HEAVY WATER DETRITIATION TO SUPPORT CANDU STATION MAINTENANCE ACTIVITIES

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Abstract

Heavy water and tritium control are important aspects of CANDU® operation and have a major impact on station maintenance activities. Station personnel are trained to understand the importance of heavy water management and the economics and environmental impact of tritiated heavy water losses. This paper discusses new GE technology that can now make a major improvement in CANDU® maintenance activities through significant reductions in station tritium levels.

Tritium is of particular concern in the CANDU® industry given the nature of heavy water reactors to build up high levels of tritium over time. High tritium levels in the reactor vault significantly slow down maintenance activities in the reactor vault due to the requirement for personnel protective equipment, including breathing apparatus and cumbersome plastic air suits. The difficulties increase as reactors age and tritium levels increase.

Building upon GE's extensive operational experience in tritium management in CANDU® reactors and its own tritium handling facility, GE♦ has developed a new large-scale diffusion-based isotope separation process as an alternative to conventional cryogenic distillation. Having a tritium inventory an order of magnitude lower than conventional cryogenic distillation, this process is very attractive for heavy water detritiation, and applicable to single and multi-unit CANDU® stations. This new process can now provide a step change reduction in CANDU® heavy water tritium levels resulting in reduced environmental emissions and lowering reactor vault tritium MPC(a) levels. Reactor vault tritium can be reduced sufficiently for maintenance activities to be done without plastic suits, leading to shorter outages, improved station capacity factors, and improved station economics.

1. Introduction

Tritium builds up in a CANDU® moderator and heat transport systems due to neutron capture by deuterium. This is a characteristic of heavy water reactors, and one of the major safety concerns at CANDU® stations.

♦ In this paper GE refers to both GE Healthcare and GE Hitachi Nuclear Energy Canada Inc.

GE has developed extensive experience based upon its own tritium handling facilities, the delivery of the Tritium Waste Treatment & Enrichment Facility [1] and long term experience in system design and reactor service work for CANDU® power stations.

This paper discusses new GE technology that can now make a major improvement in CANDU® maintenance activities through significant reductions in station PHT and moderator tritium levels.

2. GE's Experience

In April 1955 Canadian General Electric created the Civilian Atomic Power Department at it's Peterborough, Ontario facility to begin work on design of the prototype nuclear plant; the NPD at Rolphton. GE was the prime contractor for the design, supply, installation and start-up of the Nuclear Power Demonstration Station (NPD) at Rolphton, Ontario. In 1965 GE signed a contract for the turnkey supply of the Pakistan Atomic Energy Commission's 137 MW Kanupp PHWR. GE followed the success of the CANDU® design with participation in the subsequent design and build of Pickering, Bruce A and B, Darlington, Gentilly, Point Lepreau, Embalse, Wolsong and Cernovado.

In 1943 a research facility was established in Amersham, UK, later becoming a national centre for radiochemical research under the UK Atomic Energy Authority. After the Second World War, the centre began producing radiochemical labelled compounds with tritium and carbon-14. Today, as GE Healthcare, GE is the world's largest supplier of radiolabelled molecules, supplying around one quarter of all labelled drugs used by the pharmaceutical industry. Through the successful long-term operation of these facilities, GE has gained a great deal of knowledge in the handling of highly tritiated compounds including pure tritiated water. Building on this experience, GE recently designed and installed award winning technology for the separation and recovery of tritium at it's radiochemical manufacturing site in Cardiff, UK.

The establishment of the Light Isotope Technology Centre of Excellence at GE-Hitachi Canada's headquarters in Peterborough, Ontario has centralised GE's knowledge base of heavy water and tritium handling.

Today GE's core products and services to the CANDU® fleet include fuel, fuel handling machines, inspection and maintenance tooling, computer control systems, reactor field services, heavy water systems, heavy water upgraders and tritium removal systems.

This paper provides GE's assessment of existing CANDU® operation with respect to management of heavy water and tritium and its impact on operational performance, safety, and environmental discharges.

3. Impact of tritium for an operational CANDU®

A CANDU® 600 type reactor nominally produces $2x10^6$ Ci/y of tritium, with approximately 95% of the tritium formed within the moderator heavy water (D_2O). Tritium in heavy water contributes 30-50% of the annual radiation dose received by operation personnel and represents up to 20% of the radioactivity released from the reactor to the environment [2]. Tritium discharges to the environment from current CANDU® power stations are up to 20 times higher than from light water reactors [3]. Therefore management of tritium is an important and unique aspect of operating heavy water reactors.

4. Lower Vault Tritium Concentrations

CANDU® utilities are increasingly recognizing the importance of reducing reactor vault tritium airborne concentrations. Operating with a tritium concentration above the current adopted threshold of 100 MPC(a) [Maximum Permissible Concentration airborne]* means that outage activities within the vault are conducted within cumbersome air-suits. Working within air-suits increases the time taken to perform a single outage activity by two to three times in comparison to working with respirators. Reducing tritium airborne levels within the vault below the 100 MPC(a) threshold would have a two-fold improvement for an operating company, firstly reducing occupational dose during an outage and secondly reducing the overall duration of a planned outage; this would directly improve the station capacity factor and revenue.

Occupational dose received during outage work dominates annual dose figures at CANDU® stations. Reducing vault tritium levels below the air-suit threshold reduces both the internal dose (predominately attributed to tritium) and also external dose during an outage; as shorter durations in the vault will subsequently lead to lower exposure to external radiation.

Whilst tritium concentrations grow more rapidly and to higher levels in the moderator circuit of the CANDU®, it is the tritium in the PHT system that typically leads to chronic airborne concentrations within the vault during an outage. The PHT system is a pressurized high temperature system, that is more prone to small leaks during operation and during outages small leaks occur continually from the pressure tube end fittings.

Current practices in CANDU® stations involve the use of reactor vault vapour recovery dryers. These systems use adsorption technology to reduce the dew point of the atmosphere within the vault. These dryers collect both tritiated D_2O vapour and light water vapour present in the vault. The collected downgraded D_2O is sent back to the upgraders following regeneration of the dryer beds. This approach has performance limitations as well as practical and economic limitations. Also over time the adsorbent becomes degraded, reducing its performance. Replacement of the adsorbent is possible but leads to generation of radioactive waste that needs to be appropriately handled for disposal/storage.

* 1 MPC(a) = $10\mu Ci/m^3$ HTO

A more effective alternative, as adopted by some CANDU® utilities, is to reduce the tritium source term in the heat transport system. Lower levels of tritium within the heat transport system directly reduce the tritium vault concentrations.

GE has modelled the relationship between tritium vault concentrations, dryer performance and tritium heat transport concentrations.

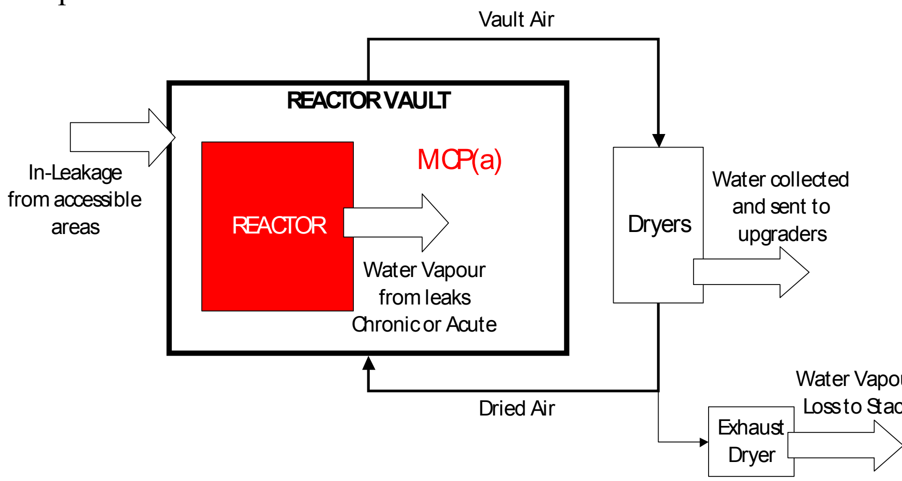

Figure 1: GE's Vault MPC(a) Model

As Figure 1 illustrates, this model accounts for the vault volume, in leakage from accessible areas, losses of water vapour to stack from the exhaust dryer, dryer performance, PHT tritium concentration and both chronic and acute dose scenarios.

The model calculates the vault tritium concentrations as a function of dryer performance.

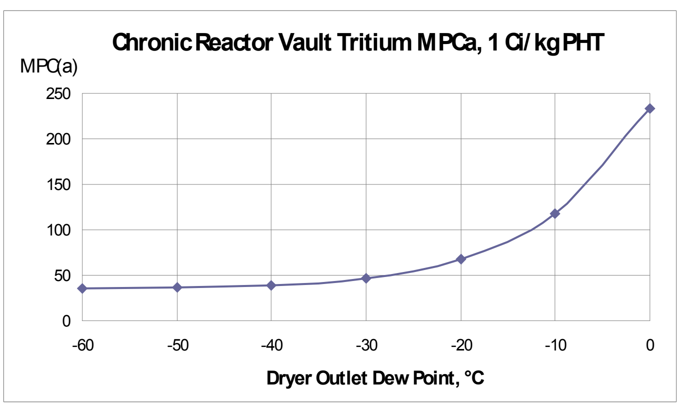

Figure 3: Vault Tritium MPC(a) with 1 Ci/kg PHT – Chronic release scenario

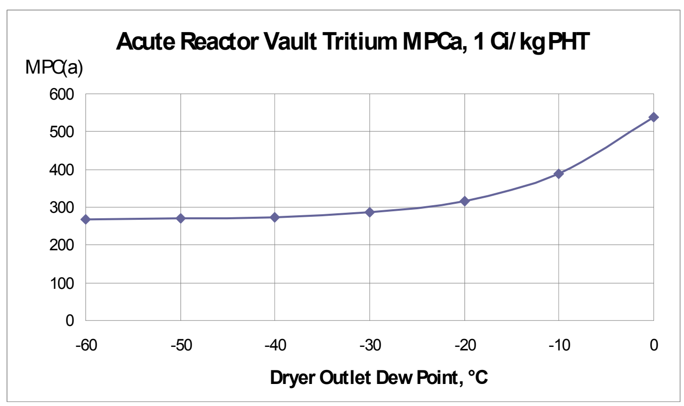

Figure 2: Vault Tritium MPC(a) with 1 Ci/kg PHT – Acute release scenario

The results of the model calculations under typical operating conditions in Ontario reactors (nominally 1 Ci/kg in the PHT system) are shown in Figures 2 and 3. Two important observations are:

1) Increasing dryer performance to achieve outlet dew points lower than –30 °C has marginal impact on vault tritium MPC(a) levels.
2) Operating at a PHT tritium concentration of 1 Ci/kg does not lower the acute release scenario below the 100 MPC(a) threshold for the use of respirators.

The model was re-run with a lower PHT tritium concentration of 0.3 Ci/kg with the following results:

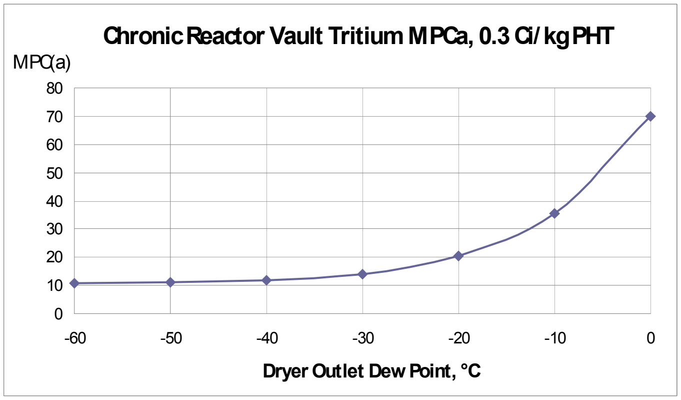

Figure 5: Vault Tritium MPC(a) with 0.3 Ci/kg PHT – Chronic release scenario

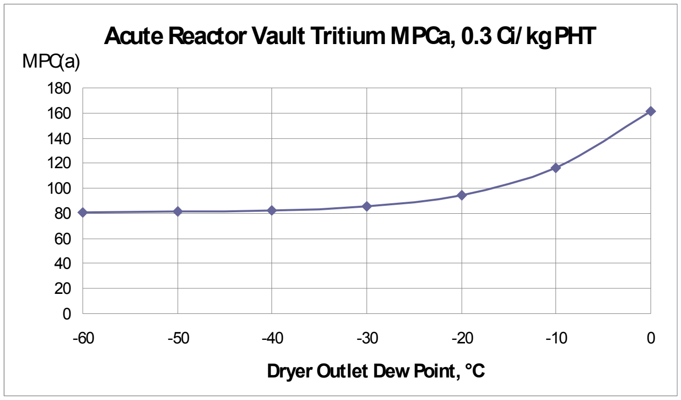

Figure 4: Vault Tritium MPC(a) with 0.3 Ci/kg PHT – Acute release scenario

As Figures 4 and 5 illustrate, operating with a PHT system heavy water tritium concentration of 0.3 Ci/kg would safely ensure that the vault tritium MPC(a) level is below the threshold for safe use of respirators in both chronic and acute release scenarios.

5. Achieving low PHT Heavy Water Tritium Concentrations

In order to achieve this dramatic reduction in vault tritium MPC(a) levels, the PHT heavy water must have significantly low tritium concentration.

As previously discussed, tritium is continuously produced within the PHT system through neutron capture by deuterium. Roughly 12 Ci/h of tritium is generated in an 850MW CANDU® heat transport system. As in any continuous process, in order to maintain low concentrations of an impurity a purge stream is required. In this case, given the high value of virgin heavy water, a tritium separation technology must be employed so that detritiated heavy water can be returned to the reactor.

Current solutions employed for tritium separation at CANDU® stations have used cryogenic distillation. The use of cryogenic distillation technology for detritiation of heavy water has proven to be complicated, expensive and susceptible to low reliability, mainly due to complications associated with the cryogenic process. Also given the cost and physical practicalities of the technology, existing facilities have provided limited detritiation of the heat transport system.

GE has developed a new concept; the Tritium Separation Centre (TSC) [4]. This facility houses new proprietary GE processes and technology capable of extensively detritiating both the moderator and heat transport systems' heavy water.

While the heat transport system is attributed to causing chronic dose of operators and maintainers, it is the moderator that dominates environmental emissions [5] and acute dose risk when tritium levels are high. The moderator of a 850MW CANDU® continuously produces around 250 Ci/h of tritium and without tritium removal, the moderator tritium concentration will rise to approximately 93 Ci/kg, at which point tritium production is balanced by radioactive decay and losses. Several CANDU® stations have already seen tritium levels in excess of 65 Ci/kg after years of operation without tritium removal.

The TSC solution is a simpler process designed to replace cryogenic distillation, employing a combination of proven isotope separation technologies; gaseous diffusion and thermal diffusion. This process is a less expensive and safer combination of isotope separation technologies to replace cryogenic distillation. The attractive feature of this technology is simplicity, low inventory, scalability, and no requirement for cryogenic systems with their inherent complexity. The simplified flow schematic for the TSC is as shown in Figure 6.

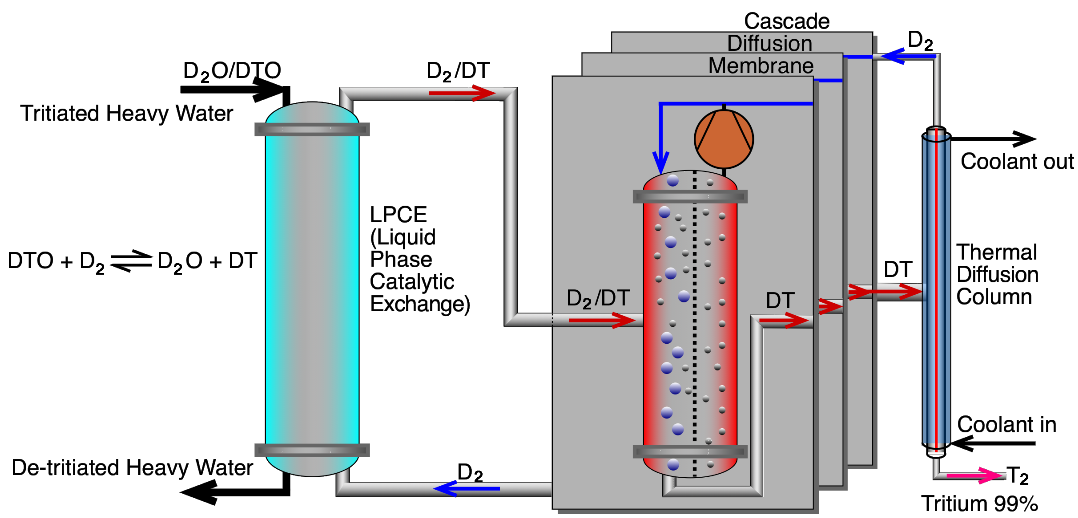

Figure 6: TSC Process Block Diagram

A rigorous process model with mass and activity balance including the station moderator and PHT has been developed to show how a TSC facility could be integrated into an existing CANDU® site. The model includes tritium production source terms in both moderator and PHT systems. Figure 7 shows the scheme with molar flows, concentrations and production rates.

The illustrated scheme represents a CANDU® station with six 850MW reactors on site served by the TSC with a throughput capacity of 400 kg/h (20 kmol/h) D_2O. The steady state moderator concentration is maintained below 5 Ci/kg, which exceeds currently best in class requirements, while the heat transport system is maintained to below 0.3 Ci/kg. At this level, the routine vault tritium MPC(a) concentration would be lower than 100 MPC(a) threshold meaning that outage work could be conducted without plastic suits [6] – leading to significantly reduced outage duration while reducing maintainer dose.

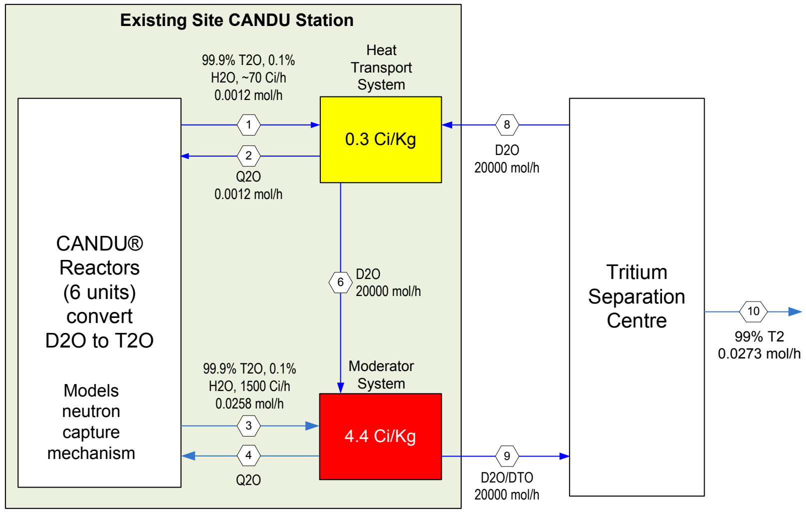

Figure 7: Tritium Separation Centre model for a 6 reactor scheme

It is possible to achieve even further vault tritium MPC(a) reduction for outage work from the same onsite TSC. This is achieved by dedicating the TSC to processing the heat transport system heavy water of the reactor planned for the outage for a 2-3 month campaign prior to the outage. Figure 8 illustrates the impact of such a dedicated campaign on the heat transport system tritium concentration. Achieving levels of around 0.02 Ci/kg PHT tritium concentration would lead to very low vault tritium concentrations, less than 1 MPC(a) for chronic release scenario.

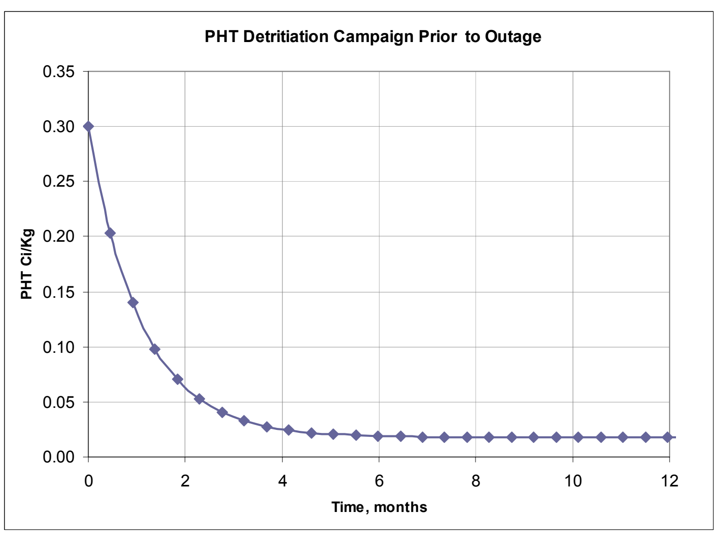

Figure 8: Dedicated PHT detritiation of one reactor prior to shutdown

6. Conclusion

GE has a long history of bringing innovative best practice solutions to the CANDU® industry. The establishment of the Light Isotope Technology Centre of Excellence in Peterborough, Ontario has centralised GE's knowledge base of heavy water and tritium handling. The Centre of Excellence has developed new technology and through analysis of existing CANDU® operation, provides an opportunity, through GE's innovative Tritium Separation Centre (TSC) product, to make a step change improvement in management of heavy water and tritium at CANDU® stations, leading to shorter maintenance outages and improved CANDU® station economics.

7. References

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