RADIATION RISK ANALYSIS OF TRITIUM IN PWR NUCLEAR POWER PLANT

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Abstract:

Tritium is a common radionuclide in PWR plant existing mostly in the manner of HTO, its radiation risk is mainly internal exposure when intake from inhalation. In this paper, the relationship between saturated HTO concentration in air（SHCA）, HTO concentration in water (A_{TW}), and the water temperature was derived. Which is:

$$SHCA = 4.86 \times 10^{-6} \times 10^{\frac{6.9t}{230+t}} \times A_{TW}.$$

In the normal operation of Nuclear Power Plant, the practical HTO concentration in air (PHCA) is 30 to 60 times lower than SHCA. The radiation risk analysis of HTO revealed that, in PWR plant, the radiation risk of HTO is quite limited, no routine individual monitoring, no routine area or air monitoring and no special protection is needed for HTO.

Key words: radiation/risk/analysis/HTO/tritium

1. Radiation risk of tritium

Tritium is a common radionuclide in PWR plant existing mainly in the manner of HTO, its radiation risk is mainly internal exposure when ingested by the following ways:

A. Absorption from skin when contaminated by Tritium. In a PWR plant, as effective individual protective measures are taken for contamination risk, large surface and high level skin contamination are normally averted. The possibility of Tritium intake by this way is quite low.
B. Intake from month. Because of the individual and collective protective measures implemented in PWR plant, the possibility by this way is low too.
C. Intake from inhalation: It is the main way of HTO ingestion.

HTO in water enter air mainly by evaporation. In the PWR plant, most of the radioactive systems are maintained enclosed in normal operation, except:

A. The spent fuel pool (in the Fuel Building): Always open to the air with surface of around $106m^3$.
B. Reactor pit and fuel transfer pool (in the Reactor Building): Filled with water in some periods of outage with a surface of around 150 m^3.
C. Liquid waste sumps: they are normally located in isolated rooms with small surface.
D. The reactor building during power operation: During power operation, the Reactor Building is maintained closed with only internal ventilation. As there is always some leakage collected in liquid waste sumps, after a certain time of operation, the HTO in air way be saturated with liquid and reach $10^4 \sim 10^5 Bq/m^3$. Because access to reactor building is strictly controlled in power operation period, the internal exposure for workers from HTO is low.

In summary, the radiation risk of Tritium in RWR plant is mainly exist in the Fuel Building, and the Reactor Building during outage. The highest HTO concentration in air is the saturated HTO concentration in air（SHCA）when equilibrium has been set up with water phase.

2. Relationship between SHCA and HTO concentration in water (A_{TW})

When the water temperature is low, there is :

$$p_S \times V = n_S RT \quad (1)$$

Here Ps is the partial pressure of saturated steam in air, n_s is the mole number of saturated steam in air, R is a constant, R=8.31 J/mole.k, V is the volume of air, T is the absolute temperature.
For HTO in air .

$$p_{TS} \times V = n_{TS} RT, \quad \frac{n_{TS}}{V} = \frac{p_{TS}}{RT} \quad (2)$$

Here P_{TS} is the partial pressure of HTO in the saturated steam, n_{TS} is the mole of HTO in air.
The activity of HTO in air:

$$A_{TS} = \lambda \times N_{TS} = \lambda \times \eta \times n_{TS} \quad (3)$$

Here, n_{TS} is the number of HTO molecules, λis the decay constant of HTO, ηis a constant, $\eta = 6.023 \times 10^{23}$
The saturated HTO concentration in air (SHCA) when equilibrium is set up between air and water is:

$$SHCA = \frac{A_{TS}}{V} = \frac{\lambda \times \eta \times n_{TS}}{V} = \frac{\lambda \times \eta \times p_{TS}}{RT}. \quad (4)$$

If the HTO concentration in water is A_{TW}(Bq/m^3), the mole of HTO is n_{TW}, there is :

$$A_{TW} = \lambda \times n_{TW} \times \eta \quad (5)$$

$$n_{TW} = \frac{A_{TW}}{\lambda \times \eta} \quad (6)$$

$$n_w = \frac{10^6}{18} mol = 5.56 \times 10^4 mol$$

In 1 m^3 water, the number of mole of H_2O is

$$\frac{n_{TW}}{n_W} = \frac{A_{TW}}{\lambda \times \eta \times 5.56 \times 10^4} = \frac{1.8 \times 10^{-5} A_{TW}}{\lambda \times \eta} \quad (7)$$

So the relationship between P_{TS} and Ps is:

$$p_{TS} = \frac{n_{TW}}{n_W} \times p_S = \frac{1.8 \times 10^{-5} A_{TW} \times p_S}{\lambda \times \eta} \quad (8)$$

When (8) is combined with (4), there is:

$$SHCA = \frac{\lambda \times \eta \times p_{TS}}{RT} = \frac{1.8 \times 10^{-5} A_{TW} \times p_S}{RT} = \frac{2.17 \times 10^{-6} A_{TW} \times p_S}{T} \quad (9)$$

The partial pressure of saturated steam in air (Ps) has the following relationship with water temperature:

$$\text{Ps} = 2.24 \times 10^{\frac{6.9t}{230+t}} \times T \quad (11)$$

As a result:

$$SHCA = 4.86 \times 10^{-6} \times 10^{\frac{6.9t}{230+t}} \times A_{TW} \qquad (12)$$

According to (12), at the typical temperatures, the relationship of HTO concentration in air (SHCA) and in water (A_{TW}) are:

$$SHCA_{20\,°C} = 1.73 \times 10^{-5} A_{TW} \qquad (13)$$
$$SHCA_{30\,°C} = 3.04 \times 10^{-5} A_{TW} \qquad (14)$$
$$SHCA_{40\,°C} = 5.12 \times 10^{-5} A_{TW} \qquad (15)$$
$$SHCA_{50\,°C} = 8.30 \times 10^{-5} A_{TW} \qquad (16)$$

The above relationship could be illustrated in Fig1.

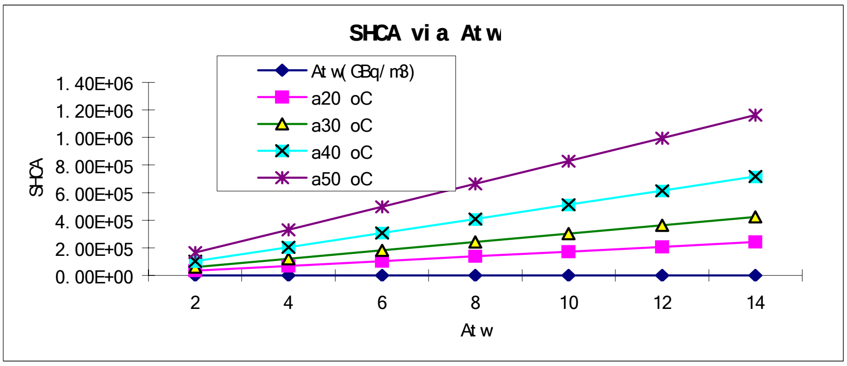

Fig1. SHCA via Atw

For a PWR plant, when the purification and residual heat removal system for the reactor pit and spent fuel pool is in normal operation, the designed highest water temperature is normally 50°c, the practical temperature is normally 30°c. For respiratory intake, the DAC of HTO is 8×10^5 Bq/m^3 . According to fig. 1, when the water temperature is 30°c and the HTO concentration (A_{TW}) is 3GBq/m^3, the *SHCA* reaches 0.1DAC, when A_{TW} is 8GBq/m^3, *SHCA* reaches 0.3DAC, when A_{TW} is as high as 28GBq, *SHCA* reaches 1DAC.

According to equation (12), at different A_{TW}, for example, when A_{TW}=4GBq/m^3, the relationship between *SHCA* and water temperature is:

$$SHCA = 1.94 \times 10^{4} \times 10^{\frac{6.9t}{230+t}} \qquad (17)$$

Fig 2 is the relationship between *SHCA* and water temperature at different level of A_{TW}.

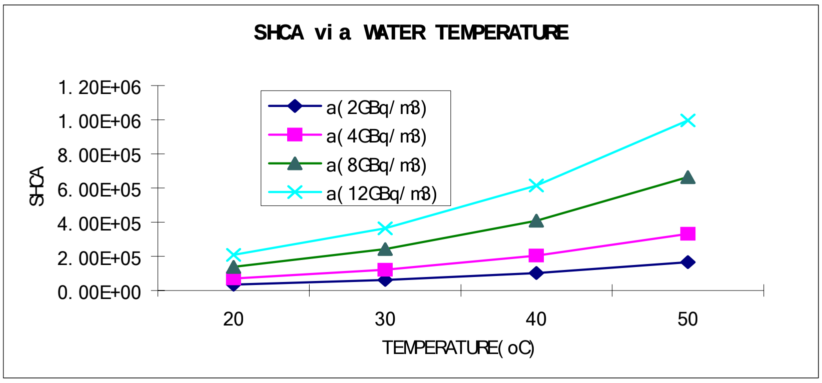

Fig 2.   Relationship between *SHCA* and water temperature at different level of A_{TW}

From fig 2, the equilibrium HTO concentration in air increase evidently with water temperature, when water temperature is 50°c, the *SHCA* is 2.7 times to that of 30°c, and 4.8 times to that of 20°c. when A_{TW}=8GBq/m^3, t=20°c, *SHCA* =1.4×10^{5}Bq/m^3, t=30°c, *SHCA* =2.43×10^{5}Bq/m^3, when temperature reach 50 °c, *SHCA* shall reach 1DAC.

3. The practical radiation risk analysis of HTO

Fig 3 is the practical HTO concentration in air (PHCA) over the reactor pit in the Reactor Building (1RX) and over the spent fuel pit in the Fuel Building (1KX) in the 3rd outage of unit 1 of the Daya Bay Nuclear Power Plant.

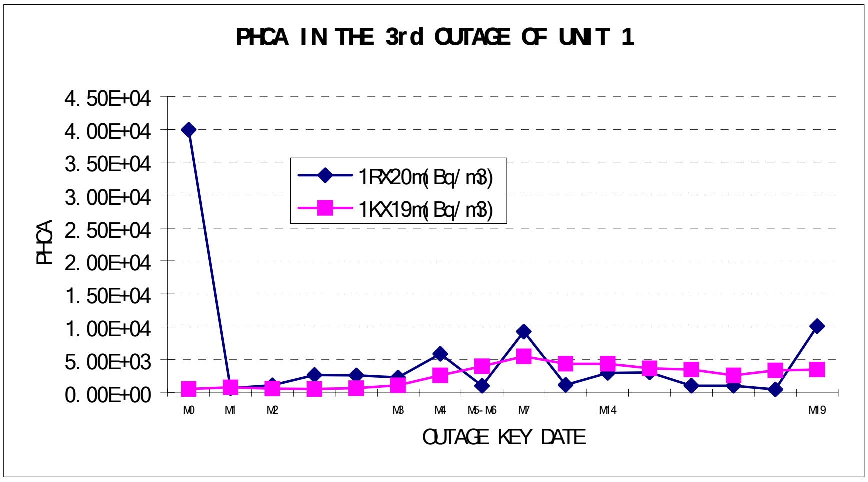

Fig 3 . PHCA in the 3rd OUTAGE IF UNIT 1

The X axial is the key date of the outage. Mo is the date of unit shutdown for outage, M1 is the date that unit reach cold shutdown, M2 is the date when the pressurizer manhole was opened, M3 is the date of unloading, M4 is the date the fuel transfer ended. Between M5 and M6, the reactor pit is empty to facilitate maintenance on the primary circuit. M7 is a specific period in the outage for reactor building pressure test, M_{14} is the refueling period , M_{19} is the end of the outage and the unit reached hot shutdown status .

According to the practical monitoring results of A_{TW} in the outage, the A_{TW} of spent fuel pool was around 3GBq/m3, while the reactor pit was around 6GBq/m3. Suppose the water temperature was maintained at 30°c, the SHCA in 1KX and 1RX shall be 9.12×10^{4}Bq/m^3 and 1.82×10^{5}Bq/m^3, the PHCA was around 3KBq/m3 , which is 3.23% and 1.65% of the SHCA.

Another factor affecting the HTO concentration in air is the A_{TW}. The practical results of DaYaBay NPP in the past 8 years demonstrate that the HTO concentration in primary coolant was about 50GBq/m3 during power operation, and less than 20GBq/m3 in the outage. As a result, the HTO in the spent fuel pool and the refueling water tank shall normally not be more than 20GBq/m3. If HTO concentration in air is 50 times lower than its SHCA when ventilation system is in operation, at 30 ^{o}C, the PHCA shall not reach 1DAC except when the A_{TW} reaches 1.3TBq/m3.

4. Conclusion and proposals to HTO monitoring and protection

1) There is only limited areas existing radiation risk in RWR Nuclear Power Plant, with the practical situation that ventilation in operation, low water temperature and lower A_{TW}, the radiation risk of HTO is quite low.
2) For individual protection, no special protection is needed for HTO in PWR plants.
3) For individual dose monitoring, except the monitoring for selected samples of workers, no routine monitoring is needed.
4) For the area monitoring, except the special monitoring, no routine monitoring is needed.
5) Maintain normal operation of the ventilation system and the spent fuel pool cooling system is needed and effective to limit HTO in air.

Reference documents:

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