A Method of Locating Leakage of Heavy Water in CANDU Reactors Using Ratio of Tritium to Heavy Water in a Water Vapor Sample

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Heavy water systems in CANDU reactors

The CANDU reactor is a pressurized heavy water reactor. It uses heavy water as coolant and moderator. It has two great systems, Primary Heat Transport System (PHT) and Moderator System (MOD), which contain heavy water. PHT system is a coolant system named differently than Reactor Coolant System of pressurized water reactor.

While heavy water in these systems circulates through the reactor, deuterium in the heavy water is activated and becomes tritium. So heavy water in the systems contains much amount of tritium. But the tritium concentrations of heavy waters in the two systems are not same, because the heavy waters in PHT system and MOD system are separated each other and their volumes and staying times inside the reactor are different. In Wolsong Power Plant II, the tritium concentration of PHT heavy water is about 2 Ci/kg and MOD heavy water, 40 Ci/kg.

Leakage of heavy water in CANDU reactors

If the heavy water leaks, it vaporizes into air in the reactor building. Actually, in all CANDU reactors there is small amount of usual leakage of heavy water. It causes a low level of tritium concentration in air in the reactor building. In Wolsong plants, this concentration is between 1 DAC and 3 DAC in normal condition.

Sometimes leakage of heavy water increases and makes the tritium concentration in air in the reactor building high. Indeed, we can find out there is an increased leakage somewhere through the increased tritium concentration in air.

High tritium concentration in air can increase internal dose of workers. Most of leaked Tritium is collected back by Heavy Water Vapor Collection System, but about 10% of tritium spreads into the environment. So, it is urgently demanded to locate the leakage and repair it when there occurs an unusually high leakage. But, it is not easy to locate the exact spot of leakage in a short time because PHT system and the MOD system are great and complicated systems. When one of these systems leaks heavy water, it probably takes a few weeks to search the leakage point. The leakage from high pressure system tends to become greater with time. If we fail to find the point of leakage within a few weeks, we occasionally should stop the reactor to search the point. But it is not always possible to find quickly the leakage point even though we stop the reactor. Therefore it is also difficult to stop the reactor before we have confidence that the leakage point is in the area where we cannot access while the reactor operates.

Discrimination of leaking system

If we have a way to discriminate from which system heavy water leaks, PHT system or MOD system, we can more easily locate the exact leakage point. As mentioned before, the tritium concentrations of the two systems are largely different. We can use this point to find the way.

Suppose that PHT system and MOD system are leaking heavy water and the heavy water is vaporizing into air directly. Also suppose we have a sample of water that has captured water vapor from the air. Let us designate tritium concentrations of PHT heavy water and MOD heavy water as A and B respectively. If amount of PHT heavy water in the sample is X, the amount of tritium from PHT system in the sample will be AX. It is because the tritium concentration of PHT heavy water means the ratio of tritium to heavy water in the PHT system and the ratio remains the same even if the tritium and heavy water moved to other location. In the same way, if amount of MOD heavy water in the sample is Y, the amount of tritium from MOD system in the sample will be BY. The amount of heavy water from the two systems in the sample is merely summation of the two amounts of heavy water from the two systems. The amount of tritium from the two systems in the sample is in the same situation. So, the amounts of heavy water and tritium will be $X + Y$ and $AX + BY$.

Now, suppose again that we measured amount of heavy water and tritium in the sample and the values are H and T. Our goal is to find out how much PHT heavy water and MOD heavy water leak. So we should calculate X and Y from H and T. In order to calculate X and Y, we should make a system equation as followings.

$$AX + BY = T$$
$$X + Y = H$$

where A is tritium concentration in PHT heavy water (known)
B is tritium concentration in MOD heavy water (known)
X is PHT heavy water in sample (unknown)
Y is MOD heavy water in sample (unknown)
T is tritium amount in sample (measured)
H is heavy water amount in sample (measured)

After simple calculation, we can get the solutions like these.

$$X = (T - BH) / (A - B)$$
$$Y = (T - AH) / (B - A)$$

So, we can get the values of PHT heavy water and MOD heavy water in the sample from tritium and heavy water measurements of it. This method is comparing tritium ratio to heavy water in the sample with the same ratios of the PHT system and MOD system. In other words, it is comparing tritium concentration of heavy water in air with the same concentrations of PHT heavy water and MOD heavy water.

Using the method mentioned above, we can know the distribution ratio of PHT system and MOD system to the leakage of heavy water and the tritium concentration in air in the reactor building. When the tritium concentration in air in the reactor building rises high, we can collect a sample and measure the values of tritium and heavy water in the sample, and then we can calculate the distribution ratio of the two systems to the heavy water leakage.

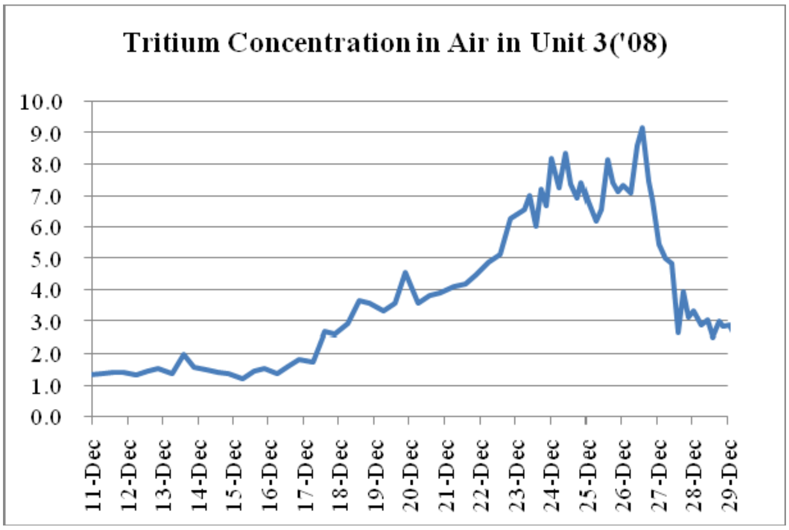
Wolsong Power Plant II's two recent experiences

Unit 3, Dec. 2008

Tritium concentration in air in the reactor building in Wolsong Unit 3 suddenly rose high on December 17, 2008. And the concentration kept going higher for 10 days. We collected some samples of water vapor in the reactor building air using gas washing bottles which captured humidity from the air passing through water in the bottle. We could get following values.

The tritium amount in 1g of the sample (T) = 25.9 kBq
The heavy water amount in 1g of the sample (H) = 26.4 mg

We had to compensate for deuterium's isotope ratio of 0.015% in nature. The heavy water amount in 1g of the sample was corrected to 9.7 mg.



We had already the tritium concentrations of the heavy waters in the PHT system and MOD system because we had analyzed them periodically.

The tritium concentration in PHT heavy water (A) = 1.714 Ci/kg
The tritium concentration in MOD heavy water (B) = 37.92 Ci/kg

With those values, we could calculate the contribution ratios of the two systems to the heavy water leakage. 85% of leaked heavy water was found out to have come from PHT system, and 15% from MOD system. But the tritium concentration in MOD heavy water is much higher than PHT system. So, contribution ratios to the tritium concentration in air were reversed.

The tritium in air in the reactor building from PHT system = 20%
The tritium in air in the reactor building from MOD system = 80%

In normal conditions that tritium concentration in air had remained low, this ratio of the PHT system had been higher than 90%. So we could conclude that this unusual leakage had occurred in the MOD system. After that, we surveyed the MOD system intensively for a few days and we found the leakage point at a junction near a pressure instrument of the MOD system. After the defect was repaired, the tritium concentration in air in the reactor building decreased right away.

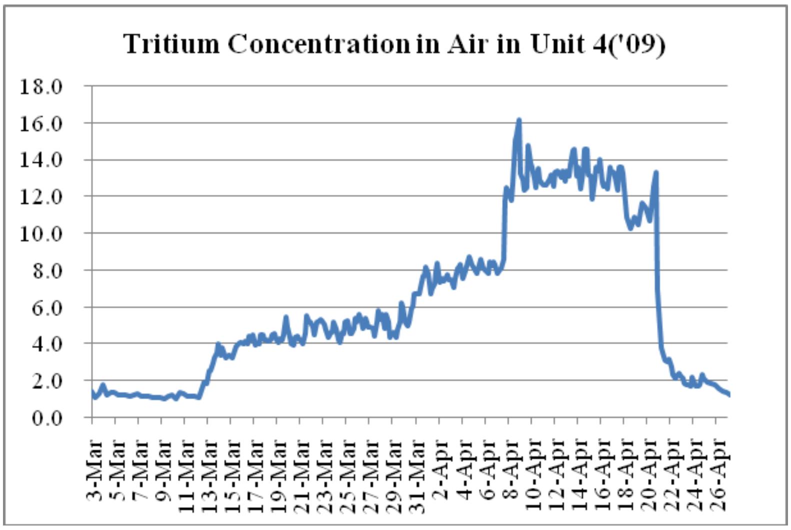
Unit 4, Apr. 2009

Tritium concentration in air in the reactor building in Wolsong Unit 4 rose high on March 12, 2009. The concentration jumped up a few times for about 40 days. We collected some samples of water vapor in the reactor building this time too. We got following values.

The tritium amount in 1g of the sample (T) = 50.3 kBq
The corrected heavy water amount in 1g of the sample (H) = 93.0 mg
The tritium concentration in PHT heavy water (A) = 1.513 Ci/kg
The tritium concentration in MOD heavy water (B) = 36.99 Ci/kg

With those values, we calculated the contribution ratios of the two systems to the heavy water leakage and the tritium concentration in air in the reactor building.

The heavy water in air in the reactor building from PHT system = 100.14%
The heavy water in air in the reactor building from MOD system = - 0.14%
The tritium in air in the reactor building from PHT system = 103.7%
The tritium in air in the reactor building from MOD system = - 3.7%



It was obvious that the unusually increased leakage of heavy water was from the PHT system and the number bigger than 100% or less than 0% seemed to be due to an experimental error. We surveyed the whole PHT system and its related system except the parts in non-accessible area. But we could not find out the leakage point for a long time. Instead we found out that the irrational results for the contribution ratio which are greater than 100% or less than 0% were repeated when we collected and analyzed some more samples.

We took notice to stagnant heavy water stored apart from the reactor core like as the water in the Coolant Storage Tank. This water had been isolated so long that the tritium concentration was expected to be a little less than that of the heavy water circulating between the core and steam generators.

We sampled that water and analyzed to figure out the tritium concentration in the heavy water in the Coolant Storage Tank was 1.40 Ci/kg while the concentration of main PHT system was 1.51 Ci/kg. That result was what could explain the ratio of tritium in the water vapor sample to the heavy water in the same sample, 1.46 Ci/kg.

We again surveyed isolated systems carefully and finally found out the leakage point on the Degas Condenser Tank which was a semi-isolated system. The defect had not been found because it was beneath the heat shield. After the defect was repaired, the tritium concentration in air in the reactor building decreased rapidly.

The Conclusion

There is a way to find out from which system heavy water and tritium leaks, using tritium ratio to heavy water in air which the leaked heavy water and tritium spread into. The sample we need is some amount of water which contains water vapor from the air with the leaked heavy water and tritium. We can know the contribution ratio of the PHT system and MOD system to the heavy water leakage or tritium concentration in air. Some isolated parts of the PHT system have a little different tritium concentration and this fact can be an additional clue to locate the leakage.