MANAGEMENT OF TRITIUM EXPOSURES FOR PROFESSIONALLY EXPOSED WORKERS AT CERNAVODA 1 NPP

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1. ABSTRACT

Operating experience to date of CANDU reactors has indicated that the major contributor to the internal dose of professionally exposed workers is the tritiated heavy water (DTO).

CANDU reactors are both moderated and cooled by heavy water (D_2O). Tritium is produced in CANDU reactors by neutron reactions with deuterium, boron, and lithium and by ternary fission.

Even small leaks from these systems can produce important contaminations with tritiated water vapours of the air in the reactor building and thus increased individual and collective internal doses.

Professionally exposed workers are subject to a combination of acute and chronic tritium exposure and HTO dosimetry program at Cernavoda NPP is based on multiple sample results. The routine urine bioassay program performs the monitoring and dosimetry functions for DTO. A specialized laboratory using Liquid Scintillation Spectrometry methods currently determines tritium activities in urine samples. The frequency of biological samples submission depends on the tritium concentration in the last sample.

Dose assignments resulting from routinely measured weekly and monthly urinary levels of tritium oxide are based on the method of linear interpolation unless it is known that there has been no exposure between samples (vacation). All information about these doses is stored into a dedicated electronic database and used to make periodical reports and to ensure that the legal and administrative individual and annual limits are not exceeded.

A chronic unprotected exposure to small tritium dose rate (< 50µSv/h) may lead to internal doses that exceed the intervention level. In case of acute exposure an increased daily water intake combined with a proper medical intervention could reduce the effective half time of tritium 2-3 times.

2. INTRODUCTION

Situated at 180 km east of Bucharest, Cernavoda Nuclear Power Plant is a CANDU 6 type NPP. CANDU (CANadian Deuterium Uranium) is a Canadian design power reactor, which employs natural uranium as fuel and heavy water as a neutron moderator and as the thermal agent.

The thermal neutron flux in the CANDU reactor, by activation of deuterium, is the major producer of tritium but other nuclear reactions could also produce tritium as listed below.

a. Activation reactions
   1) ${}^{2}_{1}H + n \rightarrow {}^{3}_{1}H$
   2) ${}^{6}_{3}Li + n \rightarrow {}^{3}_{1}H + {}^{4}_{2}He$
   3) ${}^{10}_{5}B + n \rightarrow {}^{3}_{1}H + 2\,{}^{4}_{2}He$
b. Ternary Fission
c. Reconversion of ${}^{3}He$ from ${}^{3}H$ Decay

Very small amounts of DTO may escape from moderator and heat-transport systems of CANDU reactors during maintenance and normal operation.

Even small leaks from these systems can produce important contaminations with tritiated water vapors of the air in the reactor building and thus increased individual and collective internal doses. That why the ventilation systems were carefully designed to control water vapor concentration in radiological areas and special dryers remove moisture from the air in order to maintain the tritium doses well below the limits.

Despite the protection measures operating experience to date of CANDU reactors has indicated that the major contributor to the internal dose of professionally exposed workers is the tritiated heavy water (DTO) which is present chronically at many work locations.

3. TRITIUM CHARACTERISTICS

Exposure to an atmosphere contaminated by tritiated water results in intake of that substance both by inhalation and by absorbtion through the intact skin, in a ratio assumed to be 2 to 1.

Vapours of tritiated water are considerred to be of SR-2 absorbtion class that means the tritiated water is instantaneously absorbed into body fluids and uniformly distributed among all the soft tissues and is eliminated with a nominal half time of 10 days. In addition a very small fraction is incorporated in non - exchangeable form and eliminated with a much longer half time.

Tritium (H-3) is a pure beta emitter, with an average energy of beta radiation of 0.0057 MeV. Its presence in the body can be detected by measuring the urine samples using the liquid scintillation counting and it presents no detection problems.

4. INTERNAL DOSIMETRY FOR DTO

The principal objectives of individual monitoring for intakes of radionuclides are:

- to obtain an assessment of the committed effective dose;
- to contribute to the control of operation and the design of the plant;
- in the case of accidental exposure, to provide valuable information for the initiation and support of any appropriate health surveillance and treatment.

Professionally exposed workers are subject to a combination of acute and chronic tritium exposure and DTO dosimetry program at Cernavoda NPP is based on multiple sample results. Body DTO concentration is integrated over time and multiplied by the dose rate per unit concentration factor as in relation (4.1).

$$E = 5.8 \cdot 10^{-2} \sum_{i=0}^{k-1} [(C_{i+1} + C_i)/2] \cdot (t_{i+1} - t_i) \tag{4.1}$$

where E is the effective dose in mSv. The urine concentrations C_i are given in MBq/L, and the time is expressed in days. Tritium doses are registered into personal records with a registration level of 0.17 mSv.
The committed dose (mSv) associated with a ^{3}H concentration C (MBq/L) in case of an acute intake is computed as follows:

$$E_{(50)} = 0.84 \cdot C \tag{4.2}$$

where the dose factor 0.84 was computed by using tritium physical characteristics, anatomic and metabolic data for Reference Man [Popescu, Chitu, 2001].

4.1 Bioassay for intakes of DTO

Bioassay monitoring for internal dosimetry of DTO is relatively simple involving the sampling of a single void urine sample. The method consists of mixing 1 mL of urine sample with 10 mL of scintillation cocktail. (Packard ULTIMA GOLD ™). This mixture is well shacked for 10 minutes to ensure the homogeneity of the sample and then measured by the liquid scintillation spectrometer CANBERRA-PACKARD TR/LL – 2550.
A monthly frequency of bioassay submission is used at Cernavoda NPP for professionally exposed workers who are infrequently exposed or exposed to low tritium levels (urine concentration remains below 100 kBq/L).

If the urine tritium concentration is greater than 100 kBq/L weekly sampling will be required.
When concentration exceeds 1 MBq/L, the investigation level, daily sample submission is required.

In case of acute exposures, which significantly exceed chronic levels, the most important error in dosimetry arises from the estimation of the time of intake. Therefore special monitoring is required when planned exposures to DTO are foreseen, the worker should submit additional samples before and after the task completion. When working conditions are unexpectedly changing and could produce abnormal exposures to DTO, all the personnel involved will submit additional samples.

Dose assignments resulting from routinely measured weekly and monthly urinary levels of tritium oxide are based on the method of linear interpolation unless it is known that there has been no exposure between samples (vacation).

A chronic unprotected exposure to small tritium dose rate (< 50μSv/h) may lead to internal doses that exceed the intervention level, as can be seen in Figure 1.

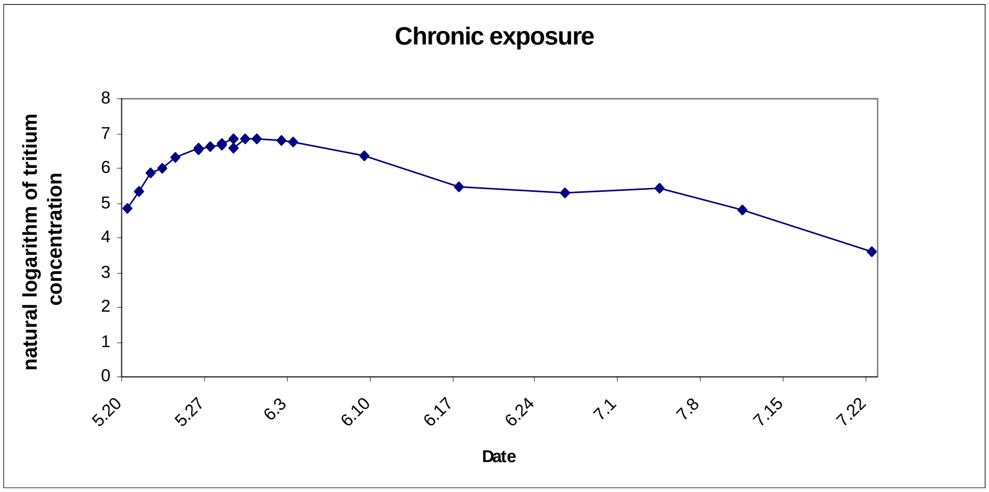

Figure 1

In case of acute exposure dose-mitigating actions are recommended by the Occupational Medicine Specialist in consultation with Dosimetry Program responsible. The primary treatment for reducing internal dose from a tritiated water uptake is to accelerate the turnover of body water. This can be done by substantially increasing the fluid intake rate of an individual through oral or intravenous means, and/or using diuretics. Cernavoda NPP experience intakes indicating that a sustained drinking regime gave a clearance half-time of about 5 – 6 days compared with a 10 day normal clearance half-time.

Figure 2 illustrates tritium dynamics in urine following unusual DTO incorporation based on daily measurements. Tritium clearance was accelerated with diuretics under physicians surveillance, which resulted in low tritium effective half-times, 5.4 days. This value is obviously smaller than the mean value of 10 days which is conservativelly used in dosimetric calculations.

During the investigation period this worker was not allowed to enter in tritium contaminated areas until the tritium concentration in urine had decrease below 1 MBq/L.

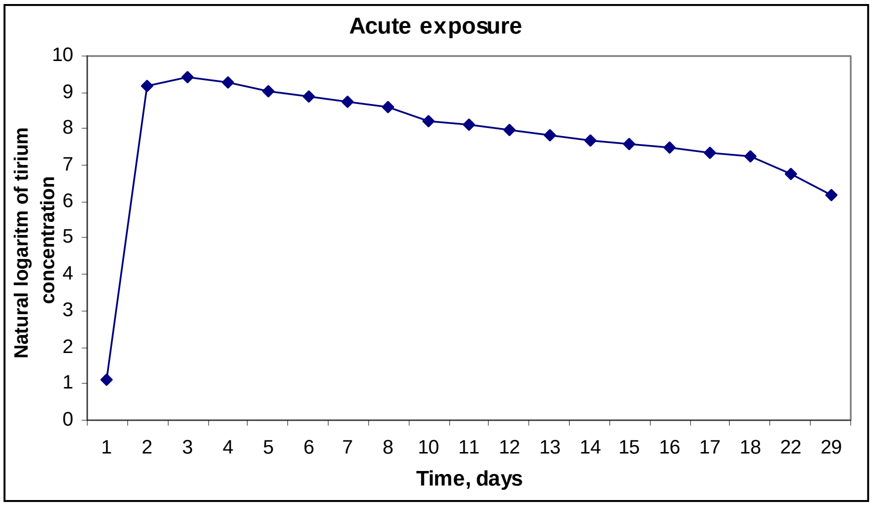

Figure 2

All information about these doses is stored into a dedicated electronic database and used to make periodical reports and to ensure that the legal and administrative individual and annual limits are not exceeded.

5. CONCLUSIONS

Tritium is an important contributor to the internal exposure of radiation workers in Cernavoda NPP. Collective dose for professionally exposed workers reached a value of 818.28 man mSv in 2003 and internal doses raised from 1.9% in 1996 to about 40% in 2002.

Table I presents the internal dose distribution by dose interval due to tritium intake between 1999 and 2003. As can be seen most of the results were below the Recording Level, the majority of recordable doses were less then 1 mSv.

Year	0.0	>0.0 <1.0	1.0 – 5.0	5.0 – 10.0	10.0 – 15.0	15.0 – 20.0	Over 20.0
1999	1353	236	23	0	0	0	0
2000	1399	243	32	0	0	0	0
2001	1419	327	37	0	0	0	0
2002	1571	343	57	1	0	0	0
2003	1580	505	83	0	0	0	0

Table I. Internal dose distribution (mSv) by dose interval 1999 – 2003

The actual levels of internal doses due to tritium exposures reveal the effectiveness of implementation of the Radiation Safety Policies and Principles established by the management of the Cernavoda NPP, based on the ALARA principles.

REFERENCES

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- Safety Series No. 115, International Basic Safety Standards for protection against Ionizing Radiation and for the safety of Radiation Sources, Table II-IX, page 274, IAEA 1996