Modernizing Liquid Waste Processing

Thinking outside the box, the nuclear sector puts a new spin on a pharmaceutical tool.

By Richard J. Lowery and Emil Byström

We live in a world where we are continually driven to increase efficiency while decreasing costs—to do more with less. The nuclear industry is no different. Developing innovative techniques or adapting creative ideas found in other industries can support that pursuit to reduce cost and, in this case, volumes of waste, while providing program certainty. Such actions build confidence in our industry and allow nuclear power to continue to be part of the narrative of our clean-energy future.

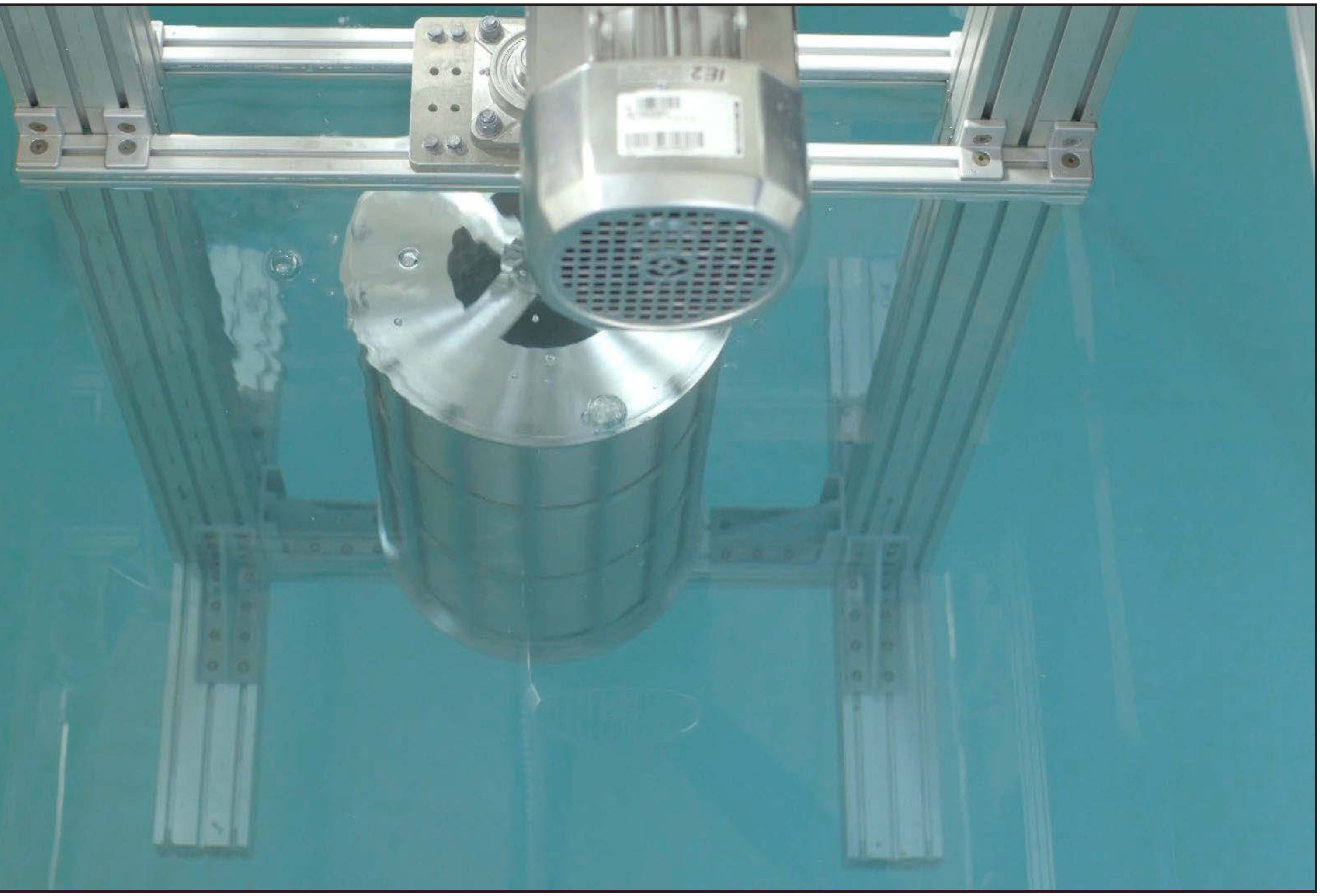
It goes without saying that the nuclear fuel cycle produces a variety of liquid waste as part of the process. The nature of each effluent determines if it will be stored on-site in an approved containment or processed and then discharged. There are several well-established techniques to tackle liquid waste, one being the fixed-column ion-exchange system. Ion exchange is a process that employs beads of ion-exchange media (resins) that exchange noncontaminated ions with contaminated ions in the liquid. This is done with a bed of ion-exchange media enclosed in a fixed cartridge or column, similar to residential water purification cartridges. Deployment of this technology has had significant operational success, but it also has its challenges, including:

- The inefficient use of ion-exchange media,
- The inability to process different liquids with significantly different matrix,
- Channeling/wall effects, and
- The amount of equipment required to be installed.

Out-of-the-box thinking has taken a non-nuclear solution to decontaminate liquids and introduced it to the nuclear industry. A tested process using a rotating bed reactor (RBR)—a patented technique called Spinionic—is scheduled for application in several nuclear environments this year. The technology removes radioactive or other undesired elements from wastewater or other fluids while increasing efficiency of the cleanup process through the better use of the media and a simplified process. The RBR was developed by the Swedish technology company SpinChem AB and was first successfully deployed as a research tool in the pharmaceutical industry, which sought to improve the chemical processing of liquids. With a similar need, the Canadian company SNC-Lavalin partnered with SpinChem to develop the RBR system for deployment in nuclear environments.

RBR technology works differently from a traditional column system where the media are packed into a cylinder. When the fluid is actively pumped through a column system, interactions with the media absorb impurities, and a clean fluid leaves the other end of the column. A variety of columns, implemented sequentially, might be needed to treat different impurities, as normally only one media type can be placed in each column, based on the distribution of particle sizes.

In contrast, an RBR, with its multiple compartments, can hold media of different particle sizes and characteristics, thereby treating more than one type of impurity at the same time. Also, the RBR can be loaded with any media a column unit uses, in addition to media that cannot be used in columns due to mechanical stability. A common problem in column treatment is the inefficiency of the packed bed and the use of all material in an imperfectly packed column. The pressurized flow takes the path of least resistance and creates a problem that is normally referred to as channeling (or, if the least resistant path is close to



Large-scale testing is done on the Spinionic rotating bed reactor system.

the wall, "wall effects"). Such limitations are avoided when using RBR because the principles applied to create flow through the packed media are different.

The rotating bed reactor explained

Used to treat liquid waste, the RBR is a cylinder packed with media that is restrained by a robust mesh. As the RBR rapidly spins in a liquid it aspirates the liquid through the bottom of the tank and percolates it through the media, therefore allowing the RBR to act as a pump and ensuring all liquid waste passes through. Because of its simplicity, the media are deployed directly into the containment structure holding the liquid waste. With the addition of minimal external equipment, cleanup can occur *in situ*. In doing so, it offers the following key benefits:

- Greatly simplified installation, reducing human interaction with ionizing radiation and enhancing safety by reducing worker exposure to radiation.
- When mounted to the container/tank opening or suspended above open containments, the RBR can run *in situ* for hours to days or weeks, as required, without operator intervention.
- No hoses, pumps, filters, ion-exchange columns, or associated shielding are required.
- Limited equipment is required; installation and demobilization can be done in less than a day, saving plant support and associated costs.
- More effective media utilization means less waste is generated.

The RBR makes it possible to minimize slow-reaction kinetics caused by poor mass transfer between the fluid and solid phase. The Spinionic design is flexible and can be used for numerous applications *in situ* to treat tanks for radioactive waste, or in-process to treat continuous waste streams. The solid-phase ion-exchange media are kept inside a rotating cylinder. As the cylinder spins, solution is repeatedly passed through the packed bed by centrifugal force. This allows every liquid parcel to do multiple passages through the bed at high flow rates without exposing the solid particles to excessive pressure or stress.

The RBR design allows multiple ion-exchange materials, selectively targeting multiple isotopes, to be used in parallel within a single reaction process, giving it the ability to remove multiple radioactive ions from the waste stream. Species in equilibrium, such as iodide and iodate in an aqueous solution, can be removed simultaneously by using two different ion-exchange media in the RBR compartments.

Using the RBR typically results in faster processes, higher decontamination factors, and/or reduced generation of secondary waste, depending on the type of process used. In addition, the RBR extends the lifetime of the solid-phase particles by minimizing grinding and attrition, while at the same time simplifying the solid-phase collection and recycling or disposal.

Spinionic may be used as the sole process method or used as a pretreatment upstream of installed equipment to remove impurities that may cause harm and potentially result in larger volumes of waste generation and extended system downtime. It can also be used as a polisher downstream of existing equipment.

Ultimately, it has the potential to replace or protect large mobile or in-plant column-based ion-exchange or membrane systems. Applications include:

- Scavenging of oil and grease using activated granular carbon,
- The removal of a wide range of ions with standard anion and cation media,
- Isotope-specific removal with ion-specific media,
- The removal of activity from chemically tainted solutions with elevated levels of acid or basic solutions,
- Process-contained solutions or spills that do not have an existing pathway to process equipment, and
- Preconditioning solutions prior to plant equipment.

From pharmaceutical to nuclear

The RBR technology originated as a protection aid for a solid-phase catalyst in pharmaceutical applications. The catalyst was made of palladium-soaked ion-exchange beads. Problems, however, arose with conventional stirring techniques in batch reactors in which the beads were damaged. This led to the exploration of a solution to mechanically protect the beads, with the first result involving the use of plastic tubing and magnets, ultimately culminating in the use of more sophisticated tools. The desire to create flow through packed media beds was the driving force throughout the development. First applications were small-volume screenings for catalysts, adsorbents, and ion-exchangers, eventually expanding to larger volume applications in the thousands of liters.

RBR technology was then used in research and development applications in the pharmaceutical, cosmetics, and food industries to either modify an active ingredient molecule to add new functionalities or to change its properties. Immobilized enzymes, so-called biocatalysts, have been the most commonly used solid-phase material in the RBR, using biological proteins to modify functional groups of complex molecules in fewer steps compared to classical synthetic chemistry. Using immobilized enzymes saves time and money while new synthetic routes are made possible.

Other applications evolved to remove unwanted byproducts or metal residues that are prohibited in final products. Downstream processing and industrial wastewater cleaning are areas that were explored, where RBR made a difference in the speed of processing large volumes of liquids compared with conventional technologies. Such applications were in line with the removal of radioactive isotopes in the nuclear industry, leading to nuclear waste management applications.

Over the years, SNC-Lavalin has developed and deployed a number of approaches to the application of ion-exchange processes to radioactive liquid wastes. These included submersible ion-exchange columns, magnetic ion-exchange particles, and seeding with powdered ion exchange for subsequent removal by cross-flow filtration. The company worked to nuclearize the SpinChem RBR and, working closely with SpinChem, initial prototypes were readily realized and demonstrated.

Preparation and deployment

Liquid waste is sampled to determine the best media for the desired removal. Testing and computational fluid dynamics (CFD) computer modeling help determine the RBR size to deploy and operational parameters to use. The selected media are loaded in the RBR compartments, which can contain one or more different types of media, separated or mixed. The RBR assembly is submerged into the fluid, and the drive motor is engaged at the desired speed. As the RBR spins, a continuously circulating flow develops inside the tank or vessel.

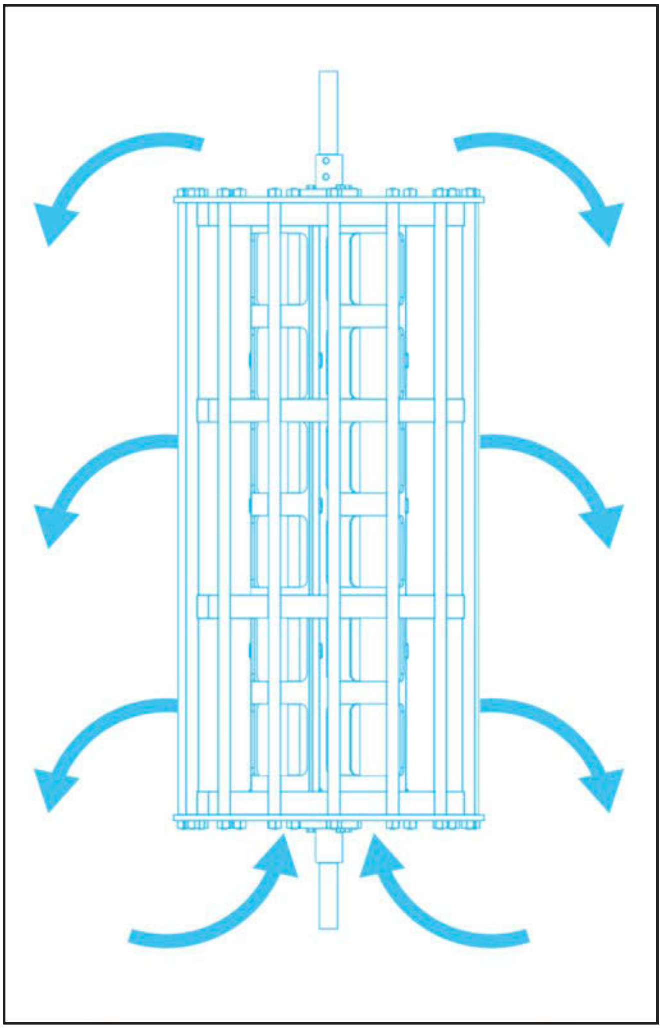


Fig. 1. The flow of liquid through the RBR as it rotates.

The fluid inside the RBR is thrown out through the outer wall retention screen by centrifugal force, and new fluid is pulled into the top and bottom openings (Fig. 1). The fluid is then efficiently passed through the media-loaded annulus. There is continuous circulation through the RBR while it mixes the tank. There are several different ways of deploying the Spinionic technique—in batch or continuous mode—depending on the requirements in that specific location.

Real-life applications in 2020

Historically, in terms of schedule and cost, introducing a new technology into the nuclear fuel cycle has been challenging due to the highly regulated environment. But as the industry is now recognizing the challenges that it faces, the door is open to new ideas that could offer efficiencies and cost reductions while still meeting stringent nuclear regulations. Spinionic is being implemented in nuclear environments this year on three different continents for three different nuclear applications by the end of 2020.

North America

An operational nuclear station has a volume of contaminated water in a purpose-built vessel. Due to the chemical content of the water, it currently cannot be processed via the plant's onsite treatment facility. A number of lab trials have shown that

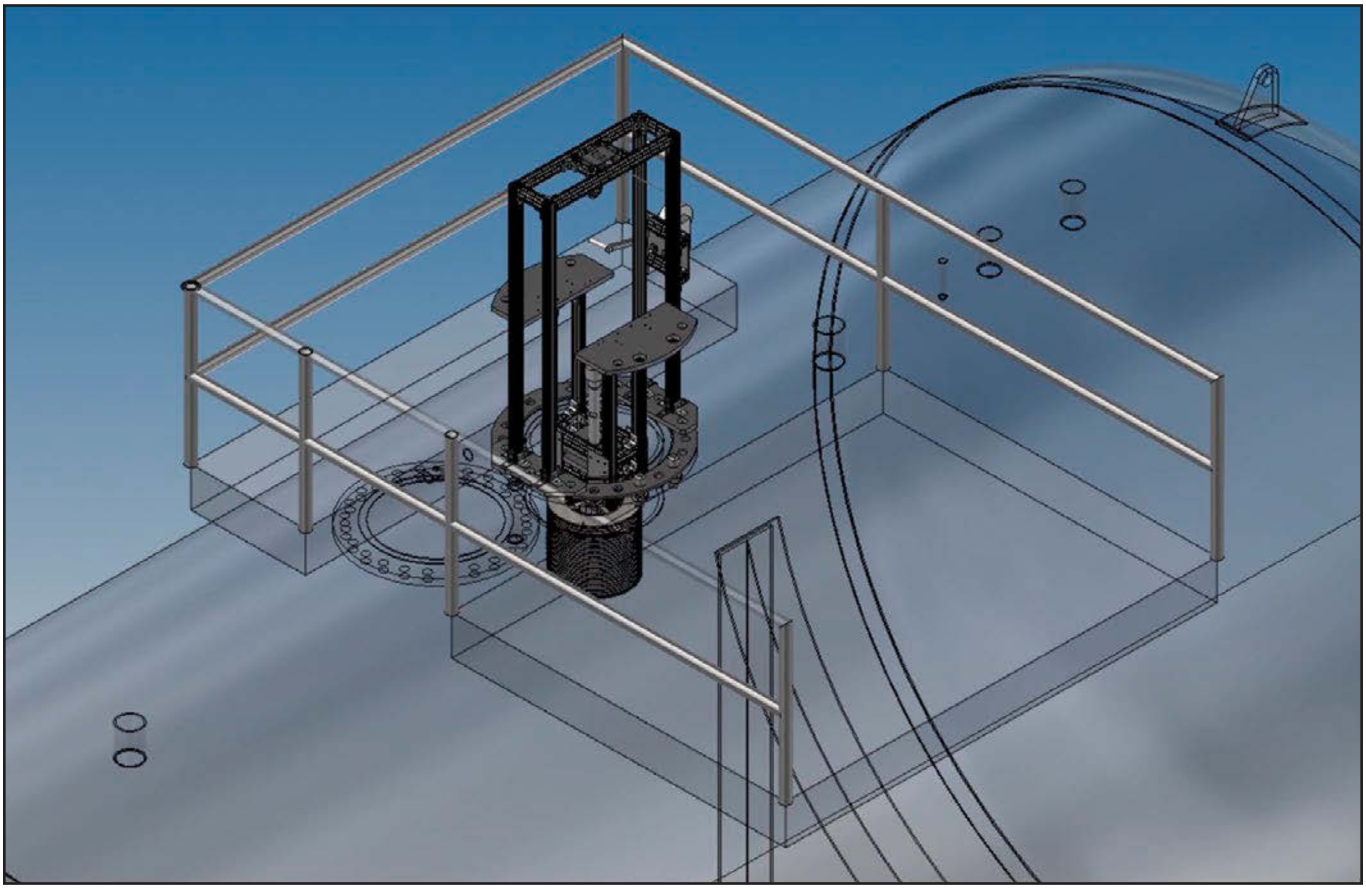


Fig. 2. A detailed design showing the in-tank RBR deployment.

Spinionic could be deployed to remove the impurities. The configuration and location of the tank access was restrictive, so the deployment of the technology has been developed such that it can be operated through an existing opening in the vessel and installed in modules to minimize the working time of operators. The Spinionic technology will allow the operator to use media that target the specific contaminants and process the water *in-situ*. Deployment is planned to take place in the first quarter of 2020.

Europe

A fuel pond at a research facility has now entered the decommissioning phase of its life cycle. Due to the nature of the work in the facility, there are significant levels of radioactivity, which hamper the operation required to decommission the facility. One of the radioactive sources within the facility is the fuel pond water. Spinionic will be deployed in the pond through existing penetrations in the concrete structure, allowing the operator to manage the radiation levels within the facility and accelerate decommissioning activities. Laboratory-scale trials are currently being conducted to select media and test the application, while full-scale deployment will be in development through 2020.

Asia

A nuclear power station here is undergoing decommissioning and has been processing a significant amount of contaminated water. The on-site treatment facility has successfully removed many impurities, but in some cases trace quantities of residual radionuclides remain. This has left a large quantity of water stored on-site until it is subject to future processing or a decision is made regarding its safe disposition. The Spinionic technology has demonstrated a high degree of efficiency in removing trace quantities of radionuclide contaminants and is therefore well suited to the task. To facilitate Spinionic deployment, a modular system that can be deployed directly into the storage tanks has been developed. Currently, work is being done to evaluate the efficacy of Spinionic for full-scale deployment in this situation.

Size and volumes

The RBR can range in size from less than one liter to over 100 liters of media capacity depending on the application (drums, totes, large tanks (> 2,000 m^3), ponds, fuel pools, sumps, or large-area basins). The system's equipment, frame, and drive motor are designed to fit container openings or tank manways (Fig. 2). Larger deployments, such as open basins, sumps, and pools, may require more than one RBR to adequately circulate the solution. The only service required for operational support is electrical power, depending on solution/tank size and deployment equipment and motor size.

To accelerate the deployment of RBR technology, SNC-Lavalin and SpinChem have fully funded a five-year plan with the aim of further maturing Spinionic to develop a range of products to address the various challenges of treating liquid waste. Cost-effective management of nuclear waste continues to be important in ensuring that nuclear power remains a viable choice and key contributor to the energy mix for future generations. ■

Richard J. Lowery is chief engineer of nuclear with SNC-Lavalin, and Emil Byström is chief executive officer of SpinChem AB.