of the tritium studies was to develop technologies and materials that could be utilised for tritium breeding blankets in fusion reactors. After a thorough review of a number of lithium-bearing target materials, the best choice was found to be high melting point ceramic lithium aluminate ($LiAlO_2$). Four demonstration production runs led to the production of an estimated 9.4 kg of tritium, which was extracted at the SRP vacuum furnaces.[2] (6)(14)

The shutdown of the SRP reactors in 1988 was soon followed by the collapse of the Soviet Union in 1991 and the end of the cold war, which in turn was followed by a major reduction in the number of nuclear weapons. The need for tritium could then for a long time be covered by existing stocks and by processing and recycling tritium from excess weapons.

In the mid-1990s, the United States began planning for new tritium production as different future disarmament scenarios would lead to a lack of tritium sometime in the 2005–2015 timeframe. After investigating various options such as using a specially designed reactor or APT, the National Nuclear Security Administration (NNSA) decided in 1998, at least initially, to make use of commercial light-water reactors (CLWR) (18). This solution was both the cheapest and the quickest to implement. The main concerns were the combined use of the same reactor facility for both civilian and military purposes and the increased proliferation risks associated with that. (11)

Modern reactor fuel used in the United States is generally manufactured from enriched uranium of foreign origin, which is allowed to be used only for peaceful purposes. After closing down its last enrichment facility, a gaseous diffusion plant in Paducah, Kentucky, in 2013, the United States no longer has a source of fresh, unobligated uranium fuel[3] for the commercial reactors to be used in the CLWR programme. If two reactors are used for tritium production, the stocks of domestically enriched reactor fuel will start to run out in the mid-2020s. While awaiting the construction of a new enrichment facility, which could maybe be operational in the mid-2030s, the unavoidable temporary solution seems to be to blend down existing highly enriched uranium. Another possibility could be to reprocess the large amounts of spent naval nuclear fuel in storage at Idaho National Laboratory and use this as a source of enriched, unobligated uranium. (6)(19)

The CLWR approach is illustrated in Figure 2.2. Most CLWRs make use of ceramic rods containing boron-10 as burnable absorbers. To produce tritium, many of these rods are replaced with specially designed ceramic rods containing neutron-consuming lithium-6 in the form of lithium aluminate. These special rods are referred to as *tritium-producing burnable absorber rods* or TPBARs. In the words of the NNSA (20), the tritium produced in the TPBARs is "captured almost instantaneously in a solid zirconium material in the rod, called a 'getter.' The

[2] The amounts of produced tritium quoted in this chapter do not add up to the total quoted in Section 1.2. This illustrates the uncertainty of these estimates.
[3] "Unobligated" uranium is not constrained by international obligations and may be used for any purpose.

solid material that captures the tritium as it is produced in the rod is so effective that the rod will have to be heated in a vacuum at much higher temperatures than normally occur in the operation of a reactor to extract the tritium for eventual use in the nuclear weapons stockpile." The extraction takes place in the vacuum furnaces at the Savannah River Tritium Enterprise at the SRS. (20)

So far, all TPBARs have been irradiated in Unit 1 at Watts Bar Nuclear Plant, which is operated by the federally owned Tennessee Valley Authority (TVA). This unit began operation in 1996, and the first irradiation (with 240 TPBARs) to produce tritium took place in its sixth 18-month fuel cycle starting in the autumn of 2003. The number of TPBARs remained low during several cycles because of unexpectedly high releases of tritium. In 2009, the reactor was licenced for up to 704 TPBARs, and this number of rods were irradiated in Cycle 13 and Cycle 14. Production data was published in 2017 up to and including Cycle 14 (21). At that time, a total of 3824 TPBARs had been irradiated producing 3601 g of tritium, which implies an average of about 0.94 g per TPBAR. The tritium was extracted at the new Tritium Extraction Facility at SRS, which opened in 2007. (6)

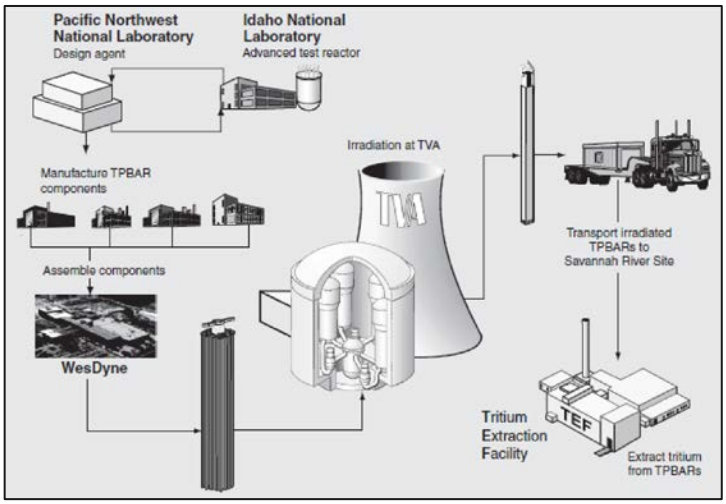

Figure 2.2 Present-day United States approach to tritium production (20). The drawing illustrates the flow of materials and shows the actors involved. TVA is the federally owned Tennesse Valley Authority, which among other tasks operates three nuclear power plants.

Watts Bar Unit 2 began operation in 2016, and currently the plan is to produce tritium also in this unit, starting in its Cycle 4 in 2022. In combination with a higher maximum number of TPBARs being allowed in each cycle, tritium production will most likely increase significantly in the near future. Current plans (as of 2017) are shown in Table 2.1. If they are carried out, the irradiation runs up to approximately 2028 would provide an estimated 15–16 kg of tritium. Furthermore, as long as both reactors remain fully operational, they will meet the NNSA tritium production target of 2.8 kg per 18-months cycle (22).

Table 2.1 Planned irradiation of TPBARs at Watts Bar Nuclear Plant Unit 1 (WBN1) and Unit 2 (WBN2). Each cycle lasts about 18 months, and Cycle 21/Cycle 8 should be complete in 2028. (Data from Ref. (21).)

WBN1	WBN2	Number of TPBARs	
Cycle	Cycle	WBN1	WBN2
15	2	1104	0
16	3	1408	0
17	4	1552	704
18	5	1504	1504
19	6	1504	1504
20	7	1504	1504
21	8	1504	1504
		10080	**6720**

In addition to Watts Bar, Sequoyah Nuclear Plant, which also belongs to TVA, is authorised for CLWR production of tritium. There does not appear to be a need for this extra production capacity in the foreseeable future, however. (6)

2.3 Availability of lithium-6

Presently, all large-scale production of tritium starts from lithium-6. In other words, there must be a supply of natural lithium, and one must have facilities for isotope separation to produce material enriched in lithium-6.

Lithium is one of the lightest elements in nature and exists in fairly large quantities around the world. Presently, an estimated 65% of all lithium on the global market is used in the manufacture of rechargeable batteries for all kinds of products from mobile telephones to cars. Another major area is ceramics and glass production (18%). The present demand for this material is large, and this has in turn led to an increase in identified lithium resources, which are presently about 80 million (metric) tons worldwide. In 2019, the demand for lithium fell compared to 2018, and the price of lithium therefore fell as well. Estimated production from mining of lithium is presented in Table 2.2. World production fell almost 20% to an estimated 77 000 tons in 2019, while the reserves are still quite plentiful.[4] (23)

For tritium production, natural lithium must be enriched in lithium-6. Because the relative mass difference between lithium-6 and lithium-7 is quite large, this isotope separation not as difficult as separating, for example, uranium-235 from uranium-239, but it is still a complex process. Efforts to develop suitable lithium isotope separation processes began in 1949 at Oak Ridge in Tennessee, USA. The resulting COLEX (for "column exchange") process made use of the fact that lithium-6 has a greater for affinity for mercury than does lithium-7. In the COLEX process,

[4] In the words of Ref. (23), *reserves* "may be considered a working inventory of mining companies' supplies of an economically extractable mineral commodity." *Identified resources* imply amounts known to exist, but not necessarily available for (profitable) extraction.

a counter-current flow of lithium amalgam[5] and an aqueous solution of lithium hydroxide (LiOH) passes through a cascade of stages until the desired enrichment is reached. Lithium-6 is subsequently separated from the amalgam, and lithium-7 is electrolysed from the solution of lithium hydroxide.[6] Column exchange processes containing mercury are reportedly still used for large-scale lithium isotope separation in Russia and China. Other methods, such as atomic vapour laser isotope separation (AVLIS) and chemical separation using crown ethers, have been investigated and developed (25)(26), but they have apparently not been applied to commercial production yet. (27)(28)

Table 2.2 World mine production and reserves of lithium. Figures for 2019 are estimated. "NA" indicates that a given figure is not available. Production figures for the United States were not published to avoid disclosing company proprietary data. (Data from Ref. (24).)

	Mine production		Reserves
	2018	2019	
Argentina	6 400	6 400	1 700 000
Australia	58 800	42 000	2 800 000
Brazil	300	300	95 000
Canada	2 400	200	370 000
Chile	17 000	18 000	8 600 000
China	7 100	7 500	1 000 000
Namibia	500	0	NA
Portugal	800	1 200	60 000
United States	NA	NA	630 000
Zimbabwe	1 600	1 600	230 000
Other	0	0	1 100 000
World total (rounded)	**95 000**	**77 000**	**17 000 000**

Large-scale use of the COLEX process took place at the Y-12 Plant at Oak Ridge from 1955 until 1963, when lithium isotope separation ended in the United States. The COLEX process employed large amounts of mercury. Used mercury was purified and reused, but significant amounts were lost in wastes, spills and through evaporation. In all, close to 11 000 tons of mercury was employed in the COLEX process at Y-12. Of this, about 900 tons have not been accounted for, and an estimated 330 tons of this are believed to have ended up in the surrounding environment. (27)(28)

When lithium-6 enrichment ended in 1963, the United States had generated a large supply of enriched lithium-6 for future use. No new lithium-6 has been produced in the country since then, but material from old nuclear weapons is being purified and reused. Efforts are ongoing to

[5] An *amalgam* is an alloy of mercury with other metal(s).
[6] Note that while lithium-6 is of interest in this report because of its high neutron cross section for tritium production, there is a large demand for lithium-7 in the nuclear industry for the opposite reason; it has a very low neutron cross section (24).

establish a new Lithium Processing Facility at Y-12. Until now, the old facilities from the days of the Manhattan Project have still been used. The official strategy of the NNSA includes

(1) sustaining the current Manhattan Project-era infrastructure and equipment until transition to the Lithium Processing Facility;

(2) increasing the usable supply of lithium by dismantling and recycling lithium components using small-scale technologies to purify and convert lithium; and

(3) designing and constructing the Lithium Processing Facility to house lithium processing capabilities by 2030.

Detailed information about processes and numbers are not available. (22)

2.4 Availability of helium-3

As mentioned in Section 2.1, APT utilises helium-3 as breeding material for tritium. Natural helium contains a very small fraction of helium-3 (1.34 ppm (9)), too small for commercial or nuclear weapons use. Instead, one makes use of the fact that helium-3 is a decay product of tritium, cf. reaction (1.1). All helium-3 used in the Western world comes from the Savannah River Tritium Enterprise at SRS where it is recovered during the tritium purification process. The amounts produced are not publicly available. Helium-3 has civilian uses in, for example, neutron detectors, generation of ultra-cold temperatures, oil exploration, medical imaging and fusion research, and it has in recent years been valued at between 2000 USD and 2500 USD per litre. (4)

Future availability of helium-3 from APT is somewhat of a chicken-and-egg situation: Sufficient amounts of tritium must be produced to generate the necessary quantities of helium-3, which in turn will be used to produce tritium. This can only work if there are other sources of tritium in addition to what is produced by APT.

3 Final remarks

This report has discussed the entire chain of facilities required to produce tritium. This is a complex and expensive endeavour as illustrated by the picture in Figure 3.1 of the Savannah River tritium facilities, which just processes existing tritium.

Tritium is radioactive, and about 5.5% of existing stocks undergo radioactive decay to helium-3 every year. Tritium is produced in nuclear reactors by neutron capture on lithium-6, and remaining stocks are processed regularly to remove (and capture) the accumulated helium-3. As

shown in the report, this provides a sufficient supply for the foreseeable future for the United States, and one would expect the same conclusion for other nuclear-weapon states as well.

The infrastructure required for tritium production, including the production of the feed material lithium-6, is discussed in the report and illustrated by extensive information about relevant conditions in the United States. Processes are complex and expensive, but no serious, potentially show-stopping bottlenecks were identified.

The production of fissile materials for a nuclear-weapon programme requires in itself a comprehensive infrastructure of dedicated facilities. The extra complexities required to produce tritium would not be expected to halt any weapons programme, large or small.

Figure 3.1 Savannah River tritium facilities at the Savannah River Site in South Carolina, USA. (Picture from Ref. (4).)

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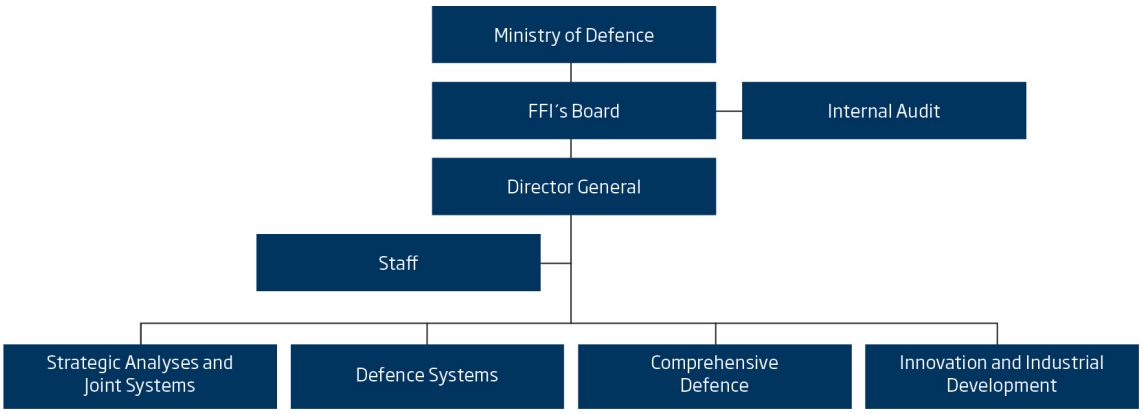

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