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# Advanced Membrane Degassing Technology for Radiation Source Term Reduction and Corrosion Control in Nuclear Power Plants

Dissolved gas control in a nuclear power plant's water system, including the primary make-up water storage tank and refueling water storage tank, can be essential to reduce radiation source term (defined as a release of radioactive material). In particular, controlling dissolved gases can also help reduce the formation of unwanted radionuclides, such as $^{14}C$ and oxides of $^{60}Co$, and alleviate primary water stress corrosion cracking (PWSCC).

$^{14}C$ nuclides are produced by neutron-induced reactions on isotopes of carbon, nitrogen and oxygen molecules. Since these elements are present in the fuel, cladding, coolant, moderator, and structural materials of nuclear reactors, removing the dissolved gases from the process water can reduce the formation of $^{14}C$ nuclides.

$^{60}Co$ and $^{58}Co$ nuclides are generated by a neutron reaction with steel alloy components within a reactor. $^{60}Co$ oxide is formed when $^{60}Co$ nuclides are exposed to the dissolved oxygen in the reactor water. Reducing the concentration of dissolved oxygen in the reactor coolant system can reduce the amount of these corrosion products in the reactor.

CRUD (Corrosion Related Unidentified Deposit) such as $^{60/58}CoNiFe_2O_3$ is known to be a primary cause of radiation build-up in nuclear power plants. This type of corrosion product should be removed in order to reduce employee exposure during plant overhaul or decommissioning. Reducing the concentration of dissolved oxygen in the reactor make-up water storage tank (RMWST) and refueling water tank can reduce the production of these radioactive corrosion products.

Degassing System

During normal operating conditions, nuclear power plants produce various nuclides. Although nuclear plants are designed to contain and minimize the release of gaseous radionuclides into the environment, small quantities do escape their systems. Some nuclides are typically discharged in

gaseous effluents. A small amount of $^{14}C$ is released in the form of $^{14}CO_2$ and $^{14}CH_4$ through normal effluent gaseous discharge paths such as plant vent stacks. Due to the long half-life (5730 years) of $^{14}C$ nuclides, the isotope remains in the environment for a long time and is assimilated into the cells of plants and animals.

Recently, several nuclear power plants have installed 3M™ Liqui-Cel™ Membrane Contactors into their water systems to remove dissolved gases to help reduce the formation of radionuclides. This can also help protect plant operators and the environment. Liqui-Cel degassing membrane systems are compact and can be installed virtually anywhere inside a plant due to their small footprint and flexible system design.

## 3M™ Liqui-Cel™ Membrane Contactor Technology

3M™ Liqui-Cel™ Membrane Contactors use a microporous hollow fiber membrane to remove gases from or add gases to liquids. Gas flows across one side of the membrane with liquid on the other side. Because the membrane is hydrophobic, only gases can pass through the pores.

Applying a vacuum or using an inert sweep gas lowers the partial pressure of the gas and allows the dissolved gases in the liquid to easily transfer through pores in the membrane wall of the hollow fiber. The excess gases are then carried away into the vacuum.

## Degasification Opportunities in a Nuclear Power Plant

### Reactor Make-up Water Storage Tank

The RMWST typically uses a bladder or floating disk to prevent ambient air from entering the tank, although some plants use a nitrogen bubbling process to extract the dissolved oxygen. These technologies may not adequately prevent air from entering the tank and may increase dissolved nitrogen level in the water. This make-up water is fed back into the reactor coolant system to control the reactivity, and its dissolved nitrogen and oxygen can increase the formation of $^{14}C$ and CRUD.

Membrane contactors efficiently remove and reduce the amount of dissolved oxygen and nitrogen in the primary make-up water system. Water can either be re-circulated back through the membrane contactor system and into the RMWST or make a single pass through the degassing system and then back into the reactor coolant system.

### Boric Acid Recovery System

Boric acid controls reactor power in a Pressurized Water Reactor plant. During the boration and dilution process, a large volume of diluted water is stored in a hold-up tank. Most nuclear power plants use a boric acid evaporator to recover boron and pump water from the recovery condenser back to the RMWST. This condensed water contains slightly elevated concentrations of dissolved oxygen and nitrogen that can lead to the formation of $^{14}C$ and corrosion products. To help alleviate this issue, Liqui-Cel membrane contactors can be installed to reduce the amount of dissolved oxygen and nitrogen in the condensed water. (See Figure 1)

### End Shield Cooling System

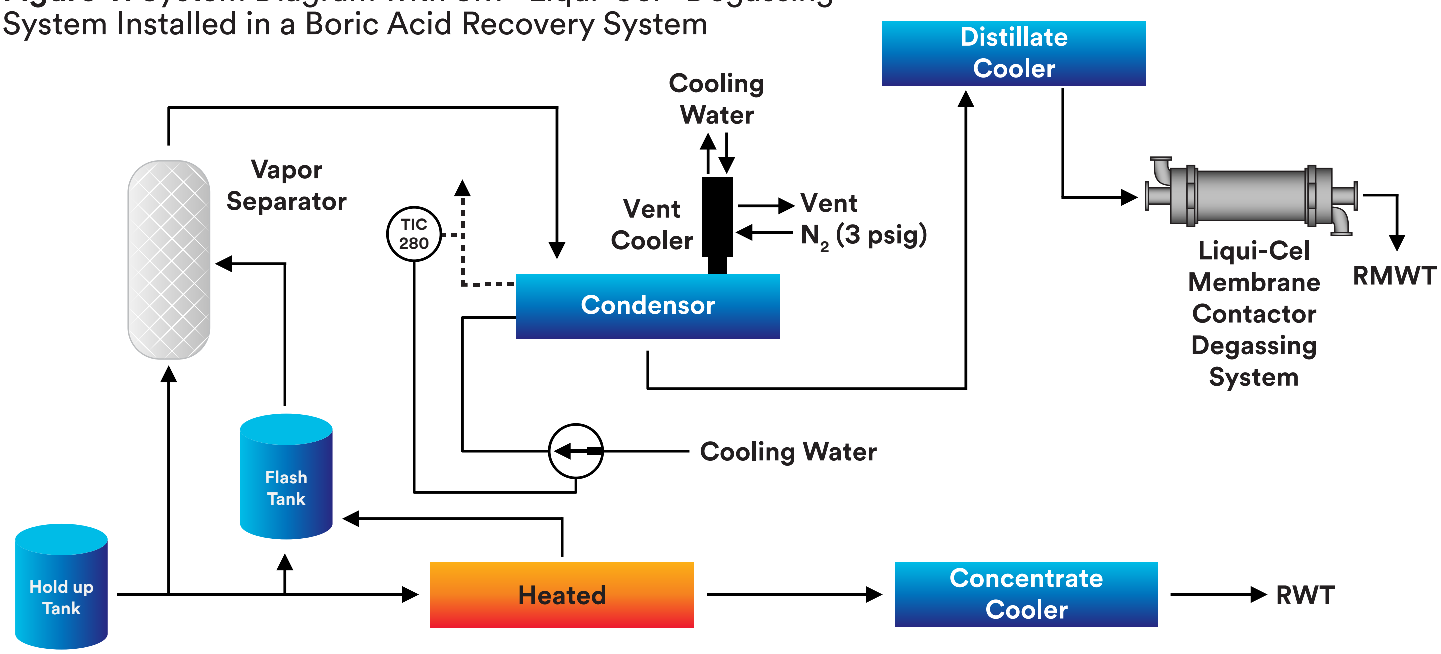
The purpose of the end shielding system in a CANDU (CANada Deuterium Uranium) reactor is to protect workers from radiation exposure during fuel on-loading. The end shield cooling system is a wall of steel balls encased in a concrete structure that prevents radiation from passing through. Pumped water removes the heat generated from radiation striking the steel balls, but if the water's oxygen levels exceed the limit value, the steel balls may oxidize and compromise the system's integrity. By continuously re-circulating the end shield cooling water through a Liqui-Cel membrane contactor degassing system, dissolved oxygen levels can be kept extremely low.

### Refueling Water Tank

A refueling water tank is not typically equipped with a rubber membrane bladder or floating disk. This can lead to high levels of dissolved oxygen and nitrogen in the water and a rapid build-up of $^{60}CoO$ and $^{58}CoO$ radiation at nuclear power plants. High levels of oxygen and nitrogen can also produce elevated $^{14}C$ activity.

Membrane contactors help protect against $^{60/58}CoO$ spiking in the reactor coolant system by continuously re-circulating the refueling water through the degassing system.

**Figure 1.** System Diagram with 3M™ Liqui-Cel™ Degassing System Installed in a Boric Acid Recovery System



## Acknowledgments

This information was compiled with the help of Kang Duk Won, Ph.D. He has tested, designed, and commissioned several membrane contactor systems in Korean nuclear power plants. Dr. Kang has over 34 years of experience in the nuclear power industry: nine with the Kori Nuclear Power plant and 25 with KEPCO Research Center. Currently, he is Director of Radiation Engineering Center for Hankook Jungsoo Industries Co., Ltd., a consulting firm for the nuclear power industry.

For additional information, please contact your 3M representative or visit 3M.com/Liqui-Cel.



**3M Company**
**3M Separation and Purification Sciences Division**
13840 South Lakes Drive
Charlotte, North Carolina
28273 USA
Phone: +1 980 859 5400

**3M Deutschland GmbH**
**3M Separation and Purification Sciences Division**
Öhder Straße 28
42289 Wuppertal Germany
Phone: +49 202 6099 - 0

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