Chapter 1

Dealing with the civilian/military ambivalence toward tritium

1.1 Introduction

Tritium has various military as well as civilian applications. The latter have always lagged behind military applications and were partly enabled or triggered by the availability of tritium from military production.

Tritium is believed to be used by all nuclear weapon states in most of their nuclear warheads. Even de facto nuclear weapons states have engaged in tritium technology. Tritium on its own is neither sufficient to produce nuclear weapons, nor a necessary component to design a simple nuclear warhead. It becomes strategically significant only when it is combined with either plutonium or highly enriched uranium-235 (HEU) in a complex design which requires a high degree of technical competence. Whereas plutonium-239 and uranium-235 are the fissile materials that provide the yield, the main military application of tritium is to fuse it with deuterium so as to release neutrons which in their turn increase ("boost") the efficiency and thus the explosive yield of a given amount of plutonium-239 and uranium-235. Due to its short half-life of 12.3 years, tritium has to be replenished on a regular basis. Since no natural resources are available, tritium has to be produced in nuclear reactors, which implies the diversion of nuclear energy for military purposes.

With the horizontal and vertical proliferation of know-how and the capacity to produce nuclear weapon, tritium and tritium technology are clearly gaining significance within the nuclear proliferation process. This is exemplified by the partially successful attempts of undeclared nuclear weapons states to acquire tritium and tritium technology or by the large investments planned by the U.S. to develop and establish a new military tritium production facility despite the progress in nuclear disarmament.

In the 1990s, the control of tritium became a topic on the political agenda which resulted in several activities to strengthen and harmonize export control measures

and in a mandate for EURATOM to control tritium that is being supplied by Canada to fusion research facilities in EURATOM member states. A further prominent proposal is to consider tritium during negotiations for a verified agreement on a production cutoff for fissile materials. Tritium might even play a key role in the nuclear disarmament process due to its radioactive decay.

Neither the quantity of tritium nor its mode of production, chemical state, physical condition, or degree of purity determines or indicates an intended military or civilian use. Since it is impossible to physically differentiate between "military tritium" and "civilian tritium," the respective sociotechnological environment has to be taken into account if a judgment is required. Since physical barriers can never be completely tight, the most efficient way to prevent the diversion of tritium for military purposes, besides binding and verified political commitments, is to minimize any production and application.

1.2 Tritium and tritium technology

Tritium[1] (symbol: T or ^{3}H) is the superheavy isotope of hydrogen, which is the lightest element with just one proton in its nucleus. Ordinary hydrogen (H or ^{1}H) has no neutron; heavy hydrogen (D or ^{2}H), also known as deuterium, has one neutron; and tritium has two neutrons in its nucleus. Their relatively large mass differences have no significant influence on the chemical behavior of the three hydrogen isotopes. Tritium is a gas and appears in molecular form as T_2. It can substitute ordinary hydrogen in any of its compounds. Of particular importance is its oxidized form as "superheavy" water (T_2O), as tritiated water (HTO), or tritiated heavy water (DTO). The main physical data are summarized in Table 1.1.

Table 1.1 Main physical data of tritium.

atomic weight	3.017
half-life [years]	12.36
decay path	beta (100%)
decay product	^{3}He
maximum beta energy [keV]	18.6
average beta energy [keV]	5.7
specific activity of T_2 [TBq/g]	358
specific activity of T_2O [TBq/g]	268
specific activity of HTO [TBq/g]	53.7
volume of 1 g tritium at standard temp. and pressure [l]	3.720
decay heat [W/Bq]	9.2×10^{-16}
biological half-life [days]	8–12
dosage produced by 1 GBq in man (70 kg) [mSv/day]	1.19

The physical properties of the three hydrogen isotopes differ significantly. Their different mobilities and boiling points can be used for isotopic separation. The most remarkable characteristic of tritium as compared to the other two hydrogen isotopes is its radioactive decay. It emits a beta particle to become the stable isotope helium-3.

$$\mathrm{T} \rightarrow {}^{3}\mathrm{He} + \beta^{-} + \bar{\nu}_e + 18.6\ \mathrm{keV}. \tag{1.1}$$

The half-life of tritium is 12.3 years, i.e., a given quantity of tritium decreases at a rate of about 5.5% per year by radioactive decay. The specific activity of pure tritium is 360 TBq/g. Due to its decay, tritium does not accumulate. In the biosphere, tritium exchanges rapidly and establishes equilibria between various systems (International Atomic Energy Agency [IAEA], 1979). It is not possible to find any water sample which does not contain tiny amounts of tritium.

The bulk of natural hydrogen is the normal hydrogen and some 0.015% is deuterium. The concentration of naturally produced tritium is one atom of tritium in 10^{18} atoms of hydrogen. Accordingly, the unit for tritium concentration has been defined as 1 TU = 10^{-18}. This corresponds to 0.120 Bq/l. The whole natural inventory of tritium in the hydrosphere amounts to a mere few kilograms.

Artificial production and emission of tritium has increased the natural concentration several times. About one hundred kilograms have been emitted from artificial sources, basically by atmospheric testing of nuclear weapons in the late 1950s and early 1960s. Table 1.2 shows the total steady state inventory of the biosphere from natural and artificial sources.

In terms of radiation safety, tritium is a major radionuclide emitted by nuclear reactors and reprocessing plants during normal operation.[2] A survey on the containment performance of various tritium facilities and the radiological impact of tritium emissions showed that the radiation dosages received by the most exposed individual during normal operation of large facilities can come close to the regulatory limits (Kalinowski, 1993). However, in the case of accidents at proposed fusion reactors which use state-of-the-art technology, compliance with regulatory limits cannot be guaranteed (Kalinowski, 1993).

The natural abundance of tritium is so low that it cannot be economically exploited. It has to be produced artificially by means of a nuclear reaction. This can be done in nuclear reactors (see Section 2.4). In thermonuclear weapons, tritium is produced in situ from lithium deuteride via the following nuclear reaction:

$${}^{6}\mathrm{Li} + n \rightarrow \alpha + \mathrm{T} + 4.78\ \mathrm{MeV}. \tag{1.2}$$

Most civilian applications use the energy of the beta particle which results from the decay of tritium (see Section 1.3.1). A mixture of gaseous tritium and deuterium is used in nuclear weapons as a source of neutrons (see Section 1.3.2). For this purpose the following nuclear reaction is used:

$$\mathrm{D} + \mathrm{T} \rightarrow \alpha + n + 17.6\ \mathrm{MeV}. \tag{1.3}$$

This reaction releases fusion energy, but the insertion of gaseous tritium adds little to the explosive yield of the nuclear weapon. In thermonuclear weapons, tritium is produced in situ and most of the total energy release originates from the fusion of tritium and deuterium (see Section 1.3.2).

If the amount of tritium handled exceeds a certain limit, it will be necessary to undertake a certain technological effort in order to contain the tritium and to protect workers and the environment from contamination. With the exception of some medical and tracer research applications, tritium beyond this limit is usually required.

Table 1.2 Tritium inventory in the biosphere from natural atmospheric production, nuclear weapon tests, and emissions from nuclear facilities.

source	production rate [triton/(cm^2s)] [a]	production or emission rate [g/y]	steady state content in the biosphere [kg]	remark
natural prod.	0.12−1.2	100−1000	1.8−18	review of 13 studies (1953−67) (UNSCEAR, 1977)
natural prod.	0.14−0.90	110−700	1.9−12	review of 5 studies based on cosmic ray and nuclear cross-section data (Phillips and Easterly, 1980)
natural prod.	0.25±0.08	200±64	3.5±1.1	good estimate (Craig and Lal, 1961)
natural prod.	0.14−2.0	110−1600	1.9−28	review of 5 studies based on geochemical inventory (Phillips and Easterly, 1980)
natural prod.	0.5±0.3	400±240	7.0±4.2	best estimate (Craig and Lal, 1961)
natural prod.	0.39+0.09−0.29	310+70−230	5.5+1.2−4.0	more recent study Röther (1980)
emissions	–	500−700	9−12	see footnote [b]
nuclear expl.	–	–	90−56+230	see footnote [c]
total			100−200	see footnote [d]

[a] A triton is the completely ionized nucleus of tritium. The earth surface area is 510.1×10^6 km^2.

[b] In the past, the largest contribution to tritium releases from nuclear facilities stemmed from emissions of tritiated heavy water from nuclear power plants at a rate of some 1% of the inventory per year. Reprocessing of spent fuel constitutes the second largest contribution. A significant increase in this kind of release is expected for the next ten years. See Section 2.6.9.

[c] The total release of tritium by nuclear weapons tests in the late 1950s and early 1960s was about 465 kg (United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), 1977). The figure was calculated from an estimate of the total inventory in 1970 (300 kg). Allowing for decay, some 90 kg did exist at the end of 1991. The total explosive power of thermonuclear bomb tests above ground was 318 Mt TNT. Estimates for the production factor range from 190 to 1800 PBq/Mt TNT (Phillips and Easterly, 1980). Therefore, the total tritium production from thermonuclear bomb tests lies between 170 and 1600 kg, i.e., between 34 and 320 kg did still exist. Contributions from fission bomb tests are less than 4 kg.

[d] According to CFFTP (1988), the total amount in the atmosphere (0.6 kg, 0.4%), continental waters (18 kg, 12.5%), and oceans (129 kg, 90%) was 144 kg in 1986. According to UNSCEAR (1977) 7.2% can be found in the atmosphere, 27% in land surface and biosphere, and 65% in oceans.

Safe handling of tritium involves various technology components for transporting, storing, measuring, handling, and containing tritium. A minimum configuration for tritium handling encompasses storage (e.g., uranium getter storage), instruments for inventory measurements (e.g., a steel tank with pressure gauge, thermometer, and mass spectrometer), equipment for transfer processes (e.g., pipes, loading device, vacuum pump), provisions for radiation protection (glove box, emergency device to remove tritium from air), devices for emission control and monitoring (molecular sieve and catalyst for oxidizing tritium gas, stack, and room air monitor), and a waste treatment facility.

The establishment of a complete production line necessitates the use of more sophisticated tritium technology for breeding (irradiation target for nuclear reactor), purification, and isotopic separation (e.g., gas chromatograph) (see Section 2.4 and Albright and Paine, 1988).

Measurement of tritium concentrations in air for radiation monitoring is very difficult. Tritium is one of the most challenging isotopes to detect because it emits only beta rays which have an exceptionally low energy (maximum of 18.6 keV). The average travel distance of these beta particles before being absorbed is some 5 mm in air and 6 μm in water. The most widely used method to measure tritium is to apply a scintillation detector. In this case, air or water samples are mixed with a liquid scintillator. Gas proportional counters can be employed if the tritium to be measured is made to replace an ordinary hydrogen atom in the counter gas methane.[3]

1.3 The use of tritium

1.3.1 Civilian uses of tritium

Tritium is offered commercially as gas with a typical purity of about 90% (Lieser, 1980) or as tritiated water.

The development of commercial tritium applications was intensified in the early 1960s, primarily because excess amounts of tritium were made available by the U.S. Atomic Energy Commission (USAEC). USAEC made 100 g of tritium available in 1959, which was subsequently sold by the Oak Ridge National Laboratory (ORNL) for peaceful applications. In comparison, 4.1 g of tritium had been sold in 1958, and only 1.3 g in the period between 1948 and 1957 (Anonymous, 1959). Tritium was primarily welcomed as a pure beta emitter to replace radium in self-powered light sources whose gamma radiation causes unacceptable radiation doses.

The historical development of worldwide civilian demand can be seen in Figure 1.1. At the end of the 1960s, the worldwide consumption of tritium was about 20 g per year. In the early 1970s, the European tritium industry put annually about 30 g of tritium in luminous paints and 20 g in self-luminating lights ("beta-lights") (Desroches, 1973). The worldwide demand increased slightly to 100 g per year in the mid 1970s, basically for radio-luminous paints and self-luminating lights ("beta-lights"). For 1978 the amount of tritium used in consumer goods was estimated to be 100 g in Europe and 200 g worldwide (Krejci, 1979). In 1979 the commercial consumption of tritium peaked[4] at approximately 800 g, but in 1980 it dropped markedly back to about 100 g/y because safety regulations were tightened

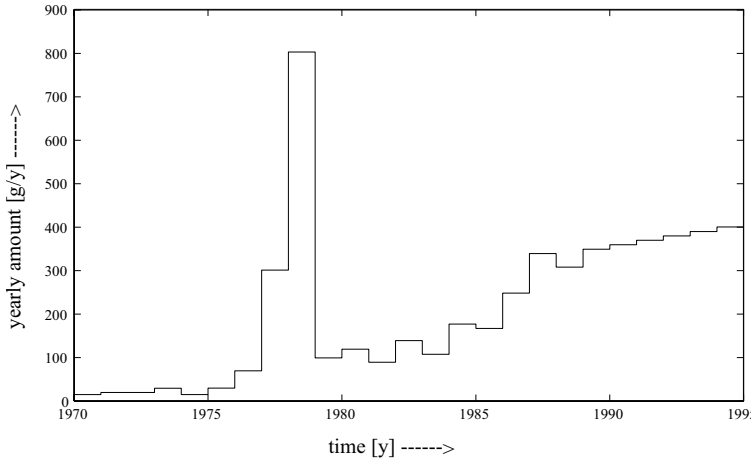

Figure 1.1 Historical development of worldwide civilian demand for tritium. Values for 1991 to 1995 are estimates.

after concerns about radiological problems arose. Since then, the yearly tritium demand slightly increased again to about 400 g/y at the beginning of the 1990s. The international trade in the 1980s was on average slightly more than 220 g per year.[5]

Demands for fusion research have increased their share to about 10%. Shipments of more than 1 g are received from manufacturers at most two to five times a year. A single production charge for luminous paints contains a maximum of 0.1 g of tritium. Only 4 out of 21 large commercial tritium manufacturing and trading facilities are located in the nonnuclear-weapons states, Canada, Germany, and Switzerland (see Appendix A on tritium facilities).

Nearly all civilian demand was satisfied by supplies from the ORNL sales office.[6] Its price has risen from $10,000 per gram in the early 1980s to $29,000 in the late 1980s.[7] It is conceivable that China, the U.K.,[8] France, and Russia[9] would be able to export tritium originating from their military production in significant quantities (several tens of grams). Smaller amounts of tritium are available from civilian sources in Belgium[10] and France.[11] In the early 1990s, Ontario Hydro (Canada) appeared as the main supplier of tritium from civilian sources on the world market. This company initially intended to gain approximately 2.5 kg of tritium per year from its newly built Tritium Removal Facility (TRF) at Darlington. It started to undertake a special effort with the support of the Canadian government to establish new applications of tritium (especially runway landing lights) to increase the market and to sell as much as possible of its tritium. The rest of the material is left to decay.

The main importing countries are the U.K., Japan, and Switzerland. The stated uses are basically for self-powered lights and radio-luminous paint. Table 1.3 presents the variety of commercial products which make use of tritium. Most of them contain very small quantities of tritium, as can be seen from the table, which shows the different applications ordered by the decreasing quantities typically required.

Table 1.3 Tritium in commercial products.

product	content [GBq] [a]	content [μg]
radio-luminous products containing tritium in paint or plastic		
compasses	0.2−2	0.5−5
instrument dials and markers, automobile shift quadrants	1	2.5
sprit levels	0.2−1	0.5−2.5
timepieces	0.04−1	0.1−2.5
automobile lock illuminators	0.07−0.6	0.2−1.5
bell pushes, rims for underwater watches	0.01	0.03
radio-luminous products containing tritium in sealed tubes [b]		
runway landing lights for remote airfields	<40,000	<100,000
exit signs	70−4000	200−10,000
helicopter rotor blade tip markers	2000	5000
night sight for artillery weapons	70−2000	200−5000
aircraft instrument panel illumination	70−700	200−2000
map readers for night use	200	500
markers	150	250
instruments, signs and indicators, step markers, mooring buoys and lights	70	200
marine compasses	7−70	20−200
public telephone dials	20	50
night sights for small arms (pistols, rifles)	4−20	10−50
timepieces, ordinary compasses	7−15	20−40
backlights for liquid crystal displays in watches, light switch markers	7	20
bell pushes	0.4	1
electronic and other devices		
tritium targets for neutron source, typical size	0.04−100	0.1−300
tritium targets for neutron source, large special	<220,000	<615,000
gas chromatographs	10	25
electronic tubes	0.0001−0.4	0.0003−1
antistatic devices contained in precision balances	0.04	0.1
cold-cathode tubes	0.003	0.008
glow lamps	0.0004	0.001
low-energy electric lights	0.2×10^{-6}	0.5×10^{-6}

[a] Figures are taken from International Atomic Energy Agency (1979) and other sources.

[b] These products are sometimes called "beta lights" or gaseous tritium light sources (GTLSs).

There are also some applications of tritium in research (Evans, 1974). Most research applications require only very small quantities (a few μg or less). In the following list the various applications are arranged in order of decreasing requirements:

- Fusion energy research (presently a few 100 g worldwide)[12]
  In recent years, fusion research makes increasing use of tritium. The main goal is to learn about the behavior of tritium in various components of fusion reactors, such as breeder blankets, off-gas processing systems, structure materials, etc. If a fusion power reactor ever started operation, it would contain a steady inventory of a few kg and burn about 180 kg per $GW_e y$.

- 14 MeV neutron sources (up to 600 mg each) (Kobisk, 1989)
  Tritium can be used for relatively compact generators of 14 MeV neutrons.[13] These high energy neutrons are useful for various applications such as neutron activation analysis, production of tiny amounts of special radionuclides, and for the study of nuclear reactions induced by 14 MeV neutrons.

- Biological, medical, chemical, and geological research, especially as tracer (μg quantities)
  Tritium is frequently used as tracer for chemical compounds which contain hydrogen. Some of the hydrogen is replaced by tritium. The behavior of the labeled molecules (pathways, residence time, etc.) can be studied by measuring the activity of different samples. Tracer studies are conducted especially in biology, medicine, physics, chemistry, agriculture, and geology. Small amounts of tritium are used in experiments as a source of Bremsstrahlung or beta particles.

1.3.2 Military uses of tritium

There are various military applications of tritium within the category of conventional weapons. These are primarily dual-use applications, mostly using tritium as self-powered light sources for conventional weapon systems. They are similar to commercial applications of tritium and are included in Table 1.3. The largest quantities of tritium for these applications are used in airfield runway landing lights like those employed during the U.S. invasion of Grenada.

Some tritium is used for research in inertial confinement fusion (ICF). These experiments are closely linked to nuclear weapons research (Schaper, 1991 and Gsponer and Hurni, 1998).

The largest amount of tritium required for military purposes is used in nuclear weapons. In these, tritium is mainly used to generate neutrons from fusion with deuterium according to the following equation:

$$\mathrm{D} + \mathrm{T} \rightarrow \alpha + n + 17.6\ \mathrm{MeV}\,. \tag{1.4}$$

The fusion energy released by this reaction does not contribute significantly to the total yield of the nuclear weapon.

Although attempts have been made to construct thermonuclear weapons which do not require a fission primary, it is generally believed that they have not been

successful. Some analysts (Gsponer and Hurni, 1998; Makhijani and Zerriffi, 1998; Jones and von Hippel, 1998; and Jones *et al.*, 1998) fear that this might change with the increased research efforts regarding thermonuclear weapons physics (U.S. Department of Energy, 1996). Thus, tritium is neither sufficient nor necessary to produce a nuclear weapon. Obviously, it is less significant for nuclear weapons than uranium and plutonium. However, it becomes strategically significant as an addition to fissionable material. Tritium is believed to be a component of most nuclear weapons currently in the stockpiles of all nuclear weapons states. Its primary purpose is to increase ("boost") the explosive yield of a given amount of fissionable material. Hence, the particular significance of tritium for the nuclear arsenal is to guarantee a higher total yield. Without tritium the total yield would be lower by one order of magnitude (see Sections 1.6.2 and 1.6.3).

Tritium is further used for selectable yields, for radiation enhanced weapons, and for the thermonuclear stage in fusion weapons. The use of tritium in nuclear weapons, therefore, leads to vertical proliferation from first-generation fission devices to more sophisticated boosted or thermonuclear weapons.

The following list explains the different uses and estimated quantities of tritium in nuclear warheads:[14]

1. *Neutron generator (0.1 mg):* The nuclear fission chain reaction is started by a shower of neutrons. In early weapon designs a bimetallic neutron source was used for this purpose. Pulverized beryllium and an alpha emitter are mixed and generate neutrons according to the nuclear reaction $^{9}\mathrm{Be} + \alpha \rightarrow {}^{12}\mathrm{C} + \mathrm{n}$. A Ra-Be neutron source with 10 Ci Ra-226 emits some 10^8 neutrons per second (see, e.g., Lieser, 1980). Within the first generation of neutrons[15] this source emits just one neutron. A stronger pulse of neutrons is desirable because the higher the number of neutrons in the first generation, the more reliably can the beginning of the chain reaction be predicted.[16] Precise timing of the pulse is more important, however, as it has a considerable impact on the yield.

   This can be achieved with an electrostatic neutron generator in which deuteron ions accelerated by a high voltage strike a metal tritide target.[17] Typical targets contain up to 0.1 mg of tritium (see, e.g., Evans, 1974). Neutron showers with some 5×10^{12} neutrons per second are available for civilian purposes (Lieser, 1980). Such neutron generators were first used by the U.S. in 1953 and are today as small as a fist (Cochran, 1987a).

   In contrast to the bimetallic neutron source, this type of neutron generator is an external neutron source, i.e., neutrons are shot from the outside into the core of the critical mass. The cavity in the core is a precondition for the boosting which is described in the next paragraph.

2. *Boosted fission weapons and boosted primaries in thermonuclear weapons (2–3 g):*[18] The principle of fusion-boosted fission bombs was declassified in 1974.[19] In these devices a mixture of tritium and deuterium gas is injected from an external gas capsule at high pressure (about 10^7 Pa) into the hollow core of the plutonium sphere before the chain reaction is initiated. For a short time, both temperature and pressure in the center of the nuclear explosion are high enough to allow tritium and deuterium to fuse. The neutrons released

from this fusion induce further fissions, thereby increasing the efficiency of the fissionable core and possibly of the surrounding tamper (fertile material, e.g., uranium-238). As a result, the yield can be multiplied — depending on the fission efficiency without boosting — by a factor of 2 to 10 (Hansen, 1988) or even 100.[20]

As a consequence, boosted weapons can achieve explosive yields up to 400 kt,[21] but are still heavy. However, thermonuclear weapons with boosted primaries can have high yield-to-weight ratios (see Figure 1.4), allowing high-yield (100 to 500 kt) warheads to be small and light enough (100 to 400 kg) to fit into long-range missiles with multiple warheads, as well as into torpedoes and artillery shells (see Figure 1.4).

In addition, it may be assumed that boosted weapons are more reliable than ordinary fission bombs concerning their explosive yield, because the reduced quantity of plutonium is easier to compress by means of a conventional explosion and thus has a reduced probability of predetonation. To put it another way, the probability of predetonation remains the same when a plutonium bomb with a lower content of plutonium-239 utilizes tritium.

Boosting is believed to be applied in most of the small fission weapons and in all triggers of thermonuclear weapons in the current U.S. nuclear arsenal (see Section 1.6.2).

The quantity of tritium used for boosting (2–3 g) can be estimated from the U.S. stockpile on the assumption that all nuclear weapons make use of boosting and that not all military tritium is used for this purpose.[22] The complete fusion of 3 g of tritium with 2 g of deuterium releases enough neutrons to induce fission of 240 g of plutonium. The fission releases more than 4 kt of TNT, whereas the fusion energy contributes no more than 0.4 kt. In thermonuclear weapons the largest fraction of the energy comes from fusion (see item 5 below).

A high purity is required for the mixture of tritium and deuterium.[23]

3. *Selectable yield (2–3 g):* This is a special feature used for some boosted warheads. The desired yield can be selected immediately before its delivery by varying the timing of its application or by inserting more or less (from zero to all) capsules each containing a fraction of the total tritium. There are some other methods that can be used as well to enable yield selection. The new modification of the B61 (mod. 11) has the widest known range of yields from 0.3 to 340 kt (Mello, 1997).

4. *Neutron bomb (Gsponer, 1984 and Huaqiu, 1988) (10–30 g):*[24] Tritium is used in a similar way in radiation enhanced weapons (neutron bombs), which are designed to maximize the portion of energy which is carried by the neutrons. The 14 MeV neutrons generated by fusion have a higher probability of escaping than of being stopped by inducing further fissions. Therefore, these weapons have a comparatively low yield (about 1 kt of TNT) and a large flux of high-energy neutrons. The amount of tritium needed for this sort of nuclear weapons is of the order of a few tens of grams.

When no tritium is inserted, a neutron bomb works like a simple low-yield fission weapon.

5. *Thermonuclear weapon:* The primary material of thermonuclear stages is LiD. Tritium is bred in situ from lithium by capturing a neutron. Some of the lithium hydride can be added in the form of LiT. This is not necessary, but is probably done in some weapon designs to facilitate the beginning of the fusion reaction (see, e.g., Winterberg, 1981). Quantities are not publicly known.

Most information regarding the use of tritium for nuclear weapons is classified. More details are described elsewhere (see, e.g., Albright and Paine, 1988; Cochran *et al.*, 1984; Gsponer and Hurni, 1998; Hansen, 1988; Seifritz, 1984; and Winterberg, 1981). All quantities given above are educated guesses which have been neither confirmed nor denied by official sources.

The strategic significance of tritium for the nuclear arsenal is to provide a high total yield or a high yield-to-weight ratio (see Section 1.6.2).

The military facilities for the production of tritium and their capacities in the nuclear weapons states are described in Section 2.7. Tritium-related activities in de facto nuclear weapon states are dealt with in Section 1.7.

1.3.3 Civilian/military ambivalence of tritium

Tritium has various military (nuclear and nonnuclear-weapons related) as well as civilian (industrial and scientific) applications.[25] The relationship between civilian and military uses of tritium becomes particularly apparent when reviewing the historical development.

History of civilian and military uses of tritium:[26]

1934 The British scientist Lord Rutherford discovers tritium by a nuclear reaction.

1939 Luis Alvarez from the University of California discovers the radioactive decay of tritium.

1944 During World War II, the first calculations regarding the use of fusion energy in nuclear weapons are undertaken by scientists of the Manhattan Project in Los Alamos.

1950 Under the impression that the first Soviet nuclear weapon test has been carried out, research on thermonuclear weapons is enhanced in the U.S.

1951 On May 8, tritium is used for the first time in a nuclear weapon test by the U.S. During "Operation Greenhouse," a fusion-boosted fission device with the code name "George" is tested on the Enewetak Atoll in the West Pacific.

1952 On November 1, the U.S. explodes the first thermonuclear device at the same site. This shot, called "Mike," weighs 82 tonnes and has a yield of 10.4 Mt of TNT, that is, 500 times the yield of the Nagasaki bomb.

1955 At the Savannah River Plant (South Carolina, U.S.), the first military reactor dedicated to the production of tritium starts operation. Further military tritium production reactors are commissioned at Marcoule (France, 1956), Chelyabinsk (U.S.S.R., 1957), Chapel Cross (U.K., 1958), China (1968), and Dimona (Israel, 1968).