NUCLEAR POWER INDUSTRY EXPERIENCE
WITH
WASTE PROCESSING EQUIPMENT

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ABSTRACT

This paper documents the performance and contrasts the features of evaporator and filtration/ion exchange (FIX) systems used for processing radioactive liquid waste streams at U.S. commercial light water reactors (LWRs). Miscellaneous, floor drain, and equipment drain stream applications are the primary focus of this study. Data were acquired from detailed discussions with suppliers of mobile FIX systems and services and telephone interviews with radwaste personnel at 48 nuclear power stations representing 71 operating reactors. In addition, a written questionnaire was forwarded to the individual contacted at each utility, and the information supplied from the 24 returned questionnaires is included in the data.

Somewhat more than half each of the PWR and BWR plants use FIX systems as their primary processing option. More specifically, 25 use ion exchange, 20 use evaporation, and the remaining four plants use combined systems*.

Data were also obtained on FIX and evaporator performance including throughput capacity and operating problems. The data allows a performance comparison of these process options.

INTRODUCTION

The purpose of this paper is to present the results of a study of the performance of filtration/ion exchange (FIX) systems and evaporator systems used for radioactive waste treatment in commercial light water power reactors. The scope includes a survey of operating plants, review of portable FIX vendor data, and comparison of performance for each type of system.

The survey of operating plants was performed using telephone survey and written questionnaire. The operators of 48 commercial power plants representing 71 reactor units were contacted by telephone. The questionnaire used for telephone interviews was subsequently mailed to each station for supplementary data entry and checking. Twenty-four questionnaires were returned.

Additional information on the use of portable FIX systems was obtained from interviews with vendors and review of vendor literature and published technical papers on this subject.

*Number of plants or process applications may not appear consistent throughout the paper due to multiple unit sites, availability of data, and combined process systems.

DISCUSSION OF SURVEY RESULTS

For the 48 plants surveyed, the breakdown of principal liquid waste processing systems by type is as follows:

23 plants currently use evaporators (representing 32 units)

12 plants currently use portable (disposable) FIX systems/services (representing 14 units)

18 plants use permanently installed FIX systems (representing 26 units)

On a reactor type basis, the data break down as follows:

Method of Processing	PWRs	BWRs
Evaporation	12	8
Disposable FIX	6	2
Permanent FIX	9	8
Combined Evaporation and Disposal FIX	3	
Combined Disposable and Permanent FIX	1	—
	31	18

In addition, 10 plants reported that they have or had evaporators as part of their liquid waste treatment systems but either never used them or have abandoned their use.

Evaporator Experience

Radwaste or miscellaneous waste evaporators of various types continue to be used in many plants in spite of their generally unfavorable image in the industry today. Table I summarizes the types of units operating and their performance in terms of design and actual capacity, years of operation, distillate quality and conductivity, and bottoms concentration normally achieved.

The data can be summarized as follows:

- Average evaporative capacity achieved is 72 percent of design capacity
- Average years in service is 7 years
- Average distillate quality is "good" and in terms of conductivity is 10 μmhos/cm
- Average bottoms concentration for boric acid achieved in PWRs is 15 percent
- Average bottoms concentration for sodium sulfate achieved in BWRs is 26 percent

Based on these factors alone, the evaporators operating at the 23 plants recorded in Table I could be judged to be performing reasonably well.

An effort was made to catalog the most frequently mentioned problems with these operating units. Table II summarizes the data that were obtained in this survey and gives some indication of the areas of concern to radwaste operators. For

TABLE I
Evaporator Performance

		TYPE ***	CAPACITY (GPM)		YEARS OF OPERATION	DISTILLATE		BOTTOMS CONCENTRATION
			DESIGN	ACTUAL		QUALITY	CONDUCTIVITY	
PWR	PLANT 1 *	FC	20	15 - 18	5		2 μmho/cm	6-9% H_3BO_3
PWR	PLANT 2 *		30	20	2 & 4	GOOD		17% H_3BO_3
PWR	PLANT 3	FC	15	7 - 10	10	GOOD		8% H_3BO_3
PWR	PLANT 4	NC	2	2	14	GOOD		12% H_3BO_3
PWR	PLANT 5	FC	20	8 - 10	8	GOOD	2 μmho/cm	8-15% H_3BO_3
PWR	PLANT 6	FC	6	5	11	GOOD		14% H_3BO_3
PWR	PLANT 7 **		15	10	7	GOOD		12% H_3BO_3
PWR	PLANT 8	FC	20	14 - 20	10	GOOD	20-40 μmho/cm	8-11% H_3BO_3
PWR	PLANT 9 *	FC	35		5 & 7	GOOD		20% H_3BO_3
PWR	PLANT 10 *	FC	5	3 - 5	10	GOOD		12-15% H_3BO_3
PWR	PLANT 11	FC	30	30	10	GOOD		8.5% H_3BO_3
PWR	PLANT 12	FC	30	30	<1	GOOD		50% H_3BO_3
PWR	PLANT 13							
PWR	PLANT 14 *							
PWR	PLANT 40	FC	6	2 - 6	7	GOOD		12% H_3BO_3
BWR	PLANT 15 *	FC NC			8 & 12	VARIES	10 μmho/cm	23% Na_2SO_4
BWR	PLANT 16 *	NC	50	20	**** START UP	MEDIUM	1-10 μmho/cm	23% Na_2SO_4
BWR	PLANT 17 *	FC	10	10	2		10 μmho/cm	23-27% Na_2SO_4
BWR	PLANT 18 **	FC		≈1.7/2 UNITS	8	GOOD	3.5 μmho/cm	30% Na_2SO_4
BWR	PLANT 19	NC	20	10 - 12	*****	GOOD	3-4 μmho/cm	25% Na_2SO_4
BWR	PLANT 20	FC	30	15 - 20	2.5		<10 μmho/cm	25-30% Na_2SO_4
BWR	PLANT 21	FC	20	15 - 17	6	GOOD	12 μmho/cm	25-30% Na_2SO_4
BWR	PLANT 22	NC	30	30	4	VARIES	<20 μmho/cm	24% Na_2SO_4

* 2 UNITS ***FC = FORCED CIRCULATION **** THIRD EVAPORATOR IN 8 YEARS

** 3 UNITS NC = NATURAL CIRCULATION ***** TWO EVAPORATORS. PLANT HAS BEEN OPERATING 8 - 9 YEARS EACH EVAPORATOR REPLACED TWICE

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the successfully operating systems, there does not appear to be an obviously common problem that generally pervades evaporator experience. It is interesting to note that only one plant reported that the evaporator was an unusually high maintenance item. However, three of the 23 plants still using evaporators reported that they have replaced the originals twice, i.e., they are on their third generation units.

The lower portion of Table II lists plants surveyed which have discontinued the use of evaporators originally provided for radwaste processing. The table provides a summary of reported problems or difficulties in qualitative terms and lists the number of responses obtained for each general problem area.

For those plants that have discontinued the use of evaporators, the following reasons were given:

- Not effective - wrong design for the application
- Produced poor quality distillate
- Faulty instrumentation
- Expensive to operate
- Did not want to solidify concentrate
- Overall poor performance

TABLE II
Frequently Mentioned Problems With Evaporators

	Designer and/or Manufacturer	Type of Evaporator	Number of Plants	Problems: No Problems	Plugged Lines	Corrosion	Distillate	Instrumentation	Design	Pump Seals	Pump Cavitation	Miscellaneous	No Response
Presently Using Evaporation *	AMF Beaird, Inc	Forced	1			1				1		1	
	(AMF)-Riley Beaird	Forced	1									1	
	Aqua Chem	Forced	2					1				1	1
	Aqua Chem	Natural	1			1						1	
	HPD	Forced	2	1						1			
	HPD	Natural	1			1						1	
	S&W	Forced	4		1		[illegible]		1	1		3	
	Swenson	Natural	1										1
	Unitech	Forced	2		1	1	1	2	1	1	1	1	
	Westinghouse	Natural	4		1		3		1		1		1
Presently Using IX	(AMF)-Riley Beaird	Natural	1										1
	S&W	Forced	2		1							1	
	Westinghouse	Forced	3			1		2	1			2	
	Westinghouse	Natural	4				1	1				2	2
Totals			29	1	4	5	5	6	4	4	2	14	6

PPROBEVAP

* BASED ON DATA AVAILABLE

It is unclear from the limited amount of operating problems reported for this study why evaporators at these 23 stations perform satisfactorily and why 10 others have been abandoned. For example, most of the operating evaporators are fabricated from 300 series stainless steel and evidently have not displayed signs of chronic corrosion. On the other hand, most of the defunct evaporators were also 300 series stainless steel and some failed from corrosion-related effects. An attempt to correlate failures with various parameters such as plant type and cooling water chemistry has not provided any clear picture for this distinct difference in experience. In fact, stainless steel evaporators have been operating for 11 years on a seawater-cooled site and stainless steel units have repeatedly failed due to corrosion though located on freshwater-cooled sites. However, the data sample was small and sufficiently detailed information on related factors, such as feed chemistry and utility operating and maintenance practices, was not obtained.

Filtration/Ion Exchange Experience

Filtration/ion exchange processing of various power reactor streams has, of course, been a common and successful water purification method. As previously noted, 18 of 30 plants surveyed, that are using FIX, have permanently installed systems. Many are based on the original plant design. Together with portable FIX, these systems provide a useful comparison with and contrast to the use of evaporators.

From the plants surveyed, seven have utilized portable FIX services on a one time or infrequent basis for emergency or backup cleanup efforts and 12 stations are currently using portable FIX systems on a regular or long term basis for routine processing of radwaste streams. Of this last group, 9 are using the FIX process to replace evaporators.

Table III contains data provided by 30 plants surveyed. Although a limited data sample is available for each parameter listed, the following observations can be made:

- Average years in service is 8 years.
- Average throughput per cubic foot of resin usage is 20,500 gallons.
- Average inlet stream activity is 1.0×10^{-2} µci/cc and effluent stream activity 2.2×10^{-5} µci/cc.

Note that the use of ion exchange processing frequently involves the use of feed pretreatment, filtration, and/or organic removal operations. These operations may be required where ion exchange materials alone are inefficient or ineffective in removing high levels of suspended solids, colloids such as colloidal cobalt, and various chemicals from the feedstream.

These steps add to the amount of expended material generated by this cleanup method. Where disposable FIX vessels are used, a considerably larger volume is discarded as solid waste. For example, the average throughput for disposable FIX systems is 4700 gallons per cubic foot of all materials discarded (including vessels).

TABLE III
Ion Exchange Performance

System	Type	Plant	Years of Service	No. of Beds in System: Anion	Cation	Mixed	Filters	[illegible]	Throughput (Gal/Cu. Ft.): Anion	Cation	Mixed	Filters	[illegible]	Streams (µCi/cc): Input	Output	Average DF	Gal. Throughput/Cu. Ft. Disposal Volume
Permanently Installed Ion Exchange System	PWR	PLANT 23	10	0	1	1	7	0	N/A				N/A	VARIES	1–5x10^{-5}		
	PWR	PLANT 24*	10/3	0	0	8	8	6	N/A	N/A			N/A	UNKNOWN	UNKNOWN		
	PWR	PLANT 25	10	2	2	2	1	0					N/A	10^{-2}			
	PWR	PLANT 26				4	1	1			16,000		N/A	10^{-2}	10^{-4}	100	
	PWR	PLANT 27	6	2	2		7	0					N/A	10^{-1}			
	PWR	PLANT 28*	0	2	4	0	0	0			N/A	N/A	N/A	10^{-2}	10^{-4}	100	
	PWR	PLANT 29															
	PWR	PLANT 30*	2	0	0	2		1	N/A	N/A	6,250						
	PWR	PLANT 31	23	0	0	2			N/A	N/A							
	PWR	PLANT 10*	14	0	0	1	4	0	N/A	N/A			N/A				
	BWR	PLANT 32	10	0	0	2	2		N/A	N/A				10^{-6}	10^{-6}	1	
	BWR	PLANT 33	5–10	0	0				N/A	N/A				10^{-5}			
	BWR	PLANT 34**				2											
	BWR	PLANT 35		0	0	1	3	0	N/A	N/A		27,110 / 13,079 / [illegible]	N/A				
	BWR	PLANT 36*		0	0	1	2		N/A	N/A	13,333		N/A				
	BWR	PLANT 37*															
	BWR	PLANT 38*	3	1	3	1	1	0	10,000	3,000	10,000	150,000	N/A				
	BWR	PLANT 39	13	0	0	1	1	0	N/A	N/A	22,222		N/A	10^{-4}	10^{-5}	10	
Disposable Ion Exchangers	PWR	PLANT 10*	3		1	1	0	0	N/A			N/A	N/A				
	PWR	PLANT 40	4	0	0	4	1	1	N/A	N/A	4,400		4,400	10^{-4}	10^{-6}–10^{-7}	550	1,346
	PWR	PLANT 41	6														
	PWR	PLANT 42	1	0	0	2	1	1	N/A	N/A				10^{-3}	10^{-6}	1000	
	PWR	PLANT 43*	3	0	0	2	1	1	N/A	N/A	18,200		9,600	5–10x10^{-6}	1–50x10^{-7}	100	4,766
	PWR	PLANT 44	1	2	0–3	0	1	0	8,430	11,174	N/A		N/A	10^{-3}	10^{-6}	1000	3,794
	PWR	PLANT 45	SETTING UP	0	0	5	4	0	N/A	N/A	6,000–20,000		N/A	10^{-3}–10^{-5}	10^{-5}–10^{-7}	100	
	PWR	PLANT 46*	5	0–2	0–2	1	2	1	21,875	21,875	5,263			10^{-3}–10^{-4}	<10^{-15}	5.5x10^{13}	3,072
	PWR	PLANT 13															
	PWR	PLANT 14*		0	0	4	0	0	N/A	N/A		N/A	N/A				
	BWR	PLANT 47*				2	2	0			33,750 / 120,000		N/A				10,700
	BWR	PLANT 48	7			1	1	0					N/A				

* 2 UNITS
** 3 UNITS

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In addition, all disposable FIX systems currently in service allow boric acid to pass through and therefore do not remove boric acid from the waste stream. Vendor data illustrate that boric acid removal significantly reduces the throughput capacity of ion exchange resins. Similarly, FIX normally would not be used on very high conductivity streams such as condensate polishing regeneration fluids.

COMPARING EVAPORATION WITH FILTRATION/ION EXCHANGE

Figures 1 and 2 illustrate and compare the volume reduction capabilities of FIX vs. evaporator processing. The figures combine data obtained in the survey for both ion exchange and evaporator performance as well as calculated evaporator throughput based on feed concentration of boric acid.

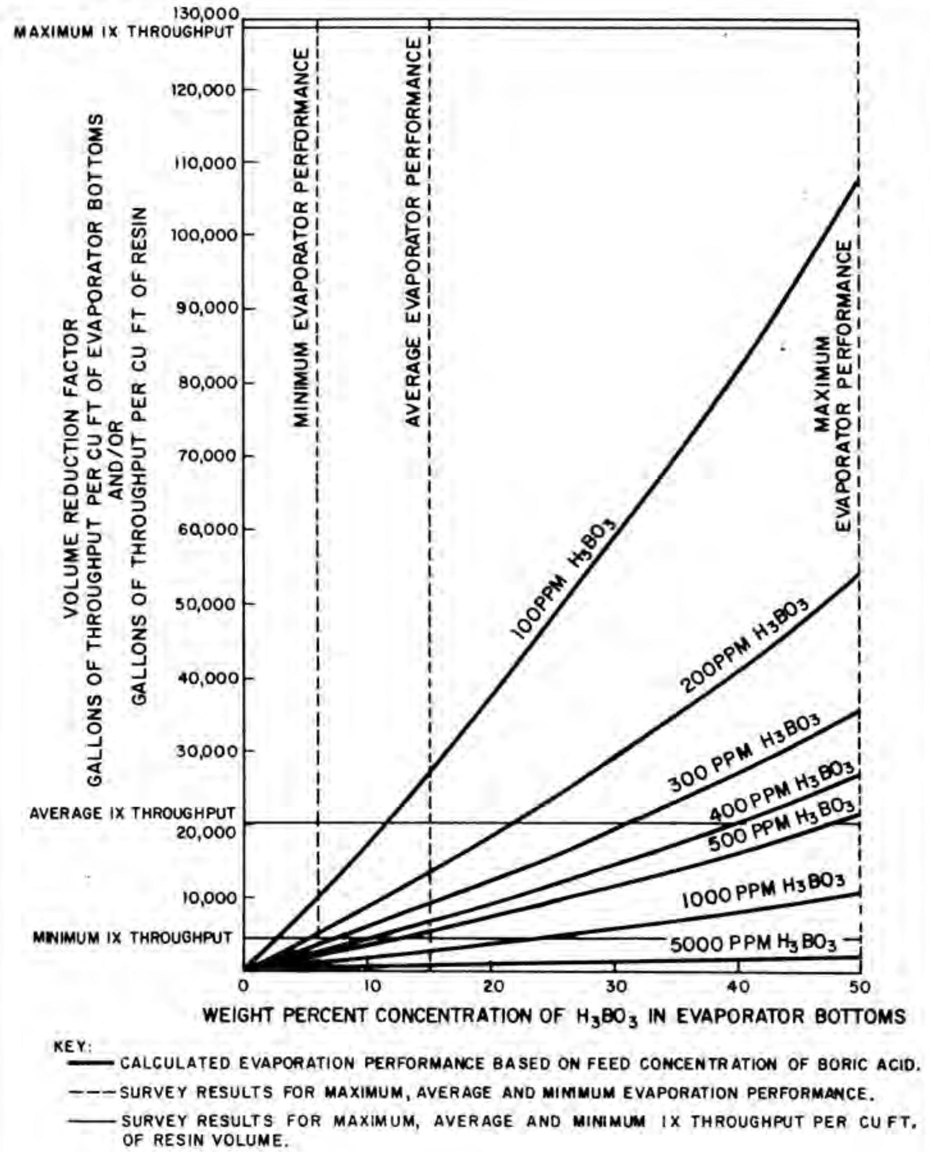

FIG. 1 EVAPORATOR & ION EXCHANGE VOLUME REDUCTION AT VARIOUS FLUID CONCENTRATIONS
CASE I: ION EXCHANGE RESIN USAGE.

Figure 1 illustrates with a family of curves the calculated amount of evaporator concentrates that can be expected for various feed stream concentrations of boric acid and bottoms concentration factors. The curves allow a determination of evaporator volume reduction (VR) factors in terms of gallons of feed per cubic foot of evaporator bottoms. For example, if evaporator performance is 12 percent bottoms concentration and feed concentration is 200 ppm boric acid, then the volume reduction factor can be read as 10,000 gallons of feed per ft^3 of bottoms produced.

Superimposed on Fig. 1 are minimum, maximum, and average performance values for evaporation and FIX processing as determined from the survey data. Average evaporator performance can be compared to average FIX performance assuming a feed stream boric acid concentration of 200 ppm. For this case, the average of all ion exchange liquid waste processing data indicates a throughput of 20,500 gal/ft^3 of resin expended (without boron removal) whereas an "average" evaporator would have processed 13,500 gal/ft^3 of bottoms produced.

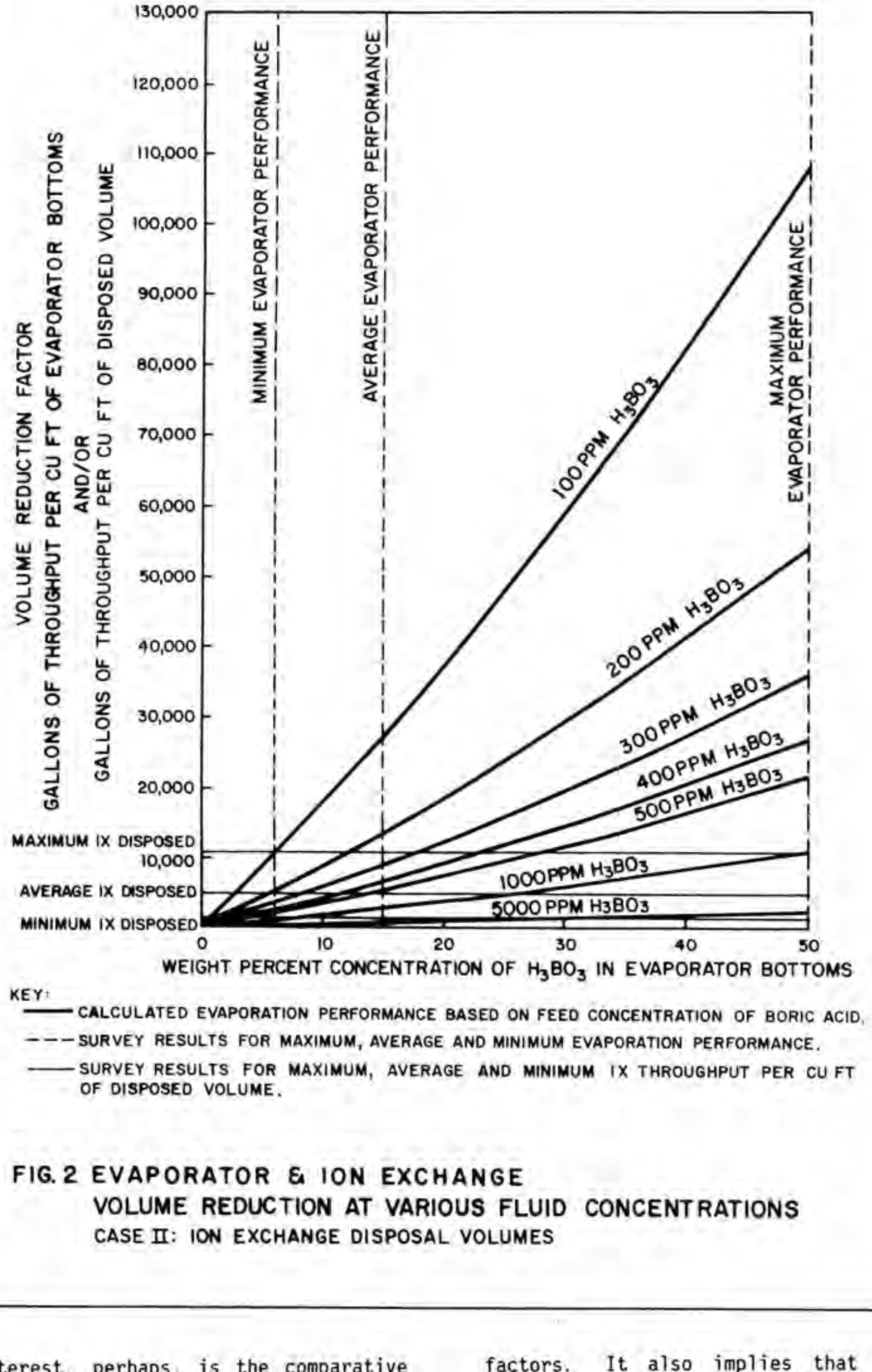

FIG. 2 EVAPORATOR & ION EXCHANGE
VOLUME REDUCTION AT VARIOUS FLUID CONCENTRATIONS
CASE II: ION EXCHANGE DISPOSAL VOLUMES

Of more interest, perhaps, is the comparative information presented in Fig. 2. This display contrasts evaporator performance (VR or throughput) with actual disposable volume produced by portable FIX systems. Again, for a similar hypothetical case of 200 ppm boric acid feed, the "average" evaporator processes 13,500 gallons of feed per cubic foot of bottoms generated. The "average" portable FIX process attained a VR factor of 5000 gal/ft^3 of disposable material (without boron removal).

Figure 2 illustrates the point (based on operating data) that evaporation and FIX processes can provide comparable throughput efficiencies or VR factors. It also implies that one or the other process can be clearly superior in terms of VR.

Table IV provides additional data from vendor literature and published information from which useful comparisons can be made. It illustrates portable FIX processing efficiencies relative to feed stream conductivity. The data are not inconsistent with the data obtained from operating plants by this survey.

The combined data of Figs. 1 and 2 and Table IV, therefore, provide a base which can allow comparison of evaporator performance and ion exchange performance for a given case.

TABLE IV

Filtration/Ion Exchange System Throughput in Gallons of Feed/Ft^3 of Disposal Volume

SYSTEM SUPPLIER	FEED CONDUCTIVITY IN μmhos/cm			
	50	100	500	1000
VENDOR A *	2588	1765	441	NA
VENDOR B *	7253	3868	822	435
VENDOR C **	4264	2777	711	374

NOTES:
* DATA DOES NOT INCLUDE VOLUMES OF FILTER AND ORGANIC REMOVAL MEDIA & VESSELS
** DATA INCLUDES FILTER MEDIA & VESSELS

Table V summarizes the small amount of data available on processing costs for either evaporation or FIX. However, four plants reported cost ranging from \$.38/gallon to \$.76/gallon for evaporator processing with an average value of \$.50/gallon. A comparable cost of \$.44/gallon including all processing and disposal costs has been previously reported.[1]

FIX processing costs were reported in a usable form by six plants. Costs range from \$.04/gallon to \$.27/gallon of liquid processed. The average cost is \$.17/gallon. Reported costs for portable FIX ranged from \$.12/gallon to \$.27/gallon with an average of \$.21/gallon. Costs of \$.06/gallon to \$.08/gallon, including all disposal costs, are reported in the literature for portable FIX processing.[1]

TABLE V

Cost of Processing

TYPE OF PROCESSING	NUMBER OF PLANTS RESPONDING	AVERAGE COST	MAXIMUM COST	MINIMUM COST
EVAPORATION	4	\$.50	\$.76	\$.38
DEMINERALIZATION	7	\$.17	\$.27	\$.04

OTHER OBSERVATIONS

Some other observations should be made. Obviously, many factors must be considered when comparing evaporation and FIX. For example, Figs. 1 and 2 do not reflect the packaged volume of evaporator concentrates. This factor and other costs associated with evaporation and ion exchange must be accounted for in a complete analysis of the effectiveness and overall costs of these processes for a given application.

Depending on the application, some of the following considerations could also apply:

- Operator's current or previous experience with the process
- Inertia involved in making changes if a given process is "working" or can be made to work
- Operator/utility preferences
- Operator/utility operating and maintenance philosophies and practices

It is probably safe to say that evaporator systems require a significant amount of attention to ensure proper operation. Their successful application is in part a function of the user's desire to make them work. The user should provide appropriate training programs and operating and maintenance personnel dedicated to radwaste systems and operations. The burden of such administrative and operating requirements may make the convenience and relative process simplicity of portable FIX systems attractive to some users.

With these observations in mind, it is interesting to note that the data in Table II do not point to any one or two major evaporator problems. Also, the previously noted reasons given for abandoning the use of evaporators do not provide a common theme. Furthermore, the reported difficulties with both operating evaporators and those which have been abandoned are very much the same. One could speculate then that, at least in some cases, the decision to discontinue the use of evaporators was significantly influenced by the organizational, philosophical, and procedural characteristics of the users in addition to the nature of the equipment.

Finally, based on survey results and other available data, the use of ion exchange generally can be considered to be efficient or appropriate where inlet stream conductivity is reasonably low (vendors say 100 µmho or less) and when boric acid removal from the feed stream is not necessary. (Boric acid removal significantly reduces resin capacity.)

CONCLUSIONS

Many evaporators have operated successfully for years while some others are no longer operating. From this study sample, it has been shown that of the 33 radwaste evaporators originally scheduled for service, 23 are still operating and 10 are not operating for a variety of reasons. The survey also reveals that 30 plants are using either permanently installed or portable FIX in lieu of evaporation for waste stream cleanup. Based on actual operating experience, both processes can be considered reliable and effective waste treatment techniques for commercial LWRs.

The performance comparision of FIX systems and evaporators has been made using reported operating data, vendor information, and calculated data. As has been shown, both can be effective volume reduction processes, each being superior to the other for various water feed stream conditions. However, the choice among them or the decision to replace one with the other involves additonal considerations and must be fully studied for each case. Process selection must be based on factors such as detailed feed stream chemistry evaluations, VR expected for each process, process reliability, user operating/management philosophy and practices, packaging requirements and packaging system availability, and overall costs associated with implementing and operating each system. The data presented here provide a useful comparison of the capabilities and suitability of each process and place in perspective the actual experience with each.

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