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Liquid waste management

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Radwaste Desk Reference

Volume 3, Part 1: Processing Liquid Waste

Prepared by
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Melbourne, Florida

Radwaste Desk Reference

Volume 3, Parts 1 and 2

This volume of the *Radwaste Desk Reference* contains fundamental practical and regulatory information on the processing and management of liquid radioactive wastes at nuclear power plants. Because its information is based entirely on industry practice, the work can serve as an extensive "how-to" manual for both the newcomer and the experienced radwaste professional responsible for liquid waste activities.

INTEREST CATEGORIES

Radioactive waste management
Occupational radiation control

KEYWORDS

Low-level radioactive wastes
Liquid waste processing
Liquid waste management

BACKGROUND The technical, regulatory, and economic factors affecting radwaste management are so broad that no one individual is an accomplished expert in all facets of radwaste management. Hence, a need exists for a comprehensive reference manual capturing the collective knowledge of recognized industry experts on a variety of radwaste issues. In late 1987, radwaste experts from member utilities joined with EPRI to identify radwaste issues, collect authoritative information, and divide it into discrete modules. The resulting *Radwaste Desk Reference* comprises several volumes of expert information on a broad range of radwaste management activities.

OBJECTIVE To develop a reference manual specific to the processing and management of liquid radioactive waste at commercial nuclear power plants.

APPROACH The project team selected a question-and-answer format for this report because such a format could be accessed by radwaste professionals with a variety of experience and interests. The questions were generated at two meetings of utility radwaste professionals and EPRI contractors, with supplemental questions produced during development of the individual reports. The project team then selected acknowledged industry experts to draft responses to the questions, some of which were combined or divided into further questions. Utility experts reviewed and commented on the responses, and their comments and recommendations were incorporated into the final publication.

RESULTS Volume 3, Part 1 of the *Radwaste Desk Reference* offers a comprehensive guide to processing liquid radioactive waste. This part includes several sections on liquid waste processing fundamentals—such as ion exchange, filtration, evaporation, and adsorption—providing valuable training information for new radwaste technicians and supervisors. Other sections address operation of liquid waste demineralizers, filtration systems, and evaporators.

Volume 3, Part 2 of the *Radwaste Desk Reference* provides a complete guide to managing liquid radioactive waste. It includes extensive information and operating practices related to liquid waste generation and control, liquid waste processing systems at existing U.S. nuclear plants, processes for managing wet wastes (handling, dewatering, solidifying, processing, and packaging), and liquid waste measurement and analysis.

In all, the two parts of this very readable report can be used as a primary resource reference book for nuclear managers and experienced radwaste supervisors as well as colleges and universities. Volume 1 of the *Radwaste Desk Reference* addresses dry active waste generation, processing, and measurement. Volume 2 describes low-level waste storage, transportation, and disposal.

EPRI PERSPECTIVE The radwaste technician, engineer, or supervisor can use this report to obtain both general and specific information on a wide range of liquid radioactive waste processing and management issues. The report's format addresses complex issues in the same fashion as they arise in the field—as a question. The responses to the questions are based on existing nuclear industry knowledge and actual field practice, thereby minimizing the need for field testing and maximizing the transfer of practical experience. Related EPRI research includes the following: *Sourcebook on Ion Exchange for Liquid Radwaste Treatment* (EPRI report TR-103326), *BWR Radwaste Precoat Filter Optimization* (report NP-5483), *Pretreatments and Selective Material for Improved Processing* (report NP-5786), and *Engineering Evaluation of Selective Ion Exchange Radwaste Processing at Susquehanna* (report NP-6120).

PROJECT

RP2414-34
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Radwaste Desk Reference

Volume 3, Part 1: Processing Liquid Waste

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Abstract

EPRI began, late in 1987, to produce a Radwaste Desk Reference that would allow each of the member utilities access to the available information and expertise on radwaste management. EPRI considers this important because radwaste management involves a wide variety of scientific and engineering disciplines. These include chemical and mechanical engineering, chemistry, and health physics. Radwaste management also plays a role in implementing a wide variety of regulatory requirements. These include plant-specific technical specifications, NRC standards for protection against radiation, DOT transportation regulations and major environmental legislation such as the Resource Conservation and Recovery Act.

EPRI chose a question and answer format because it could be easily accessed by radwaste professionals with a variety of interests. The questions were generated at two meetings of utility radwaste professionals and EPRI contractors. The names of the participants and their affiliation appear in the acknowledgments.

The questions were organized using the matrix which appears in the introduction and below. During the writing phase, some questions were combined and new questions added. To aid the reader, each question was numbered and tied to individual Section Contents. An extensive index provides additional reader assistance.

EPRI chose authors who are acknowledged experts in their fields and good communicators. Each author focused her or his energies on specific areas of radwaste management activities, thereby contributing to one or more volumes of the Radwaste Desk Reference.

Volume 1, which is already in publication, addresses dry active waste generation, processing and measurement. ***Volume 2*** addresses low level waste storage, transportation and disposal. This volume, ***Volume 3***, is being issued in two parts. Part 1 concentrates on the processing of liquid radioactive waste, whereas Part 2 addresses liquid waste management.

Acknowledgments

This volume of the Radwaste Desk Reference includes the work of many individuals who helped guide the project, generate the questions, edit and illustrate the text, and prepare this text. The project manager at EPRI responsible for this volume was Carol Hornibrook.

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Table of Contents

Note: *This is a summary Table of Contents intended to provide the reader with an overview of the information contained in each section of the report. A detailed section Table of Contents is included beginning on page 2 of each section of the report.*

Section Contents —

What is ion exchange, anion resins, cation resins, ion removal, radioactive ion removal, resin intrusion, types of anion and cation resins, using silicates for cation removal, equivalence and capacity conversion, radwaste ion exchange system, types of ion exchange systems, mixed resin beds vs single beds, mixed resin beds vs layered beds, determining cation/anion mixed bed ratios, organic vs inorganic ion exchange materials, fluid flow in resin beds, channeling through resin beds, temperature effects on resin performance, temperature limits of ion exchange materials, performance effects of resin type and form, influent chemistry effect on decontamination factor, flow rate, residence time and DF, relating ion exchange capacity to DF, predicting DF's for different resin types, improving DF in a radwaste system, effects of elution processes, rehydrating dried resin, condensate polisher run lengths, resin test column programs.

Section Contents —

PWR and BWR waste processing systems, monitoring water quality, selecting an ion exchange system, typical resin capacities, advantages of powdered and bead resin systems, preparing zeolites for use in radwaste systems, calculating operating capacity of resins, optimizing

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Section Contents —

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Section Contents —

Comparing ion exchange, absorption and adsorption, impurities removed by activated carbon, effect of pH on carbon adsorption efficiency, available types of activated carbon, selecting activated carbon material, sizing activated carbon for an ion exchange system, activated carbon replacement criteria.

INTRODUCTION

Introduction

This volume, the third in the series entitled the *EPRI Radwaste Desk Reference,* deals primarily with liquid waste processing and management. Due to the large volume of information, it has been divided into two parts:

> **Processing Liquid Waste**: This report focuses on the principles of ion exchange, filtration, evaporation and absorption processes.
>
> **Liquid Waste Management**: This report focuses on the operational aspects of liquid waste generation, control, minimization and measurement within nuclear power plants.

For Volumes 1 and 2, a matrix was proposed in an effort to identify those areas of radwaste management that, potentially, could be included as independent sections of a Desk Reference volume. Section numbers were proposed where the reader might look to find information on specific subjects. However, as the Desk Reference series of reports has developed, the original matrix concept no longer offers the best mechanism for identifying radwaste topical areas.

Accordingly, the table on the next page replaces the matrix used in previous volumes. It identifies both the applicable volume and section number for various radwaste subject areas. In addition, this page can be used as an errata sheet to replace the matrix pages from Volumes 1 and 2. As new volumes are published, additional errata sheets will be produced for this pages to replace outdated tables.

Cautions

It is important for the user to realize that each nuclear facility has different operational capabilities and constraints. Therefore, the information contained herein does not precisely reflect questions every radwaste professional will ask. Instead, they cover the major issues which affect liquid waste processing and management. In other words, *they offer information and guidance to resolve plant-specific questions.*

RADWASTE DESK REFERENCE REPORT SERIES

SUBJECT AREA	RWDR VOLUME	SECTION NUMBER
Dry Active Waste	**1**	—
DAW Generation	1	1100
DAW Handling	1	1200
DAW Assay	1	1600
Transportation and Disposal	**2**	—
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LLW Storage	2	1800
Shipping and Shipping Documentation	2	1900
LLW Disposal	2	2000/2100
Miscellaneous Transportation and Disposal Information	2	2200
Radwaste (Transportation and Disposal) Fundamentals	2	2300
Transportation Checklists	2	2400
LLW Management Inspection and Audit Checklists	2	2500
Processing Liquid Waste	**3, Part 1**	—
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Operating Ion Exchange Systems	3, Part 1	2700
Special Ion Exchange Applications	3, Part 1	2800
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BWR Liquid Waste Processing Systems	3, Part 2	3500
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Mixed Waste	**4**	—
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Mixed Waste Packages and Packaging (being developed)	4	4100
Mixed Waste Storage (being developed)	4	4200
Mixed Waste Disposal (being developed)	4	4300

Looking for Information

If you need specific information on a particular topic, there are several ways to find it:

- If it is basic, the Glossary section may be all you need. If the required information is more complex, first try to determine what the major subject area is (ion exchange, filtration, plant systems, solidification, etc.). Next consult the table on the previous page.
- As an alternative, refer either to the Table of Contents or the Section Contents that appear at the beginning of each volume or section, respectively. Question numbers and topics appear in the individual Section Contents.
- As a third approach to locating information, review the alphabetical Index at the end of each volume. The Index provides the page numbers where the topic is discussed. For Volume 3, the Index is combined for both Parts 1 and 2. Looking in the Index of either report will point you to the specific report and page number.
- A bibliography is included for assisting the reader to locate additional related information outside of the Desk Reference.

SECTION I

(2600 SERIES QUESTIONS)

FUNDAMENTALS OF ION EXCHANGE

Section I Contents

Fundamentals of Ion Exchange

Item Topical Description **Item Number**

Ion Exchange Materials

Ion Exchange Systems

Operating Considerations Affecting Ion Exchange Materials

Listing of Illustrations

Illustration Topical Description **Figure Number**

2601

What is ion exchange?

Ion exchange is a process wherein ions in solution change places with ions that are attached to a solid through which the solution is passed.

The solids that are capable of exchanging ions come in two types:

1. Solids capable of exchanging positively charged ions (cations) are appropriately called cation exchange resins.

2. Solids capable of exchanging negatively charged ions (anions) and are called anion exchange resins.

Commonly encountered cations include sodium (Na^+), calcium (Ca^{++}), cesium (Cs^+) and cobalt (Co^{++}). Typical anions include chloride (Cl^-) sulfate ($SO_4^=$), iodide (I^-) and nitrate (NO_3^-).

There are a number of different kinds of materials that are capable of exchanging cations and an even greater variety of materials that exchange anions. In a radwaste system, both cation-exchanging and anion-exchanging materials are needed. They are frequently used in a single unit called a bed. When both cation- and anion-exchanging materials are mixed together, they are referred to as a mixed bed.

In nuclear plants, the most common ion exchange solids are resins. These may be either in the form of resin beads or powdered resin. Thus, nuclear plant demineralizers may use either bead or powdered anion resin beds, cation resin beds, or mixed bed resins.

> *Note: As a general rule, powdered resins are not mixed with resin beads in the process vessel, except for specialized testing or cleanup processes.*

In nuclear plant applications, the ions that are commonly attached to the solid resins are the hydronium ions (H^+) on cation resins and the hydroxide ion (OH^-) on anion resins. These ions will change places with the contaminant ions in the water, thereby removing the contaminants. The hydronium and hydroxide ions from the resins combine to form water (H_2O).

Both cations and anions are adsorbed by (become attached to) a given ion exchange material with different tightness (or affinities). In ion exchange processes used to treat radwaste, resins do not distinguish between a radioactive and a nonradioactive ion of the same element. Moreover, because different ions (both radioactive and nonradioactive) are adsorbed on the resins with different affinities, a specific contaminant ion that is attached on a specific exchange site of the resin may be displaced by another ion with a greater affinity. Thus, the removal of ions from a liquid process stream is affected by other ions in the waste water competing for a limited number of ion exchange sites on the resins.

Still, there are materials that will hold large, heavy ions, such as cesium or cobalt, in preference to small, lighter ions, such as sodium. These materials are termed "selective" ion exchange resins. The use of such materials where an effluent containing nonradioactive ions may be discharged often is advantageous. It increases the volume of liquid that may be treated with a given volume of ion exchange material and, therefore, reduces the volume of solid radioactive waste to be disposed.

In systems where water is to be reused, such as a plant primary makeup system, all ions must be removed. In these situations, the use of selective ion exchange material is of little value.

2602

How do anion exchange resins work?

Anion resins work in two ways, depending upon their chemical structure. Resins that are called strong bases and which contain quaternary ammonium groups ($-CH_2N(CH_3)_3)OH$ for example) work in a way that is quite similar to sulfonic acid cation resins. They exchange hydroxide (-OH) ions for other anions, such as chloride (Cl-) ions, in a reaction that is written:

$$R\text{-}RH_2\text{-}N(CH_3)_3OH + Cl^- \longrightarrow R\text{-}CH_2\text{-}N(CH_3)_3Cl + OH^-$$

where R = the insoluble polymer.

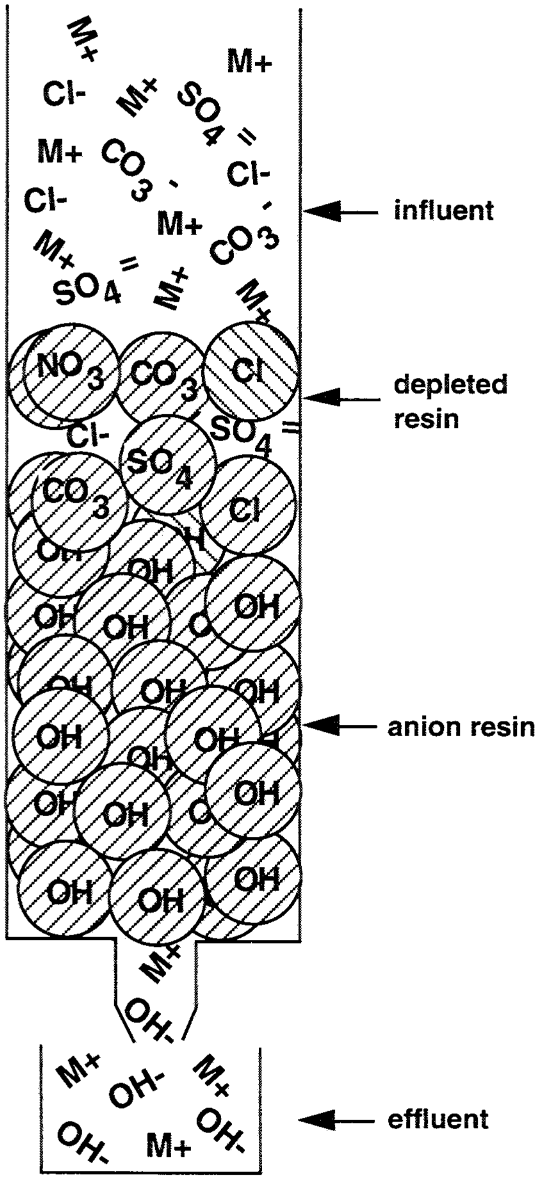
If this reaction takes place at the same time or subsequent to the cation exchange reaction, pure water is the only product. The reaction is reversed in the regeneration step with sodium hydroxide.

The so-called weak base resins come in many different polymeric forms. They may be primary ($-CH_2\text{-}NH_2$), secondary ($-CH_2\text{-}NH\text{-}CH_2\text{-}$) or tertiary ($-CH_2\text{-}N(CH_3)_2$) 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:

$$-R\text{-}CH_2N(CH_3)_2 + HCl \longrightarrow -R\text{-}CH_2N(CH_3)_2HCl$$

Figure 2602
Anion Resin Column:

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



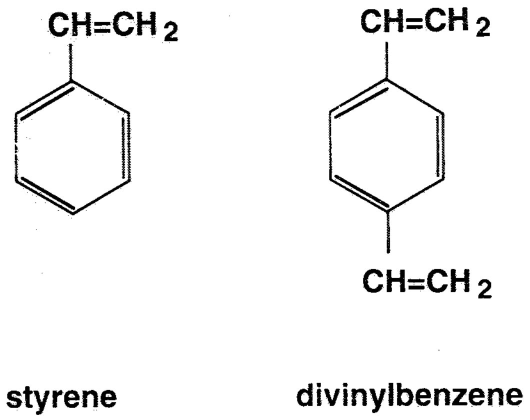
Hence, they work only on an acidic influent, such as that produced by first passing the water to be deionized through the hydrogen form of a strong acid cation exchange resin. Further, many of them have little or no ability to react with anions that do not form strong acids, so their silica and carbonate removal ability is very poor. For this reason, they are usually followed by a bed of quaternary anion resin. Where the chloride and sulfate concentration of the water is high, however, their use is very economical. This is because they regenerate back to their original free base form with only a slight excess of sodium hydroxide. The weak base resins offer the advantage of having a capacity twice that of the strong base anion resins.

2603

How do cation exchange resins work?

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 (-SO_3H) to its surface.

Figure 2603a
Styrene and Divinylbenzene Molecules

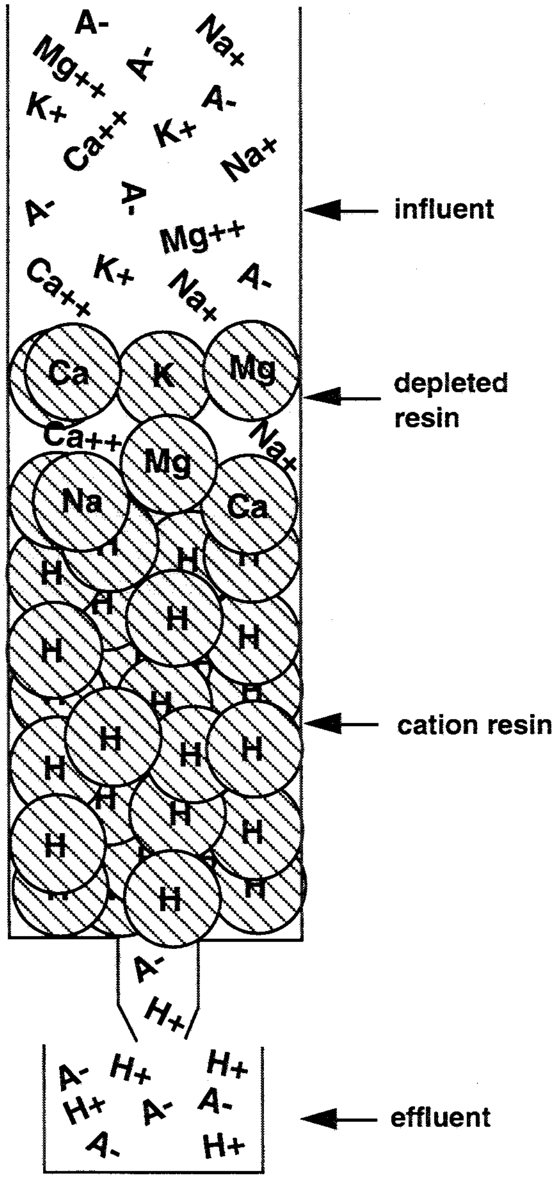


It is the H of the sulfonic acid group that exchanges with ions in the liquid radwaste that passes through it. The reaction is usually written in this form:

$$R\text{-}SO_3H + Na^+ \rightleftharpoons R\text{-}SO_3Na + H^+$$

Figure 2603b
Cation Resin Column:

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



Note that the reaction is written as a reversible one. The sodium may be replaced by other cations, such as:

$$2R\text{-}SO_3Na + Co^{++} \rightleftharpoons (R\text{-}SO_3)_2\,Co + 2Na^+$$

Either reaction may be reversed by adding acid to the bed:

$$(R\text{-}SO_3)_2Co + xs\text{-}H^+ \rightleftharpoons 2R\text{-}SO_3H + Co^{++}$$

and

$$(R\text{-}SO_3)Na + xs\text{-}H^+ \rightleftharpoons R\text{-}SO_3H + Na^+$$

In all these equations, R represents the insoluble polymeric network that does not take part in the reaction. In the latter equations, an excess (**xs**) of acid is used. These equations represent the regeneration of the resin so that it can be reused. Resins in radwaste systems normally are not regenerated since the excess acid containing radioactivity represents a greater problem for disposal than the original waste or the solid resin.

There are other cation exchanging structures available, particularly the carboxylic (-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 the 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.

2604

Is the exchange affinity different for different ions?

Not only is the exchange affinity different for different ions but for every different type of resin. Cation resins are somewhat simpler to understand than anion resins in that simple (i.e., non-complexed) cations usually maintain the same order on all resins, although the magnitude of their selectivity relative to each other may change. In general trivalent cations, such as aluminum, are held more firmly than divalent ions, such as calcium and magnesium. In turn, these are picked up in preference to monovalent cations such as sodium and potassium. If the cations all carry the same charge, the one with the higher ion weight has the higher selectivity.

Anion selectivity is hard to generalize in this fashion. Contrary to what is sometimes seen in the literature, anions with the highest charge, such as phosphate, usually do not have the greatest affinity. However, if one has a series of anions of similar structure—for example, chloride, bromide and iodide—the heaviest one will have the highest affinity. When one tries to compare things like bicarbonate and carbonate on quaternary (strong base) resins, bicarbonate usually has the higher affinity. The affinity of hydroxide, on the other hand, is comparatively low on a strong base resin and very high on a weak base one where it easily removes all other ions. The order of selectivity on acrylic-based anion resins is usually different from that of styrene-based materials, and the effect of cross-linkage on the order of selectivity is often far greater than it is in the cation resin systems.

2605

How do ion exchange resins remove radioactivity?

The mechanism of radioactivity removal in an ion exchange system depends on the form in which the radioactive species exist in the liquid. In many liquid waste streams, the radioactive species are not in solution but are, instead, present as suspended matter or colloids. When this is the case, the ion exchange resin simply acts as a filter. It is often a more effective filter than chemically inert material, such as a sand, due to the possibility of electrostatic attraction of the suspended matter to the ionic surface. Resins in powdered form are frequently used to remove such suspended or colloidal matter.

When the radioactive species are present in the waste in true solution and, therefore, in ionic form, they are usually removed by changing places with an ion that was attached to a functional group on the resin. For example, soluble cesium (Cs^+) will exchange with the hydrogen ion (H^+) on a sulfonic acid cation exchange resin by a reaction that is usually written:

$$\text{R-SO}_3^-\text{H}^+ + \text{Cs}^+ \rightleftharpoons \text{R-SO}_3^-\text{Cs}^+ + \text{H}^+$$

Cations with two positive charges such as cobalt (Co^{++}) will displace hydrogen ions from two functional groups:

$$2\text{R-SO}_3^-\text{H}^+ + \text{Co}^{++} \rightleftharpoons (\text{R-SO}_3^-)_2\,\text{Co}^{++} + 2\text{H}^+$$

Note that both of these reactions are written with a small reverse arrow indicating that the removal of cobalt or cesium is a reversible process. This will happen if a solution with a high concentration of hydrogen ions enters the column.

Dissolved anions in solution exchange with ions on the functional groups of an anion resin by a similar reaction. Most commonly the ion involved is a hydroxyl (OH^-) ion, such as:

$$R\text{-}N(CH_3)_3^+OH^- + I^- \rightleftharpoons R\text{-}N(CH_3)_3^+I^- + OH^-$$

2606

What happens if resins get into the primary or secondary system?

Perhaps the greatest danger from resin intrusion into the primary system is that they will decompose in the reactor environment and contribute corrosive ions, such as sulfates, to the reactor coolant. However, from a technical standpoint, if resins get into the primary system, they lose their "spots." That is to say the functional groups come off the styrene-divinylbenzene copolymer leaving little white hydrophobic beads that have, in some systems, been recovered in the blow down.

The loss of functionality from the cation resin releases sulfate and whatever cations are associated with it from the resin into the primary loop. We also know that anion resins lose nitrogen, probably first as something like trimethylamine. However, these amines are capable of further oxidation in a primary loop so that a variety of end products—including nitrates, if the right catalysts are present—are theoretically possible. Any released carbon probably is first oxidized to formic acid and ultimately escapes as carbon dioxide.

The intrusion of resin into the secondary loop, as in a PWR, may occur more often in systems with powdered resin condensate polishers. However, bead resin systems also leak resin fines. Local conditions in the steam generators may take the functionality off the anion resin just as expected in the primary loop. However, this is seldom a problem for condensate polishers since amines are added intentionally.

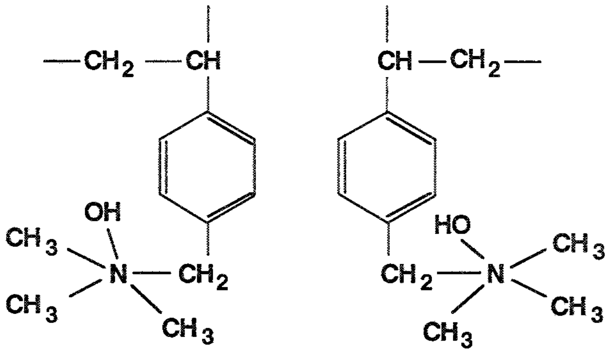
2607

What types of anion exchange resins are used in radwaste treatment?

The most commonly used anion resin found in radwaste applications are the so-called Type I quaternary resins. These are styrene-divinylbenzene copolymers that have been functionalized with a trimethylamine quaternary group. The working function has a structure as shown in Figure 2607.

Like the cation polymer, this is a three dimensional sponge-like network. It may be either a gel type with fairly uniform holes or a macroporous type with dense areas and fairly small holes that surround open areas with large, easily penetrated holes. Gel polymers from different manufacturers differ somewhat

Figure 2607
Type I Quaternary Resin Functional Group



from each other as there are several ways to make resins of this type. As a result, particularly when a gel polymer is used, a variety of porosities are available. Unlike the cation resins, porosity is not directly related to divinylbenzene content.

Two other types of quaternary resins are available. One has a trimethylamine functionality built onto an acrylic-divinylbenzene polymer base. The other is similar to the Type I resin in polymer structure but has one of the methyl groups replaced by a dimethylethanol ($-CH_2CH_2OH$) group. Both of these are less basic than the true Type I resin. What this means, in practical terms, is that they are more easily regenerated with sodium hydroxide. Where resins are to be used over and over again, this sometimes can be an advantage. However, for single-use general radwaste applications, selectivity for radioactive components is usually more important.

In addition, there are an assortment of weak base anion resins available. Some of these have properties that make them useful in special radwaste operations, particularly where complete deionization is not required. None of them will remove silica from the waste, and selected members of the group have little or no effectiveness in removing either carbonate or borate. Resins in this group include:

Tertiary amines:

1. On styrene-divinylbenzene polymers.
2. On acrylic polymers.

Primary-secondary amines:

1. On styrene-divinylbenzene polymers.
2. On acrylic polymers.
3. Condensed with phenolic monomers.
4. Epoxy structures.

All of these differ from one another in both chemical and physical properties. Optimizing their use in a particular radwaste system usually requires on-site testing.

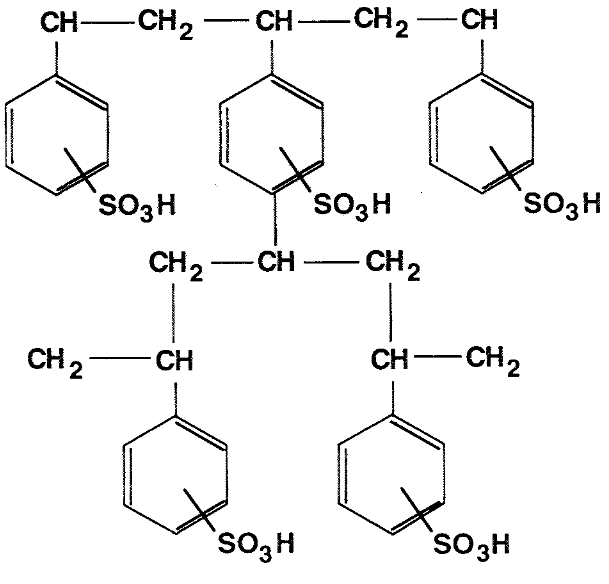
2608

What types of cation exchange resins are used in radwaste treatment?

The most commonly encountered cation exchange resins in liquid radwaste processing systems are sulfonated styrene-divinylbenzene copolymers. They are made with amounts of divinylbenzene ranging from four to sixteen percent by weight. The most commonly used ones, however, contain either eight or ten percent divinylbenzene.

This polymerization produces a three-dimensional net work of benzene-like six-membered rings. The polymer is then sulfonated to add a sulfonic group capable of exchanging to its cation in each ring. It is usually represented on paper as:

Figure 2608a
Sulfonated Styrene-Divinylbenzene Functional Group



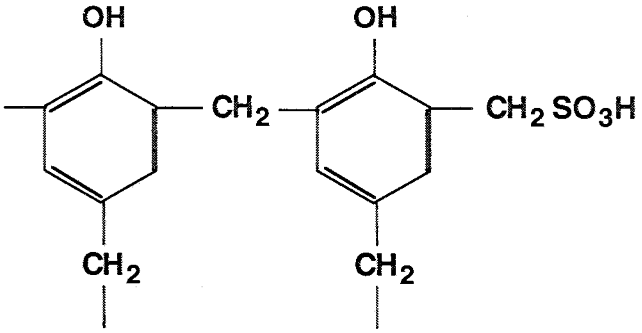
It is the H on the -SO3H group that takes part in the exchange reaction with other cations.

The styrene-divinylbenzene polymer may be formed as either a gel or a macroporous structure. In a gel polymer, the porosity (size of the holes) is fairly uniform. Their size is governed by the amount of divinylbenzene used. Polymers with differing amounts of divinylbenzene differ from one another in the amount of water they absorb. The lower the divinylbenzene, the higher the percentage of water retained. Also, the lower the divinylbenzene content the smaller the number of exchange groups per unit volume of resin.)

Macroporous polymers, on the other hand, are made by adding a solvent to the styrene and divinylbenzene before the polymer beads are formed. This permits one to make a bead with a higher amount of divinylbenzene. It is more rigid but has smaller holes. The solvent present during the polymerization creates a second set of holes usually much larger in size and which permits ions to slip freely in and out of the structure.

A slight variation on this theme is the older <u>methylene sulfonic acid</u> resin which is made by cooking phenol, formaldehyde and sodium sulfite together. It produces a structure that contains both weak acid (phenolic) groups and strong acid (sulfonic) groups. This structure is generally represented as follows:

Figure 2608b
Methylene Sulfonic Acid Resin Functional Group



This material is not produced in uniform beads like the styrene-divinylbenzene polymers. It is normally produced in sheets that are broken into granules similar in appearance to activated carbon. This polymer type has a greater selectivity for heavy atoms such a cesium and strontium. By contrast, the styrene-divinylbenzene resin is highly selective for calcium and magnesium.

The other class of cation exchange resins widely available commercially is the carboxylic acid resins. These are made by copolymerizing divinylbenzene with acrylic or methacrylic acid. The functional group of both is a weak acid: -COOH.

Both gel and macroporous structures are available here as well. Choice of the starting material results in slight differences in polymer structure which in turn shift selectivities slightly.

Both types of carboxylic acid polymers have a disadvantage for general radwaste. This structure will not exchange its hydrogen for other cations in a neutral or acidic waste. To be useful, it either must be converted to a salt form by an alkali prior to use or be fed a relatively high pH waste. This means that it will not produce ion-free water.

2609

Can silicates be used to remove cations?

Although they are not resins, silicates have been found useful for removing cations in radwaste treatment processes. Like the carboxylic acids, silicates are weak acids that must be used in the salt (usually sodium) form. However, they can be made in porosities that have enormous selectivity for cesium. As such, they are useful as components in combination with resins in some radwaste systems.

Similarly, other cation exchange materials, such as cationic glasses, phosphoric acids and chelants, also are available. All have application in special situations.

2610

What is a milliequivalent?

A milliequivalent, to put it in ion exchange terms, is that weight of an ion that will combine with one ion exchange group. Numerically, it is different for every ion. It is equal to the atomic (or molecular) weight of the ion divided by the charge on it. If the weight is in grams, the units are "equivalents" (or more properly gram-equivalents). If the weight is in milligrams, the units are "milliequivalents."

For example, sodium (Na^+) has an atomic weight of approximately 23 and one positive charge. Its equivalent weight, then, is 23 grams, and its milliequivalent weight is 23 milligrams (23/1). Calcium (Ca^{++}) with an atomic weight of 40 has two positive charges and, thus, is able to tie up two groups on the resin. Therefore, its milliequivalent weight, or the weight that will exchange with one group, is 40/2 or 20 milligrams.

Anions works the same way. Chloride (Cl^-) has an equivalent weight numerically equal to its 35.5 atomic weight. For an ionic like sulfate ($SO_4^=$), one adds the weight of the sulfur (32) to the weight of four oxygens (4 x 16 = 64) and divides by 2 charges to arrive at an equivalent weight of 48 [(64+32)/2]. But watch out! If conditions are such that the ion is actually HSO_4^-, then the equivalent weight will be 97 [(96+1)/1].

2611

How do you convert from capacity in kilograins of $CaCO_3$ ft^3 to meq/ml (or eq/l)?

The simple method that most people use is to "Divide by 21.8." Where does this method come from?

1 kilograin $CaCO_3$ = 64.80 grams
1 equivalent of $CaCO_3$ = 50.0 grams
1 cubic foot = 28.32 liters
1 equivalent/liter

Therefore,

1 kilograin of $CaCO_3$ = 64.80 grams = 1.296 equivalents of $CaCO_3$

$$\frac{1\ \text{ft}^3\ 28.32\ \text{liter}}{1.296\ \text{equivalents of}\ CaCO_3} = \frac{1\ \text{equivalent}}{\text{liter}} = 21.85$$

Note: Equivalents/liter and milliequivalents/milliliter are the same numerically.

2612

What is the operating objective of radwaste ion exchange systems?

Radwaste ion exchange systems do not all have the same objectives. In general, they may be divided into three categories:

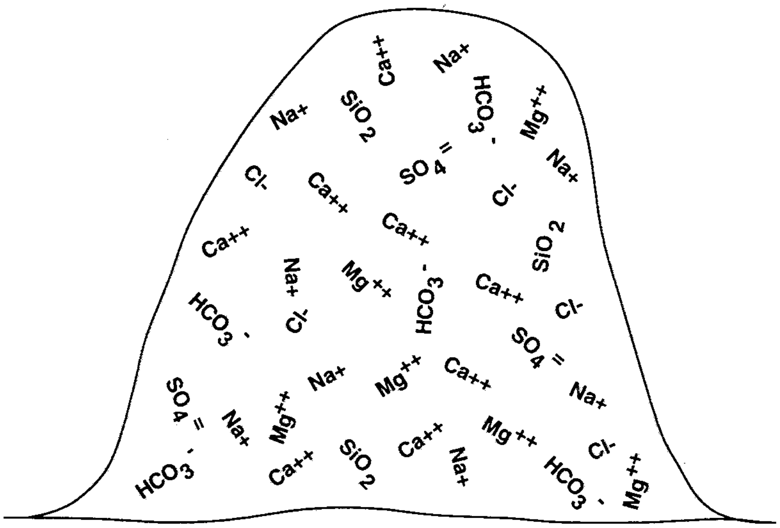
1. Systems that remove soluble contaminants from in-plant systems.
2. Systems that remove radioactivity prior to liquid discharge.
3. Systems that remove both radioactive and nonradioactive ions prior to in-plant reuse of the effluent.

In the first case, the ion exchange system is expected to produce ultra-high purity water suitable for feeding directly into a nuclear boiler. All impurities, whether or not they are radioactive, must be removed.

The second system is intended to remove radioactivity down to discharge limits. Simple ions—such as sodium, chloride and silica—that are nonradioactive are allowed to pass through the resin bed into the external receiving stream. Ideally, such a system would selectively remove only radioactive species so that the maximum amount of water may be treated per unit volume of resin. Unfortunately such high selectivity is closer to dream than to reality.

Water for in-plant reuse differs from condensate polishing in that it treats miscellaneous waste at much lower flow rates than units operating on radioactive condensate. The influent is more likely to have a significant background on nonradioactive ions as well as organics. The operating goal is high purity water usually of quality at least equivalent to the influent to the condensate polishing systems that is free of radioactivity. Silica removal is often a limiting parameter in such a system.

Figure 2612
Looking for the Radioactive Needle in the Ordinary Ion Haystack



2613

What different types of ion exchange systems are there?

If the type of resin used is included as one of the variables in the term "systems" probably no one has ever made a head count of the different types of ion exchange systems that are in operation.

On the other hand, if the choice of resin type is taken out of the equation and the answer is confined to systems that process large volumes of liquid, then there remains four fundamentally different types of equipment. These are based on the particle size of the resins used:

1. Continuous systems using resin in the 16-40 mesh range, where both the liquid process stream and the resin move in the equipment.
2. Fixed bed systems using resin in the 16-40 mesh range (only the liquid process stream moves through the equipment).
3. Fixed bed systems using 60-100 mesh resin in very short cycles in a flat pancake configuration.
4. Powdered resin systems using 100-600 mesh resin supported as a thin layer on a porous medium.

Fixed Bed Systems

Fixed bed systems may be further subclassified as:

1. Single bed systems containing only one type of resin.
2. Layered bed systems containing two or more different resins (hopefully in separate zones within the equipment).
3. Mixed bed systems where two or more types of resins are mixed together during the service run.

Single fixed bed systems that are regenerated have the additional possibility of being operated with the process stream flow and the regeneration flow in the same direction (concurrent) or with one upflow and the other downflow (countercurrent).

Mixed, fixed bed systems come in a wide variety, depending on how and where the resins are separated and regenerated. A rough line of differentiation may be drawn between mixed beds that are separated and regenerated in the service vessel (in situ regeneration) and those with central regeneration stations. In the latter case the resin is sluiced out of the service vessel into a separation vessel. After at least partial separation, one (or both) of the components is transferred again for regeneration. After regeneration the components are remixed for reuse. There are as many variations on how this is done as there are equipment manufacturers. A given central regeneration station will normally be used for four to ten service vessels.

Flat Fixed Bed Systems

Fixed bed systems designed in a flat pancake configuration almost always use a single resin. These systems normally operate countercurrent and only for short times cycles. They are **not** used to produce high purity water, such as is required in condensate systems.

Continuous Systems

These systems normally operate with a single resin type. In some designs the resin actually moves continuously countercurrent to the liquid being treated. In other designs, it moves in small discrete batches at pre-chosen time intervals. The continuous system design is most often seen where some component in the liquid processing stream is to be recovered.

Powdered Resin Systems

Powdered resin systems are always once-through systems. They may consist of a single resin type, mixed bed resins, or layered bed resins, and they often contain non-ion exchange materials as well as ion exchange resins. There are a great many variations in the resin ratios and types of resins used in powdered resin systems.

In liquid radwaste processing streams, fixed bed and powdered resin systems are most frequently encountered. Since the resins are used only once in this application, simplicity of design is a major factor in the choice of system.

2614

How do you determine the most efficient cation/anion mixed bed ratio?

If you are talking about a single-use, bead-form mixed bed, the safest bet is to start with a mixture containing one equivalent of cation resin in the hydrogen form mated with one equivalent of anion resin in the hydroxide form. **Note that this does *not* mean one part cation by volume to one part anion by volume**. A typical cation resin has twice as many hydrogen ions per unit volume as an anion resin has hydroxide ions.

Regrettably, the fact that the mixed beds in most BWR condensate polishers and radwaste systems are radioactive has deterred most BWRs from doing the sort of spent resin analysis that is now routinely done in PWR condensate systems. And, unfortunately, since the latter normally feed a condensate treated with ammonia or some other amine (and in some cases borate as well), the experience gained there is not directly applicable to the BWR or the radwaste system. However, even with ammonia feed, systems with two volumes of cation resin to one volume of anion—which is a four to one ratio on a milliequivalent basis—have been found to be anion capacity limited. In the small amount of BWR condensate data available, that system also appears to terminate by utilization of the anion capacity by carbonate (or probably carbon dioxide).

In the radwaste system, we recognize that the optimum anion/cation resin ratio is dependent upon what happens to the treated water. For water being discharged, where carbonate, silica, and even chloride removal is not critical, it is possible that a higher cation resin content might be possible. On the other hand, the work at Millstone showed slightly anion-rich mixtures had better capacity for radioactive cobalt. In other words, you win some, and you lose some.

Fortunately, the concept of analyzing the spent resin (at least in condensate systems), despite its radioactivity, is generating increasing interest. Inevitably this will lead to a more efficient resin balance in the future. Unfortunately, plant-to-plant variations may make this, too, a plant-specific parameter.

2615

What are the advantages of a mixed resin beds over single beds used in series?

Mixed beds and single beds in series each have their optimum place in the water treatment picture. Basically, they are intended to do different jobs.

Single beds are usually the lead vessels in makeup systems where water of appreciable ionic content—say 25 to 500 ppm total solids—is treated. They are easier to regenerate than mixed beds and, therefore, are the units of choice where handling an elevated ionic load results in frequent regenerations. Further, since they permit the water to pass first through a hydrogen-form cation resin bed that is strongly acidic, they handle polyvalent cations, such as aluminum and calcium—which tend to become insoluble in neutral or high pH surroundings—more efficiently than a mixed bed.

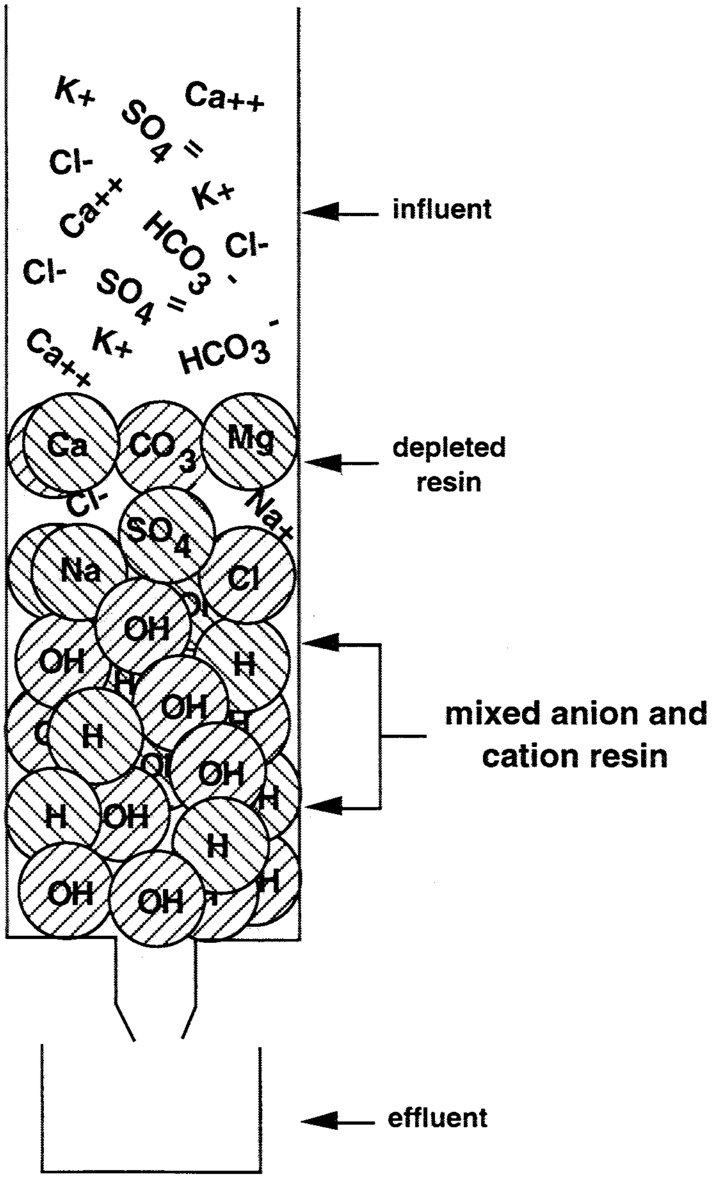
The acidic effluent that such a cation bed produces is taken up very efficiently by a single anion bed. Indeed, where chloride and sulfate are a major percentage of the anion population, they can be easily removed on a single bed containing weak base anion resin. This usually results in a saving in the amount of caustic regenerant needed. The attention of the strong base resin in a third single bed can be focused on removing carbon dioxide and silica in the most efficient manner.

Mixed beds, on the other hand, are intended to produce water of the lowest ionic content. They are polishing systems. They work best when they are fed the effluent from single bed trains, from reverse osmosis systems, or condensate that is to be reprocessed for recycle. If balanced with equal amounts of hydrogen form cation resin and hydroxide form anion resin, they take the residual ions and cations out of the liquid stream simultaneously producing as close to ion-free water as possible. Further, the cation resin picks up the traces of organic amine that inevitably is present when anion resins are used in a single bed. Similarly, the anion resin picks up any organic sulfonate that may wash off the cation resin. Between them, they will still miss the little chlorinated hydrocarbons and things like methanol and other totally non-ionic organic materials. However, if one is careful to exclude these from the influent, a mixed bed has the advantage of producing very close to theoretically pure water.

On the other hand, mixed resin beds are more complicated to operate in regenerable systems because the two anion and cation resins must be separated before they can be regenerated. For radwaste systems (where the resin is used only once) there are distinct advantages to buying the mixed bed regenerated and mixed by the supplier at the optimum ratio.

Figure 2615
Mixed Bed Resin Column

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



2616

What are the advantages of mixed beds versus layered beds containing the same resins.

This question refers to layered beds composed of anion resin in the hydroxide form and cation resins in the hydrogen form as opposed to a physical mixture of the same materials. There are, of course, layered beds with two anion or two cation resins. While they often end up mixed in the real world, they are not usually called mixed beds.

There is no basic difference in function between resins used in a layered bed and resins used in separate beds except that the layers are usually thinner than the resin bed in a full unit. Hence, the capacity per unit volume of resin, which is a function of bed depth, is lower.

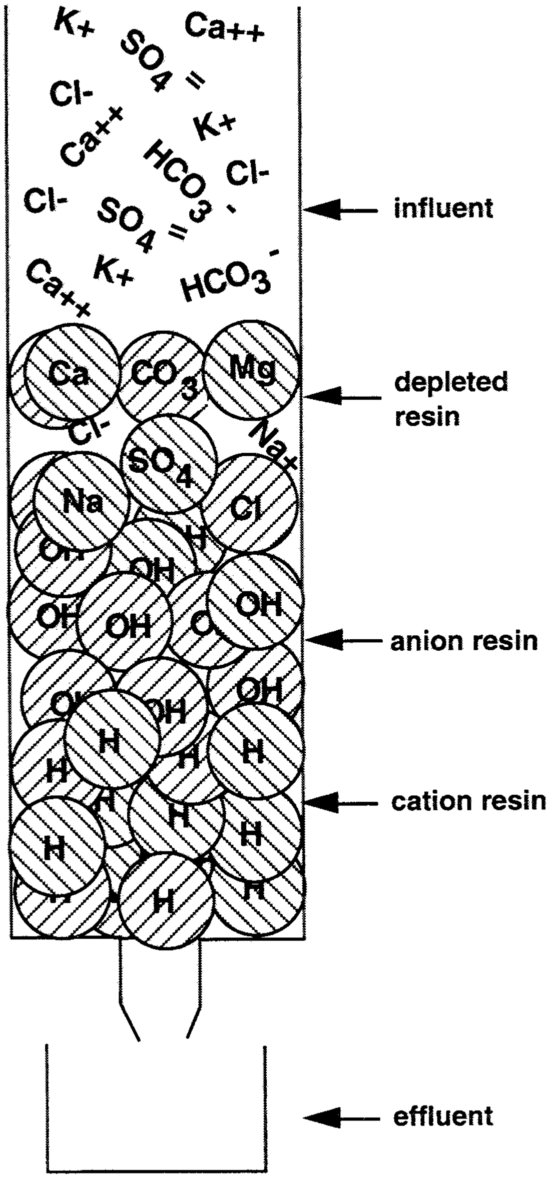
As to the relative efficiency of the same resins used in layers in a single unit versus being used as a mixture in a unit having the same dimensions, the definitive data is still lacking. There is no doubt that good water can be produced in layered beds. Many plants producing good water in this mode are in operation. Whether water of ultimate quality, including control of organics, can be produced in this mode is currently being evaluated.

Layered versus mixed beds have been evaluated under comparable conditions for radwaste treatment under EPRI supervision (NP-5099, "In-Plant Testing of Radwaste Ion-Exchange Materials, July 1987). These comparisons were made in beds of similar dimensions. A number of resin combinations were evaluated in both configurations under identical operating conditions. Although the differences were usually slight, the mixed beds generally showed lower leakages than the layered beds. However, it should be noted that the best performance was attained with a combination of the two configurations (i.e., with a mixed bed topped with a layer of a third type of material, an inorganic zeolite).

In regenerable systems, better performance may be obtained with individual component beds operated in separate compartments of a single unit than from a mixed bed occupying the same space. This is because the problems due to incomplete separation of the mixed resin during the regeneration process are avoided. This, however, is a fundamental difference in the regeneration system rather than a difference in the resin configuration.

Figure 2616
Layered Bed Resin Column

(Like with mixed bed resins, all anions and cations are replaced with H^+ and OH^- ions, producing pure water as an effluent.)



2617

What are the advantages of organic and inorganic ion exchange materials?

The organic materials used in radwaste treatment were originally selected because of their "We do everything" reputation. When they are used, the plant does not have to have a detailed analysis of what goes into the radwaste system. A nuclear mixed bed is expected to blot up everything.

Inorganic materials, on the other hand, have excellent and very high selectivity for certain specific isotopes. They are often pH sensitive, however, and some of them only function when they are in the salt form. While using them often has major cost benefit, they generally must be used with an organic resin mixed bed if complete removal of everything is required.

2618

What affects the flow of fluid through a resin bed?

The flow of fluid through a resin bed is primarily governed by the original bed design. Given a selected flow rate into the vessel, the pressure drop in the upper distribution system, the depth of the resin bed, and the design of the collector system at the bottom of the unit combine to produce a total pressure drop that must be overcome by the system pump.

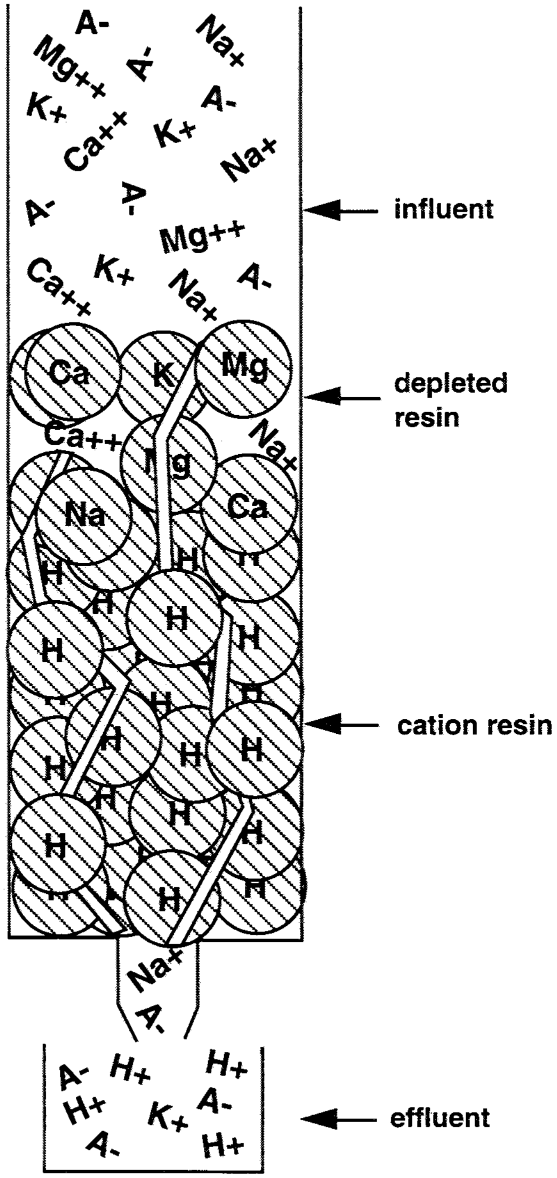
During the service run, however, this will be modified and further limited if the influent to be treated contains suspended matter. Such material often builds up as a mat on the top of the resin bed acting like a blanket to slow the flow. (Essentially, it plugs the available flowpaths through the resins.) Flow rate also may change during the service run due to volume changes of the resin itself as it is converted to different ionic forms. In some systems, bead breakage or other deformation of the resin beads reduces the flow. By contrast, resin beds experiencing channeling may actually have higher flow rates than those specified in the equipment design.

2619

What do you mean by channeling through a resin bed?

Perhaps "tunneling" is a better word choice than channeling to describe what is meant here. We say that a bed has channeled when some of the water finds a path down through the bed that is bigger and offers less resistance to flow than the normal spaces between the beads. This uneven flow leads to uneven resin utilization in the bed and usually results in a short service run due to premature breakthrough.

Figure 2619
Channeling of Ions through a Resin Bed



2620

What can cause channeling?

Generally, channeling occurs when something collects on the surface of some of the beads that causes them to clump together so that they backwash as an agglomerate instead of individual beads. This could be caused by a polymer from the pretreatment, by organics in the influent water (fatty acids do a spectacular clumping job in a cation bed), or by precipitation of some inorganic salts, such as calcium sulfate.

Channeling may also arise from faulty distribution systems—either top or bottom—that produce non-uniform flow patterns. In such cases, channels may develop in the regions of higher flow.

2621

How does temperature affect ion exchange resin performance?

Again, the answer to this depends on the type of resin, the ionic form, and what the resin is expected to do.

Consider a situation where we start at so-called ambient temperatures of 70-80 degrees Fahrenheit. Also consider that we can go up or down in temperature while using the performance in the ambient temperature range as a base line. Going up in temperature does not have a dramatic effect on the behavior of strong acid cation resin. Probably their kinetics are a bit better. Their chemical stability at elevated temperatures—barring oxidative conditions—is generally good.

By contrast, drop the temperature, and the performance of cation resins declines. Leakage increases and run lengths are shorter. This seems to be particularly true if the acids and water used in the regeneration are very cold.

Anion resins are altogether different. They, too, operate better if the regenerant is warm, but some don't like it too warm. They vary considerably in their response to treating water at elevated temperatures. And elevating the overall operating temperatures is a certain way to shorten anion resin life in regenerable systems. Little has been published concerning their performance in waters below ambient temperature. Since each anion resin is different, a consultation with the manufacturer of temperature effects on the specific polymer being used is advised.

2622

What are the temperature limits of ion exchange materials?

That depends on what the materials are, the form in which they are operated, and the system in which they operate. In general, cation resins can withstand higher temperatures than anion resins. Also, resins in any salt form are more stable to heat than resins in either the hydrogen form or the hydroxide form.

Each manufacturer supplies notes containing precise temperature limits for different forms of the resins produced. They should be consulted. For example, some hot lime softeners operate at temperatures substantially above the boiling point of water. Type I quaternary resins have been operated continuously at 60°C and at even higher temperatures for short periods of time. By contrast, Type II anion resins in the hydroxide form show rapid capacity losses at temperatures exceeding 90°F.

2623

What is the effect of resin type and form on performance?

Both the type of resin used and the form in which it is used govern the performance of the system. Looking first at the cation resins in power plant operations, they normally are used in either the hydrogen or the ammonium form. If used in a single bed, the effluent will either be acidic (if the hydrogen form is used) or somewhat alkaline (if the ammonium form is used).

This is true whether a strong (sulfonic) acid cation resin is used or a weak acid. However, in the latter case, essentially nothing happens if the resin is in the hydrogen form and the influent either is neutral or acidic.

Anion resins come in many different flavors ranging from the strongly basic Type I quaternary to some primary-secondary amine resins that are essentially neutral and only remove strong acids from water. All anion resins are normally used in either the hydroxide or free base form. That is to say, they are used with sodium hydroxide as the regenerant. The nature of the effluents produced varies with the properties of the resin itself. Strong base resins fed an acidic influent will produce a neutral effluent. Weak base resins often produce slightly acidic effluents primarily because they do not remove carbonates, bicarbonates and carbon dioxide. They also have little and often no ability for the removal of silica.

The important parameter in selecting resin type and form, as well as the system in which it is operated, is the service that is to be performed (i.e., what the influent is and what the effluent should be). Every system is unique, and it is wise to obtain expert, independent advise before materials are chosen.

2624

What is the effect of influent chemistry on decontamination factor (DF)?

Everything that goes into an ion exchange system has an effect on everything else. When converted to concentration units comparable to those used in ordinary water analysis (parts per million or equivalents per liter) the radioactive components are very insignificant in concentration compared with the nonradioactive components.

The ion exchange process is a complex—and not always totally organized—game of musical chairs. When the waste solution enters the ion exchange bed, all the ions in it scramble for positions on the ion exchange resins. Those present in the greatest numbers will occupy the greatest percentage of available sites. Hence, the DF will initially be related to the relationship that the concentration of radioactive ions bears to the total ion concentration in solution in the waste.

However, unlike musical chairs, one player in the ion exchange game can evict another from its position on the resin. The tendency for this to happen again depends on the ion concentration in solution. The more ions of a specific type, the higher the probability becomes for displacing a radioactive ion. Displacement also depends on the relative selectivity of the ions involved. That is to say, how tightly they bond to the resin sites. Calcium and cobalt, for example, are bonded more tightly than sodium. In a population with perhaps 20 different species, not even a computer can predict accurately what the DF will be. One thing is for certain: the lower the concentration of competing ions, the higher the DF will be.

2625

What is the relationship between flow rate, residence time and DF?

Flow rate and residence time are mutually dependent variables. *The slower the flow rate, the longer the residence time.* If the flow rate is doubled, the residence time is cut in half.

On the other hand, the relationship between residence time and DF is not that simple. It is safe to say that *the longer the residence time, the higher the DF.* However, it is possible that the improvement in DF as the flow rate is dropped (i.e., longer residence time) may not be detectable at low concentrations of radioactive species due to measurement uncertainties.

The DF in any system decreases as more and more waste is processed by a given volume of resin. It is here where the effect of flow rate on DF is usually most apparent. The resin usually has a good selectivity for radioactive species, such as cesium and cobalt, if there is sufficient residence time to permit these relatively slow moving ions to diffuse into the resin structure. When the surface groups are spent, the time required for this removal increases. Thus, a slow flow rate often has a more beneficial effect on the rate of decrease of the DF than it may have had on the DF at the start of the service run. In ordinary ion exchange, we say that leakage increases with increasing flow. A decrease in DF is actually an increase in leakage.

2626

How do you relate ion exchange capacity to DF?

In two words, you don't. Some systems with maximum available exchange capacity may, for a particular radioactive species, have an initial DF of l. This means that the resin does not exchange with a particular radioactive isotope in the form that it exists in that particular waste. It may be that the pH of the waste is too high or too low.

Also, there will be nonradioactive ions present that compete with the radioactive species. Usually, the higher their concentration the lower the DF, and the smaller the volume of the waste that can be treated with a given amount of resin with a fixed amount of capacity.

2627

How do you predict DF's for different resins?

If there were only one radioactive species in each waste and nothing else, we could probably make a fairly accurate prediction of its relative DF on different resin types. We could factor in the effect of the pH of the waste and extrapolate from what we know of the selectivities of the various resin types for the ion of concern.

In real life, there may be ten or more radioactive species. There also may be an equal number of nonradioactive species present in the liquid process stream and at anywhere from a thousand to multimillions of times the concentration of the radioactive species. Each has a different affinity for each type of resin.

In a few cases, the DF can still be predicted in general terms. For example, for comparing cesium on the sodium form of a special zeolite to a sodium form sulfonic resin, we can still say that its DF will be very much better on the zeolite. However, this is only true if the pH is neutral or slightly alkaline. But for some of the other radioactive species, it may be very difficult to say with certainty that resin type A will be any better than type B for a specific waste, let alone trying to predict how much better it will be. It also will be difficult to predict that the performance will be the same on the next batch of waste that the plant produces.

2628

How do you improve the DF of a radwaste system?

There are a number of ways to improve the DF of a radwaste system. The most obvious one is rigorous control of the amount of nonradioactive ions that find their way into the radwaste system. *The higher the total ion concentration of the waste, the lower the DF will be.*

Another approach is to reduce the flow rate through the bed. This may not improve the initial DF, but it often slows the rate at which it decreases. This is because, as the resin loads up with ions, it allows more time for the radioactivity to find sites occupied by ions that it is capable of displacing.

A much more complicated approach to improving the DF is to determine which specific radioactive species is not being satisfactorily picked up by the resin system. Actually, one needs to know both what the element is and whether it is present as an ion or as suspended matter. With the answers to those questions, it may be possible to recommend changes in what is used in the radwaste system to improve the DF.

2629

Under what conditions would radionuclides be eluted from ion exchange resins?

If the ion exchange system is run substantially beyond the equilibrium leakage of a particular radionuclide on an influent that contains appreciable concentrations of nonradioactive ions, the possibility exists that these nonradioactive ions will displace the radioactive ones from the resin sites. Indeed, if the column is run long enough, it is even possible that the concentration of radioactive ions leaving the system will be higher than that entering it.

This is more likely to happen with monovalent isotopes of low molecular weight, such as Na-24, than with heavier or polyvalent cations, such as Cs-134 or Sr-90. The likelihood of it happening depends on the relative selectivity of the resin for the ions involved and the relative concentrations in the waste. *Selectivity of cations increases with increasing ion weight and ion charge.* The tendency of one ion to displace another also increases with increasing concentration. This makes control of the concentration of nonradioactive ions in the radwaste extremely important.

2630

What are the effects of elution processes for either chemical or radiochemical species?

There are two types of elution processes that can be considered. The first is elution by the solution being processed, sometimes called self-elution. This occurs in every ion exchange system where more than one kind of cation and/or more than one kind of anion is present in the water being processed. Every ion has a different tendency to be picked up on the resin sites, usually called its selectivity or affinity. Further, this affinity is different for the same ion on different types of resins. For example, when a solution containing different types of cations is passed through the hydrogen form of a cation exchange resin, the ions will initially exchange in a disordered scramble with the first sites they encounter. As the service run progresses, however, some of these early arrivals are displaced from their sites by other ions in the water with a greater affinity for the resin. The ions displaced then move further down into the bed and reattach themselves. If the column is long enough and the influent is dilute, thereby producing a run that is relatively long, bands of ions of different affinities will form in the unit. For example, at the end of the run the resin at the top may be all in the calcium form while the sodium will be mainly at the bottom of the bed if a downflow pattern is used in the operation.

In general this displacement occurs whether or not a given ion is radioactive. In other words, radioactive and nonradioactive cobalt will act the same. Therefore, we cannot depend on self-elution to concentrate the radioactive species. Concentration of both forms of the cobalt near the top of the column should occur in the same ratio as they are present in solution. (There are a few special situations where some slight banding of isotopes of different atomic weights can be seen, but these are not normally found in general radwaste treatment.)

The banding established during the service cycle is dependent both on the fundamental nature of the ions being picked up and their concentrations relative to each other. For example, if the water being treated contains a high concentration of sodium relative to its concentration of cesium, some displacement of cesium at the top of the column by sodium will occur. This will result in the cesium band being less well-defined, and it will spread further down the resin bed. If the column is run to a breakthrough of radioactivity, this will cause a short run.

We take advantage of the ability of an ion of lower affinity but higher concentration to displace ions with higher affinity in the regeneration process. If enough of this eluting solution is used, solutions containing a high concentration of hydrogen (or sodium) ions will displace a major portion, but seldom all, of the ions of higher affinity from the resin. In effect, in the regeneration process, we go back to square one and recreate a resin form that may treat a new volume of water. This type of eluting process is used in makeup water systems where radioactivity is not involved. It is theoretically feasible to use in columns that have treated radwaste. However, the problem of disposal of what is still essentially four percent hydrochloric acid or four percent sodium hydroxide—now having a significant level of radioactivity—makes regeneration of radwaste resins less attractive.

2631

What happens when a dried resin is rehydrated?

Sometimes nothing, and sometimes one ends up with a coarse grade powder. It all depends upon the resin and its ionic form.

In general, the resin beads swell. Gel system resins that are tightly cross-linked (that is to say have lower water retention capacities) will swell less. Therefore, they are less likely to break, although they may crack. Porous resins with high water retention are usually more sensitive to breakage. If the resins are strong acid resins, the hydrogen form is most fragile. With strong base anion resins the hydroxide form swells most. In both cases, the salt forms are more stable. However, if the resins are weak acid or weak base, the salt forms are more prone to breakage than the acid or base forms.

In general, resins classified as macroporous are less likely to break on rehydration than gel resins. Indeed, some of them are successfully operated in processes that involve dehydration and rehydration. This rule does not always cover macroporous weak base resins, which are often made on polymers containing amounts of cross-linkage no greater than gel resins.

2632

What controls condensate polishing run lengths?

It is necessary to consider the different kinds of condensate systems separately. To radwaste treatment personnel, the condensate systems used in BWR installations are the most important. On the other hand, there are PWR's with primary-secondary leaks where the secondary condensate resin picks up sufficient radioactivity to require that it be handed and disposed of as radwaste.

In a BWR, both powdered and deep bed condensate systems are found. Both of these are usually single-use. In the powdered resin system the run length may be limited by either pressure drop or poor water chemistry. Which of these occurs first seems to be system specific. Some systems produce more filterable crud than others and, hence, build up pressure faster. Others, with either less crud or more condenser leakage, the service run will terminate based on conductivity. In addition, the system itself is often a factor. What kind of elements are used, their age, their winding, the resin mix used, and how the system is precoated are all run length factors in the powdered resin system.

The amount of crud and ionic inleakage also are run length factors in deep bed systems. Where ultrasonic cleaning is employed and the resins are moved from one vessel to another, run length also depends on how frequently the beds are cleaned and the success of doing so without separating the resins and dumping the denser, used resins to the bottom of the operating unit. Then, too, there is the matter of matching the single-use mixture to the ions in the condensate. Often, carbon dioxide, which is seldom measured, is a critical factor in the units failing to meet conductivity specifications.

In a regenerable condensate system, such as those used in a PWR, a given service run may be terminated for any of the above reasons. Usually the anion component is the limiting factor in the total life of the bed. Its life span is connected both to the operating temperature in the service cycle and to the frequency of regeneration. Of course, the length of an individual run in such systems depends on the efficiency of the separation, regeneration, rinsing and remixing of the resins.

2633

How do you know when to remove a condensate bed from service?

The resin bed tells you in one of the following ways:

1. The internal pressure drop is so high that it cannot deliver the volume of water required per unit time.
2. It can no longer produce water of the required quality.

In the case of a substantial pressure drop across the resin bed, it is likely that there are both differential pressure gauges and flow rate indicators to transmit the bad news.

A significant decrease in effluent quality may be indicated in a number of ways. Certainly every condensate polisher has a continuous conductivity (or resistivity) monitor. Each condensate polisher has a personal conductivity (or resistivity) limit beyond which that particular charge of resin is not operated. However, many systems now have, in addition, specific monitors and maximum concentration limits for ions that they consider particularly hazardous to the health of their reactors. These include sodium, chloride, silica, sulfate, organic sulfonates and, more recently in some systems, copper.

2634

When do you initiate a resin column test program?

The time to run a resin column test program is after you have done enough base-line, **complete** analyses of a series of waste tanks to know precisely what is going into the radwaste treatment system. This should include the simple ions, such as sodium, calcium, chloride and sulfate. It should also include suspended matter, oil and grease, and silica.

After collecting all these data, sit down and figure out where it is coming from. Change the laundry materials and the plant cleaning compounds if they are a suspect source. Make a decision as to whether a better prefilter or an oil removal system would cut down on the load.

After you have done everything practical to clean up or exclude extraneous matter from the radwaste system, after you have read and digested such EPRI reports as NP-5099 and NP-5786, after you have selected materials that are structurally different—not just made by different manufacturers—after you have decided which elements you are having the most trouble controlling, and when you have at least three months before a scheduled maintenance outage, then it is time to set up test columns and see what happens with your waste.

2635

How do you perform a resin column test program?

Probably the first thing you should do when planning a column test is to study what has been published. EPRI Reports NP-5099 and NP-5786 both describe resin column tests. Reading them will provide suggestions for the physical setup. If you plan to compare the small column performance with the present plant performance, it is important that flow rates in the test column match those in the real plant on a volume of liquid per volume of resin per unit time basis. Ideally, the test column would be the same height as the real plant unit, but this is often not practical. However, a bed depth of less than 12 inches may not produce results that scale up reliably.

Column dimensions are not as critical, however, when the object of the test is merely to compare alternatives with each other. What is of importance in comparison testing is that all columns are run in the same way and that a large enough volume of test solution is available so that they can all be run using the same influent. Further, before running the test, you should have accumulated enough analytical information to know that the material you are going to use is typical of both the radioactive population and the total population of your waste stream.

Then, of course, decisions have to be made on what to monitor in the effluent and how often to do so. The parameters chosen will depend on what is normally done with the waste.

If the treatment process merely has to remove radioactivity to discharge limits, the primary analysis will be radiochemical. In addition, tracking the conductivity of the treated streams and performing an occasional analysis of the principal nonradioactive cation and anion will help you to understand why the materials being tested perform differently.

Running column tests where the effluent is intended for in-plant reuse will take considerably more analytical time. Here the nonradioactive constituents will probably control the run length, and things like silica and total organic carbon may be of greater importance and present greater challenges than the radioactive components. In designing the tests, it is important that sufficient effluent be available for the following all the parameters of interest.

There are pitfalls in the selection of the materials to be included in the test program too. Ideally, a comparison of materials should be done with samples having the same particle size distribution. This factor rapidly increases in importance as the diameter of the column being used gets narrower. The materials used in the testing program should not only be of known size but their ion exchange properties—at least so far as water retention and exchange capacity—should be determined and recorded. Subsequently, if a material is good, you can tell someone precisely what its properties were. This would include ionic form where regenerated resins are used.

In summary, the most important part of running a column test is in the planning stage. If you have never done it before, outside experienced help for that phase is a worthwhile investment.

SECTION II

(2700 SERIES QUESTIONS)

OPERATING ION EXCHANGE SYSTEMS

Section II Contents

Operating Ion Exchange Systems

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2701

PWR Waste Processing Systems

The systems which collect and process liquids throughout the plant are different (in design) for nearly every PWR. Therefore, it is impossible to describe "typical" processing systems that are applicable to every plant. This section describes, in general terms, the operational objectives of the various PWR liquid processing systems and addresses operational issues relevant to each system.

In general, PWR processing systems which clean up and maintain water quality throughout the plant consist of the following:

- RCS Cleanup (Chemical and Volume Control System — CVCS)
- Boron Reclamation
- Secondary Side Cleanup - Condensate Polishing System (CPS)
- Steam Generator Blowdown
- Spent Fuel Pool Cleanup System (SFPCS)
- Liquid Radwaste System:
  - Floor Drains or Low Purity Liquids **
  - Equipment Drains or High Purity Liquids **
  - Chemical Drains
  - Detergent or Laundry Wastes

** Floor and equipment drains are combined in many PWRs

Although not completely accurate for all PWRs, Figure 2701 illustrates a general system flow diagram for typical PWR processing systems.

2702

BWR Waste Processing Systems

All boiling water reactors (BWRs) in the U.S. are of General Electric design. However, the systems which collect and process liquids throughout the plant are different (in design) for nearly every BWR. Therefore, it is impossible to describe "typical" processing systems that are applicable to every plant. This section describes, in general terms, the operational objectives of the various BWR liquid processing systems and addresses operational issues relevant to each system.

Figure 2701
One Type of PWR Liquid Waste Processing Systems

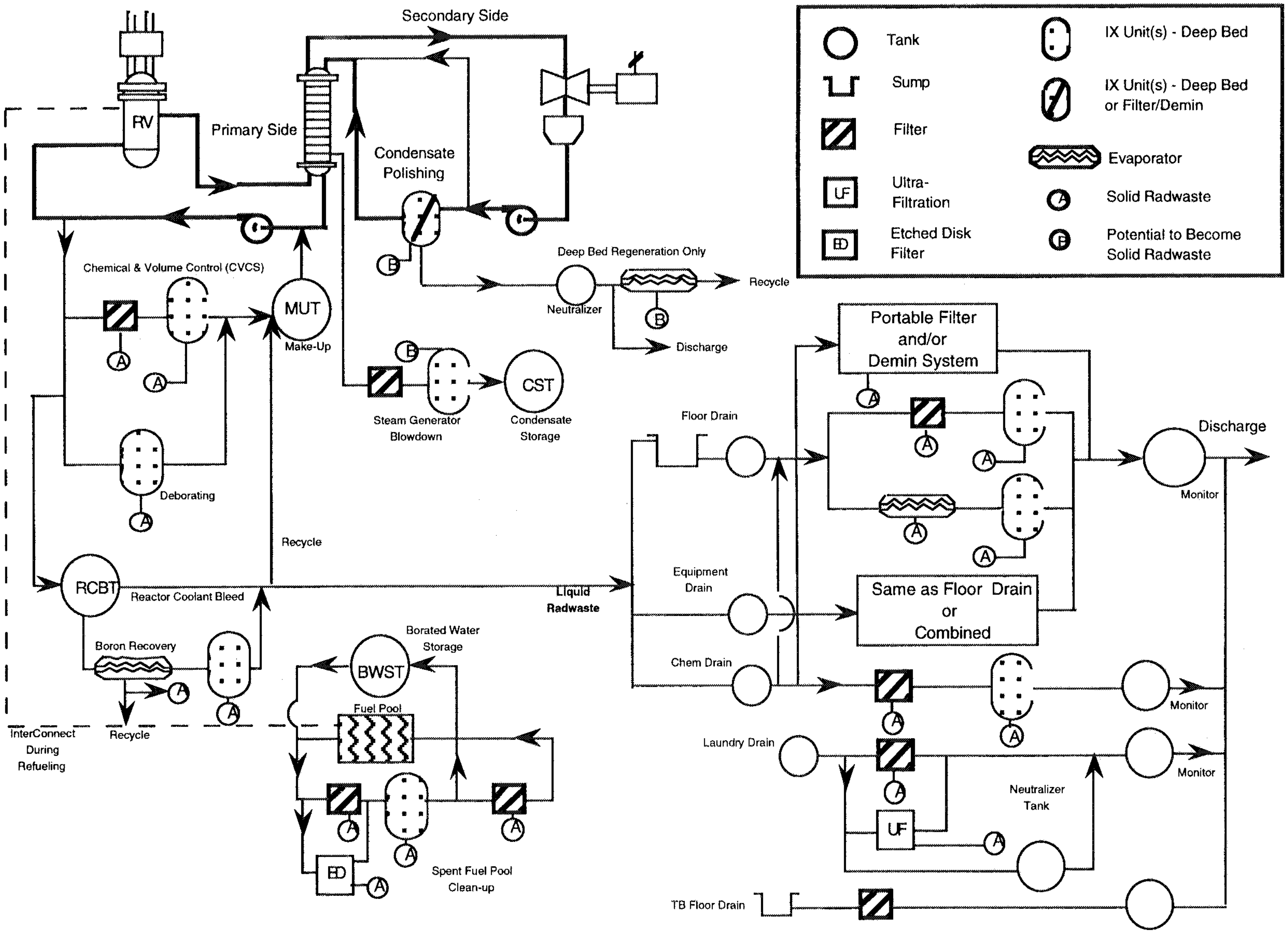
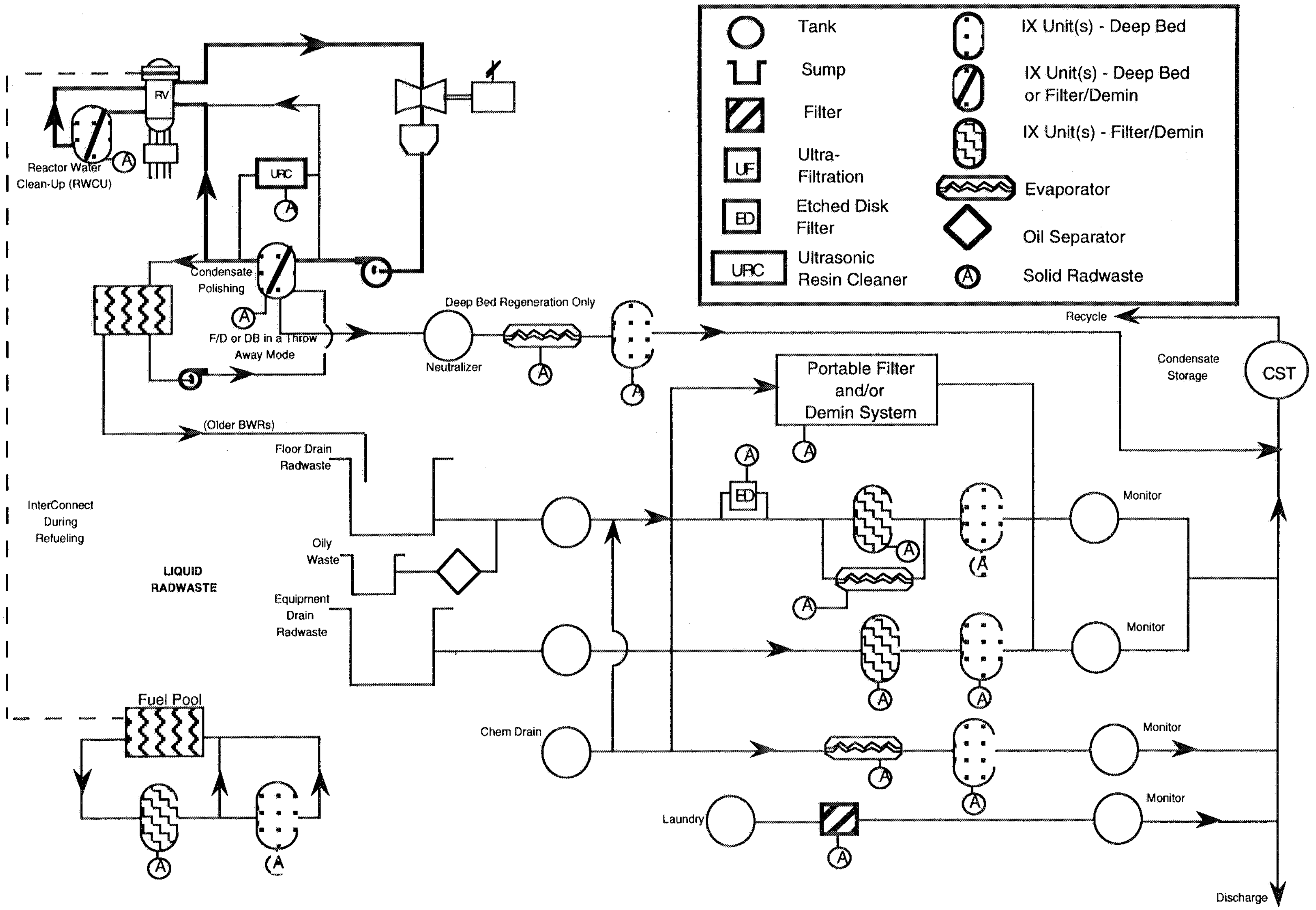


Figure 2702
One Type of BWR Liquid Waste Processing Systems



In general, BWR processing systems that clean up and maintain water quality throughout the plant consist of the following:

- Reactor Water Cleanup System (RWCU)
- Condensate Cleanup or Condensate Polishing System (CPS)
- Spent Fuel Pool Cleanup System (SFPCS)
- Liquid Radwaste System:
  - Floor Drains or Low Purity Liquids
  - Equipment Drains or High Purity Liquids
  - Chemical Drains
  - Detergent or Laundry Wastes

Although not completely accurate for all BWRs, Figure 2702 illustrates a general system flow diagram for typical BWR processing systems.

2703

What parameters are typically monitored to maintain water quality and minimize liquid radwaste generation?

The following system parameters impact on plant water quality. As such, they affect radionuclide generation and the corrosion rate in plant piping and equipment. They also can contribute to or inhibit other forms of deterioration in components and pressure barriers. Control of these parameters can help in reducing radwaste generation in Light Water Reactors.

1. pH — This is a measure of the degree of acidity or alkalinity in coolant water. Controlling pH retards the effects of corrosive compounds on plant components.

2. **Conductivity** — Conductivity is the concentration of dissolved salts in a liquid.

3. **Chloride** — Chlorides are halogens, along with iodides, bromides and fluorides. Halogens have been shown to accelerate certain types of cracking in the various stainless steels used in plant components.

4. **Oxygen** — Careful control of oxygen helps minimize corrosion. Oxygen is a contributor to stress corrosion cracking. It also can contribute to shorter powdered resin precoat filter service runs.

5. **Hydrogen** — Hydrogen has been shown to aid embrittlement in some components used as pressure barriers in nuclear power plants.

6. **Heavy Metals** — This includes mercury, which can combine with other available metals to form a special type of replacement corrosion.

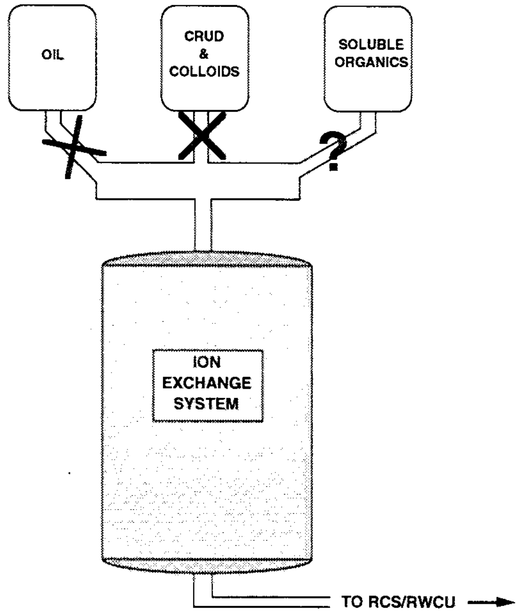
7. **Organics** — These are carbon-hydrogen based compounds, such as oils, greases, mineral acids, solvents, plastics, etc. Organics may raise the conductivity and corrosive potential of the coolant. It is usually measured as T.O.C. (Total Organic Carbon).

8. **Silica** — This weakly ionic compound (usually found as SiO_2) usually comes from surface water runoff. Diatomaceous filtration systems, boric acid, and high density boraflex fuel racks are additional sources of silica. Silica has been found to impede heat exchange on fuel cladding. In some BWRs, silica also can affect turbine performance if carried over in steam.

9. **Total Suspended Solids**— This is a measure of the amount of undissolved solid matter contained in a liquid. This parameter is not usually specified in coolant but is instead specified as the degree of "turbidity" in feedwater.

10. **Miscellaneous** — Such chemicals as sulfur, copper, iron, zinc, and dissolved gases also are monitored due to their effects on the coolant or on the formation of other potentially harmful compounds.

Figure 2703
Maintaining Water Quality by Controlling Contaminants



2704

How do you determine what ion exchange system to use?

If you are starting from the beginning (i.e., pre-engineering design phase), the best way is to hire a team of consultants who sell neither equipment nor resins. They should have enough experience in working with ion exchange systems to have seen the mistakes that are operating in most plants. Provide them with a complete historical analysis of the water to be treated. (Don't try to design a system on one water analysis done four years ago in January on a Northern river water and expect to get a plant that will perform satisfactorily in the midst of an August drought.)

Make a realistic estimate of the quantity and quality of the water required. Listen when the experts say you will need more and want better. Let them size the plant, choose the components, and recommend the monitoring. Do not expect a freshly minted engineer who has never seen an ion exchange resin to make these decisions. The peddlers may snow him with recommendations and he will end up falling back to the safety of a design used 20 years before which never has worked properly.

2705

What are the primary factors to consider in selecting an ion exchange system?

The two primary factors determining the selection of an ion exchange system are:

1. What is in the water to be treated?

2. What must the quality of the treated effluent be?

The question of what is in the water is a matter both of what kind of ions and how much of each kind is present in the water. Whether radioactive ions are there also makes a difference in that their presence invariably tips the scale toward a single-use, nonregenerable type system. The presence of suspended materials (crud) favors the use of a filtering system, such as powdered resin, as at least a component of the treatment.

In those radwaste applications where resins are operated on a throw-away basis after exhaustion, multi-bed systems are generally favored. These configurations offer the advantages of:

- Higher effluent qualities.
- Greater utilization of resin capacities.
- Greater flexibility to employ different resins to achieve optimum performance.

However, multi-bed systems are more costly because of the larger number of vessels, valves, instrumentation, etc. Thus, they will require larger facilities, increased capital equipment costs, and increased installation costs. They also require more sampling and monitoring of vessel effluents between beds as compared to a simpler single-bed or two-bed arrangement of mixed resins, thereby increasing operating costs.

Systems intended to treat raw water are usually more complex than those that polish condensate or treat reactor blowdown. They may start with coagulation and filtration, and they may have a carbon bed for dechlorination. They also may have what is usually called a primary system of two to four single beds of different types followed by a secondary system which could be more single beds or one or more mixed beds. Portions of this system may be replaced by reverse osmosis units. Systems that process water containing a high carbonate content may have a degasifier. This also will help control low molecular weight organic contaminants. High organic waters may include an organic trap.

By contrast, condensate systems may seem easy to select. These also require multiple decisions to be made:

- Single-use versus regenerability?
- What is the optimum resin ratio?
- What chemical additives are best?
- Powdered resins vs deep beds?
- Variables such as flow rate, resin particle size, type of separation process and vessel design.

2706

What are typical resin capacities for radwaste IX systems?

There is no "typical" resin capacity for radwaste systems, because there is no "typical" radwaste system. As a result, there is no "typical" mode of operation.

Relatively accurate estimates of capacity are made for resin systems used to produce makeup water if a good water analysis is available. That capacity generally depends on the concentration of a relatively few ions (Na+, Ca++, Mg^{++}, Cl^-, $SO_4^=$, HCO_3 and $HSiO_2^-$) that are present in concentrations from 1-600 ppm. These concentrations are either relatively constant or vary seasonally in a predictable manner.

A radioactive waste, however, may contain 20-25 components, all of which may have some influence on the system capacity. If the endpoint of the run is on breakthrough of radioactivity, this may be caused by a component whose concentration in the influent was much less than l part per trillion and whose form in the waste (i.e., ion or suspended compound) is unknown. No data exists at these levels that will enable us to estimate the breakthrough. Further, obtaining the data would be an expensive analytical process. It also would be a wasted effort, because the next batch of waste treated may be totally different.

However, if the length of the radwaste run is based on conductivity or silica breakthrough, the capacity may be calculated—just as any water capacity is—from the concentrations of the major ions present. The problem here is that a complete analysis of the waste, including nonradioactive components, is seldom made, and, again, today's waste may be totally different from yesterday's or tomorrow's. However, where day to day variations in influent characteristics are small, the notes published by all resin suppliers are as useful for estimating radwaste system capacity as they are for nonradioactive systems.

If a premixed "nuclear grade" mixed bed is used to a conductivity endpoint, then 0.6 equivalents per liter (13 kgr/ft^3) is a typical capacity value. To translate this into gallons/ft^3, one needs a typical analysis of the influent waste, preferably expressed in terms of equivalents per liter. A waste with 500 ppm NaCl (as NaCl) would have 0.014 equivalents per liter. Therefore, 43 volumes of it could be treated with one volume of resin. If the influent concentration were only 5 ppm, one hundred times the volume could be treated.

2707

What are the relative advantages and disadvantages of powdered resin and bead resin systems?

As plants are now discovering, it is nice to have both types of resin operating in series, configured with the powdered resin in the lead position.

Where the water to be treated contains crud—or to name it more formally, suspended matter—powdered resin is a great removal tool. A powdered resin system is very versatile. Since a unit of powdered resin operates with a relatively small amount of resin, the nature of the resin can easily be changed to cope with a change in influent. It can, for example, be overcoated with carbon to handle an oil leak. It has the disadvantage of a relatively low capacity for handling ions in solution, since the advantage of its high surface area is balanced by the disadvantage of having only a thin layer resin in the service path.

Bead resins in the 16-40 mesh range, as well as those more narrowly sized, are not as efficient in filtering out crud as the powdered resins are. However, the fact that they are normally used in fixed beds that are typically 36 inches deep makes them more efficient for the removal of ions in solution even though the individual particles of resin are larger. Further, they can be regenerated and used over and over in systems where radioactivity is not involved. In single-use radwaste applications, the relatively longer cycle length of the deep bed reduces labor requirements.

Powdered resins are never used alone when the ionic load is high. In radwaste applications, however, their use with a deep bed following may represent the best approach to both BWR condensate polishing and general radwaste treatment.

2708

How do you prepare zeolites for use in radwaste systems?

It is presumed that the zeolite is purchased in the sodium form. If it is to be used in a deep bed operation it probably will need to be backwashed to removed excess alkali and fines before it is put into service. If only a few cubic feet are needed (e.g., for a topping on a mixed bed) this backwashing can be accomplished in a drum with an inlet pipe dropped to the bottom of the barrel and a second pipe inserted near the top to control the effluent. Washing should be continued until the effluent is clear and with a pH of less than 8.5.

If zeolites are used in powdered form, it is presumed that the supplier has washed out excess alkali before grinding. A check of this by slurrying some of the material with deionized water and measuring the pH is, however, a wise precaution.

2709

What special preparations are necessary when zeolites are used in radwaste systems?

Zeolites must be used in some form other than the hydrogen form. Most commonly, they are sold in the sodium form. If they are to be used in radwaste systems, they often need to be washed thoroughly to remove excess sodium hydroxide. Otherwise the sodium hydroxide will consume the capacity of any hydrogen form cation resin in the system.

Zeolites are granular materials that are seldom treated during the manufacturing process to remove fines. Even when they are, there is a possibility that more will form during shipping. ***These should be removed by backwashing before use.***

2710

How do you calculate the operating capacity of ion exchange systems?

Low-level radioactive waste systems are operated in two different modes. In one of these, the effluent is discharged and the unit is continued in operation until the radioactivity in the treated effluent reaches some preset level. It is very difficult to calculate an operating capacity for these system because the total ion concentration, the ratio of ions relative to each other, and the ratio of soluble to insoluble radioactivity usually varies from day-to-day. Sometimes this variation may be several orders of magnitude, and one spill somewhere in the plant may upset a system that might have run for several weeks longer had the spill not occurred.

In other systems the effluent from the low-level radioactive waste treatment system is reused, usually in place of makeup water for the condensate system. In those systems, conductivity, silica breakthrough, or sodium leakage are used as signals to terminate the run. In such cases, manufacturer's data may be used to predict the breakthrough if a regular analysis of all the ions in the influent is made.

A general approach for estimating the capacity of ion exchange systems in radwaste applications is to measure the conductivity in each collection tank treated through the system. The product of the number of gallons treated and the conductivity of each batch, in combination with a conversion factor, will result in a reasonable estimate of the operating capacity in a given application. A typical conversion factor determined for several plants was 0.0079 meq/liter/μmho/cm. Thus, the capacity used by a collection tank batch of 20,000 gallons with a measured conductivity of 30 μmho/cm would be calculated as:

(20,000 gal) (3.785 gal/l) (0.0079 meq/l/μmho/cm) (30 μmho/cm)
= 17,940 meq (or 17.9 equivalents)

The trouble with radwaste influents is that, unlike a raw water supply, their total ion concentration as well as the nature of the included ions may vary by orders of magnitude from batch-to-batch. Since leakage from anything but a newly installed bed will increase as the influent concentration increases, premature breakthrough or short runs are not uncommon in these systems. This is true even when sufficient analysis is available to predict capacity.

Reactor water cleanup units represent an even more complex system, since their main function is the control of corrosion products and, in some systems, maintaining water chemistry in a specified range. In most cases, their run length depends upon the rate of production of these impurities. In some systems, the buildup of radioactivity in the resin is a limiting factor. Others, such as the lithiated mixed beds, may have their runs terminated by chloride leakage. Some plants simply replace resin on a time basis or because they are shut down for other reasons. Calculations based on RWCU capacity are seldom, if ever, made in conventional water treatment terms, although new resins should be checked to be certain that the minimum capacity exists.

2711

How do you optimize resin performance in a conventional ion exchange system?

Whether the system is conventional or unconventional, the time and place to optimize its performance is before it is purchased. The primary steps in providing optimum performance are:

1. the size of the unit;
2. the mode of its generation;
3. the flow rate through the unit;
4. the selections of the resins to be used; and
5. the number and configuration of the beds.

Once the system is built, one can sometimes improve its performance by:

1. changing the resin types;
2. removing contaminants that will foul the resins (e.g., crud and TOC);
3. slowing down the flow rate; and/or
4. increasing the amount and/or frequency of regeneration.

In such cases it is necessary first to look at the state of resins after regeneration and again after exhaustion. Such studies may be as simple as finding that a mixed bed has not separated and, hence, is not being regenerated at all. It may be that the resin itself has degraded and is no longer capable of exchanging ions in the anticipated manner. It may be that the units are overrun so that the amount of regenerant leaves too high an ion content behind. Resins also may have become fouled with metals or organics. Indeed, there may no longer be the amount of resin intended in the unit. Stories are told of cases where no resin at all was ever charged. In any event, many of these problems are correctable to give improved results.

In short, the initial step to optimizing an existing unit is to figure out why it does what it is doing, or perhaps better said, why is it not living up to expectations.

2712

How do you determine the optimum flow rate of an ion exchange system?

The optimum flow rate is always as slow as possible. This ensures the maximum residence time and, consequently, the maximum removal for ions in solution. The tight rope that one walks is strung between the amount and quality of water required per unit time and the cost of the system including initial installation and operating costs. Normally, some minimum flow rate is recommended to prevent channeling or other maldistribution of flow through the resin bed.

With the requirement that a certain amount of water is needed per unit time, reducing the flow rate means larger or more numerous units are needed to keep up with the volume of water to be processed. This will, of course, increase the capital cost. This cost will be offset somewhat by higher efficiency of resin utilization at lower flow rates and less frequent regenerations of a given unit. Chemical usage, however, will remain essentially the same, as this is dependent on the ion load on the system.

It is possible to balance these cost factors if given a good analysis of the water to be treated and the purity requirements for the treated effluent. Care must be taken to factor the characteristics of the resin to be used and the configuration of the units into the equation. Where very low solids water is being treated at ambient temperatures, some consideration should be given to the fact that *it is the regeneration process that keeps bacterial growth in check and that service cycles that are too long may develop problems with growth of organisms.* The additional fact that the water in a condensate system is boiled eliminates this problem in most power applications.

2713

What methods can be used to precisely control pH adjustments in make-up demineralizers?

Most makeup demineralizers consist of at least:

- a cation bed with the resin operated in the hydrogen form,
- a strong base anion resin operated in the hydroxide form, and
- a mixed bed composed of a mixture of these two.

If these beds are properly sized in relation to each other and to the ion content of the water being treated, the effluent pH should be as close to seven as it is technically possible to measure.

Note: *It should be pointed out that pH measurements in high purity water have little or no meaning even when on-line sensors are used.*

There are makeup systems that contain additional types of resins. If these are followed by a properly constituted mixed bed, the effluent pH from the anion system should be neutral. If a mixed bed is not used, however, the pH will often be high at the beginning of the run, may drift lower, and may even end up slightly acidic toward the end of the run, particularly if the run termination point is silica leakage.

Installation of a properly balanced mixed bed is the conventional way of producing an effluent that is neutral. Regrettably, many unbalanced mixed beds are being used in today's plants due, apparently, to a lack of understanding of the fundamentals of their operation. A properly balanced mixed bed has one cation-exchanging group in the hydrogen form for every anion exchanging group in the hydroxide form. ***This does not mean one volume of cation resin mixed with one volume of anion resin.*** A typical cation resin has about 1.6 times as many functional groups per unit volume as typical anion resin in the hydroxide form. (There are 1.8 milliequivalents per milliliter for the cation resin and 1.1 milliequivalents per milliliter for the anion.) Thus, a balanced mixed bed is closer to 1 part cation to 2 parts anion by volume. There are units in existence that are actually 2 parts cation to one part anion. These have very short service cycles and an inclination to produce a low pH effluent.

If one is faced with entrenched anti-mixed bed sentiment, the pH can sometimes be controlled by finishing the train with a weak acid or a weak base unit. This is more frequently seen in process stream recycles than in conventional makeup applications.

2714

How do you decide which resin to use in a specific system?

In radwaste applications, the goal of resin selection is to achieve the required effluent quality with a minimum quantity of resin consumed. With this goal in mind, there are two fundamental questions that must be answered:

1. What are the concentrations of the radioactive and nonradioactive ions in the water to be treated?

2. What is the desired quality of the effluent from the system?

In other words, what are the impurities in the waste water, what level of what impurities can be tolerated in the effluent, and what is going to be the run-terminating ion (including its concentration)? With a defined influent and effluent, the resin selection can proceed.

Depending on the influent, standard strong acid and strong basic cation and anion resins may be appropriate. However, the weak acid and weak base resins, followed by strong acid and strong base resins, may be beneficial in achieving larger capacities. Selective resins, in combination with strong acid and strong base resins, may be useful in removing Cs-137.

2715

What parameters should be included in a specification for an anion resin?

As a minimum, an anion resin specification should include:

1. A clear statement describing the material to be purchased in generic terms, including the type of polymer, porosity, functionality and ionic form.
2. A range for water retention in a specific ionic form as well as for as received solids if the hydroxide form of a strong base resin is purchased.
3. A minimum total anion exchange capacity. Most writers do this in milliequivalents per milliliter but milliequivalents per gram dry, or gram wet, in the case of the hydroxide form of strong base resin, is a much more fundamental number. Using both does not hurt.
4. For hydroxide form strong base resin, a minimum percent of sites in the hydroxide form. For many nuclear applications, this usually is accompanied by the maximum percentages of sites for carbonate, chloride and sulfate ions.
5. A desired particle size. What this is and how detailed it is determined by the intended use. Consider that it is nice to know the size of the resin that goes into the unit as well as what is being kept out.
6. A shipping weight, usually as a minimum number of pounds per ft^3. This is also called "backwashed and settled density" in test methods. Resins are actually packaged by weight instead of volume.
7. A maximum total ash if the resin is destined for direct nuclear operation without regeneration. Sodium is the primary metal to worry about in an anion resin purchased in the hydroxide form.
8. A minimum whole bead content. (Beds with 100% beads are not necessary for many, if not most, applications.)

2716

What parameters should be included in a specification for a cation exchange resin?

As a minimum, a cation resin specification should include:

1. A clear statement of the kind of resin you wish to buy and the ionic form it is to be in.
2. A range for water retention capacity in the form in which it is being purchased (since this is the best indication of cross-linkage).
3. A minimum total exchange capacity. Most writers do this in milliequivalents per milliliter but milliequivalents per gram dry (or wet) is a more fundamental number. Using both does not hurt.
4. A desired particle size. What this is and how detailed it is determined by the intended use. Consider that it is nice to know the size of the resin that goes into the unit as well as what is being kept out.
5. A shipping weight, usually expressed as a minimum number of pounds per ft^3. This is also called "backwashed and settled density" in test methods. Resins are actually packaged by weight instead of volume.
6. For any resin that will not be regenerated before it is put into service, a maximum water extractable content. Again, whether this is measured as total weight, as organic carbon or as some specific entities will depend on the intended use.
7. A maximum total ash if the resin is bought in the hydrogen form. This will control the percent regeneration more precisely than the method written to determine that parameter. For certain applications, maximums for specific ash components may be added.
8. A minimum whole bead content. (Beds with 100% whole beads are not necessary for many, if not most, applications.)

2717

Do mixed bed resins have the same specifications as resins used in separate beds?

Yes and no. If the resins are purchased separately for use as components of a regenerable mixed bed, the parameters in the specifications are the same as those for separate beds. The difference usually lies in a more careful specification of the particle size to eliminate cation fines and to make certain that the anion and cation are sufficiently different in size to separate properly. *The mean size of the anion should be smaller than that of the cation.*

If resins are purchased premixed and are intended for a single-use—as is the case in most BWR polishing systems and in radwaste deep beds—the intent of the specifications is usually similar, but the way they are written is different. The resin types should be clearly specified, of course, as should their ratio in the mixture. There is a specific method in the ASTM system (D-4548) that measures this ratio if it is expressed in milliequivalents (as it should be).

If the ratio is right, then the capacities of the components are likely to be right. Anionic impurities may be specified and checked in the mixture as easily as they can for the anion alone. Ash can also be specified and determined on the mixture. Perhaps surprisingly, the particle size of the mixture is of little importance unless, overall, it is so small that the pressure drop is excessive or so big that the bed capacity is low. It does not matter what the relative sizes of the anion and cation resins are.

It is possible to specify what the operating capacity of a resin mixture shall be by a procedure (ASTM D-3375) that dates from the beginning of their use in polishing applications. While this method will compare one batch of resin with any other, the numerical values obtained from it should not be converted into expectations for run length in either a radwaste bed or a condensate polisher. Both of these terminate their service runs at leakage levels a thousand and sometimes hundred of thousands of times lower than the end point in the test method.

2718

What ionic forms of ion exchange resins should be used for radwaste treatment?

In general, strong acid resins used in radwaste are introduced into the system in hydrogen form, so that the only ion released in the exchange process with them is hydrogen. They are then coupled with strong base resins in the hydroxide form or weak base resins used as free bases, so that the only product formed in the treatment of the waste is water.

An exception to this is when weak acid cation resins or silicates are used. If weak acid cation resins are to function properly, they either must be converted to some salt form or the solution that they treat must be adjusted to produce a high pH influent. When silicates are used, they are generally in the sodium form. This is not a problem if their effluent is destined for discharge. If a deionized effluent is required for reuse, however, these materials must be followed by a hydrogen form strong acid resin to remove the sodium liberated.

2719

What factors govern when a radwaste ion exchange system is removed from service?

The principal factor governing the end of a service run is what is going to happen to the effluent.

If the effluent is being discharged from the plant site, the unit is run until it no longer meets the permitted limits for radioactivity, either when discharged directly or when mixed with nonradioactive streams. These limits may be total radioactivity or limits for a specific isotope.

If the effluent is being reused as feed for the boilers and is discharged into the hot well, it can be run only until its characteristics—such as conductivity, sodium, silica, and total organics—meet those imposed on the water from the makeup system. It is usually expected that these will be exceeded before reaching the limit on radioactivity.

If the effluent were fed back to the beginning of the makeup water treatment system, it is likely that longer runs of the radwaste system would be possible. Normally, even when the resin is taken off line, the quality of the effluent is considerably better than that of the raw water supply. If radioactivity is not present in the effluent, there is an overall advantage in total waste generated if the effluent can be substituted for the raw water used in most systems.

2720

Can ion exchange systems be used past the conductivity end point?

If the water is not to be reused in the plant and the radioactivity level is below discharge limits, the radwaste run is normally continued past the conductivity end point. In such a case, the run continues until the radioactivity in the effluent reaches unacceptable levels.

2721

How do you determine the rinsing endpoint for removal of resin fines?

This question indicates some confusion in the terminology used in operation of ion exchange units. The operation during which fines are removed is the backwash step at the completion of the service run. This involves flowing water in a countercurrent direction ("upflow" or backwards) through the bed to expand it and wash out the fines.

In many units, the removal of resin fines is done on a time cycle. If excess fines are a problem and need to be removed, they are usually monitored visually. Many units have a sightglass in the backwash line that permits this. If this is not possible, a labor-intensive effort is often necessary to collect and examine the effluent.

Rinsing, of course, is the operation that follows regeneration. Even in a bed that has an upflow regeneration, rinsing is not conducted in a way that expands the bed. Hence, no resin fines removal occurs during the rinsing process.

2722

How do you improve condensate polisher performance to reduce radwaste?

For BWRs, the first step would be the determination of what the limiting parameter is in the performance of the existent polisher. More is needed than just a generalization that the units go off on pressure drop or high conductivity. What is necessary is a determination of what the "crud" is if pressure drop is limiting the polisher's run. If the run terminates on water quality, it is necessary to know specifically which ion or ions are causing the high conductivity. Certainly one should at least find out if it is due to anions or to cations.

A more fruitful but more experimentally challenging approach is to look at the degree of exhaustion of the resin phase when the bed goes out of service. This is now done routinely in PWR and BWR condensate polishers. The questions to be answered by such an analysis are what the relative degree of utilization of cation and anion exchange capacities have been and what ions have been involved. In some cases, it has even been possible to study the flow patterns within the unit.

The trouble is that few, if any, condensate polishers in use in BWR plants have any provision for being sampled. New units are being built with sampling capability, and it is expected that studies of samples take from them will be of value to the industry in general.

There is a move afoot to provide double protection in BWR condensate systems by installing fine filters for crud removal with deep beds following them. This lets each component in the system concentrate on what it can do best. A thin layer of resin on a filter is not the optimum configuration for the removal of ions; nor is a deep bed of bead form resin coated with crud. And, in the latter case, transfer of resin out of and back into the service vessel not only disturbs the exchange zone but often results in the separation of the resins involved so that the system no longer exhibits the properties of a mixed bed.

As a general approach, the improvement of condensate performance for radwaste warrants the establishment of a group effort including chemists, design and operating engineers and, of course, those interested in cost considerations. Having outside input by experienced experts usually pays off as well.

2723

What is the economic impact of using spent condensate resins in the radwaste system in a BWR?

The use of "spent" condensate resins in the radwaste system not only reduces the cost of buying fresh resin but has the potential of cutting the volume of radioactive resin that must be disposed of by as much as 50 percent.

Consider that a typical "spent" condensate resin in a BWR must, by regulation, still has 50% of its initial operating capacity left. It is more likely, by actual analysis, to have its run terminated because it fails to produce water within specification when it still has 75% of its potential left. The magnitude of the economic benefit will depend somewhat on what ratio of resins was used in the condensate polishing system. A condensate polisher charge with a cation:anion ratio of 2:1 will require the addition of some fresh anion resin in the radwaste system if the maximum capacity of the cation resin is to be consumed.

At that point, the existing plant design and equipment configuration becomes a major cost factor. This leads to the following plant-specific questions:

1. How difficult is it to move used condensate resin to the radwaste system?

2. If spent condensate resin now goes into a common holding tank with spent radwaste resin, can that transfer system be diverted into a separate tank to feed the radwaste tank? (The contents of a single condensate polisher may fill the radwaste tank several times.)

3. How much capacity is really left in your spent condensate resin?

4. Will it be necessary to remix the resin at the radwaste treatment site?

These are only a few of the parameters that must be vectored into the economic picture. They all were addressed recently at one site by a committee of chemists and engineers with extensive ion exchange experience in process design, equipment design and plant operation. The technical problems appear to be solvable, and, in view of current and escalating disposal costs, the installation cost payback is attractive.

2724

How can I transfer BWR condensate resins into radwaste?

Transfer the resin to a suitable container and transport the containers to the radwaste area. Presumably, at that point, they would be handled much like new resin with the addition of contamination and ALARA controls. The trick in doing this is to keep the resin mixed at roughly the ratio that it was used in the condensate system. This is not always easy when resins that are designed to separate easily have been used in the system.

A second method is to install the necessary transfer lines and sluice the entire condensate bed into a new resin transfer tank sized to hold one or more bed volumes. The tank will require a mixing capability and both resin and water level sensing instrumentation. The system can be designed to transfer an entire bed or a partial bed to the radwaste demineralizer.

Of course, such a system would require the capital cost of the piping, tank, and instrumentation, and it would require additional building space for the transfer tank. However, it is likely that, for many plants, the capital costs could be justified based on the significant benefit of re-using the condensate resins in radwaste.

2725

What are the technical and economic considerations for regeneration of ion exchange resins?

This question does not pertain to resins that are used in the treatment of waters containing radioactive ions. Regeneration of resins that have been used to remove a miscellaneous population of radioactive isotopes is generally not considered to be economically practical. The regeneration procedure requires the use of concentrated solutions of acids and bases which, when contaminated with radioactivity, represent a more expensive disposal problem than the resins themselves do.

That is not to say that resins used to pick up radioactive isotopes cannot be used in regenerable systems. However, when they are, it is usually when the radioactive isotope—such as uranium-235—is a major constituent in the waste and is recoverable in economic concentrations from the spent regenerant. In ordinary radwaste treatment, the radioactive components are overwhelmed by the concentration of nonradioactive components, such as sodium, calcium and chloride, and are not recoverable even when they might have economic value.

Some newer plants employ an HPD evaporator/crystallizer to concentrate radioactive regenerant solutions. The presence of a crystallizer can turn the economic equation in favor of regeneration. This concept recognizes that resins are expensive to replace, and chemicals are relatively cheap. In the presence of a crystallizer and a commercially available resin volume reduction (RVR) system, the radioactive evaporator bottoms can be treated to produce drums of "dry radioactive salt." The volume of the salt drums is far less than the volume of single use resin that would be generated without regeneration. Such drums also can serve as a convenient container for long term storage (i.e., easier remote handling than for commonly used steel liners). Of course, this assumes that the containers will also satisfy long-term integrity and industrial packaging requirements.

The regeneration of resins used in ordinary water treatment is a well established engineering technique that permits the resins to be used over and over again. The cost of regeneration is highly variable depending on:

- What is in the water to be treated?
- How much of it is present?
- What must the purity be of the treated water?

It also depends upon the type of system (that is, single or mixed bed units) in which the resin is used. All resin manufacturers publish technical notes that permit the cost of a regeneration system to be estimated based on the type of resin used, the ion population in the water to be treated, and the water quality desired. Even though the waste regenerants will not be radioactive, the cost of their disposal must be considered in the design of the system.

SECTION III

(2800 SERIES QUESTIONS)

SPECIAL ION EXCHANGE APPLICATIONS

Section III Contents

Special Ion Exchange Applications

Item Topical Description **Item Number**

Listing of Illustrations

2801

What resins can be used for pH control?

Any resin can be used for pH control depending on what level of effluent pH is desired. If one desires an acidic pH, using the hydrogen form of a sulfonic acid cation resin will produce it. If the solution is already acidic, the free base form of most weakly basic anion resins will pick up the acid, producing effluents with pH values between 4 and 8 depending on what is in the water and which resin is used.

Strong base resins, on the other hand, will produce an effluent with a high pH if fed a neutral water. When its influent is acidic, it will produce an effluent that is essentially neutral . If one wishes to make an alkaline solution neutral, either a sulfonic acid cation resin or a carboxylic acid resin in the hydrogen form will do it. If a carboxylic resin is used, some care must be taken to allow for its volume charge. If a sulfonic acid resin is used and the influent contains neutral salts as well as alkaline components, the effluent will be acidic reflecting the conversion of salts into the corresponding acids.

Usually when one talks of controlling pH, the intent is to produce a neutral effluent or at least one in the 6-8 pH region. To do that, a mixed bed is usually the resin system of choice. By combining the hydrogen form of a strong acid resin and the hydroxide form of a strong base anion resin, excess acidity or basicity is removed simultaneously even when salts are also present. As a result, an effluent that is not only neutral but deionized is produced.

2802

What resins produce pH shifts?

Any resin can produce a pH shift depending on how and what liquid is processed. They do this in several ways. They may exchange a neutral cation or anion for hydrogen or hydroxide ion from the resin's functional groups, This produces an acidic effluent if a hydrogen ion is released to the solution. It will produce a basic effluent if a hydroxide ion is exchanged.

If the resins treat an influent containing strong acids, such as hydrochloric or sulfuric, they may simply pick up the acid if a weakly basic anion resin is used. On the other hand, the resins will neutralize the influent if the hydroxide form of a strong base resin is used. Alkaline influents can be neutralized with hydrogen form cation resins.

2803

How is suspended matter removed from radwaste?

Some systems remove suspended matter directly in the deep bed ion exchange unit. This is not as efficient a process as removing it separately on a device designed to be a filter. This could be strictly a device of controlled porosity or a filter system provided with a renewable coating of ion exchange resin, diatomaceous earth, or cellulosic filter acid.

One problem encountered in the use of controlled porosity filters is that the systems are frequently equipped with filters too porous to retain the particles that cause the real problems in the radwaste system. Of course, any type of filter generates a radioactive waste that must be dewatered before it can be disposed economically. Nothing is really easy in radwaste treatment.

2804

How are soluble organics removed from radwaste.

The best way to remove soluble organics from radwaste is not to let them get in. This is particularly true of low molecular weight solvents like methyl, ethyl and isopropyl alcohols which are completely miscible with water and almost impossible to remove from it. But low molecular weight chlorinated solvents also are surprisingly soluble in water. Carbon tetrachloride (to select just one example) dissolves to a concentration of 800 ppm. These will be picked up by activated carbon, but the capacity of the carbon for them is very low.

Organic surface active agents of all types are things to be kept out of the liquid process stream if at all possible. Those that are anionic or cationic will be removed by the ion exchange resins. However, they occupy a lot of space on the resin surface and, thus, inhibit the exchange of smaller ions. They are generally removable on carbon. Non-ionics—and many of the common laundry materials are non-ionic—are just plain hard to remove.

2805

How do you optimize the LRW for selective radionuclide removal?

This question implies that the effluent from the liquid radwaste treatment system will be discharged rather than be reused. Even when that is the case, the total population of ions in the radwaste is an important parameter, including simple nonradioactive ions like sodium and chloride. These ions inevitably compete with the radioactive ions—no matter how selective the material used in the radwaste system is—because they are usually present in concentrations that may be a million times more than those of the radioactive components.

Therefore, the first step is to find out what is in the liquid waste stream being treated and where the nonradioactive components come from. Anything that can be done to minimize the concentration of the materials that get into the radwaste tank will be a plus in the run lengths of the ion exchange system.

There are materials with high specificity for certain radioactive ions that may be added to an existing radwaste system. A study of EPRI reports like NP-5099 and NP-5786 will reveal some of these. Many of these materials may be tried easily in a real system by simply layering them on a standard mixed bed. Some also lend themselves to trial in powdered resin systems.

An optimization study should also include particulate material and water immiscible organics. Frequently a major percentage of the radioactive load is in the insoluble or particulate population which can be removed by the installation of a better filter. Frequently, this material is not picked up efficiently in a deep bed ion exchange system, and, by slipping though the ion exchanger, produces a radioactive effluent that terminates the run.

2806

How do you remove antimony-125?

The best answer to this may be that we do not know. Antimony has some rather complicated dilute solution chemistry. There is a strong possibility that, in a neutral system, it is not ionic but exists as some type of a hydrous, oxygen-containing blob. If chlorides are present, antimony might also be present as SbOCl, which is not ionic.

In a given plant, if antimony is a problem, a little experiment comparing hydrogen form cation with hydroxide form anion and traditional mixed bed resins may be helpful in guiding you to the best system for removing antimony. However, don't be surprised if it ignores all three; it may be insoluble, existing as small particulate matter in a colloidal state.

Antimony-125 **(Sb-125)**	
Oxidation States +5, +3, -3	
Radiological Decay	
2.73y	β, γ

2807

How do you remove cobalt-60?

Cobalt is one of those elements that has delighted the inorganic chemist's heart from the beginning of chemical time. It reacts with all sorts of things forming ionic complexes that, in many cases, are excitingly colorful. Even the blue color that most people assume is simply a Co^{+2} cation is really a complex with water $Co(H_2O)_6^{+2}$. Add a few molecules of ammonia, and the water gets displaced with NH_3 while the color gets progressively bluer.

Further, cobalt exists as both Co(II) and Co(III). The latter, in the presence of the right partners, forms quite stable anionic complex ions. One of these partners is carbonate forming $Co(CO_3)_3^{-3}$. Therefore, the common assumption that cobalt is a divalent cation and should be removed on a cation resin or a cation- rich mixed bed may not always be true. Indeed, the work at Millstone (EPRI Report NP-5099) suggested that, for the Millstone system, an anion-rich mixed bed would be more efficient for cobalt removal. The subsequent full plant trial (EPRI Report 5991) confirmed this.

To complicate matters still further, some of these complexes can have no charge at all and slide right through an ion exchange system.

Cobalt-60 **(Co-60)**	
Oxidation States **+3, +2**	
Radiological Decay	
5.258y	β, γ

2808

How do you remove cesium-134 and cesium-137?

The EPRI study at Millstone detailed in EPRI report NP-5991 describes the use of a synthetic zeolite in the sodium form as a layer on top of the mixed bed for removal of the two cesium isotopes. This proved to be a highly successful operation.

Another material with high specificity for cesium is a sulfonic ion exchange resin made from phenol. It is generally called a methylene sulfonic acid resin, because there is a methylene group between the sulfonic acid and aromatic ring. Similarly, cationic polymers with phenolic and carboxylic functionality show great specificity for cesium. Like the zeolites, however, they must be operated on an alkaline influent or be used in the sodium form.

Any one of these materials can be used as a layer on top of a conventional mixed resin bed. About ten inches is a recommended thickness. The mixed bed then picks up any sodium shed by this top layer.

Cesium-134 **(Cs-134)**	
Oxidation States **+1**	
Radiological Decay	
2.06y	β, γ

Cesium-137 **(Cs-137)**	
Oxidation States **+1**	
Radiological Decay	
30.2y	β, γ

2809

How do you remove strontium-90?

Strontium 90 is usually encountered as a soluble cation. There are three cation exchanging materials that have been tested and shown to have an unusual affinity for Sr-90. One is a resin that is usually called a methylene sulfonic cation resin. It is still available if you look hard enough.

Another possibility is a large pore zeolite of the mordenite type. These are available as synthetic materials with a 20-50 mesh particle size. These were used as an overlay, primarily for cesium, in the EPRI study at Millstone. There is also a resin containing carboxylic and phenolic groups that is used for Sr-90 removal. These last two have the disadvantage of requiring that the solution they treat be alkaline. Otherwise, they need to be converted to the sodium form prior to use. This, of course, results in a sodium-containing effluent which, if the water is destined for reuse, must be further treated to remove it.

Strontium-90 **(Sr-90)**	
Oxidation States **+2**	
Radiological Decay	
28.9y	β

2810

How do you remove iodine-131?

It is nice to discuss an atom with at least some degree of predictability. Iodine has the possibility of existing in the whole range of oxidation states from -1 to +7. However, in low concentrations in water, there is a high probability that the influent will be anionic. Therefore, a strong base anion resin in the hydroxide form is used to pick up the iodine. This will even pick up iodine present as I_2.

However, it should be kept in mind that the iodides of Ag(I), Cu(I), Hg(I) and Pb(II) are quite insoluble. Where they may be present, iodide may be carried with them as a colloid that is very difficult to remove.

Iodine-131 **(I-131)**	
Oxidation States +7, +5, +1, -1	
Radiological Decay	
8.065d	β, γ

2811

How do you remove silver-110?

Silver has a habit of not staying in solution in ion form unless the solution is quite acidic. Not only does it form colloidal silver hydroxides, but, if there is any concentration of halides—chloride, bromide or particularly iodide—present, these may also be associated with the silver as non-ionic materials. To complicate things still further, silver forms a large number of complex ions, some of which are cationic and others of which are anionic.

Therefore, if silver-110 is a problem in a particular system, a bit of pilot plant work with the real waste is in order. Just comparing a cation bed in the hydrogen form and an anion bed in the hydroxide form with the usual standard mixed bed should provide some clues as to how it is best removed.

Silver-110 (Ag-110m)	
Oxidation States +1	
Radiological Decay	
253d	β, γ

2812

How do you remove niobium-95?

If you have to make a guess about the ionic state of niobium, guess that it isn't ionic. Like most transition metals, niobium has a handful of oxidation states ranging all the way from -3 to +5. However, it doesn't form a good cation in any of them, and it only forms a water soluble anion in an alkaline solution.

Consider that niobium sits between zirconium and molybdenum in the periodic table. Like them, niobium is more inclined to exist in pure neutral water as a large, fluffy collection of more than one niobium atom bedded in multi-oxygens. These probably do not ever ion exchange but are rather coagulated or precipitated on a resin surface (which could theoretically be either the anion or the cation).

Niobium-95 (Nb-95)	
Oxidation States +5 , -3	
Radiological Decay	
35.1d	β, γ

2813

How do you remove ethylene glycol?

Generally, the only hope here is to use activated carbon that has, at best, a very low capacity for things as water miscible as ethylene glycol. As a matter of fact, ethylene glycol, methanol, ethyl alcohol and propanol-2 are probably harder than anything else to remove from water.

One utility has reported some success in removing ethylene glycol through the use of reverse osmosis. However, the best approach is to identify the potential sources and implement a program to keep all of them out of the liquid process stream.

2814

How do you remove cement leachate?

Cement leachate is like any other inorganic material: ions, primarily calcium, sodium and carbonate. These will easily be removed by the mixed bed resins. If the leachate contains particulate material or colloidal silica, a filter will take care of them.

2815

Can you process reactor building sump water containing trisodium phosphate?

The answer here depends on how much trisodium phosphate is involved. Trisodium phosphate is a great cleaning agent, because it is easily and efficiently removed by ion exchange. But at high concentrations, it is as strongly alkaline as sodium hydroxide. At concentrations over 500 ppm or in large volumes, it would be better handled in a two-bed operation with hydrogen form cation resin followed by a high capacity weak base anion resin. The effluent should then be polished by a mixed bed. This approach is preferable to using a relatively low capacity mixed bed.

SECTION IV

(2900 SERIES QUESTIONS)

FUNDAMENTALS OF FILTRATIONS

Section IV Contents

Fundamentals of Filtration

Item Topical Description **Item Number**

Filtration Principles

Precoat Materials and Applications

Filter Aid Materials and Applications

Using Filter Aid Materials in the Condensate and RWCU Filter/Demineralizers

Listing of Illustrations

Illustration Topical Description **Figure Number**

2901

What is the objective of radioactive liquid filtration?

Filtration can be provided for one of three separate functions in a radioactive system:

1. **Roughing or prefilter service** — This service is intended to prolong the life of a downstream component (e.g., an ion exchanger, deep bed filter, or fine filter). This filter should remove or screen out particulate matter that would cause a high differential pressure (DP) prematurely on the downstream component.

2. **Resin trap** — This service is intended to remove resin fines which could damage downstream equipment or adversely affect effluents.

3. **Particulate activity removal** — This service is intended to remove particulate activity from the liquid that passes through the filter. This service is also performed in combination with the two preceding services.

2902

What type of filters are available for radioactive particulate?

Many types of particulate filtration systems have been used in operating power plants. The most common are:

- Cartridge filters
- Precoat backflushable filters
- Bag filters
- Deep bed media filters (e.g., activated charcoal)
- Etched disc backflushable filters
- Ultra-filtration (UF)
- Reverse osmosis (R/O) membranes
- Hollow fiber filters

Cartridge filters are primarily used in PWRs, whereas **precoat filters** are primarily found in BWRs. This difference in selection is based upon the high suspended solids content of BWR radioactive liquids.

Bag filters and deep bed filters have been used primarily in liquid radwaste systems.

Etched disc filters have been used in spent fuel pool and radwaste systems.

UF and R/O membranes have been used in boron recycle and laundry systems.

Hollow fiber filters have been used to replace or substitute for precoat filters to reduce solid radwaste generation.

2903

What type of pretreatment options are available to remove particulate activity?

Generally, a portion of the cobalt activity will exist in a particulate form that cannot be removed by ion exchange and may require filters with pore sizes as low as 0.2 microns. Removal of particulate activity can be enhanced by pretreatment.

For example, particles can be solubilized by **adjusting the pH** so that the activity can be removed by ion exchange. Extreme pH conditions, however, greatly reduce the capacity of ion exchange media. In addition, particulate activity can be **treated by polyelectrolytes** to enhance the ability for ion exchange media or filters to remove the particles. Polyelectrolytes have been used by Duke Power Company, Pacific Gas & Electric Company, Indian Point, and Southern California Edison Company to remove activity on ion exchange resin or filters that otherwise could not have been removed. All four utilities experienced substantial success and at very little cost.

Pretreatments can fail when the surface charge on the particulate species change. This was the case at Diablo Canyon. After a cycle of elevated pH in the primary system in 1989, particulate cobalt activity—which was successfully removed on resin with pretreatment from 1986 to 1989—could no longer be removed. Submicron cartridge filtration had to be employed to remove the altered particulate species. It is likely that another polyelectrolyte would have been successful at destabilizing the colloidal material.

2904

What is precoat filtration?

Precoat filtration is the removal of solid particles by passing a liquid through a thin layer of filter aid material that has been deposited on the filter septum prior to the start of the filtration process. The layer of filter aid material protects the filter septum and provides a finer filter matrix for the removal of smaller particles.

The filter aid material typically has a large number of microscopic holes and passageways for the liquid to flow through. As the holes and passageways retain solids, they become plugged, reducing the number of holes and passageways for the liquid to flow through. The pressure drop across the layer increases as the number of passageways decreases. When the pressured drop reaches a predetermined value, the filtration process is terminated.

After being removed from service, the thin layer is removed, normally by backwashing the filter. A new layer is then deposited on the septum, and the filtration process is renewed. Figures 2904a through 2904c demonstrate the precoat process.

Figure 2904a
Applying the Precoat to the Filter Septu

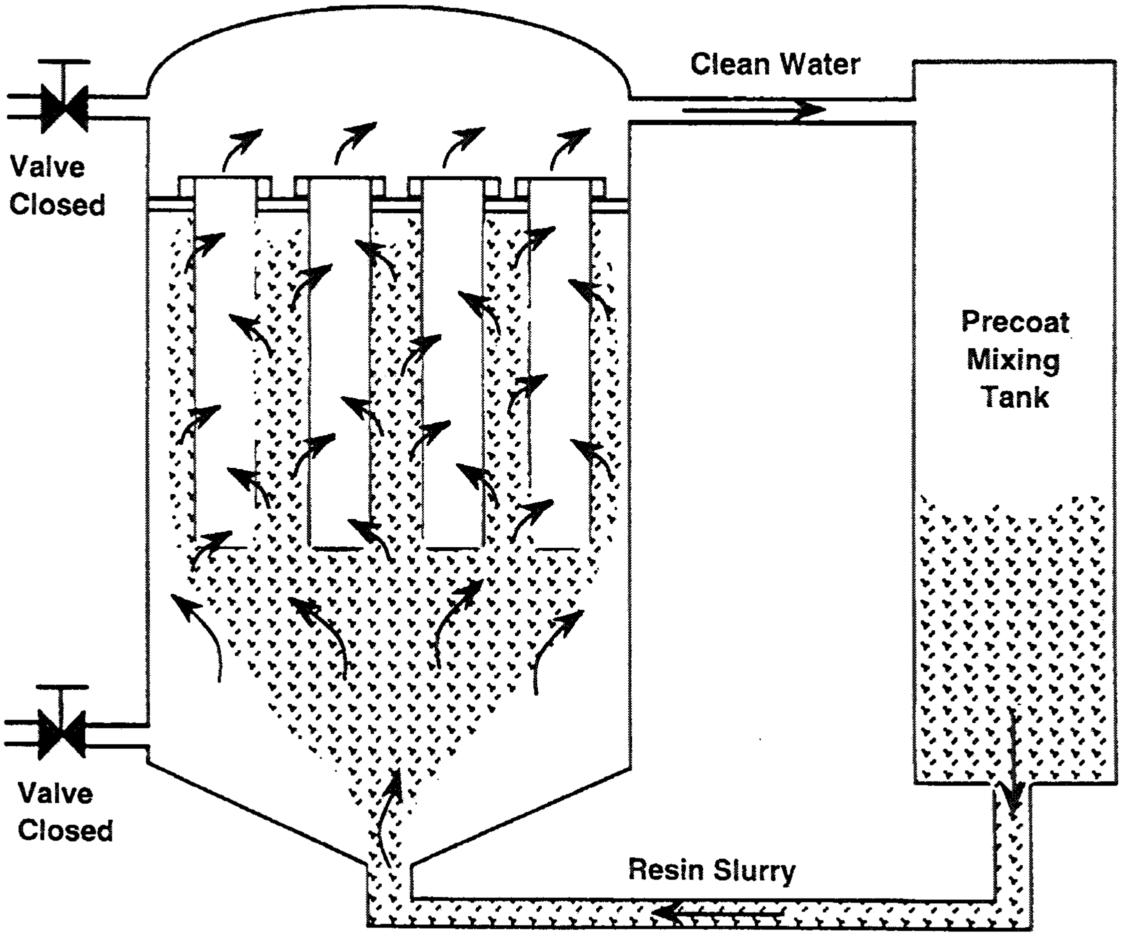
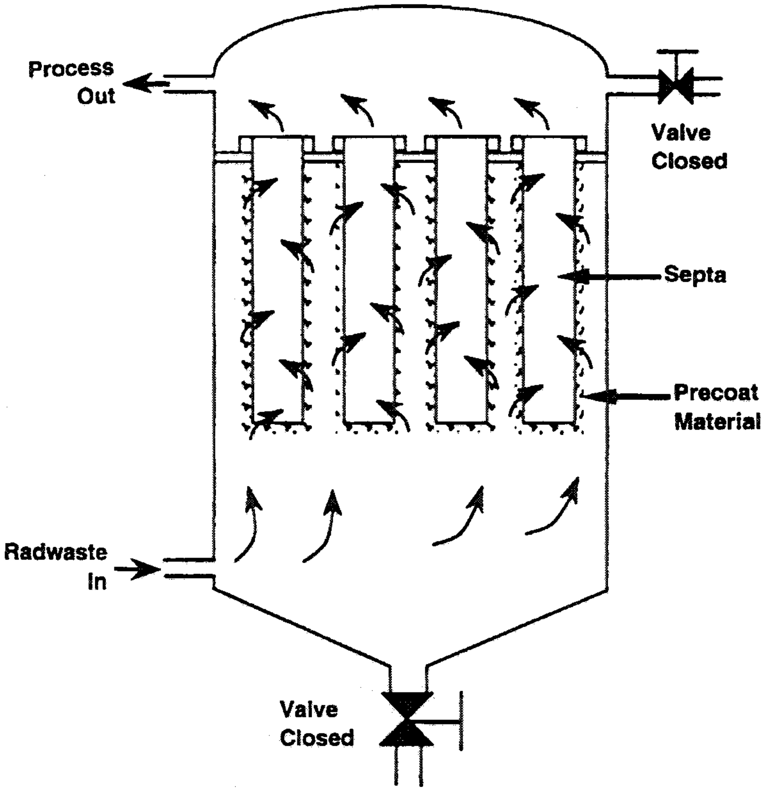


Figure 2904b
Using the Precoat with the Filter Septum



2905

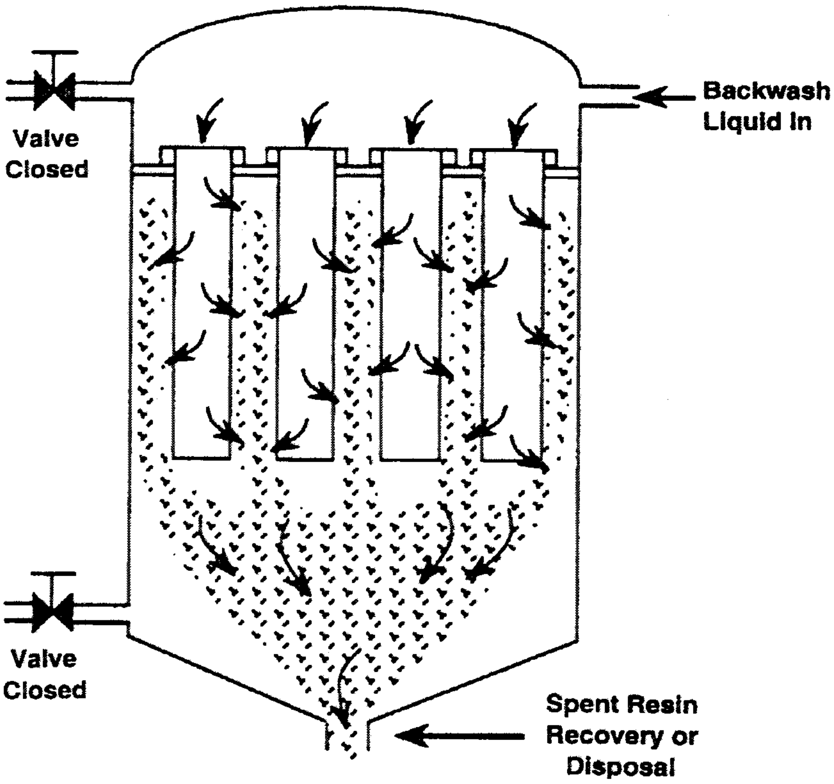
Where is precoat filtration used in nuclear power plants?

Precoat filtration is commonly used in Boiling Water Reactors (BWRs). It is used in:

1. the reactor water purification (clean-up) system (RWCU);
2. the fuel pool purification system;
3. the equipment and floor drain sub-systems of the liquid radwaste treatment system; and
4. the condensate polisher system of many plants.

Precoat filtration may also be used in the condenser hotwell clean-up system on some plants.

Figure 2904c
Removing the Precoat for Recovery or Disposal



2906

How does a flatbed filter work?

A flatbed filter is actually a large flat screen that is up to 10" wide by 60" long. The filter screen must be precoated with some type of filtration material prior to being placed in service. The precoat material may be diatomaceous earth, powdered resin, some type of cellulose fiber material, etc.

The precoat is mixed with water in a slurry and introduced onto the flatbed filter screen. Once placed in service, the precoat media will block the passage of particulate matter and, depending on the precoat material, may perform ion exchange functions.

When it is time to replace the precoat material (e.g., due to high differential pressure or a filtration automatic timing cycle), the flatbed is removed from service. Air is frequently is used at this point to dry the precoat media prior to removing it from the filter screen. This compresses the precoat media and drives out excess water. The flatbed filter screen is then automatically rolled around the filter bed until all of the precoat media has fallen into a disposal receptacle (typically a liner or a drying rack). The filter is returned to its starting position, and the precoat process begins again.

Figure 2906a
Typical Flatbed Filter Arrangement

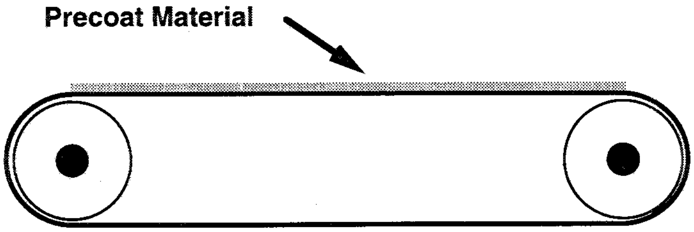
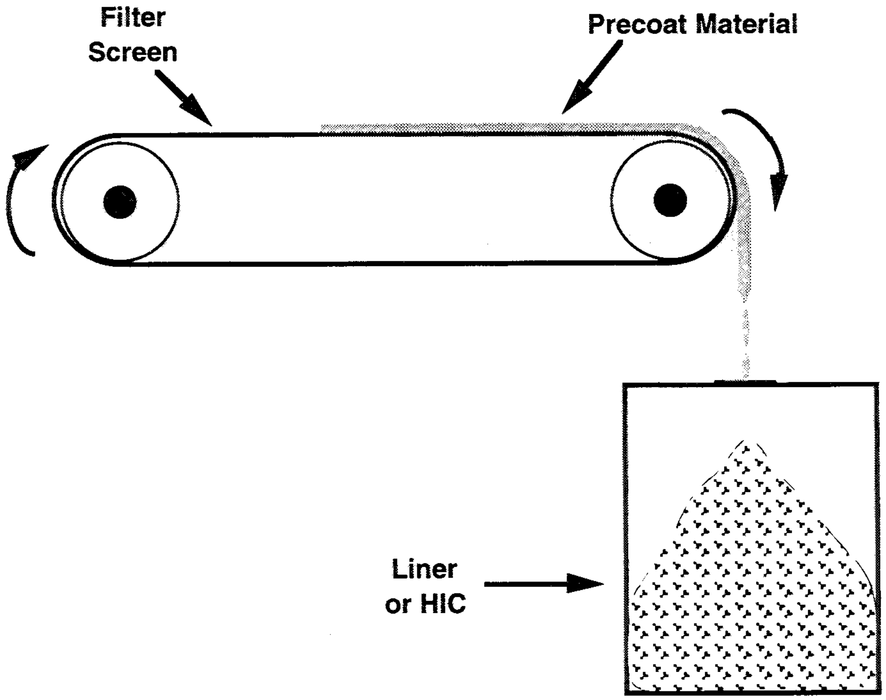


Figure 2906b
Unloading Spent Precoat from a Flatbed Filter



2907

What are typical precoat materials?

Typical precoat materials include:

- Powdered cation ion exchange resins
- Powdered anion ion exchange resins
- Pre-mixed cation-anion ion exchange resins
- Pre-mixed resin-fiber mixtures
- Diatomaceous earth
- Cellulose fiber
- Pre-mixed fiber-activated carbon mixture

2908

What are the characteristics of precoat materials?

Each precoat material has its own unique characteristics:

Powdered cation ion exchange resins

This consists of finely ground cation ion exchange resin, typically regenerated to the hydrogen form. It is normally used in combination with anion resin and is rarely used independently in any precoat application.

Powdered anion ion exchange resins

This finely ground anion ion exchange resin is typically regenerated to the hydroxide form. It also is used normally in combination with cation resin, although a few plants use powdered anion resin as an overlay to the base precoat.

Pre-mixed cation-anion ion exchange resins

This is a mixture of powdered cation and anion resins that have been pre-mixed or flocced by the supplier. The pre-mixing is done such that the floc size is controlled for lower porosity precoats. The pre-mix can be supplied in virtually any ratio of the two resins. They are used in all-resin precoat applications and, because they are pre-flocced, they don't required the use of "Sol A" in the precoat step.

Pre-mixed resin-fiber mixture

This is a mixture of powdered cation and anion resin that has been flocced together with a cellulose fiber. The resin:fiber ratio can be adjusted for the desired filtration and ion exchange properties. The ratio of cation:anion resin can also be varied, but it is typically provided at near-stoichiometric ratios. The pre-mixed resin-fiber material is usually easier to precoat. It also is less susceptible to precoat cracking in service as compared to all-resin precoats.

Diatomaceous earth

This is a mined material of a deposit of the silicified skeletons of marine organisms called "diatoms." The material contains no ion exchange material and, consequently, it performs only mechanical filtration. It is available in several particle size grades so that the grade can be selected to match the filtration application. It is typically used as the base precoat over which an overlay of an ion exchange material is applied. (Flatbed filters are an exception.)

Cellulose fiber

These are fine fibers of purified cellulose. It is essentially the same fiber as that used in the pre-mixed resin-fiber mixture. When used as the sole material in a precoat, it is very porous and exhibits poor removal efficiencies for finer particles. It is typically used as a body feed material. Its performance as a body feed material is unsurpassed by other filter aid materials.

Pre-mixed fiber-activated carbon mixture

This is a mixture of purified cellulose fiber and activated carbon. These materials are flocced together by the supplier in a pre-mixed material. The material is used both as a sole precoat material and as an overlay to a base precoat of another filter aid material. The carbon particles are extremely fine, such that if they de-floc from the fiber under agitation, they are difficult to handle in the filtration process.

2909

How do you select a precoat filter media?

A basic filtration principle is that the filter matrix should not be finer than what you need to meet your process objectives. In other words, why remove smaller particles if you don't have to, especially if it results in higher filtration costs and higher waste disposal costs.

In radwaste processing, one or more of the following objectives will dictate the selection of the type of precoat filter aid material.

1. Prevent particles from overloading downstream ion exchanger.
2. Prevent or minimize plugging of the filter septa.
3. Reduce environmental release of insoluble radioactive contaminants.
4. Reduce environmental release of soluble environmental contaminants.

Testing of the precoat material using actual waste water to determine if these objectives are met is the only way to select a precoat material. The testing could be done on the full-scale equipment. However, this is expensive and time consuming. Moreover, because the influent waste stream properties vary from batch to batch, it is difficult to make direct comparison between materials.

Membrane filter testing is an alternative to full-scale testing that eliminates the above difficulties. The screening tests can be conducted on the same influent waste water. In addition, the tests are short, inexpensive and have no impact on the performance of the full-scale equipment.

2910

What is a precoat overlay and when it is used?

A precoat overlay is an additional layer of filter aid material that is deposited on top of the precoat layer. It is applied after the precoat step and prior to the start of the filtration process.

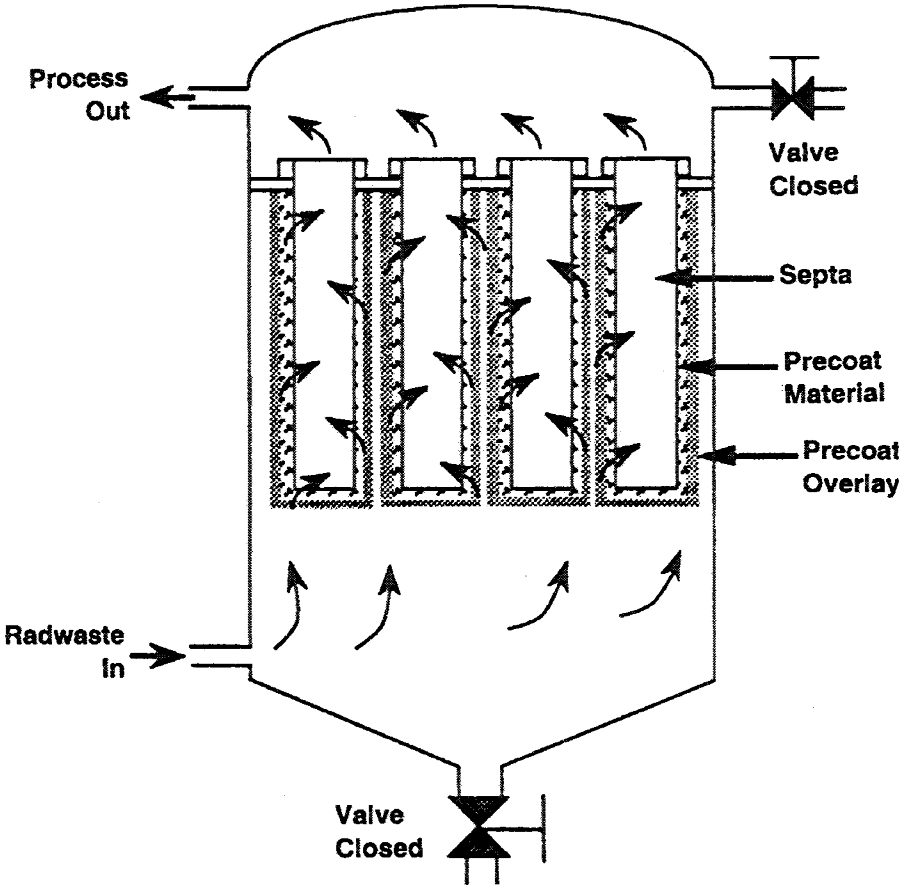
It generally is used when a combination of the precoat and the overlay material properties is desired in the filtration process. Typical uses are:

1. An overlay of powdered anion resin is used on top of the resin-fiber precoat of RWCU filters to increase the anion and silica removal capacities of the filter.
2. An activated carbon-fiber material is used as an overlay on the precoat material of equipment and floor drain filters to remove organic materials.
3. A polyacrylic fiber is used on top of an all-resin or resin-fiber mixture in condensate polishers to prevent precoat cracking.
4. A resin-fiber mixture is used on top of a diatomaceous earth precoat to improve the filtration properties and to provide an ion exchange capability.

5. A resin-fiber mixture is used on top of a fiber-only precoat to improve the filtration and to increase the ion exchange capability.

Figure 2910 illustrates a precoat overlay.

Figure 2910
Application of a Precoat Overlay
Over Previously Precoated Filter Septum



2911

What are the effects of too much or too little precoat material?

Too little precoat material may lead to:

1. Incomplete precoats.
2. Poor effluent quality.
3. Septa plugging by particle penetration of the precoat.

Too much precoat material may lead to:

1. Higher waste volumes.
2. Incomplete backwashing.
3. Bridging between filter septa and ultimately complete blockage of the filter.

2912

Where is powdered resin precoat used?

A precoat of powdered ion exchange resin is referred to as an all-resin precoat. It is typically used on the condensate and the RWCU filter/demineralizers, although most plants have shifted to a resin-fiber precoat in the RWCU system.

The all-resin precoat is used to maximize the quantity of ion exchange resin in the precoat layer. This maximizes the capacity for the removal of soluble contaminants in systems such as the RWCU.

In the condensate system, all-resin precoats are used, because lower porosity precoats can be achieved as compared to resin-fiber precoats. This provides greater protection from plugging of the filter septa.

2913

Where is a resin-fiber material used a precoat and why?

Resin-fiber precoats are used in virtually all water purification systems in a BWR, including:

- Reactor Water Clean-up (RWCU) System
- Condensate System
- Fuel Pool Clean-up System
- Floor Drain System

The resin-fiber mixture is used for the following reasons:

1. Lower cost.
2. More consistency in precoat quality.
3. Does not require coagulant aid addition to the precoat tank as does an all-resin precoat.

2914

Where is a fiber-only material used as a precoat?

All-fiber precoats are used primarily as a base layer precoat over which a layer of a different material is applied. All-fiber precoats are useful for cleaning up very turbid or dirty water where effluent quality is not too important—much the same as a "roughing" filter. An all-fiber precoat is generally very porous and will allow passage of the smaller particles. This produces longer run lengths and less solid waste volume. Subsequent filtration may be required using a finer filter matrix, depending on the final disposition of the water.

2915

Where is diatomaceous earth precoat used?

Diatomaceous earth (DE) usage is limited primarily to the liquid radwaste treatment system of BWRs. It has been used as the sole filter aid material in the precoat. It has also been used in combination with an overlay of a resin-fiber filter aid material.

DE is an excellent filter aid material and is available in several particle-size grades that allow the user to select the grade to best fit their filtration needs. DE is relatively inexpensive compared to other filter aid materials. Because of the particle shape of DE compared to cellulose fibers, DE users believe that it can be backwashed from the filter septa easier and, thereby, reduce the plugging frequency of the septa.

There are three drawbacks to the use of DE in a plant:

1. Being composed mostly of silica, water passing through the precoat layer will leach a small amount of silica and, therefore, add to the silica loading on demineralizers.

2. Being skeletons of marine organisms, the material is abrasive and adds to the wear on plant equipment.

3. If not mixed with other less dense filter aid material, DE will form a fairly dense layer in a settling tank (phase separator) that is more difficult to re-suspend than other filter aid materials.

2916

Where is a carbon-fiber filter aid material used?

A carbon-fiber material has been used on both equipment drain and floor drain filters to remove organic compounds from the water. Shortened run lengths can generally be expected with the use of a carbon-fiber precoat. This results from the greater removal capability of smaller particles as compared to other filter aid materials.

2917

What is body feeding?

Body feeding is the injection of a filter aid material into the liquid being filtered during the filter run. The body feed material mixes with the contaminant particles as they deposit on the precoat. The body feed material keeps the particles from forming a dense layer. This adds porosity to the layer and, thereby, increases the filter run length. In general, *the greater the injection rate of body feed material, the longer the filter run length.*

2918

When do you use body feed in precoat filters?

Body feed is generally beneficial in any filter application where the run length is governed by differential pressure. It is especially beneficial in situations where run lengths and throughput capacities are small. The floor drain filter is a primary candidate for body feeding. Some plants also have found it advantageous to body feed the equipment drain filter and the condensate filter/demineralizers.

2919

What are typical body feed materials and their characteristics?

Body feed materials can include any of the filter aid materials used to precoat the filters. The more common body feed materials are:

- Resin-fiber Materials
- All-fiber Materials
- Carbon-fiber Materials
- Diatomaceous Earth (DE)

Studies have shown that, at equivalent dosages, both DE and all-fiber materials will extend the filter run lengths greater than the carbon-fiber or resin-fiber materials. The poorer performance of the carbon-fiber and resin-fiber materials is caused by the gradual de-floccing or separation of the carbon or resin from the fibers. The detached carbon or resin particles act the same as the contamination particles in plugging the holes and passageways in the precoat.

2920

How do you determine what body feed material to use?

In filtration, it is virtually impossible to quantitatively predict the performance of filter aid materials in a precoat or body feed application without testing or using the actual waste water. The testing can be conducted on the full-scale filter. However, such tests are time-consuming and potentially very expensive. Moreover, because of changing influent water conditions, the results are both difficult to interpret and inconsistent.

As an alternative, the testing can be conducted on membrane filter equipment. This eliminates the above problems. The testing can be conducted in a short time period, is inexpensive, and the results can be directly compared to determine the most effective filter aid material as a body feed.

2921

What are coagulant aids?

Coagulant aids are long-chain organic polymers termed "polyelectrolytes." They are used as a pretreatment in liquid radwaste process systems to destabilize colloidal particles in the waste water. This allows the particles to agglomerate into larger particles, thus improving the filterability of the water. Improved filterability leads to longer filter run lengths and, ultimately, to less solid waste generation.

Coagulant aids also are used in PWR radwaste treatment to destabilize colloids of radioactive manganese, chromium and cobalt. This can help the plant to achieve larger DFs and lower effluent releases.

When powdered cation and anion resins are added to the precoat tank without using a coagulant aid, the electrical attraction between the particles causes them to form a very fluffy floc. If applied in this condition, a very porous, and perhaps incomplete, precoat will result. A cationic polyelectrolyte, such as "Sol A," is added to defeat some of the negative charges on the anion resin. This reduces the floc size that is formed and, thereby, decreases the porosity of the precoat.

When used in combination with body feeding, the use of pretreatment coagulant aids can produce dramatic increases in filter run lengths and decreases in solid waste volumes.

2922

What are the characteristics of the coagulant aids used in liquid waste treatment systems?

Coagulant aids used in liquid waste treatment systems are long-chain cationic organic polymers. Being cationic, sites along the polymer chain carry positive charges. The positive charges react with the negative charges surrounding the colloidal particles to neutralize the particle charge.

There are many cationic polymers available that could potentially be used. They differ in three basic properties:

1. The charge density (i.e. the number of positive charges along the chain).
2. The molecular weight of the polymer (typically 500,000 to a few million).
3. The basic molecular structure of the polymer.

These properties may make one polymer effective and others ineffective in a given application. They also affect the dosage levels that are effective. Testing the polymers using actual waste water is the only method of screening to find the polymer(s) that is effective.

2923

When are pretreatment coagulant aids used?

Conceivably, they could be used in all precoat applications and with varying degrees of success. At present, however, they are used primarily in the floor drain filter system. The benefits of their use in other systems are not as great, and there is a concern with any residual coagulant aid in systems that connect directly or indirectly to the primary reactor system. Pretreatment coagulant aids also can be used to increased removal DFs for radioactive species when some fraction of the species in the influent is in a colloidal state.

2924

How do you determine what coagulant aid to use?

As in the case of filter aid material selection for precoating and for body feeding, testing of the coagulant aid using actual waste water is the only method for selection. In fact, it is even more important for selection of a coagulant aid.

Also, as with the testing for precoat and body feed material selection, the testing is best performed on membrane filter equipment. Testing on this scale allows the influent properties to be controlled. This allows for the interpretation of the results without the interference of fluctuating influent properties, as is generally the case for full-scale testing.

2925

What is the advantage of using both body feed and pretreatment coagulant aids?

When the coagulant aid destabilizes the colloid particles in the waste water, the particles agglomerate naturally to form larger particles. If body feed particles are present, the contaminant particles join with the body feed particles to form even larger particles. These larger particles do not plug the precoat passageways as rapidly as would the smaller particles. In essence, they create larger surface areas for trapping suspended particles. Longer run lengths are then achieved because of the larger particles.

2926

What precoat materials are used in condensate demineralizers?

There are three basic types of precoat materials in use in these systems:

1. Powdered cation and anion ion exchange resins.
2. Pre-mixed powdered cation and anion ion exchange resins.
3. Pre-mixed powdered ion exchange resin and fiber mixture.

2927

Why do condensate filter/ demineralizer run lengths decrease with an increase in the number of backwashes?

Run lengths decrease due to iron fouling of the filter septa. This is particularly true for low micron-rated ($<5\mu$) septa. After a few backwashes, the delta pressure rise of the operating filter/demineralizer is controlled by the plugging of the septa and not the precoat layer. Some fraction of the iron holding capacity in the septa is restored by backwashing. An increasing fraction of the capacity is lost as the number of backwashes increase.

2928

What are advantages of body feeding the condensate filter/demineralizers?

The advantages are twofold:

1. Body feed will increase run lengths of the condensate filter/demineralizers and, ultimately, reduce the waste volume generation rates.
2. If the body feed material contains an ion exchange resin component, the filter effluent quality will be improved. If an ion exchange component is not contained in the body feed material, the suspended solids concentration in filter effluent will be reduced.

These advantages are the result of essentially the same effect as adding more filter aid material to the precoat, thereby giving a thicker filtration layer.

2929

What precoating techniques improve precoat performance for filter/demineralizers?

For condensate and RWCU filter/demineralizers, the resin or resin-fiber precoat material should be thoroughly mixed in the precoat tank prior to initiation of the precoat application.

The precoat tank clearing time after initiation of precoating should *not* be shorter than 15 minutes. Twenty to twenty-five minutes will produce a better precoat performance. The precoat application time can be slowed down by the proper adjustment of the precoat tank bypass flow. Ideally, the precoat material should be metered into the precoat tank over a 15-20 minute period.

Studies have shown that the practice of adding precoat material to the precoat tank at timed intervals to slow the precoat application time produces inferior precoats. The reason for this is incomplete mixing of the precoat material prior to the precoat application.

2930

What are typical filter aid materials used for the RWCU filter/demineralizers?

Typical RWCU filter aid materials include:

1. Powdered cation and anion ion exchange resin. This is usually precoated over a layer of fiber material.
2. Pre-mixed resin-fiber mixture with a 2:1 resin-fiber mix and 1:1 cation-to-anion equivalent mix

3. Pre-mixed resin-fiber mixture with a 9:1 resin-fiber mix and 1:1 cation-to-anion equivalent mix

2931

Is there an advantage to the use of body feed on the RWCU filter/demins?

There is very little advantage to the use of body feed on the RWCU filter/demineralizers. The reason is that the filter is typically backwashed based on chemical exhaustion of the ion exchange resin in the precoat and not based on the delta pressure.

Delta pressure is a filtration end point parameter. If the run lengths were controlled by delta pressure, then body feed would be beneficial.

2932

Is there an advantage to using coagulant aids in the RWCU and condensate filter/demineralizers?

Coagulant aids are normally used in filtration processes to improve the filterability of the liquid and, thereby, increase the run lengths. For the RWCU filter/demineralizers, the run lengths are not normally controlled by a delta pressure endpoint. Consequently, the use of a coagulant aid would have limited benefits.

A majority of the iron particles in the condensate system are extremely small and, conceivably, could be agglomerated by the use of coagulant aids. Whether or not this is feasible has not been tested. In addition, there is a concern with the introduction of any residual organic coagulant aid into the reactor via the feedwater system.

SECTION V

(3000 SERIES QUESTIONS)

OPERATING FILTRATION SYSTEMS

Section V Contents

Operating Filtration Systems

Item Topical Description **Item Number**

Filter Selection and Performance

Precoat Applications and Considerations

Filter Aid and Body Feed Material Considerations

Optimizing Performance of Filter Septa

URC Operations

Listing of Illustrations

Illustration Topical Description **Figure Number**

3001

How do you specify a new cartridge filter?

To specify a replacement cartridge filter, many parameters must be addressed. These should include:

- Filter geometry/size
- Construction materials
- Filter collapse pressure
- Total and leachable contaminants (for recycle service)
- Flow rate
- Temperature of influent
- Filtration performance specifications

Of the above items, flow rate and filter performance are the most difficult parameters to obtain a comparison of filters. The flow rate through a filter vessel in a power plant results in large flux density (gpm/ft^2). Values of 5 gpm/ft^2 or larger are common, and filter manufacturers generally have little or no performance data at these levels. Filter performance data at low flows is not applicable to higher flow rate conditions.

It is important that the flux density for the intended service be determined first and performance data at this density only be used to compare filters.

3002

How do you select the proper micron rating for filters?

To select a proper micron rating for a filter, an analysis of the suspended solid size distribution for the liquid to be treated must be conducted. The mass of particulate (mg/l) above each micron (μ) size must be determined (e.g., 25μ, 10μ, 5μ, 3μ, 1μ, etc.). This analysis can only provide a starting point for filter size selection. Full scale in-plant service is the only sure means to select a filter size.

Micron rating terminology can be very confusing. There are nominal ratings, absolute ratings, and beta efficiency ratings. In general, absolute ratings are gaining preference.

A media rated at X microns absolute usually refers to a media that removes 99% of all particles of size X and above. These ratings are dependent on flow rate, type of challenge particles, and the method of counting particles upstream and downstream of the filter media. There are also absolute ratings "at size," which means 99% removal of all particles at X microns to X+1 microns. This is a more stringent rating, since the removal efficiency cannot be "enhanced" by removal of large quantities of particles much larger in size than X.

Some common approximations for particle sizes for various systems are as follows:

Reactor coolant/Seal water	3.0 - 0.2μ
Spent fuel pool/Boron recycle	2.0 - 0.2μ
Floor drain prefilter	10.0 - 6.0μ
Equipment drain prefilter	5.0 - 1.0μ
Resin dewatering filter	10.0 - 5.0μ
Resin trap filter	5.0 - 0.5μ

3003

What is the impact of high flow rates on small micron filter selection?

In this case, small micron filters are considered as being less than five microns. The flow rate of the liquid process stream impacts on the selection of these filters as follows:

1. Most manufacturers test their filters at low flow rates (e.g., 0.5 gpm/ft^2).
2. At high flow rates (e.g., 5.6 gpm/ft^2), the vast majority of vendors cannot supply performance data on their filters without specific testing.
3. It is expensive to do a full scale test.
4. One supplier learned that filters below 3 microns (based on low flow performance) could not meet the high flow performance at a given micron size.
5. To get good clarity (i.e., remove turbidity), a 1 micron filter is needed. Submicron filters are needed for radioactivity removal.

3004

What are the common filter performance test standards?

There are several filter performance test standards. A single pass particle challenge test (ASTM F-795) is perhaps the best test to specify, as it simulates full scale operation. The choice of particle challenge media (AC test dust, AC fine test dust, or iron oxide), the concentration of those particles in the test feed stream, and the flow rate must all be specified. Although there is considerable data on AC fine test dust, iron oxide is probably closer to the material that must be filtered in the RCS, boron recycle, and equipment drains.

Neither AC fine test dust nor iron oxide can be used alone for submicron filters. This is because an insufficient number of submicron particles are contained in these materials. Bacteria or latex beads should be used to compare submicron media. Although there is a substantial amount of filter performance data available based on bacteria challenge, radioactive particulate is not bacteria, and such tests are usually performed at low flux densities. latex beads are very expensive, and, due to the relatively high cost, cannot be tested at high flux densities.

CAUTION: *If the crud-holding capacity is being evaluated in a test mode, it is important to note that few, if any, of the performance results will accurately reflect the crud-holding capacity achieved in actual service.*

A comparison of submicron filter media based on latex beads can be used to ensure various media will retain the same size particles. Such a comparison should be coupled with tests at high flux density tests (say with iron oxide) to provide some indication of full scale performance.

3005

What parameters are typically considered as filter run length endpoint indicators?

These parameters will vary slightly between plants. However, they are usually selected in accordance with the operating objectives and the filtering characteristics of the specific filter application. The following are typical of most of the precoat filters in BWRs:

Filter/Demineralizer	Endpoint
RWCU	Conductivity/Silica
Fuel Pool	Conductivity
Condensate	Delta Pressure
Equipment Drain	Delta Pressure
Floor Drain	Delta Pressure

3006

What is the optimum precoat application rate?

Precoating times should be in the range of 15 to 25 minutes. This is especially true with resin-fiber filter aid material. Any time shorter than 15 minutes is too fast and will likely result in a poor precoat. Longer times (i.e., closer to 25 minutes) are preferable.

3007

What is an acceptable range for flow rate during precoat application?

The optimum precoating flow rate depends on the filter aid material being used, the filter type and the internal configuration of the filter. However, a generally acceptable range of precoat flow rate for most filter aid materials is:

$$1.2 \text{ to } 2.0 \text{ gpm/ft}^2$$

3008

What is the optimum %solids concentration in the precoat tank

For precoat systems with a return line bypass around the precoat tank, the precoat material addition should be controlled to 0.2% to 0.6% (by dry weight) in the filter feed line. The concentration should preferably be on the lower end of this range.

For precoat systems with the return line to the precoat tank, the initial concentration in the precoat tank should not exceed 1.5% (by dry weight).

3009

What is the *dis*advantage of adding precoat material to the precoat tank during precoating?

Adding precoat material to the precoat tank during precoating does *not* allow enough time for mixing in the tank to disperse the material prior to depositing it on the filter. As a consequence, lumps of material are deposited resulting in a porous or incomplete precoat.

Precoat material may be added to the precoat tank during the precoating process for two reason:

1. To reduce the precoat application rate.
2. To reduce the concentration of material in the precoat tank.

3010

How do you determine if a good precoat has been achieved?

A good precoat suggests a complete and consistent (uniform) precoat. To verify this, effluent samples can be collected shortly after a filter has been placed into service. Suspended solids, turbidity and conductivity measurements on the samples can be used to gauge the quality of the precoat. However, it may be difficult to interpret the results if there is no reference for comparison.

One solution is to perform a membrane filter test using the actual waste water and the identical precoat material and loading as the full-scale unit. The millipore-scale precoat is normally uniform and complete. Therefore, the measurements on the effluent samples should provide a reliable reference for comparison with the full-scale unit.

3011

How do you determine an optimum flow rate for a specific precoat filter?

The optimum flow rate is the lowest flow rate attainable in the filter system where the incoming waste volume can be comfortably processed without affecting plant operation. This stems from the fact that the lower the flow rate, the slower the delta pressure rise and, therefore, the longer the run lengths.

There is an absolute minimum for many filters where the flow is so low that the filter cake will not stay on the septa. For most filters, this is usually 0.2 gpm/ft^2 of filter material. Filters have been operated at 6-8 gpm/ft^2, but these are considered extraordinary. Most radwaste filters should not be operated much above 1.2 gpm/ft^2.

3012

What is the optimum residence time for the filter aid material in the precoat tank prior to precoating?

Adequate mixing time of the filter aid material in the precoat tank is required to thoroughly disperse the material in the precoat water. If adequate time is not allowed, small lumps of filter aid material remain and are applied in the precoat step. This leads to poor quality precoats. A minimum mixing time of 15 minutes should be provided.

3013

What is the optimum location for the body feed injection point in the liquid radwaste treatment system?

If a coagulant aid is not being used in conjunction with the body feed, the injection location upstream of the filter is not critical.

However, if coagulant aid is being used, then the injection point should be downstream of the coagulant aid injection point. Ideally, the arrangement would have:

1. the coagulant aid injection point in the filter feed pump suction line;
2. an adequate piping length from the pump to the body feed injection to provide a 30 second reaction; and
3. adequate piping length between the body feed injection and the filter to allow another 30 second reaction time.

3014

How do you determine an optimum body feed injection rate?

In nuclear plants, the optimum injection rate is that which maximizes the throughput capacity (in terms of gallons/ft^3) for any filter. Body feed will generally increase the filter run length and the throughput capacity. However, at excessive body feed injection rates, the run lengths may increase, but the throughput capacity will decrease. Therefore, it is important that the injection rate be established somewhere between being too little and too much.

This is best determined using membrane filter equipment and using actual waste water. The influent water conditions are controlled, and the effects of the different body feed injection rates can be directly quantified. The optimum injection rate can be correlated with the influent turbidity by conducting a series of tests. This provides a practical tool to be used for the full-scale filter.

3015

What is the optimum coagulant aid injection point in the liquid waste treatment system?

Ideally, the coagulant aid should be injected into a highly turbulent flow of the waste water. This thoroughly disperses the polymer in the water so it can make contact with the particles.

Sufficient elapsed time is needed between the time of polymer injection and the time the agglomerated particles reach the filter. This elapsed time allows the polymer to work and the particle to agglomerate. The time should be 1/2 to 2 minutes.

3016

How do you determine an optimum coagulant aid dosage?

Testing on membrane filter equipment has been shown to be an effective method for determining coagulant aid dosages. Using sample water collected from several different collector tank batches, a test series can be conducted resulting in a correlation between turbidity and coagulant aid dosage.

For most waste water there are minimum and maximum effective dosages. The span between these two is termed the "operating range." At the minimum there is not enough coagulant to destabilize a majority of the colloidal particles. At the maximum, the colloids are reformed, and the liquid process stream is in what is termed an "overdosed" condition.

3017

How do you determine the optimum contact time for the coagulant aid?

Optimum contact times can only be determined in a laboratory-scale testing program using vacuum filtration equipment, membrane filters, and actual waste water. The treated waste water is allowed to mix on a stir plate for the specified time and is then poured into the vacuum filter funnel. The time required for the water to clear the filter is measured and recorded. Minimum contact times can then be related to the filtration times.

3018

How do you identify a coagulant aid overdose condition?

An overdose of coagulant aid will cause the colloidal particles to gain a positive charge and interfere with the agglomeration process. In effect, it restabilizes the colloid. When this occurs, the filter will experience a rapid delta pressure rise, and the effluent of the filter will exhibit higher turbidity levels.

3019

How do you recover from a coagulant aid overdose condition in the collector tank?

Two methods can be tried in an effort to overcome the overdosed condition. The first is to add a box (one cubic foot) of resin-fiber filter aid material to the collector tank while the tank is being recirculated. The anion resin in the material will trend to neutralize the charged colloidal particles.

The second method is to transfer a portion of the water to another tank (for example, the surge tank), and add new waste water that has not been treated with coagulant aid. This will introduce particles with an opposite charge.

3020

What filter process parameters should one monitor?

For the liquid radwaste filters, the parameters that are important to monitor for each run are:

- Precoat delta pressure
- Initial delta pressure
- Throughput capacity

The precoat and initial delta pressures provide an indication of screen plugging. The monitoring of the throughput capacity (calculated in gallons/ft^3) is primarily aimed at tracking filter performance and potential shifts in the filtering conditions of the influent waste water. The throughput capacity may also trend downward as the filter septa plug or become fouled.

3021

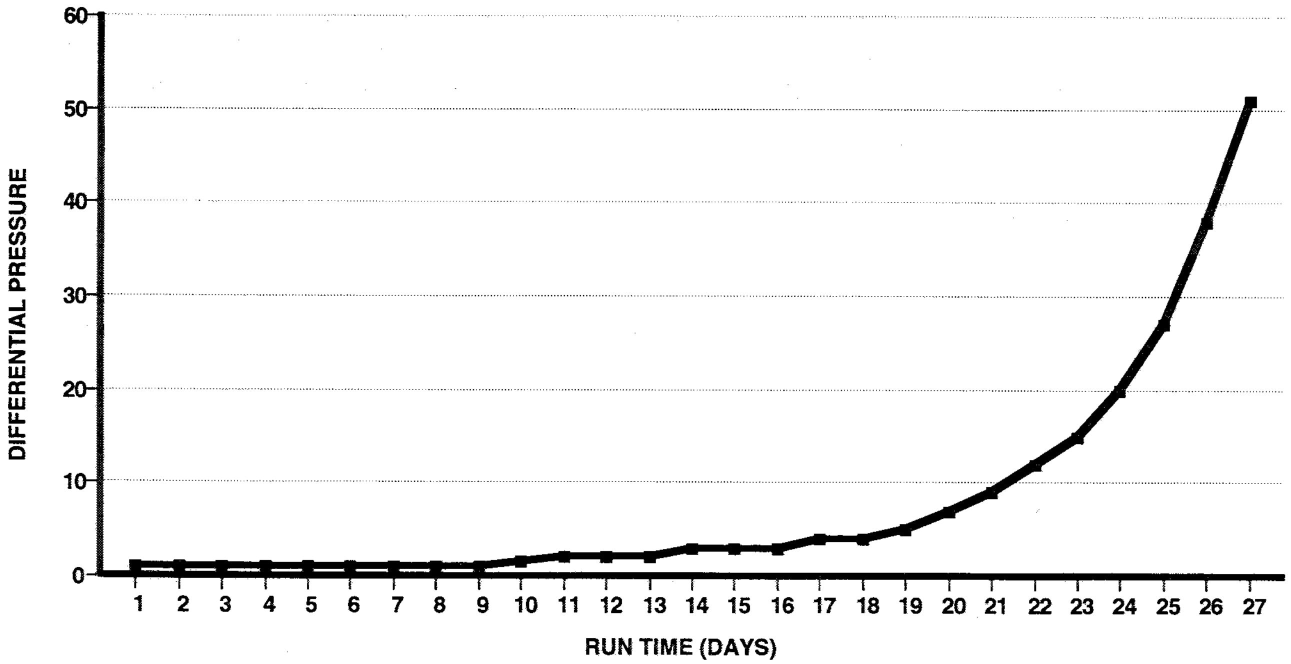
How do you determine if filter septa are plugging and need to be cleaned?

In liquid radwaste filters, there are two parameters that would indicate progressive plugging of the septa:

1. Higher delta pressure across the filter during precoating than previous precoats.

2. Smaller throughput capacities when averaged over a few filter runs.

Figure 3021
Determining When to Clean Filter Septa



3022

What methods are available for cleaning filter septa?

Three methods have been employed:

- Steam Cleaning
- Hydrolazing
- Chemical Cleaning

The effectiveness of one method over another depends on the design of the filter septa. Generally, steam cleaning and hydrolazing are preferred to chemical cleaning, because of the problem of disposing of the chemical solutions. The chemicals used may include sulfamic acid, citric acid and/or EDTA. Experience to date indicates that the cleaning method rarely restores the elements to the clean condition of the original new septa.

3023

What actions can be taken to eliminate long system outage times because of plugged septa?

Many utilities have purchased a spare set of filter septa. When the septa in the filter plug, the plugged septa are removed and replaced with the spare set. This allows the filter to be returned to service while the plugged set is cleaned and readied for re-installation should the spare set of septa become plugged.

3024

What can be done to increase run lengths on condensate filter/ demineralizers?

There are two basic approaches:

1. Restore the iron holding capacity of the septa in the backwash step; or
2. Provide greater plugging protection for the septa by lower porosity precoats.

Restoration of the iron-holding capacity can be done by improved backwash techniques (e.g. air surge) for fiber-wound septa. Chemical cleaning can be performed on metal septa.

Lower porosity precoats can be achieved by:

1. Improving precoating techniques where better distribution in the filter is achieved.
2. Improved backwashing techniques to remove residual precoat material.
3. Use of overlays.
4. Use of body feeding.
5. Use of all-resin precoat material.
6. Use of optimum coagulant aid addition in the precoat tank for all-resin precoat material.

3025

How do you select precoat material for condensate filter/ demineralizers?

Recent research results suggest that lower porosity precoats are needed to provide greater protection from plugging of the filter septa.

Lower porosity precoats are generally achieved with all-resin precoat materials. The precoat porosity generally increases as the fiber content of the resin-fiber mixture increases.

Testing on a membrane filter can be conducted using actual precoat materials and condensate to determine precoat porosities for the material being screened. A membrane filter is precoated at loadings equal to the full-scale unit. Delta pressure rise and iron penetration are recorded for each filter material.

3026

How can the removal capacity for silica be increased for RWCU filter/ demineralizers?

Silica removal capacity can be increased by using a 9:1 resin-to-fiber pre-mixed filter aid material instead of a 2:1 mix. Alternatively, an overlay of powdered anion resin can be placed over the top of the normal precoat layer.

The application of the anion overlay should not be initiated until the normal precoat has been established. This prevents penetration of the anion resin fines. A sharp delta pressure should be expected during the application of the anion overlay.

3027

What is an optimum URC frequency for condensate deep-bed resins?

There is some controversy regarding the optimum URC frequency. Some utilities believe that to maintain acceptable iron concentrations in feedwater, the bed should be cleaned frequently. The bed is cleaned after a specified time period, typically 21 days.

Others believe that disturbing the beds in the cleaning operation causes higher iron levels in the feedwater. These plants clean the beds either when the delta pressure across the bed reaches a specified value or when the throughput reaches a specified value. There have been few studies to determine which approach is the best.

3028

How do you optimize URC performance?

Maintaining proper flows for all four of the URC functions is important for optimum performance. Three flow rates, in particular, are extremely important.

1. The **feed flow** to the cation regeneration tank should be carefully controlled, such that resin feed to the URC does not exceed 1.5 ft^3/min. Some plants have found through-valve leakage from the condensate system into the cation regeneration tank causes higher than desirable resin feed rates.

2. The **backwash flow rate** is important to carry resin fines and crud out of the system. This allows the ultrasonic field to adequately clean the resin.

3. The **resin eductor flow** is important to ensure that too much water is not withdrawn by the eductor from the URC chamber.

3029

How can you minimize resin fracture during URC?

To minimize fracture of the resin beads in the URC operation, it is important that the resins be purchased with minimum friability requirements. The supplier of the URC equipment, General Electric, specifies the following friability requirements:

1. Average crush strength = 350 g/bead.
2. 57 out of 60 beads must test >200 g/bead.

3030

How do you monitor for resin losses during URC operations and transfers?

The total bed volume is checked in the mix-and-hold tank by visually determining the resin level using sight glasses on the tank. Resin is added to bring the level up to the full bed level.

3031

How do you determine residual resin capacity after URC?

All that the URC does is remove part of the particulate matter that the resin bed has filtered out. The only measure of its efficiency is:

1. The reduction in pressure drop when the bed is put back into service; and
2. The length of the next run before excessive pressure builds up again.

<u>The process does not restore ion exchange capacity</u>. *However, disturbance of the ion exchange bands in the service vessel by frequent ultrasonic cleaning does lead to a reduction in the ultimate service life of the ion exchange resin.*

3032

How do you process URC backwash water?

Although the suspended solids concentrations in the URC backwash water are high, the water is not particularly difficult to filter. The use of body feed and coagulant aid are effective in achieving long run lengths for this backwash water. However, if correlations have been developed between the influent turbidity and the required dosages of body feed and coagulant aid, care is required not to overdose the water. Studies have shown that approximately one-half of the dosages required for normal waste waters are adequate for the URC backwash water.

SECTION VI

(3100 SERIES QUESTIONS)

EVAPORATION PROCESSES

Section VI Contents

Evaporation Processes

Item Topical Description **Item Number**

Operating Waste Evaporators

Working with Boric Acid in Waste Evaporators

Listing of Illustrations

Evaporation Processes

3101

What analyses are needed for evaporator operations and performance monitoring?

Both chemical and radiochemical analyses are needed:

Chemical:

1. It is essential to monitor **system pH**. If the pH becomes extreme, corrosion begins. Evaporators tend to move to the acidic side. Therefore sodium hydroxide additions are required to maintain a neutral pH.
2. In PWRs, it also is important to control the **boron concentration**. When the boron concentration is only a few ppm, careful observance is not critical. However, as the boron increases above a few percent, rapid concentration begins, and close observance is critical. Otherwise, the concentration will become so great that the system will "rock up.
3. Organics in the influent may cause TOC carryover and fouling of the heat transfer surfaces.

Radiochemical:

1. If the radiosolids concentration goes up—in particular the activation products, such as Co-58 and Co-60—the dose rates will increase proportionately. If the waste transfer and disposal system is not prepared for such high dose rates, then dose rates may become greater then the system is capable of processing for shipment.

3102

What contaminants in the evaporator feed will adversely impact evaporator operation?

The most significant evaporator chemical concerns are:

1. Contaminants such as fluorides and chlorides (the halogens) are a concern in stainless steel evaporator bodies because of the potential to induce stress corrosion cracking.
2. Sulfates will become a corrosive acid (sulfuric acid) at low pH.
3. Excessive quantities of radionuclides will raise the dose rates in the evaporator concentrator tanks.
4. Surfactants and organics may cause foaming leading to reduced system performance.

5. Oils may char rather than evaporate, thereby leaving a heat losing film on heat transfer surfaces.

6. TOC in the influent may cause excessive carryover of TOC and fouling of the heat transfer surfaces.

3103

What is the source of evaporator chemical contaminants?

Chemical contaminants are delivered to the evaporator by the RCS. However, these chemicals normally originate from the plant water supply.

Chlorides are found in normal water supplies in concentrations of up to 250 mg/liter. These water supplies will have a salty taste in the presence of sodium, as NaCl. However, this salty taste will be absent in waters of up to 1000 mg/liter if the predominant cations are calcium or magnesium. Chlorides in the water are more of a concern for salt or brackish water cooled plants than fresh water plants.

Sodium is found in fresh water supplies in concentrations varying from less than 1 mg/liter to 500 mg/liter. Higher concentrations will be found in hard water supplies softened by the sodium exchange method. Power plants should limit sodiums to less than 3 mg/l.

Nitrogen, which forms nitrites and nitrates, are found in concentrations of natural fresh water of up to 30 mg/l. In its natural state, nitrogen is found in covalent states. If, due to heat or radiation, it forms its ionic state, it will bond with oxygen to form a nitrate or with hydrogen to form ammonia.

3104

How do you optimize the use of an evaporator?

A waste evaporator works best when not under conditions of full stress (i.e., maximum temperature, pressure or extreme pH). In order to operate an evaporator properly, the objective should be to achieve maximum boiling with minimum temperature. This is accomplished by using Boyles' law: pressure is inversely proportional to temperature.

If the pressure within the evaporator can be reduced, then the boiling temperature can also be reduced. With less temperature strain, fewer corrosive products will be produced. Moreover, the evaporator can now be throttled by using pressure to adjust the temperature. In addition, to prevent heat loss when processing liquids in an evaporator, proper insulation must be installed and maintained.

Frequent cleaning of the evaporator using a dilute acid solution will allow for good flow through the system. The acid should be totally neutralized at the end of the cleaning process and removed. Acid cleaning should be performed at least twice a year.

Chemistry controls are also important. Foaming will reduce the evaporators efficiency by providing a heat loss mechanism. Oils will burn rather than evaporate, leaving an insulating film that reduces heat transfer. Hence, oils must be prevented from entering the radwaste system.

Finally, a dedicated operating crew responsible for operation of the evaporator will always have the system performing better than individuals who maintain it as part of their shift rotation.

3105

How do I pretreat evaporator feed?

Left unattended, evaporator concentrate will become acidic. Raising the pH prior to and during the evaporation process by using NaOH will keep the pH more neutral.

To prevent foaming, treatment prior to operation is a necessity. Many commercial defoamers are available that will reduce foaming to a negligible problem. Trisodium phosphate may be used to prevent potential stress corrosion cracking problems in the evaporator.

3106

What are the concerns of influent chemicals on evaporator tubing material?

Chemicals can effect evaporator performance by corroding internal surfaces or by depositing a scale or film on the heat transfer surfaces.

For example:

1. Halogens (chlorides, fluorides, iodides) are electron acceptors. They potentially may cause stress corrosion cracking of the evaporator materials.
2. Oils and other organics (e.g., ion exchange resins) will not evaporate but, instead, form a film on the heat transfer surfaces of the evaporator. This causes a loss in efficiency.
3. Insoluble salts of calcium and magnesium may form scales on the heat transfer surfaces, leading to reduced operating efficiency. (Sulfates also contribute to the formation of salts.)

3107

What material should be used in constructing an evaporator?

If the evaporator is for boric acid recycle, the evaporator should be made from type 316 stainless steel (316SS) or better, assuming ion exchange systems are employed upstream from the evaporator. However, if the evaporator is for miscellaneous liquid wastes, the evaporator should be made from inconel.

Most waste evaporators made from 316SS have failed due to corrosion from Fl^-, Cl^- and $SO_4^=$, since there were no feed demineralizers upstream to remove these corrosive ions. By contrast, inconel can withstand the corrosive effects of the Fl^-, Cl^- and $SO_4^=$ ions commonly found in high conductivity waste feed water.

3108

What is the optimum boron concentration for evaporator bottoms prior to transfer?

The boric acid concentration that can be achieved in an evaporator depends on the length of pipe run required to transfer the waste to the loading area. As the concentrate cools during the transfer, it will tend to clump and "rock up" the system. (The term "rock up" refers to blocking or plugging the system equipment or piping with chunks of crystallized boric acid concentrated to a rock-like density.) Accordingly, if the lines are heat traced, this becomes less of a problem.

Boric acid falls out of solution at between 130 and 150 degrees Fahrenheit when at a concentration of 30% or less. At higher concentrations, the boric acid compound will fall out of solution at a lower temperature. Unless the transfer lines are not only well heat traced but also well insulated, it is not recommended to go above a 30% boric acid concentration.

> Note: *If the lines are not heat traced nor insulated properly, a 15% boric acid concentration over a 30-foot length of pipe may be sufficient to see the concentrate fall out of solution and, potentially, block the pipes.*

3109

What pumps are best suited to transporting boric acid?

The challenge in transporting boric acid concentrate is the potential for the concentrate to fall out of solution and block (jam) the pump. It is important to note that all pumps will jam if the solids concentration becomes to high or if the boric acid falls out of solution during transport. However, centrifugal open impeller pumps and progressive cavity pumps are less likely to jam while transporting solids than a diaphragm pump. Magnetic drive pumps will have lower maintenance in terms of seal leakage, provided that sufficient suction is provided.

3110

When and how do you rock up a waste evaporator?

An evaporator becomes rocked up near the end of its maximum concentration processing cycle. Most commonly, this is due to operator inattention.

When an evaporator first begins concentration, solids such as boric acid are usually in the low ppm range. At low concentration levels, the rate of evaporation and concentration will not be rapid and will require little operator control. As the solids become more concentrated, the solids can be considered as a percentage by weight within the solution. The concentrating process becomes rapid now, requiring close operator control. A few moments of taking the evaporator beyond its operating parameters will probably cause the boric acid or solids concentration to fall out of solution and to begin caking on the bottom of the concentrator. Eventually, the liquid will boil off, leaving a very radioactive block of boric acid to deal with.

3111

How can an evaporator be unrocked?

Once the boric acid has begun solidify, hot distillate must immediately be added to the system to resuspend the solids. This liquid will be pumped into the waste hold up tank. Hot liquid also must be pumped through the bottom of the concentrator tank to break up the boric acid cake. If this is not possible, the dried cake may require manual break up, provided the dose rate is not excessive.

Once the solidified cake is broken up, additional water, as close to boiling as possible, must be added in an attempt to resuspend the remaining solids. This process must be repeated until the evaporator is free of the cake.

Freeing up the evaporator is a long and difficult process, which creates a lot of additional liquid waste water to process, as well as having no guarantee of success. This is why an experienced, dedicated evaporator operating crew can pay big benefits.

3112

What happens if your boric acid precipitates in the waste container prior to solidification?

When boric acid precipitates from (falls out of) solution and phase separates, it will not allow a shear mixer to break up the compound formed. Thus, it will not allow for proper mixing with the solidification agent. The solution either must be reheated or broken up to allow encapsulation by the solidifying agent.

If the container is not filled significantly, then 120 degree Fahrenheit water may be added to dilute the boric acid into a soluble form. With this heat maintained, shear action may begin, eventually allowing proper mixing for solidification.

It is important to keep the container heated during the resuspension. This is not difficult when using 55 gallon drums, as industrial heating blankets are readily available. If larger liners or plastic containers are used, internal heating techniques will be required.

3113

How do you clean up boric acid crystals?

If the boric acid crystals are caked on the item to be cleaned, they first can be manually broken off or chipped away. **Be careful not to damage the contaminated equipment.** Also, boric acid crystals may contain large amounts of radiocontaminants or other hazardous materials, so proper radiological controls must be established. Accordingly, prior to the start of the cleaning process, the crystals must be wetted down to prevent any contaminants from becoming airborne. Wetting the surface down may need to be repeated as each layer of boron is removed.

When aggressive decontamination might produce equipment damage or other concerns, or if the boric acid crystals are not heavily built up, then a more gentle process should be used. Spray the boric acid crystals with a mixture of warm water and a decontamination agent, such as DC-13 or a 3% solution of hydrogen peroxide (H_2O_2). Let the solution soak into the boric acid crystals for about five minutes. Then use a scouring pad to remove the soaked layer. Repeat this process until the entire amount of boric acid is removed.

3414

What is the purpose of the boron recovery system?

In PWRs, soluble boron is added to the reactor coolant system for control of reactor criticality. (Boron is a neutron absorber.) At the beginning of a refueling cycle, the boron concentration is established at several thousand ppm, and this concentration is gradually reduced to several hundred ppm near the end of the refueling cycle through the use of RCS feed and bleed operations and deborating demineralizers. The reduction in boron concentration is performed at the end of the cycle to maintain reactor criticality when all control rods have been withdrawn fully from the core.

Reactor coolant water containing high boron concentrations and which is "let down" from the RCS typically is collected in large shielded tanks called Reactor Coolant Bleed Holdup Tanks or Letdown Tanks. Some plants make no effort to remove the boron from RCS letdown and merely process the water to remove radioactive contamination prior to discharge. Other plants attempt to recycle as much water as possible.

To permit reuse of the water at lower boron concentrations, the boron must be removed, typically through the use of a Boron Recovery Evaporator (BRE). The resulting concentrated boron (bottoms) from BRE operations are usually handled in one of two ways: the boron concentrates are either temporarily stored for addition back into the RCS (recycle) or are packaged for disposal as radioactive waste.

The decision is generally based on several factors, including the following:

- Purity of the concentrates (i.e., levels of other undesirable chemical impurities such as silica, organics, etc.).
- Storage capacity for boron concentrates.
- Availability and cost of replacement boric acid.
- NPDES release limits for boron.
- Operability of the BRE.
- Plant philosophy to maximize recycle capability.

3115

What is a "boron recycle system"?

The boron recycle system (BRS) initially was designed and supplied by Westinghouse Corporation as an option to its PWRs. The system collects reactor coolant discharged from the primary system, purifies it, and converts it to a concentrated boric acid solution and reactor makeup quality water. Such systems can recover and recycle two million or more gallons of liquid annually.

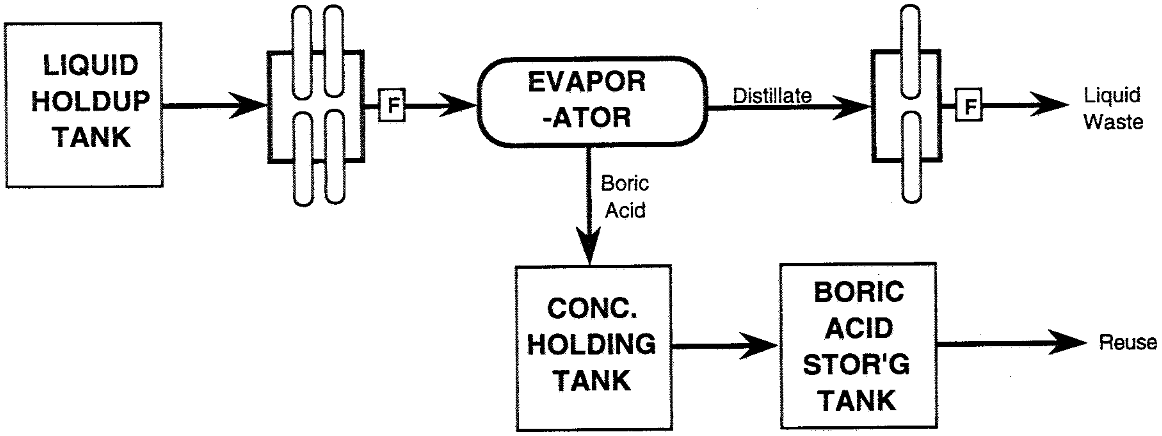
For a typical BRS, discharged reactor coolant is collected in Liquid Holdup Tanks. The liquid from these tanks is pumped through demineralizers and then through a resin trap filter to the evaporator package. The *evaporator distillate* is pumped through another demineralizer and a second resin trap filter to the primary water storage tank.

The *concentrated boric acid solution* is pumped from the evaporator through a filter to the concentrates holding tank. It then is sent to the boric acid storage tank for reuse in the plant.

A BRS provides five major benefits:

1. Reduces processing load on the liquid radwaste system.
2. Eliminates the need for boric acid radwaste solidification.
3. Reduces purchasing requirements for replacement boric acid.
4. Reduces makeup water requirements.
5. Reduces the discharge of treated tritiated water.

Figure 3115
Boron Recycle System



3116

What start-up considerations apply?

When returning a moth-balled boric acid evaporator to service, and when starting a new boric acid evaporator, ensure that there are operational ion exchange systems and filter systems installed upstream. The purpose of these systems is to remove radionuclides and any potentially corrosive ions. This will extend the life of the evaporator and prevent excessive radiation buildup in the boric acid concentrates. In so doing, it will reduce shielding requirements and minimize radwaste disposal volumes.

3117

What concentrations have been used for boron recycle?

Boron recycle evaporators generally produce 12 wt% bottoms. However, some plants have moved to 4 wt% in response to NRC concerns over plugged piping from "boron rocks" (crystallized boron chunks). In addition, the lower concentration reduces the overall maintenance requirement for heat tracing.

3118

Can boric acid concentration be measured during operation?

For waste evaporators, solids concentration can be determined by measuring the electrical power (current/amperage) draw of the concentrates pumps. The amperage requirement then is correlated to the density of the concentrates.

However, unlike waste evaporators, the density of a 12 wt% boric acid solution does not place much of a load on the concentrates pumps, and a 4 wt% concentration imposes even less of a load. Since the amperage draw by the pumps is unaffected by the boric acid concentration, a watt meter placed on the circuitry of a boric acid evaporator concentrates pump cannot be correlated to the density of the concentrates. Therefore, to measure boric acid concentration, a density cell is required.

3119

Can silica concentration create problems?

Yes, a high silica concentration can adversely impact boric acid recovery systems. In fact, boric acid is considered as a major source of silica in reactor systems. Most plants find it beneficial to review their boric acid purchasing specifications and specify a low silica content boric acid. In addition, if the spent fuel pool (SFP) contains high density fuel racks, efforts should be taken to isolate the SFP water from the reactor cavity and reactor coolant system (or RWCU system in a BWR) to the extent practical. (High density fuel racks typically are boraflex racks which contribute to SFP silica concentrations.)

Silica is difficult to remove from any liquid process stream. However, it is possible to use fine mesh filters (0.3 microns) with a zeta potential to improve silica removal before it arrives at the evaporator. The filters should be installed in the distillate and boric acid filters. In addition, some plants report success in silica removal using reverse osmosis. This will enable the plant to continue to recover the boric acid.

SECTION VII

(3200 SERIES QUESTIONS)

ABSORPTION PROCESSES

Section VII Contents

Absorption Processes

Item Topical Description **Item Number**

Listing of Illustrations

Listing of Tables

3201

What is the difference between ion-exchange, absorption and adsorption?

Ion-exchange, absorption and adsorption are three separate processes often misrepresented or misunderstood and sometimes confused with one another. All three methods are used in water treatment and purification, although the results obtained are significantly different.

Ion-Exchange

As used herein, ion-exchange involves the transfer of an ion from the liquid being treated to an exchange site in the resin and the subsequent release of an ion from the resin's functional groups into the liquid. An example of this is as follows:

> Water with soluble, ionized impurities—radioactive or not—such as Ca^{++}, Na^{+}, Cs^{+}, is passed through an ion exchange column containing the hydrogen form of a sulfonic acid cation resin. The effluent water will have a lower concentration of the original cations (Ca, Na, Cs) and a lower pH as a result of a higher concentration of hydrogen. In this case, the Ca^{++}, Na+ and Cs^{+} ions in the influent water were replaced by hydrogen ions in the effluent.
>
> This can be represented by:

$$2RSO_3^-H^+ + Ca^{++} \rightleftharpoons (RSO_3^-)_2Ca^{++} + 2H^+$$
$$RSO_3^-H^+ + Cs^+ \rightleftharpoons RSO_3^-Cs^+ + H^+$$
$$RSO_3^-H^+ + Na^+ \rightleftharpoons RSO_3^-Na^+ + H^+$$

Where R is a styrene-divinylbenzene polymer.

When treating water through ion-exchange, it is a normal practice to balance cations and anions removed by using either a combination of separate cation and anion beds or by using a mixed-bed resin (e.g., cation mixed with anion in the same vessel). This results in an effluent with a balanced pH and a lower concentration of ionic impurities, both cation and anion, usually measured by conductivity. When ion-exchange is used to remove ionic impurities, the process is called "deionization."

Adsorption

Adsorption consists of the concentration of one or more components (adsorbates) of either a gas or a liquid at the surface of a microporous solid (adsorbent). The attractive forces causing the adsorption are different in nature and are generally weaker than those in ion exchange-chemical bonds. *It is primarily a surface phenomenon.*

Commercial adsorbents are divided into four major classes:

- Molecular-sieve Zeolites
- Activated Alumina
- Silica Gel
- Activated Carbon

Since adsorption is a surface-related phenomenon, all of these groups are characterized by large ratios of surface area to weight. Typical values range from 300 to 1200 m^2/gram.

Activated carbon is by far the most widely used adsorbent worldwide. In the nuclear waste arena, it is commonly used to remove trace oils and organics that are introduced in the waste holdup tanks. These contaminants could, possibly, shorten the useful life of an ion-exchange bed through fouling.

The reason for activated carbon's affinity for some organics is its hydrophobic (i.e., water repellent) surface selectivity. The vapor-phase-activated carbon will preferentially adsorb organics that are not soluble in water rather than adsorbing the water or water-soluble organics. By contrast, most zeolites and activated alumina (i.e., absorbents) are hydrophilic (i.e., absorb water). This property plays a significant role in the selective extraction of certain ionic impurities.

Absorption

Absorption usually involves the transfer of one or more components of a gas phase into a liquid phase in which the component is soluble. The application of absorption as a practical process requires the generation of an extensive area of liquid surface in contact with a gas phase under conditions that favor the mass transfer. Absorption processes can be categorized into three general types:

1. Physical solutions: The component being absorbed does not react chemically with the absorbent.
2. Reversible reaction: The absorbate reacts with the absorbent but can be recovered via a reverse reaction.
3. Irreversible solution: The absorbate reacts with the absorbent, resulting in a stable compound that is difficult to reverse.

The most widely used application of absorption in the chemical recovery area is probably the absorption of SO_3 in either water or dilute sulfuric acid to produce concentrated sulfuric acid. In radwaste, however, its application is doubtful.

The major differences between the three mass transfer operations are summarized in the following table:

Table 3201
Comparison of Ion Exchange, Absorption and Adsorption

	Ion Exchange	**Adsorption**	**Absorption**
Principle Involved	Transfer of ionized components from liquid to resin functional groups through chemical bonding.	Transfer of components from liquid to the surface of the adsorbent based on their mechanical and electrostatic affinity.	Transfer of components from a gas phase to a liquid phase, in which the components are soluble.
Capacity Parameters	Based on the number of available exchange sites. Usually expressed in (milli) equivalents per gram (eq/gm or meq/gm).	Based on the degree of affinity and surface area available. Usually expressed in m^2/g or pounds or absorbate per pound of absorbant.	Equilibrium concentration is a function of the partial pressure of the absorbate in the gas phase.

3202

What impurities are effectively removed by activated carbon?

Activated Carbon, sometimes called activated charcoal, is relatively effective at removing trace quantities of oils, detergents, and some organic solvents from liquid radwaste (LRW) streams. The type of contaminant found in LRW that can be removed by granular activated carbon (GAC) through a true adsorption process is limited to some organic compounds.

In general, trace quantities of organics are found in LRW. These organics are probably the result of decomposition of organic material that is part of the wet waste system. They may also be introduced by intrusion through the floor drain system or chem-lab drains. Regardless of their origin, these organics are capable of fouling IX beds and can significantly reduce their service life. Therefore, it is desirable to remove them ahead of the IX columns.

As a general rule, the adsorbability of the specific compound increases with the following characteristics:

- Structure (cyclic, aromatic or long chain)
- High molecular weight (100-1000)
- Weak ionization
- Low polarity
- Low aqueous solubility (< 5%)

Examples include:

Compound	**Adsorbability (% reduction)**
Di-isobutyl Ketone	100.0
n-Hexanol	95.5
Benzaldehyde	94.0
Propylene Dichloride	92.8
Acetic Acid	24.0
Formaldehyde	9.2
Ethylene Glycol	6.8
Methanol	3.6

Although many other contaminants are also "trapped" in a carbon bed, the process responsible for their capture may not be adsorbtion. It may, instead, be filtration. In a fixed, down flow GAC (granular activated carbon) bed, the typical mean particle size is 1.5 mm. This provides for an initial filtration capability of approximately 25 microns. This is subsequently reduced to about 15 microns as the suspended, retained solids create a precoat effect in the top third of the bed. These solids have, themselves, varying capacity to adsorb certain particles or compounds. They also temporarily retain impurities, which through mechanical action, are later released and moved downwards toward the effluent side of the vessel.

Cobalt and other metals that can sustain a colloidal state in equilibrium with ionic species are more susceptible to coalesce and form larger particles. These large particles can then be retained in the interstitial cavities of the GAC. The effectiveness of GAC in removing most of the non-organic contaminants should not be based on the properties of the GAC itself but, instead, on the waste stream characteristics (TSS, pH, etc.) passing the GAC bed.

The only exception to the above is for iodide. In fact, iodine is used to measure the degree of microporosity of GAC by the "iodine number"*. However, it should be noted that the adsorption of iodine by GAC is not necessarily representative of its capacity to remove I^- or $I0_3^-$.

> *Note: The "iodine number" is the number of milligrams of iodine adsorbed by one gram of carbon when the Iodine concentration in the residual filtrate is 0.02 normal.*

3203

What is the effect of pH on GAC adsorption efficiency?

The effect of pH on the granular activated carbon (GAC) adsorption efficiency for any compound *is limited to the effect of pH on the specific compound.* For example: a significant reduction of pH in a stream containing a relatively high concentration of oils and greases will facilitate its separation *prior to reaching the GAC column.*

However, a pH change may increase the total ionic burden significantly, thereby reducing the life of the IX beds downstream from the GAC. Under normal conditions (i.e., concentration of oils and greases at less than 5 ppm), a pH change is not recommended.

With respect to the removal of total suspended solids (TSS), the concentration of TSS in the waste stream should be evaluated based on the effect on the GAC beds. If a premature, high differential (delta) pressure condition is frequently achieved, a prefilter (up to 25µ) should be installed.

3204

What types of activated charcoal are available?

There are two broad categories of activated carbons:

1. Gas adsorbent carbons
2. Liquid-phase carbons.

For radwaste applications, we are primarily interested in the latter, but it is important to note that the main distinction between them is the difference in pore size distribution (i.e., the ratio of micropores to transitional and macropores).

Most liquid-phase carbons in the U.S. are produced by high-temperature oxidation with steam of previously charred carbonaceous substances (coal, char, charcoal) These originate from lignite, bituminous coal or petroleum coke. A further division among carbons is introduced with its physical form. It can be granular or powdered. Both forms are used in liquid radwaste applications.

3205

How do I select a specific activated carbon material?

The selection of the appropriate activated carbon is made taking into account a number of considerations. These are related to the effectiveness of the carbon to remove the contaminants. They are also related to the mechanical constraints defined by the treatment equipment (backpressure allowed, etc.).

The variables to be evaluated in the overall performance are the following:

- Particle size
- Pore size distribution
- Abrasion resistance
- Adsorptive characteristics
- Price, delivery, and availability

Note: *Reactivation capacity is not being considered. This is because the spent GAC in LRW applications is discarded rather than reactivated.*

To determine the feasibility of a certain GAC to adsorb the desired contaminants, a relatively simple test is performed using *pulverized* GAC on a batch basis. The date is plotted on logarithmic paper showing the relationship between the amount of impurities adsorbed on unit weight of activated carbon and the amount of impurities remaining in the wastewater. This produces an adsorption isotherm.

Although this isotherm cannot give definitive scale-up data, it will provide:

- A general idea of how effectively this carbon will adsorb impurities present and/or if it will meet the effluent requirements.
- An estimate of the maximum quantities of carbon needed to meet those requirements.
- A preliminary cost evaluation.

The following detailed method can be used to evaluate GACs:

1. Add several quantities of carbon (0.05, 0.10, 0.25, 0.50, 1.0, 2.0, 10, 20 g) to a constant volume of wastewater (100 ml).
2. The mixtures are agitated vigorously for about 30 minutes.
3. Remove the carbon by filtration.
4. Analyze the treated wastewater for the level of impurities (generally by TOC, COD, GC, or similar tests).

The criteria used to evaluate performance is not as clear as an endpoint in a titration. It will depend on the overall economics surrounding the entire water treatment system, including ion exchange demineralizers and filters.

For example:

> A plant has a waste system with average T.O.C. values of 10 ppm. It also has 5 ppm oil and grease and total dissolved solids (TDS) of 1,100 ppm (measured as a specific conductance of ~2,000 µmho/cm).
>
> The question is whether the reduction in TOC, oil and grease should be 50% or 95% prior to directing the flow to the IX columns. Under the above conditions, a reduction of 50% is probably acceptable, since the low life expectancy of the IX beds will not allow a very large amount of organics to foul the resins and, consequently, *significantly* reduce the overall efficiency of the entire system.
>
> If, on the other hand, the TDS level is low (i.e.; <100 ppm), the relevance of the GAC performance is increased, and a higher DF on organics is recommended, even at the expense of additional carbon requirements. The reason for this is that the extended life of the IX columns, based on low TDS, would allow greater throughput if the level of organic contaminants is significantly reduced.

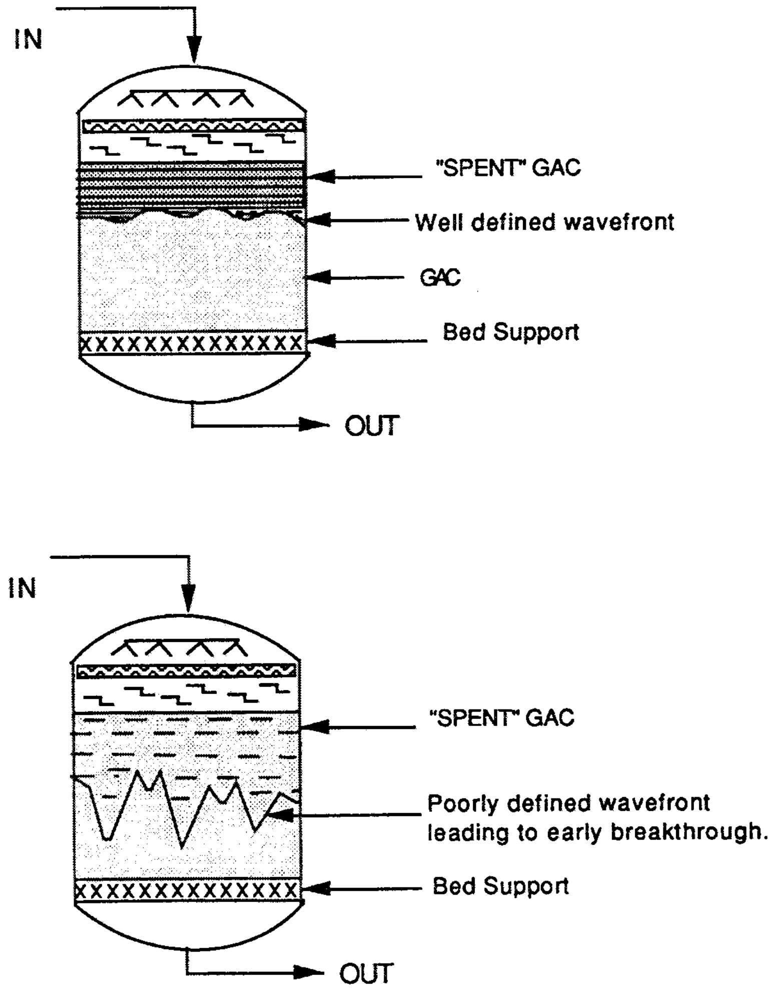
3206

How do you size activated carbon for an IX system?

Assuming that the appropriate type of activated carbon has been selected, the sizing of a carbon bed ahead of an IX system is a relatively straight forward process.

The diameter of the vessel needs to yield a 2 gpm/ft^2 or lower linear flow rate. If higher flow rates are used in the IX system, a larger diameter vessel—or two parallel vessels—can reduce flow rates to effectively use GAC in a uniform way (narrow and well-defined adsorption wave front). This delays the breakthrough point and extends the life of the bed.

Figure 3206
Loading GAC to Maximize Bed Life



Pressure drop across the bed can become one of the most restrictive parameters. Ample allowances must be made to accommodate increased delta pressure with accumulated suspended solids in the intergranular space. Curves of delta pressure versus bed depth (the minimum depth of bed is generally 32") at various flow rates are available from all major carbon suppliers. When such a curve is available, data from a sand filter of equivalent particle size can be used to estimate pressure drops.

Note: A major consideration to be made is that the GAC column will probably be operated as a filter as much as an adsorption bed. Therefore, all design parameters included as part of the bed design and carbon type selection loose some meaning.

3207

What criteria do I use for replacing activated carbon?

The criteria used to replace a carbon bed will vary from plant to plant. Replacement is generally based on:

- The initial concentration of contaminants (including TDS & TSS).
- The desired DF on overall and/or specific contaminants.
- The mechanical set-up and ability to backwash.

However, most plants should change out carbon beds under any of the following conditions:

- High delta pressure across the bed *and* no ability to backwash.
- Longer than 4 months in service, with significant down time. (This promotes biological growth in the bed.)
- Low DF on aromatic organics.

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GLOSSARY

Glossary

absorbent	A material that takes in another material, as a sponge absorbs water.
absorption	The action of an absorbent.
absorption, self	See self absorption.
AC	Alternating current, usually 110 volt, 60 hertz.
accelerator	An additive used during solidification to enhance or expedite the drying or curing process.
acidity	The quantitative capacity of a liquid to react with hydroxide ions.
ACM	Asbestos containing material.
activation	The process of inducing radioactivity by irradiation. Activation occurs primarily in neutron radiation fields.
activation DRP	A discrete radioactive particle formed by activation. The predominate activation product in activation DRPs is cobalt-60.
activation product	A radionuclide formed by activation. Cobalt-60 is often the predominate activation product.
adsorbent	A solid material that holds a contaminant on its surface, as activated carbon holds iodine.
air lift	A hoisting procedure done in air. Usually refers to a lift of a radioactive source without shielding.
air scrubber	A pneumatically operated air file which has been adapted for use as a scrubbing and cleaning tool by attaching scouring pads to the vibrating surface. (Wet scrubbers used on contaminated exhaust systems in some industries are also sometimes called air scrubbers. They are rarely if ever used in nuclear power plants.)
ALARA	As low as is reasonably achievable. As low as is reasonably achievable taking into account the state of technology, and the economics of improvements in relation to benefits to the public health and safety and other societal and socio-economic considerations, and in relation to the utilization of atomic energy in the public interest. (This definition is from pre-1989 versions of 10CFR20).

ALARA paint	The trademark name for a brand of strippable coating.
aliquot	A portion of the whole. A measured part, usually of a liquid sample.
alkalinity	The quantitative capacity of a liquid to react with hydrogen ions.
alpha emitter	A radionuclide that emits alpha radiation.
alpha radiation	Radiation consisting of alpha particles, helium nuclei without associated electrons. The mass of an alpha particle is that of 4 protons.
ANI	American Nuclear Insurers.
anion	A negatively charged ion or radical. Examples include chloride ions (Cl^-), bromide ions (Br^-) and sulfate ions ($SO_4^=$).
anti-coincidence counting	See coincidence counting.
anti-contamination clothing	Protective clothing.
anti-Cs	Anti-contamination clothing. Protective clothing.
anti-springback device	A device which prevents compacted material from expanding after it is compacted. Anti-springbacks are available for both drums and LSA boxes.
Aquaset	A proprietary liquid solidification agent used commonly for oil solidification.
atomic number (Z)	The number of protons in the nucleus of a neutral atom.
background radiation	The radiation that is independent of the sample being measured. It is also used to mean natural background radiation.
backwash	To clean by reversing the normal direction of flow, as in backflushing a filter to wash off the precoat or filtered matter.
bar code	A series of vertical bars representing the binary code for a number from 0 to 9. This is another name for a Universal Product Code. (UPC) label. Bar codes are used on most products to identify the product and manufacturer. They are also used on containers to identify contents.
bar code reader	An optical scanner used to read bar codes.

bare pick	Hoisting a radioactive source (usually a resin liner) in air without shielding.
barge	A non-self propelled vessel.
Barnwell	The NRC licensed low level waste disposal site at Barnwell, South Carolina operated by Chem-Nuclear Systems, Inc.
Below Regulatory Concern	A waste stream that is exempted from NRC concern and control after it is dis posed. Specific reactor wastes or waste streams may be exempt under the provisions of 10CFR20.302.
beta emitter	A radionuclide that emits beta radiation.
beta radiation	Radiation consisting of charged particles emitted from the nucleus of an atom during radioactive decay. The mass of a beta particle is 1/1837 that of a proton.
binder	The solidification media used in processing waste for stabilization and/or disposal (e.g., cement, asphalt).
blowdown	*v.* To exhaust steam and condensate from a system component. *n.* The condensate and steam that is exhausted, usually from the secondary side of a steam generator.
boric acid	The additive used for "chemical shim" reactivity control in PWRs and used in the emergency shutdown systems of BWRs.
BRC	Below Regulatory Concern.
BRE	Boron recovery evaporator (PWRs only).
breakthrough (of ion exchange resin)	The first indication of the failure of a resin column to continue to remove a contaminant that it previously removed.
bremsstrahlung radiation	Photons (X-rays) produced when heavy nuclides (those with a high atomic number) interact with beta radiation.
B.t.u.	British thermal unit. A measure of heat.
bubble hood	An air-suppled respirator that consists of a plastic enclosure over the head. It provides cooling as well as clean breathing air.
B&W	Babcock and Wilcox, Inc., a supplier of pressurized water reactors.
BWR	Boiling water reactor.

BWST	Borated water storage tank.
by-product	A secondary waste or material from decontamination or other process.
byproduct material	According to 10CFR20.3, byproduct material is "any radioactive material (except special nuclear material) yielded in or made radioactive by exposure to the radiation incident to the process of producing or utilizing special nuclear material". That is, all radioactive material in the plant except part of the fuel.
cargotainer	A shipping container that can be transported by truck, rail or barge. Most measure approximately 8 feet by 8 feet by 20-40 feet. Also called an ISO container, sea-land container, or sea van.
carrier	A person engaged in the transportation of passengers or property. In this Desk Reference, a carrier is the transportation company.
car wash	In a nuclear plant, this slang expression is usually used to mean a temporary steam cleaning facility used to decontaminate large equipment.
cation	A positively charged ion or radical. Examples include iron ions (Fe^{++} or Fe^{+++}), sodium (Na^{+}), silver (Ag^{+}), and ammonium (NH_4^{+}).
cask weeping	See weeping (cask).
C.E.	Combustion Engineering, Inc., a supplier of pressurized water reactors.
Celatom	The brand name of a diatomaceous earth-type absorbent approved for use at the Richland, Washington disposal site.
Certificate of Compliance	A document attesting to the fact that a particular shipping cask is approved for certain uses by the NRC.
cf	Cubic feet. Also, abbreviated ft^3.
CFR	Code of Federal Regulations.
channeling (of resin columns)	A condition resulting from improper packing of a resin or charcoal bed in which the solution being treated follows relatively particle-free paths through the bed.
characterize	Usually, to determine radiological characteristics, including chemical and physical characteristics (chemical form and/or particle size).
charcoal	A term that is often used for activated carbon adsorbent in either liquid and gaseous cleanup systems.

chelating agent	An organic compound that forms a chemically stable ring with a metal ion, promoting its solubility. Chelating agents are sometimes used in decontamination solutions. Their disposal is limited because they may promote the migration of radioactive ions in waste.
cherry picker	A term for one type of drum handling device. (This is another name for an "engine hoist.")
Ci	Abbreviation for curies, a measurement of activity.
CITROX	A decontamination agent employing citric and oxalic acid.
Class A waste	Waste comprised primarily of short-lived radionuclides and usually segregated from other waste classes at the disposal site. The physical form and characteristics of Class A waste must meet the minimum requirements set forth in 10CFR61.56(a).
Class B waste	Waste that must meet more rigorous requirements on waste form to ensure stability after disposal. The physical form and characteristics of Class B waste must meet both the minimum and stability requirements of 10CFR61.56.
Class C waste	Waste that must meet more rigorous requirements on waste form and requires additional measures at the disposal facility to protect against inadvertent intrusion. The physical form and characteristics of Class C waste must meet both the minimum and stability requirements of 10CFR61.56.
>Class C waste	See "greater than Class C waste."
clean waste verification	Verification that waste contains no radioactive contamination and therefore can be disposed of without restrictions because of radioactivity.
closed transport vehicle	A transport vehicle equipped with a securely attached exterior enclosure that, during normal transportation, restricts access of unauthorized persons to the cargo space containing the radioactive materials. It must limit access from the top, sides and ends.
cobalt-60 DRP	See activation DRP.
COD	Chemical oxygen demand.
coincidence counting	Counting that uses two stacked detectors. Only counts that occur within the same time interval (due to the same particle or same nuclear decay) are recorded. The same equipment may also be used in the opposing mode to record events that occur in only one of the two detectors. Technically, this is anti-coincidence counting.

C of C	Certificate of Compliance.
cold pump	The pump used to recirculate water through a filter demineralizer to hold the resin in place while the demineralizer is out of service.
colloid	Very small, non-settling particulate material.
Compact Authority	See Low Level Waste Disposal Compact.
compaction	Reduction of volume by physical compression.
condensate polisher system (CPS)	An ion exchange system that treats the condensed steam from the turbines to re-purify it so that it is suitable for re-use in the boiler. The CPS is part of the primary system in a BWR and part of the secondary system in a PWR.
consignee	The intended recipient of a shipment; the individual (person, company or corporation) listed on the bill of lading to receive a shipment.
container venting	Under certain conditions described in Volume 2 of this Desk Reference, a container of waste can generate gases within the closed container. These gases must be vented (released) from the container prior to shipping.
contamination	Contamination means material where it is not wanted. Usually used to mean radioactive contamination; radioactive material where it is not wanted.
core	The active region of a reactor where neutron irradiation and fission take place.
cpm	Counts per minute. The number of radiation events detected by an instrument in one minute.
CPS	Condensate Polishing System. The secondary system in a PWR.
cps	Counts per second. The number of radiation events detected by an instrument in one second.
CRDM	Control rod drive mechanism (occasionally used to mean the internal filter which the CRDM contains).
critical path	The time line of those activities which determine the length of a project. In a power plant, the project is usually an outage.
critical radionuclide	The radionuclide that will give the most biologically significant dose to the human body under the postulated release conditions.

cross contamination	Inadvertent contamination of clean or previously cleaned areas from contaminated areas.
crud	A common term for corrosion product layer in reactor piping, or on fuel.
CRW	Circulating Raw Water (the turbine cooling system in some PWRs) or Clean Radwaste. Liquid radwaste that is low in dissolved and suspended contaminants (usually BWRs).
CST	Condensate storage tank, the main, primary system, make-up tank in a BWR.
CTV	Closed transport vehicle.
curie	One curie equals 3.700E+10. That amount of radioactive material which disintegrates at the rate of 37 billion atoms per second.
curie content	The number of curies of radioactivity in a package of radioactive material or radwaste.
curing time	The time required for a solidification or encapsulation binder (e.g., cement) to dry and harden.
CVCS	Chemical volume control system, a term used in BWRs for the condensate cleanup system. It is called the Make-up and Purification System in some plants.
daughter radionuclide	Decay product. A radionuclide resulting from the radioactive disintegration of a radionuclide, formed either directly or as the result of successive transformations in a radioactive series. A decay product may be either radioactive or stable.
DAW	Dry Active Waste.
DB	Deep bed. Deep bed ion exchange columns are large vessels containing bead (not powdered) resin. Activated carbon or other absorbents may also be present in deep bed systems.
dead time	The time when a counter cannot function because the count rate is so high that it overloads its detector. High activity samples have a greater dead time than low activity samples.
decay rate	The rate at which a radioisotope decays. Decay rate is usually given in disintegrations per minute.
decontamination	The complete or partial removal of radioactive contamination.

decontamination factor	For a liquid treatment system or process, Decontamination Factor (DF) is the ratio of initial or influent concentration to final or effluent concentration. (A DF of less than one indicates that contamination is being added, not removed.) For surfaces, DF is the ratio of contamination level before decontamination to the contamination level after decontamination.
dedicated equipment	Equipment that is reserved for some exclusive use, such as dedicated equipment for processing DRP waste.
deep pocket	Financial resources. Many lawyers make it a point when filing a suit to include among the defendants those with "deep pocket" in hopes of being able to collect any judgement.
delisting	Excluding or not listing a specific nuclide as part of the shipping papers.
delta	Change or differential.
delta P (ΔP)	Change in pressure. Pressure drop, as across a filter.
demineralize	A process intended to remove ionic constituents.
demineralizer	An ion exchange vessel used to remove some or all of the ions present in a liquid. In radwaste, the term is often used to mean any ion exchange vessel used for water cleanup.
de minimis	An increment of dose equivalent or a radioactive material concentration (above background) so small that it poses no hazard to the general population. At the present time, no such level has been established.
demurrage	A detention fee or other charge for detaining a truck or freight car. (This is normally incurred when on-site problems delay the shipment of a loaded waste vehicle.)
detention charge	A fee charged by a transportation company to cover the expenses (labor, motel, etc.) of a truck driver when the driver must wait at the plant for an inordinate amount of time. Most transporters allow from two to six hours time to pick up a load at the plant site. After that time, the additional time during which a driver and load is detained will be billed to the utility as a detention charge.
dewatering	The removal of water, usually by gravity or pumping (as distinguished from drying). As the term applies to the processing of spent resin, there are two similar but distinctively different meanings:

(1) When solidifying spent resin, the resin is dewatered to obtain the desired resin:water:binder ratio. It is not intended that all free standing water be removed from the resin before addition of the binder. This dewatering effort is a subcomponent of the utility's **solidification** process control program approved by the NRC.

(2) When dewatering resin for disposal without the intent of solidifying, the dewatering pump and system continues to draw water from the resin until the free-standing water is less than 0.5 percent. This dewatering effort is a subcomponent of the utility's **dewatering** process control program approved by the NRC.

DF	Decontamination factor.
difficult-to-measure radionuclides	Radionuclides that are not abundant and do not release easily detected gamma radiation. Difficult-to-measure radionuclides include strontium-90, carbon-14 and iron-55.
discrete radioactive particle	A highly radioactive small particle. Also called hot particle or "fuel flea."
disposal allocation	The amount of radwaste disposal space allocated without penalty to each nuclear generating station under the Low Level Radioactive Waste Policy Amendments Act.
disposal volume	The volume of radioactive waste being shipped for disposal. This is calculated using the exterior dimensions of the package, and it is , therefore, typically greater than the interior volume.
divisible load	A divisible load is one which can be separated into smaller components. The determination is normally only made when a shipment is being considered for an overweight permit.
dose	A general term denoting the quantity of radiation or energy absorbed. For special purposes, it must be qualified (Radiological Health Handbook. US Department of Health Education and Welfare, 1970).
dose rate	A term denoting the rate at which radiation dose is absorbed. See dose.
DOT	US Department of Transportation.
dp	Differential (delta) P, change in pressure, pressure drop, as across a filter.

dpm	Disintegrations per minute. The number of nuclear events occurring in the sample in one minute.
dps	Disintegrations per second. The number of nuclear events occurring in the sample in one second.
drop-off charge	A fee charged by a transportation company to drop off a trailer for loading at a later time. This fee is usually much lower than the charges incurred if the driver must wait at the plant while the trailer is being loaded. (See detention charge.)
DRP	Discrete radioactive particle, also called hot particle or fuel flea.
dry active waste	Dry, solid, low level radioactive waste.
EDTA	Ethylenediaminetetracedic acid. One of the most powerful and widely used, chelating agents.
efficiency (of a counter)	A measure of the probability that a count will be recorded when radiation strikes a detector. The counts per unit time recorded divided by the disintegrations in the same time.
effluent	The solution that flows from a liquid process stream (either a treatment system or the plant itself).
electro-etch	A process of decontaminating a metallic component by dissolving a layer of the metal surface by employing an electric current.
emergency allocations	Special allocation of waste burial volume allotted under the provisions of the Low Level Radioactive Waste Policy Amendments Act.
energy dependence	In a radiation detector, energy dependence is the variation in pulse height (voltage) with the energy of the incoming radiation. Energy dependence allows discrimination and identification of radionuclides if the system has the electronics to resolve the results.
EPA	US Environmental Protection Agency.
EPRI	Electric Power Research Institute.
EP Tox	EP Toxicity.
EP Toxicity	The toxicity of a chemical as determined by a series of definitions and tests established by the Environmental Protection Agency. The EP Toxicity is one method of determining if a new compound or mixture is hazardous.

etched disk filter	A type of in-line filter employing a porous metal filter media with good mechanical resistance to high pressure drops. Etched disk filters can be cleaned by backwashing.
ethylenediaminetetracedic acid	See EDTA.
exclusive use	As defined by 49CFR173.403(i), exclusive use (also referred to as full load or sole use;) means the sole use by the shipper of a transportation vehicle, for which all loading, transportation, and unloading of the vehicle is carried out under the direction of the shipper or destination. No other material may be picked up by the vehicle while under this designation.
exclusive use shipment	As defined by 49CFR173.403(i), exclusive use means the sole use by the shipper of a transportation vehicle, for which all loading, transportation, and unloading of the vehicle is carried out under the direction of the shipper or destination. No other material may be picked up by the vehicle while under this designation.
exclusive use vehicle	A vehicle used in making an exclusive use shipment. (See "exclusive use.")
exempt quantity	A quantity of radionuclides that is exempt from the transportation regulations of 49CFR.
FD	(Sometimes written **f/d.**). Filter demineralizer(s). Engineered systems that perform both ion exchange and filtration on the liquid being treated.
fifth wheel	A typical waste trailer (40-foot long trailer) has four sets of tires, all located near each other at the rear of the trailer. When the trailer is connected to a tractor (the truck), the tractor acts as the fifth set of wheels for the trailer. The connection point between the trailer and tractor is the adjustment point for the fifth wheel, which adjusts the tractor cab-to-trailer separation.
fines	Finely divided ion exchange material.
fire loading	Using ANI standards, the average weight of combustibles per unit areas. ANI fire loading standards are usually in pounds per square foot. (Permissible values are usually in the range of 20 to 100 lb/ft^2). NFPA gives fire loading in B.t.u./ft^2.
fission product	A nuclide that is formed by nuclear fission. Fission products of concern are usually the radioactive ones such as Cs-137 and the plutonium isotopes. Ordinarily, fission products are confined within the fuel and are only of concern if fuel has been breached.

fixed contamination	Contamination that is not easily removed without disturbing the base material. Contamination that is not transferred to the sample when a wipe or smear sample is taken.
flashpoint	In steam cleaning, the location where spray flashes from water to steam and creates turbulent scrubbing action.
flea	See fuel flea.
Floor Dry	The brand name of a diatomaceous earth-type absorbent approved for use at the Richland, Washington disposal site.
Florco	The brand name of a clay-type absorbent approved for use at the Richland, Washington disposal site.
Florcox	The brand name of a clay-type absorbent approved for use at the Richland, Washington disposal site.
Freon	The brand name of several chlorinated, fluorinated hydrocarbons used for degreasing, cleaning and decontamination.
FPCU	Fuel pool cleanup, more often called SFPCU, spent fuel pool cleanup.
free release	Disposal or recycle without restrictions imposed because of radioactive contamination. See also the preferred term, clean waste verification.
ft^3	Cubic feet. Also abbreviated *cf.*
fuel cladding failure	Breaches in the cladding of fuel of any size that release dissolved or particulate radioactive contamination into the primary system.
fuel DRP	A discrete radioactive particle containing fission products from the reactor fuel.
fuel failure	See fuel cladding failure.
fuel flea	A discreet radioactive particle (DRP) derived from irradiated fuel.
gamma emitter	A radionuclide that emits gamma radiation from its nucleus.
gamma radiation	High energy, short wavelength electromagnetic radiation emitted from the nucleus. Gamma radiation is more penetrating than either alpha or beta radiation. Gamma rays are similar to X-rays, except in their formation. They are normally more energetic.

GC	Gas chromatograph or gas chromatography.
GE	General Electric, the only supplier of boiling water reactors in the United States.
GeLi	Lithium drifted germanium. Sometimes abbreviated Ge(Li). A common and useful radiation detector. A GeLi detector coupled with the right electronics, will resolve the energy of the radiation striking it so that isotopes can be identified.
generation volume	The volume of waste measured before any processing other than collection.
GET	General employee training.
G-M detector	Geiger-Mueller detector.
greater than Class C waste	Waste that is "not generally acceptable" for near-surface disposal. It is waste for which waste form and disposal methods must be different, and in general more stringent, than those specified for Class C waste. In the absence of specific requirements in 10CFR61, proposals for disposal of this waste must be submitted to the NRC for approval, pursuant to 10CFR61.58.
half-life	The time required for one half of a quantity of a pure radionuclide to decay.
halides	Chemicals of the halogen group in the periodic table of elements. Generally, chlorides, fluorides and iodides.
Hanford	Usually used to mean the licensed low level waste disposal site operated by US Ecology near Richland, Washington. Occasionally, the term is used to mean the Hanford Nuclear Reservation operated by the US Department of Energy near Richland, Washington.
hazardous chemical	See hazardous material.
hazardous material	A material that has hazardous properties as defined in 40CFR261. Hazardous materials would be classified as hazardous waste if they were waste. They are hazardous materials while they yet have a use.
hazardous substance	See hazardous material.
hazardous waste	Listed hazardous waste or waste that exhibits defined hazardous properties. See 40CFR261.

High Density Polyethylene	A type of polyethylene plastic in which the molecules are arranged in tight vertical rows to improve puncture resistance and horizontal tears. For a high integrity container, many layers of this plastic are bonded perpendicular to each other. This greatly enhances tearing in either a vertical or horizontal fashion. The resultant material is called "cross-linked polyethylene" and is an exceptionally strong and long-lived plastic.
HDPE	High Density Polyethylene.
heat stress	Any of a series of physiological conditions that may occur if the deep body temperature exceeds 38°C (102.2°F). Symptoms may include fainting, heat cramps, heat rash, heat exhaustion and heat stroke. Monitoring of the deep body temperature is impractical, so an evaluation of potential heat stress conditions usually requires evaluation of the wet bulb globe temperature in the work area, the work conditions and duration, and the protective clothing
HEPA filter	High efficiency particulate air filter. HEPA filters, by definition, must retain at least 99.97% of particulate material 0.3 microns or larger in diameter.
Herculite	The trademark name of a brand of flexible protective covering used for floors, walls, etc. for contamination control and surface protection.
HIC	High integrity container.
Hi Dri	The brand name of a clay-type absorbent approved for use at the Richland, Washington disposal site.
high integrity container	A container that is designed to contain buried waste for 300 years or more when buried.
High Radiation Area	An area, accessible to personnel, where a major portion of the body could receive in any one hour a dose in excess of 100 millirem.
	hot spot For the purposes of the Desk Reference, a hot spot is a small spot on a radwaste container which produces a substantially higher dose rate than most of the container surface.
HVAC	Heating, ventilating and air conditioning.
HX	Heat exchanger.
hybrid decontamination process	Decontamination processes that are part chemical and part mechanical. Strippable coatings are considered hybrid decontamination processes.

hydrolazer	A type of high pressure water cleaner used for decontamination.
IAEA	International Atomic Energy Agency.
ICRP	International Council on Radiation Protection.
I&E	The Inspection and Enforcement branch of the NRC.
IFF	Irradiated fuel fragment. Other names are fuel DRP and fuel flea.
important to safety	10CFR50, Appendix A says that structures, systems and components that are important to safety are those that "provide reasonable assurance that the facility can be operated without undue risk to the health and safety of the public."
Inconel	The trademark name of an alloy used in heat exchanger tubes and other reactor components.
influent	The solution that enters an ion exchange system.
ingrowth	The accumulation of daughter radionuclides from the radioactive decay of the parent.
INPO	Institute of Nuclear Power Operations.
Instant-Dri	The brand name of a clay-type absorbent approved for use at the Richland, Washington disposal site.
internal waste volume	The volume of waste which a container can hold. This is calculated using the interior dimensions of the container, and it is, therefore, typically less than the disposal volume.
irradiated components	For the purposes of this Desk Reference, the term "irradiated components" refers to neutron activated components.
irradiated fuel fragment	Fuel DRP or "fuel flea."
ISO container	A type of shipping container that can be transported by rail, truck or cargo vessel. ISO containers are often used for temporary on-site waste storage or to ship waste to processors. They are also called sea vans, cargotainers, etc.
ISOSHLD	The name of a shielding code.

isotopes	Nuclides having the same number of protons in their nuclei, and hence the same atomic number, but differing in the number of neutrons, and therefore the mass number. Almost identical chemical properties exist between isotopes of the same element.
isotopic composition	The content of a sample by radioisotope. Stable (non-radioactive) isotopes are usually not considered.
IX	Ion exchange.
Johnson Screen	A brand of metal screen used to retain resins in ion exchange columns.
Krolite	The brand name of a vermiculite-type absorbent approved for use at the Richland, Washington disposal site.
liquid scintillation cocktail	The organic solvent used in low level beta counting. It usually contains toluene or similar organic solvents.
liquid scintillation counting	Scintillation counting in the liquid state. Liquid scintillation counting detects beta radiation. See scintillation counting.
limited quantity	Maximum amount of a hazardous material for which there is a specific labeling and packaging exception.
listed hazardous waste	Waste containing components listed in Subpart D of 40CFR261.
live time counter	A counter that automatically corrects for dead time in sample counting.
LLD	Lower limit of detection.
LLW	Low level waste.
LLRW	Low level radioactive waste; more commonly referred to as simply LLW.
LLRWPAA	Low Level Radioactive Waste Policy Amendments Act of 1985.
LOMI	Low oxidation metal ion. A decontamination method employing a dilute solution of vanadium picolinate.
long-lived radionuclide	A relative term, indicating the period of time a radionuclide will be detectable in a significant amount. Radionuclides with a half-life of less than 60 days are rarely considered long-lived. Those with a half-life of 100 years or more almost always are.

lower limit of detection	Usually the least amount of material that can be detected with 95% confidence.
low quality steam	Steam at a temperature and pressure very close to the point at which it will become liquid. Sometimes a mixture of steam and water.
Low Level Waste Policy Amendments Act of 1985 (LLWPAA)	A law passed by the US Congress which outlines state and regional responsibilities for the disposal of low level radioactive waste. The LLWPAA also establishes minimum utility waste disposal volumes from 1986 through 1992 and establishes allowable disposal volume surcharges which may be levied against nuclear stations located in unsited compact regions.
Low Specific Activity (LSA)	LSA (Low Specific Activity) is a class of material in which the activity is essentially uniformly distributed and in which the estimated average concentration per gram of contents does not exceed the specifications of 49CFR173.403(n). This allows less restrictive requirements to be applied during shipping.
LPRM	Low power reactivity monitor.
LRW	Liquid radwaste.
LSA	Low specific activity.
LSA box	A box in which LSA waste is shipped. Metal boxes of about 98 ft3 are common.
LWR	Light water reactor, any water cooled reactor except a heavy water cooled reactor.
magnehelic gauge	A type of differential pressure gauge used in air moving systems.
make-up and purification	One of the designations used for the principal reactor coolant cleanup system in a PWR. In a BWR, this is commonly referred to as the make-up demineralizer (MUD) system.
(MUP) system	pressurized water reactor.
manometer	A type of differential pressure gauge used in air moving systems. This is commonly used to measure the flow rate of air through a ventilation system.
massalinn cloth	A low lint, treated cloth often used industrially for wiping and dusting.
maximum permissible concentration	From 10CFR20, Appendix B. The maximum permitted concentration of a radio nuclide in air or water in a restricted or unrestricted area (separate values). Maximum permissible concentrations in restricted areas were calculated to give an individual exposed to this concentration 40 hours per week, 50 weeks per year the

	maximum permissible radiation exposure (5 rem/year whole body for radionuclides for which the whole body is the critical organ) after a period of 50 years. Maximum permissible concentrations in unrestricted areas were calculated to give an individual exposed to this concentration continuously for 50 years, the maximum permissible exposure for people in unrestricted areas (170 mrem/year whole body for radionuclides for which the whole body is the critical organ). Maximum permissible concentrations are being replaced with a new unit, derived air concentration (DAC).
mCi	Abbreviation for millicuries, a measurement of activity.
MDA	Minimum detectable activity.
MICROSHLD	The name of a shielding code.
minimum detectable activity	The smallest concentration or quantity of a radioactive material in a sample that yields a net count above system background with 95% confidence.
mixed bed (resins)	A physical mixture of anion exchange and cation exchange materials.
mixed waste	Mixed low-level radioactive and hazardous waste. Waste that satisfies the definition of low level radioactive waste (LLW) as defined in the Low Level Waste Policy Amendments Act and contains hazardous waste that either (1) is listed as a hazardous waste in Subpart D of 40CFR261 or (2) causes the LLW to exhibit any of the hazardous waste characteristics identified in Subpart C of 40CFR261. (Definition is from Joint EPA/NRC letter, "Guidance of the Definition and Identification of Commercial Mixed Low-Level Radioactive and Hazardous Waste and Answers to Anticipated Questions".)
MPC	Maximum permissible concentration.
MSDS	Material Safety Data Sheets.
multi-channel analyzer	An electronic counting system that is able to discriminate between pulses of different voltages. Multi-channel analyzers are widely used for gamma spectroscopy for radionuclide identification.
mung	A slang term for solids in liquid radwaste streams, possibly a contraction of mud and dung, two elements which share some of its properties.
MUP	Make-up and purification system.
muriatic acid	A technical grade of hydrochloric acid, usually containing some free chlorine. A 1% solution is sometimes used for cleaning concrete.

MWST	Miscellaneous waste storage tank.
MWT	Miscellaneous waste tank.
NaI	Sodium iodide, usually means a thallium drifted sodium iodide detector.
NaI(Tl)	Thallium drifted (activated) sodium iodide detector.
natural background radiation	The radiation in the natural environment, including cosmic rays and radiation from naturally-occurring radioactive elements, both inside and outside the human body.
NCRP	National Council on Radiation Protection.
neutron	An uncharged elementary particle with a mass slightly greater than a proton.
neutron flux	A measure of the rate of neutron flow. Usually measured in number of neutrons per square centimeter.
new waste stream	A term used to refer to a waste stream that has not been characterized according to 10CRF61.
NGA	Not generally acceptable for shallow land burial (i.e., > Class C waste).
NFPA	National Fire Protection Association.
NIST	National Institute of Standards and Technology, formerly the National Bureau of Standards.
non-compactible DAW	DAW consisting of pipe, valves and reactor components that cannot be reduced in volume by the equipment available. What is considered compactible from one plant to the next will vary depending on the compaction equipment available.
non-divisible load	A non-divisible load is one which cannot be separated into smaller components, such as a single resin liner in a shipping cask, a steam generator, or other large component.
non-sited compact region	From the Low Level Radioactive Waste Policy Amendments Act, any area of the United States which is not a sited compact region.
N.O.S.	A shipping designation meaning "not otherwise specified." In other words, there is no other designation for the material on the shipping tables in 49CFR171.8.
NPDES	National Pollutant Discharge Elimination System.

NRC	US Nuclear Regulatory Commission.
Oil-Dri	Formerly called Safe-n-Dri. The brand name of a clay-type absorbent approved for use at the Richland, Washington disposal site.
O&M	Operation and maintenance.
Origen-2	A computer code used to determine the radionuclide inventory from fission and activation during reactor operation. It has been used to determine the radionuclide inventory of activated components.
ORW	Oily radwaste (liquid).
OTSG	Once through steam generator - a steam generator containing straight tubes (these are used in some B&W reactors.)
outage	That period when a piece of equipment is out of service. Often used to refer to a nuclear reactor outage.
overpack	A large container, into which a smaller container is placed. This is frequently used when the smaller container is damaged or contains liquid which must be surrounded by absorbent. The technical definition from 49CFR171.8 is an enclosure that is used by a single consignor to provide protection or convenience in handling of a package or to consolidate two or more packages. (A freight container is not an overpack.)
package	The packaging together with the contents. For example, a 55-gallon drum is considered as packaging when still empty and consists of the drum, lid, bolt/nut, retainer ring and gasket. When it is filled, closed and ready for shipment, it now becomes a complete package.
packaging	The assembly of components necessary to ensure compliance with the packaging requirements of 49CFR171.8 and 10CFR71. (See package.)
packaged volume	The volume of waste as it is packaged ready for disposal. This includes the volume of the burial containers.
parent radionuclide	A radionuclide that decays to form a radioactive daughter radionuclide. A single radionuclide may be both a parent and daughter in a decay chain.
PASS	Post accident sampling system.
passivation	A chemical process to condition a surface to prevent further corrosion or deposition of materials onto it.

pathway	The route by which a radionuclide travels to give a radiation dose. Radionuclides in airborne or liquid effluents may give a population dose through a food chain pathway.
pCi	Abbreviation for picocuries, a measurement of activity.
PCP	Process Control Procedure, a standard method of verifying the effectiveness of waste processing procedures, e. g., solidification.
PC	Protective clothing.
Petroset	A proprietary solidification agent for hydrocarbons and other chemicals.
pH	The negative logarithm of the hydrogen ion concentration in a liquid (or the log of the reciprocal of the hydrogen ion activity). Essentially, this is a measure of the hydrogen ion concentration. A value of <7.0 is considered acidic, whereas a value of >7.0 is considered basic. A value of exactly 7.0 is considered as having a neutral pH.
photon	A quantum or packet of energy emitted as electromagnetic radiation. Gamma rays, X-rays and visible light consist of photons.
P&ID	Pipe and instrument diagram. A common tool to determine the interconnection of systems or the connection of floor drains.
placarding	The placement of prescribed placards delineating the hazard of a material in transport.
planchet	A metal disk used to position samples for counting. Planchets are most often used in proportional counters.
planer/joiner	A wood working device used to remove the surface from wood. Also called a planer/jointer.
pOH	14 minus the pH value. Essentially, this is a measure of the hydroxide ion (OH^-) ion concentration in a liquid.
polishing	Usually final cleaning of high quality water (as condensate polishing demineralizers).
polyvinyl chloride	A plastic material used in plastic products, such as bags, gloves, booties, bubble hoods, and rain suits. It is also a type of pipe used in some temporary piping installations. (Note: PVC releases chlorine gas when burned, which limits its use for incineration operations.)

POPOP	2,2-p-phenylenebis (5 phenyloxazole) a common liquid scintillator.
PPO	2,5 diphenyloxazole, a common liquid scintillator.
predominate radionuclide	An isotope which, because of its concentration, half-life, or chemical characteristics, appears to be the most prevalent constituent of a sample or waste stream. Cobalt-60 and cesium-137 are usually predominant nuclides in reactor waste.
prefilter	A filter that precedes another filter. Usually an air filter that precedes a HEPA filter.
pressurized water reactor	A light water reactor that transfers heat to a secondary (uncontaminated) steam/ water system which powers the turbine.
primary side	The part of a nuclear power plant that contains primary coolant, the water that is heated directly by the fuel.
prior notification shipment	A shipment of radioactive material or waste which presents a hazard sufficient to require notification of the various states along its route of travel. This notification must be made prior to the shipment entering the state.
process control procedure	A standard method of verifying the effectiveness of waste processing procedures, e. g., solidification.
progeny radionuclide	See daughter radionuclide.
proper shipping name	The name of the hazardous material shown in Roman print (not italics) in 49CFR172.101.
pulse pileup	The effect of so many pulses in a counter that the electronics cannot analyze them. The result is the inability of the detection system to account for all the ionizing events.
PVC	Polyvinyl chloride. A plastic material used in plastic products, such as bags, gloves, booties, bubble hoods, and rain suits. It is also a type of pipe used in some temporary piping installations. (Note: PVC releases chloride gas when burned, which limits its use for incineration operations.)
PWR	Pressurized water reactor.
QAD	A shielding code. QAD stands for quick and dirty.
Radiacwash	A brand of mild chemical decontamination solution reportedly containing oxalic acid.

radiation control area	Any area controlled for the purposes of limiting exposure to radiation or radioactive contamination. Normally, the area immediately surrounding a reactor primary system.
radioassay	Analysis for radionuclides.
radiochemical analysis	Analysis using the chemical properties of the radionuclide of interest to separate it from the bulk of the material before radiological counting. Radiochemical procedures generally have much lower MDAs than direct radiological counting.
radioiodine	A radioactive isotope of iodine. The most common ones are I-129 and I-131.
RADMAN	The name of a shielding code that is geared to the needs of the radwaste professional.
radwaste	Radioactive waste.
raw water	Untreated water from wells, lakes, rivers, or other surface sources.
RCA	Radiation control area. Any area controlled for the purposes of limiting exposure to radiation or radioactive contamination. Normally, the area immediately surrounding a reactor primary system.
RCBT	Reactor coolant bleed tank.
RCDT	Reactor coolant drain tank.
RCRA	Resource Conservation and Recovery Act.
RCS	Reactor coolant system.
RDA	Reliably detectable activity.
regeneration (of ion exchange resins)	Chemical treatment to convert or restore the functional groups in an ion exchange material to a specific ionic form.
regenerative heat exchangers	Heat exchangers that transfer heat from primary system water (as it is removed from the primary system for treatment) to the effluent from a treatment system to warm it prior to reintroduction into the primary system.
Reg Guide	See Regulatory Guide.

Regulatory Guide	One of a series of documents published by the NRC which identify one acceptable method of performing some required task or function.
removable contamination	Contamination that can be removed by hand wiping or other nondestructive measures. It is also called smearable contamination. It is usually quantified as the number of disintegrations per 100 square centimeters.
reportable quantity	The quantity specified in column 3 of the Appendix to 49CFR172.101 for any material identified in column 1 of the same Appendix.
RHR	Reactor Heat Removal (System). One of the principle emergency systems in a reactor.
right-to-know	A series of laws that prescribe the information on various work place and environmental hazards that must be available to workers, and in some cases residents and/or emergency workers, in the vicinity of a generator or processor of a hazardous substance.
R/O	Reverse osmosis, a water purification process using a semipermeable membrane.
rock up	A slang term for crystallization, usually applied to boric acid solutions.
RPT	Radiation protection technician.
RQ	Reportable quantity.
RW	Radwaste.
RWCU	Reactor water cleanup.
RWST	Reactor water storage tank.
Safe-T-Sorb	The brand name of a clay-type absorbent approved for use at the Richland, Washington disposal site.
safety related	Important to safety. 10CFR50, Appendix A says that structures, systems and components that are important to safety are those that "provide reasonable assurance that the facility can be operated without undue risk to the health and safety of the public".
SARA	Superfund Amendments and Reauthorization Act.

scabbler	A device used to decontaminate concrete surfaces. The device works by battering and chipping away at the surface many hundreds to thousands of times per minute with many small tips attached to a heavy-duty vibrating motor. Most scabblers also have attached or built-in vacuum systems for controlling dust and airborne particulate material.
scaler	An instrument used to count pulses or events registered by a detector.
scaling factor	Known ratios of radionuclides in reactor waste streams which are used to calculate the quantity of some radionuclides which are known to present but are not directly measured in each waste package. Activation radionuclides such as iron-55 and nickel-63 are usually scaled to cobalt-60. Fission radionuclides such as the plutonium isotopes are usually scaled to cesium-137.
scattering	The change in direction of subatomic particles or photons as a result of a collision or interaction.
scintillation cocktail	The fluid used in liquid scintillation counting for beta radionuclides. Most scintillation cocktails contain toluene or other organic solvents.
scintillation counting	The combination of a phosphor, photomultiplier tube, and associated electronic circuits for counting light emissions produced in the phosphor by ionizing radiation.
scintillator	A material that emits light when struck by radiation.
Scotch-Brite	A brand of abrasive pad used for decontamination.
sea-land container	A large cargo container frequently used to haul bulk waste. A typical sea-land container is 8'Wx8'Hx40'L. Their large size also makes them an ideal storage container for reusable radioactive components.
sea van	Sea-land container.
segregation	The process of separating waste according to radiological considerations. This may involve separating bags of trash by dose rate (e.g., 0-5, 5-50, and >50 mrad/hr), separating trash containing discrete radioactive particles from the more routine radioactive trash, or similar segregation systems.
self absorption	Absorption of radiation by the material in which the radioactive atoms are located: in particular, the absorption of radiation within a sample being assayed.
SFPCU	Spent fuel pool cleanup.

SFPCS	Spent fuel pool cleanup system.
S/G	Steam Generator.
SGBD	Steam generator blow down.
shipping cask	A shielded container used to transport one or more other containers. The other containers fit inside the shipping cask and usually are high dose rate and high concentration packages.
shipping paper	A shipping order, bill of lading, manifest or other shipping document serving a similar purpose and containing the information required by 49CFR171.8.
short-lived radionuclide	A relative term indicating the period of time a radionuclide will be detectable in a significant amount. Radionuclides with a half life of less than 30 to 60 days may be considered short-lived for radwaste management purposes.
SI (units)	The term for an international system of standard radiation units. See conversion tables for specific units.
SIMPLE	The name of a shielding code.
sited compact region	From the Low Level Waste Policy Amendments Act, a compact region in which there is located one of the regional disposal facilities at Barnwell, in the state of South Carolina, Richland in the state of Washington, or Beatty in the state of Nevada.
SLCS	Secondary leakage collection system. The system that collects leakage from the turbine condenser cooling system in a BWR.
sludge	Wet particulate solids.
smearable contamination	Contamination that can be removed by wiping with a cloth or rag.
smear survey	A test for loose or removable contamination. Also called a swipe survey.
SNM	See special nuclear material.
sock filter	A slang term for a cloth bag filter used in liquid processing systems.

sorting	The process of organizing, separating, or arranging waste types by characteristic. This usually involves sorting through a container or bag of waste to separate and organize the contents into separate piles or containers. These separate containers may consist of potentially clean waste to be surveyed for release, recoverable protective clothing, wet rags and mop heads, metals and/or noncompactibles, aerosol cans, recoverables tools and equipment, and/or similar categories.
source material	According to 10CFR20.3 ‘source material’ means: (i) Uranium or thorium, or any combination thereof, in any physical or chemical form; or (ii) ores which contain by weight one-twentieth of one percent (0.05%) or more of (a) uranium, (b) thorium or (c) any combination thereof. Source material does not include special nuclear material.”
Spec 7A	Specification 7A of the DOT. It is strictly a “performance specification” for Type A quantities of radioactive material.
special form radioactive material	Those materials which, if released from package, might present some direct radiation hazard but would present little hazard due to radiotoxicity and little possibility of contamination. (49CFR173.389(d)).
special nuclear material	According to 10CFR20.3 ‘special nuclear material’ means: (i) plutonium, uranium-233, uranium enriched in the isotope 233 or in the isotope 235, and any other material which the Commission, pursuant to the provisions of Section 51 of the act, determines to be special nuclear material, but does not include source material’ or (ii) any material artificially enriched by any of the foregoing but does not include source material”. Reactor fuel is special nuclear material.
specific activity	The total activity of a radionuclide (or all radionuclides) per unit weight of a compound, element, radionuclide or waste.
Speedi-dry	The brand name of a clay-type absorbent approved for use at the Richland, Washington disposal site.
stabilization	The process of converting a non-solid waste form, such as resin beads or filter media, into a stable and solid monolith. A typical example would be to mix resin with cement to form a concrete monolith.
stable	Not subject to radioactive decay, non-radioactive.
stable form radioactive material	Radioactive material that has less stringent handling requirements because of its non-dispersible form. See 10CFR20.

State Form 802	The form required by the state of South Carolina before waste is shipped to Barnwell. Failure to file this form can result in fines or in the waste being returned to the shipper.
Stellite	The trademark name of a very hard alloy material used in valve seats. Stellite contains cobalt which, when activated, forms cobalt-60 and contributes to the radioactivity of the corrosion product layer on piping and to activation DRPs.
stress corrosion cracking	A failure mechanism of metals exposed to chemical stresses, heat and/or pressure. Stress corrosion cracking is promoted by the presence of halides such as chloride, especially in hot systems.
strong outside container	The outermost enclosure which provides protection against the unintentional release of its contents under conditions normally incident to transportation. (This is frequently referred to as a strong, tight container.)
strong, tight container	A container which will not leak any of the contained radioactive materials during conditions normally incident to transportation.
sulfonic acid resin	A cation exchange resin containing the -SO_3H functional group.
Superfine	The brand name of a diatomaceous earth-type absorbent approved for use at the Richland, Washington disposal site.
swipe sample	A test for loose or removable contamination. Also called a smear sample.
tankage	Water storage capacity in on site tanks.
tare	A deduction from the gross weight of a container and its substance for the weight of the container.
TCLP	Toxic contaminant leaching procedure.
Technical Specifications	Part of the licence of NRC licensed nuclear plants. This sets forth the technical parameters and requirements for safe operation of the nuclear plant.
Tech Specs	Technical Specifications. Part of the licence of NRC licensed nuclear plants.
Teflon	A trademark for a chemically nonreactive fluorinated hydrocarbon.
theoretical density	The density of a material without air.
thermal cycling	Significant increases and decreases in temperature. Example: waste stored at 60 degrees Fahrenheit subjected to freezing temperatures.

thoron	An older name for Rn-220. Thoron daughters, like radon daughters, are primarily alpha emitters.
T.O.C. (or TOC)	Total organic carbon.
torus	An area of a BWR that is designed to collect excess coolant in certain postulated accidents.
traceable calibration	A calibration that can be traced to the National Institute of Standards and Technology, formerly the National Bureau of Standards.
transport vehicle	A motor vehicle or rail car used for the transportation of cargo by any mode. Each cargo-carrying body (trailer, railroad freight car, etc.) is a separate transport vehicle.
transuranic	Material that contains more than 100 nano-Curies (nCi) per gram of transuranium isotopes.
TRU	See transuranic.
TSCA	Toxic Substances Control Act.
Type A quantity	Type A quantities are divided per 49CFR171 into two categories: A1 and A2. The A1 and A2 values are found in both 49CFR173.435 and 10CFR71. They are defined as follows: A_1 — special form: A material which, if released from the package, might present a direct hazard from the radiation, such as an encapsulated source, but little hazard from the radiotoxicity and little possibility of contamination; and A_2 — normal form: All other radioactive materials.
type "A" package	A package which is designed in accordance with the general packaging requirements of 49CFR173.24 and 173.412 and which is adequate to prevent the loss or dispersal of the radioactive contents and to retain the efficiency of its radiation shielding properties if the package is subject to the tests prescribed in 49CFR173.465.
Type B quantity	When the A_1 and A_2 values are exceeded (49CFR173.435), or when the sum of the fractions exceeds unity, then the amount of radioactive material that is being shipped is considered as a Type B quantity.

type "B" package	A package which meets the standards for type "A" packaging and in addition meets the standards for the hypothetical accident conditions of transport as prescribed in 10CFR71.
uCi	Abbreviation for microcuries, a measurement of activity.
uncontrolled use	Any use of material that is not controlled by the NRC or state by means or a radioactive materials licence. Sometimes called free release.
UF	Ultra-filtration. A method for removing very small particulate material. **Or,** ureaformaldehyde, an uncommon waste solidification agent for aqueous waste.
unsited compact	A group of states that have entered into a compact under the low level waste policy amendments act, but have not yet selected a disposal site.
unsited region	See non-sited region.
ureaformaldehyde	A thermosetting synthetic resin made by condensing urea with formaldehyde. The resultant product forms a semi-stable mass. When mixed with spent resin from a nuclear plant liquid waste stream, it is intended to stabilize the spent resin.
URC	Ultrasonic resin cleaner.
U-tube manometer	See manometer.
vacuum lift	A lifting device that relies on a vacuum created between the waste container and a plate hanging from the crane hook.
voids	The space between the particles in a resin bed.
void space	The dead (empty) space at the top of a liner or HIC. This normally occurs due to settling of the waste during the dewatering process. It also is sometimes used to refer to empty space left in a solid waste package (e.g., drum or box).
VR	Volume reduction.
waste class	The mechanism used by disposal sites to segregate various radioactive wastes according to their half-lives. Long-lived radionuclides offer a greater hazard to future generations and must, therefore, be segregated from short-lived radionuclides. There are four classifications for low level waste: Class A, Class B, Class C, and greater than Class C. See specific class definition for individual description.
waste, mixed	See mixed waste.

water gauge	A measure of differential pressure equivalent to one inch of water. (This does not refer to a gauge for measuring water.)
weeping (cask)	The phenomenon in which certain casks, after removal from underwater storage basins and after decontamination, subsequently exhibit an increase in the level of contamination during and after transportation (see also text).
WEPA	A Westinghouse pressure washing system for reactor cavities.
Westinghouse	A supplier of pressurized water reactors and reactor services.
w.g.	Water gauge.
WISE	Waste Inventory and Shielding Estimator - a shielding and curie estimation code.
X-radiation	Electromagnetic radiation emitted from the electronic structure of an atom. X-rays are similar to gamma rays, except in their formation. They are normally less energetic.
Z	Atomic number.
zeolite	Hydrous silicates of either natural or synthetic origin.
Zonolite	The brand name of a family of clay-type absorbents. Grades 2, 3 and 4 are approved for use at the Richland, Washington disposal site.
50.59 review	A review to assure that a facility or procedure change, or a proposed test experiment, is permissible under 10CFR50.59. The 50.59 review essentially calls for a determination of whether the proposed change, test or experiment involves a change in the facility technical specifications or an unreviewed safety question.

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About EPRI

EPRI creates science and technology solutions for the global energy and energy services industry. U.S. electric utilities established the Electric Power Research Institute in 1973 as a nonprofit research consortium for the benefit of utility members, their customers, and society. Now known simply as EPRI, the company provides a wide range of innovative products and services to more than 1000 energy-related organizations in 40 countries. EPRI's multidisciplinary team of scientists and engineers draws on a worldwide network of technical and business expertise to help solve today's toughest energy and environmental problems.

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