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Tritium Bioassay and Dosimetry at a CANDU Reactors

Hee Geun Kim, Kyung Yeong Yoo
Korea Electric Power Research Institute

(Abstract)

Tritium dose management is an important aspect of the radiation protection program at CANDU type reactor sites. This paper describes the bioassay and dosimetry of tritium at CANDU reactor sites, especially for Wolsung Nuclear Power Plant. It presents a compilation of information drawn from published papers, technical reports, international and national guidelines as well as practical experience both in Korean and Canadian CANDU Nuclear Power Plants. The implementation of this program would provide a technical basis for demonstrating to workers, managers and regulators that tritium bioassay measurements, dose calculations and records should be of acceptable quality and should meet overall radiation protection program objectives.

I. Introduction

Tritium is produced in large quantity at heavy water nuclear power reactors via neutron activation reaction D-2(n, γ)T-3. At Wolsung nuclear power plant which has a CANDU reactor, the tritium concentrations in coolant and moderator are 1.5 Ci/kg-D_2O and 35 Ci/kg-D_2O, respectively, after 12 years of operation. The airborne tritium concentration in main access area is normally less than 5 MPCa except short-term peaks. The average tritium concentration in main access controlled area is also normally less than 100 MPCa.

Tritium is normally present in the air of workplace of CANDU reactors as a tritiated water vapour(HTO). Airborne tritiated water vapour entered into the workers body via inhalation and absorption through skin can result in a significant dose. The occupational doses from tritium at Wolsung Nuclear Power Plant have been maintained below 1 man-Sv per year so far. The tritium contribution to the total plant man-Sv lies between 30 percent to 50 percent.

This document is a compilation of the current understanding of tritium dosimetry, through reviews of a series of the published papers(Okada and Momoshima, 1993; Hill and Johnson, 1993), technical reports(NCRP, 1979; Whillans and Thind, 1995), and international guidelines (FPWG, 1987; ANSI, 1994) that are related to HTO metabolism and dose evaluation. The document identifies the scientific basis for the estimation and recording of tritium doses arising from the occupational exposure to HTO. The objective of this technical document is to provide practical guidance and recommendations on tritium dosimetry in the CANDU environment, especially for Wolsung NPP.

Ⅱ. Tritium Characteristics

Tritium is a radioactive isotope of hydrogen with an atomic number of 1 and mass number of 3. Tritium has a radioactive half-life of 12.3 years and decay to He-3 by emission of a low-energy beta particle. The beta particles have a maximum energy of 18.6 keV with an average energy of 5.7 keV. The maximum range of tritium beta rays is less than 6 ㎛ in water(nearly equivalent in human tissue).

Because of the short range of tritium beta-rays, the radionuclide does not constitute an external radiation hazard. The reason is that human skin is composed of the epidermis, 20-100 ㎛ thick, and the dermis, 1-3 ㎛ thick(ICRP, 1991). The target cells for skin cancers and skin damage of other types are present at basal layer of the epidermis and in the dermis. Thus, electrons emitted from tritium outside of the body could never reach in these radiosensitive targets.

Ⅲ. Exposure Pathways and Metabolsim

Most of the occupational exposure from HTO in the workplace results from inhalation and through skin absorption of vapor form of HTO(Osborne, 1972). The splashing of the skin with tritiated heavy water can occur accidentally while handling and transferring tritiated heavy water(e.g., drums overfilling, valving errors). Other pathways for HTO intakes(e.g., ingestion) are infrequent in the CANDU environment.

Once inside the body, the HTO diffuses freely and rapidly across membranes of the soft tissue, equilibrating throughout the total body water pool(Trivedi et al., 1995). HTO is distributed in intracellular and extracellular body water, and consequently, tritium retention in the body follows the biokinetics of the body water as indicated by its turnover rate in the urine. The conentration in urine, 2 or 3 hr post-exposure, is expected to be the same as in the other body fluids. The standardization of tritium dosimetry is based on the calculation of soft tissue dose due to HTO that is assumed to be uniformly distributed throughout the soft tissues of the body(Johnson, 1982). The ICRP-56(1989) recommended the assumption be made that internalized HTO is completely and instantaneously absorbed and mixed rapidly with the total body water. Accordingly, at all times, the concentration in urine and body fluids(e.g., sweat, sputum, blood, insensible and exhaled water vapor) are assumed to be in equilibrium with the body water. The uniform concentration of tritium in the body after HTO intakes results in the radiation dose being uniformly distributed amongst all tissues of the body.

The tritium in the body water metabolically exchanges with hydrogen atoms in biomolecules of the body. The metabolism and retention of tritium in the body are dependent on the nature of the chemical bonds in which tritium exists in the body. The tritium bound to oxygen, nitrogen, phosphorous, or sulphur atoms can readily exchange with hydrogen found in the body water pool and, thus, will have the same metabolism and distributions for HTO in the body for dosimetric purposes. This type has been called the exchangeable bound tritium. Tritium also exchanges metabolically with hydrogen in carbon-hydrogen bonds of biomolecules. Once bound to carbon, tritium will be difficult to remove and, thus, has been named as the nonexchangeable bound tritium or as organically bound tritium(OBT). Such

covalently bound tritium is normally released only as a result of enzymatic breakdown of the molecule containing this carbon-tritium bond. The average dose increase from OBT is considered to be 10% of the average dose due to tritium-in-body water(FPWG, 1987).

Ⅳ. HTO Bioassay and Dosimetry

Various guidelines originating from both regulatory and advisory agencies dealing with tritium dosimetry are applied in this technical basis document, in particular, Canadian "Guidelines for Tritium Bioassay(FPWG, 1987)," and the American National Standards Institute's "Internal Dosimetry programs for Tritium Exposure-Minimum Standards(ANSI, 1994)." Both of these documents were prepared by groups of experts that had considerable experience in internal dosimetry programs for tritium, including those associated with CANDU reactors.

For the purpose of radiation protection in an occupational setting, the ICRP(1977) has recommended the use of secondary limits, and have defined both an Annual Limit on Intake(ALI) and a Derived Air Concentration(DAC), for tritiated water. The ALI value for HTO is 8.1×10^4 μCi for both inhalation and ingestion intake. The DAC value for HTO of 22 μCi/㎥ assumes that an individual's intake by inhalation is augmented by 50% due to skin absorption.

Bioassay programs are based on the measurement of tritium concentrations in urine, and are structured to allow dose calculations without always having exact information regarding the extent and duration of exposure or the frequency of intakes. Two primary types of bioassay programs are identified, i.e., routine and nonroutine: A routine bioassay program is required when chronic exposures occur, or when the time of a series of acute intakes is unknown and not usually determined. Measurements are performed on those individuals that regularly work in an environment where tritium intakes can occur, or when the use of personal protective equipment is needed to prevent or limit HTO intakes. A nonroutine bioassay measurement is made in response to off-normal conditions regarding the individual's exposure, or as a means of providing intake information about a specific operation or exposure event.

Ⅵ. Dose Evaluation and Control

In a routine and nonroutine HTO dosimetry program most intakes fall under one of the following patterns:

1) chronic intakes between successive bioassays(linear estimate),
2) a single intake at a known time between successive bioassays, or
3) a single intake, preceding a chronic intake, at a known time between successive bioassays.

In calculations of effective dose equivalent in a CANDU environment, pattern 1) is the most common and is well suited for computer calculations. For very complex intake patterns, a combination of algorithms may have to be used, and it is important that the radiation

protection program has mechanisms to identify when a more complex dose calculations must be made.

Control of tritium intakes at a CANDU station is conducted in much the same manner as the control exercised on external dose. Control points need to be established to alert the individual and supervision when intakes are significant relative to regulatory limits as well as when there are indications that the rate of uptake could approach an ALI. For external dose, the ICRP in publications 35 (1982) suggests that an appropriate value for significant dose is about 30% of the dose limit when they recommend the use of regular monitoring of individuals. Since tritium dose is treated like external dose in view of dose control objectives, many CANDU stations have set an administrative control level(ACL) on monitoring results. The ACL is based on tritium uptake rate corresponding to 30% of the reguatory dose limit. At the other end of the scale, for the purpose of dose management, intake of an ACL is assumed as that of 1 ALI or annual dose limit(5 rem). The following equation can be used to derive ACLs for individual bioassay results that indicate rates corresponding to a fraction, f, of the regulatory dose limit.

$$ACL(\mu Ci/l) = f \cdot 5{,}000(mrem) / \{365(day) \cdot 0.22(mrem/day/\mu Ci/l)\}$$

Recommended ACLs are summarized in Reference of AECL Report, RC-1554.

Ⅶ. Conculsions

This report describes the hazards and dosimetry of tritium in CANDU reactor program. Implementation of the tritium dosimetry program are important in establishing an effective tritium dosimetry program. These program should provide a tool for demonstrating to workers, managers and regulators that tritium bioassay measurements, dose calculations and records are of acceptable quality and meet overall radiation protection program objectives.

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