LOW LEVEL LIQUID WASTE TREATMENT

M. Kaczmarsky, Chairman
D. Enegess, Co-Chairman

TRENDS IN BWR CONDENSATE POLISHING SYSTEM OPERATION:

"IDENTIFICATION OF RADWASTE SOURCES AND REDUCTION TECHNIQUES" (EPRI PROJECT RP1557-3)

C. P. Deltete, Gilbert Associates, Inc.
R. B. Wilson, Gilbert Associates, Inc.
M. D. Naughton, Electric Power Research Institute

ABSTRACT

The onsite reduction of low-level radioactive waste (LLW) sources and the waste volumes to be processed from nuclear power plant operations has become an extremely important element in lessening the economic impact of radwaste disposal. To meet this challenge, Electric Power Research Institute (EPRI) commissioned an operations-related project (RP1557-3) in late 1981 to develop a methodology which can be used by utility operations managers in evaluating the radwaste generation rates at their nuclear stations, and in identifying successful volume minimization techniques which can be applied to reduce these radwaste sources. The effort incorporated actual plant operating experience and the development of a data base for use as a reference to assist individual utilities in assessing the improvement they may achieve when implementing the recommended methodology.

Background

Disposal of low-level radioactive waste from nuclear plant operations is becoming increasingly more burdensome, primarily as a result of burial site closures, regulatory restrictions, and dramatic escalation in transportation and disposal costs. This situation is resulting in the decision by many utilities to install advanced volume reduction treatment systems to minimize the volume of radwaste requiring temporary onsite storage and disposal. However, over the next several years before these systems become operational, and for plants where economics do not justify such capital investments, the onsite reduction of waste sources and the waste volumes to be processed will become extremely important elements in lessening the economic impact of radwaste disposal. To meet this need, Electric Power Research Institute (EPRI) commissioned an operations-related project late in 1981 to develop a methodology which can be used by utility operations managers in evaluating the radwaste generation rates at their nuclear station, and identifying management control methods and plant process optimization improvements which can be applied to reduce these radwaste sources.

The objectives of this study, EPRI Project RP1557-3, "Identification of Radwaste Sources and Reduction Techniques," were:

a. To develop a systematic methodology for use by nuclear plant operators in evaluating their effectiveness in managing specific categories of radwaste in relation to industry experience.

b. To develop radwaste generation guidelines for specific waste categories and corresponding recommendations for waste minimization.

c. To identify radwaste techniques which have been successfully implemented in utility waste management control programs.

Gilbert Associates, Inc. of Reading, Pennsylvania, is the contractor for the study, which is nearly complete and scheduled for final report publication in the late spring of 1983.

The project was aimed at establishing a reliable data base of various categories of nuclear plant radwaste which could be used for comparative purposes with plants of similar size, age, system configuration and operations. A standardized assessment methodology was developed to enable a utility to evaluate the volume of specific radwaste categories emanating from their plant operations, against similar waste sources from other plants included in the data base. Rather than normalizing waste volumes to plant capacity in MW(e), as has been done historically, new methods which consider actual plant operating history, and outage work involving radioactive systems/areas, were extensively employed. Detailed comparisons were made of wet waste (e.g. resins, sludges, concentrates, etc.), from operational systems and waste processing systems; and dry active waste (DAW) in the form of compactible and non-compactible material.

In this paper, which addresses only one of a large number of operational volume minimization techniques reported in this EPRI work, the authors intend to illustrate the substantial wet waste reductions achieved by several Boiling Water Reactors (BWRs) that altered the operational processing of condensate polishing system (CPS) wastes. First however, a brief review of EPRI Project RP1557-3 will be made to emphasize the breadth and depth of the utility data base gathered to support the conclusions reported in this paper.

Data Base Development

It became evident early in the project that the establishment of an extensive and reliable data base of various categories of radwaste from a wide cross-section of the nuclear utility industry was imperative. This data base was considered particularly necessary if the project was going to be successful in developing credible correlations and comparisons of radwaste generation rates as a function of plant size, age, system configuration, and operation. To meet this need, considerable effort was devoted to defining sufficiently detailed information necessary to perform in-depth analyses of waste generation rates and actual inplant sources, and more importantly, in soliciting the assistance of as many operating nuclear plants as possible.

The data collected to support the project was considerably different from previous studies in that additional, more detailed information related to waste sources and operational characteristics was obtained and included in the data base. This allowed a more in-depth analysis and comparison of waste generation rates and actual in-plant sources. In addition, the project conducted a unique subjective evaluation of plant waste management performance in an attempt to correlate subjective performance factors against actual plant waste generation.

The data identified for gathering concentrated in the following main areas:

a. Radwaste system design information, as related to design specifications and operating parameters on systems generating waste, on systems processing waste and on solids handling equipment.

b. Waste generation rates, characteristics and sources for both wet and dry forms of waste.

c. Waste handling (i.e. packaging and solidification) of both wet and dry waste, and in particular packaging efficiencies, characteristics and container loadings.

d. Data on subjective areas such as plant operational philosophy, organization, management structure, intensity of outages, training, etc.

To standardize the data collection, a detailed questionnaire was prepared specifically for this EPRI study which requested information in the four areas previously mentioned. Further, the questionnaire sought to identify waste reduction techniques which have been successfully implemented at nuclear stations. The project attempted to categorize these waste minimization techniques into categories consisting of General/Administration, Dry Waste and Wet Waste. In addition, the questionnaire attempted to quantify each waste reduction technique for its potential benefit in reducing radwaste at any plant. Many of the plants which submitted responses to the questionnaires were also visited by a project team to assess actual radwaste minimization techniques.

In order to perform meaningful comparisons of waste generation rates in relation to plant size, age and system configuration, all PWR's and BWR's were divided into discrete categories for comparative purposes. Figure 1 shows the breakdown for PWR's, while Fig. 2 shows a breakdown for BWR's, which further subdivides plants by type of condensate polishing system. Also indicated on these two figures are the specific plants for which detailed radwaste data were obtained as a result of this study.

To assist in the reduction and analysis of the data, a computerized file structure was developed to store the data, suitable for later analysis and comparison. This program permitted storage of the principal project data base, and the development of a larger number of more varied and statistically accurate comparisons and projections of waste generation rates/characteristics.

<u>Data Base Credibility</u>

Without major support from the nuclear industry in the form of providing detailed radwaste data from operating plants, the ability of this project to draw definitive conclusions and present recommendations from a credible data base would have been impossible. To insure the widest possible participation from operating nuclear power plants, the project team devoted considerable effort to encouraging nuclear utilities to participate in the program. In particular, four primary methods were used to insure the widest possible dissemination of information relative to the project and to obtain the assistance of plants being considered for the study.

a. Early in the project, letters were sent to the superintendents of nearly every U.S. light water reactor requesting their active support of this project.

b. Three regional workshops were held in early 1982 to acquaint plant radwaste managers with the EPRI project and to describe the entire data gathering process.

c. Followup contacts were made with those plants that were not represented at the regional workshops in order to request participation in the project.

d. Throughout the project, status reports were sent periodically to each utility radwaste manager participating in the project to update participants on the project, and to ensure continued involvement.

The effort resulted in 53 operating nuclear power plants which expressed interest and a commitment to participation in the study. This quantity represents 77% of the 69 plants in commercial operation as of December 31, 1981 and 88% of the plants which were specifically considered for inclusion in the study. The project intentionally excluded from evaluation plants with less than one full year of commercial operation through December 31, 1981, plants with electrical generating capacity of less than 200 MW(e) and those plants possessing special characteristics such as Fort St. Vrain and TMI-2. Although these plants were excluded from the study, much of the anticipated outcome of the project is expected to be equally applicable to any and all nuclear plants, both domestic and foreign.

Of the 53 plants which expressed an interest to participate in the study, 44 individual plants (or 83%) representing 29 stations completed the standardized data gathering questionnaire. This represents nearly two-thirds (64%) of the units in commercial operation as of December 31, 1981 (Fig. 3).

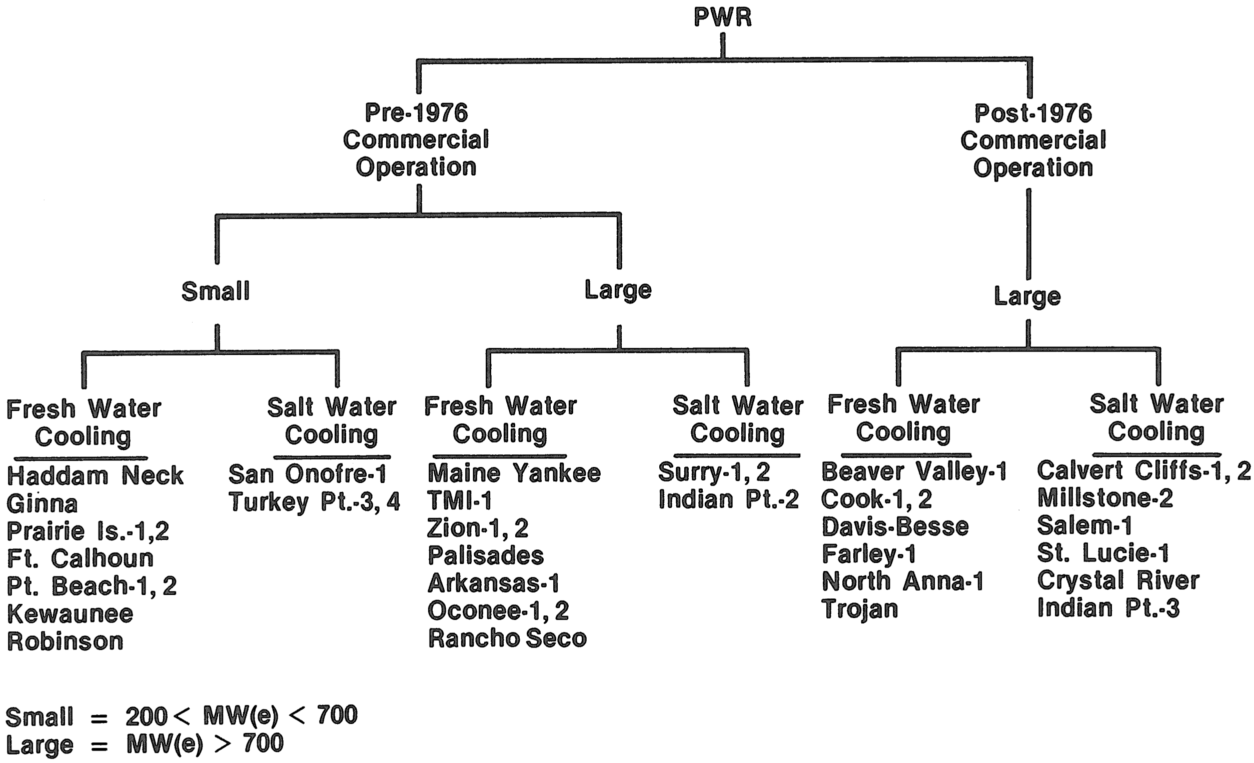

Fig. 1. PWR Plant Breakdown.

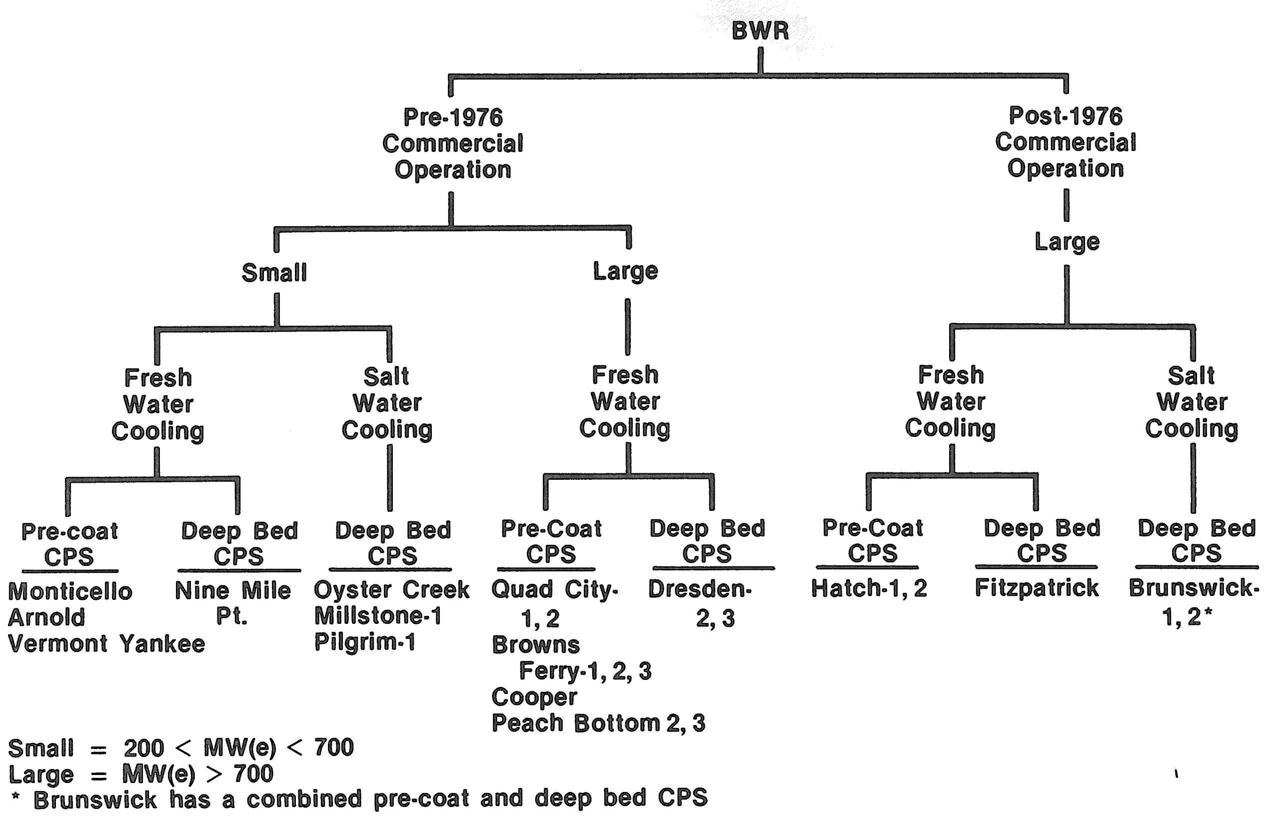

Fig. 2. BWR Plant Breakdown.

	Commercial Operation (12/31/81)	Considered for EPRI Study	Identified As Active Participants	Data Received	Plant Visits
PWR					
Units	45	38	35	29	16
Stations	30	30	25	20	11
BWR					
Units	24	22	18	15	7
Stations	16	14	12	9	5
Total					
Units	69	60	53	44	23
Stations	46	44	37	29	16

Note: Millstone Station considered as a BWR. Fort St. Vrain excluded.
Excludes plants in power ascension on 12/31/81.
Units in commercial operation from NUREG—0020.

Fig. 3. EPRI RP1557-3 Plant Summary.

During the plant visit phase of the project, a total of 21 individual units representing 16 stations were visited by a project team to review the plant responses to the questionnaire and to assess radwaste management and minimization techniques in practice at the station.

The data base generated by this project is considered by the authors to be fully as complete as any comparable industry study and to be highly representative of actual radwaste generation rates and characteristics throughout the United States. The completeness of the data received from most participants confirmed that the information gathered for this project represents an accurate and credible data base for use with the project.

The remainder of this paper will deal with a rather significant trend in BWR condensate polishing system operation which appears to offer the potential to reduce the wet waste generation rates of some BWR's by up to 50%. The specific method involves the disposal of deep bed CPS resins upon chemical exhaustion, rather than regenerating the anion and cation constituents, with the subsequent evaporative processing of the regenerant solutions. Before actually presenting the conclusions of this trend made by the study, a brief review will be made of BWR condensate polishing systems.

Condensate Polishing System Operation

In a typical BWR, the cooling water in contact with the nuclear fuel elements is allowed to boil under a pressure of 1000 to 1500 psia. The resultant steam is transported directly to the turbine-generator, and is then reduced to liquid condensate in a condenser prior to being returned to the reactor for reuse. The cooling water used in the condenser circulation system varies with the plant location, and can range in chemical purity from high conductivity seawater to relatively clean fresh water from inland lakes and rivers.

Because of the demands for ultra-pure reactor grade water in contact with the nuclear fuel elements, and the direct interconnection of the reactor vessel with the large feedwater and condensate system which is continually undergoing minute phases of corrosion, BWR's are normally always operated with full flow condensate polishing systems to maintain exceptionally strict water quality limits on reactor feedwater. These systems are designed, installed and operated to perform the following primary tasks:

a. To remove corrosion products (both particulate and ionic) developed during system startup and operation.

b. To remove silica and other volatiles to avoid steam contamination.

c. To purify condensate to allow continued plant operation with minor condenser leakage.

d. To provide sufficient protection to the reactor during shutdown in the event of a major condenser leak.

Over the years, two principal condensate polishing system (CPS) designs have emerged for application in BWR's, as well as other condensate polishing applications. Most plants have available either one or the other, although there are some units which employ both principal CPS designs in series operation. Each of the two designs functions to polish steam condensate through filtration of corrosion products (such as iron and copper oxides) and ion exchange of soluble impurities (such as sodium and chlorides). The first major polishing design developed for this application consisted of large process vessels containing up to several hundred cubic feet of synthetic organic resins. These resins generally have a polystyrene matrix and exist as spherical beads with particle sizes of 0.4 to 0.7 mm. This type resin is used in a homogeneous mixed-bed of strong-acid cation and strong-base anion exchange resins, and consequently is termed a "deep-bed" (DB) system. The second major polishing system design involves the use of conventional tubular filter elements coated with a thin layer of finely ground resin in a homogeneous cation-anion mixture. The ground resin mixture, or "powdered resin," has significant filtration capability for very low insoluble impurity levels and small size, in addition to ion-exchange capabilities. This entire system is generally referred to as a filter/demineralizer (F/D), or precoat, system.

CPS Waste Processing

Even though both major CPS design types perform basically the same operational functions of filtration and ion-exchange, the two types differ significantly in their respective requirements for waste treatment upon resin exhaustion. Deep bed CPS resins require the most complex treatment process, and as will be illustrated later, have historically generated substantially larger amounts of waste products than the filter/demineralizer CPS design. The method usually employed at BWR's to treat deep bed CPS resins is via a chemical regeneration process that treats the anion and cation exchangers independently. Before regeneration, the contents of a deep bed resin vessel must first be backwashed, a step which serves to classify the two resin components, with lighter anion resins favoring the top as heavier cation resins remain at the bottom. The individual resin components are then generally transferred to separate regeneration tanks, a step which seldom results in complete physical separation of the resin components. The exhausted cation resins are chemically regenerated back to the hydrogen (H^+) form with a 4-8% sulfuric acid (H_2SO_4) solution, while the exhausted anion resins are also chemically regenerated, but back to the hydroxide (OH^-) form with a 4% sodium hydroxide (NaOH) caustic solution. (Note that this represents only one of a number of regeneration methods employed in commercial BWR plants, and is provided only for illustrative purposes.) The two resin components are then thoroughly rinsed and transferred to a resin storage tank for mixing and to await reintroduction back into an operational CPS process vessel.

To complete the deep bed treatment process, the spent regenerant solutions (each containing chemical and radiochemical species, as well as some insolubles, removed from the steam condensate) are transferred to a neutralizing tank before being used as the influent feed to an evaporator. The evaporation process generally produces a 10-12^{w}/o concentrates solution which must then be solidified prior to disposal as radioactive waste. It is the result of these last two steps which typify the deep bed CPS option as a relatively high radwaste generation technique. Evaporators in use at most BWR's are only designed to concentrate the resin regenerant solutions to the 10-12 $^{w}/o$ range, which is quite inefficient as an overall volume reduction process. This fact, combined with the need to solidify the resultant concentrates before disposal (itself an inefficient process resulting in a larger volume after treatment than before) causes the deep bed CPS option to generate a large quantity of radwaste for burial. In fact, over 50% of the so-called "wet waste" from BWR's employing deep bed CPS systems, consists of evaporator concentrates from the regeneration process. Therefore, any method able to reduce this waste source could reap substantial benefits in terms of lower radwaste generation rates with attendant reductions in O&M costs for processing and disposal of the waste.

By contrast, powdered resin filter/demineralizers require a relatively simple, straight-forward method to treat exhausted resins from CPS applications. The powdered resins, including filtered solids, are backwashed from the tubular filter elements to a set of receiving tanks where the resin and solids are allowed to settle. The supernate liquid is decanted off and processed as ordinary liquid radwaste. The resultant sludge is dewatered using centrifuges or pumped suction, and packaged for disposal. Most utilities favor dewatered packaging in steel liners or High Integrity Containers (consistent with burial site regulations) because of the ease, lower cost, and improved packaging efficiency over solidification. There are several plants however, that for a variety of reasons, continue to solidify CPS resin sludges.

Trends in CPS Waste Generation

To examine the effect of CPS design on BWR waste generation, a comparison was made of the average annual wet waste shipped for disposal in each of five years (1977-81) for fifteen (15) BWR units included in the RP1557-3 data base. Of the fifteen (15) units, twelve (12) had fresh water condenser cooling and three (3) were salt water cooled. Nine (9) of the fresh water plants had powdered resin (precoat) CPS systems, while three (3) fresh water units employed deep bed systems. All three (3) of the salt water plants used deep bed resins in their condensate polishing systems. (Note: There are no salt water cooled BWR's employing strictly powdered resin filter/demineralizers for CPS operation in the U.S.)

In Fig. 4, which illustrates this comparison, it is clearly evident that deep bed BWR's generate considerably more wet waste than precoat F/D-type plants. Precoat plants have consistently shipped an average of about 8,300 ft^3 of wet waste, while D/B-type units ship an average of more than twice that amount. An interesting feature apparent in this figure however, is what appears to be a very definite decreasing trend in waste generation for deep bed plants. To negate the effects on wet waste generation from non-CPS sources, only CPS wastes from the same units were then compared. The results are shown in Fig. 5.

Again, deep bed plants generate a larger volume of CPS waste (about 3 times), but the decreasing trend is much more distinct after 1979, indicating a substantial (about 40%) volume reduction was being achieved by several, if not all, plants. During the same time period, the average CPS waste generation from precoat F/D plants remained relatively constant. To identify the plants responsible for this volume reduction effort, a comparison of CPS wastes was made for strictly fresh water cooled units. From the results shown in Fig. 6, there is an almost negligible deviation in the average annual CPS wastes from fresh water deep bed plants, thus indicating that the larger decrease shown in Fig. 5 is due primarily to the contribution from salt water cooled plants. Since precoat F/D plants are all fresh water cooled, the average values for these units are identical in both Figs. 5 and 6.

While the plant operators of fresh water cooled deep bed and precoat plants are certainly working toward CPS waste volume reduction, it appears that their efforts have been overshadowed by measures implemented by the three salt water units included in the data base. And in fact, fresh water BWR plant operators have made credible progress prior to 1982 (the end of RP1557-3 data gathering) in extending CPS processing (thereby reducing waste generation) times through measures such as minimizing condenser tube leakage, improved resin selection, tighter CPS chemistry control, ultrasonic resin cleaning (URC) techniques, and improved air backwash methods for precoat F/D's, to name a few.

While some of these same improvements were implemented at the salt water plants under investigation, it appears that a further technique was responsible for the major CPS waste reductions observed for these plants. On the basis of information obtained from these plants during EPRI project RP1557-3, it has been concluded that the singular most important reason for the observed waste reductions was the decision by the managers of all three units to implement a "throw-away" mode for CPS resins upon exhaustion, rather than the regeneration method discussed previously. Therefore, while the total quantity of bead resins actually increases, the quantity of evaporator concentrates shipped for disposal decreases considerably. Figure 7 displays the overall effect for the same three salt water plants discussed previously, all of which converted to the resin replacement, or "throw away mode" for CPS operation. Two of the units implemented this operational mode in mid-1980, and the third in mid-1981. Before a closer evaluation of Fig. 7, two items should be noted regarding the data to construct the figure. First, the annual CPS waste quantity for 1977 was only based on one unit, as detailed wet waste information for this year was not available for the other units. Second, two of the salt water units operate combined deep bed and precoat filter/demineralizer CPS systems, with the precoat F/D's preceding the deep bed units. In order to provide a common base for comparative purposes, F/D sludges from CPS operation at these units have been excluded from Fig. 7. While F/D sludges do contribute to total CPS wastes from these units, the average annual contribution has only been about 14%, and therefore excluding this source is not expected to adversely affect any conclusions concerning resin and evaporator concentrates ratios.

Figure 7 clearly shows that the salt water plants being evaluated reduced the average annual generation of CPS wastes considerably. The reduction, which in 1981 amounted to 60% of the 1978-79 average, is attributed almost exclusively to the shift to resin replacement as the preferred method of treating CPS wastes. Further evidence to support this conclusion is the relative composition of CPS wastes from these plants over the last several years. In 1979 (prior to either station adopting the resin replacement philosophy), deep bed resins

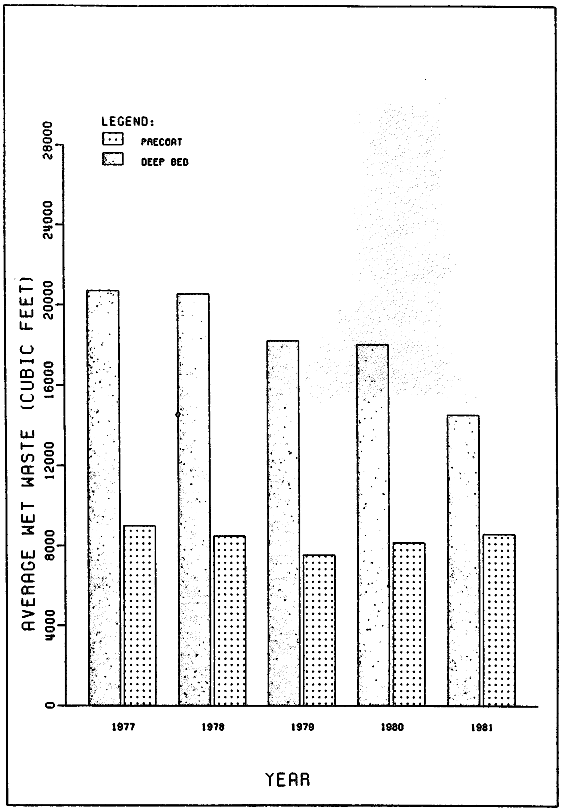

Fig. 4. All BWR's Precoat vs Deep Bed CP's Wet Waste vs Year.

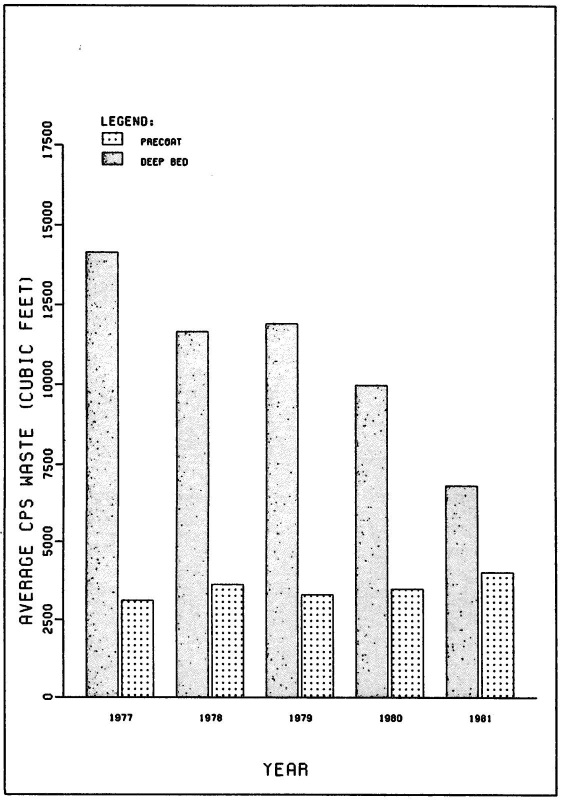

Fig. 5. All BWR's Precoat vs Deep Bed CP's—CPS Waste vs Year.

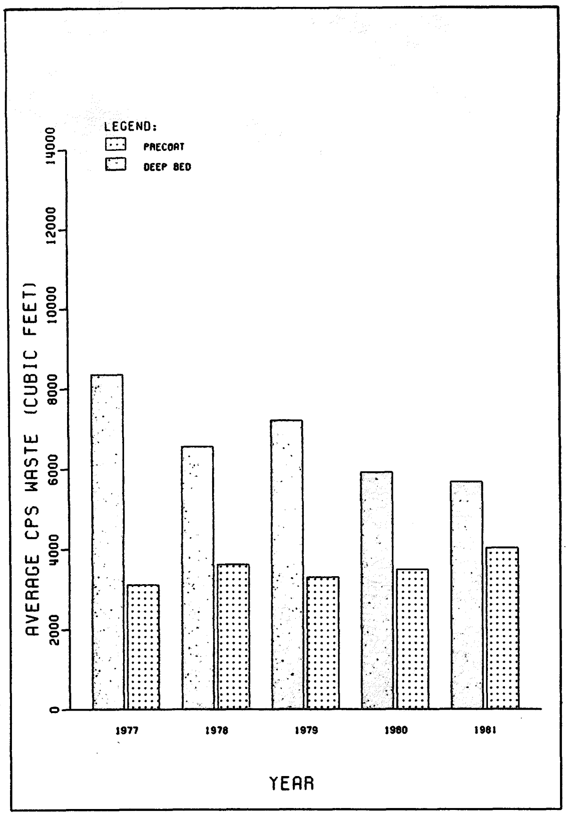

Fig. 6. Fresh Water BWR's Precoat vs Deep Bed CPS-CPS Waste vs Year.

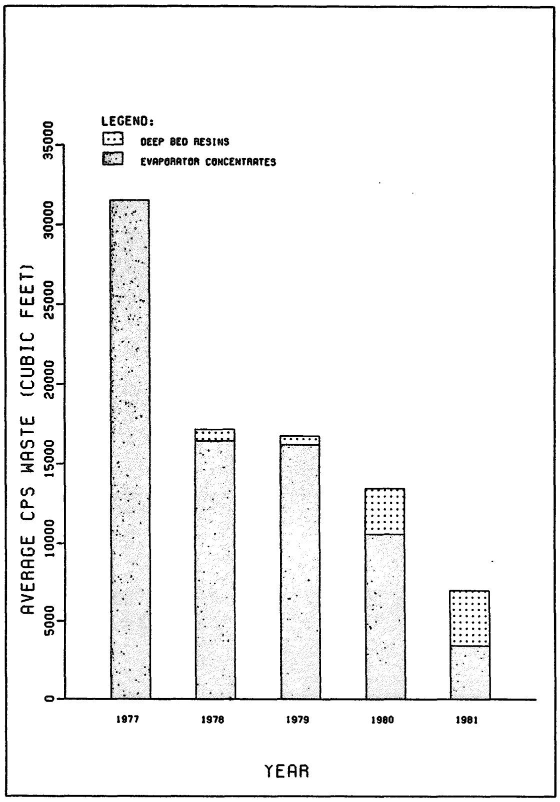

Fig. 7. Salt Water BWR's Deep Bed CPS-CPS Waste vs Year.

accounted for only 3.3% of the total CPS wastes (again excluding F/D sludges from two of the units). By 1981, the percentage of resins in the as-shipped waste jumped to 51% of the total, while the percentage of evaporator concentrates decreased the same amount. Since the resins from these plants are generally shipped dewatered while the concentrates are solidified (with a larger packaging volume increase), the actual percentage contribution from resins increased from about 4.6% in 1979 to 59% in 1981.

Not only have these three units been able to reduce the shipment of CPS wastes by nearly 60%, they have also experienced sizeable savings in O&M costs. One unit estimated annual savings of $1,000,000 by implementing CPS resin replacement, while the other station (which has considerably lower radwaste transportation charges due to its proximity to a radwaste burial ground) estimated annual savings of $250,000. Although not quantified, it has also been estimated that radiation exposures to radwaste operators have been reduced by not operating the installed evaporators and solidification equipment.

Another potential benefit of the replacement method of operation is the ability to transfer CPS resins to liquid radwaste (LRW) applications in order to get even more service life from the resin. Since CPS chemistry control normally dictates that deep bed resins be removed from service when only about 60% exhausted, these resins can be used in higher conductivity LRW systems (where effluent water quality standards are not as restrictive) to utilize the remaining 40% resin capacity. Several plants are currently doing this and have not observed a decrease in LRW system performance. Therefore, in essence, a plant is able to maximize the capability of an individual resin bed by use in two systems, and without having to purchase new resins for application in LRW systems.

Conclusion

In summary, the conclusion reached by this review is that BWR plants operating deep bed condensate polishing systems can potentially realize substantial reductions in radwaste volumes by converting to a resin replacement philosophy rather than historical regeneration methods. This method is by no means limited to salt water cooled plants, and in fact, the authors know of at least one fresh water plant included in the RP1557-3 data base that is adopting this approach and has projected a 33% reduction in CPS wastes. This is not to imply that every plant will realize this degree of volume reduction, nor that this technique should be implemented by every BWR. Rather, the results presented are intended to stimulate plant managers to conduct detailed evaluations of their own plant operations to determine if CPS resin replacement methods offer sufficient advantages over resin regeneration to warrant implementation.

The volume reduction technique presented in this paper is only one of a number of successful VR methods developed as a result of EPRI Project RP1557-3. Additional waste minimization techniques are being reviewed and finalized for publication in a forthcoming EPRI technical report.