

4.0 LIQUID WASTES

Low-level radwaste in a light water reactor (LWR) is generated by contamination of various materials by radionuclides generated in the reactor or released from the fuel cladding surfaces into the reactor coolant system and, to a lesser extent, into the spent fuel storage pool. Figure 4.1-1 shows the basic sources of radioactivity in the reactor coolant.

The structural materials in the reactor core and the components confining the reactor corrode and erode slightly with time to create fine particulates identified broadly as corrosion products. These corrosion products circulate through the core of the reactor where neutron bombardment, or activation, causes them to become radioactive. The radioactive materials so formed usually consist of many of the radioisotopes of elements such as:

- Iron
- Chromium
- Cobalt
- Manganese

Tritiated waste is usually abundant in reactors that use boron in the reactor coolant to control the fission process (pressurized water reactors). Tritium, a radioactive isotope of hydrogen, is formed as the result of neutron absorption by boron, lithium, or deuterium. Tritium is also a ternary fission product.

Most of the activity in low-level waste originates from:

- Activation of materials surrounding the fuel
- Fission products
- Tritium

The radionuclides are formed in, or released into, the primary coolant water at the reactor and the cooling water at the spent fuel storage pool. Generally, it is extremely difficult to confine and limit the radioactivity to the systems containing the reactor primary coolant and the spent fuel pool water because each of these systems connects directly with several other auxiliary systems. There is leakage from system components such as valves and pumps. Consequently, the traces of radionuclides can be found in several systems throughout the power plant.

Because of the potential hazards caused by the accumulation of radioactive materials in various systems throughout the plant, it is necessary to continuously remove these radionuclides to keep radiation levels and radioactive contamination as low as possible. Waste management systems are designed to remove radioactivity from the reactor process streams and to concentrate and contain radionuclides with minimal release to the environment. Typical low-level radioactive liquid waste sources are summarized in Table 4.1-1.

Radionuclide composition in low-level radwaste is basically the same for all LWRs. However radionuclide concentrations can vary appreciably depending on:

- Steam cycles employed [BWR or PWR]
- Reactor size and age
- Construction materials
- Reactor coolant chemistry
- Waste management techniques employed

4.1 GENERAL DESIGN

Liquid radioactive waste disposal systems can be complex and they vary significantly in design and intended methods of operation from plant to plant.

10 CFR 50, Appendix I establishes the design criteria in terms of quality for liquid radwaste discharged from a LWR to the environment. The Appendix I criteria set relatively low limits of exposure to any member of the public. Modifications and backfits to comply with these criteria and other guidance contribute to the complexity of the liquid waste system.

The Decontamination Factor (DF) is a term used to describe the efficiency of a processing method removing contaminants from a process stream. The DF is the ratio of the initial amount of activity in a stream to the final amount of activity in a stream following the treatment by a given process. Therefore, if a given process has a DF of 2, the final activity level is one half of the original activity.

Liquid waste systems can utilize any or a combination of several mechanisms for cleanup of liquid radioactive waste to obtain a prescribed DF. These include:

- Filtration
- Demineralization
- Adsorption
- Evaporation
- Phase separation
- Reverse osmosis

Liquid radioactive wastes are generally treated by one or more of these processes for radionuclide removal.

In general high purity wastes are treated by demineralization or ion-exchange. Low purity wastes are filtered and discharged.

Liquid radwaste demineralization and ion exchange is more cost effective and produces the desired volume reduction. To some extent, these units also serve as adsorbers. Demineralization is discussed in sections 4.7 and 4.8.

Adsorption involves the use of materials such as charcoal or zeolite to retain or retard movement of a material, i.e., iodine. It is not discussed separately but because when used at LWR to process radioactive liquids, it is likely to be used in conjunction with ion exchange. Adsorption is more commonly used for processing gases and the technology is discussed in Chapter 7, which discusses processing of airborne radioactivity.

Evaporation is cost effective for processing liquid wastes containing high concentrations of total dissolved solids. For liquid wastes containing low concentrations of total dissolved solids, evaporation is too expensive because enormous steam consumption is required to drive the water from the waste. It is discussed in sections 4.5.1.3. Evaporation is not used as commonly today due to the high cost of waste disposal for solidified evaporator bottoms, and processing problems associated with solidification.

Section 4.5.1.4 provides a brief description of phase separation. Phase Separator Systems are discussed in more detail in Chapter 5 as part of reviewing solidification practices.

Reverse osmosis has also been applied to LWR liquid wastes and is discussed in section 4.5.1.5 and in section 4.6 as a special filtration process.

4.1.1 ALARA Considerations

ALARA considerations apply to all these systems and include:

- Cubicles for separation and shielding
- Adequate space for maintenance
- Shielding of specific components
- Utilization of remotely operated valves

A high degree of versatility is designed into the system to allow transfer of waste volumes among the sub-systems and various storage tanks. To the extent practicable, the design precludes inadvertent liquid waste transfer and leakage from one system or tank to another.

Optimally:

- (1) The liquid waste storage tanks have sloped bottoms with drains located at the extreme lowest points. They are equipped with a spray header ring inside to facilitate remote washdown and flushing.
- (2) Recirculation pumps and piping are installed for proper mixing of the sample tank volumes prior to discharge. The recycle capacity must be adequate to obtain two complete tank volumes within a reasonable time (< 4 hours). The ability to recirculate during discharge is incorporated into the design.
- (3) Waste storage tanks are fabricated with non-corrosive metal; i.e., stainless steel.

Many original liquid radwaste systems are undersized by a factor of two or three because of changes in waste processing since the time that they were designed and installed. Consequently, the service life of some components, such as evaporators, is drastically reduced from original estimates. Moreover, heat exchangers and pumps wear out, or leaks occur from chloride stress corrosion. A number of evaporators are removed from service or replaced because they do not perform to current requirements.

4.1.2 BWRs versus PWRs

The difference between the BWR and PWR steam cycles accounts for the principal variation in major liquid waste sources.

In BWRs, the light water coolant circulates by either natural or forced convection through the reactor core where it boils and produces steam. The steam passes through the turbine, is condensed, purified and returned to the reactor. The bulk of the BWR's low-level waste fission and corrosion products are generated in this reactor coolant system and consequently the reactor coolant cleanup system typically has the highest concentration of radioactivity. The waste type is ion exchange resins.

In a PWR, the reactor coolant is not allowed to boil. The high temperature, high pressure liquid is pumped to a steam generator where heat is transferred to water contained in a separate circulation loop. The water in this loop does boil and it produces steam for the generator. The highest concentrations of radioactivity in a PWR liquid waste stream are generated as a result of the operation of the CVCS. Low-level wastes generated from this system's operation include boric acid, sodium diborate wastes, ion exchange resins and filter media.

4.2 SOURCES OF LIQUID RADWASTE IN LWRs

With the exception of the reactor coolant cleanup operation and the chemical and volume control system operation, sources of liquid radwaste generation are similar for BWRs and PWRs. They are wastes from:

- Spent Fuel Pool Cooling and Cleanup
- Condensate cleaning
- Miscellaneous sources

At PWRs, the liquid processing system collects and transfers liquid drained to the CVCS for processing from:

- Reactor coolant loops
- Pressurizer relief tank
- Reactor coolant pump secondary seals
- Excess letdown during startup
- Accumulators
- Valve and reactor flange leakoff.

4.2.1 Wastes From Spent Fuel Pool Cooling and Cleanup Operation

The operation of spent fuel cooling and cleanup results in low-level waste generation. The wastes generated from this operation are primarily depleted resins and filter media containing fission and activation products.

4.2.2 Miscellaneous Liquid Waste

The miscellaneous liquid wastes generated by LWRs include liquid waste from:

- Floor and equipment drains
- Chemical drains
- Detergent drains
- Decontamination drains.

In addition, PWRs may generate liquid waste from steam generator blowdown.

4.3 QUANTITY OF WASTE IN INPUT STREAMS

The quantity of liquid waste produced varies with the plant design and with the degree to which water conservation measures are factored into the plant operating procedures. Tables 4.3-1 and

4.3-2 provide a listing of the expected liquid waste input rates for PWRs and BWRs respectively for use in source term calculations. The values specified in these tables are considered to be representative for all PWRs and BWRs. Waste sources vary significantly between individual plant designs and such variations are not reflected in these tables.

Liquid waste is generally categorized by the treatment required to meet plant criteria for recycling water or applicable criteria for waste discharges. A determination can be made on the daily inputs into each processing subsystem, based on the design of the waste collection system (i.e., the manner in which wastes are segregated prior to treatment).

4.3.1 Fission and Activation Products

Table 4.3-3 shows the typical fission and activation products in the reactor coolant water for a PWR at full-power operation. Table 4.3-4 shows the same for a typical BWR at full-power operation.

As shown in the two tables, the types of radionuclides and their concentrations vary widely between a PWR reactor coolant and a BWR reactor coolant.

For example, a high concentration of tritium (H-3) is normally present in the PWR reactor coolant water because of neutron absorption by boron, whereas tritium is not normally found in BWR reactor coolant water. The volatile (gaseous) fission products also differ significantly with PWRs having only the noble gases and BWRs having only nitrogen and fluorine. The spectrum of radionuclide activation products for a BWR is larger than a PWR where only Mn, Co, Fe, and Cr are typically present.

4.4 REGULATIONS GOVERNING LIQUID RADWASTES IN LWRS

In 1971, the Nuclear Regulatory Commission, then part of the AEC, issued Appendix I to 10 CFR 50. It requires nuclear power plants to limit the amount of radioactive liquid effluent in accordance with more restrictive limits than specified in 10 CFR 20 and consistent with the principle of "As Low As Reasonably Achievable (ALARA). This necessitated additional processing. This degree of reprocessing means that much of the water is suitable for reuse within the plant.

Environmental regulations governing the temperature of condenser cooling water also restricts discharge by limiting the amount of effluent dilution water. This resulted from a switch for once-through cooling to closed cycle cooling to limit the thermal impact on the receiving body of water. The adoption of cooling towers and similar cooling modes reduces the dilution flow by 90 to 95%.

These are the primary regulatory influences on liquid radwaste processing. 10 CFR Part 50, Appendix I provides the design objectives and limiting conditions for operation for meeting the criterion ALARA. 40 CFR 190 addresses environmental radiation protection for nuclear power operations and 10 CFR 20, Appendix G pertains to waste transfer and disposal manifests.

4.4.1 Processing/Stabilization

Section 56 of 10 CFR Part 61 includes the requirements for processing and stabilization of all low-level radwastes for disposal at a licensed near-surface low-level radioactive waste disposal site. A brief discussion on minimum waste characteristics is provided in Chapter 6.

4.4.2 Effluent Discharge

10 CFR 20 Appendix B contains the concentration limits for all radionuclides in air and water. These concentrations are provided by isotope in both soluble and insoluble form. Table 1 of Appendix B shows the limits within restricted areas, while Table 2 shows the radionuclide limits in effluent to unrestricted areas. The limits in Table 2 are lower than the limits in Table 1. These are still effective for a large number of licensees.

4.4.3 Design Requirements

The Liquid Radioactive Waste Processing System shall be designed to meet the requirements of 10 CFR 50 Section 50.34a and the limits specified in 10 CFR 20; control and monitoring of releases shall meet the requirements of 10 CFR 50, Appendix I.

The Liquid Radioactive Waste Processing system shall be designed, constructed and operated so that no single active failure or administrative failure can result in a release to the environment or exposure to the general public exceeding 10 CFR 20 limits.

"Standards for protection against radiation" 10 CFR 20 states that licensees should make every reasonable effort to maintain exposures to radiation as far below the limits specified in that part as reasonably achievable.

Proper planning, design, construction, and operation of a Liquid Radwaste Processing System is necessary to ensure the licensee can meet the criterion that exposures of station personnel to radiation during routine operation are ALARA. "Reasonably Achievable" is judged by considering the state of technology and the economics of improvements in relation to all of the benefits from these improvements. The goals of the ALARA effort are to maintain:

- Annual dose to individual station personnel as low as reasonably achievable
- Annual integrated (collective) dose to station personnel as low as reasonably achievable.

In addition to limits on radiological effluent, environmental regulations nearly concurrent with Appendix I established controls on condenser cooling water.

Several plants have had to convert from once-through cooling to a closed cooling-water system. Allowing only for periodic blowdown, this effectively reduced the dilution flow by 90 - 95%. Since discharge limits had applied to the concentration of radioactivity, this resulted in reduction of the total quantity of radioactive effluent that may be discharged within existing regulations.

Minimizing liquid discharges during normal plant operation requires that the plant maintain a water balance and maximize internal water reuse. Adequate storage and processing equipment are essential to water recycle.

4.5 LIQUID RADWASTE PROCESSING SYSTEM

The liquid radioactive waste system collects, segregates, processes, stores, treats, monitors, and disposes of all liquid radioactive waste.

If the quality of the processed water is acceptable, it is returned to the plant makeup water inventory. A large portion of the radioactive liquid collected by this system is recovered as reactor grade water and stored for use as reactor makeup.

Liquid radwaste is classified, collected and treated as:

- High purity (reactor grade)
- Low purity (non-recyclable)

High purity and low purity refer to conductivity, not radioactivity.

The makeup water is stored for return to the reactor coolant system.

Liquid waste processing systems are designed to recycle as much reactor grade water as practicable. Segregating equipment drains and waste streams to prevent intermixing of liquid wastes from non-compatible sources is one common approach towards assisting in meeting this objective.

The low quality, low activity water is discharged at a controlled rate. Water with radioactivity above acceptable concentrations for discharge is processed further.

If processing capacity is available and is effective in further reducing releases consistent with ALARA, water that is acceptable is also reprocessed.

Some radioactive liquid wastes are discharged in plant effluent water. Therefore, the liquid radioactive waste system has provisions for obtaining representative samples for analyses prior to discharge and for monitoring effluent during discharges. Liquid radioactive waste discharges are normally batch processes.

Inadvertent or accidental release is mitigated by administrative controls governing discharges. At least two valves must be manually opened to enable discharge of radio-active liquid to the plant effluent. One of these valves is normally locked closed. Proper authorization is required before it is allowed to be opened. The effluent stream is monitored. A control valve closes on a high effluent radioactivity signal. These controls are provided to prevent discharges without adequate dilution.

There is no universally adopted radwaste system or industry-wide standard practices. Differences occur as the industry and regulations evolve. Furthermore, structure, system and component nomenclature is often site specific. However, a typical *original* plant system for liquid waste processing is shown in Figure 4.5-1 for a PWR and Figure 4.5-2 for a BWR.

The discussion below is representative, but does not fully apply to all sites. It should, however, provide a basis for understanding the general design characteristics of liquid waste processing at either a PWR or a BWR. System modifications and/or operating practices continue to evolve, albeit at a reduced level from earlier history.

Specific size and design of the radwaste system components differ in systems that process wastes from multiple units rather than a single unit plant.

The requisite decontamination factors for liquid waste processing are obtained by the selection and combination of a number of unit operations.

The extent of radionuclide removal is calculated using a generically applicable decontamination factor (DF). Decontamination Factor is defined as the ratio of the inlet isotope concentration to the exit isotope concentration. Generally, a larger DF indicates greater removal of radionuclides and process components are typically combined to achieve higher DF.

For each system, the overall DF is the product of the individual component DF for each component in a series. For example, if a BWR radwaste evaporator (DF = 1,000 for iodine) and an evaporator condensate demineralizer (DF = 10 for iodine) are used in series, the overall subsystem DF would be $1000 \times 10 = 10,000$ for iodine. The ionic behavior of a radionuclide in a particular process component determines the DF.

Generally, noble gases and water-activation products (N-16, O-19, N-13) are not included in the liquid source-term calculations because experience has shown their effect on the source term is negligible.

Tritium is not included above because state of the art liquid processing components are not effective for tritium removal.

Currently, the industry practice is to use vendor supplied multivessel demineralizer and filter systems to treat floor drain water (high conductivity/low radioactivity), rather than the originally installed evaporator units.

4.5.1 General Processing Methods

Common methods of removing radioactive contaminants from liquid waste streams are:

- Filtration
- Ion Exchange/Adsorption
- Evaporation
- Reverse osmosis.

4.5.1.1 Filtration

Filtration is defined as the separation of undissolved particulate, suspended solids from a fluid mixture by passage of most of the fluid through a septum or membrane that retains the solids on or within itself.

Particulate filtration is used to separate solids and suspended solids from liquid radwaste streams. Filtration is generally applied to:

- Floor and equipment drains
- Reactor water cleanup stream
- SFP and refueling pool cleanup stream
- Condensate polishing stream

In the filtration process, solids are removed from a liquid waste stream by passage of the liquid through porous media, such as sand and gravel, diatomaceous earth, anthracite, and activated carbon.

Combinations of the various filter media are sometimes used. The porous media remove coarse solids and, depending on the type of filtration media, some colloidal solids.

Filtration is sometimes preceded by a chemically induced precipitation to maximize the recovery of radioactive materials. The recovered solids are included with the filtration media as a solid waste, or removed from the filter (e.g., by back washing) for further treatment.

4.5.1.2 Ion Exchange/Adsorption

Ion exchange treatment, along with activated carbon adsorption, is normally used for the following waste streams:

- Floor, equipment, and chemical drains
- Chemical and volume control system wastes
- Spent fuel pool and refueling pool cleanup
- Condensate polishing
- Reactor water cleanup
- Steam generator blowdown wastes.

Fixed bed activated carbon units are used at the front end of the ion exchange columns to guard the resins and zeolites from dissolved organics and oil fouling. Organic resins and zeolites have a tendency to produce much lower DF and process capacity declines if substantial amounts of organics are present in the waste. Oil tends to coat the resins making the exchange sites unavailable for ion exchange. Several varieties of activated carbons are used for removing organics and dissolved oil. Activated coconut charcoal is shown to be the most effective variety.

An ion exchanger is a device that uses a polyelectrolyte to exchange mobile ions of equal charge from the surrounding solution. A common polyelectrolyte is essentially a plastic bead that has ions weakly attached. When a liquid passes across this bead, it readily exchanges the ions on the bead with the ions of the same charge in the liquid.

There are two basic types of resin beads, called cation and anion. The cation resin has a positive hydrogen ion in the exchange position. The anion resin has a negative hydroxyl ion in the exchange position.

Ion exchange involves the removal of ionic species, principally inorganic, from an aqueous or partially aqueous phase. Ion exchange methods have been widely used for removing dissolved radioactive materials from liquid low-level radwaste. The process involves exchange of ions between the liquid and a solid matrix. Both cation and anion exchange resins and zeolites are used.

The DF attributed to ion exchangers vary from 1 to 100. The value depends on:

- Conductivity of the solution
- Location of the ion exchanger in the process stream
- Whether a single or series of ion exchangers are used

Fixed-bed ion-exchange operations are relatively simple systems that require a cylindrical ion-exchange bed, tanks for solution storage, and pumps. The choice of materials is governed by the chemical environment. Types of materials that are in use or that have been proposed for use as ion-exchange materials include inorganic crystals (both natural and synthetic zeolites) and synthetic organic resins. The last type is by far the most important for general ion-exchange systems in nuclear power plants.

When the exchangers have become fully loaded, they are removed from service and treated as radioactive waste or they can be regenerated by strong acids and bases which yield liquid radioactive wastes of high salt content. Such chemical resin regeneration is infrequently used

today. In BWRs, condensate resins are often “reused” following ultrasonic resin cleaning of the spent beds.

In addition to removing ions by ion exchange, the demineralizer filters remove suspended particles larger than the clearances between resin beads.

Common practices in power reactor facilities include the use of deep bed ion exchangers as well as filter/demineralizers. Deep bed ion exchangers (demineralizers) consist of a large vessel with an inlet and outlet filled with the desired form of resin.

Demineralizers containing anion and cation resins in a mixture are called mixed-bed demineralizers, while those containing only one form are called single-bed demineralizers. Single beds are generally installed in pairs, one anion and one cation. Single-bed demineralizers have the advantage of simpler regeneration than mixed-bed demineralizers.

Besides deep bed demineralizers, filter demineralizer units are also used to remove radioactive materials. A filter demineralizer is similar to a precoat filter, except that a very finely divided or powdered form of mixed-bed ion-exchange resin is used instead of the filter medium. The small particle size of the resin permits rapid ion exchange, because of greater surface area and the thin layer of resin on the septa acts as a filter and can also remove the normally small quantities of suspended material. When the resin becomes depleted or when the filter develops a high-pressure drop, the resin coating is back washed off and sluiced to a storage tank. The resins are not regenerated; they are stored for decay, dewatered or solidified and disposed of as solid waste.

A variety of specific ion exchange resins are currently available to allow for the removal of specific types of contaminants from the liquid process streams. Table 4.5-1 lists an example of some of these commercially available ion exchange resins.

4.5.1.3 Evaporation

Evaporation is the process by which a solution or slurry is concentrated via boiling.

Evaporation is a unit operation for the separation of a solvent from a solute, where the solute has essentially negligible vapor pressure. This process leaves most of the solids behind and the condensed steam is essentially pure water.

Evaporators:

- Remove soluble and insoluble materials
- Reduce volume
- Remove water from a solution
- Produce relatively pure water from impure water.

Basically, an evaporator consists devices to:

- Transfer heat to the solution
- Separate the vapor and liquid phases.

During evaporation, a solution or slurry is concentrated by vaporizing or boiling away the solvent.

This boiling causes the radioactive gases to leave the solution. These gases are collected and vented to the waste gas system. The steam is collected, condensed and treated as deaerated, pure water. It is then recycled.

The solution left behind in the evaporator bottoms is called concentrate. The concentrate generally has a high concentration of radioactive material. This solution can be recycled for further processing, but most likely it is transferred to the solid radwaste system for solidification.

Although rarely used at power reactors today, evaporation technology is still used at some waste vendor facilities (For example, the DCF at the EnergySolutions complex in Snelling, SC) to treat waste from their Thermex treatment system. This system utilizes several demineralizer and filter units in conjunction with a reverse osmosis membrane (Section 4.5.1.5) to treat floor drain water. The waste from the reverse osmosis unit, called “brine,” can then be shipped to the vendor where it is treated by evaporation, prior to disposal.

4.5.1.4 Phase Separation

The phase separator is a large tank with a conical bottom. Liquids with high solids content are transferred to these tanks where the solids are allowed to settle. The liquid above the solids interface is pumped back to the liquid waste system for further processing or discharge. The solids are transferred to the solid waste disposal system for stabilization and packaging for disposal. The solids often have high radioactivity. This process is discussed further in Chapter 5.

4.5.1.5 Reverse Osmosis

Reverse osmosis is a membrane process that, simply stated, acts as a molecular filter to remove almost all dissolved minerals and dissolved organics with molecular weights over 100 and all biological and colloidal matter from water. With this process, pure water is separated from a salt solution by a semipermeable membrane that passes water readily, but retards the flow of ionic solids.

Osmosis is the natural process whereby pure water flows through the membrane from a dilute solution into a more concentrated one, thereby diluting the latter. However, if pressure is applied to the salt side at a level that is greater than this osmotic pressure of the salt solution, it forces pure water to flow across the semi-permeable membrane from the salt solution.

A reverse osmosis system can be effective when combined with ion exchangers in minimizing total organic carbon (TOC) and silica in liquid streams. Table 4.5-2 shows plant data for one such system.

4.5.1.6 Areas of Concern/Troubleshooting

Design of liquid radwaste processing systems must have provisions for proper maintenance of valves, pumps, instruments, etc. The operations of the major units should minimize operator radiation exposure. The primary areas of concern for the operation of a liquid radwaste processing system are:

- Operation of demineralizers
- Operation and maintenance of pumps, valves, and contact-measuring instrument

The major problems with liquid radwaste systems include:

- Insufficient processing capacity
- Insufficient tankage
- Inability to accommodate high organic contaminants in waste streams

The following areas have large potential for crud buildup in a liquid radwaste processing system:

- Collection sumps/tanks
- Pump niches/bases
- Valve glands/packings
- Tanks storing wet solids/sludges
- Lines carrying resin fines in the nooks and crevices
- Pipe routings with improper slope

Crud buildup in those areas essentially produces a high radiation field because of entrapped particulate activation/corrosion products. A liquid radwaste system with potential for high crud buildup translates into higher operational radiation exposure. The following approaches to maintenance should be considered in areas of crud buildup:

- Semi-remote or remote methods such as long-handled tools
- Robots for high radiation areas
- Portable shields to minimize exposure
- Allowing reasonable time for decay (at least for short-lived isotopes) before performing maintenance

4.6 FILTRATION

Filtration is defined as the separation of undissolved, particulate solids from a fluid by passage of most of the fluid through a septum or membrane that retains the solids on or within itself. The fluid that passes through the septum is called a filtrate. The septum is called a filter medium. The visible layer of solids accumulated on the filter medium is the filter “cake.” Filtration is the mechanical removal of suspended matter from a fluid by passing the fluid stream through filter media.

Filtration is particularly important in power plants because filters remove entrained or suspended solids from domestic water, feedwater, and discharged gases and liquids. As particles are continuously collected, the differential pressure across the medium increases. Continued operation could eventually result in filter break through. The solids retained in the filter unit are subsequently backflushed or the filter medium is removed for disposal. The filtrate is available for further processing, reuse or disposal as a controlled effluent.

Filters are installed upstream of demineralizers to remove suspended material before it can foul ion exchange resins. Filters are also used downstream of the ion exchangers to prevent resin fines from passing into the feedwater heaters. In cooling water systems, filters prevent suspended material from clogging small orifices and valves and from fouling heat transfer surfaces. They are used to remove particulate matter from waste effluent streams prior to discharge. Although filters are used in both gas and liquid streams, this section focuses on liquid filtration.

Water is filtered by passing it through a porous material that mechanically removes suspended matter. The filter medium retains suspended matter that is too large to pass through the small openings by a straining action. As these larger particles collect on the filtering surface, they form a mat, which also acts as a filter. The smaller size suspended matter that can pass through the pores of the filter are retained by frictional resistance of this mat and of the filter medium. The water leaving the filter is relatively free of suspended insoluble matter.

About one-fourth of the activated corrosion products tend to be suspended solids. Typically, filters selected for radwaste reduce the concentration of insoluble materials in the liquid stream to less than 1 ppm.

4.6.1 Filter Media

A large variety of materials, quartz sand, silica sand, anthracite coal, calcite, garnet, magnetite, etc., are used for filters; however, only a few types of filters are used in LWR's. These are discussed as individual types of filters below.

Table 4.6-1 lists the advantages and disadvantages of filters to process radioactive liquids at a LWR.

The size and shape of particles govern the efficiency with which the medium removes solids. Sharp, angular particles form large voids and remove less fine material than rounded particles of equivalent diameter. The medium must be coarse enough to allow sludge to penetrate the bed for several inches. Desirable attributes of a filter medium include:

- Ability to bridge solids across its pores quickly after beginning the feed (minimum propensity to bleed)
- Resistance to wedging particle over or into the pores (Minimum propensity to blind or plug)
- Minimum resistance to filtrate flow (high production rates with low pressure drop)
- Resistance to chemical attack
- Sufficient strength to support filtering pressure
- Ability to cake easily and cleanly
- Ability to conform mechanically to the filter type to be used
- Minimal cost

Most suspended solids are trapped at or near the surface, some penetration is absolutely essential to prevent a rapid loss of head.

The finer the medium, the shallower is the zone that retains suspended matter. Large pressure drops develop more rapidly in the finer media and limit their useful life. The most desirable medium size depends on the suspended solids characteristics, as well as the requirements for the effluent quality and filter design.

Reactor coolant is not the only water that is processed by filtration. It is also necessary to treat the raw water supply to a plant prior to using it as makeup water. The makeup water treatment system processing includes a couple of filtration steps. The clarifier effluent is filtered through anthracite to remove suspended impurities and an activated carbon filter is subsequently used to remove organic molecules. This stream processes natural or public water supplies and, therefore filtrates from this stream are not considered radioactive wastes.

4.6.2 Filtration Methods

The general categories of filter designs used to process liquids are:

- Cartridge
- Precoat
- Edge

Filters are commonly used in liquid radwaste applications. They are shown in Figures 4.6-1 through 4.6-5.

4.6.2.1 Cartridge Filters

Cartridge filters (Figure 4.6-1) are designed with replaceable elements that are discarded when plugged. A single element cartridge filter is shown in Figure 4.6-5.

These elements are usually constructed of pressed paper, matted fibers, or porcelain materials. In general, these types of elements are best suited for the removal of gross contamination from low pressure, low temperature systems.

In the cartridge filter, the filter medium consists of a special fiber yarn wound around a central porous metal tube to form a cylindrically shaped cartridge or pleated epoxy impregnated paper. Depending on the application, the yarn is a woven fabric or fiber made of cotton-viscose, nylon, fiberglass, or polypropylene. For high temperature or high pressure applications, the cartridge can be made of porous stainless steel, Inconel or Monel.

Cartridge filters are enclosed in a vessel that is constructed to direct all flow through the filter cartridge. Flow is normally from the outside, but in some designs the flow is from the inside. Fluid is forced through the yarn into the central core and exits via the filter outlet.

A cartridge filter can include several cartridges in series or several stacks in parallel, depending on the desired flow rate. Such arrangements provide a large surface area and enable higher flow rates.

When arranged in a series beginning with larger pored roughing filters, each filter can remove particles above a prescribed size and pass the smaller material to the next filter in the series. Progressively finer pored filters can be used to obtain the desired purity in a step fashion. This approach reduces the differential pressure across the filters and extends their process life.

Cartridge filters are commonly used in radwaste treatment facilities primarily as a pretreatment step. They are relatively simple and inexpensive to install and straight forward to operate. Most cartridge types are disposable.

Replacement of cartridge filters has been a problem at various operating plants due to their relatively high radiation rates and potential for occupational radiation exposures. Therefore, the cartridge filter system is designed for:

- Isolation and draining
- Rapid removal with long handled tools
- Shielded access during removal

4.6.2.2 Precoat Filters

Precoat filters (Figure 4.6-2) use elements designed as retainers to prevent a precoat material from being flushed down-stream. The actual filtering of system contamination is accomplished by the precoat material. When the filter becomes contaminated, the precoat material is replaced. This type of filter can provide high levels of filtration efficiency, but is limited by temperature and pressure extremes. The large quantities of precoat material that must be disposed of can present significant problems in terms of handling and disposal.

Pre-coat filters are usually housed in large cylindrical vessels. Precoat filters consist of a bundle of perforated or porous vertical screen tubes (septa). There may be several hundred septa in a filter. The septum tubes are coated with a slurry of filter medium. A typical septum is a tube about one inch in diameter about three feet long and made of a fine mesh screen.

The septum tubes are constructed of nylon fiber, porous stone, paper, or stainless steel screen and supported on a base plate. The filtering medium is usually diatomaceous earth (diatomite), perlite, or cellulose (like Solka-Floc).

Cellulose is generally used for processing water that will be returned to the reactor. In some cases, a combination of filter medium and powdered ion exchange resin is used to provide both filtration and demineralization.

When a precoat filter is put on line, solids in the process stream are trapped in the precoat cake until the maximum design pressure is reached. The filter medium with its entrained solids is backwashed to the mixing and packaging system for solidification.

When a pre-coat filter is in use, water enters the filter vessel, passes through the filter medium deposited on the septa and leaves through the outlet. Before a precoat filter can be put into operation, the filter medium (precoat) must be installed. Filter medium is mixed with demineralized water to form a slurry that is pumped through the filter and deposits on the septa. Water pressure holds the filter medium in place. After the septa have been precoated, the filter is put into service and kept on-line until the pressure drop indicates that the filter medium is becoming plugged. When this occurs, the accumulation of filtrate and the filter coating is sloughed off by the backwash. The filter bed is precoated again. Filters are usually installed in pairs, so that one filter can remain in service while the other is undergoing the backwash and precoat process. Sludges from backwashing are dewatered or solidified and disposed of as solid waste.

4.6.2.3 Edge Filters

Edge, or etched disc, filters (Figure 4.6-4) are similar to the cartridge filter, but an edge filter is reusable and can often be cleaned in place. The edge filter is made up of about 800 mechanically compressed metallic discs, each about 0.0254 mm thick, stacked to form a cartridge and placed over a central perforated pipe. The discs consist of a central disc with several small "fingers" attached to the periphery of the disc. Each finger contains a small, chemically etched area with a pre-determined flow pattern. The pore size is controlled to provide the proper micron rating. The discs are spaced in such a fashion as to create the desired clearance.

A complete filtering unit has several individual elements stacked together with etched surfaces against non-etched surfaces to ensure flow through the etched pores only. The flow paths extend from the discs outer edge to the inner edge.

This design is conducive to lowering the differential pressure (dP) through the disc with a precoat added prior to filtering. Thus, the precoat and the filter element operate synergistically to reduce dP. The system can be operated at a relatively high dP (about 75 psi).

The filter system can be designed to automatically backwash and de-cake the filter when the dP reaches a prescribed limit.

Fluid is forced through the disks and out the filter outlet.

Edge filters are usually cleaned by backflushing water or air through the filter and collecting the residue. Although backflushing creates a volume of contaminated liquid, the amount of liquid involved is many times smaller than the liquid processed between backwashings.

4.6.2.4 Other Filtration Methods

Other filtration methods for treating liquid radwaste are ultrafiltration and reverse osmosis.

In reverse osmosis (or hyperfiltration) pressurized feed is passed through a selective membrane that retains salts and other low molecular-weight solutes while allowing the pure water to pass through. The pure water is collected by a holding tank where its ultimate disposal is determined. Impurities deposited on the wall of the membrane are disposed of with the membrane element when it becomes saturated.

Ultrafiltration and reverse osmosis are both membrane filtration technologies with the following differences:

- Ultrafiltration is a particulate filtration technology that normally removes particles in the range of $0.001\mu\text{m}$ to $0.02\mu\text{m}$. Ultrafiltration does not remove soluble species but can remove some colloids, fine suspensions and emulsions.
- Reverse osmosis is a molecular filtration technology which removes dissolved solids in the particle size range of $0.0001\mu\text{m}$ to $0.001\mu\text{m}$. Reverse osmosis units separate species based on an osmotic pressure difference. Reverse osmosis is a high pressure process and normally has high maintenance and energy costs.

4.6.3 Typical Applications in LWR

Particulate filtration is used to separate insoluble and suspended solids from the liquid radwaste streams. Filtration is generally applied to:

- Equipment drains
- Reactor water cleanup stream
- Spent fuel and refueling pool cleanup stream
- Condensate polishing stream

In the filtration process, solids are removed from a liquid stream by passage of the liquid through a porous medium. The porous medium removes coarse solids and, depending on the type of filtration medium, some colloidal materials. Filtration is sometimes preceded by a chemically induced precipitation to maximize the recovery of radioactive materials. The recovered material is either included with the filtration medium as a solid waste or removed from the filter (e.g., by backwashing) for further treatment.

4.6.3.1 Cartridge Filters

Cartridge type filters are employed in a variety of liquid processing streams in a LWR.

The cartridge type filters come in a variety of porosities. The coarser ones are typically roughing filters to remove the larger particulates and debris, and protect the more expensive fine filters from premature plugging.

Many applications in a LWR use micron and submicron size filters. The later are often used for "polishing" to ensure a high grade effluent. Cartridge filters in the submicron range have been installed at a number of PWRs, especially in the CVCS system, to remove Co-60.

4.6.3.2 Precoat Filters

A good example of the use of precoat filters in radioactive liquid waste processing is the waste collector filter of a BWR. This is a pressure precoat filter consisting of a dished head pressure vessel with a removable flanged top section. Perforated septa, covered with a fine stainless steel screen, are rigidly suspended from a tube plate, which is supported at the vessel flange.

The individual filter units are typically 2-3/4" in diameter and 60" long. The overall housing is 3' in diameter and nearly 11' long. It houses several hundred individual filter tubes.

The system has a holding pump to maintain the filter cake in place when there is no processing flow through the system. The holding pump recirculation flow passes through an air cooler to maintain recirculation water temperature below the filter design temperature; i.e., less than 140° F.

4.6.3.3 Operating Characteristics

Filter operation is normally controlled on the basis of dP across the filter.

A high dP indicates the filter is plugging and should be replaced or back washed to remove collected solids.

An abnormally low dP indicates leakage around the filter medium or through a perforation in the medium.

As indicated, precoat filters must be washed periodically to remove accumulated sludge. Inadequate cleansing permits the formation of permanent clumps over large areas, which decreases filter capacity.

Methods used to determine need for filter changes or recoating:

- Monitoring of radioactivity of filter housing. If the filter becomes a radiation problem or if the high radiation level indicates excessive loading of the filter.
- Testing the effluent for solids or excessive radiation levels.
- Monitoring the pressure drop across the filter system. An increase in the normal range of dP over the system could indicate a plugged filter, while an unusually low dP indicates a "break-through."

Either condition can result in a decision to remove the filter from service. The "limits" are dependent upon the system and are controlled by operations procedures and technical standards. Allowing a

breakthrough to occur prior to changing the filter is an unacceptable alternative since it increases loading of the next section of the system and significant increases in radiation levels at other parts of the system.

4.6.4 Disposal of Filters and Filter Material

The spent filters are wet solid wastes and are handled in accordance with the facility solid waste management program. The exhausted precoating materials and their associated filtrates are backwashed and collected in a waste sludge tank. After the solids settle, the water is decanted to another tank for further processing or discharge as a station effluent. The remaining slurry is fed to a concentrate tank for processing and solidification for disposal as radioactive waste.

4.7 ION EXCHANGE

The use of ion-exchange at PWRs is more common in recent years because it is simple and reliable. It is also economically competitive with evaporation if the ion-exchange beds are operated beyond boron saturation; i.e., some boron is released to the environment.

LWRs commonly use ion exchange demineralizers to prepare make-up water, purify circulation coolant, and treat waste effluent.

For example, ion exchangers are used in power plants to remove unwanted ions from solutions to ensure that the water used for reactor cooling is as impurity free as practicable. This water has low conductivity and is, therefore, amenable to effective purification by ion exchange.

The use of ion exchange, particularly on untreated streams, is often preceded by some sort of pretreatment such as filtration, organic separation or even reverse osmosis.

Ion exchange evolved from water softening processes, which exchange calcium and magnesium in water for sodium in the ion exchange media. Certain natural clays, particularly the zeolites built on sodium aluminum silicate, exhibit this ability.

Demineralizers remove both entrained and soluble impurities, but are not effective in removing organic materials, insolubles, or colloids except by filtering action. The soluble impurities are removed by ion exchange resins with active sites on the beads. Entrained or suspended solids are removed by filtration or trapping as the water passes between the resin beads. Insoluble gases are not removed, but they can decrease the useful life of the resin.

Ion exchange is a primary method used in LWRs to maintain water quality, but it is restricted to relatively low conductivity liquids. In PWRs demineralizers aid in pH control.

Ion exchange material has the ability to:

- Exchange one ion for another
- Hold it temporarily in chemical combination
- Give it up to a strong regeneration solution

These abilities result from a difference in affinity for various ions in dilute versus concentrated solutions.

Ion exchange demineralizers accumulate the impurities that include radionuclides. Demineralization reduces solution radioactivity and radiation levels from plant piping and equipment carrying reactor cooling water. Therefore, the ion exchangers can become extremely radioactive and require isolation in shielded cubicles. Demineralizers on systems such as BWR condensate become moderately radioactive and are normally shielded as a group.

The resins are a major source of solid radioactive waste in LWRs.

4.7.1 Ion Exchange Resins

Ion exchange resins are insoluble high molecular weight polyelectrolytes that reversibly exchange their mobile ions of equal charge with the surrounding solution.

There are three general classes of ion exchange demineralizer beds. They are:

- Cation
- Anion
- Mixed

Impurities that dissolve in water dissociate to form positively or negatively charged particles.

The positive ions are called cations. Examples of cations are the ions of hydrogen (H^+) and the various metals such as ferrous iron (Fe^{++}) and lithium (Li^+).

The negative ions are called anions. Examples of anions are hydroxide (OH^-) and the various radicals such as borate (BO_3^{--}).

Those exchangers in which the anionic portions are able to react, or are mobile, are anion exchangers; those in which the cationic portion is mobile are cation exchangers. The class of demineralizer depends on the type of resin used in the bed. The mixed bed demineralizer is simply one in which the cation resins and anion resins are intimately mixed. Each resin retains its separate and distinct properties. The cation resin has the ability to remove positively charged ions (cations); the anion resin removes negatively charged ions (anions). If either of the resins is used alone, the demineralizer is named for the type of resin it contains.

Various chemical compounds can be formed by matching the cations and anions. For example, the hydrogen and hydroxyl ions combine to form water and the ferrous ion combines with the hydroxyl ion to form ferrous hydroxide.

Resins used in radioactive liquid waste applications are either in the hydrogen or in the hydroxyl form.

Two other important reactions in a PWR, are the formation of boric acid from hydrogen and borate ions, and of lithium hydroxide from the lithium and hydroxyl ions.

The cation demineralizers in the CVCS of a PWR remove lithium and control cesium-137 activity from fuel defects. These demineralizers are charged with hydrogen base cation exchange resin. When a lithium hydroxide molecule contacts the cation resin, lithium is exchanged for hydrogen in the resin. A similar reaction occurs for cesium.

Cation resins are denser than anion resins. This difference is used to separate mixed beds for regeneration. In mixed beds a third type of bead that is intermediate in density between the anion and cation resins (a buffer or gel type) is sometimes added to assist in defining the boundary between the anion and cation resins during backwashing prior to regeneration.

Deionization with mixed bed ion exchange resins is capable of producing a water of exceptional purity. This technique involves the passage of an aqueous solution through an intimate mixture of a cation resin in the hydrogen form and an anion resin in the hydroxide form.

By using strong acid and strong base resins, known as Type 1, it is possible to consistently produce an effluent having a conductivity of less than 1 μmho at 25 °C.

On occasion, the effectiveness of an ion exchange is impaired by the accumulation of insoluble materials, such as oil, colloids or particulates, on the surface and in the interior of the ion exchange particles.

4.7.2 Ion Exchange Chemistry

Anion resins work in two ways, depending upon their chemical structure. Resins that are called strong bases and which contain quaternary ammonium groups ($(-\text{CH}_2\text{N}(\text{CH}_3)_3\text{OH})$ for example) work in a way that is quite similar to sulfonic acid cation resins. They exchange hydroxide ($-\text{OH}$) ions for other anions, such as chloride (Cl^-) ions.

If this reaction takes place at the same time or subsequent to the cation exchange reaction, pure water is the only product.

The so-called weak base resins come in many different polymeric forms. They may be primary ($-\text{CH}_2\text{-NH}_2$), secondary ($-\text{CH}_2\text{-NH-CH}_2-$), or tertiary ($-\text{CH}_2\text{-N}(\text{CH}_3)_2$) amines, and often contain more than one nitrogen per functional group. They differ from quaternary resins in that they do not actually exchange one ion for another. Instead they pick up acids by a neutralization process. Figure 4.7-1 shows the functioning of an anion resin column.

A cation exchange resin is an insoluble solid that has ionic structures attached to it. These ionic structures are generally referred to as functional groups. The resin most commonly used in radwaste is made by putting together two organic molecules, styrene and divinylbenzene to form a very large three dimensional structure (polymer) and then attaching sulfonic acid groups ($-\text{SO}_3\text{H}$) to its surface. It is the H of the sulfonic acid group that exchanges with ions in the liquid radwaste that passes through it.

There are other cation exchanging structures available, particularly the carboxylic ($-\text{COOH}$) containing polymers and inorganic silicates. These have high selectivity for cations with more than one positive charge (divalent and trivalent ions). They have the disadvantage of having a very high affinity for hydrogen ions. To be effective in a radwaste system, they must be in some salt form, such as a sodium or ammonium form. Thus if water is to be reused, the carboxylic containing polymers and the inorganic silicates must be followed by a bed containing a sulfonic resin in the hydrogen form to remove the sodium or ammonium ions that they liberate. Figure 4.7-2 shows the functioning of a cation resin column.

Figure 4.7-3 shows the functioning of a mixed bed (both anion and cation resin) column.

4.7.3 Factors Affecting Performance

In general, it is desirable to minimize the pressure drop across the resin bed and to maximize the resin bed stability.

Physical and chemical properties of a resin that are important to the performance of an ion exchange system include:

- Exchange capacity
- Ion-exchange kinetics
- Swelling equilibrium
- Degree of cross-linking
- Hydrocarbon network
- Resin particle size
- Ionic selectivity
- Chemical and physical stability

Important operating conditions include:

- Chemical and physical forms of species in the feed solution
- Feed solution temperature, pH and flow rate
- Design/dimensions of the ion-exchange bed
- Level or degree of regeneration

4.7.4 Exchange Capacity

The exchange capacity of resins is expressed in terms of milliequivalents per gram of dry resin, or equivalents per liter of wet resins. The latter is more useful.

The exchange capacity depends on the number of reactive sites on the chain. This, in turn, depends upon the polymer structure, the amount of cross-linking, and the type of reactive group. Various grades are available for differing applications.

In general, strong anion resin capacities are about half that of strong cation resins. A typical strong cation resin capacity is about 2 equivalents per liter of wet resin; whereas, a strong anion resin exchange capacity is in the range of 1 to 1.2 equivalents per liter of wet resin.

Only a portion of the resin exchange capacity can be used because ion exchange is a reversible equilibrium process and cannot be driven to completion when high purity effluent is desired.

4.7.5 Kinetics

The kinetics of the ion exchange process are normally controlled by diffusion of the ion from the solution to an active site of the resin particle. This requires a balance between flow rate and bed depth. Higher flow rates decrease residence time available for diffusion into the resin particle.

To provide the required residence at higher flow rates, deeper beds are necessary. The bed depth can be reduced by using smaller resin beds. However, this results in a higher pressure drop, which combined with the higher pressure drop attributable to high flow rate itself could be unacceptable. In radioactive waste applications the bed-depth varies between one and two feet.

Recommended flow rates for this bed depth are in the range of 5-10 gpm/ft². Flow rates for regeneration types of demineralizers may be in the range of 50 gpm/ft². Lower flow rates also lead to greater processing capacity prior to breakthrough.

4.7.6 Cross-linking

The degree of cross-linking of polymer chains determines:

- Resin solubility
- Mechanical strength
- Amount of water absorption
- Extent of resin swelling

The styrene polymer without cross-linking is not sufficiently rigid. When ion exchange sites are added, they are too water soluble to be a suitable plastic for water treatment. By mixing a certain proportion of divinyl benzene with the polystyrene, cross-links (similar to that in a tire chain) are formed between the strands of styrene. This forms the plastic structure into a three dimensional network that is tighter and more rigid. The percent of divinyl benzene crosslinking governs many of the resin characteristics.

Resins containing low amounts of divinyl benzene, and have a low cross-linking, are softer, more open, wetter resins that exhibit greater swelling. They are resistant to oxidation and chlorine, have good diffusion and high capacity. But they have poor physical and chemical stability.

As the amount of divinyl benzene crosslinkage increases, the resin bead becomes harder and denser. Its water content and resistance to oxidation decreases as well. Higher cross-linkage provides higher chemical stability and affects the ion exchange capacity and rate of ion exchange. Highly cross-linked resins have better mechanical properties but fewer reactive sites and poorer diffusion properties. Those containing 30% or more divinyl benzene are so rigid that they are not useful as an ion exchange media. Resins of interest typically have 4 to 10% cross-linking.

4.7.7 Resin Bead Size

The bead size of regular grade strong acid cation and strong base anion resins commonly used in nuclear applications generally range between 0.4 and 0.7 mm. The use of a small bead size resin increases the capacity of the bed for the same flow rate. Smaller beads have greater physical stability, but a resin with too fine of a bead size produces a high pressure drop through the bed. Larger spheres tend to break during fabrication, regeneration and handling.

The advantage of small particle sizes led to the development of a fine powdered mixture (>90% - 325 mesh) of cation and anion ion-exchange resins. Powdered resins are used to coat the outside surfaces of filter cartridge elements with thin layers (1/8" to 1/2") of resins. In this arrangement, the resin functions both as a filter and as an ion exchanger.

Powdered ion-exchange resins are used in other industries for efficient removal of colloidal silica, iron, copper and nickel. Pressure vessels for this purpose are typically about six-feet in diameter and over six feet high. They hold as many as 300 filter cartridges with a total surface area of about 800 ft². With a 4 gpm feed flow, the pressure drop for fresh resins is from 2 to 5 psi and from 20 to 30 psi for resins near exhaustion. Exhausted powdered resins are not regenerated.

4.8 DEMINERALIZER APPLICATION

LWR's typically use strong-acid cation and strong- base anion ion exchange resins of polystyrene matrix. These resins are routinely used in many large-scale treatment operations. Therefore, experience using these resins is extensive. However, the modes of operation of radioactive waste ion-exchange resins often differ from those in water treatment experience. This is because of the differences in required water quality of the effluent. In radioactive waste systems, very large volumes of water are processed before regeneration or replacement.

A number of BWR's use a finer resin (90% -.03 mm) than is typical of other facilities. These are used in very shallow beds with large surface areas. They function as both a filter and ion exchanger for treatment of primary coolant (RWCU) and steam condensate.

Recycling of effluent through an ion-exchange system does no good if the:

- Resin is loaded or partially loaded
- Distribution coefficient is low for the species being removed
- Species is not in an ion-exchangeable form

4.8.1 Mixed Bed vs. Separate Bed Demineralizers

Most often, mixed-bed units are used; although, separate cation and anion units are common. For example, in PWR's, separate-bed units have been used to process steam generator blowdown, primary coolant, and boron recycle system feed and condensate.

The major advantage of the mixed bed is that it removes both cation and anion impurities from the liquid because it is composed of both cation and anion resins. For example, if a salt such as ferrous iron chloride enters the mixed bed, it contacts both types of resin. The ferrous ion is exchanged for lithium on the cation and the chloride displaces the borate on the anion. Lithium and borate ions are released to solution.

Mixed bed demineralizers contain an intimate mixture of cation and anion resin. In the CVCS, they remove any ionic impurities except lithium hydroxide and boric acid.

The cation resin in this mixed bed is of a lithium form; i.e., the active exchange sites are occupied by lithium atoms rather than hydrogen atoms. As a result the lithium in the resin is not displaced by the lithium in solution, but is displaced by cations that are more strongly attracted to the resin.

The anion resin in this mixed bed starts in the hydroxide form but soon transforms into a borate form by its removal of boric acid from the coolant. Once the anion is saturated with borate, it ceases to remove boric acid from solution but continues to remove other anions such as iodide and chloride.

In addition to being chemically bonded to the resin, some boric acid is absorbed by the resin beads. This occurs until an equilibrium is established with the coolant. If the concentration of boric acid in the coolant is increased, the anion resin absorbs more boric acid; if it is decreased boric acid leaches to the solution to re-establish equilibrium. Unlike boric acid, lithium is not absorbed by the resin.

Mixed bed demineralizers generally contain twice as much anion resin as cation resin. This ensures the bed effluent contains neutral molecules rather than charged ions.

The efficiency and favorable solution ionic equilibrium depends on the cation and anion exchange occurring simultaneously. This depends on the resins being in an intimate mixture. The liquid stream is fed to the top of the bed. Backwashing causes the lighter anion to separate from the heavier cation, and thus reduces the efficiency of subsequent use.

When impurities begin to leak through the bed and ionic contaminants begin to appear in the effluent in significant concentrations (breakthrough) the resin ion exchange capacity is about 80-90% exhausted. It is necessary to discontinue feed and replace, or regenerate, the resin.

High temperature water degrades the resin and must not be passed through the ion exchangers. Because the resins are organic, if operated above 145° F, they break down and foul the reactor cooling system.

A disadvantage of the mixed-bed system is the time required for regeneration. This entails separating the cation and anion resins by flotation, followed by transferring each resin to individual separate regeneration vessels (Some mixed beds can be regenerated in a single vessel). After regeneration, they must be returned to the demineralizer vessel and thoroughly mixed.

Regeneration of a separate-bed is much simpler than a mixed-bed. Separate-bed ion exchangers can be designed to be more contaminant specific than a mixed-bed.

4.8.2 Deborating Demineralizers

The deborating demineralizers in the CVCS of a PWR are anion exchangers and are used to remove boric acid at the end of core life. These have a hydroxide form of resin. When boric acid molecules contact the anion resin, hydroxide in the resin is exchanged for the borate ion. The companion product of this exchange is water.

The deborating demineralizers have the ability to remove other anions, such as chloride and iodide.

Resin has the ability to release the ions that it removes from solution to a strong regeneration solution, thereby reversing the ion exchange process. The deborating, and evaporator condensate, demineralizers are regenerated with sodium hydroxide.

After back washing to remove insoluble particles and loosen the resin bed, sodium hydroxide from the caustic tank is pumped through the demineralizer. This recharges the active sites of the resin with hydroxide and releases the borate, which combines with the sodium to form sodium borate. The sodium borate is a salt that is sent to waste disposal for deposition. After rinsing the resin is ready for use for anion exchange again. Anion exchangers are often called base removal ion exchangers.

4.8.3 Deep Bed Demineralizers

The resin in deep bed demineralizers is typically about three feet thick. If the water has high undissolved solids, differential pressure across the bed limits the demineralizer operation; otherwise, depletion of active exchange sites by soluble impurities control demineralizer service life.

In either case, the demineralizer is removed from service when a limiting condition occurs. The spent resin is then either replaced or regenerated. Normally, if radiation levels are high, it is replaced; if radiation levels are low-to-moderate, it is regenerated.

The regeneration of deep bed demineralizers produces acidic and caustic waste. There must be provisions to handle and process these regenerant wastes.

4.8.4 Filter Demineralizers

Filters can be precoated with a variety of materials. These materials include:

- Powdered ion-exchange resin
- Diatomaceous earth
- Zeolites
- Flocked cellulose fiber

Finely powdered ion exchange resins (Powdex) are the dominant choice in BWR's, particularly for the treatment of equipment and floor drains.

Powdex resin is precoated on septums by similar equipment to that used to precoat filters or by a mixture of powdered resin and a filter medium. This yields a filter-demineralizer.

In certain cases the demineralizer could act as much as a filter as an ion exchanger. For such uses, this arrangement improves filtration without a major loss in ion exchange efficiency (about 90% compared to 99%).

Any drain lines under the filter-demineralizer must be carefully routed and shielded to avoid unwarranted radiation exposure.

4.8.5 Condensate Demineralizer (BWR)

The condensate demineralizer in a BWR maintains the water quality of the coolant in the feedwater. The system varies from plant to plant because either Powdex or Deep Bed Demineralizers are used. This system treats the entire condensate flow at any rate from 0 to 100% of normal flow (18,000 gpm for a 2500 MWt plant).

Flow rates in condensate demineralizers are higher than in other nuclear applications (50 gpm/ft² instead of 5 gpm/ft²). The higher flow rate considerably reduces the size and hence the cost of a unit and the influent from the hotwell condensate is relatively high purity.

4.9 RESIN EXHAUSTION

While the number of active ion exchange sites is very large, they are not unlimited. After prolonged exposure to solution containing impurities, all available sites are filled with ions for which the affinity is high by the exchange process, and the resin is termed "exhausted". It can no longer effectively and efficiently remove and retain the impurities of concern. At this time, impurities begin to leak through the resin bed and it must be replaced, or regenerated. It is undesirable to run a demineralizer until the resin is exhausted because the removal efficiency deteriorates rapidly before complete exhaustion occurs. Therefore, the use of resins is discontinued when the DF is no longer satisfactory.

Methods used to determine exhaustion of resin beds are:

- Monitoring the conductivity of the effluent
- Testing the effluent for breakthrough of a specific ion
- Monitoring the radioactivity of the influent and effluent
- Monitoring pH
- Monitoring pressure drops.

When the pH of a cation resin is high, the efficiency of the resin for removing positive ions decreases. When the pH is low, the efficiency of an anion bed for removing negative ions is reduced. Mixed beds should be replaced when the pH of effluent is not in a specified range.

A new bed has a pressure drop of approximately 5 psi. The pressure drop of a new bed depends upon the bead size of the resin. The smaller the bead, the larger the pressure drop. As the bed becomes clogged with solids removed from the liquid stream, the pressure drop becomes greater. An old bed may have a pressure drop of 20 psi or greater.

4.9.1 Removal of Suspended Solids

The ion exchange process removes ionic impurities from the stream, but not suspended solids. As indicated earlier in this section, demineralizers are effective in removing suspended solids. This is attributable to filtration rather than ion exchange.

Reactor coolant contains suspended solids (crud) consisting of corrosion and erosion products from the various alloys used in the construction of the system that is in contact with the coolant.

Filtration occurs because demineralizer resin beds have the characteristics of a good filter medium. The resin beads are small and closely packed, suspended solids are forced to take tortuous routes through the media. They are unable to penetrate very far into the bed before they are trapped in pore spaces within the bed.

As the surface layer of the resin collects the suspended material it further restricts the movement of suspended solids into the bed. A layer of filtrate develops and further enhances filtration of the insoluble material. As more solids deposit, the dP across the bed increases and the flow rate of water through the bed diminishes. At some point the dP across the bed reaches a point where the bed can no longer be used. It must be regenerated, or discarded.

This collection of suspended materials also leads to channeling and loss of ion exchange capacity or effectiveness.

4.9.2 Ultrasonic Resin Cleaning

In the ultrasonic resin cleaner, the resin moves down the column with ultrasonic transducers mounted on the sides. A flow of demineralized water is pumped up through the column to keep the resin beads suspended and to sweep away crud removed by the cleaning operation.

Ultrasonic cleaning is very effective in removing iron oxide from resin beads. This type of resin cleaning is typically utilized to regenerate condensate polishing demineralizers.

4.10 BWR LIQUID RADWASTE SYSTEM

A diagram of a typical *original* system for processing liquid radioactive waste at a BWR is shown in Figure 4.5-2. Because other processes and their combinations are possible, this reference system should not be interpreted as a standard system.

In a BWR the liquid radwaste system is divided into several subsystems to segregate and process liquid wastes from diverse sources separately. Cross connection between subsystems provides flexibility in handling and processing the various waste streams.

The subsystems of the liquid radwaste system include:

- Waste Collector System
- Floor Drain System

Collection of liquid wastes from the general plant begins in collection tanks and sumps located throughout the plant. The drain sumps are arranged and piped to appropriate radwaste subsystems based on their liquid waste classification.

The input drains to the liquid waste subsystems are:

- Equipment drains
- Floor drains

Some BWRs segregate chemical regeneration wastes from drains and use evaporation to treat the chemical regeneration wastes.

4.10.1 Waste Collector System

High purity (low conductivity) liquid wastes are collected and processed in the Waste Collector System from:

- Drywell Equipment Drain Sumps
- Reactor Building Equipment Drain Sumps
- Radwaste Building Equipment Drain Sump
- Turbine Building Equipment Drain Sumps
- Reactor Water Cleanup Systems
- RHR Cleanup Systems
- RHR Systems
- Decantate from Cleanup Phase Separators
- Decantate from Condensate Phase Separators
- Waste Package Drain Tank
- Off-gas Condensate Collector Sump
- Turbine Building Condensate Pump Pit Equipment Drain Sumps
- Standby Gas Treatment Building Sump

The waste surge tank is large and located outside; therefore, provisions could be required to prevent freezing.

The waste collector and waste surge pumps are identical, each drawing suction from its respective tank. A suction line cross connection and normally closed manual valve allow either pump to draw suction from the opposite tank. Each tank has an indicator with high/low level alarms. A low level pump cutout switch for each tank trips its respective pump and protects the pump in operation.

The waste collector filter is equipped with a precoat holding pump to hold the precoat on the filter tubes when the filter is not in use.

The waste demineralizer is a mixed bed type. Its effluent conductivity is monitored and is automatically routed to the waste sample tanks (if $< 1.0 \mu\text{mho}$) or back to the waste collector or waste surge tank (if $> 1 \mu\text{mho}$). The waste sample tanks serve as a collection and monitoring point for process wastes before returning them to the condensate storage tank. An alternate flow path is available to route water to the discharge canal.

The high purity wastes are processed by filtration and ion exchange and pumped to waste sample tanks for sampling. If satisfactory for reuse, this water is transferred to the condensate storage tank for use as makeup water.

If the liquid waste effluent exceeds conductivity ($> 1 \mu\text{mho}$) or radioactivity ($> 10^{-3} \mu\text{Ci}$) limits for reuse or discharge, it is returned for additional processing. Otherwise, it can be discharged provided that it complies with other requirements of state or federal effluent discharge permits.

4.10.2 Floor Drain Collector System

Low purity (high conductivity) liquid wastes are collected and processed in the Floor Drain Collector System (Figure 4.10-1). These wastes are from:

- Drywell Floor Drain Sumps
- Reactor Building Floor Drain Sumps
- Radwaste Building Floor Drain Sumps
- Turbine Building Floor Drain Sumps
- Turbine Building Condensate Pump Pit Floor Drain Sumps
- Chemical Waste Tank
- RHR Systems
- Radwaste Backwash and Receiver Pit Floor Drain Sump

These wastes are generally low purity and have low concentrations of radioactive impurities; therefore, processing consists of filtration and subsequent transfer to the floor drain sample tanks.

4.10.3 Waste Demineralizer

The waste demineralizer is a vertical cylindrical dished head pressure vessel with a conical bottom. It contains about 125 ft^3 of mixed cation and anion resins. It is sized to provide adequate head space for mixing and settling replacement resins.

After filtration, the liquid waste water enters the demineralizer at the top and is distributed across the resin bed by an inlet header with multiple header sprays. The demineralized water is collected in a stainless steel underdrain and discharges through the bottom of the demineralizer.

If its conductivity is below limits (1.0 μmho), the water is directed to a waste sample tank. If not, it is returned to a waste collector tank.

When required, new resins are added via a resin fill line. Spent resins are slurried to the spent resin tank using air pressure applied to the top of the demineralizer vessel. Resins can be regenerated, but the trend appears away from regeneration.

4.10.4 Instrumentation and Controls

Control of the liquid radwaste system is from the radwaste control room panel. Instrumentation is provided to monitor and control the process equipment and for detection of abnormal conditions.

While this instrumentation is supplemented by local instrumentation and readouts, centralized control from the main radwaste panel provides better and more complete information.

4.11 PWR LIQUID WASTE PROCESSING SYSTEM DESCRIPTION

The function of the PWR Liquid Waste Processing System is to collect, segregate, and process the reactor-grade and other liquid wastes generated by operations, refueling, and maintenance. A diagram is shown in Figure 4.5-1.

The liquid radwaste system is designed with sufficient capacity, redundancy and flexibility to ensure that under reasonably anticipated conditions functional requirements of the system are met. It consists of:

- Reactor coolant drain tank and pumps
- Chemical drain tank and pumps
- Tritiated drain collector tank filter and pumps
- Sump tanks and pumps
- Floor drain collector tank and pumps
- Waste condensate tanks and pumps
- Associated instrumentation and controls

This system begins at the interfaces with the reactor coolant pressure boundary and the interface valve(s) in lines from other systems, or at those sumps and floor drains provided for liquid waste with potential of containing radioactive material. It terminates at the point of:

- Controlled discharge to the environment
- Interface with the Waste Solidification System
- Recycle back to storage for reuse

Provisions are made to sample and analyze fluids and based on laboratory analysis, these wastes are recycled for reuse, released under controlled conditions via the Cooling Water System, or retained for further processing.

The Liquid Radioactive Waste Processing System is arranged to recycle and reuse as much reactor grade water entering the systems from the Reactor Coolant System (RCS) as possible by processing this water through the Boron Recovery System.

Overall the liquid waste processing system is designed to separate the vent and drain effluent from the Reactor Coolant System and its associated subsystems to handle the different sources of water in two categories:

- Reactor-grade stream
- A non-recyclable stream

Normally the recyclable liquid is composed of all tritiated effluent; the non-recycled liquid contains little or no tritium.

Equipment and components within the Liquid Radioactive Waste Processing System are located and arranged to reduce radiation exposure to plant personnel during operation and maintenance.

Process equipment is located and arranged to provide space for removal and replacement of components and the equipment itself. Process subsystems are arranged to reduce the length of piping runs. Process equipment such as filters, ion exchangers and evaporators are located in individual cells. Equipment design that facilitates rapid disconnect for removal and replacement or ease of in-place maintenance is generally used.

4.11.1 Reactor Grade Water (Recycle)

One channel collects all recyclable effluent and separates them into aerated and non-aerated streams. This channel transfers liquids directly to the reactor coolant drain tank for processing and recovery by the CVCS from:

- Reactor coolant loops
- Pressurizer relief tank
- Reactor coolant pump secondary seals
- Excess letdown during startup
- Accumulators
- Valve and reactor vessel flange leakoffs
- Refueling canal drains

The water from these sources is high grade water containing tritium and can be readily recovered as reactor grade water.

The bulk of the radioactive liquids discharged from the RCS are processed by the CVCS recycle train. Therefore, only relatively small quantities of low-activity water are sent to the liquid radwaste system.

The recycle section processes reactor grade water that enters the Liquid Radioactive Waste Processing System.

Considerable surge and processing capacity is incorporated in the recycle portion of the Liquid Radioactive Waste Processing System to accommodate abnormal operations; e.g., leaks that develop in the reactor coolant and auxiliary systems.

Non-reactor grade liquids are processed by the second subsystem and disposed in compliance with prevailing regulations and regulatory guidance. This subsystem is often referred to as the liquid radwaste system.

4.11.2 Waste Water

The liquid radwaste portion of the system collects water of lower quality and also lower radioactivity and only small amounts of tritium. This is non-reactor grade or waste water. It includes:

- Steam generator blowdown
- Secondary system wastes.

During normal operations, this part of the PWR Liquid Waste Processing System processes liquids from:

- Equipment drains and leaks
- Demineralizer flushing and backwashing
- Sampling system

Non-reactor grade wastes have various levels of suspended solid content. They are generally filtered, then evaporated and/or demineralized, depending on the quality of the waste and degree of processing desired.

The liquid waste processing system also provides for handling and storage of spent-ion exchange resins.

Primary water from the sample room sinks and from equipment drain to a waste hold-up tank. Other aerated drainage is collected and pumped to the waste holdup tank for processing. Therefore, the waste holdup tank is the initial collection point for aerated recyclable liquids.

The non-recyclable waste stream collects effluent from the primary plant that is unacceptable for reuse because of chemical makeup, etc. Solid constituents are normally concentrated and prepared for shipment to a licensed radioactive waste burial site. The water is processed sufficiently to make it suitable for discharge into a nearby waterway.

Newer designs use four process steps for treatment of miscellaneous waste streams:

- Filtration
- Carbon adsorption
- Ion exchange

Filtration removes the bulk of the suspended solids. The activated carbon bed removes organic contaminants and some fine suspended solids. The ion exchangers, operated in a boron saturated mode, remove most of the remaining activity and dissolved trace contaminants. The evaporator is used to polish the waste and remove boron.

4.11.3 Floor Drains

Liquids entering the floor drain collector tank are usually non-detergent wastes. These are processed in the miscellaneous waste system. The volume is small and the radioactivity is often below permissible discharge limits.

The water in the floor drains is sampled and analyzed to determine its fate. It is routed to the waste monitor tank for floor drains either directly or through a demineralizer.

The containment sump is normally drained to the floor drain tank. However, if sample analyses indicate high water quality in the sump, it can be routed to the waste holdup tank for recycling.

After sufficient processing, the water is discharged into the plant effluent stream at a rate consistent with available dilution capacity.

Normally the tank can be discharged without treatment other than filtration.

4.12 COMMERCIAL SYSTEMS

Attachments 4-1 through 4-9 at the end of this chapter show several commercially available systems that have been purchased or rented by LWRs for processing of liquid radioactive waste. Generally these systems are used in the floor drain processing system in lieu of originally installed processing equipment (such as waste evaporators).

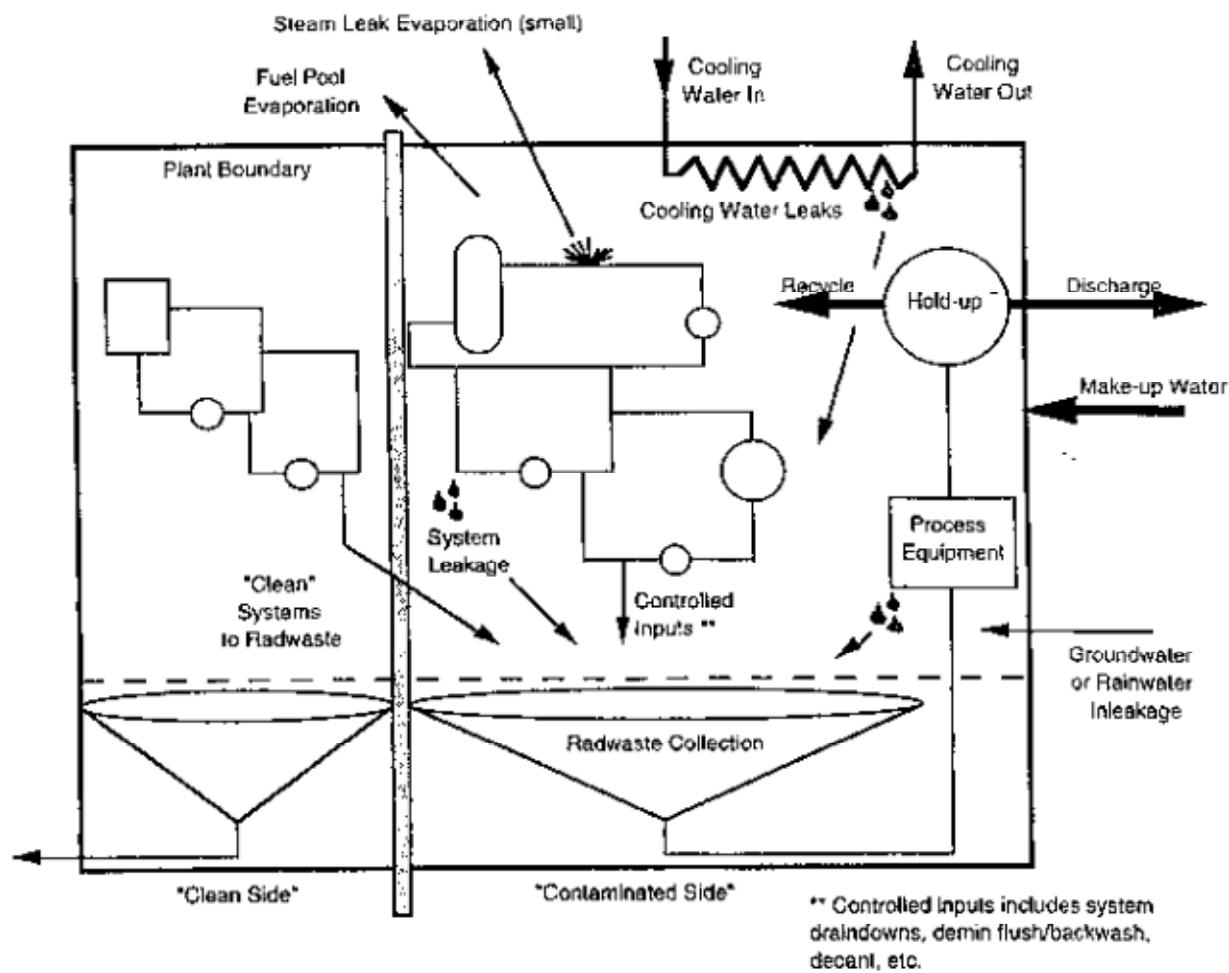


Figure 4.1-1 Water Management Sources and Losses

| <u>Waste Category</u> | <u>Waste Description</u> |
|--------------------------------|---|
| Salt Solutions | Concentrated salts or mixtures of salts, including Na_2SO_4 , H_3BO_3 , $\text{Na}_2\text{B}_2\text{O}_7$, $(\text{NH}_4)_2\text{SO}_4$, miscellaneous decontamination agents |
| Precipitates and Slurries | Filter/demineralizer sludges consisting of powdered ion exchange resins, cellulosic filter aids, diatomaceous earth (primarily used in BWRs) |
| Surfactant/Detergent Solutions | Concentrated laundry wastes, surfactant-containing decontamination agents |
| Organic Liquids | Lubricants, hydraulic fluids, laboratory solvents (these may be included with miscellaneous aqueous wastes) |
| Wet Particulates | Bead resins, cation and anion |

Source: G. Trigilio, Volume Reduction Techniques in Low-Level Radioactive Waste Management (NUREG/CR-2206), Sept. 1981.

Table 4.1-1: Source and Description of Wet or Liquid Low-Level Radioactive Wastes

| Expected Daily Average Inputs, gal/d | | | | | |
|---|---|--|--|--|------------------|
| | Plant with Deep Bed Demineralizers and Percentage of Primary Ultrasonic Resin Cleaner ^b | Plant with Deep Bed Demineralizers and no Ultrasonic Resin Cleaner ^b | Plant Using Filter- Demineralizers ^b (Powdered Resin) | Plant with Blowdown Treatment; Product not Recycled to Condenser or Secondary Coolant System | Coolant Activity |
| <u>Sources^a</u> | | | | | |
| <u>Reactor Containment</u> | | | | | |
| Primary coolant pump seal leakage | 20 | 20 | 20 | 20 | 10 |
| Primary coolant leakage, miscellaneous sources | 10 | 10 | 10 | 10 | 167 |
| Primary coolant equipment drains | 500 | 500 | 500 | 500 | 0.1 |
| <u>Primary Coolant Systems (Outside of Containment)</u> | | | | | |
| Primary coolant system equipment drains | 80 | 80 | 80 | 80 | 100 |
| Spent fuel pit liner drains | 700 | 700 | 700 | 700 | 0.1 |
| Primary coolant sampling system drains | 200 | 200 | 200 | 200 | 5 |
| Auxiliary building floor drains | 200 | 200 | 200 | 200 | 10 |
| <u>Secondary Coolant Systems</u> | | | | | |
| Secondary coolant sampling systems drains | 1,400 | 1,400 | 1400 | 1400 | 0.01 |
| Condensate demineralizer rinse and transfer solutions | 3,000 | 12,000 | --- | --- | 1E-06 |
| Condensate demineralizer regenerant solutions | 850 | 3,400 | --- | --- | ^c |
| Ultrasonic resin cleaner solutions | 15,000 | --- | --- | --- | 1E-04 |
| Condensate filter-demineralizer backwash | --- | --- | 8,100 | --- | 2E-04 |
| Steam generator blowdown | --- | --- | --- | --- | --- |
| Turbine building floor drains | 7,200 | 7,200 | 7,200 ^a | 7,200 | ^c |
| <u>Detergent and Decontamination Systems</u> | | | | | |
| On-site laundry facility | 300 (1,130) | 300 (1,130) | 300 (1,130) | 300 (1,130) | Negligible |
| Hot showers | Negligible | Negligible | Negligible | Negligible | ^d |
| Hand wash sink drains | 200 (760) | 200 (760) | 200 (760) | 200 (760) | ^d |
| Equipment and area decontamination | 40 (150) | 40 (150) | 40 (150) | 40 (150) | |

Totals

a These data should be supplemented by the use of known or expected flows and activities from other sources.

b Deep-bed condensate demineralizers.

c Filter-demineralizer (powdered resin) condensate demineralizer.

d Calculated by Gale Code.

SOURCE: Radioactive Waste Technology, A.A. Moghissi, H.W. Godbee, S.A. Hobart, The American Society of Mechanical Engineers, New York, NY, 1986

Table 4.3-1: PWR Liquid Waste Flow Rates and Activities

| Sources ^a | Plant With Ultrasonic Resin Cleaner gallons | Expected Daily Plant Without Ultrasonic Resin Cleaner gallons | Average Inputs, Percentage of Primary Coolant Activity gal/d |
|--|--|---|--|
| <u>Equipment Drains</u> | | | |
| Drywell | 3,400 | 3,400 | 100 |
| Containment, auxiliary building and fuel pool | 3,700 | 3,700 | 10 |
| Radwaste building | 1,100 | 1,100 | 10 |
| Turbine building | 3,000 | 3,000 | 0.1 |
| Ultrasonic resin cleaner | 15,000 | ---- | 5 |
| Resin rinse | 2,500 | 5,000 | 0.2 |
| Subtotal | 28,700 | 16,200 | --- |
| <u>Floor Drains</u> | | | |
| Drywell | 700 | 700 | 0.1 |
| Containment, auxiliary building and fuel pool | 2,000 | 2,000 | 1 |
| Radwaste building | 1,000 | 1,000 | 1 |
| Turbine building | 2,000 | 2,000 | 1 |
| Subtotal | 5,700 | 5,700 | --- |
| <u>Cleanup Phase</u> | | | |
| Separator Decant | 640 | 640 | 0.2 |
| Laundry Drains | 1,000 | 1,000 | --- |
| Laboratory Drains | 500 | 500 | 2 |
| Regenerants ^b | 1,700 | 3,400 | d |
| Condensate Demineralizer Backwash ^c | | 3,100 | 2E-04 |
| Chemical Laboratory Waste | 100 | 100 | 2 |
| Totals | 38,340 | 35,650 | --- |

^a These data should be supplemented by the use of known or expected flows and activities from other sources.

^b Deep-bed condensate demineralizers.

^c Filter-demineralizer (powdered resin) condensate demineralizer.

^d Calculated by Gale Code.

SOURCE: Radioactive Waste Technology, A.A. Moghissi, H.W. Godbee, S.A. Hobart, The American Society of Mechanical Engineers, New York, NY, 1986.

Table 4.3-2: BWR Liquid Radwaste Flow Rates and Activities

| <u>Activation Products</u> | <u>μCi/ml</u> | <u>Non-Volatile Fission Products</u> | <u>μCi/ml</u> |
|--|---------------|--|---------------|
| Mn-54 | 3.64(-4) | Y-90 | 9.4(-5) |
| Mn-56 | 7.85(-2) | Sr-91 | 1.15(-3) |
| Co-58 | 1.09(-2) | Y-91 | 4.4(-3) |
| Fe-59 | 2.52(-4) | Y-92 | 4.06(-3) |
| Co-60 | 1.29(-3) | Zr-95 | 5.22(-4)) |
| Cr-51 | 8.10(-5) | Nb-95 | 5.19(-4) |
| | | Zr-97 | 1.60(-5) |
| <u>Gaseous Fission Products</u> | | Mo-99 | 1.97 |
| Kr-85 | 4.21 | Ru-105 | 4.5(-4) |
| Kr-85 | 1.01 | I-131 | 1.50 |
| Kr-87 | 0.693 | Te-132 | 1.65(-1) |
| Kr-88 | 2.49 | I-132 | 5.54(-1) |
| Xe-133 | 1.66(-2) | I-133 | 2.42 |
| Xe-135 | 4.57 | Te-134 | 1.86(-2) |
| Xe-138 | 3.18(-1) | I-134 | 3.40(-1) |
| | | Cs-134 | 1.60(-1) |
| <u>Non-Volatile Fission Products</u> | <u>μCi/ml</u> | I-135 | 1.30 |
| H-3 | 2.5 (max) | Cs-136 | 1.30(-2) |
| Br-84 | 2.6(-2) | Cs-137 | 8.69(-2) |
| Rb-88 | 2.48 | Cs-138 | 4.44(-2) |
| Rb-89 | 5.8(-2) | Ba-140 | 5.37(-4) |
| Sr-89 | 2.5(-3) | La-140 | 5.53(-4) |
| Sr-90 | 7.5(-5) | Ce-144 | 1.91(-3) |
| | | Pr-144 | 2.06 |

Table 4.3-3: Reactor Coolant Water Equilibrium Activities in a PWR (Coolant Temperature 583°F)

Volatile Activation Products

| | |
|------|----------|
| F-18 | 4.00(-3) |
| N-13 | 3.70(-2) |
| N-16 | 5.30(+1) |

Non-Volatile Activation Products

| | |
|---------|----------|
| Ag-110m | 6.0(-5) |
| Co-58 | 5.0(-3) |
| Co-60 | 5.0(-4) |
| Cr-51 | 5.0(-4) |
| Cs-134 | 5.45(-5) |
| Cs-136 | 3.64(-5) |
| Cs-137 | 6.24(-5) |
| Cs-138 | 7.54(-2) |
| Fe-59 | 8.0(-5) |
| Mn-54 | 4.0(-5) |
| Mn-56 | 5.0(-2) |
| Na-24 | 2.0(-3) |
| Ni-65 | 3.0(-4) |
| P-32 | 2.0(-5) |
| W-187 | 3.0(-3) |
| Zn-65 | 2.0(-6) |
| Zn-69m | 3.0(-5) |

Fission Products

| | |
|---------|----------|
| Br-83 | 5.0(-3) |
| Br-84 | 1.0(-2) |
| Br-85 | 6.76(-3) |
| Ba-139 | 6.24(-2) |
| Ba-140 | 3.12(-3) |
| Ba-141 | 7.02(-2) |
| Ba-142 | 6.76(-2) |
| Ce-141 | 1.38(-5) |
| Ce-143 | 1.22(-5) |
| Ce-144 | 1.22(-5) |
| I-131 | 4.68(-3) |
| I-132 | 4.42(-2) |
| I-133 | 3.12(-2) |
| I-134 | 9.10(-2) |
| I-135 | 4.68(-2) |
| Mo-99 | 7.80(-3) |
| Nb-95 | 1.43(-5) |
| Nd-147 | 4.94(-6) |
| Np-239 | 3.3(-1) |
| Pr-143 | 1.33(-5) |
| Ru-103 | 6.76(-6) |
| Ru-106 | 9.10(-7) |
| Sr-89 | 1.0(-3) |
| Sr-90 | 8.0(-5) |
| Sr-91 | 2.50(-2) |
| Sr-92 | 4.16(-2) |
| Tc-99m | 1.04(-1) |
| Tc-101 | 5.46(-2) |
| Te-129m | 1.38(-5) |
| Te-132 | 1.69(-2) |
| Zr-95 | 1.8(-5) |
| Zr-97 | 1.4(-5) |

Table 4.3-4: Reactor Coolant Activitiy Concentration in a BWR (in $\mu\text{Ci/mL}$ @ full power)

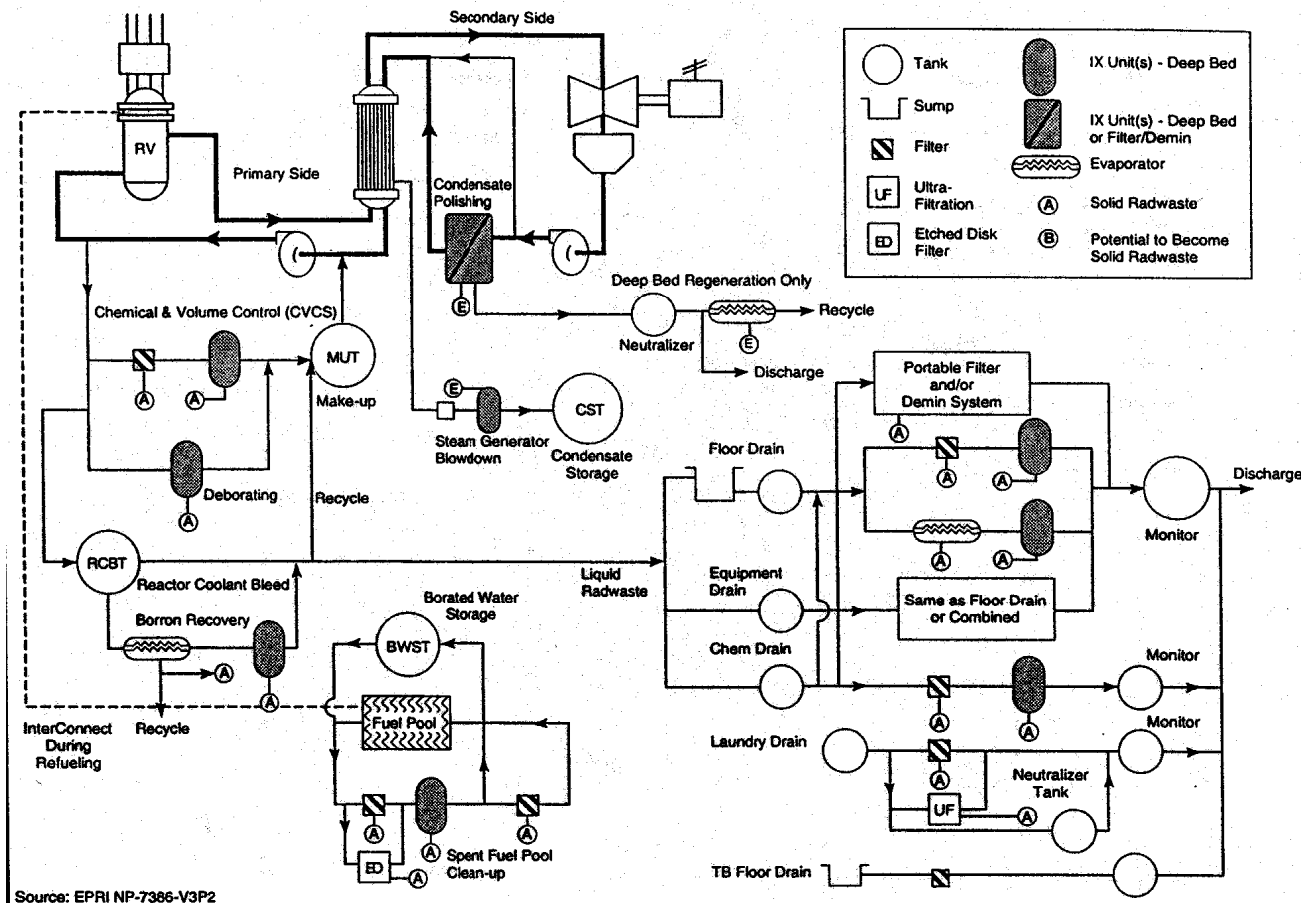


Figure 4.5-1 Typical PWR Liquid Waste Processing System

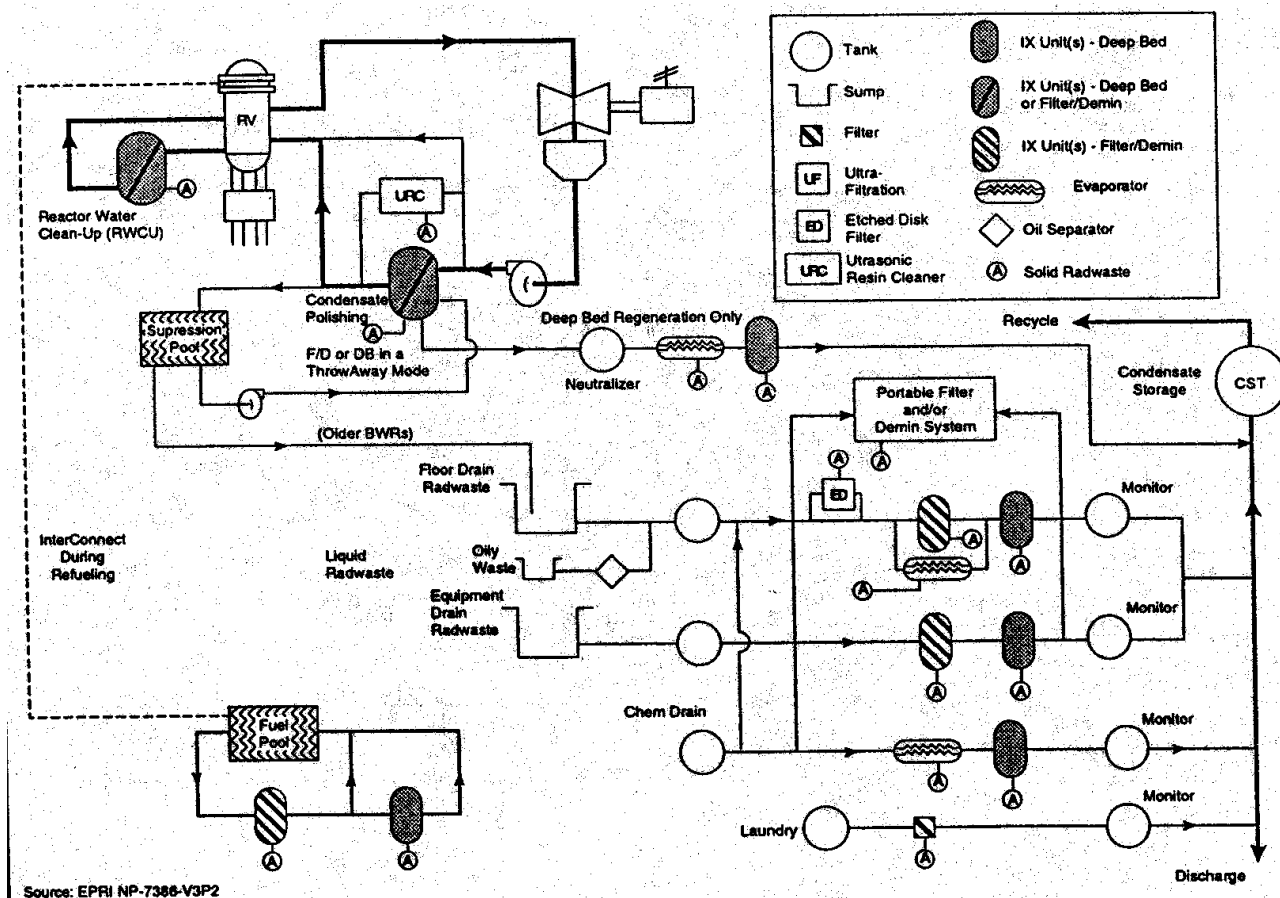


Figure 4.5-2 Typical BWR Liquid Waste Processing System

Table 4.5-1: Commercially Available Ion-Exchange Media

| Model | Description |
|-----------|--|
| CN-100 | Specialty Grade hydroxyl form strong base, low in chloride and fines, 1.2 meq/ml |
| CN-150 | Specialty Grade macroporous resin in hydroxyl form, low in chlorides and fines, 1.15 meq/ml |
| CN-160 | Strongly basic, Type I, macroreticular anion exchange resin, 3.8 meq/g dry |
| CN-170 | Specialty Grade, macroreticular, low in chlorides and fines, for protection against organic fouling, 1.2 meq/ml |
| CN-200 | Specialty Grade, low in chloride resin for sodium and fines, 1.9 meq/ml |
| CN-250 | Specialty Grade, low in chloride and fines, 1.9 meq/ml |
| CN-300-11 | Specialty Grade hydrogen/hydroxyl form mixed bed resin, low in sodium and fines, 1:1 equivalent ratio. |
| CN-400-12 | High Grade, coconut-based filtration carbon. |
| CN-400-20 | High Grade, coconut-based filtration carbon used for removal of oil, organics and solids. |
| CN-400-30 | High Grade, high capacity, nut-based activated carbon, fine grade for the removal of organics and solids. |
| CN-500 | A specialty grade exchange medium for the removal of cesium, with low specificity for sodium and lithium. |
| CN-600X | A specialty grade experimental water processing media, developed specifically to remove EHC residuals. Concentrations of 50 ppm is temporarily upper limit. |
| CN-700X | A specialty grade, water processing media, developed specifically to remove antimony (Sb) residuals. Limitations in use include: |
| CN-D-70 | Specialty Grade patented Durasil ion specific carbon-based sorption/cation exchange medium for removal of cobalt and other metals, especially in the presence of high levels of sodium, potassium and magnesium. |
| CN-D-230 | Specialty Grade Durasil ion specific inorganic oxide based cation (sodium) exchange medium for removal of cesium, with low specificity for sodium and lithium. |
| CN-D-261 | Specialty Grade Durasil ion specific carbon based anion (nitrate) exchange medium for removal of iodine. |

Table 4.5-1 (Continued)

| | |
|------|---|
| -10 | Specialty Grade ion specific glass-based cation (sodium) exchange medium with high specificity for cesium, cobalt, manganese and strontium, and low specificity for sodium and lithium. |
| -60 | A carbon based sorption/ion exchange medium for removal of molecular, organic and dissolved iodine. |
| -190 | Specialty Grade ion specific glass-based cation (sodium) exchange medium that replaced Durasil-10 with higher capacity for cesium. |
| -231 | Specialty Grade ion specific inorganic oxide-based cation (sodium) exchange medium for removal of cesium. |
| -260 | Specialty Grade ion specific carbon based anion exchange medium for removal of iodine. |
| -460 | Specialty Grade ion specific inorganic oxide based anion exchanger with high specificity for radioactive iodine. |

INLET:

| TK PA 5/96 | 6/96 | 7/96 | 8/96 | 9/96 | 10/96 | 11/96 | 12/96 | 1/97 | 2/97 | |
|------------|-------|-------|-------|-------|-------|-------|-------|-------|------|-------|
| 1A TOC | 131 | 221 | 661 | 368 | 375 | 293 | 222 | 292 | 306 | 130 |
| COND | 1.25 | 1.97 | 0.972 | 1.16 | 2.21 | 2.32 | 1.31 | 1.90 | 3.14 | 1.73 |
| SILICA | 29.70 | 45.30 | 252.0 | 525.0 | 24.2 | 88.8 | 46.2 | 39.6 | 42.3 | 80.5 |
| 1B TOC | 187 | 203 | 207 | 644 | 527 | 188 | 117 | 186 | 209 | 268 |
| COND | 2.23 | 2.04 | 0.952 | 1.19 | 1.89 | 2.53 | 1.51 | 2.17 | 2.09 | 1.90 |
| SILICA | 22.30 | 54.90 | 248.0 | 126.0 | 21.8 | 132.0 | 34.8 | 46.8 | 43.0 | 51.4 |
| 1C TOC | 117 | 174 | 105 | 249 | 414 | 196 | 178 | 212 | 149 | 171 |
| COND | 2.48 | 1.37 | 0.96 | 1.19 | 1.98 | 1.69 | 1.68 | 1.87 | 2.24 | 1.97 |
| SILICA | 25.5 | 40.6 | 152.0 | 79.0 | 25.2 | 103 | 44.8 | 43.7 | 35.3 | 59.3 |
| 2A TOC | 598 | 909 | 896 | 606 | 1649 | 3122 | 829 | 609 | 749 | 1144 |
| COND | 39.0 | 29.6 | 25.6 | 8.84 | 146.0 | 324.0 | 60.4 | 21.8 | 88.9 | 139.0 |
| SILICA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| 2B TOTO | 574 | 781 | 801 | 1046 | 2785 | 2819 | 767 | 1348 | 719 | 1312 |
| COND | 54.4 | 16.1 | 23.0 | 13.5 | 28.1 | 82.4 | 35.0 | 315.0 | 70.9 | 177.0 |
| SILICA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |

AVERAGES:

| | | | | | | | | | | |
|--------|-------|-------|-------|-------|--------|--------|-------|-------|-------|-------|
| TOC | 321.4 | 457.6 | 534.0 | 582.6 | 1150.0 | 1323.6 | 422.6 | 529.4 | 426.4 | 605.0 |
| COND | 19.9 | 10.2 | 10.3 | 5.18 | 180.2 | 82.6 | 20.0 | 64.2 | 33.5 | 64.3 |
| SILICA | 25.8 | 46.9 | 217.3 | 243.3 | 23.7 | 107.9 | 41.9 | 43.4 | 40.2 | 57.1 |

EFFLUENT:

| TK PA 5/96 | 6/96 | 7/96 | 8/96 | 9/96 | 10/96 | 11/96 | 12/96 | 1/97 | 2/97 | |
|------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| 4A TOC | 77.4 | 99.4 | 62.5 | 152 | 197 | 79.4 | 85.3 | 88.6 | 85.4 | 75.9 |
| COND | 0.563 | 0.59 | 0.585 | 0.561 | 0.563 | 0.574 | 0.608 | 0.643 | 0.641 | 0.682 |
| SILICA | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.62 | 5.0 | 5.11 | 8.46 | 5.0 |
| 4B TOC | 80.8 | 97.1 | 76.5 | 133.0 | 178.0 | 89.3 | 80.6 | 55.4 | 89.4 | 66.1 |
| COND | 0.569 | 0.568 | 0.576 | 0.560 | 0.569 | 0.569 | 0.612 | 0.661 | 0.639 | 0.664 |
| SILICA | 5.0 | 5.1 | 5.0 | 5.0 | 5.0 | 5.03 | 5.0 | 5.0 | 6.0 | 5.0 |
| 5A TOC | 75.5 | 97.7 | 52.1 | 124.0 | 3425 | 70.1 | 58.4 | 67.1 | 76.5 | 80.1 |
| COND | 0.575 | 0.681 | 0.597 | 0.550 | 0.648 | 0.592 | 0.664 | 0.617 | 0.649 | 0.685 |
| SILICA | 5.0 | 5.12 | 5.0 | 5.0 | 5.0 | 5.32 | 5.0 | 5.17 | 25.8 | 5.0 |
| 5B TOC | 71.2 | 63.2 | 59.0 | 130.0 | 332.0 | 69.4 | 61.3 | 67.0 | 76.3 | 52.2 |
| COND | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| SILICA | 5.0 | 5.09 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 31.4 | 5.0 |

TOC = ppb
COND umho/cm
Silica = ppb

Table 4.5-2 Effectiveness of an Ion Exchange/Reverse Osmosis System

| Type of filter | Advantages | Disadvantages |
|---|---|--|
| Disposable Wound cartridge | Compact; low solid waste volume; no backflush gas or liquid to treat; good solids removal | Remote and/or automatic change out difficult because of nonuniformity and poor arrangement; change out frequently done on radiation level rather than pressure drop; media migration may occur |
| Pleated paper cartridge | Compact; low solid waste volume; no backflush gas or liquid to treat; good solids removal | Remote and/or automatic change out difficult because of nonuniformity and poor arrangement; change out frequently done on radiation level rather than pressure drop; media migration may occur |
| Pleated wire screen | Can operate at elevated temperatures; good solids removal; little or no media migration | Fair mechanical strength when adequately supported; plugging may cause uneven flow and nonuniform cake buildup |
| Reusable without precoat Stacked etched disk | Short backflush time with thorough cleaning; expected to last for plant life; amenable to automatic and/or remote operation; low solid waste volume; compact; high mechanical strength | Low crud-holding capability; corrosion characteristics unknown; backwash waste to treat; low oil-holding capacity |
| Reusable with precoat Backflushable tubular bundle | Amenable to automatic and/or remote operation; powdered resin and/or diatomaceous earth precoat can be used; relatively compact | Precoat loss on loss of flow or fluctuation in pressure; excessive or uneven cake can cause strain and possible collapse of supporting screen; incomplete back flushing causes uneven precoat |
| Dry cake discharge Centrifugal discharge | High crud-holding capacity; can handle automatically and remotely all plant wastes with same filter; low maintenance requirements; no precoat loss caused by loss of flow, pressure, or power | Relatively high headroom; cake overloading can cause distortion; generates large sludge volume; some cake difficulty with Solka floc or resins alone |
| Flat bed | High crud-holding capacity; can handle automatically and remotely all plant wastes with same filter; no precoat loss caused by loss of flow, pressure, or power | Relatively large floor space and high headroom; cake overloading can cause belt wear; generates large sludge volume; some cake difficulty with resin alone; may require fairly high belt maintenance |

Source: Radioactive Waste Management, Table 6.15. Yang, Y. S. and James H. Saling. Hemisphere Publishing Corporation. New York, NY, 1990. Originally from Low-Level Radioactive Waste Treatment Technology by EG&G Idaho, Inc., National Low-Level Radioactive Waste Management Program, DOE/LLW 13 Tc, 1984, U.S. DOE.

Table 4.6-1: Potential Advantages and Disadvantages of Filters for Liquids in LWR

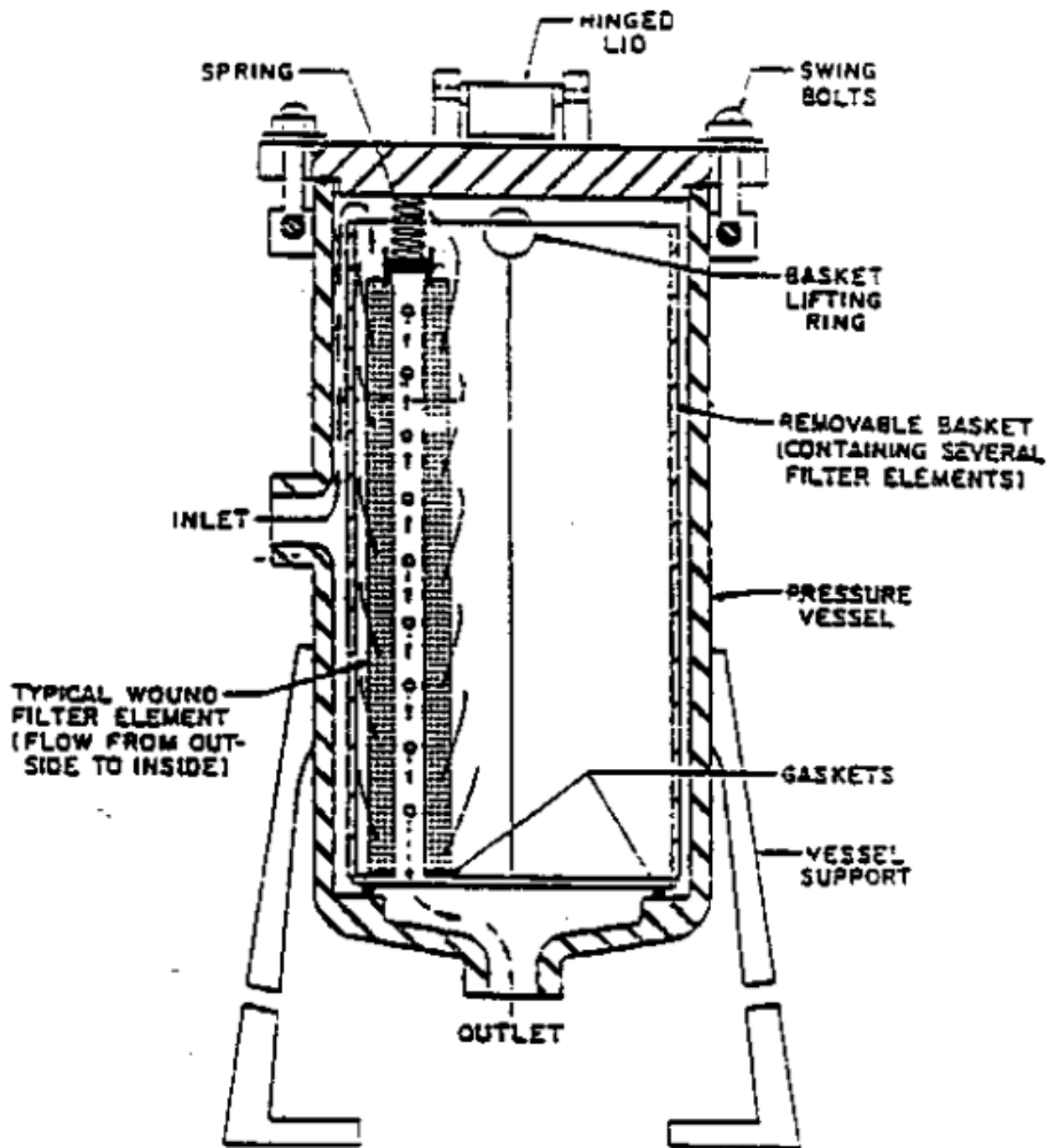


Figure 4.6-1 Typical Disposal Cartridge Filter Illustrating Liquid Flow from Outside to Inside of Element

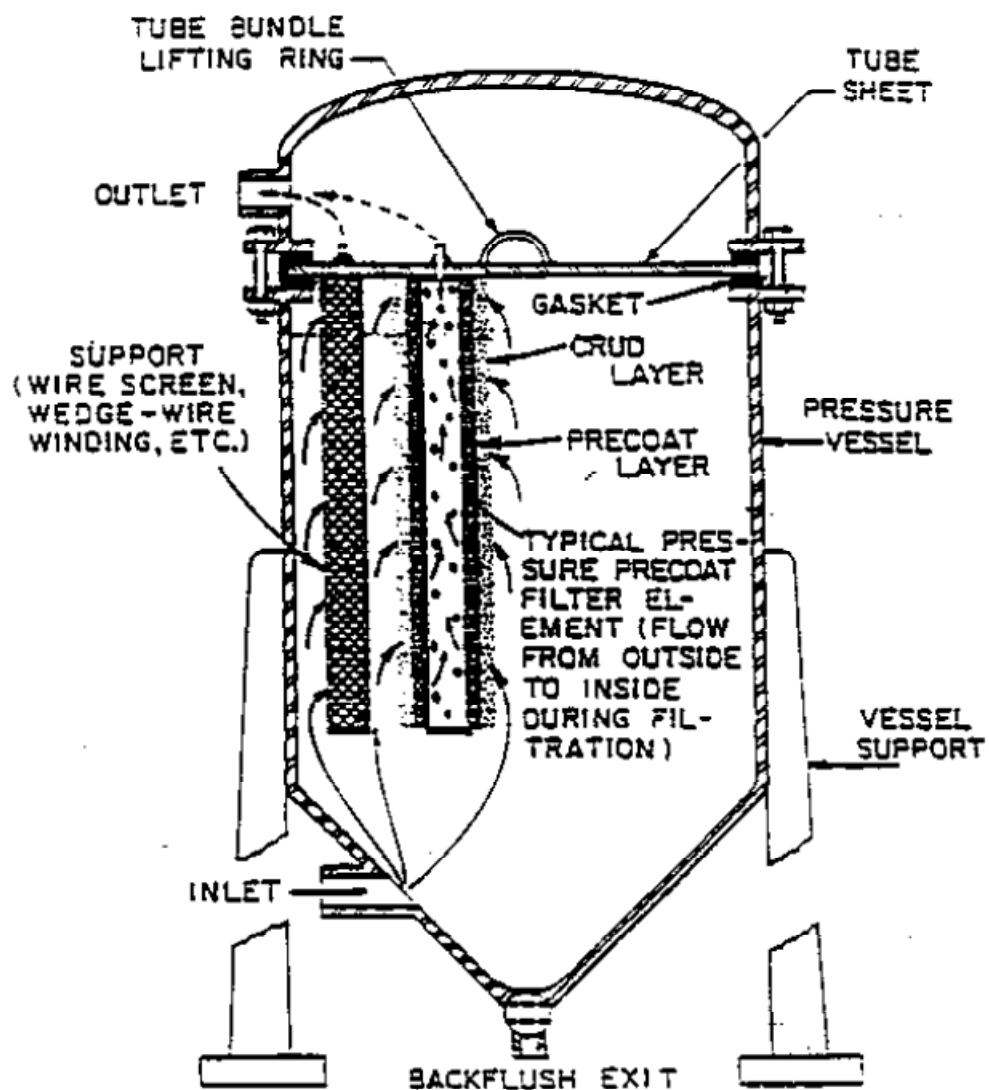


Figure 4.6-2 Typical Tubular-Support Pressure Precoat Filter

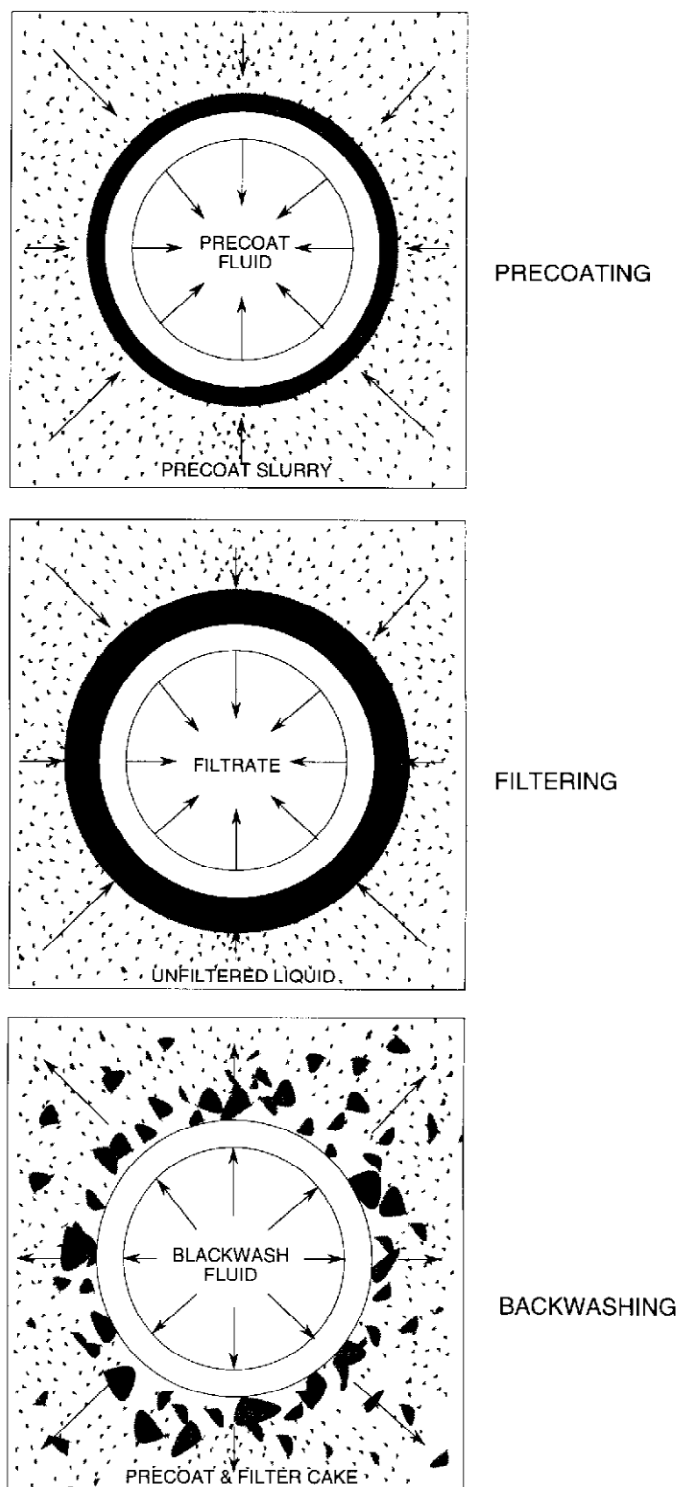


Figure 4.6-3 Precoat Filter Operation

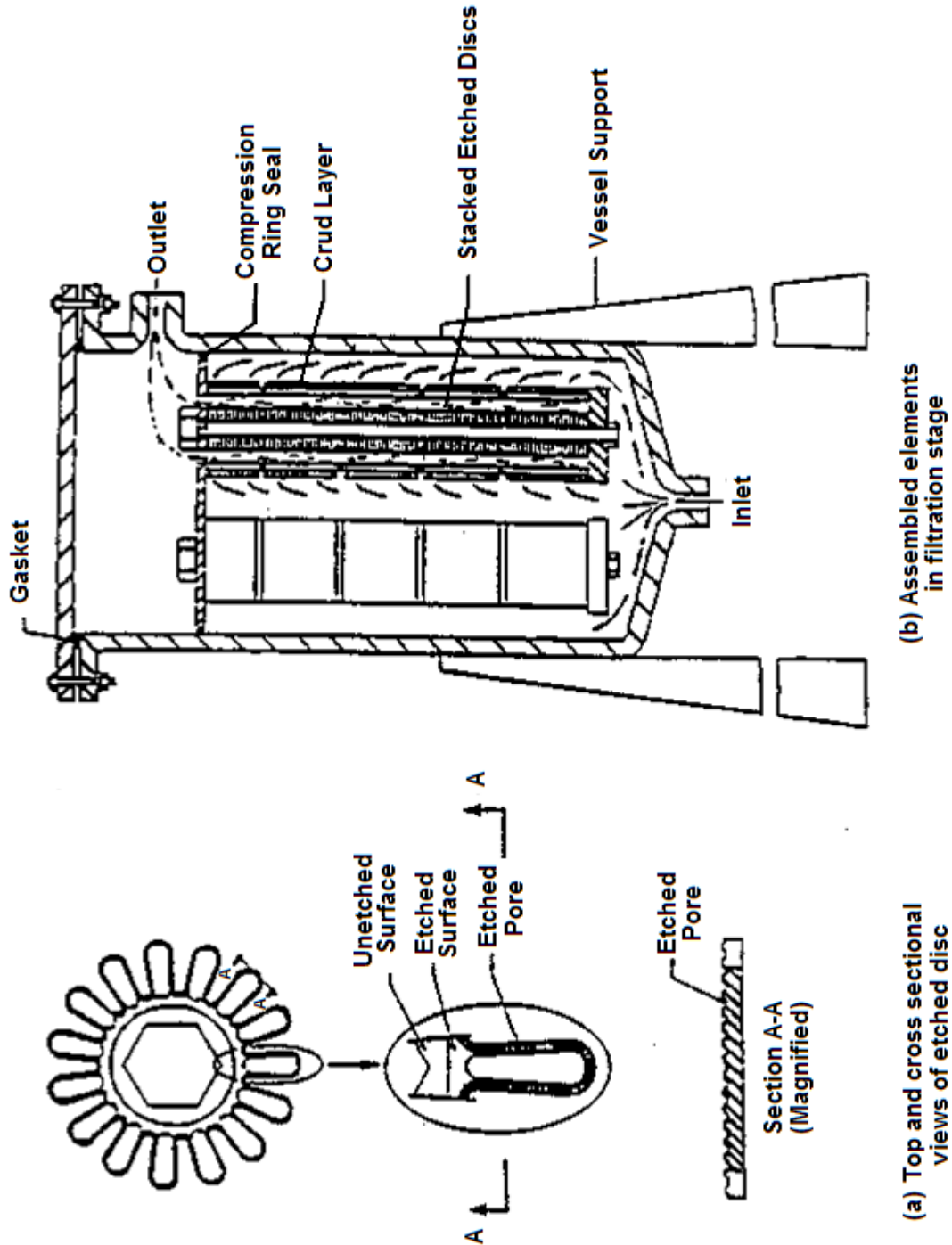


Figure 4.6-4 Views of Etched Disc and Schematic of a Typical Etched-Disc or Edge Filter

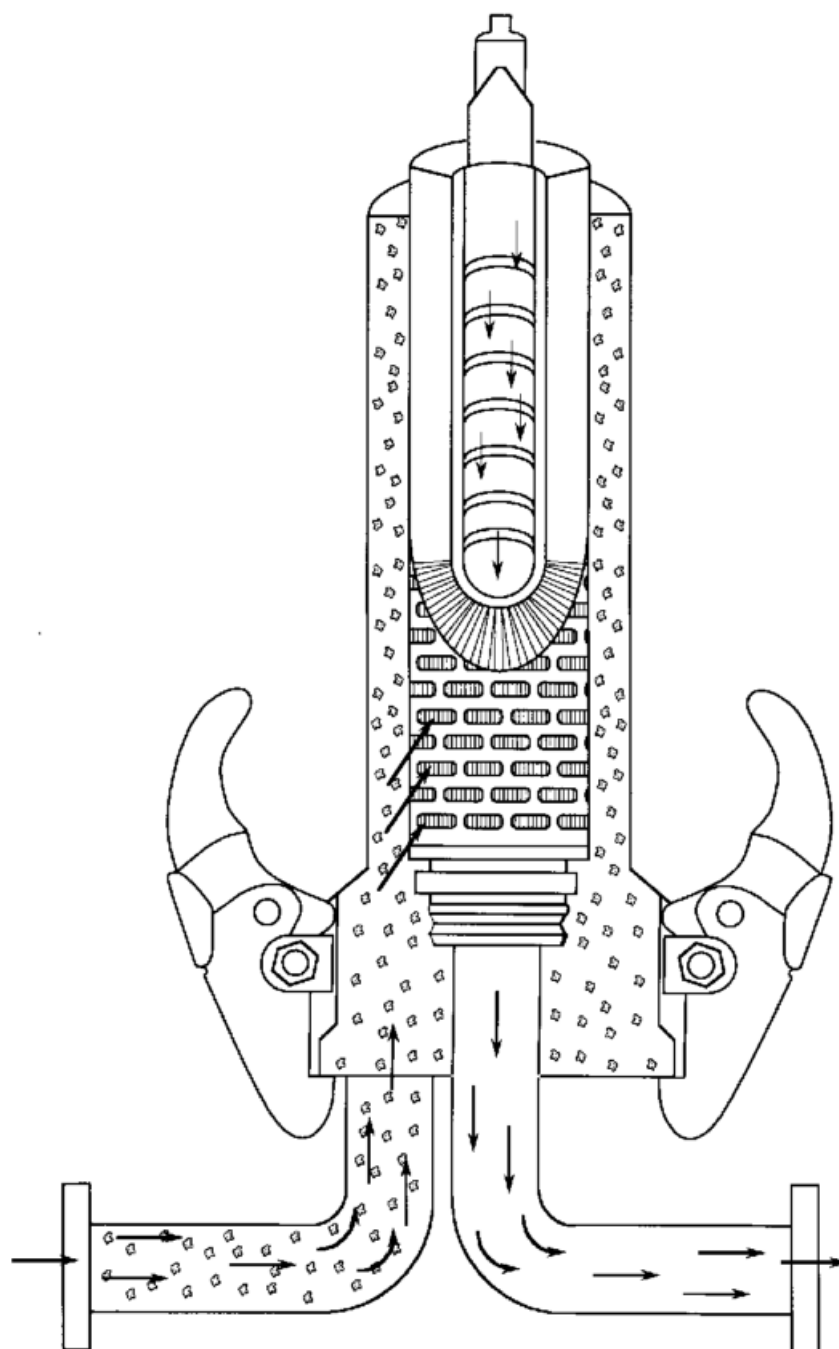


Figure 4.6-5 Single Element Cartridge Filter

Substitution of Hydroxide Ions for All Anions
(All anions are removed from influent and replaced with hydroxide ions in effluent)

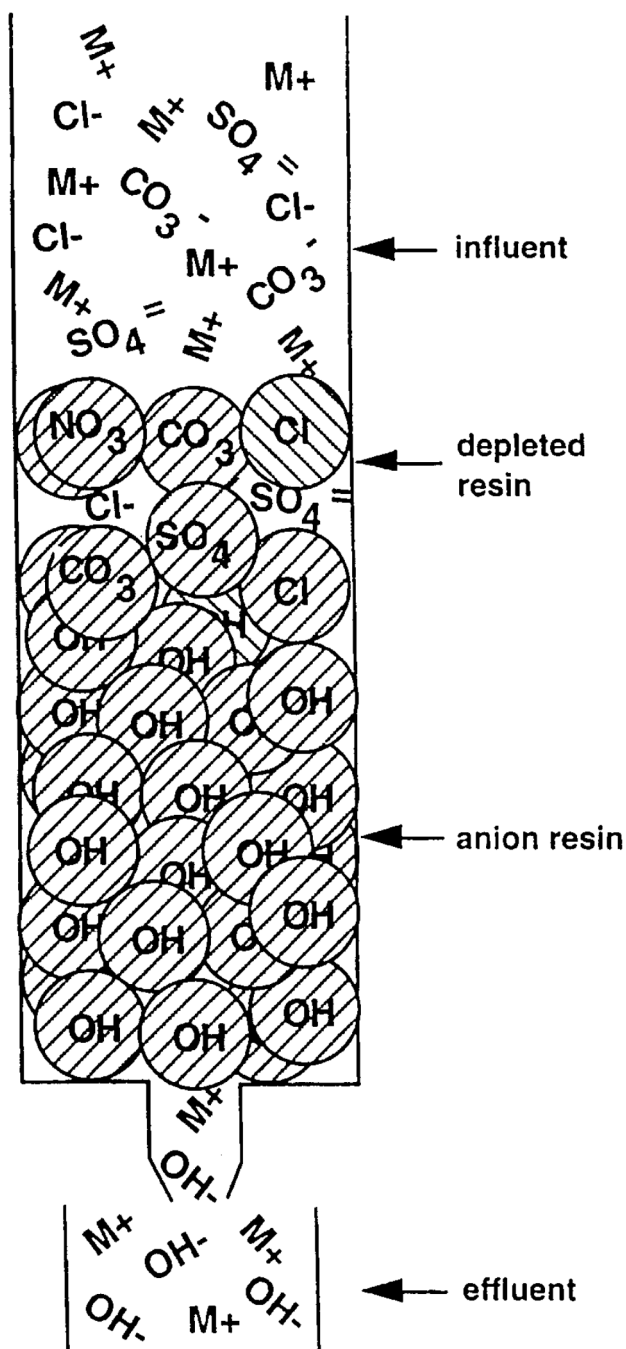


Figure 4.7-1 Anion Resin Column

Substitution of Hydrogen Ions for All Cations
(All cations are removed from influent and replaced with hydrogen ions in effluent)

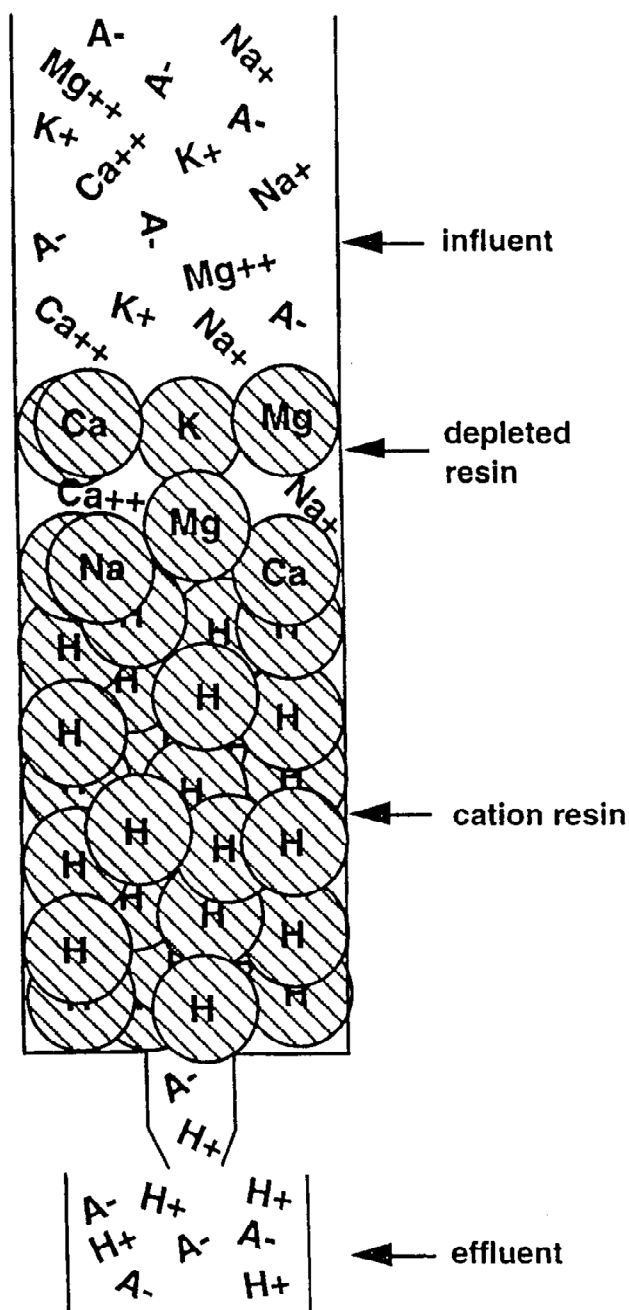


Figure 4.7-2 Cation Resin Column

(All anions and cations are replaced with H^+ and OH^- ions, producing pure water as an effluent.)

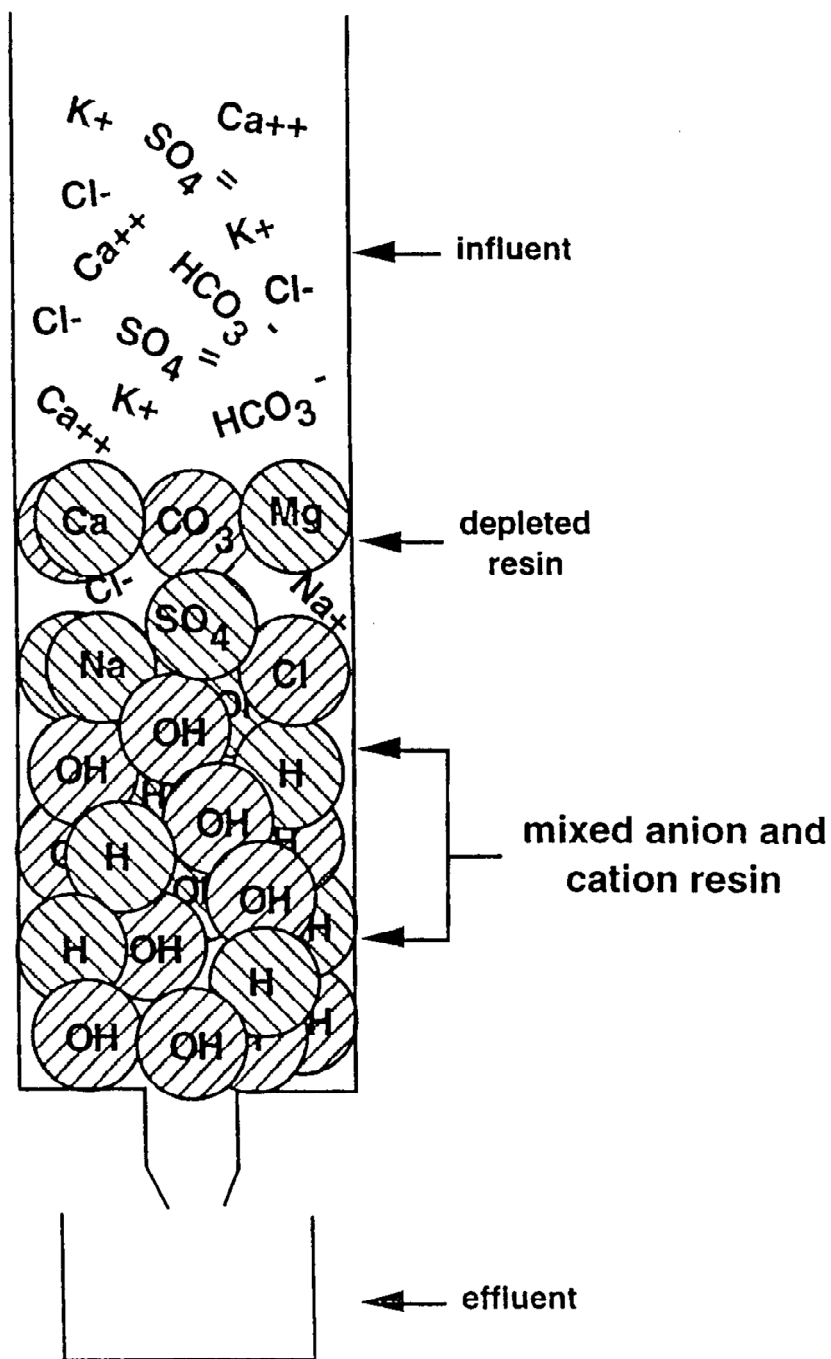


Figure 4.7-3 Mixed Bed Column

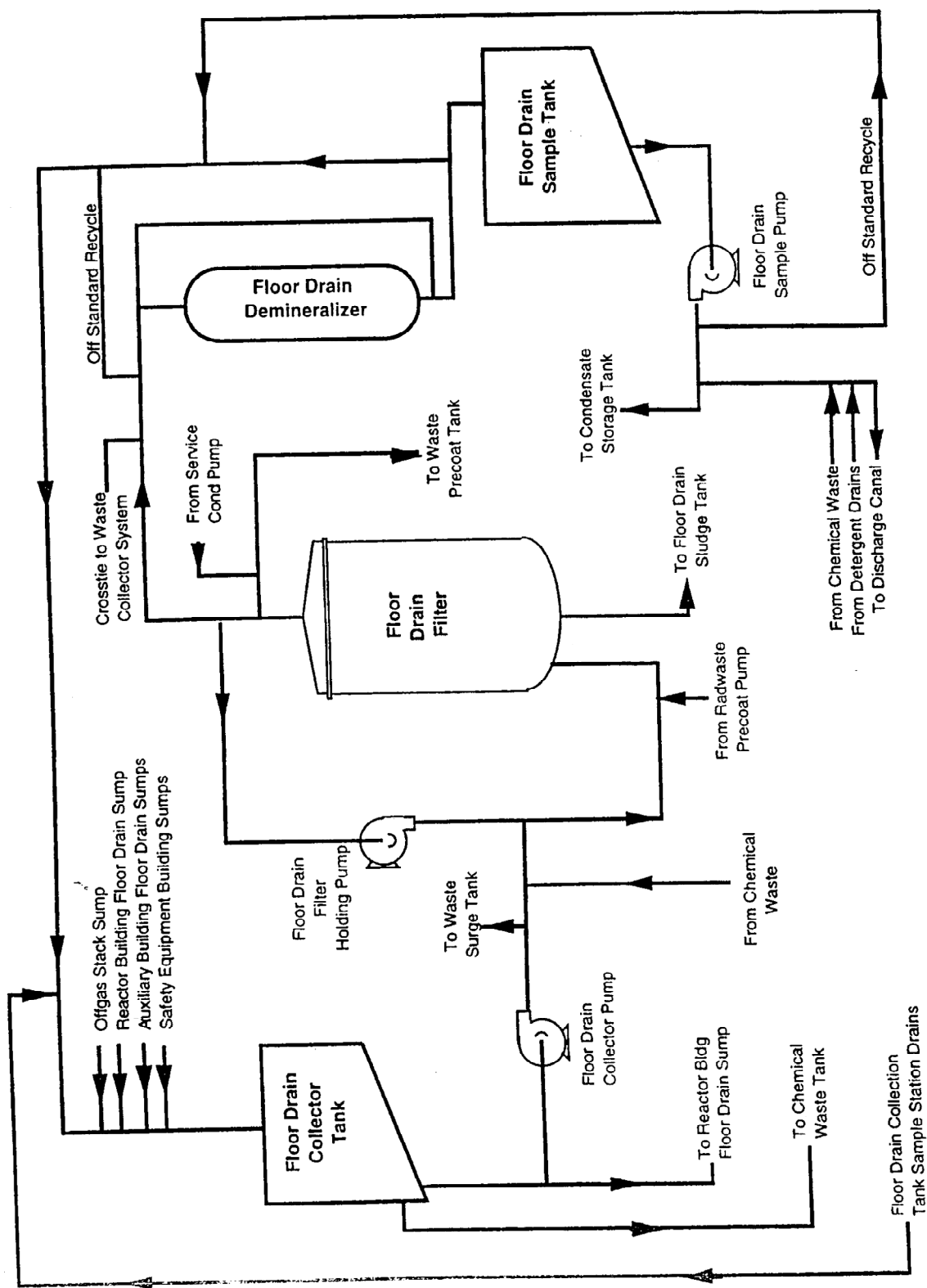


Figure 4.10-1 Floor Drain System

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Chapter 4

Attachments

Note: The following attachments include information from vendor brochures and websites, and are not a comprehensive list of the commercially available products or services used for processing liquid radioactive waste.

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Thermex™ Liquid Treatment System

EnergySolutions' patented Thermex™ technology provides a facility with the ability to:

- o discharge zero contaminants to the environment
- o reduce waste generation by 80 to 90% over resin-based systems
- o produce theoretically pure water
- o exceed EPRI, INPO, and manufacturers' guidelines for reactor feedwater total organic carbons



Thermex unit

Thermex™ is a customized, membrane-based technology for processing contaminated liquid wastes. It incorporates a multi-stage process of filtration, membrane treatment, and demineralization for the removal of contaminants. Since contaminants are not reintroduced to the facility, over time these systems become less contaminated, thus providing additional benefits to a site:

- o no wastewater released to the environment
- o savings in makeup water and plant life cycle costs
- o greater fuel reliability

Thermex™ is a turnkey liquid treatment service. Energy Solutions provides the equipment and certified operating technicians to operate and maintain the system and ensure its reliability.

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ALPS™ - Advanced Liquid Processing System

EnergySolutions' ALPS™ technology provides our customers with the ability to

- minimize waste generation
- reach decontamination factors of >10,000
- provide superior ion exchange media use
- produce excellent colloidal and particulate filtration
- produce exceptional total organic carbon

For the selective removal of iodine, cobalt and cesium in high conductivity or high temperature applications, the ALPS™ system uses the Duracil family of patented glass, ion specific and ion exchange resins to ensure reliable and consistent removal.

ALPS™ is easily customized to meet your specific wastewater processing needs. Its sluicable pressure vessels are designed to optimize deep bed flow characteristics, flow distribution, and particulate flow dynamics. Features of the ALPS™ design include

- minimal facility interface requirements
- compact, modular design to meet irregular floor plans
- site compatibility
- significant reductions in radiation exposure flexible shielding designs



ALPS system installed at the Callaway NPP

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RWE NUKEM's ALCON™ Liquid Waste Services

Purified Effluent

RWE NUKEM Corporation's Advanced Liquid CONcentration (ALCON™) technology combines a variety of individual processes into a powerful processing package that results in clean purified effluent water with the smallest residual waste volume possible.

RWE NUKEM has for years successfully utilized varying combinations of its ALCON™ components, some of them Patent-Pending, including robots, Hydro-Fracturing Systems (HyFrac), Backflushable Filtration Systems (BFF), Membrane Based Systems, such as Ultrafiltration and Reverse Osmosis, Ion Exchange Systems, and Concentrate Dryers. RWE NUKEM tailors each system to meet the specific client need and when an ALCON™ technology is correctly configured to address a specific waste stream, ALCON™ will meet and exceed the strictest effluent criteria. ALCON™ systems yield:

- Reactor-grade make-up water
- Recovery of radioactive liquids for "Zero-Release"
- Exceptional volume reduction for waste minimization
- Superior media utilization
- Sustained decontamination factors

Reg Guide 1.143 Compliant

As with all RWE NUKEM services and equipment, ALCON™ systems are backed by an approved quality assurance program. Equipment is constructed to meet the intent and/or the requirements of Reg Guide 1.143 and ANSI/ANS-40.37-1993.

Superior Equipment

ALCON™ Liquid Waste Services consistently accomplish superior results by using one or any combination of RWE NUKEM's field proven technologies:

- Membrane-Based Systems (UF/MF/RO)
- Membrane reject management utilizing RWE NUKEM's Solids Collection System
- Demineralization (Ion-exchange) Systems
- Concentrate-Dryer Systems
- Dewatering Services, Systems, and Approved Containers (HICs)
- Backflushable Filter Systems

Secondary Waste Management

RWE NUKEM treats the entire waste stream. Secondary wastes are processed for disposal or storage using a variety of RWE NUKEM processes. These include:

- **Dewatering Systems** and highly efficient disposal containers
- **CD-1000 and CD-600 Concentrate-Dryer Systems** for evaporator concentrates, sump and tank sludge, and most water based solutions
- **Off-Site Processing** at RNC's Fixed Based Facility of membrane-based systems effluent concentrates, as well as other sludges and solids - a flexible alternative to on-site services
- **Membrane Reject Management** utilizing RWE NUKEM's patented passive, non-thermal Solids Collection System.



RWE NUKEM Corporation provides safe, compliant, and cost-effective solutions to radioactive waste management problems through the innovative application of proven technologies.

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RWE NUKEM's ALCON™ Membrane-Based Systems

Membrane Application

RWE NUKEM Corporation's Advanced Liquid CONcentration (ALCON™) Membrane-Based Systems provides unsurpassed proven performance that will directly improve upon a plant's operational and financial goals. RWE NUKEM's Membrane Based Systems will:

- Improve water chemistry
- Reduce curies released
- Lower dose to public
- Significantly reduce secondary waste generation
- Eliminate the need for polymer/chemical injections
- Virtually eliminates any need for off-site processing of membrane reject.
- Will likely result in achieving an upper quartile INPO ranking

ALCON™ Membrane-Based Systems produce:

- Reactor-grade make-up water
- Recovery of radioactive liquids for "Zero-Release"

Reg Guide 1.143 Compliant

As with all RWE NUKEM services and equipment, ALCON™ systems are backed by an approved quality assurance program. Equipment is constructed to meet the intent and/or the requirements of Reg Guide 1.143 and ANSI/ANS-40.37-1993. RWE NUKEM's attention to detail results in superior, reliable service.

Demonstrated Capability

Prior to installing a full-size system, each ALCON™ Membrane-Based System is first supported by on-site waste stream evaluation. This evaluation ensures:

- Accurate, detailed information on the physical and chemical characteristics of the waste stream
- Determination of a correctly and appropriately sized system
- The elimination of long and costly start-up and system shakedown periods

Secondary Waste Management

RWE NUKEM treats the entire waste stream. Secondary wastes are processed for disposal or storage using a variety of reliable dewatering and/or drying systems. These include:

- Standard Dewatering Systems for ion-exchange and filter media with excellent disposal container efficiencies
- Membrane reject management utilizing RWE NUKEM's patented passive, non-thermal Solids Collection System.



RWE NUKEM Corporation provides safe, compliant, and cost-effective solutions to radioactive waste management problems through the innovative application of proven technologies.

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LPW-5 Equipment Series

EnergySolutions has completed the design and construction of a new 5-gallon per minute equipment series to provide the perfect solution for smaller liquid waste processing campaigns where full-scale processing equipment may not provide enough added value to compensate for the increased mobilization and installation effort and larger process area requirements.

1. RAW Water System
2. Filter/Demin System
3. Reverse Osmosis Systems (ROS)
4. Ultra-Filtration Systems (UFS)
5. Product Water System (PWS)



This LWP-5 equipment also offers a solution to sites where intermittent processing campaigns are more desirable than continuous, long-term processing campaigns.

5 Gallons per minute conversion table:

- 300 gallons per hour
- 7,200 gallons per day
- 50,400 gallons per week
- 201,600 gallons per month
- 2,419,200 gallons per year

EnergySolutions' LWP-5 Liquid Waste Processing equipment is designed to perform as both a long-term processing solution AND a fast-response Demand Processing System. The LWP-5 system can operate as independent systems or added together and configured as necessary to meet specific process requirements and goals. Each LWP-5 piece has self-contained shielding for ALARA operations and the individual system's dimensions are small in comparison to larger, full-scale equipment. This minimizes the floor space requirements as well as reduces material handling efforts for equipment installation and positioning.



Thermex 5-gpm unit in use at Cooper Station.



Filtration & Ion Exchange

The DTS Waste Processing System (WPS™) is the most effective system for filtration and ion exchange of liquid streams. Use it for:

- Liquid Radwaste Processing
- Reactor Water Cleanup
- Fuel Pool Cleanup
- Cleanup of Chromated Systems
- Groundwater Cleanup

This system maximizes throughput, decontamination factors (DFs) and volume reduction (VR) using carbon, organic, inorganic, and selective process media. Its normal processing rate is 50 to 100 gpm; DTS has designed units to process from 5 to 100 gpm.

WPS™ Advantages

Flexible

- Variable process logic
- Modular components can be added or removed to fit space and function

Efficient

- Quick reaction to changing water chemistry and process conditions
- Can bring vessel on-line or bypass it in 30 seconds, change logic in 3 minutes

User-Friendly

- Strategically placed instrumentation
- Multiple interface/connection points
- Two-way auto shutoff quick connects
- Cam-lok connections

Superior Design

- Corrosion-resistant sluceable pressure vessels in 15, 30, and 50 cubic foot sizes

ALARA

- Stainless steel clad lead panel shields
- Low-profile vessels reduce over-shield shine
- Few moving parts means reliability and low maintenance



WPS™ with Overhead Canopy Shielding

Compliance

The WPS™ is designed, procured, and built to meet the requirements of:

- Nuclear Regulatory Guide 1.143
- NRC ETSB Branch Tech. Position 11-3
- ASME Boiler and PV Code, Section VIII
- 10 CFR 50.59, 10 CFR 61, 10 CFR 71
- ASME/ANSI NQA-1
- NIST Traceable Calibration

AVOID Costly Vessel Failures

Many plants have experienced processing delays when ordinary system vessels failed. DTS meets this challenge with:

Corrosion Resistance: By integrating vessel design and material, we have eliminated Microbiologically Induced Corrosion (MIC) that causes retention element failure, and the reducing atmosphere that causes stainless steel vessel failures.

Removable Cores: Each vessel's core can be taken out for inspection or repair without moving the vessel (see photo on reverse).



50 cf PreConditioning Filter with core removed
(core includes retention elements, sluice line, sluice jets, effluent piping)

Removeable Core with top fittings
positioned in 50 cf vessel



WPS™ Operation

Liquid flows from plant tanks to the WPS™ via a **Booster Pump**, to ensure optimum pressure and flow rate for processing. It enters the system through an **Influent Manifold**, which monitors flow rate, pressure, conductivity, and temperature.

Control Manifolds regulate influent and effluent from each vessel. They let the WPS™ operator change the waste's path from vessel to vessel, depending upon chemistry.

PreConditioning Filter removes solids, detergents, solvents, and oils that could foul downstream beds. Later vessels are loaded with carbon, organic, inorganic, and/or selective ion-exchange media.

Decontaminated water leaves the WPS™ through the **Effluent Manifold**, which records waste volume and monitors effluent parameters. This Manifold has a resin strainer, sight glass, and sample point.

Sample Sink lets the operator draw samples from all critical processing points, including the influent and effluent of each vessel. Integrated pressure gauges show pressure drops across each process bed.

Utility Manifold provides service air and water for several uses at once, including sluicing, and flushing and blowing down lines. Pressure gauges and isolation valves provide control over each line. Multiple manual and automatic check valves prevent back-flow into plant systems.

The **Sluice Manifold** permits the operator to sluice depleted media from the process vessels. Sluice jets in each vessel assure complete media removal. A sample port in the Manifold allows representative Part 61 samples to be taken during sluicing.

Moveable **Shield Panels** surround WPS™ vessels in any arrangement. Panels provide attachment points for instrumentation, manifolds, and the Sample Sink.

These WPS™ Options enhance system efficiency safety, and usefulness:

Polisher Vessels apply small quantities of selective media to remove specific isotopes, improve effluent quality, and reduce media consumption.

Overhead Canopy Shielding provides a personnel access barrier (see photo on reverse).

Chemical Injection/mixing System allows chemical adjustment, precipitation, flocculation, coagulation.

Dike Containment protects against sluicing spills.

Mechanical Filter removes gross suspended solids before ion exchange occurs.

DTS offers many other options to meet your plant's needs. We specialize in finding sensible, innovative solutions to processing problems.



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Reverse Osmosis

Reverse Osmosis (RO) is a technology that has many applications in water processing at nuclear power facilities.

How RO Works

In RO, pressure is applied to contaminated water on one side of a semi-permeable membrane.

The water and selected molecules, for example boric acid, pass through the membrane. Contaminants such as minerals, salts, and colloidal solids cannot pass through the membrane, and are "rejected."

RO Applications

- RO is a proven cost-saving method of removing TDS and TOC from liquid radwaste (LRW) streams.
- RO is an ideal waste concentrator. Used upstream of an evaporator, it can reduce the evaporator's workload by up to 99%.
- RO selectively removes radioactive and dissolved contaminants from plant systems — especially PWR LRW streams — while passing bulk materials such as boric acid.
- RO can be used at BWRs to process LRW for recycle by removing TDS and activity; the product is recycled as high-purity water (<1 μmho).
- RO units can be configured for single- or double-pass processing: double-pass units consistently yield reactor grade water.

Membrane Selection

The basic building block of an RO system is the membrane module. DTS uses several types of membranes in its systems; each selected to achieve the rejection/passage characteristics that you need for your project.



**50 gpm RO System
(Boric Acid Recovery System)**



**4 gpm RO System
(Boric Acid Recovery System)**

DTS RO Systems

DTS designs, fabricates, installs and operates stand-alone and skid-mounted RO systems in many sizes and configurations

Our turnkey systems handle flows from a few gpm to more than 100 gpm. Programmable Logic Control (PLC) systems and Man-Machine Interface (MMI) touch screens allow automatic remote operation, data logging, and fine-tuning of process parameters.

Spiral Reverse Osmosis

For years, plants have been limited in their use of RO in LRW applications due to the susceptibility of Spiral Reverse Osmosis (SRO) membranes to particulate fouling. This fouling plugs the membranes and creates high dose fields.

Use of a Tubular UltraFiltration (TUF™) system upstream of SRO units makes it possible to process high TSS water without membrane fouling. Combining TUF™ and SRO technologies extends SRO membrane life beyond five years, and decreases accumulated dose to a few mR.

The combination of TUF™ and SRO removes all TSS and TDS, to produce reactor grade water. The use of polishing ion exchange beds downstream of the SRO makes it possible to routinely produce 0.07 µmho water.

The SRO system can handle influent from 1 to 3,000 µmhos, consistently producing effluent that is from 0.1 to 1 µmho. Each pass of a double-pass SRO rejects more than 99% of almost all isotopes and dissolved solids (except tritium and noble gasses).

Summary of RO Results

Combining RO with advances in equipment design and membrane technology yields superior operational results. DTS routinely integrates filtration, membrane, and drying technologies to optimize processing performance, maximize water quality, and minimize waste volume.

Our systems:

- Reduce activity levels, with DFs from 100 to as high as 100,000 for most isotopes.
- Produce 100% water recovery with evaporation of reject to dry solids.
- Remove silica from borated water, with 85-98% recovery of boric acid.
- Produce high-purity product:
BWR <0.1 µmho, PWR <10 µmhos
- Reduce waste disposal volumes by a factor of more than 10 (compared to evaporation or ion exchange) when processing LRW.



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UltraFiltration

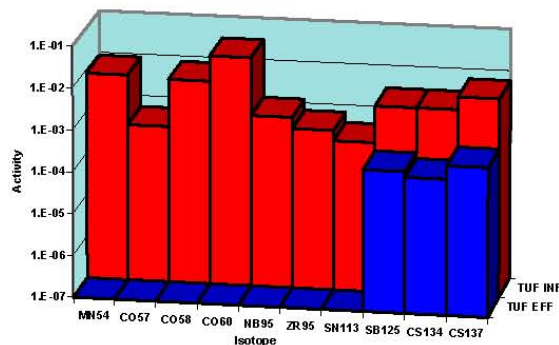
Materials separation has long been a challenge in liquid radwaste (LRW) processing. Many of the solutions tried over the years have fallen short of expectations. For example:

- Cuno-type filters are expensive, dose-intensive, and effective only to a low micron level.
- Mechanical filtration has been ineffectual, since most insoluble activity (primarily Co) is sub-micron: 0.5 to 0.05 microns.
- Chemical pretreatment is a fragile technology that can worsen filtration problems if not properly applied.

Ultimately, our industry needs a separation technology that targets the necessary micron range, generates little or no secondary waste, and is simple to apply and reasonably priced.

The TUF™ System

The Tubular UltraFiltration (TUF™) System meets the needs of a nuclear power plant's LRW operation. Filtering the process stream to 0.05 micron, the TUF™ removes virtually 100% of suspended solids, oils and greases, metal complexes, and most colloidal material from the LRW by passing it through a series of cross-flow membranes.



Typical TUF™ Performance
Processing PWR Sluice Water



DTS TUF™ System

Reduced Curies

Because it's so effective at removing the Co that constitutes a majority of activity releases, ultrafiltration helps reduce curie discharges. Removal percentages of 50 to 100 have been achieved for Co, Fe, and Cr.

Minimum Waste Volume

Unlike conventional filters that generate waste volumes many times greater than the contaminants they remove, TUF™ removes only the volume of dirt, and generates no secondary waste. And the cross-filtration TUF™ needs no messy, dose-intensive element changes.

TUF™ and Demineralization

Used upstream of a demin system, the TUF™ removes non ion-exchangeable materials and fouling agents. Co, Cr, Fe, Mg, Mn, and Nb are all greatly reduced before reaching the demins. Eliminating fouling materials from the waste stream improves DFs and total throughput of downstream resin beds.

Innocuous ionic materials like Na, Ca, Cl, SO₄, and B pass through the TUF™ for discharge to the environment.

TUF™ and Reverse Osmosis

Used in front of an Reverse Osmosis (RO) system, the TUF™ prevents membranes from fouling, and removes many of the challenges to RO processing.

With the TUF™ there's:

- Little or no RO cleaning required
- No secondary waste
- TOC removal/destruction available
- Direct feed to RO - no intermediate tanks
- Constant feed - no filter backwashes or element changes
- Extension of RO membrane life by 3-5 years

System Operation

Plant feed enters a **pretreatment tank** where, if required, biological growth and organics are converted to CO₂ and water. Solids are concentrated and settle to the tank's conical bottom for removal to a High Integrity Container (HIC), Spent Resin Storage Tank, or other disposal container.

A **feed pump** sends wastewater from the pretreatment Tank to the TUF™.

The heart of the TUF™ consists of stainless steel **pressure vessels** arranged in series. Flow through each vessel is divided into parallel tubular channels. Inside the tubes, membranes reject waste stream contaminants, while clarified water is permitted to pass through to collect on the shell side of the vessel.

The process flow (less the permeate), circulates continually back to the pretreatment tank for re-processing. A booster pump pressurizes the permeate stream to drive this water thorough a demineralizer or RO unit, without intermediate tanks.

EXCLUSIVE Technology

DTS is the exclusive U.S. representative for the tubular ultrafiltration technology of PCI Membrane Systems Ltd., a leading manufacturer of membranes for industrial processes in the United Kingdom.

This technology, which is widely used in Europe, has provided the U.S. nuclear industry with the answer to its LRW materials separation challenges.

TUF™ Membranes

TUF™ membranes are selected for their ability to tolerate insults from dirt, organics, biological growth and complexed materials. The high flow rate of the TUF™ sweeps away fouling agents that accumulate on the membrane surface, and helps to extend run times and membrane life.

System Flexibility

Because the TUF™ is modular, you can add capacity as needed. This unit can be integrated to downstream demin or RO systems for LRW cleanup for discharge or recycle.

Process Control

The TUF™ includes a Programmable Logic Controller (PLC) that automatically adjusts operating parameters, optimizing system flow rates and pressures. The PLC provides system alarms and automatic shut down if parameters fall outside the norm.



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ZERO™ System

DTS provides integrated membrane process systems for total recycle of liquid radwaste (LRW) at BWRs, and for water release at PWRs.

The Zero Environmental Release Option (ZERO™) System is an efficient, economical approach to LRW processing for both types of plant.

The ZERO™ Approach

In the ZERO™ System, DTS combines several complimentary technologies to give you the greatest benefits of each.

Since each ZERO™ sub-system is a separate module, components can be added or removed to meet your operational and financial needs.

System Components

Process Stream Conditioning: The Ozonator™ destroys organics before prefiltration to prevent fouling of membranes and media.

Prefiltration: This is the key to efficient operation of membrane systems. Depending on your plant's needs, prefiltration can be accomplished with a Tubular UltraFiltration (TUF™) unit, a Candle Filter System (CFS™), or a profiled deep-bed activated carbon filter.

Dissolved Solids Removal: Reverse Osmosis (RO) in a double-pass spiral wound configuration is ideal for removing dissolved solids.

Permeate Polishing: An ion exchange post-polisher helps to ensure consistent production of <0.1 µmho water.

Reject Concentration: A small, specialized RO unit super-concentrates reject volume before it is sent for drying.

Drying: A single- or double-headed Drum-Dryer™ dries concentrates to granular solids.



ZERO™ System

Dry Solid Product

Solids removed from the water are concentrated and dried. The granular end product represents Volume Reduction (VR) as high as 100,000:1 for BWRs and 10,000:1 for PWRs.

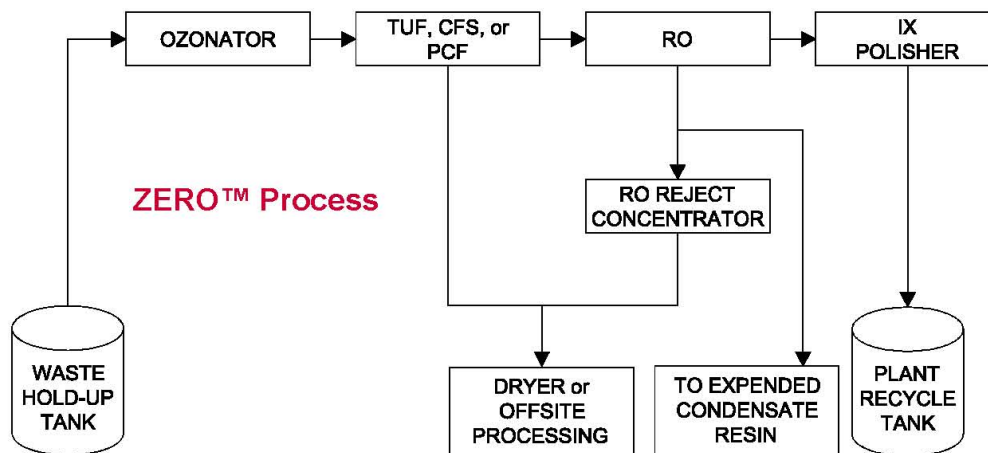
Drying sterilizes the waste, depriving microbes of the moisture they need, and eliminating microbial action (gas generation). The absence of moisture also eliminates the risk of chemical attack on storage containers.

Dry product is ideal for storage in High Integrity Containers (HICs), steel liners, or drums for future disposal. Dried waste can also be stabilized with DTS' polymer solidification process, which is approved by the NRC for Class B and C waste forms (no HIC required).

Total Process Control

The ZERO™ System offers maximum operating flexibility. A Programmable Logic Controller (PLC) automatically adjusts operating parameters to optimize processing results under varying influent conditions.

A Man-Machine Interface (MMI) allows remote monitoring and operation, data logging, report generation, and data trending.



Process Stream Conditioning

TOC in the process stream is a chronic problem for both BWRs and PWRs. The Ozoneator™ destroys TOC and light oils before they reach the membrane systems. This improves system performance and reduces membrane fouling and the need for membrane cleaning.

Prefiltration

Quality prefiltration is essential to assure long run times and low dose buildup for the RO membranes. The Tubular UltraFilter (TUF™) removes virtually all of the membrane-fouling TSS and TOC. With an effective filtration capacity of 0.05 micron, it provides protection 100 times better than the minimum recommended by membrane manufacturers.

The Candle Filter System (CFS™) provides a lower-cost yet effective filtration capacity of <5 micron, meeting the minimum recommended by membrane manufacturers. When used with a precoat, the CFS™ provides sub-micron filtration that enhances downstream RO performance.

A 50 cf PreConditioning Filter (PCF™), loaded with a profiled depth bed of activated carbon, can be used where space is restricted and

budgets limited. With downstream mechanical filtration, the PCF™ provides adequate protection for the RO membranes in most applications.

Dissolved Solids Removal

The process stream is directed to a double-pass three-stage RO unit for further reduction of contaminants. This system produces high-quality effluent, even when system influent varies greatly.

Permeate Polishing

Clean water (permeate) product from the double-pass RO can be directed to an optional ion exchange polisher that produces better than reactor grade water — typically 0.07 µmho.

Reject Concentration

A small, high-pressure RO unit super-concentrates the reject volume before it is sent for drying.

Concentrate and Sludge Drying

The DrumDryer™ can be used to dry the RO concentrates and collected solids to a dry solid waste form that is approved for disposal at Barnwell, South Carolina and Envirocare's Utah facility.



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