CHAPTER II

NATURAL OCCURRENCE, RADIOACTIVE PROPERTIES AND HAZARDS OF TRITIUM

II.1 Natural Occurrence

There are now three well-known isotopes of hydrogen namely:

^{1}H, hydrogen or ptotium (stable)

^{2}H, deuterium or 'heavy hydrogen' (stable)

^{3}H, tritium (radioactive)

Tritium arises in nature both by natural and artificial processes. Natural tritium was first detected in the atmospheric hydrogen by Faltings and Harteck and was later shown to be present in rainwater by Libby and his collaborators[1/].

Prior to the testing of thermonuclear weapons in 1954 the amount of this natural tritium on the earth was calculated to be about 900 g which in terms of radioactivity is approximately 9 million curies[1/]. This tritium is the result of nuclear reactions induced by cosmic radiation in the upper atmosphere,

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1/ Evans, E. Anthony 1966. Tritium and its Compounds. London; Butterworths, P. 1-5.

where fast neutrons, protons and deuterons collide with molecules to produce tritium. Examples of such reactions are given in the equations (2.1) to(2.3):

$$^{14}_{7}N + ^{1}_{0}n \longrightarrow ^{3}_{1}H + ^{12}_{6}C \quad \text{.....(2.1)}$$

$$^{14}_{7}N + ^{1}_{1}H \longrightarrow ^{3}_{1}H + \text{fragments} \quad \text{.....(2.2)}$$

$$^{2}_{1}H + ^{2}_{1}H \longrightarrow ^{3}_{1}H + ^{1}_{1}H \quad \text{.....(2.3)}$$

The energetic tritium atoms (tritons) produced in these reactions are incorporated into water molecules, by exchange or oxidation (2.4), and the tritium falls onto the earth's surface as rain-water.

$$^{3}_{1}H \begin{cases} \xrightarrow{\text{oxidation}} {}^{3}_{1}H_2O \\ \xrightarrow{\text{exchange}} {}^{3}_{1}H\,{}^{1}_{1}HO + {}^{1}_{1}H \end{cases} \quad \text{....(2.4)}$$

There are many nuclear reactions which can be used to produce tritium artificially. Tritium was first produced artificially in 1934 by bombardment of deuterium with cyclotron produced (accelerated) deuterons.

$$^{2}_{1}H + ^{2}_{1}H \longrightarrow ^{1}_{1}H + ^{3}_{1}H \quad \text{..... (2.5)}$$

In the cyclotron tritium can readily be produced by the bombardment of a beryllium target with deuterons reaction.

$$^{9}_{4}Be + ^{2}_{1}H \longrightarrow ^{8}_{4}Be + ^{3}_{1}H \quad \text{..... (2.6)}$$

The beryllium target is then dissolved in 6 N HCl in a vacuum system. The hydrogen and tritium evolved are passed over copper oxide at 550°C and the tritiated water is collected in a liquid air trap.

In 1935 experiments with the Wilson cloud-chamber showed that collisions between neutrons and lithium led to the nuclear reaction.

$$^{6}_{3}Li + ^{1}_{0}n \longrightarrow ^{4}_{2}He + ^{3}_{1}H \quad .....(2.7)$$

The helium and tritium atoms are ejected in opposite directions with ranges of 20 and 65 mm respectively in air at atmospheric pressure. These early experiments formed the basis for the method now adopted for the production of tritium.

Heavy water moderated reactors produce tritium oxide as a result of neutron capture by deuterium.

$$^{2}_{1}H + ^{1}_{0}n \longrightarrow ^{3}_{1}H + \text{gamma} \quad .....(2.8)$$

The helium-3 which is the natural decay product of tritium also undergoes a nuclear reaction(2.9) and is converted into tritium and hydrogen.

$$^{3}_{2}He + ^{1}_{0}n \longrightarrow ^{3}_{1}H + ^{1}_{1}H \quad ..... \quad (2.9)$$

II.2 Radioactive Properties

Tritium is an isotope emitting low-energy pure β-radiation; there are several values reported in the literature for the average energy and the maximum energy of tritium β-particles. The best values for the half-life have been determined by measuring the accumulation of helium-3 which is produced by the natural decay of tritium.

$$^{3}_{1}H \longrightarrow ^{3}_{2}He + \beta^{-} \qquad \text{.....(2.10)}$$

Radioactive properties of tritium are as follows:

Mass number of tritium atom	3
Mode of radioactive decay	Beta
Half-life ($T_{1/2}$)	12.26 years
Product of radioactive decay	$^{3}_{2}He$
Maximum energy of beta particles	18 Kev
Maximum range in air	7.3 mm
Average energy of beta particles	5.7 Kev
Average range in air	1.0 mm

Specific activity:

T_2O liquid	2.66×10^3	Ci/ml
HTO liquid	1.46×10^3	Ci/ml
HTO vapour	1.30	Ci/ml at NTP
DTO vapour	1.30	Ci/ml at NTP
T_2O vapour	2.60	Ci/ml at NTP
T_2 gas	2.60	Ci/ml at NTP

II.3 Exposure Hazards

Due to the increased use of tritium, more and more workers are handling this radioactive isotopes in the elemental form as HT, DT, T_2 or as oxides of tritium-HTO, DTO or T_2O or as labelled compounds. It is therefore necessary to evaluate the health hazards associated with the exposure to this radioisotope.

II.3-1 External hazards

Being pure beta emitter with low disintegration energy, tritium does not present much of external exposure hazard.

II.3-2 Internal hazards

The oxide of tritium behaves chemically in the same manner as water and is easily assimilated in the body. Persons handling tritium inevitably take small quantities of it into their bodies, sooner or later, by skin absorption, inhalation and ingestion. Thus tritium is internally hazardous. Intake of elemental tritium or HT through inhalation is negligible compared to that of HTO[2/]. Tritium is excreted from body through

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2/ Soman, S.D., Iyengar, T.S., Sadarangani, S.H. and Vaze, P.K. 1962. Estimation of Tritium by Gas-Phase Counting Technique. A.E.E.T./H.P./T.M.-10. Atomic Energy Establishment Trombay, Bombay India.

urine, sweat and insensible perspiration. Pinson and Langham observed that tritium activity level in these excretions are the same. Hence a convenient method of internal tritium hazard evaluation is urinalysis.

The internal radiation protection standards for tritium recommended by the International Commission on Radiological Protection (ICRP) are summarized in Table II-1 3/.

TABLE II-1

Maximum Permissible Limits for Tritium

Radionuclide and type of decay	Organ of reference (critical organ)	Max. Per. Burden in total body	Max. Permissible Conc. for 40 hr wk		168 hr wk	
			MPC_w	MPC_a	MPC_w	MPC_a
		μCi	μCi/ml			
$^3H(^3H_2O)$ sol	Body tissue	10^3	0.1	5×10^{-6}	0.03	2×10^{-6}
	Total	2×10^3	0.2	8×10^{-6}	0.05	3×10^{-6}
$^3H_2$(submersion)	Skin			2×10^{-3}		4×10^{-4}

The maximum permissible level in urine is 0.028 μCi/ml (Total body).

3/ Pillai, K.C. 1960. Handling Hazards of Tritium. A.E.E.T./H.P./S.M./6. Atomic Energy Establishment Trombay, Bombay India.