Mobile Tritium Removal Facility – An Affordable Option?

P. Ozemoyah and J. Robinson
Tyne Engineering Inc, Oakville, Ontario, Canada
pozemoyah@tyne-engineering.com

Abstract

Tritium removal facilities are only likely to be an issue when CANDU plants have matured and the increasing tritium levels in the water have become intolerable from a personnel health physics perspective. Even then some station owners claim that a Tritium removal facility is unnecessary, because improved health physics performance and practices is all that is required to protect against possible personnel exposure. To support this argument it is also true to say that the tritium accumulation does stabilize, and will reach a stage where the tritium content will no longer increase. However for station owners that support the view that they follow an ALARA principle in which only the lowest level achievable is acceptable, a tritium extraction plant when the plant is new or one built later when the plant is operating and in mid life, both have arguments to support the expense. For a CANDU reactor in mid-life, there are two options for siting the Tritium Removal Facility (TRF).

1. Stationary Option which will require permanent structures for each station.
2. Mobile Option which considers a complete TRF that can be moved from station to station

In most existing CANDU-6 stations, no provisions have been made to construct and operate a TRF. This would make the Stationary Option costly because space would have to be provided and newly added infrastructure would have to be installed. With appropriate seismic qualification and following the necessary codes and standards, a Mobile TRF unit could be more cost effective, particularly if there were a possibility to share the unit with other stations in like position.

1. Introduction

Tritium is an isotope of hydrogen, and it is produced in CANDU reactors (heavy water reactors) through the capture of neutron by deuterium atom. This reaction leads to the continuous increase in the tritium content of the heavy water. The CANDU reactor produces about 2400 times more tritium than the average light water reactor.

Tritium is said to be carcinogenic, mutagenic, and also acts as a teratogen. There are other unconfirmed health effects caused by tritium. The oxide form of tritium is particularly of concern since it is about 20,000 times more likely to be ingested into the human body than the elemental form. In addition to health concerns, the contamination of heavy water by tritium causes substantial expense to nuclear reactor operation. Hence the desire to remove, immobilize and store the tritium making less available to contaminate heavy water and the environment.

Tritium removal facilities can be considered for new-built nuclear reactor stations or station in its mid-life. For an existing reactor in mid-life, there are two options for siting the Tritium Removal Facility (TRF).

1. Stationary Option which will require permanent structure for each of the stations Figures 1 and 2 are examples of such units
2. Mobile Option which has a complete TRF that can be moved from station to station

In most existing CANDU-6 stations, no provisions were made for TRF, making the Stationary Option capital intensive because of the cost of the associated building and civil works. With appropriate seismic qualification and the necessary licensing, the Mobile option should perhaps be considered.

Figure 1 Darlington Tritium Removal Facility – DTRF

This presentation is primarily directed at existing single-unit CANDU-6 reactors in mid-life. For such a plant, there is the need to reduce accumulated tritium and to consider the subsequent annual generation of tritium. Unlike the heavy water upgrading plant that has always been an integral part of the CANDU reactor operation, tritium removal, because it poses no concern to new plant operation, struggles for recognition and importance. One often wonders if a CANDU station that is devoid of increasing tritium levels would be a more attractive sales option to prospective buyers.

2. Tritium Removal Facilities

For a typical CANDU-6 that uses about 260Mg of D_2O per annum as moderator water, the associated tritium produced annually in the moderator is about 5.6Ci/kg of D_2O, or nearly 1500 kCi of tritium. Similarly, in the Primary Heat Transport System (PHTS) using about 200Mg of D_2O per annum, about 0.14Ci/kg of D_2O or nearly 30kCi is produced annually. Tritium's half-life is 12.3 years. This slow decay of the tritium ensures that significant amount of the generated tritium remains in the water for years. With 34 CANDU reactors around the world technically, the extent of this problem should not be under-emphasized.

Figure 2 Wolsong Tritium Removal Facility - WTRF

While there are a number of experimental tritium removal facilities around the world, currently, there are two large-scale TRF – the Darlington Tritium Removal Facility (DTRF) in Darlington, Ontario Canada, and the Wolsong Tritium Removal Facility (WTRF) in Wolsong, South Korea. (Figures 1 and 2 respectively) The WTRF was built to serve the four CANDU units of the KHNP, while the DTRF was to serve the CANDU units in Bruce, Pickering and Darlington – all units in Ontario owned by Ontario Power Generation (OPG)

One of the reasons most existing CANDU operators do not have TRF associated with their mid-life plant is the additional cost. The cost of DTRF in 1988 was close to $100m, while the most recent WTRF is said to be over $100m. Collectively, a couple of hundred million dollars was spent in building these two facilities. It seems apparent therefore that a shared TRF between several CANDU operators will make the cost much more affordable to the station owners. One way this is being done currently is the use of DTRF by Bruce, Pickering and Darlington stations. This involves transporting the tritiated heavy water from other stations to Darlington. This regular transportation of large quantities of radioactive substances through the public highway has met and meets protest and objection from members of the public. The public outcry against such shipment can be surmised in Lynne Bates statement as quoted by David Martin [1] in the Peace Magazine. of April-May 1987 *"It's obvious that Hydro is trading off money for public safety -- they would rather have these shipments going along the 401 forever, than spend the money and build two more facilities at Pickering and Bruce."* Figure **3** shows typical transportation of tritiated heavy water between stations in Ontario.

Figure 3 Transportation of Tritiated Heavy Water to DTRF [2]

We believe that rather than the regular transportation of the tritiated heavy water through the public highways, an occasional transportation of the facility would be less harmful to the public. Wren and Hart [3] once wrote that *"Two different approaches can be adopted for the detritiation of heavy water reactors. The first is establishment of a large central extraction facility with transportation of tritiated heavy water from several nuclear power stations. The second is the establishment of much smaller extraction facilities that are integrated into individual power stations. A significant difference between the approaches is the size and timing of the capital investment that is required".* This paper is presenting a THIRD OPTION: the establishment of a

Mobile Facility. The Mobile Unit is designed to carry out the detritiation just the same way a stationary unit would.

While detailed design and costing has yet to be concluded on such an approach, preliminary data shows that using this mobile unit, a CANDU operator may not spend more than $10m (less operating cost), which is less than $1/10^{th}$ the cost of WTRF, to "own" the unit for a given period

3. Choice of Process

For a mobile unit to be feasible, the tritium removal process has to be compact, easily modularized and transportable. The process that has been considered is the Combined Electrolysis and Catalytic Exchange (CECE) process. The CECE Process as suitable is based on the isotope-exchange reaction between water and hydrogen isotopes in the presence of a wetproofed catalyst in a countercurrent exchange column. It is not the intention of the authors to go into details of the use of the CECE process in detritiation as this has been effectively covered in several publications including **[4]. [5], [6], [7].** Basically, the process comprises of two main stages:

1. The Electrolysis of heavy water in which hydrogen (protium, deuterium and tritium) and oxygen streams are generated;
2. The Liquid Phase Catalytic Exchange (LPCE) where the deuterium (with tritium) content of the hydrogen stream is stripped, and the protium content is vented with only natural abundance of the T_2 and D_2 in it.

The attractiveness here is that the process is relatively small and can benefit from the advantages of modularization.

For the tritium removal process, the deuterium (with its tritium) is further treated to remove and immobilize the tritium. Figure **4** below shows a schematic of the process.

We chose the CECE process, in addition to other advantages stated by several authors, for the following reasons

- Lower Installed Cost compared to existing processes
- Canadian Technology, hence will fit into the CANDU system effectively
- Factory-built Modules which reduces construction time spent on site
- Very low tritium emission which enhances personnel safety
- Reduced C-14 emission in consideration of the environment
- No Heavy Water loss in overheads resulting in cost savings
- No requirement for steam, minimal cooling and chilled water requirements, which also translate into savings in cost
- Minimal Seismic issues due to small footprint of the system

These advantages enabled the consideration of the Mobile Unit for the tritium removal. In addition, a compact high tritium compatible PEM electrolyzer being developed by Tyne [8] will be used with the unit

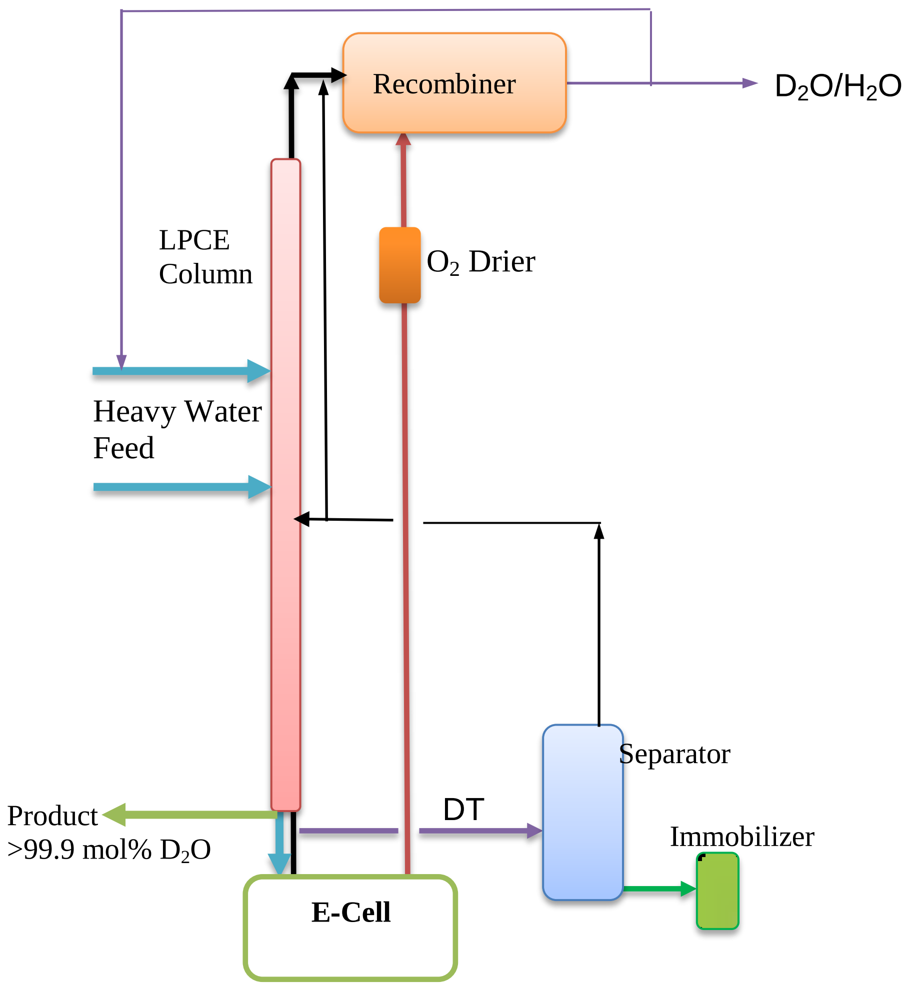

Figure 4 Simplified Schematic of the TRF Using the CECE Process

Each nuclear power station including Point LePreau, Gentilly-2, and all other CANDU stations worldwide should have tritium removal facilities. As stated earlier, one of the reasons these stations do not have such facilities is the cost. The EPC of each of the DTRF and WTRF was about $100 million.

To reduce this cost predicament, we believe that a Mobile Unit that can be shared between several stations will be the solution. The proposed Mobile Unit will comprise three trailers or “arms”. One “arm” will contain the columns and their accessories; another will contain the electrolyser, tanks and their accessories, while the third arm will contain other auxiliaries and the “back end” for the immobilization of the tritium. The unit will come complete with the appropriate piping and instrumentation. Since the unit comes complete, interfacing it with the “host” site will be easy. The configuration of the “arms” will depend on each site/station and the ease of interfacing the units with the station’s utilities, except that the columns will always be vertical.

From our preliminary design data, five years is the time necessary to reduce the accumulated tritium in a mid-life CANDU unit to acceptable and manageable level by using this unit. The Mobile Unit is considered because its cost will be shared by all the stations that would make use of it. Also, the Unit will ensure that participating stations are able to affordably resolve their tritium build-up problems. Figure **5** is a 3D sketch of the Mobile Unit, while figures **6** and **7** show typical modularized components of such unit being prepared for transportation

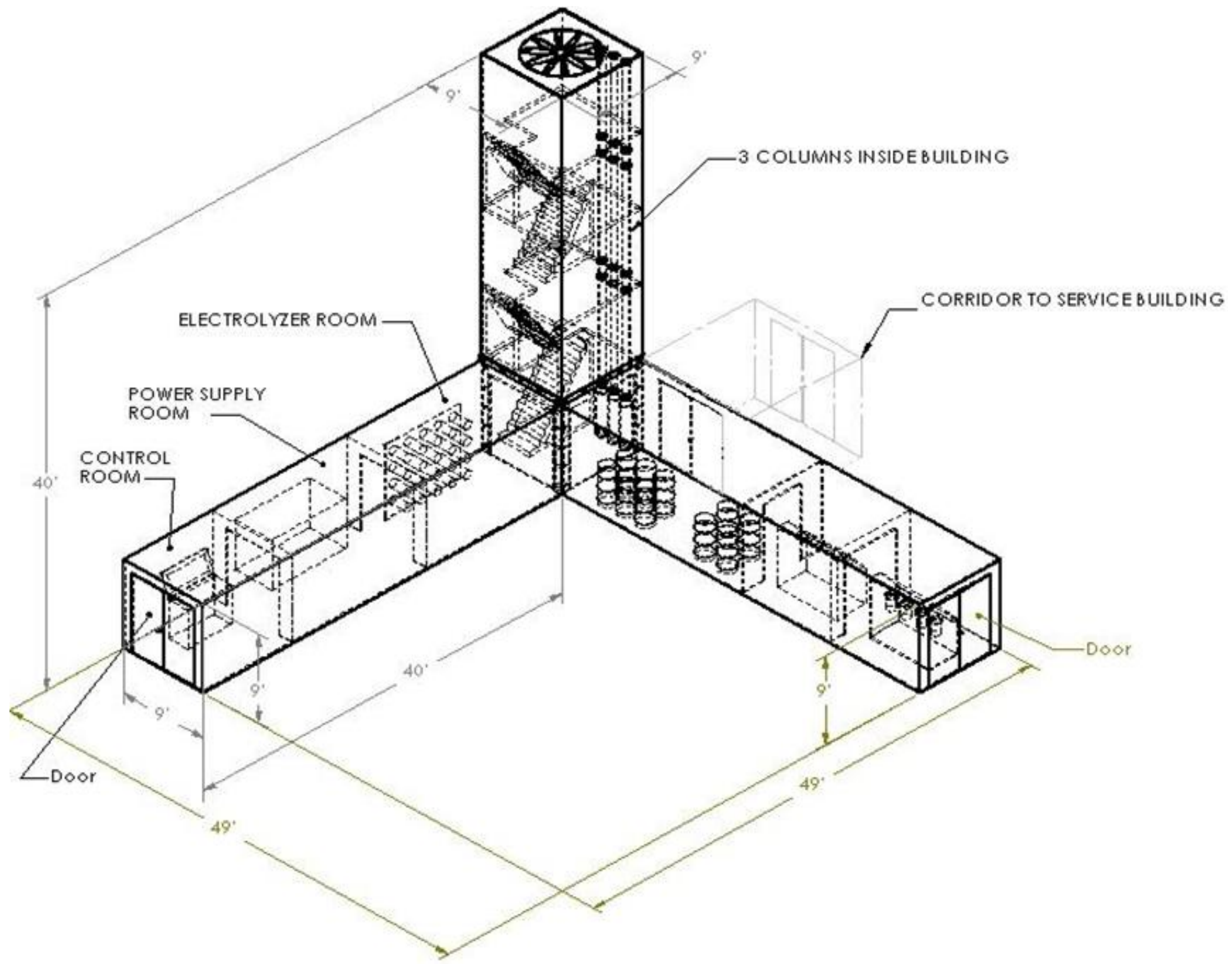

Figure 5 The Mobile Tritium Removal Facility (MTRF) as it would Look on Site

Figure 6 Complete Columns Module being prepared for Transportation

Figure 7 Complete Columns Module being Erected

4. Mitigating Possible Problems Associated with the Mobile Unit.

The mobile unit is not without its shortcomings. Some of the ones worth considering include seismic issue, transportation of radioactive – handling equipment, compatibility with structure and "skyline" of individual sites. These may translate into difficulty with licensing and acceptability of the Mobile Unit.

The criteria for classification of process systems and components will be based on the guidance given in CSA N285.0; The Mobile Unit is designed taking into consideration all codes and standards associated with the use of such system. These include but not limited to designing all major equipment (except the electrolyzer), instruments and pipes/tubing's greater than NPS of ¾" as CSA -N285 Class 3 (ASME Section III, Div. 1, Subsection ND). Due to complexity in the electrolyzer components, it will be designed as CSA-N285 Class 6, (ASME Section VIII, Div. 1) and enclosed in CSA-N285 Class 3 (ASME Section III, Div. 1 Subsection ND) Casing.

For this Mobile Unit, Tyne will follow its quality program: CAN3-Z299.3 and ISO 9001-2008 together with the appropriate Canadian Building and Fire Codes to ensure the equipment meet the necessary safety requirements. There is no gainsaying that all necessary regulatory bodies would have to approve the unit as required.

Transporting this Unit between stations is expected to take place only once in about 5 years. It will be transported liquid-free and in casings. This occasional transportation will be less hazardous compared to the regular movement of tritiated heavy water between stations.

As stated earlier in this write up, the configuration of the Mobile Unit will depend on each site. The Mobile Unit is in modules which can be interfaced as appropriate. So each site will determine which configuration best meets its site structure and "skyline"

Another issue that is worth mentioning is the usage by the various stations concerned. The logistics of how the stations share the usage of the MTRF will be dependent on the consortium involved. The details would have to be decided by the concerned members. However, for effective usage, it is expected that not more than 4 stations would share one MTRF. This implies that each consortium member would use the MTRF and get it back 15 years from the last time the member used it. This period is considered reasonable since 15 years of tritium generation would still be such that it can easily be detritiated.

5. Conclusions

The adverse effect of tritium in mid-life CANDU reactors is a potential concern to CANDU owners and operators. In most of the existing CANDU-6 stations, no provisions were made for Tritium Removal Facility (TRF). For such CANDU reactors in mid-life, the siting of a TRF can be capital intensive because of the cost of the associated infrastructure.

A suggested Mobile Unit which would contain a complete TRF that can be transported from station to station will normally cost the user significantly less than a permanent structure. With appropriate seismic qualification and following the necessary codes and standards, a Mobile TRF unit can be developed. The Mobile Unit will eliminate the associated hazard of transporting tritiated heavy water from different stations to be detritiated at the only available TRF. It will eliminate the cost, and uncertainty of cross-Border transportation of radioactive material.

Using the CECE process that can be modularized, and the availability of a tritium compatible PEM electrolyzer, will make it possible to actualize the Mobile TRF Unit.

6. References

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