OPERATING COST ESTIMATE
LOW LEVEL RADIOACTIVE WASTE
VOLUME REDUCTION
AND
PACKAGING OPTIONS

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ABSTRACT

Many nuclear power plant operators are presently or in the near future will be considering changes and improvements in their low-level radwaste management programs. These changes are being dictated by more stringent waste form technical requirements, escalating transportation and burial costs and waste disposal uncertainties which threaten continued operation of the plants themselves. Measures will take the form of programs to minimize waste generation in the first place and facilities to reduce the volume of liquid and solid wastes generated, package the resultant waste forms in compliance with regulations for storage, transportation and burial and store wastes for several years, if necesary. This paper reviews the operating economics for several volume reduction (VR) and packaging alternatives commonly being considered for three generic power plant waste streams: (1) Dry Active Waste, (2) Resins and Sludges, and (3) Liquid Wastes.

The ultimate selection of programs and equipment systems for radwaste management is dependent on site specific considerations. This not only includes technical considerations such as the number of reactors, and liquid waste treatment systems employed, but also matters such as the utility's financial position and desired return on investment. Geographic location impacts thinking on transportation concerns and future waste disposal prospects. On top of these factors, there are a host of technologies being made available for VR, solidification and packaging. Those charged with making the choice must consider widely varying VR technologies and potential application of one of several different solidification agents.

The projected operating cost data examine the differences in compaction and incineration for DAW. Two commonly achieved densities for compaction are presented, while a third case approaching the theoretical density of the cloth and paper materials shows the interesting possibilities of improved compaction. Incineration at two benchmarks for the chlorinated plastic component of typical DAW illustrates the impact waste stream make-up has on economics.

Evaporator concentrates are considered as a liquid at four concentrations (6%, 12%, 25% and 50%) and after all water has been removed for the cement and polymer cases.

Five separate processing schemes are presented for bead resins. These range from dewatering and packaging in high integrity containers to incineration with solidification.

INTRODUCTION

Many studies have been presented regarding low level waste disposal cost. All, including this one, have a common failing - they cannot take into consideration the various site specific circumstances at each given plant. As such they can serve only as a general guide for more detailed studies for given plant circumstances.

Another common failing is to base evaluation of something new upon individual experiences which in some circumstances may lead to the wrong conclusion. For example, a number of years ago a paper was given in which a major conclusion was "do not use 55 gallon drums for radwaste packaging." This conclusion was based upon the fact that the given station had no efficient handling equipment for any size container, hence, from the author's experience, the least number of container moves required was best. This station has since purchased a drum system with appropriate handling equipment. An attempt has been made to remove prejudices from the information contained herein to provide as realistic an appraisal as possible.

Operating cost is of course only one item to consider in the evaluation of new technology. The readers know most, if not all, of the others but the following issues are listed in an attempt to put "operating cost" in its proper prospective.

1. Reliability - Without this attribute the technology and its operating cost under evaluation will usually be wrong by a wide margin.

2. Applicability - Reliability infers "reliable under conditions of intended use." Excellent equipment designed for one application is not necessarily "excellent" for another application. A number of examples of mis-application in the radwaste area have become apparent, usually determined by operating experience years after selection of the equipment.

3. Accuracy and Repeatability of Operation - Without this attribute how do operators reliably and at lowest cost handle process control to insure that the product in fact is acceptable?

4. Flexibility - It is difficult on a day-to-day basis to obtain consistency of the radwaste stream(s) to be processed. How do operators know that the equipment under evaluation can handle variations due to changing technical and economic consideration over life of the plant?

5. Safety - By definition, the radwaste operation imposes physical, chemical and radiation risks to its operators and to a much lesser extent to the general public. Is there enough reliability, redundancy, and safety built in to insure an acceptable level of risk?

6. Continuity of Operation - This refers to the ability of maintaining the equipment in satisfactory operating condition over the life of the station. Presently there are at least 15 to 20 options available for radwaste equipment. The available market on a world wide basis will support only a fraction of these options on a long term basis. Key questions are:

    a. Is the supplier likely to be available when his support, spare parts, or system improvement is needed?

    b. Is the selection likely to remain a technically acceptable and economic process over life of the plant?

7. The availability of burial site space is a real concern. What equipment selection is likely to minimize difficulty and cost?

    If an "on-site" storage facility is deemed appropriate of necessity or as an insurance to guarantee continuity of operation, how will the selection of equipment influence the cost of this facility?

8. Capital cost requirements for the various options.

9. Cost change sensitivity - The current relationships of various cost elements, as included in this paper, may be altered over time due to a range of changes likely to affect individual cost elements.

In view of the above, the authors realize that an economic, technically acceptable selection of radwaste equipment is extremely complicated, particularly when little or no "operating experience under plant conditions" is available for a number of the potential selections.

The operating cost figures included in this paper represent, in the authors judgment, relatively ideal results based upon the processes being considered. This is done to represent the relative process comparisons on as equal a basis as possible and to emphasize the potential of each process. In addition an attempt was made to insure that each evaluation will not only meet required technical criteria but that, where possible, the technical results are reasonably equal. Using these guidelines, comparative evaluations of most major treatment options are included for each generic waste classification.

The authors also recognize that this single more or less generic evaluation cannot represent all variations in cost or even contain all realistic cost increments. For example:

1. The cost of containers vary substantially with size, construction materials, methods of fabrication, etc. The cost figures used are representative of those used in the industry.

2. The cost of services - electricity, water, steam, etc. varies substantially with various V/R processes used. No attempt was made to include this cost increment in the study.

To assist evaluation and understanding of the data, an addendum to the paper briefly explains the basis for the figures shown on the various tables. The addendum provides sufficient information to permit verification or means to change the data to fit specific needs.

Dry Active Waste

DAW, normally boxed or compacted using present U.S. technology, may be classed into two categories:

1. Compactible
2. Non-compactible

Essentially all of the compactible material is also burnable. A significant amount of non-compactible material is not burnable.

Attention to date has been directed at V/R of Category 1. If information obtained in recent plant surveys is correct, the compactible increment of DAW in U.S. plants average 40% to 60% of the total DAW volume shipped.[a] Pipe, conduit, filters, glass, wood, tools, concrete, concrete block, composite materials, metals, dirt, electrical gear, etc. that become contaminated, average about the same shipment volume as the compactible material. In the USA waste generators have generally not attempted to volume reduce this segment of DAW. It is obviously more difficult to do but there is significant volume reduction potential.

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[a] Personal communication with Mr. Michael Naughton, EPRI and individual nuclear power station personnel.

Figures 1 thru 4 illustrate the potential for compaction improvement as currently practiced at the Netherlands Energy Research Center[b] using a high pressure compaction press designed and built by Machinefabriek A. Fontijne B.V. of Holland.

Figure 1 shows a drum of "compactible material" prior to compaction and Fig. 2 shows the results after compaction of the drum. The drum has been turned into a "hockey puck" and, of course, the drum itself serves as an "anti-springback" device.

Figures 3 and 4 represent a before and after example of previously considered "un-compactible" material, in this case heavy wall tubing.

The average density of "hockey pucks" produced at the Netherlands Research Center, including the drum weight, is 156 lbs/ft^3. Experience in the Netherlands is difficult to compare directly with that in the USA. DAW figures compared in the USA usually include, on a pounds per cubic foot of container volume, only what we consider "compactible DAW" and do not include the container weight. This is also the basis of figures compared in this paper. The 156 lbs/ft^3 figure representing experience in the Netherlands is based upon the use of 100 liter drums, normally filled but not compacted, with what in the USA would be considered both "compactible" and "non-compactible" material. The weight of the metal drums and heavy "non-compactible" (by U.S. standards) waste material is responsible for the high density of the Netherlands process. The maximum practical density of paper, cloth, plastic, etc. not including the container, is in the neighborhood of 70 lbs/ft^3. The density of "compactible" DAW as shipped in the USA today averages from a low of 6 to 8 lbs/ft^3 (if not compacted) to a high of 40-45 lbs/ft^3. The average density of "non-compactible" DAW as shipped is quite variable but is assumed to average 30 lbs/ft^3 for this study.

For evaluation of the Netherlands process to meet U.S. conditions, the authors have assumed that:

1. 55 gallon drums would be pre-compacted per present practice to a density of 20 to 40 lbs/ft$_3$ of paper, plastic, cloth, etc.
2. "Non-compactible" material, if small, could be placed in drums with the "compactible" material. Otherwise, it would be loaded into separate drums.
3. All drums would then be compacted in a press similar to the A. Fontijne machine used in the Netherlands.

This concept substantially reduces the number of containers requiring disposal and also utilizes the container as a "built in" anti-springback device.

Table I illustrates operating cost for a range of compaction densities including "compactible" and previously considered "uncompactible" material in Columns 1 thru 4. Incineration potential, the option to compaction, is summarized in Columns 5 thru 7.

Columns 1 thru 4 indicate the potential economic and volume saving from no compaction to maximum compaction. What is considered "compactible" is summarized on line 22, comparable non-compactible figures are summarized on line 29 and the total DAW evaluation is summarized on lines 30 thru 33.

.The figures in Columns 1 thru 4 indicate that:

1. Compaction equipment in operation in the USA is capable of saving about 61% of the operating cost and 67% of the volume of waste shipped as compared to no compaction.
2. Higher capacity and higher priced equipment in use in Europe can increase the volume savings to about 84% and the operating cost reduction to about 79%, by compressing the waste to near maximum density.

There are, of course, potential problems associated with attempting to obtain maximum density.

1. The containers may be ruptured. They, therefore, may require overpacks or sealing in some manner prior to transporting and/or burial.
2. Machine maintenance may be higher per unit of waste compared to other equipment (line 17).
3. Depending upon the design of the equipment, its amount of automation, the amount of preparation of the non-compactible waste necessary to effectively utilize the equipment for most, if not all of the DAW, plant labor cost could be higher than that indicated on line 15.

Conversely, if Column 3 is a reasonable representation of best USA practice, as indicated on Line 31 high energy compaction can offer nearly 50% reduction in waste volume. This has positive operating cost implications. Further, where burial allocations are restricted and/or on-site storage may be needed, the additional volume reduction could have significant positive effect upon capital expenditure budgets.

The alternative to compaction is incineration. Operating cost variables are shown in Columns 5 thru 7. The three main variables affecting incineration operating cost and subsequent solidification are:

1. Ash Characteristics - All ash is not created equal. As with most everything else, the density, average particle size, average surface area and chemical make-up varies substantially with the type of incinerator used, its actual operation variables, variation in DAW feed, etc. As the average particle size and/or density decreases, the surface area normally increases. Therefore, more solidification agent is needed to adequately coat the larger surface area. The net result is less waste in each container.
2. Scrub Solution - Chlorinated plastic or other items in the waste may require scrubbing of the hot gas to comply with emission regulations. Ten per cent chlorinated plastic, as an example, may create more dry salt for disposal than the

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[b] "Sea Disposal Experience of the Netherlands" by A.W. Van Weeks, B. Verkerk and C. Koning presented at Waste Management '82.

quantity of ash generated in the incinerator.

3. Carbon, Trace Metals, Etc. - With some solidification agents, these products in small proportion can require revision to solidification formulas.

In the as-solidified condition, Column 5 considers the ash and scrub solution salt to be 40 lbs/ft^3. Column 6 considers the ash and scrub solution salt to be 66.7 lbs/ft^3. Based upon tests completed to date with various ash samples, this range of density probably covers all types of incinerators,operating variables, and feed variables. These values represent as-solidified ash/salt densities, exclusive of solidification agent and evidences the wetting action of the solidification process for increasing the as-generated bulk density of the ash product.

These columns demonstrate the effect of ash density on V/R . Note that the volume of waste shipped in Column 5 is almost twice that in Column 6. (Line 7).

Columns 6 and 7 show the variation in cost and volume assuming 10% PVC (Column 6) and no PVC (Column 7). The volume of waste shipped without PVC is less than half of that with PVC at 10% of the waste quantity. The inclusion of PVC also increases cost about 33%.

Information obtained from operating plants indicates that the PVC fraction of DAW typically varies from 5 to 20%, although individual plants report higher or lower values.

This study assumes that scrub solution is reduced to dry salt for disposal, hence providing the least waste volume. This assumption may not be possible with some incinerator designs partially dependent upon the amount of PVC, hence, amount of scrub solution generated. Under some conditions, it may also be economically desirable to dispose of this solution as a solidified liquid.

A perfect answer to eliminate scrubbers and scrub solution would be to reduce PVC and potentially other troublesome DAW constituents to a point where they would not be a problem from a regulatory, noxious, equipment or maintenance standpoint. This would reduce capital and operating cost, eliminate a potential disposal problem and reduce maintenance cost (line 17, column 7).

Elimination of scrubber equipment may be an option only if the incinerator is limited to burning DAW and only then if the chlorinated plastic content of the waste is quite low. If EPA regulations[c] which limit HCl discharge to a maximum of 1.8 kg/hr. or otherwise require 99% HCl removal, are applicable, chlorinated plastics are limited to a low percentage of the waste regardless of practical incinerator size. There appears to be no final agreement as to the applicability of this regulation to radwaste incineration applications, but compliance with Federal, State and Local emission regulations is essential.

Major conclusions from this review of DAW disposal costs are:

1. Maximum density compaction and incineration offer similar operating cost advantage.

2. Considering compactable material only, the V/R potential of incineration is in the neighborhood of 12 to 16:1 compared to the best compaction scheme. When considering all DAW, the advantage for incineration becomes a net reduction of 36% in waste volume shipped (Line 31).

3. The largest cost fraction for all compaction cases, regardless of density, is burial cost. It varies from 81% to 57% of total cost.

4. Labor and maintenance cost (combined) is the single largest cost element with the incineration option. Burial cost is a relatively insignificant 5 to 10% of total burnable waste cost (Line 21). (37% considering all DAW re Line 21 plus Line 28).

5. There appears to be no generic answer to solve DAW volume reduction objectives. Both compaction and incineration appear to be viable solutions that may be desirable under specific circumstances.

   While not evident from the data, where large quantities of DAW are available, it may be desirable to segregate the waste to take advantage of the best features of compaction and incineration at the same site. This suggests the possibility of regional DAW processing centers because most plant sites do not have sufficient waste to justify both technologies.

   Where the quantity of DAW is low, high density compaction or incineration may not be viable.

   These conclusions relate only to dry active waste options. Incinerators may have advantages with other waste streams that must be considered with the DAW options.

6. A potential option, not addressed here, is placing dry ash and/or scrub solution salts into high integrity containers without solidification. On the surface, this solution appears to have advantage from both a V/R and economic standpoint.

   There are sound reasons why this option should not be utilized.

   a. The apparent volume reduction potential may be an illusion when compared to solidification. Bulk density of ash and powder, while quite variable, is usually substantially greater after it is wetted with a

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[c] EPA ammended regulations Sec. 264.343 "Performance Standards for HCL Emmissions"

solidification agent. Tests performed to date indicate the weight of powder that may be solidified within a given size container may be 50 to 100% (or more) greater than the weight of dry powder that may be poured into the same container.

b. Dry powder product, after V/R, will have a significantly higher activity level. A high proportion of this product is quite fine and is easily dispersed over a wide area in case of an accident.

Table I

OPERATING COST ESTIMATE

DRY ACTIVE WASTE OPTIONS

COLUMN NO.	1	2	3	4	5	6	7
1. Process	N	----------COMPACTION----------			INCINERATE - SOLIDIFY		
2. Solidification Agent	N	N	N	N	---------POLYMER---------		
3. PVC in Waste, %	10	10	10	10	10	10	0
4. Compactible DAW, Lbs.	-------------------300,000-------------------				--	--	--
5. Ash and Salt, Lbs.	--	--	--	--	44,341	44,341	18,000
6. Waste Density, Lb/Ft^3	7	26	40	70	40	66.7	66.7
7. Cu. Ft. Shipped	42,857	11,535	7,500	4,286	1,108	665	270
8. Cont. Rads, mr/Hr	1	2	3	6	30	50	109
9. Ft^3 Each Shipment	2,560	1,280	750	562	450	450	157
In Plant Cost							
10. Containers - \$1.95/Ft^3	\$ 83,571	--	--	--	--	--	--
11. Containers - \$4.67/Ft^3	--	\$ 53,830	\$ 35,000	\$ 20,016	--	--	--
12. Containers - \$9.34/Ft^3	--	--	--	--	\$ 10,349	\$ 6,211	\$ 1,712
13. Labor - \$1.50/Ft^3	\$ 64,286	\$ 17,302	--	--	--	--	--
14. Labor - \$3.33/Ft^3	--	--	\$ 24,750	\$ 14,144	--	--	--
15. Labor Incineration	--	--	--	--	\$ 69,600	\$ 69,600	\$ 69,600
16. Solidif. Agent-\$34.13/Ft^3	--	--	--	--	\$ 37,816	\$ 22,696	\$ 9,215
17. Maintenance Est.	0	\$ 2,000	\$ 1,000	\$ 10,000	\$ 50,000	\$ 50,000	\$ 30,000
18. In Plant - Subtotal	\$ 147,857	\$ 73,132	\$ 60,755	\$ 44,160	\$167,765	\$148,507	\$110,527
Transportation Cost							
19. Unshielded, \$1000/Shipment	\$ 16,471	\$ 9,012	\$ 10,000	\$ 7,626	\$ 2,462	\$ 1,478	\$ 3,955
20. Shielded, \$2300/Shipment	--	--	--	--			
Burial Cost							
21. At Barnwell Rates	\$ 697,141	\$187,636	\$122,000	\$ 69,710	\$ 18,027	\$ 10,820	\$ 6,332
22. Sub-total-Comp. & Incin.	\$ 861,469	\$269,780	\$192,750	\$121,496	\$188,254	\$160,805	\$120,814
23. Non-Compactible DAW, Lbs.	-----------------300,000-----------------				------------150,000------------		
24. N-C Boxed at 30 Lb/Ft^3	10,000	10,000	10,000	--	5,000	5,000	5,000
25. Compacted, Ft^3	--	--	--	4,000	--	--	--
Non-Compactible Cost Summary							
26. In Plant Cost	\$ 61,702	\$ 61,702	\$ 61,702	\$ 31,880	\$ 30,851	\$ 30,851	\$ 30,851
27. Transportation Cost	\$ 7,812	\$ 7,812	\$ 7,812	\$ 7,117	\$ 3,906	\$ 3,906	\$ 3,906
28. Burial Cost	\$ 162,708	\$162,707	\$162,708	\$ 65,088	\$ 81,354	\$ 81,354	\$ 81,354
29. Sub-total Non-compactible	\$ 232,222	\$232,222	\$232,222	\$104,085	\$116,110	\$116,110	\$116,110
30. Total Cost	\$1,093,691	\$502,002	\$424,972	\$225,581	\$304,364	\$276,915	\$236,924
31. Total Volume, Ft^3	52,857	21,535	17,500	8,286	6,108	5,665	5,270
32. Cost Reduction, %	0	54	61	79	72	75	78
33. Volume Reduction, %	0	59	67	84	88	89	90

RESINS AND FILTER SLUDGES

Resins and sludges, historically solidified or dewatered prior to shipment and burial, may now be handled by four (4) basic processes.

1. Solidify as a slurry.
2. Dewater without solidification.
3. Dry and solidify.
4. Incinerate and solidify.

Most U.S. stations currently utilize methods 1 and 2. Drying technology available or soon to be available includes:

Thin film evaporators
Heated extruders
Direct fired units
Water (or other fluid) heated units

A most effective dewatering device is the centrifuge which is in successful use at a number of stations.

A number of incinerators of the fluid bed, starved air and excess air types are being marketed for resin and filter sludge incineration. Most of this equipment, as well as some of the drying equipment is "general purpose" meaning it can also dry or incinerate other waste products.

Table II arranges various resin options in order of volume reduction potential. The following is indicated by the data.

1. Incineration with solidification, has the potential of providing approximately 90% volume reduction and a cost reduction in the neighborhood of 55%.

2. Drying, with solidification, has the potential of providing approximately 67% volume reduction and a cost reduction of approximately 24%.

3. Dewatering, without solidification, has the potential of providing about 28% volume reduction. If liners may be utilized (waste less than 1 μci/cc), a 11% cost saving is apparent. Where high integrity containers (HIC) must be utilized, operating cost increases about 28% compared to the base example.

4. Burial cost is the largest cost increment for each of the examples utilized in this study. A comparison of the figures on Line 20 indicate that the more extreme V/R techniques appear to provide a means of minimizing this inflation prone increment. Drying reduces burial cost 43% and incineration reduces burial cost 69%.

5. Burial cost calculations for these examples are shown in Addendum I, Item 10. They indicate that the total radiation and curie content surcharges for these examples are 51% to 78% of the total burial cost. Lower radiation content of the waste material can substantially reduce cost.

The following points should be considered when reviewing data on Fig. 2.

1. As stated in the previous section concerning DAW, variation in ash characteristics can alter solidification results. Column 5 on Table II probably represents the most favorable example for incineration. Actual results may vary in a manner similar to that indicated in Table I, Columns 5 and 6, for DAW.

2. Considering the radiation content of the resin and slurry, it may not be prudent or even feasible to incinerate all of the resin or slurry. If not, the advantages indicated on Table II would be reduced and alternate disposal means would be required for the portion not incinerated.

3. The advantage of drying resins is that the resins physically shrink in size as the water is removed. Totally dried resins, as compared to new resins containing about 50% water, occupy about 1/2 the volume of the new resin.

   Conversely, if exposed to water, the resins will expand to their original volume. A wet cement solidification process is therefore not practical for solidification of dried resins.

   The authors' have attempted to consider evaluations made in this paper on the basis of equal technical results where possible to do so. Because laboratory results indicate polymer is superior to bitumen in preventing intrusion of water into a solidified mass, bitumen has not been considered in this study. This in-house evaluation indicated a reduction in solidification agent cost and an increase in waste volume shipped if bitumen were to be substituted for polymer.

4. Characteristics of the waste product may preclude obtaining the full potential of the VR process.

   a. Diatomaceous earth is a rock. Incineration or drying would not be expected to provide significant volume reduction.

   b. When dried, some products tend to fluff up providing a lower bulk density within the container.

   c. If not thoroughly dried, some materials tend to sticky. This makes them difficult to handle and provides a high angle of repose making it difficult to properly fill a container.

Table II

OPERATING COST ESTIMATE

RESIN AND SLUDGE OPTIONS

(10,000 FT^3 - NEW RESIN)

	COLUMN NO.	1	2*	3	4	5
1.	Process	Slurry	Dewater	Dewater	Dry	Incinerate
2.	Solidification Agent	Cement	None (Liner)	None (HIC)	Polymer	Polymer
3.	Cu. Ft. (Lbs.) Waste Only	11,500	10,000	10,000	4,545	(105,000)
4.	Cu. Ft. Shipped	16,120	11,926	13,338	5,285	1,575
5.	Rad. Level, r/Hr	4.5	13	13	28	44
6.	Cu. Ft. Each Shipment	105	200	195	52.5	22.5
	In Plant Cost					
7.	Containers $4.67/Cu. Ft.	$ 75,280	--	--	--	--
8.	Containers $9.34/Cu. Ft.	--	--	--	$ 49,362	$ 14,711
9.	Containers $18.68/Cu. Ft.	--	$ 222,778	--	--	--
10.	Containers $40/Cu. Ft.	--	--	$ 533,520	--	--
11.	Solidif. Agent $1.55/Cu. Ft.	24,986	--	--	--	--
12.	Solidif. Agent $34.13/Cu.Ft.	--	--	--	180,377	$ 53,755
	Labor					
13.	Dewater Only	--	$ 23,852	$ 26,676	--	--
14.	Slurry-Solidify	$ 53,680	--	--	--	--
15.	Dry-Solidify	--	--	--	$ 35,714	--
16.	Incin-Solidify	--	--	--	--	$ 54,119
17.	Maintenance	$ 20,000	$ 5,000	$ 5,000	$ 35,000	$ 50,000
18.	In Plant Sub-total	$ 173,946	$ 251,630	$ 565,196	$300,453	$172,585
19.	Transportation Cost @ 2300/Load	$ 353,105	$ 137,149	$ 157,320	$231,500	$161,000
20.	Burial Cost 83 Barnwell Rate	$ 699,124	$ 727,247	$ 841,361	$400,603	$216,657
21.	Total, Dollars	$1,226,175	$1,116,026	$1,563,877	$932,556	$550,242
22.	Vol. Red., %	0	26%	17%	67%	90%
23.	Dollar Savings, %	0	9%	(28%)	24%	55%

* Column 2 is included at the radiation limits compatible with this study's assumptions and is for comparative information only. The activity is over 1 µci/cc, the limit for shipping dewatered in standard liners.

LIQUIDS

A number of processes are utilized to reduce the volume of liquids containing low level radioactivity. They are:

1. Evaporation
2. Evaporation - Crystallization
3. Reverse Osmosis
4. Cartridge Filtration
5. Precoat Filtration
6. Backflush Filtration
7. Demineralization
8. Drying

Precoat filtration and demineralization result in resin and filter media waste slurry. These disposal costs are covered under Table II for most nuclear plant operations. Demineralization as a means of replacing the traditional evaporation function is a relatively recent application that has been successfully applied at a number of stations. The success of its application as a volume reduction technique is heavily dependent upon the solids concentrations of the waste feed, the radiation level of the waste feed and the condition and disposition of the water after demineralization. For these reasons, this process does not appear to be a generic volume reduction solution, and it is not considered in this paper.

Cartridge and backflushable filtration also have not been considered in this paper although both are viable volume reduction techniques.

Liquid V/R in this study, limited to evaporation, crystallization and drying processes is shown on Table III. Column 1 illustrates evaporization at 6% solids concentration. This concentration is utilized as a base for evaluation simply because the evaporators operating in a number of stations are producing concentrate of 5% to 9% dissolved solids. The usual 12% (PWR) and 25% (BWR) evaporator designs are indicated in Columns 2 and 3. Evaporation-crystallization at 50% is indicated in Column 4. Drying, that is converting the dissolved solids in the waste stream to dry rad salt powders is illustrated at two waste powder densities, namely 40 lb./cu. ft. and 66.7 lb./cu. ft. in Column 5 and 6, respectively. As stated previously, the 40 lb. per cu. ft. and 66.7 lb. per cu. ft. density figures represent the range of waste density in the "as solidified" condition likely to represent the range of product from various dryers.

Information on Table III indicates the following.

1. Compared to standard (12%) PWR evaporation, 50% evaporation-crystallization offers an opportunity to reduce waste volume shipped 78%. Taking the waste to a dry powder can reduce the waste volume shipped from 86% to 90%, the incremental V/R from 50% evaporation-crystallization to drying is 33% to 55%, a significant figure.

2. Compared to standard (25%) BWR evaporation, 50% evaporation-crystallization offers an opportunity to reduce waste volume, shipped 54%. Drying provides a potential V/R of 69% to 79%. The incremental V/R from evaporation-crystallization to drying is the same as that for PWR waste.

3. Most available dryers are operated downstream of an evaporator. Hence, drying should be expected to increase plant operating cost. A dryer may also increase total operating cost, but the differences shown between columns 4, 5 and 6 are influenced by the assumed waste radiation level, cask size and solidification agent chosen for the study.

4. Burial cost decreases significantly with decreasing waste volume containing the same number of curies.

   As indicated in Column 5 and 6 transportation cost (Line 18) variation in radiation level, cask break points, etc. may reverse this overall trend in some circumstances. Without significant V/R and with relatively low transportation cost due to the selection of a short distance to the burial ground for this study, burial cost is the dominant operating cost increment (Lines 17, 18, 19). With significant V/R as illustrated by Columns 4, 5 and 6, burial cost is a significantly lower percentage of total operating cost.

Table III

OPERATING COST ESTIMATE

LIQUID OPTIONS

(1,080,000 GALLONS WATER)

	COLUMN NO.	1	2	3	4	5	6
1.	Process	Evap.	Evap.	Evap.	Evap.	Dry	Dry
2.	Concentration	6	12	25	50	100	100
3.	Solidification	Cement	Cement	Cement	Cement	Polymer	Polymer
4.	Waste, Gallons (lbs)	45,000	22,500	10,800	5,400	(27,000)	(27,000)
5.	Waste Density, Lb/Cu. Ft.	--	--	--	--	40	66.7
	In-Plant Cost						
6.	Cu. Ft. Shipped	9,375	4,688	2,190	1,013	675	450
7.	Radlevel, R/Hr	0.2	0.4	0.8	1.5	5.4	8.3
8.	Cu. Ft. Each Shipment	180	180	157.5	157.5	105	52.5
9.	Containers - \$4.67/Ft^3	43,781	21.893	10.227	4,731	--	--
10.	Containers - \$9.34/Ft^3	--	--	--	--	6,304	4,203
11.	Solid. Agt. - 1.55/Ft^3	14,531	7,266	3,395	1,570	--	--
12.	Solid. Agt. - 34.13/Ft^3	--	--	--	--	23,038	15,359
13.	Labor - 3.33/Ft^3	31.219	15,610	--	--	--	--
14.	Labor - Dryer (Addendum I.C.)	--	--	--	--	14,875	14,875
15.	Labor - Evap. (Addendum I.C.)	--	--	14,850	14,850	--	--
16.	Maintenance Est.	20,000	20,000	20,000	20,000	35,000	35,000
17.	In Plant - Sub Total	109,531	64,769	48,472	41,151	79,217	69,536
18.	Transport, \$2300/Load	119,792	59,902	31,981	14,786	19,714	
19.	Burial, Barnwell Rate	291,750	162,205	92,265	48,047	40,959	33,885
20.	Total Operating Cost	521,073	286,876	172,718	103,991	134,962	123,125
21.	Cost Reduct, %		45	67	80	74	76
22.	Vol. Reduct, %		50	77	89	93	95

SUMMARY

Volume reduction and packaging options are available to nuclear plant operators which with varying degrees of potential will reduce volumes of low-level waste shipped and the costs associated therewith. The authors have reviewed the operating costs of most available combinations applied to generic plant waste streams. Such a general review can only pressume to illustrate relative expectations when evaluating particular options against site specific conditions.

To complete the economic picture, the evaluator must consider costs to procure and install the process equipment being considered. Also, the specific cost of services necessary to operate the systems, such as air, water, electric power, steam, etc. are not addressed, though in-plant labor has been. These two cost areas can vary dramatically and may distort generic performance economics.

Finally, it is emphasized that the operating costs, as well as capital costs, are but one consideration. There is little or no every day operating experience for most of these advanced technologies. Hence, reliance must be placed on the quality and flexibility of the designs to meet current and potential future technical and economic needs.

ADDENDUM I

BASIS OF FIGURES UTILIZED FOR OPERATING COST ESTIMATE

1. Quantity of Waste

   a. DAW (Table I)

   300,000 lbs. of compactible material and 300,000 lbs. of "non-compactible" material were utilized for the study. It is estimated that both classifications of material average 30 lbs./cu. ft., as shipped. Therefore, the average volume shipped equals 10,000 cubic feet of "compactible" material and 10,000 cubic feet of "non-compactible" material. These quantities approximate recent survey data of BWR stations.

   Density variation for "compactible" material, Line 6, Columns 1 through 4 provide a basis of estimating cost for various compaction capability.

   All of the compactible material and 50% of the non-compactible material was assumed to be burnable providing 450,000 lb. incinerator feed.

   The average volume of "non-compactible" DAW after high energy press compaction was assumed to average 40% of the original material volume.

   Cost assumptions for "non-compactible" material, as summarized on lines 26 through 29 of Table I, were identical to those utilized for other materials as described in this addendum.

   b. Resins and Slurries (Table II)

   All columns, regardless of the process utilized for volume reduction and solidification (if any) are based on 10,000 cu. ft. of new resins containing 50% water by weight.

   c. Liquids (Table III)

   An initial waste quantity of 1,080,000 gallons of water at 2500 PPM dissolved solids concentration is the basis of all columns.

2. Cubic Feet Shipped

   The published internal capacities and Barnwell burial site container volume criteria are used as the basis of these figures. Container filling for dewatered resins assumes 86% filling efficiency.

3. Container Radiation Level and Curie Content

   Container surface radiation level is based upon the total shipping volume of waste material shipped. The radiation level variation between different columns on each table is inversely proportional to the total volume of material shipped. Adjustments have been made for the shielding capability of solidification agents, etc.

   Assumed total curie content, as necessary to calculate burial cost, was:

   Table I, DAW - Not Considered
   Table II, Resins - 2000 Curies
   Table III, Liquids - 400 Curies

   The curie content per shipment was obtained by multiplying the above figure by the percent of total waste to be shipped on each load.

   Example: Table II, Column 1

   $$2000 \text{ curies} \times \frac{105 \text{ Cu. Ft. (Line 6)}}{16{,}121 \text{ Cu. Ft. (Line 4)}} = 13$$

4. Containers

   Six (6) different containers were utilized in this study. Their size and estimated cost are:

   a. 4'x4'x8' Wood Boxes - \$1.95/Cu. Ft.
   b. 4'x4'x8' Metal Boxes - \$4.67/Cu. Ft.
   c. 55 Gallon Drums - \$4.67/Cu. Ft.
   d. 55 Gallon Drums with Mixer - \$9.34/Cu. Ft.
   e. 195 Cu. Ft. Liners - \$18.68/Cu. Ft.
   f. 170 Cu. Ft. HIC - \$40.00/Cu. Ft.

5. Labor

   All labor cost was calculated at \$25/Hr.

   a. DAW was calculated upon a cu. ft. of material shipped basis.

   Material Not Compacted - \$1.50/Cu. Ft.
   Material Compacted into Boxes -\$1.50/Cu. Ft.
   Material Compacted into Drums -\$3.33/Cu. Ft.

b. Dewatered Resins - $2.00/Cu. Ft.

c. Labor for evaporation, drying, incineration and solidification processes assumed that an operator would be required continuously during the process. The labor cost was based upon that process requiring the longest time to complete. The basis of the time estimate was:

Solidification - 1 MH/drum equiv.
($3.33/cu. ft.)
Evaporation - 30 GPM unit
Dryer, Resins - 7 cu. ft. new resin equiv. volume per hour
Dryer, Liquids - 60 lbs. dry salt per hour
Incinerator - 200 lb./hr. feed material

In many cases multiple processes are involved. For example, Table III, columns 1 through 4 involve solidification and evaporation using the above parameters. Solidification requires more time than evaporation for Columns 1 and 2. The reverse is true for Columns 3 and 4. Therefore, labor cost for solidification is utilized for Columns 1 and 2 and that for evaporation is utilized for Columns 3 and 4.

Where incineration is the controlling process, labor cost was increased 23.7% to provide additional support labor to suppliment the operator's time.

The labor cost figures are not intended to include cost for required health physics, chemical support, decontamination, or other services required to support the operator.

The authors recognize that the actual labor cost based upon the above assumptions may or may not bear a resemblance to the real world. It is an attempt, however, to evaluate processes on a relative basis. Many site specific factors may substantially vary labor cost.

6. Solidification Agent

Cost is based upon cubic foot of shipping (container) volume. The authors believe this simplification is justified because the solidification agent cost is a relatively small part of total cost. It has been normalized to avoid the confusion of slightly different cost figures between various columns.

Cement - $1.55/Cu. Ft.
Polymer - $34.13/Cu. Ft.

7. Maintenance

Maintenance figures will vary substantially with the type, complexity and quality of equipment selected as well as conditions of its use. The figures shown are estimates based upon the type and complexity of equipment and operating conditions. The figures assume high quality, well operated and maintained equipment.

8. Total In Plant Cost

The dollars shown do not include an allowance for:

a. Required services such as electric power, water, air or steam.
b. Operating supplies such as rags, protective clothing, lubricants, etc.
c. Labor for radiation services, chemical support or decontamination.

9. Transportation

A relatively short trip to the burial ground was assumed for this study.

a. The quantity (cubic foot) of waste shipped was based upon a 42,000 lb. maximum truck load limitation for shipments made without casks or the container volume placed within an appropriate cask as required by container calculated surface radiation level.
b. Unshielded shipments - $1000/trip
c. Shielded shipments - $2300/trip

10. Burial Cost

Barnwell burial site rates, effective April 5, 1983, were utilized for this study. The following is an example of these calculations as performed for Table II - Resin and Sludge Options. (See example below).

11. Cost Reduction, Volume Reduction, %

These figures were calculated in the following manner using Table I, columns 1 and 3 as an example.

$$V/R = \frac{52,857 \text{ Cu.Ft.(Col.1)} - 17,500 \text{ Cu.Ft.(Col.3)}}{52,857 \text{ Cu.Ft.(Col.1)}} = 62\%$$

Col. No.	1	2	3	4	5
Cu. Ft. Shipped	16,120	11,926	13,338	5,285	1,575
Cu. Ft./Shipment	105	200	195	52.5	22.5
Container Rads,r/Hr	4.5	13	13	28	44
Total Curries	2000				
Curries/Shipment	13	34	29	20	29
Burial Cost/Ft^3, Dollars					
Base Rate	13.2	13.2	13.2	13.2	13.2
Rad. Surcharge	15.0	30.0	30.0	40.0	40.0
Wt. Surcharge	--	3.85	4.39	--	--
Currie Surcharge	7.14	7.69	8.82	19.05	66.67
Cask Handling Fee	4.76	2.56	2.94	9.52	22.22
Escrow Fund	2.25	2.25	2.25	2.25	2.25
Sub-total	42.35	59.55	61.60	74.02	134.34
Co. Tax @ 2.4%	1.02	1.43	1.48	1.78	3.22
Total/Ft^3	43.37	60.98	63.08	75.80	137.56
Total Cost	$699,124	$727,247	$841,361	$400,603	$216,657

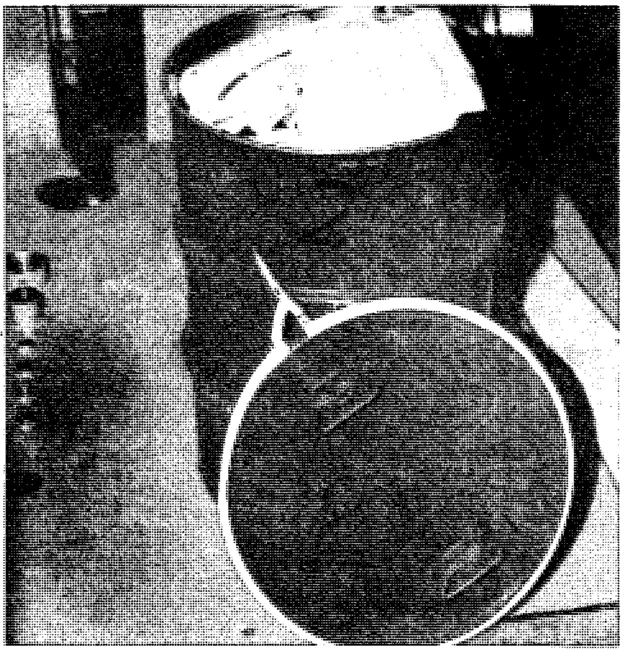

Fig. 1. Compactible waste before high energy compaction.

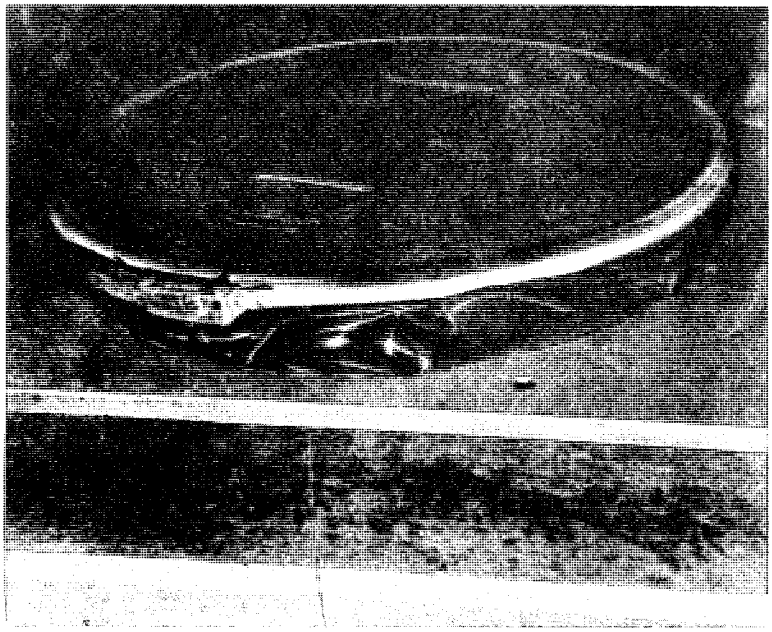

Fig. 2. Compactible waste after high energy compaction.

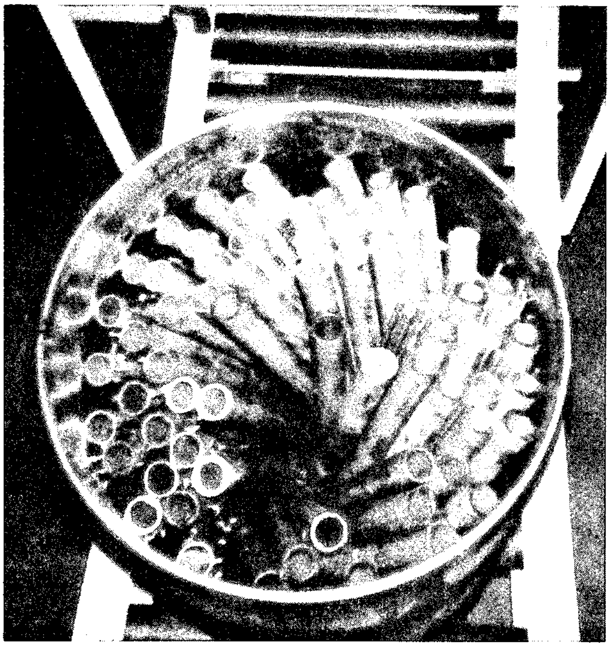

Fig. 3. Uncompactible waste before high energy compaction.

Fig. 4. Uncompactible waste after high energy compaction.