Cernavoda Tritium removal facility project implementation approach and challenges

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Abstract. As a CANDU6 Nuclear Power Plant (NPP) operator and considering the radiological impact of Tritium, Nuclearelectrica decided to build a Tritium Removal Facility at Cernavoda Nuclear Power Plant (NPP) in order to decrease the Tritium concentration in the moderator and primary heat transport heavy water and consequently reduce the operation personnel doses and radioactivity releases to public and environment. The selected option was to use a Liquid Phase Catalytic Exchange (LPCE) – Cryogenic Distillation (CD) technology and a mixed hydrophilic packing and hydrophobic catalyst, developed by the Romanian National Research and Development Institute for Cryogenics and Isotopic Technologies (ICSI). This technology has been documented in the facility conceptual design that represented the Employer's requirements used for the Plant and Design-Build the Cernavoda Tritium Removal Facility contract awarded to Korea Hydro & Nuclear Power Co., the company who operates a similar facility at Wolsong.

1 Introduction

Specific to the CANDU nuclear reactors, using heavy water as moderator and main coolant [7], the Tritium appears as a by-product, resulting from neutron absorption into the Deuterium.

The process continues with production rates of 6.5 Ci/kg/year, for moderator, and 0.13 Ci/kg/year, for main coolant [1], for the whole reactor operation life. Hence, given the Tritium decay with a 12.3 years half-life, the Tritium concentration increases up to some equilibrium values, that, for CANDU6 are about 80-90 Ci/kg (3-3.3 TBq/kg), for moderator and 2-2.5 Ci/kg (75-100 GBq/kg), for the main coolant.

Taking into account it's radiological impact, the Tritium management in CANDU units represents an important issue, both for the operation personnel and public exposure and for short- and long-term radioactive waste reduction.

For this reason, decreasing the Tritium concentration in the reactor systems, in accordance with the "as low as reasonably achievable" (ALARA) principle, represents a permanent focus for CANDU operators [3].

The solution to this issue, as implemented by the CANDU operators was to design and build Tritium Removal Facilities (TRF), used to extract the Tritium from the tritiated heavy water and safely capture it into special holders.

In addition, even though the Tritium obtained represents a by-product, it is a valuable material, taking into account it's use as a fuel in the future fusion based nuclear reactors.

A number of technologies for Tritium removal have been developed world-wide, including Vapor Phase Catalytic Exchange (VPCE), Liquid Phase Catalytic Exchange (LPCE), Direct Electrolysis (DE) and Combined Electrolysis and Catalytic Exchange (CECE), all followed by Cryogenic Distillation (CD) for Tritium concentration and extraction [1].

Two industrial scale TRFs are currently in service world-wide, first at Darlington (VPCE-CD technology) since 1990 and the second at Wolsong (LPCE-CD technology), since 2007, with significant results in tritium emissions reduction (70% decrease of tritium emissions at Wolsong after 8 years of TRF operation [2]).

In Romania, ICSI Ramnicu Valcea developed a LPCE-CD technology, including a mixed packing and catalyst, that was selected by Nuclearelectrica to be used for implementing the Cernavoda Tritium Removal Facility. By implementing the project, the following benefits are expected to be obtained [4]:

- Considering the low emissions associated with the operation of the CTRF itself, estimated at a level that is an order of magnitude below that currently achieved by the combined emissions of Units 1 and 2, operation of CTRF will result in a corresponding (4 to 5 times) reduction in tritium overall emissions from the site, thus reinforcing the ALARA principle;
- Operational cost savings in terms of radioprotection materials and radioactive wastes;
- Improve maintenance works conditions and reduced duration and cost;
- Significant decommissioning and radioactive waste storage costs savings;

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- Potential for tritium as marketable product;
- Potential for He-3 sales;
- Re-use of detritiated heavy water to cover the required make-up for operating units, after U1 decommissioning.

CTRF will be the third installation of its kind in the world, and the first in Europe.

The CTRF project is currently in the execution stage, in accordance with a Plant and Design-Build contract, signed with Korea Hydro & Nuclear Power Co. (KHNP), as the Main Contractor.

2 CTRF project presentation

In order to reduce the tritium concentration in Cernavoda NPP Unit 1 and Unit 2 reactor systems heavy water, CTRF will cover the following main processes.

The tritiated heavy water from the units will be first purified to meet the required LPCE catalyst quality specification, by removing impurities and radionuclides, other than tritium, through ion exchange purification units. The purified tritiated heavy water will then be transferred to the tritium removal facility.

The purified tritiated heavy water is fed into the LPCE columns, where it circulates counter-currently with a deuterium (D_2) gaseous stream, where the following isotopic exchange processes take place, in the presence of special packing and catalyst.

$DTO_l + D_2Ov \rightarrow DTO_v + D_2O_l$
$DTO_v + D_2 \rightarrow DT_g + D2O_v$,

where l=liquid; v=vapor; g=gas

The LPCE processes produce reduced tritium content heavy water, which is returned to the units and a stream of Tritiated Deuterium (DT) / Deuterium (D2) / Deuterated Hydrogen (HD) gaseous mixture.

This gaseous mixture will be passed through a Drying - Purification System, including cryogenic absorbers, where any remaining traces of heavy water vapors (DTO) and gases (nitrogen and oxygen) are separated from the gaseous mixture and retained. The purified gaseous mixture is transferred to the Cryogenic Distillation System.

The tritium (T2) will be separated from the gaseous mixture in the Cryogenic Distillation system columns, that are located in a 'cold-box' that maintains the cryogenic distillation process temperature (about 20 Kelvin, or -253 Celsius degrees). The Cryogenic Distillation System comprises heat exchangers and condensers, that cools and condenses the deuterium and tritium gaseous mixture and then allows gaseous deuterium to 'boil off', while retaining the tritium as a liquid.

This separation is achievable as hydrogen (protium) and deuterium have a slightly lower boiling point than tritium (see Table 1 below).

The tritium extracted at the base of the last cryogenic distillation column is transferred to the tritium gas handling and storage system located in a special 'glove box' where it is chemically bound as a titanium-tritium metal hydride into special Immobilized Tritium Containers that are further stored in a dedicated vault, thus ensuring a safe tritium storage.

Table 1. Boiling temperatures for Hydrogen isotopes

Isotopes	H_2	HD	HT	D_2	DT	T_2
K	20.4	22.1	22.9	23.7	24.4	25
C degres	-252.6	-250.9	-250.1.	-249.3	-248.6	-248

After tritium separation, the gaseous deuterium from the Cryogenic Distillation System, will be recirculated to the LPCE.

The cooling capacity required for the distillation of the gaseous deuterium / tritium mixture will be provided by a refrigeration/cryogenic unit, based on a helium cooling cycle.

In addition to the main process systems presented above, the Project includes the auxiliary systems necessary for the operation of the CTRF, the electrical equipment and cables, plant control and safety instrumented system, ventilation systems, radiation monitoring equipment, as well as fire detection and protection and connections to existing site utilities (potable water, demineralized water, sewage, power supply, etc.).

Process of main systems is presented in Figure 1, CTRF Block Diagram:

3 Few specific CTRF key process features and safety requirements

CTRF is designed to process 40 kg of tritiated heavy water per hour and achieve a detritiation factor (DF) of 100.

CTRF will process both moderator and main heat transport heavy water, with an isotopic of minimum 99.75% deuterium (for moderator) and 98% deuterium (main heat transport) and produce and store Tritium with a purity of minimum 99%.

The facility is designed to withstand external hazards (Design Basis Events) with an occurrence probability of 10^{-4}/ year and provisions are made for Beyond Design Basis Events to avoid a hydrogen explosion. More specific, a Safe Shutdown State is implemented to release the largest quantity of hydrogen from the system, in gaseous form, via the stack, through a specific seismically qualified system in order to reduce the inventory which may contribute to an explosion.

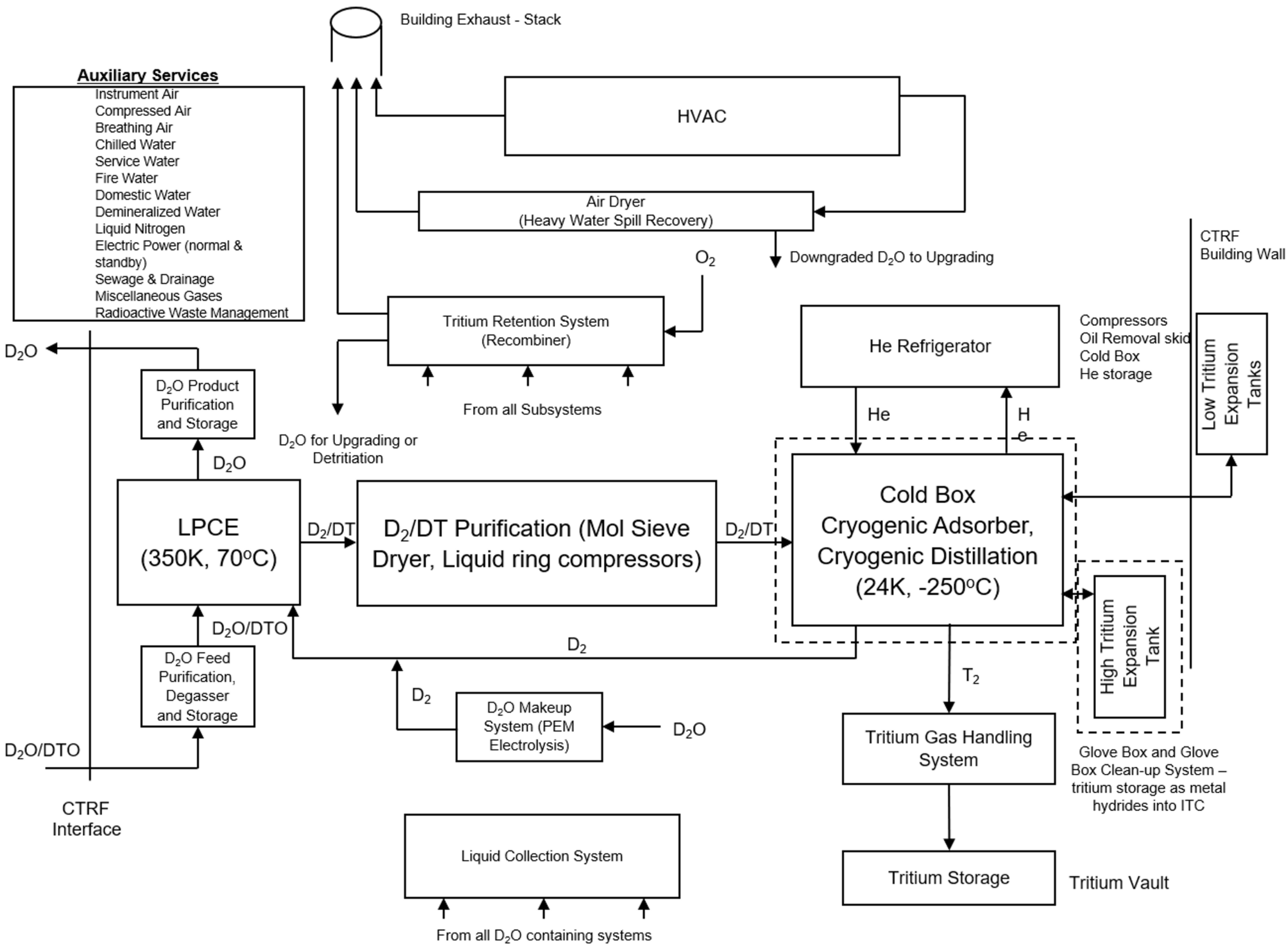

Fig. 1. CTRF Process Block Diagram

4 CTRF project implementation strategy and status

The approved project implementation strategy considers two main contracts:

- The project implementation through a Plant and Design-Build (EPC) contract, signed with an experienced organization, responsible for developing the detail design, procurement of all the necessary components, performing the construction and installation works and commissioning activities, including the operating personnel training and a six-month trial run.
- Owner's Engineer contract, with an organization proving large expertise in tritium technology safety analyses and project management, to supplement the Owner's resources involved in monitoring the CTRF Project implementation, support for developing the licensing documentation and ensuring the correct implementation of the specific technology.

To date, all the required permits and authorizations, including the Environmental Permit and the Construction Authorization have been issued, and design, procurement and construction works are in progress.

Given he tritium technology unique characteristics, a series of challenges were faced and risks identified during the project development and implementation. One of them results from the absence of recent similar experience in industrial TRF implementation (CTRF being the third facility world-wide, after Darlington, in 1990 and Wolsong, in 2007), combined with enhanced licensing requirements meanwhile. This is why the CTRF implementation revealed all the challenges associated with a "first in a while" project. It is also to be mentioned the limited potential suppliers available for some of the key specific technological components (like the LPCE columns and catalyst, the Cryogenic Distillation Cold Box, the Helium Refrigerator).

5 Conclusions

CTRF project is the newest TRF project at industrial scale and includes previous experience gained from DTRF and WTRF and at research level, being an evolution in the industrial-sized TRF market that can be considered as a reference for the construction of a new TRF that meets current technical and safety requirements. Improvements in TRF design were considered necessary to meet enhanced safety requirements following the Fukushima accident; This resulted in different design approaches to prevent hydrogen explosion - most important being the provision of the Safe Shutdown System.

Acknowledgement: Authors kindly acknowledge the National Research and Development Institute for Cryogenics and Isotopic Technologies Ramnicu Valcea and Kinectrics Inc. Canada, for their support in developing the CTRF conceptual design and associated licensing documentation and European Bank of Investment for partially financing the project.

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