Reverse Osmosis Applications for PWR Liquid Radwaste Processing

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Abstract

As regulatory, insurance and peer pressures increase, the push to further reduce already low radioactive effluent from liquid radwaste (LRW) processing at nuclear power plants continues. Today, more than ever, it is incumbent on each plant to strive to achieve for both low absolute numbers and a trend of improvement.

Ion exchange, long the preferred processing method, is at a technological peak with regard to such improvements. Though it has been tweaked and optimized, the chief drawback of ion exchange -- the fact that it forms a chemical barrier between the plant and the Monitor Tank – cannot be overcome. This chemical barrier is highly dependent on water chemistry, which may change daily in LRW.

Several plants have turned to reverse osmosis (RO) technology to further reduce radioactive effluent. Membrane systems provide a physical barrier that remains constant, irrespective of the quality and chemistry of influent water. These systems, benefiting from continued improvement and refinement, are well suited to provide a leap forward in LRW processing performance.

This paper reviews the configurations and processing results of RO installations at Fort Calhoun, Seabrook, Vogtle and Wolf Creek.

Background

Waste Minimization

Before the mid-1990's, the primary focus of PWR LRW processing was waste minimization. With treatment and disposal being substantial contributors to operating costs, reduced waste volumes could help make nuclear power economically competitive.

Most PWRs had converted from waste evaporators to ion exchange systems that were simpler to operate, required less maintenance and personnel exposure, and generated much less waste. With reduction of radioactive releases to the environment a secondary goal, it was enough that effluent activity was decreasing somewhat, along with waste volumes.

A Change in Focus

But after the mid-1990's, industry insurance ratings and peer audit groups placed steadily increasing emphasis on decreasing radioactive effluents. Plant LRW performance was now being evaluated primarily in terms of radioactive effluent (in milliCuries no less, not Curies), versus the volume of waste generated (though, for cost reasons, VR targets were never eliminated).

Ion-selective processing media, refined primary chemistry management, improved fuel integrity, reductions in volume of water generated, implementation of chemical control programs, and training of plant personnel about the impact of introductions to the LRW system all contributed to the steady downward trend in radioactive effluents. While releases of 1,000 mCi/yr (37,700 MBq) had been common in the 1980's, by the 90's, plants were routinely targeting releases of 400 mCi/yr (14,800 MBq).

Today, as individual plants continue to improve their LRW processing performance, the activity release level qualifying for "upper quartile" ranking drops every year. As a result, continual improvement is necessary just to maintain the same ranking. Releases of 20 to 30 mCi/yr (740 to 1110 MBq) or less are typical. Top quartile is currently 7 mCi/yr-unit (259 MBq) or less.

With this in mind, and with the pace of demineralization process gains at a near stand still, it is necessary for plants to look elsewhere for continued improvements. That search has led to membrane based systems, both for prefiltration and reverse osmosis.

Demineralization v. Reverse Osmosis

In the mid-to late-1990's, the first effective ultrafiltration and reverse osmosis (RO) units were applied to LRW cleanup. The benefits of RO included reduced waste volumes and improved effluent quality. In some cases, near-zero radioactive effluent was achieved.

These benefits, and the ultimate advantage of RO (a membrane technology), is simply explained. Ion exchange resin creates a chemical barrier to the passage of contaminants. Unfortunately, the chemistry of the LRW stream and chemical form of the targeted contaminants may change from day to day, even hour to hour. Accordingly, some days the chemical barrier works well then the next day little at all. This makes it difficult to achieve consistently satisfactory processing results.

In contrast, RO erects a mechanical barrier to contaminant passage that is the same every day. Because the molecular-weight openings in the membranes do not change, it does not matter whether the activity is present in soluble form, as a particulate, complexed or as a colloid — nominally 100% will be rejected. Such an absolute barrier gives consistent and reliable performance that cannot be equaled by ion exchange. .

RWRO Application

Today, the application of RO for LRW processing is just reaching its stride. DTS made the first commercially successful PWR RO installation at Wolf Creek in 1998. The system was immediately successful, and won EPRI's Award for Innovative Application of New Technology in 2000. Eight years later, Wolf Creek's results are still near the top of every industry LRW performance category, and the RO technology is being further refined and optimized.

In the first six months of 2006, DTS installed Radwaste Reverse Osmosis (RWRO) systems at Seabrook and Fort Calhoun. Then in August, a unit was placed at Vogtle.

The benefits of RWRO operations for processing LRW include:

- RWRO provides a physical barrier (200 molecular weight (MW) cutoff) that remains constant, irrespective of the quality and chemistry of influent water. RWRO performs its task whether the LRW process stream is 100 or 1000 μmho/cm (100 or 1000 μS/cm).

- RWRO rejects virtually 100% of the process stream activity; including cobalt, antimony, sub-micron particulates, colloids, and complexed or chelated activity; and prevents this activity from entering the monitor tank and the environment.

- RWRO eliminates reprocessing and special handling of problem waters.

- RWRO reduces resin consumption. Because the RWRO unit (not the resin) makes MDA or near-MDA water, demineralizer resins can be run far past normal depletion.

RWRO Configuration

The order of components for a standard RWRO installation is consistent: prefiltration, followed by ion exchange, RWRO, and post-polisher demineralization. The primary variant in the installation is the method of prefiltration. Wolf Creek and Vogtle use a tubular ultrafilter (TUF™) as a prefilter to the RWRO, while Seabrook and Fort Calhoun use a deep bed carbon filter system followed by mechanical filtration to capture tramp particulate that may migrate through the carbon prefilter. Both installations have a polisher on the RO reject stream to further scavenge activity before it is routed back to the plant or to a DrumDryer™ for reduction to dried solids.

A comparison of the Fort Calhoun and Vogtle systems is shown below:

Ft. Calhoun	Carbon Prefilter	Demins	Mechanical Filter	RWRO	Polisher
Vogtle	Tubular UF	Demins	RWRO	Polisher	DrumDryer

RWRO Operating Philosophy

Inserting demineralizers ahead of the RWRO is unconventional but effective, as the demins remove readily exchanged activity from the process stream before it reaches the RWRO. The polishing demins downstream of the RWRO capture remaining soluble activity. When these polishers become partially depleted, they are transferred to the demineralizers in front of RWRO, where they can remove gross activity, but are not required to make good quality water. The polishers are then replaced with fresh media. This resin shuttle strategy improves resin utilization and life, while consistently producing better quality effluent; since the efficacy of activity removal does not depend on substantially depleted resins.

A demineralizer is placed on the RWRO reject line to scavenge activity, particularly antimony that is rejected by the RWRO. The reject can then be returned to the LRW collection tank. The cleansed reject is small in volume and has an activity concentration typically one tenth that of the influent LRW, so activity will not be concentrated in the plant LRW system. The returning reject stream actually dilutes the activity in the plant waste system.

Whether the reject goes back to the plant for reprocessing or sent to a DrumDryer™ for drying to dried solids, it is desirable to minimize the concentration of activity in the reject stream. It is better to load the activity on ion exchange media (which is easily sluiced, dewatered and disposed of) than on filters or other difficult-to-handle media. The table below shows typical activity concentrations across key components

Table 1

Typical Activity Concentrations Across Key RWRO System Components

Stream	Activity (/ml)	DF	gpm/lpm
Influent Radwaste	1.0E-3 µCi/37 Bq		25/95
Demin Effluent	1.0E-5 µCi /0.37 Bq	100	25/95
RWRO Influent	1.0E-5 µCi /0.37 Bq		25/95
RWRO Permeate	MDA	∞	24/91
RWRO Reject	3.3E-4 µCi /12.21 Bq		1.0/3.8

The reject stream, at 5% of the processing volume, contains only 1% of the total activity (assuming a 100 DF for the demin system) of the original feed. If the upstream demin system achieves a DF of 50, then the activity returned to the plant is 2% of the total influent activity supplied to the RWRO. An operating benefit common to all RWRO operations is elimination of iron from the quarterly and annual composite releases.

This novel operating philosophy has proven effective at several of the plants where the RWRO is installed. These installations are discussed below, including unique system features and performance results.

Fort Calhoun

Fort Calhoun's installation, which began operation in April 2006, uses the carbon prefilter and demineralizer systems that were already in place at the plant.

Ft. Calhoun	Carbon Prefilter	Demins	Mechanical Filter	RWRO	Polisher

In 2006, Fort Calhoun completed a steam generator replacement outage, with the usual array of variable and difficult to process waters. For the duration of the outage, no tanks required reprocessing and a new annual radioactive effluent record was established. Releases in 2007 are promising to set a new record as well, with total releases expected to be well less than 30 mCi (1100 MBq).

The high concentration of solids encountered during the outage was a processing challenge that required more aggressive filtration than expected. The solids accumulated in the RWRO made it necessary to perform a membrane cleaning — the first ever required on an RWRO system. Under less strenuous circumstance, no cleanings are expected. Post-cleaning, the RWRO was returned to service with normal pressures and performance.

Seabrook

Seabrook's installation, which also began operation in April 2006, has a lineup similar to Fort Calhoun's. However, Seabrook installed a larger number of demin vessels, which allows more effective application of ion-selective media and reduces the reliance on the RWRO. The downstream RWRO installation replaced an upstream ultrafilter installation.

Seabrook	Carbon Prefilters	Demins	Mechanical Filter	RWRO	Polisher

When the carbon prefilter and ion exchange vessels produce a high quality effluent, the RWRO is left in by-pass. When filtration and ion exchange do not produce sufficient activity removal, the RWRO is brought into service. The RWRO consistently produces water at or near MDA, regardless of the influent.

The Seabrook installation set a new plant record for activity releases and media consumption for 2006, with an annualized release of 15 mCi (550 MBq) and an estimated 70 cubic feet (2.0 cubic meter) of media consumed. With no outage scheduled in 2007, total releases of <10 mCi (370 MBq) are targeted, with a further reduction in waste volumes.

Vogtle

In August 2006, an RWRO and DrumDryer™ were installed at Vogtle, where they joined an existing Diversified Technologies tubular ultrafilter (TUF™). Vogtle, a dual unit plant, conducted a steam generator chemical cleaning campaign and used the TUF™/RWRO system to process the usual variety of waters generated during such outages, as well as spent resin sluice water. Vogtle also set new plant records for activity releases and waste generation.

Vogtle	TUF	Demins	RWRO	Polisher	DrumDryer

The RO reject scavenger demin was particularly effective at Vogtle, where there was concern about the dose and waste classification of the dried solids generated by the DrumDryer™. The first two partially filled drums were removed from service after nine months of system operation. The contact dose rate ranged from 20-30 mRm/hr (2.0-3.0E-4Sv/hr), and presented no waste handling or disposal challenge.

Most of the Vogtle demins are operated as RWRO polishers, instead of being shared as polishers and scavengers ahead of the RWRO. After completion of the first year run in this configuration, this processing mode will be reviewed and reassessed. Though the plant has set new record lows for radioactive effluent and waste generation, we believe that further benefits can be derived from moving more of the demins into a scavenging position ahead of the RWRO. The scavenger on the reject stream, which proved so effective in minimizing dose on the dried solids, will remain.

Wolf Creek

The Wolf Creek TUF™/RWRO has operated continually since its installation in 1998 when radioactive effluent and waste generation dropped sharply from prior processing of LRW with mechanical filtration and ion exchange.

Wolf Creek	TUF	RWRO	Demin/Polisher	DrumDryer

Wolf Creek has established a Levelized LRW performance target for system operations. Though further reductions of a few milliCuries could be achieved, the effort and cost of doing so is judged to be unwarranted. The table below shows a history of stable system operations. The TUF™/RWRO combination reduces reprocessing to near-zero, irrespective of the influent activity concentration and water quality.

Table 2

History of Stable System Operations at Wolf Creek

Year	Activity Releases	Resin Volume
2003	20 mCi (740 MBq)	30 cf (0.85 m^3)
2004	19 mCi (703 MBq)	30 cf (0.85 m^3)
2005	15 mCi (555 MBq)	15 cf (0.43 m^3)
2006	14 mCi (518 MBq)	25 cf (0.71 m^3)

Summary

Consistency of results is inherent in the design of the RWRO, which forms a constant physical barrier between a plant's LRW system and monitor tanks. This is a marked improvement over the chemical barrier of ion exchange resin and chemical pretreatment, which is variable and inconsistent, and whose results may diverge widely from year to year.

The juxtaposition of demineralizer and RO units is novel and unconventional, but effective for the unique requirements and goals of LRW processing, whether the reject is returned to the plant for reprocessing or routed to a dryer system for conversion to dried solids.

Scavenging of activity from the reject stream is particularly effective at minimizing dose build-up in the dried solids or precluding the concentration of activity in the plant, when the reject is returned to the plant for eventual reprocessing.

All three of the nuclear power plants that installed the RWRO in 2006 set new plant-life record lows for radioactive effluent. Wolf Creek, a site with eight years of RWRO use, again improved on its long-term favorable performance. It is expected, as operations and decision-making is further refined, that additional improvements in processing effectiveness, as measured by reduced radioactive effluent and waste generation, will be achieved.