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Radiation Information Network's

Tritium Information Section

INTRODUCTION

Tritium is a radioactive form of hydrogen, used in research, fusion reactors and neutron generators. The radioactive properties of tritium are very useful. By mixing tritium with a chemical that emits light in the presence of radiation, a phosphor, a continuous light source is made. This can be applied to situations where a dim light is needed but where using batteries or electricity is not possible or practical. Rifle sights and exit signs are two examples of where this phenomenon is commonly used. The phosphor sights help increase nighttime firing accuracy and the exit signs can be life saver if there is a loss of power. The radioactive decay product of tritium is a low energy beta that cannot penetrate the outer dead layer of human skin. Therefore, the main hazard associated with tritium is internal exposure from inhalation or ingestion. In addition, due to the relatively long half life and short biological half life, an intake of tritium must be in large amounts to pose a significant health risk. Although, in keeping with the philosophy of ALARA, internal exposure should be kept as low as practical.

TRITIUM

Tritium, as a form of Hydrogen, is found naturally in air and water. Most hydrogen is made up of one proton, and an orbital electron, but tritium has two extra neutrons in the nucleus. In nature, it is produced by cosmic rays in two source terms:

$^{14}N + {}^{1}n \text{ ---> } {}^{3}H + {}^{12}C$

and

$^{2}H + {}^{2}H \text{ ---> } {}^{3}H + {}^{1}H$

Cosmic rays interact with nitrogen (^{14}N) or with deuterium (^{2}H) and form tritium and carbon (^{12}C). These are primarily interactions that happen in the upper atmosphere and the tritium falls to earth as rain. The unit curie is a measure of an amount of radioactivity. A curie (Ci) is the amount of a radioactive substance that has 3.7 x 10^{10} decays per second. The world wide production of tritium from natural sources is 4 x 10^{6} curies per year with a steady state inventory of about 70 x 10^{6} curies. The amount of tritium found in a typical rifle sight is about 0.012 curies and is human-made. Human-made tritium is generated by bombarding hydrogen with neutrons in a nuclear reactor or an accelerator (MLM-3719, 1991).

All atoms are composed of a center nucleus surrounded by shells of electrons. The tritium atom (^{3}H) is unstable because it has two extra neutrons in its nucleus. These neutrons give tritium an excess amount of energy. Because of this, the atom will undergo a nuclear transformation or radioactive decay. In this, the atom emits two radiations: a beta particle ($ß^{-}$), which is similar to an electron, and an anti-neutrino.

$^{3}H \text{ --> } {}^{3}He + ß^{-} + \text{anti-neutrino}$

This reduces the energy in the nucleus and the atom, now a helium atom (^{3}He), is left more stable. The anti-neutrino is of no biological significance because it does not interact with matter.

The beta is non-penetrating with a maximum energy of 18.6 keV and an average of 5.7 keV. This is a low energy beta compared to most radioactive beta emitters and it can be easily shielded. The outer layer of dead skin is enough to stop all of the beta external of the body. Only if tritium is taken into the body can it produce a significant dose.

Tritium has a single electron the same as the more abundant forms of hydrogen. This causes tritium to react chemically to form compounds in the same manner as hydrogen. The two primary forms that personnel will likely to be exposed to are HT (which is similar to hydrogen gas) or HTO (tritiated or heavy water). Of these two forms, the HTO is the only form that is a significant exposure hazard. HT gas is inhaled and exhaled with only of 0.005% of the activity being deposited in the lungs. The uptake of HTO vapor is near 100% for inhalation and ingestion. Tritium can also enter the body by absorption through the skin or open wounds. Skin contact should always be minimized to prevent absorption. Tritium will also be absorbed into materials such as gloves, clothing and metal. If not properly controlled, these contaminated materials can present an additional exposure source by releasing tritium when in contact with skin. On an up-take, some of the tritium can be held as organicly bound material, but the dose from this bound tritium is much less than the free tritium.

HTO is in the form of water, so one to two hours after an uptake, it will be evenly distributed through out the body's fluids. The amount of time it takes for half of the activity to be physically removed form the body is the biological half life. The biological half life of tritium varies significantly because of variations in bodily excretion rates, temperature dependence and fluid intake. Biological half-life of tritium is about 9.4 days, often rounded to 10 days. This can be shortened to 2-3 days (Fig 1) with ten fold increase of liquid intake (2 liters to 20 liters), or in serve cases to 4-8 hours by using dialysis machines.

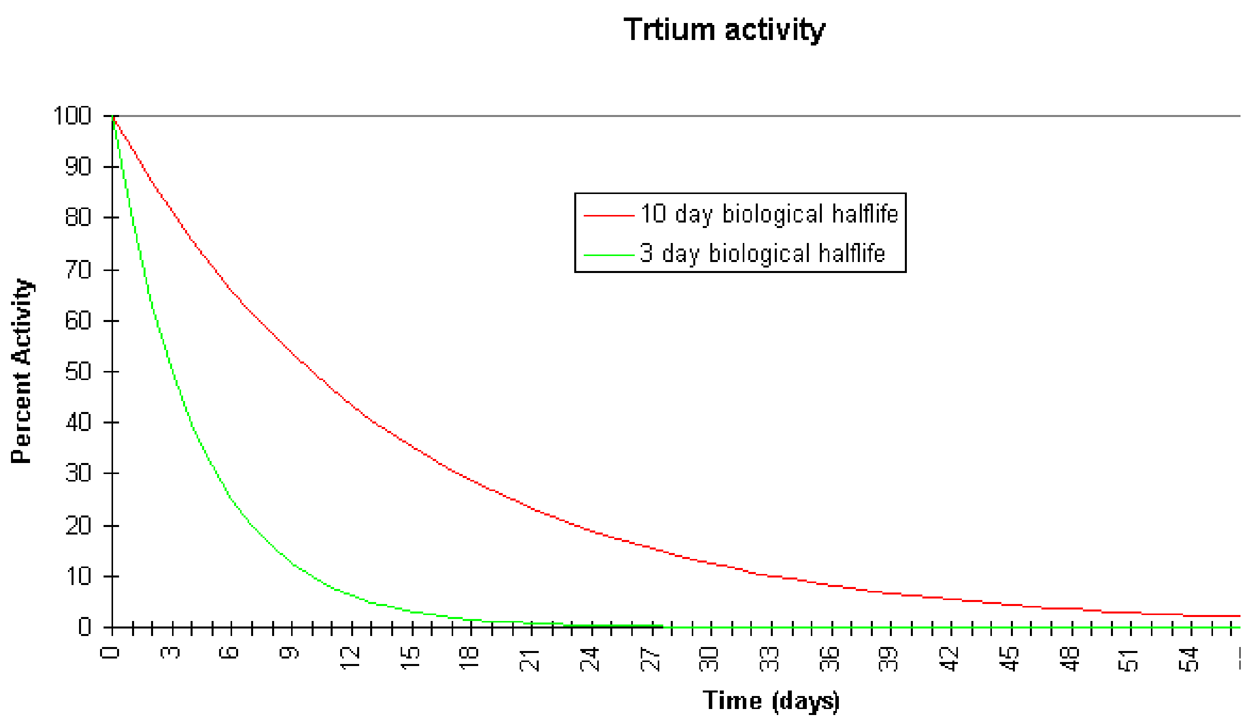

Figure one. The percent of tritium left in a human based on removal half-life of 10 day (average for humans) and 3 days (based on increased water intake).

Methods of reduction of tritium in the body must be weighed against the potential harm that the tritium will cause. Any treatment should be based on known levels of uptake and made in consultation with medical personnel.

Dose from Tritium

The dose of tritium is dependent upon how much was initially ingested and the resident time in the body. Tritium will equilibrate through out the fluid compartments of the body and deliver the dose to the whole body. Taken form the National Council on Radiation Protection (NCRP) report 30, the Annual Limit for Intake (ALI) is 80 mCi and the Committed Effective Dose Equivalent (CEDE) in soft tissue is 64 mrem per millicurie (mCi) ingested. The ALI is the amount of activity required to receive a dose of 5 rem of equivalent whole body dose for the year. To use the given CEDE dose factor to calculate the dose, estimate the amount of tritium initially deposited in the body, and divide by 1 mCi/64 mrem. The ALI and the CEDE factor are based on the biological half life of 10 days. As an example of using the CEDE factor:

If a worker ingested 4 mCi of tritium, the worker would receive a dose of 256 mrem.

The established way of calculating the amount of activity deposited is by bioassay samples. During a typical tritium bioassay, 1-5 milliliters of urine are mixed with a liquid scintillation medium and counted in a liquid scintillation counter. From these counts, the actual concentration of tritium can be determined in the urine. Then working back to the time of exposure, the initial activity can be calculated. Due to the solubility of the tritium, the concentration of the tritium in the urine equals the concentration in the soft tissues of the body.

While there are several methods available to calculate the dose based on bioassay measurements, the following are from the DOE's Health Physics Manual of Good Practices for Tritium Facilities.

The dose rate, $R(t_o)$, to an individual based on a bioassay concentration C_o

$$= C_o\left(\frac{\mu Ci}{L}\right) \times 3.7 \times 10^4 \frac{dps}{\mu Ci} \times 5.7 \times 10^3 \frac{eV}{dis} \times 3600 \times 24 \frac{sec}{day} \times \frac{42\ L}{6.3 \times 10^4 grams} \times 1.6 \times 10^{-12} \frac{erg}{eV} \times 10^{-2} \frac{rad - gram}{erg} \times 1.0 \frac{rem}{rad}$$

$$= 1.94 \times 10^{-4}\ C_o \frac{Rem}{day}$$

is:

An example of this would be if a worker had a urinalysis that indicated 1000 µCi/L, then they would be receiving an initial dose rate of 0.19 rem per day. So, if you would have a constant level of tritium in your system, you could simply calculate your dose (assuming your an average person) by:

Urine Level (µCi/L) x 1.94 x 10^{-4} rem/day per µCi/L x number of days = dose for those days at that level.

The amount of tritium in the body decreases as a function of the time, so from a single exposure, the committed dose equivalent expected to be received over fifty years, D_{50}, can be calculated

$$D_{50} = \int_0^{50} R(t_o)\ e^{-\lambda * t}\ dt$$

from:

Where lambda (up-side down "Y") is the elimination constant (ln(2)/biological half-life). As shown in Figure 1 though, most of the dose is received in the first month following exposure.

Gun Sights

Some rifles use tritium for in their front sight. They will use about 12 mCi of tritium dissolved in a phosphor liquid contained in a small glass vial. Occasionally, a sight may develop a small leak or be completely broken and pose at least a potential for internal exposure. A small amount of the total activity could be transferred to the hands of the security personnel or armorer, then ingested orally or absorbed through the skin. The use of gloves can reduce the risk of exposure. The amount absorbed through the skin would probably be small compared to the amount ingested. Other likely pathways might be a localized cloud of HTO vapor if the sight were damaged and stowed in an air tight locker. The air space of the locker could reach equilibrium conditions with the tritium. If the locker where the rifles are stored has some ventilation, then that would be enough to dissipate the tritium.

Tritium in Watches

See: The Use of Tritium in Plastic Watches

Tritium in Exit Signs

Tritium is used in some self-illuminating exit signs to light the exit in the event of an electrical outage or a fire. Signs often have several curies of tritium in them. If the exit signs were severely damaged, HT gas might escape into the local area, but it should be dispersed by ventilation or wind quickly. The damaged sign would be expected to have relatively high levels of tritium on it, and should not be handled without gloves.

Risks

The risks from tritium are small, due mostly to:

1. it is a low energy beta emitter;
2. chemically behaves like water in the body (forms HTO or T_2O - water);
3. has a 12.3 year half-life.

While not impossible, a large enough dose to cause any significant harm to a person is unlikely. It is a hazard, and should be treated like any other. Some basic precautions can minimize the risks, such as not handling a broken sign or sight with bare hands, ventilating an area where tritium is stored and proper disposal of used or damage tritium objects.

To help evaluate the potential risks from tritium exposure, consider the following made-up scenarios:

1) all of the activity of a rifle sight is ingested;

> The rifle sights contain 12 mCi of tritium. If all of its activity were ingested, the CEDE would be 768 mrem or roughly two years of dose from natural background.

2) ten percent of the activity of a rifle sight is ingested and not recognized;

> If ten percent of the activity of the tritium in a sight (1.2 mCi) would be ingested, the dose would then be 77 mrem or about two and a half months of natural background radiation.

3) ten percent of the activity of a rifle sight is ingested and the individuals water intake level is raised by a factor of 10;

> If ten percent of the tritium in the sight (1.2 mCi) were ingested and the day intake of fluids is increased 10 times then the dose would be 42 mrem (assuming five day biological half-life).

4) a more likely scenario is that some is wiped on you, you might ingest some and have some absorbed through your skin for a sum of 5% of the total activity in the sight;

> If five percent of the tritium in the sight (0.6 mCi) were ingested the dose would be 38 mrem, or about a month and a half of natural background radiation.

5) as a worker, you are told that you have 30,000 pCi/L of tritium in your urine for the whole year;

> 30,000 pCi/ liter would give a dose of 2 mrem per year.

6) as a worker, you are told that you were exposed with a single uptake of 8 mCi of tritium;

> An uptake of 8 mCi would result in a dose of 500 mrem, or about one and a half years of natural background radiation dose

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Tables

Table 1. Tritium characteristics

> Radioactive Half-life - 12.3 years
> Decay - $ß^-$
> Energy Max. - 18.6 keV
> Energy Average - 5.7 keV
> The specific activity of T_2O is 2,700 Ci g^{-1}

DAC - 2 x 10^{-5} µCi cm^{-3}
ALI - 80 mCi
Committed Dose Equivalent Soft tissue - 64 mrem mCi^{-1}
MPC - 2.8 x 10^{-7} µCi cm^{-3} non-occupational exposure
MPC - 8.5 x 10^{-6} µCi cm^{-3} occupational exposure

Other Sources of Information on Tritium:

- DOE-HDBK-1129-2008, Tritium Safe Handling and Storage (formally all of the DOE tritium handbooks)
- Tritium Fact Sheet
- Radioactivity in Nature
- The Use of Tritium in Plastic Watches

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Background and Suggested Further Reading

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