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OVERVIEW OF HEALTH PHYSICS STUDIES ON TRITIUM BETA RADIATION

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ABSTRACT

As we enter the 2000s, there are four nuclear power units of the pressurized heavy water reactor-type in the commercial operation at the Wolsung Nuclear Power Plant(NPP) site where a larger amount of tritium (^3H) is released inevitably to the site environment. This radioctive nuclide is easily distributed throghout our environment because of its ubiquitous form as tritiated water (HTO) and its persistence in the environment. Tritum has certain characterisitics that present unique challenges for beta radiation dosimety and health risk assesment. In this paper, therefore, a variety of matters on tritium are considered and reviewed in terms of its characteristics and sources, metabolism and dosimetry, microdosimetry, radiobiology, risk assessment, and transport and cycling in the environment, etc.

Key words : tritium, beta, radiation, pressurized heavy water reactor, metabolism, dosimetry, risk assessment.

INTRODUCTION

Ambitious plans for significantly increasing nuclear power capacity are evident in our country. The Korea Electric Power Corporartion is planning to build 14 more nulcear power units over 1995－2066 time-frame, with the total nuclear generation capacity scheduled to reach 23 GWe by the year 2006.[1] Among the 14 units, four are pressurized heavy water recator units that must increase tritium in our environment. Today, tritum (^3H), the heaviest and only radioctive isotope of hydrogen, is increasing in importance in nuclear energy and environmental considerations. ^3H production by nuclear power units is increasing rapidly and will in time become the dominant source. Much of the tritium that remains in the environment exists as HTO. As HTO, ^3H can enter the human body by inhalation, ingestion, or skin absorption. Since the energy associated with the beta radiation emitted upon decay of tritium is too low to present an external hazard, the fundamental question in the environmental and bilogical dosimetry of tritium is its uptake and distrbution within biological organisms. When humans are exposed to tritium as HTO, the tritium is rapidly distributed to intracelluar and extracelluar water. The low energy beta radiation and the lack of photon emissiom precludes the use of in-vivo monitoring and requires the measurement of tritum in body fluids or excreta.[2] Tritium decays with emission of an electron to form ^3He : $^3H \rightarrow {}^3He + e$. This electron

flows form ^{3}H are the beta radiation with mean energy of 5.75 keV.[3]

CHARACTERISTICS AND SOURCES

Tritium is an isotope of hydrogen which is both naturally occuring and manufactured. Its physical half-life is 12.35 y.[4] The maximum energy of beta radiations from tritium decay is 18.6keV which can give maximum track of 6μm in human tissue.[5] Human skin is composed of the epidermis, 20−100μm thick, and the dermis, 1−3mm thick.[6] Because of low beta radiation energy, dilution throughout all of the soft tissues, and partly with half-lives of 30 d and 450 d,[7] tritium as HTO has a relatively low radiological toxicity when compared to other pure beta radiation emitters, such as ^{32}P or ^{90}Sr.

For the purpose of radiation protection, ICRP recommended the use of an annual limit of intake (ALI) and a derived air concentration (DAC), replaing the earlier term used-maximum permissible concentration (MPC).[8] Recently, ICRP again recommended the ALI to be 1.0×10^{9} B_q.[9] However, ICRP had already recommended the DAC to be $8\times10^{5}B_qm^{3}$.[10]

The continuous presence of tritium in the earth's environment means that tritium could be continuously produced in the environment, counter-balancing the loss of tritium by its physical decay. The production of tritium by natural processes was discovered by its physical decay. The production of tritium by natural processes was discovered by Libby[11] and was reviewed by Nir et al.[12] The search for the origin of ^{3}He in the atmosphere led to the discovery of cosmic ray-produced tritium. As free hydrogen in day air, therefore, tritium was detected by Harteck and Faltings.[13]

Major tritium production in nature is form nuclear reaction of amospheric atoms with cosmic rays in the upper atmopshere.[14] A very minor fraction of natural tritium is produced in the earth's crust from the inventory in nature reaction of ^{6}Li in rocks.[14]

Jaworowski reported that the tritium inventory in natural occurence to be about 1.0−1.3EBq [15] The global inventory of tritium in 1990, including manufactured sources is about 53EBq [16]. Among the manufactured sources, annual rate of tritium released into the environment from nuclear power plants is 0.02EBq/y under the routine operation.[17] According to the KEPCO's study on tritum at the Wolsung Nuclear Power Plant, the total amount of tritium released from the pressurized heavy water reactor (PHWR) Unit-I into the environment is about 306 TBq/y in average for three years from 1989 to 1991.[18] Luykx and Fraser reported that the normalized tritium discharges with liquid effluents from a PHWR in the European Union(EU) was 900 TBq/GWe·y.[19] In the PHWRs, neutron activation of deterium in the moderator gives the largest contribution to tritium formation.

METABOLISM AND DOSIMETRY

The fundamental question in the environmental and biological dosimetry of tritium is its uptake and distribution within biological organisms. Once released to the atomosphere, tritium

is rapidly oxidized to tritiated water, enters the hydrological cycle, and is widely dispersed throughout the environment. Transfer to man is by inhalation, ingestion, and skin absorption. Once in the human body tritium mixes rapidly with extracellulalr and intracellular fluid, with a fraction replacing hydrogen bound in organic molecules of tissue. Fig. 1 illustrates the principal metabolic pathways of radionuclides in the human body.[20] The inhalation pathway needs to be considered if tritiated gases and/or particulates become airborne.

Usually airborne tritium can be expected to be present as either HT, HTO, or both. The tritium intake route should only be expected from the ingestion of food or liquids that have been contaminated. It is well known that HTO in both the liquid and vapor phase can be rapidly absorbed through the skin. Tritium can enter a bilogical system in the form of many different chemical compounds. For most of the radiation does to the body regardless of whether they were taken directly into the body or enter into de-novo synthesis of other tritiated compounds.[21]

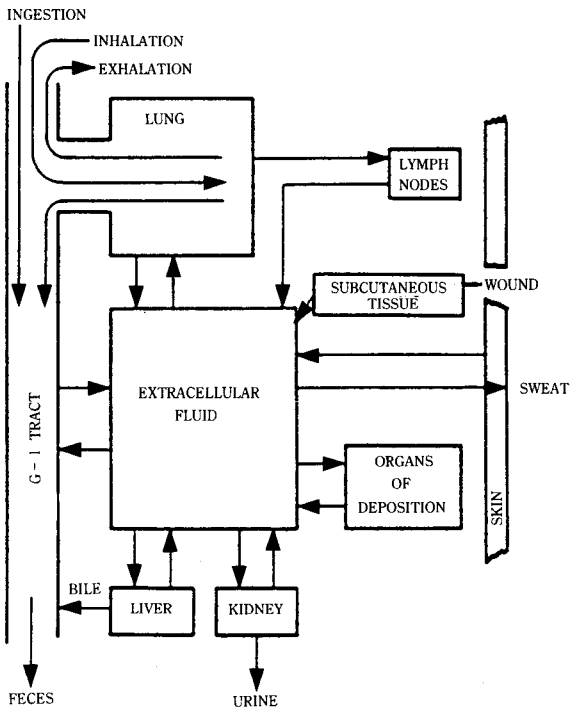


Fig. 1. Prinicipal metabolic pathways of radionuclides in the body.

The metabolic models described by Hill and Johnson[22] represent the conceptual interpretation of metabolic processes for a variety of different forms of tritum including HTO, HT gas, HT contaminated surface, OBT in foodstuffs and other organic compounds. Johnson has described a compartment model for HTO metabolism as shown in Fig. 2.[23]

The uptake of tritium in humans can by exposure to air, water, or food containing tritium.

Assessment of radiological doses received form such exposures to tritium requires modelling to estimate titium concentrations in various body tissues.

Quantitative estimates resulting form metabolic models are combined with knowledge of the does-to-risk relationship to provide estimates of risk from exposure to tritium.

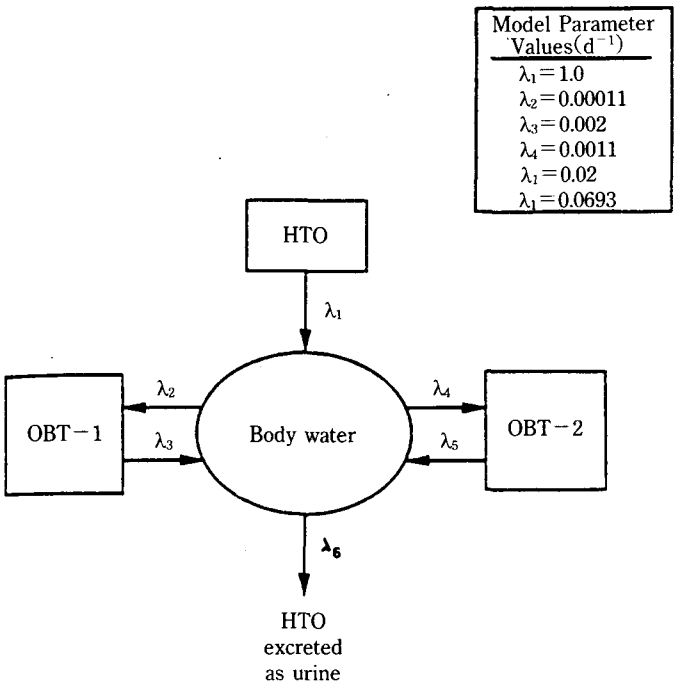


Fig. 2. Tritiated water (HTO) compartmental model

MICRODOSIMETRY AND RADIOBIOLOGY

All experimental evidence to date indicates that bilogical effects of tritium incorporated from the environment are due to its beta radiation[24] Type and degree of effects are related to the congruence between location of tritium and radiation-sensitive microvolumes in the body.

For somatic effects, these sensitive sites are taken to reside in the nuclei of stem cells, while for genetic effects they lie in germ cells.[25]

Fig. 3. presents the resulting logarithmic absorbed dose distributions in linear energy induced by tritium beta radiation for 20nm and 1μm diameter sites.[26] For comparison, the distribution due to 250kVp x-rays in a 1μm site is also displayed. 20nm may be considered as the typical size of a nucleosome, while 1μm is perhaps more representative for linear dimensions or for the mass of DNA in the nucleus. For the 20nm diameter site, the whole spectrum is shifted toward higher ionization densities. In addition, Fig. 4. illustrates the relative radiosensitivity of several biologic systems.[27]

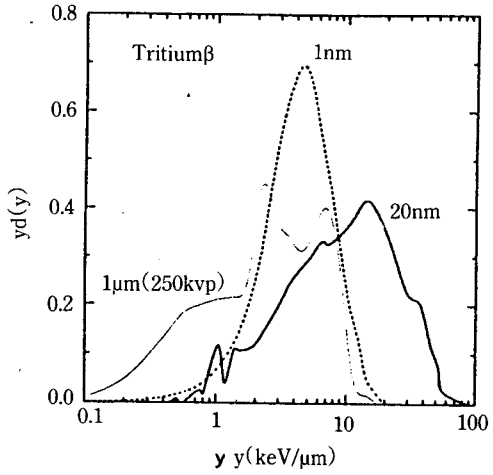
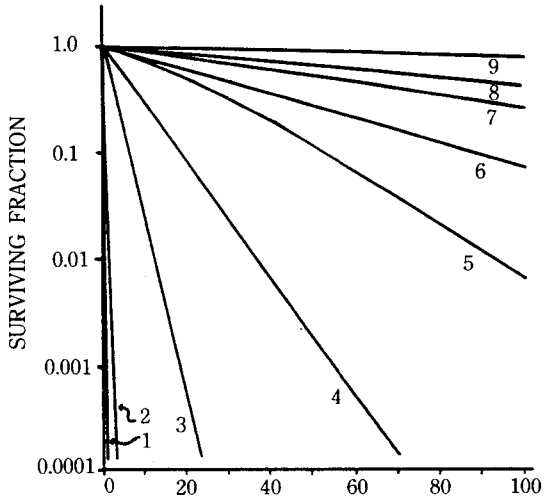


Fig. 3. Absorbed does distributions in linear energy induced by tritium beta radiation in 20nm and 1μm diameter spherical sites.



1. Mouse Leukemia cells
2. Mouse L cells
3. E. coli B
4. E. coli B/r
5. Yeast
6. Phage staph K
7. B. megatherium
8. Potato virus
9. Micrococcus radiodurans

Fig. 4. Relative radiosensitivity as the log of surviving fraction for a given does.

Tritium in body water produces the same spectrum of radiogenic effects observed following whole-body exposure to penetrating radiations such as gamma- and x-rays. However, tritium beta radiations are of greater biological effectiveness than gamma- and x-rays.[28] The radiobiological effects of tritium beta radiation in the form of oxide, HTO, is 2 to 6 times higher than for gamma radiation of ^{137}Cs.[29] Binding of the biogenic tritium compounds is higher than that of HTO.

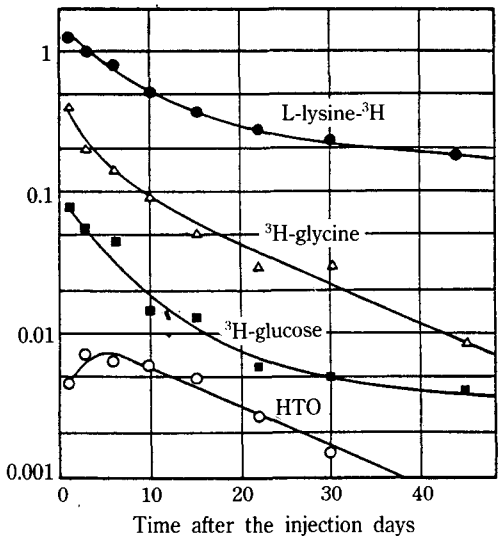


Fig. 5. Retention of specific activity of bound tritium in rat spleen with respect to dosage.

RISK ASSESSMENT

An approach to estimate tritium risks that incorporates the most recent information are provided for low-level beta exposures to tritiated water and certain tritiated organic molecules.[30] The health risks considered can be those for caner, genetic effects, and developmental abnormalities from tritium beta exposures in utero. Due to the nonexistence of human data for tritium risk, absorbed does, and relative biological effectiveness (RBE) for any of tritium beta radiation effects, extrapolations from other data are required. RBE is the ratio of the absobed does of a specific energy (usually 250kVp x-rays) to the absorbed does of any other ionizing radiation requried to produce the same biological effect. RBE is used in radiobiological work and risk assessment where best-estimate values are needed.

Fortunately, a wealth of cancer infomation is available for gamma- and x-rays from human epidemiological studies.[31]

However, health risks of tritium beta radiation should be assessed directly on humans, if possible. Two epidemiological studies available are the mortality studies which showed that an increase of prostatic cancer death might be related to internal exposure to tritium beta radiation.[32, 33] In Table 1, genetic risk estimate for HTO is compared for the first generation

following exposure to tritium beta radiations.

Table 1. Comparison of genetic risk estimates for low-level chronic exposure to HTO

Source of estimate	Genetic risk 10^{-6}/mGy
ICRP 1977	4
BEIR III 1980	0.5−7
UNSCEAR 1988	1−5
BEIR V 1990	2−5
ICRP 1991	5
LLNL 1993	7.9

The number of deaths due to exposure to HTO are so small that futher extensive studies are needed to confim these findings. Straume recommends in his work that additional analyses of the human and animal data be performed to better quantify the uncertainties associated with in utero developmental effects.[30]

TRANSPORT AND CYCLING

The transport and cycling of tritium in the environment can be understood in terms of hydrogen in the envionment. The transprot of tritiated water as the most abundant chemical form of tritium is extremely important in determining the transport of tritium in the environment and the subsequent exposure to humans. Fig. 6 shows the hydrologic cycle of tritium. As a good example the vegetation system illustrated in Fig. 7 consists of three compartments.[34]

Water flow form soil into the plant takes place by absoreption through the roots and is transported along a water potential gradient through the plant vascular system into the levels.

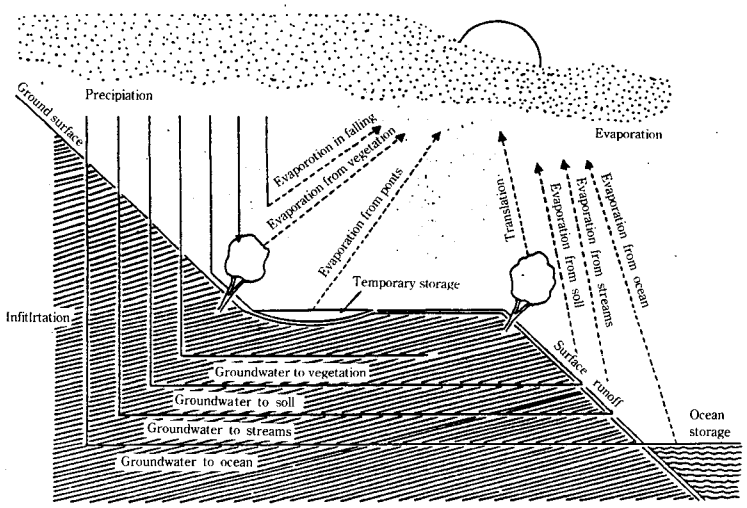


Fig. 6. Hydrologic cycle of tritium

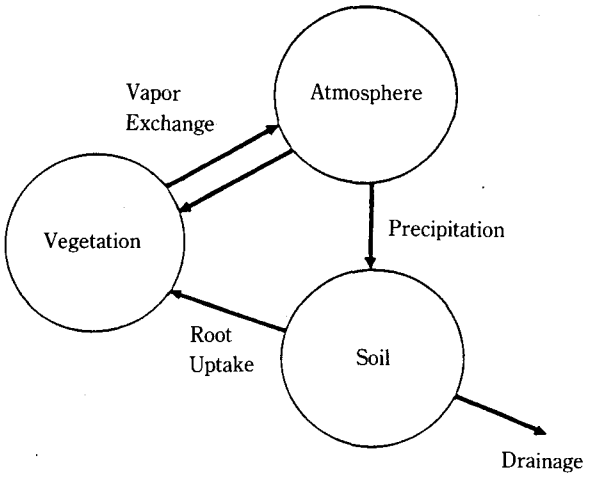


Fig. 7. Conceptual model of the soil-plan-atmoshere tritiated water(HTO) transport system.

Tritium is transported by bulk flow with the water. The uptake is diven by evaporation within the plant leaves. In the atmosphere away from nuclear facilities, the specific activity of tritiated water was found to be 16TU, 1.888Bq HTO/L.[34] The most well studied atmospheric chemical transformation involing tritium is the oxidation of tritiated hydrogen gas to tritiated water. The radiotoxicity of tritiated water has been calculated to be 20,000 times greater than that of tritiated molecular hydrogen.[10]

CONCLUSIONS

Tritium is easily spread and enters into the enviornment and humans. The radiological effects of tritium beta radiation in from of HTO is 2 to 6 times higher than for gamma radiation of ^{137}Cs.[29] Since HTO plays a primary role in most metabolic processes, it is released into the environment as tritiated water in a gaseous or liquid form (HTO) or as molecular tritium (HT) is relevant to the incorporation into living organisms and to forming organically bound tritium (OBT). OBT exhibits longer residence times in organisms than tritiated water.[35]

Tritium form nuclear facilities could be diluted as HTO and released into the ocean as means of waste disposal. All types of tritium disposals to the environment would became a problem perhaps not only for human health but also for public acceptance in the atome energy era of the 2000s.

Form this overiew of tritium health physics, we cannot but emphasize the importance and necessity workers at the occupational areas where possible exposures to tritium beta radiations are taken place.

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삼중수소 베타방사선에 관한 보건물리 연구의 적용

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삼중수소 베타방사선에 관한 보건물리 연구의 적용
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초 록

2000년대에 진입하게 되면 월성원자력발전소에서는 4기의 가압중수로형 원자로가 상업발전을 하게 되어서 많은 양의 삼중수소(^3H)가 필연적으로 주변환경에 누출될 것이다. 이러한 방사성 핵종은 삼중수소의 형태로 편재되어 있으면서도 지속성을 갖고 있어서 우리의 환경에 쉽게 분포된다.

삼중수소는 베타방사선량 계측과 보건위해 평가를 위해 독특한 과제를 제시하는 특성을 갖고 있어서 본 논문에서는 삼중수소에 관한 여러가지 문제들을 보건물리와 관련하여 특성과 원천, 신진대사와 선량계측, 미세선량계측, 방사생물, 위해평가, 환경 경로 및 순환 등의 견지에서 정리하였다.