# A Tritium Management Tool for Light Water Detritiation – 17320

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## ABSTRACT

Kurion®[1], Inc. (Kurion) has developed the Modular Detritiation System (MDS®[2]) based on the working principle of combined electrolysis catalytic exchange (CECE), offering a combination of efficiency, maturity, and cost among alternatives. The technology builds on proven heavy water solutions, and although is focused on light water, it can be adapted for heavy water detritiation.

The application of MDS® is a modular approach and allows for a flexible design that is adaptable to a range of facility sizes and processing needs. This modular approach delivers a factory quality and plug-n-process system that utilizes commercially available equipment and minimizes impact to a facility's day-to-day operations.

In addition to focusing on optimization of the MDS® technology, Kurion has strategies for a complete detritiation solution of which MDS® is a part of. The strategy, supported by modeling and numerical analysis, is a systematic approach to managing front-end pretreatment (if required), overall volume reduction, and amount and method of tritium retention.

## INTRODUCTION

The ability of the civilian nuclear power industry to maintain its position and credibility over the years has been increasingly dependent upon a strong commitment to safely dispose of nuclear waste and minimize the radioactivity released to the environment [1].

So far, the tritium produced in pressurized water reactors (PWRs) has been mainly discharged to the environment in light of the low biohazard of diluted tritium and the non-availability of economical light-water and gas detritiation technologies. However, increases in liquid effluent activity, regardless of their impact or an associated reduction in gaseous effluents, may have a negative effect related to public perception. This is reflected by the 20% surcharge the American Nuclear Insurers (ANI), experts in risk evaluation, assess in its premiums associated with tritium release [2,3,4] and their conclusion that releases from nuclear power plants are indistinctly regarded as harmful by the public [5].

[1] Kurion® is a registered trademark of Kurion, Inc.

[2] MDS® is a registered trademark of Kurion, Inc.

Public concerns over the tritiated water generated by the operation of light-water nuclear plants [6] have pushed the development of a variety of light-water detritiation technologies such as:

- “Kinetic” separation methods, such as water electrolysis
- “Physical” separation methods, such as water distillation, hydrogen cryogenic distillation, and differential adsorption
- “Chemical” separation methods are based on the different affinities of tritium for distinct chemical species.
- Graphene membranes isotope separators
- Tritium separation by laser

This paper discusses Kurion’s MDS® for light-water detritiation based on the CECE technology developed through combination of advanced numerical model and experimental verification and optimization.

## Tritium Production in Pressurized Water Reactors (PWRs) [7]

Tritium is generated in the primary coolant of a PWR mainly from the two following reactions, [4]

(Eq. 1) B-10 + n → 2He-4 + T

(Eq. 2) Li-6 + n → He-4 + T

The fast neutron capture by boron-10 accounts for about 75% of tritium production.

The thermal neutron capture by lithium-6 accounts for about 25% of tritium production.

Boric acid is introduced in the primary coolant to act as a neutron absorber and adjust the core reactivity in a uniform way. [8] The boron concentration is thus highest (~1,500-2,000 ppm [9]) at the beginning of the fuel cycle and is then decreased roughly linearly with time to offset the negative effect of fuel burnup on core reactivity. The average boron concentration over the fuel cycle is therefore of the order of 800-1,000 ppm. [4,10-13]

Lithium hydroxide is added to the primary coolant to adjust the pH and limit corrosion. The lithium concentration is thus highest at the beginning of the fuel cycle (2-6 ppm) and then progressively decreased in conjunction with boron concentration. [14] Although natural lithium contains about 7.6% lithium-6, the lithium used in the primary coolant is enriched to 99.9% lithium-7 to reduce tritium production by Eq. (2). [14]

Tritium production over a fuel cycle is therefore essentially related to the amount of boron at start-up, which is an increasing function of reactor size and maximum fuel burnup.

The estimated average tritium production is of the order of:

- 300 Ci/year for small cores (900 $MW_e$, 45 GWd/MT) [15,16]
- 700 Ci/year for medium cores (1,300-1,450 $MW_e$, 45 GWd/MT) [4,15,16]
- 1,350 Ci/year for large cores such as the European Pressurized Reactor (1,650 $MW_e$, 60 GWd/MT). [14,16,17]

**Fundamentals of Water Detritiation**

Generally speaking, a tritium removal approach combines a stripper portion and a concentrator portion.

The stripper function is to remove tritium from the feed and produce the tritium-depleted raffinate, which is re-used or released into the environment.

The concentrator's main function is to concentrate the extracted tritium in a volume sufficiently small for easier storage or disposal.

Figure 1 is a simple representation of a generic water detritiation approach.

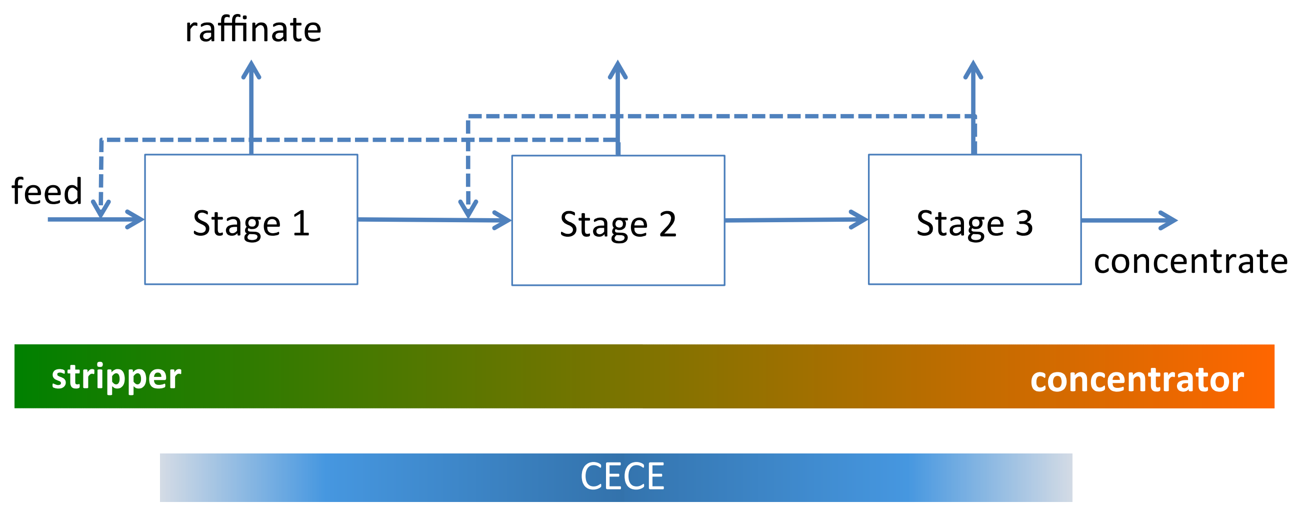


Figure 1: Generic Water Detritiation Approach

Kurion's MDS® which is based on combined electrolysis catalytic exchange (CECE) is versatile in that it performs both the stripper and concentrator functions.

**Modular Detritiation System (MDS®)**

Kurion's MDS®, applies CECE to concentrate tritium in a reduced volume of water while releasing clean hydrogen and oxygen. Conversion of tritiated water to gaseous tritiated hydrogen is accomplished using an electrolyzer. Oxygen produced by the electrolyzer is dried and released to the environment while the tritiated hydrogen gas is fed to a liquid phase catalytic exchange (LPCE) column.

Isotopic exchange occurs in the LPCE column where gaseous hydrogen flows from the column's bottom to the top in a counter-current mode to the liquid water which flows from top to bottom.

The overall isotopic exchange occurs via two reactions in a catalytic exchange column. The first is hydrogen isotopic exchange between gaseous hydrogen and water vapor.

(Eq. 3) $HT + H_2O_{vapor} \rightarrow HTO_{vapor} + H_2$

The second reaction is isotopic exchange between water vapor and liquid water.

(Eq. 4) $HTO_{vapor} + H_2O_{liquid} \rightarrow HTO_{liquid} + H_2O_{vapor}$

The resultant effluents are clean hydrogen and oxygen gas; the MDS® technology has no liquid effluent.

A simplified schematic of the CECE process is shown in Figure 2.

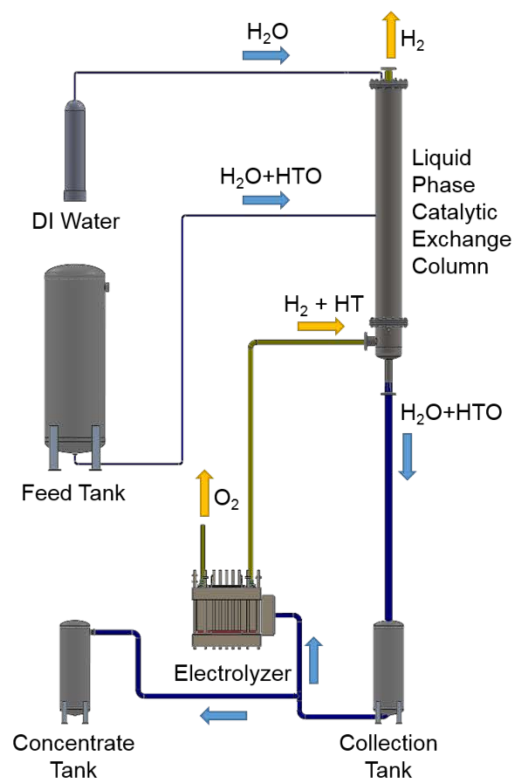


Figure 2: Simplified CECE Diagram

## Overall Detritiation Solution

Kurion's MDS® is the key element in developing an overall detritiation solution that includes an integrated approach for pretreatment, detritiation, and disposal or long-term immobilization and storage. Figure 3 shows an integrated solution.

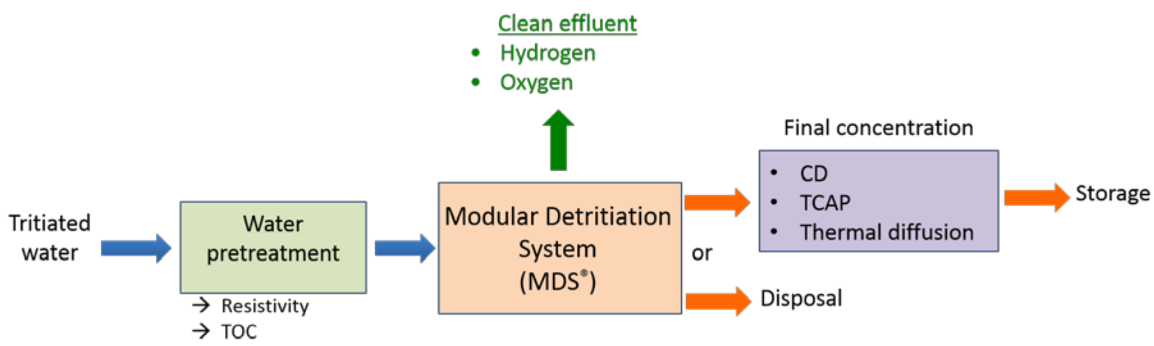


Figure 3: Overall Detritiation Solution

As shown above, MDS® can be combined with a post-processing step that further concentrates the tritium through the use of isotopic separation, such as cryogenic distillation or thermal diffusion. Following the isotope separation system, the tritium can be immobilized on a metal hydride ("getter bed") for long term storage. A metal hydride bed (Figure 4) is a pressure vessel that can contain the helium offgas resulting from tritium decay and is a standard practice within the nuclear industry for long-term, safe storage of tritium and are in use in facilities in Darlington, Canada and Wolsong, South Korea.

Figure 4: Metal Hydride (Getter Bed)

## MDS® Design

The MDS® was developed through a phase approach utilizing lab scale (.1 m3/day) and prototype scale systems (1.3 m3/day). The experimental data was combined with an advanced mass-transfer model [18] of the LPCE column which results in a versatile design tool for the MDS®. The model can be used to extrapolate performance as a function of key design parameters such as column height, feed rate, feed point, and effect from the condenser. The model also incorporates deuterium, which is critical at high concentration factors or for a heavy water application.

The MDS® is designed to be modular and utilize commercially available and proven technologies, such as the electrolyzer. It has a flexible design for a variety of facility sizes and the modular approach allows the deployment of MDS® to minimize impact to facility operations during installation and operations of the system.

As shown in Figure 5, the MDS® is based on standard ISO shipping containers and is designed to be remotely monitored and operated which requires minimal interaction and attention by facility staff.

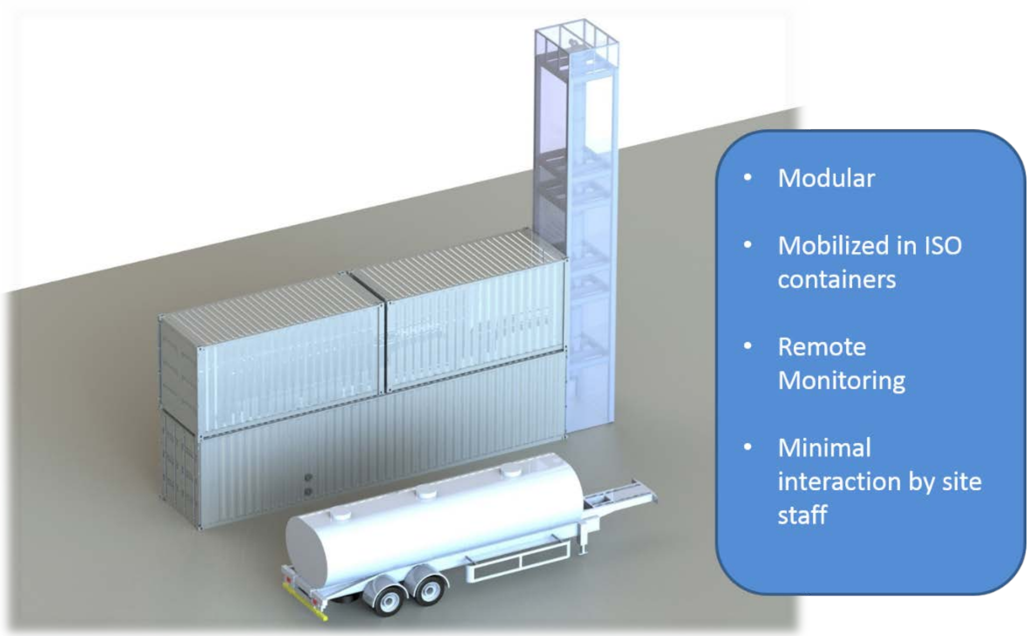


Figure 5: Conceptual Integrated MDS® Module

## Application to a Nuclear Power Plant

Figure 6 shows an example of applying MDS® to PWR effluent. Based on additional modeling [7], it is estimated that MDS® can reduce a PWR's tritium effluent by 50% by treating 420 m3 of water over the course of an 18-month fuel cycle.

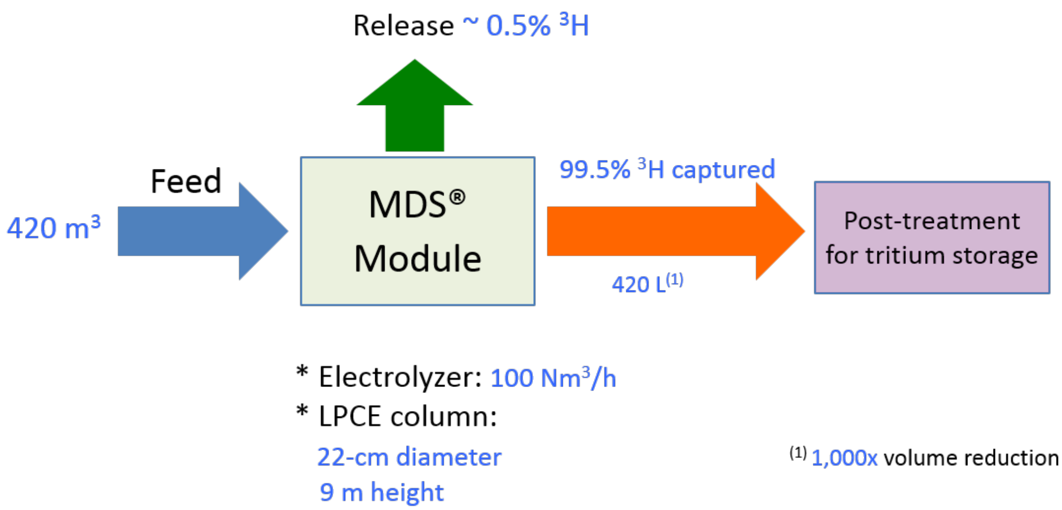


Figure 6: Example Nuclear Power Plant Scenario

The following are key take-aways from this scenario:

- Volume reduction of 1,000x is achieved before post-treatment processing
- 99.5% of the tritium is captured in the concentrate
- MDS® design is based on current performance and extrapolation by simulation
- Treatment capacity is 1.2 m3/day (size of current prototype system)
- MDS® operation is operated for 12 months per fuel cycle

## CONCLUSION

A variety of light-water detritiation methods have been developed at the laboratory and industrial scales [14,19] and a comparative analysis of industrial methods shows that CECE offers increased throughput and can delivered in a modular, compact solution, therefore suitable for large-scale applications with limited space.

Kurion's MDS® has the ability to process a large volume of water across a range of concentrations and has successfully demonstrated a prototype system that is a suitable size for PWR applications. Additionally, Kurion is able to integrate the MDS® as a tritium management tool into an overall detritiation solution for safe, long-term storage of tritium.

## REFERENCES

[1] M.I. Ojovan and W.E. Lee, *An Introduction to Nuclear Waste Immobilisation*, Second Edition, Elsevier (2014).

[2] W. WENDLAND, *Effluent Release Performance Indicators – An Insurer's Perspective*, 12th Annual RETS/REMP Workshop (2002).

[3] E. EVERETT, *Recent Changes to the ANI Engineering Rating Factors*, 22nd Annual RETS/REMP Workshop (2012).

[4] *EPRI tritium management model: Project Summary Report*. EPRI, Palo Alto, CA: 2005. 1009903.

[5] W. WENDLAND, Application of ANI Guideline 07-01, 14th Annual RETS/REMP Workshop (2007).

[6] D. Hussey, P. Saunders, D. Morey, N. Pitt, J. Wilson, B. Claes, *Modeling Tritium Lifecycle in Nuclear Plants*, WM 2006 Conference (2006).

[7] N. BONNET, *Model for the Production, Diffusion, and Containment of Tritium in PWRs*, submitted to Fus. Sc. Tech.

[8] P. MATHIEU and E. DISTEXHE, *Modeling of Boron Control during Power Transients in a Pressurized Water Reactor*, Nucl. Tech 72, 135 (1986).

[9] *Westinghouse Technology Systems Manual, Section 4.1, Chemical and Volume Control System*, http://pbadupws.nrc.gov/docs/ML1122/ML11223A214.pdf.

[10] D. HUSSEY et al., *Modeling Tritium Lifecycle in Nuclear Plants*, WM06 Conference (2006).

[11] *Tritium White Paper*, Autorité de Sûreté Nucléaire, http://www.asn.fr/sites/tritium/.

[12] B. PASTINA, *Etude de la Radiolyse de l'Eau en Relation avec le Circuit Primaire de Refroidissement des Réacteurs Nucléaires à Eau sous Pression*, Université Paris XI Orsay PhD Thesis (1997).

[13] S. GUL et al., A. Hussain, *Core Analysis of the First Cycle of Chashma Nuclear Power Plant*, www.iaea.org.

[14] Tritium White paper, Autorité de Sûreté Nucléaire, http://www.asn.fr/sites/tritium

[15] *Sources de Production et Gestion du Tritium Produit par les Installations Nucléaires*, Institut de Radioprotection et de Sûreté Nucléaire, Rapport DSU nº217.

[16] *Radioactive Effluents from Nuclear Power Plants*, Annual Report, U.S.NRC, NUREG/CR-2907, Vol. 15 (2009).

[17] Evaluation of a Low Level Waste Technology – "A Media Based Tritium Removal Process", EPRI, Palo Alto, CA, and Progress Energy, Raleigh, NC: 2002. 1006710

[18] N. BONNET, *A Model-Based Conceptual Design for Large-Scale Light-Water Detritiation by Combined Electrolysis Catalytic Exchange Technology*, submitted to AESJ Journal.

[19] G. VASARU, *Tritium Isotope Separation*, CRC Press (1993).