Advanced Volume Reduction and Waste Segregation Strategies for Low-Level Waste Disposal

Technical Report

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REPORT SUMMARY

EPRI has initiated a series of studies to mitigate the impact of limited disposal site access on continued operations. This report investigates two Class BC low level radioactive waste minimization techniques. The first is an advanced volume reduction (VR) technique for non-metal filter waste, while the second is a compilation of advanced waste segregation strategies aimed at minimizing the generation of BC wastes.

Background

Current legislation in the State of South Carolina sets a date of June 30, 2008, for the closure of the Barnwell LLW disposal site to out-of-compact waste. For the majority of commercial US nuclear plants, this eliminates the only existing option for disposal of Class BC wastes. This closure will force the affected nuclear plants into a period of on site interim storage pending an alternative Class BC waste disposal option. This also establishes a timeline during which EPRI and its member utilities can identify, evaluate, and maximize the cost effectiveness of highly efficient volume reduction technologies, thereby mitigating the impact of losing access to the Barnwell disposal facility.

Objectives

- To capture technical data on tank conversion reforming, including identification of limitations, optimum uses and VR efficiency.
- To evaluate various economic and interim storage benefits.
- To identify options for minimizing wet solid waste volumes, with the primary focus on reducing Class BC waste volumes, using Waste Logic software to quantify the potential cost and volume reduction benefits of wet solid waste minimization strategies.

Approach

Participating nuclear support vendors supplied a wide range of filter cartridge types and construction materials for the conversion reforming study. The filters were sampled and analyzed, and then loaded into the conversion reformer as part of a live demonstration of the technology. The initial waste volume and final reformed residue volume were used to calculate the volume reduction efficiency.

The STARS study involved a combination of site visits and live internet feed discussions to identify all wet solid waste sources for each participating nuclear station, and to capture all related technical data and dispositioning costs. The project team identified advanced strategies for segregating waste by Class, reducing generation of wet solid wastes, and applying alternative low cost, high efficiency post-generation volume reduction options.

The project team also used EPRI's Waste Logic Solid Waste Manager software to quantify the cost savings benefits for subsequent use in developing business cases for implementing the recommended changes.

Results

The results demonstrate that the conversion reforming study is a viable and highly efficient volume reduction technology for nuclear plant spent filters. In this study, the net disposal VR was 54:1, which translates to a very substantial reduction in disposed waste volumes, as well as stored LLW volumes for plants that do not have access to a disposal facility.

Numerous opportunities exist for reducing plant operating costs through segregation and reduction of wet solid wastes, including BC wastes, thereby minimizing the impact on interim storage. The available cost savings benefits are substantial, and utilities can apply one or more advanced strategies at almost every commercial nuclear plant.

EPRI Perspective

Conversion reforming can be a very useful tool for minimizing LLW storage and disposal volumes. It has extensive application for existing operating plants and for advanced light water reactors. If applied exclusively, a nuclear plant would likely generate less than two disposal containers of reformed filter waste during the entire operating life of the plant.

The wet solid waste minimization portion of the study identifies numerous proven advanced strategies for waste minimization, which utilities can apply at other nuclear plants. At a minimum, the magnitude of the results will likely stimulate the implementation of these and similar strategies across the industry over the next few years. The projected cost savings benefits available from industry-wide implementation of this study, including conversion reforming of filter waste, range from $15 to $20 million annually, with industry-wide implementation requiring at least five to ten years.

Keywords

Low level waste management
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Low level waste minimization
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1 INTRODUCTION

1.1 Project Overview

This two-part study included a first look at a new, advanced volume reduction technology, and the report makes recommendations for future applications of the technology throughout the commercial nuclear industry. The study also examines wet solid waste generation and segregation practices at the six STARS nuclear stations to identify opportunities to minimize Class BC wastes. The STARS study provided an opportunity to demonstrate the ability of EPRI's Waste Logic Solid Waste Manager software to evaluate numerous, complex waste minimization strategies in terms of their cost savings benefits.

It is anticipated that many of the strategies included in this report can be applied by other nuclear stations. As a minimum, the magnitude of the results will likely stimulate the implementation of these and similar strategies across the industry over the next few years.

1.2 Objectives of the Study

This is actually a two-part study, each of which has specific objectives:

- **Part 1**: Advanced VR technology – conversion reforming of nonmetal filter cartridges. Objectives of the study:
  - Capture technical data on tank conversion reforming.
  - Identify limitations of this VR technology.
  - Identify in-plant activities which will optimize use of the technology.
  - Identify typical VR efficiencies for conversion reforming of nonmetal filters.
  - Evaluate various economic and interim storage benefits.
- **Part 2**: Advanced LLW management strategies – segregation and source reduction of Class BC wet solid waste (WSW). Objectives of the study:
  - Identify options for minimizing wet solid waste volumes, with the primary focus on reducing Class BC waste volumes.
  - Use Waste Logic software to quantify the potential cost and volume reduction benefits of wet solid waste minimization strategies.

  Note: As used in this report, "waste volume reduction" and "VR" mean the same as the more common international term "waste conditioning." This refers to the process of applying a conditioning technology to reduce the volume of as-generated waste to produce a smaller disposal package.

1.3 Organization of the Report

Chapter 2 of this report provides an Executive Summary, including recommendations for industry-wide application of the results.

Chapter 3 focuses on the advanced VR technology, whereas **Chapter 4** focuses on segregation of Class BC waste.

An **Appendix** is provided to document the technical data associated with the filter conversion reforming study.

2 EXECUTIVE SUMMARY

2.1 Overview

EPRI has a continuing commitment to identify, evaluate, and promote cost-effective volume reduction (VR) technologies. Highly efficient technologies typically result in lower waste dispositioning costs, as well as reduced costs associated with interim on site storage.

EPRI also monitors the available and long range LLW disposal options and incorporates expected changes in disposal options into its LLW research activities. By anticipating significant changes, EPRI's LLW research activities remain proactive rather than reactive by identifying alternative technologies which mitigate any adverse impacts from changes in disposal options.

For example, current legislation in the State of South Carolina sets a date of June 30, 2008, after which the Barnwell LLW disposal site will close to out-of-compact waste. For the majority of commercial US nuclear plants, this eliminates the only existing option for disposal of Class B and Class C wastes (hereafter simply referred to as Class BC waste). The affected nuclear plants will be forced into a period of on site interim storage pending an alternative Class BC waste disposal option. This also establishes a timeline during which EPRI and its member utilities can identify, evaluate, and maximize the cost effectiveness of highly efficient volume reduction technologies, thereby mitigating the impact of losing access to the Barnwell disposal facility.

This study and the resulting report evaluate one such advanced volume reduction technology and makes recommendations for future applications of the technology throughout the industry. The study also examines the generation and segregation practices of Class BC wastes and proposes specific strategies which can be implemented by nuclear plants to minimize the generation, disposal, and interim storage volumes of Class BC wastes.

2.2 Conclusions Related to Conversion Reforming

The advanced technology evaluated in this study was "conversion reforming," a technology which has been developed by Studsvik-USA, Inc. This is a pyrolysis process essentially identical to the steam reforming process commonly used for volume reduction of spent resin. The primary difference for this study was the use of smaller equipment and the application of the technology for filter wastes. The study was further supported by OREX Technologies and Framatome ANP, who provided the filter cartridges used to evaluate the conversion reforming technology. The following conclusions apply:

1. The study demonstrated that conversion reforming is a viable and highly efficient volume reduction technology for nuclear plant spent filter cartridges. It is limited to nonmetal filters

and filters which are not made primarily of fiberglass. Although nonmetal filters are not widely used in commercial nuclear plants, a wide range of such filters are available to replace existing metal-reinforced filters.

2. Conversion reforming offers an exceptionally high volume reduction efficiency for filter wastes. In this study, the net disposal VR was 54:1. Even if it was only 10:1, conversion reforming would produce very substantial benefits to the nuclear industry. This exceptionally high VR efficiency translates to a very substantial reduction in disposed waste volumes, as well as reducing stored LLW volumes for plants which do not have access to a disposal facility. If an existing plant or an advanced light water reactor were forced into long term on site storage, application of this technology would reduce stored reformed filter waste to only one or two containers over the entire life of the plant..

3. If the nuclear industry broadly embraced nonmetal filters and conversion reforming technology, industry-wide cost savings over the next 25 years would reach millions of dollars.

2.3 Recommendations Related to Conversion Reforming

1. Demonstrate that this is a technology which the nuclear industry desires and will support. This is essential to encouraging Studsvik to expand their existing capabilities to handle bulk quantities and higher activity filters through automated processes. This can be accomplished by encouraging industry use of nonmetal filters through focused, plant-specific studies and field trials at selected utilities. This should be accomplished for both PWRs and BWRs.

2. Perform a full-scale testing at Studsvik of contaminated process filters generated at an operating nuclear plant. The objective of the study should be to verify VR data captured for this report, capture cradle-to-grave economic data, calculate cost savings and volume reduction benefits, and capture any lessons learned.

3. Develop industry guidance on mixing reformed resin residue and reformed filter residue for disposal characterization and concentration averaging. This should be submitted through NEI for NRC endorsement.

2.4 Conclusions Arising From STARS Study

The Strategic Teaming and Resource Sharing (STARS) alliance is a group of six PWRs: Callaway, Comanche Peak, Diablo Canyon, Palo Verde, South Texas Project, and Wolf Creek. A comprehensive study was performed in 2002 and 2003 to examine a wide range of existing, commonly used techniques, technologies, and plant system modifications which significantly reduce wet solid waste volumes and associated costs, including those associated with Class BC wastes. An important aspect of the study was a determination of whether the evaluated strategies could be replicated at other nuclear plants. The following conclusions apply:

1. Numerous opportunities exist for reducing plant operating costs through segregation and reduction of wet solid wastes. These include opportunities for significant reduction in Class BC wastes, thereby minimizing the impact on interim storage. None of the strategies

discussed in this report are new; each strategy is already a proven practice being implemented at one or more STARS stations, demonstrating that the strategies are transportable to other nuclear facilities.

2. Wet solid waste minimization efforts require support from many organizations within a nuclear utility, and the projected reduction in waste dispositioning costs is often the key factor in catalyzing support for implementing these strategies. EPRI's Waste Logic Solid Waste Manager is a very effective tool for quantifying the available cost savings and volume reduction benefits from various wet solid waste minimization strategies. The quantified cost savings can be used to develop a business case for initiating program changes, internal reviews, FSAR changes, and even plant modifications.

3. The cost savings benefits <u>already being realized</u> from previous implementation of these strategies at various STARS plants is $1.4 million dollars annually. By full implementation across the STARS fleet, an additional $1.8 million in savings could be realized. If this cost savings potential were extrapolated across the entire commercial nuclear industry, annual cost savings are projected at $15 to $20 million.

2.5 Recommendations Arising From STARS Study

1. The strategies discussed in this chapter are applicable to many other stations, including those of different plant designs. All EPRI member utilities should be encouraged to review the approach used in this report and the included strategies for local implementation.

2. Additional studies of this type should be pursued for other nuclear utilities and alliances, focusing primarily on minimizing Class BC wastes and the resultant cost savings. Special attention and priority should be given to those plants which are facing interim storage of Class BC wastes in 2008 or earlier; that is when out-of-compact LLW generators will lose access to the Barnwell Disposal Facility.

3 ADVANCED VR TECHNOLOGY – CONVERSION REFORMING OF NONMETAL FILTER CARTRIDGES

3.1 Overview

As of the date of publication of this report, high activity filter waste is the most expensive wet solid waste to manage. This is primarily due to poor packing efficiencies resulting from container void space. Some plants are addressing this via filter shredders or filter shears, typically achieving a VR ranging from 3:1 to 4:1. Another promising technology for filter reduction of nonmetal filter cartridges is steam reforming using a tank conversion reformer, which is also referred to as "conversion reforming."

In addition, new and promising nonmetal filters are now available. These include poly-vinyl alcohol (PVA) filters; "disposable media filters" made from various materials and consisting primarily of cellulous fibers and plastic support structures; and ion-specific filters (e.g., cesium-specific and cobalt-specific filters). The application of nonmetal filter technologies for low and high activity waste streams is expected to gain a strong foothold in both government applications and in the US commercial nuclear industry in 2004-2005. Of equal importance, all of these filter technologies appear to be excellent candidates for conversion reforming.

The high cost of filter waste disposal and the poor VR efficiencies associated with the disposal of most filters underscore a need for advanced filter VR technologies. The availability of one such technology—conversion reforming—and the expanding nonmetal filter technologies have the potential of meeting this need for a high efficiency, reasonably priced filter VR technology.

3.2 Approach

The evaluation of a conversion reforming system requires two components: (1) an available small-scale conversion reformer, and (2) a supply of a wide range of nonmetal filter cartridges and types. The following approach, system, and filters were used for this evaluation:

3.2.1 Selected Conversion Reforming Technology

A small scale tank conversion reformer (TCR) was recently placed in operation at Studsvik-USA, Inc. It has thus far been employed primarily for volume reduction of filters used in the dewatering laterals of spent resin liners and for reforming of segmented plastic waste containers. Although such filters typically range to several R/hr, they can be fed manually into the TCR--using remote handling tools as needed—through a small orifice for processing one filter at a time, as illustrated in Figure 3-1. The Studsvik TCR system was an ideal arrangement for this study, and Studsvik agreed to be an active participant in this study. (See Appendix B for additional detail on the methodology and procedures used for the conversion reforming study.)

Figure 3-1
Manual Loading Of Filter Cartridge Into Tank Conversion Reformer

3.2.2 Selected Nonmetal Filters

Nonmetal polyvinyl alcohol (PVA) filters have been developed by OREX Technologies. Framatome ANP also offers an extensive line of nonmetal "disposable media filters." In addition, nonmetal ion-specific filters (e.g., cesium-specific and cobalt-specific filters) were recently introduced to the US commercial nuclear industry by Framatome ANP. Accordingly, both OREX and Framatome ANP became participants in this study. Additional information on disposable media filters is included in Attachment A of this report.

> (Note: OREX Technologies is a division of Microtek Medical Holdings, Inc. PVA materials and their common applications in the nuclear power industry are discussed in EPRI report TR-1003435, *Emerging LLW Technologies: Dissolvable Clothing*.)

Approximately five cubic feet of various nonmetal filters were provided by both OREX and Framatome ANP, for a total of 27 filter types, sizes, shapes, and construction material. These were shipped to Studsvik for laboratory analyses and the volume reduction demonstration and evaluation. Figure 3-2 illustrates a random selection of the filters evaluated in this study.

Figure 3-2
Wide Range of Filters Used in Study (27 Filters and Configurations)

3.2.3 Sample Testing

Due to the complexity of the various filter media, it was necessary to test samples of the filters and structural components. All samples were ashed in a laboratory oven. This provided a preliminary indication of the expected VR for the <u>clean</u> filter media and filter structural components. It also identified any VR-associated challenges and any potential impacts to the TCR. Figure 3-3 illustrates the laboratory testing sequence.

Step 1: Cut Sample

Step 2: Ash in Lab Oven

Step 3: Final Ash Residue

Figure 3-3
Samples of Filters Ashed in Oven, Including Preparation and End Product

3.2.4 Evaluation Using Tank Conversion Reformer

The testing and demonstration of the TCR technology took place on March 25, 2003, with all participating companies present. As mentioned earlier, the Studsvik TCR is used for manual loading of low activity filters. The TCR port opening limits the filter diameter to approximately three inches (7.5 cm); the port access tube further limits the filter length to 30 inches (75 cm).

- Filters at or less than the allowable dimensions were loaded directly into the TCR port.
- Filters greater than the allowable dimensions were cut into smaller pieces, which were then placed in a cardboard tube for insertion into the TCR.

The Studsvik TCR used for this study allows the insertion of only one filter at a time. These are loaded either by hand or by a remote handling tool. Since this study involved only clean (nonradioactive) filters, all filters were inserted by hand. The reformed residue (final waste form) was collected in a high integrity container and quantified to determine the net VR.

The process of cutting and inserting various filters—including small diameter filters and filters cut and packed in cardboard tubes—is illustrated in Figure 3-4.

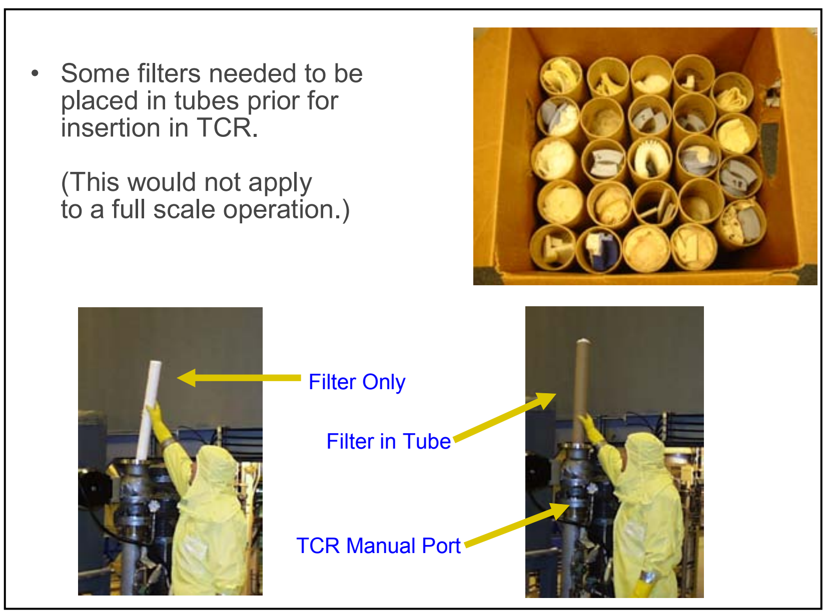

Figure 3-4
Preparation and Manual Insertion of Filters for Studsvik Tank Conversion Reformer

3.3 Studsvik TCR and Conversion Reforming Process Technical Data

3.3.1 Overview of Conversion Reforming and Steam Reforming Processes

"Conversion reforming" is essentially steam reforming, which is commonly used in the US commercial nuclear industry for volume reduction of resin. Steam reforming is a thermal treatment technology classified as "pyrolysis," which differs significantly from an open-flame incineration/combustion process. Steam reforming uses a dry (high quality) steam heat for destruction of wastes. The process relies on super-heated steam to reform or reduce waste to small gas-size particles which can then be burned in a special reactor devoid of oxygen. Thus, it is a two-stage process in which hydrocarbons are vaporized from the waste in one chamber and injected into a secondary reaction chamber with superheated steam. Within the reaction chamber, organics are converted to CO_2, CO and H_2. The remaining waste product consists primarily of metal oxides, salts, and other impurities removed from the waste generator's in-plant coolant and liquid waste systems. The resultant steam reformed waste residue appears as a dry granular media which can be disposed in liners or high integrity containers.

> Note: Since steam reforming does not employ combustion in an oxygen atmosphere to reduce waste, the US Environmental Protection Agency does not classify it as an incineration technology. Accordingly, this same determination applies to conversion reforming.

Steam reforming is ideally suited for processing mixed wastes (not currently accepted by Studsvik) and wastes exhibiting high activity levels, such as resin and nonmetal filter media. Steam reforming is capable of accepting wastes up to and, in special cases, exceeding 100 R/hr (1 Sv/hr). The potential remains for concentrating the waste so as to produce a waste form which exceeds the acceptance criteria of disposal facilities due to certain nuclide concentrations (i.e., could produce waste that is "greater than Class C" waste (US classification) or high activity intermediate level waste (international classification). Typically, this limitation is mitigated by blending high and low activity wastes prior to steam reforming to ensure a disposable end product. (GTCC waste considerations are addressed further in Section 3.6.3.)

At the present time, the only significant difference between conversion reforming and steam reforming is the equipment used for volume reduction, whereas the pyrolysis process is essentially the same. In the Studsvik plant, there are two pyrolysis units: one is for steam reforming; the other is smaller (0.1 times as large) and was originally designed as a second stage to the full size steam reforming system. This smaller unit is referred to as the "tank conversion reformer" and is currently being used for plastics and some low activity filters.

3.3.2 Existing TCR Functional Description

As discussed above, the tank conversion reformer is basically a smaller version of the fluidized bed pyractor used in the Studsvik THOR (THermalized Oxidizing Reduction) process for resin. The TCR is fluidized using nitrogen, steam, and autothermal gas. The normal operating temperature for the processing of discrete organics is between 400 and 650 degrees centigrade.

Selected materials and wastes are gravity fed through a double-valve isolation feeder into the top of the TCR, where it travels down into the fluidized bed region. After entering the high temperature fluidized bed, moisture is instantly vaporized and superheated. At the same time, the waste's organic bonds are broken, producing the following components: carbon char, metal oxides, inorganic debris, CO_2, steam, and synthesis gas (syngas, or SG).

Syngas is mainly comprised of CO and H_2. The syngas and solids (carbonated char, metal oxides, and inorganic debris) are carried over to the Conversion Reformer Filter (FCR). The high temperature ceramic filters in the FCR separate and collect the radioactive solids; they also allow the predominantly nonradioactive gases to pass through to the Submerged Bed Heater Mixer (SBH). Once in the SBH, the syngas is completely destroyed and transformed into a combination of CO_2 and steam using an open flame at temperatures above 1000 degrees C.

The carbon char, metal oxides, and other inorganic debris carried over to the FCR are filtered out to >99% efficiency and is transferred into the Reformed Residue Tank (TRR). Within the TRR, the residue is cooled and ultimately transferred to the final disposal container, which is normally an 8-120 high integrity container (HIC). The end product is referred to as "reformed residue" and is the same end product as that is currently produced by the THOR pyractor from steam reforming of resin.

3.4 Volume Reduction Efficiencies for Filter Conversion Reforming

3.4.1 Factors Affecting Net Disposal VR

As with incineration, conversion reforming reduces the weight (and mass) of the input waste substantially, which contributes to volume reduction. The volume reduction efficiency of the as-generated waste is primarily dependent upon the inorganic content of the waste: the higher the inorganic fraction, the greater the final disposed waste volume, and the lower the net VR efficiency. Certain material additions increase the inorganic content, such as vermiculite and clay absorbents, which are commonly used to absorb excess moisture in spent filter cartridges stored in waste collection containers. Note that alternative absorbent materials are available which can be processed through the conversion reformer.

For comparison purposes, consider steam reforming of resin, where the VR efficiency is directly proportional to the crud loading and the percentage of inorganic media. For example, most spent resin contains from 3% to 20% metal oxides, salts, and other impurities which originate in the nuclear plant liquid process stream. During the steam reforming process, essentially 100% of the organic media (resin) is converted to gas, leaving only the metal oxides, salts, sludges, additives, and other impurities. Thus, a crud loading of 3% would typically translate to a VR of 33:1, and a crud loading of 20% would translate to a VR of 5:1. Experiential data from US nuclear plants identified during numerous plant-specific evaluations from 2000-2002 indicates a typical resin VR of about 7:1 from steam reforming.

Unlike resin, most filter cartridges are constructed using a combination of organic and inorganic materials. For example, nonmetal filters commonly employ some type of plastic as the construction media, which is an organic material. Plastic is essentially solidified oil (a solidified organic), so it results in a 100% VR efficiency. (Polyvinylchloride (PVC) is an exception which cannot be loaded in the TCR.) On the other hand, some filters contain fiberglass, which is not normally reduced by steam reforming.

Construction materials which do not perform well in the pyrolysis process will increase the volume of the final end product, thereby reducing the net VR efficiency. Thus, one challenge in determining the net disposal VR efficiency for conversion reforming of filters is to determine the additional contribution from filter construction materials to the reformed end product.

The reduction of void space is another critical factor when calculating net VR efficiency. Filter waste contains substantially more void space than resin within the filter media, within the center of the filter cartridge, and within the waste collection container. Conversion reforming of the mechanically rigid, high void space, fixed geometry filter cartridge into a reformed residue—along with the reduction in waste container void spaces—reduces the disposed waste volume and improves net VR efficiency.

We can determine the Net Disposal VR using the following formula:

Net Disposal VR = TCR Waste VR x Void Space Reduction

where: VR = volume reduction
TCR Waste VR = volume reduction due solely to the tank conversion reformer
Void Space Reduction = void space in a collection container of spent filters

3.4.2 Determination of TCR Waste VR

Fiberglass filters and duplicate filter types were removed from the evaluation and were not loaded in the TCR. Careful measurement of the remaining filters resulted in an input volume of 5.83 ft^3 (0.17 M^3). Measurement of the residue in the waste disposal HIC resulted in 0.40 ft^3 (0.01 M^3). Additional data on filters, sample analyses, laboratory results, and Studsvik conversion reforming historical experience are included in Appendix C, along with some comparative TCR volume reduction results which validate the following calculated VR:

TCR Waste VR = 5.83 / 0.40 = **14.56:1** (= 93%)

It must be recognized that this result is based on a mixture of clean filters with a wide variety of construction materials. One might reasonably ask whether this VR ratio would apply to nuclear plant spent filter waste which contains sludge, salts, metal oxides, etc. Industry experience suggests that the answer would be yes based on the following:

- Steam reforming of US commercial nuclear plant spent resin results in a typical VR of 7:1 (based on data identified during numerous plant-specific evaluations from 2000-2002), or one-half the above calculated VR. It is assumed that sludge/salt loading would be roughly the same for filters.

- The internal void space for a filter—which includes the void space in and around any wound or pleated media, along with the void space in the center of the cartridge—is typically at least three times that of the useable filter media. This is evidenced by industry data for filter void space reduction achieved by filter shredding and filter shearing VR ratios ranging as high as 4:1.
- Studsvik has data for conversion reforming of more than 535 ft^3 (15 M^3) of contaminated filter waste which reflects an average VR of 24.7:1.

In the absence of more extensive data using high activity filter waste and filters with heavy sludge loading, it is reasonable to assume that the TCR Waste VR will fall somewhere between 5:1 (based low-end steam reforming VR) and 25:1 (based on the Studsvik experiential database for filter cartridges). The results of this study fall half way between these two values.

3.4.3 Determination of Void Space Reduction

Referring to EPRI report TR-1007863, *Waste Containers for Extended Storage, Rev. 1*, August 2003, there are two commercially available 8-120 liners and two commercially available 8-120 HICs. These are the most commonly—but not exclusively—used containers for the collection and transport of high activity filter cartridges. These four containers have an average external disposal volume of 124.03 ft^3 (3.51 M^3) and an average internal volume of 112.08 ft^3 (3.17 M^3). Industry experience indicates that the irregular shapes and sizes of filter cartridges results in only 20 to 32 ft^3 (0.57 to 0.91 M^3) of filter waste per 8-120 container. For the purpose of this analysis, it is assumed that 30 ft^3 (0.85 M^3) of filter cartridges are typically placed in an 8-120 container, with the following results:

Void Space Reduction = 112.08 / 30 = **3.74:1** (= 73%)

3.4.4 Determination of Net Disposal VR

The above results are inserted into the equation for Net Disposal VR:

Net Disposal VR = TCR Waste VR x Void Space Reduction
= 14.56 x 3.74 **= 54.45:1** (= 98%)

Note: A VR calculated based on the internal volume will produce the same net VR if the calculation is based on external (disposal) volume. Accordingly, all container cost savings analyses will use the same net VR.

3.5 Projected Volume Reduction and Economic Benefits

3.5.1 Economic Benefit Analysis

The preceding VR results represent a very substantial performance improvement over existing practices of either direct disposal, filter shredding, or filter shearing. As discussed in the determination of TCR Waste VR, actual plant results may vary significantly from the VR achieved in this study, ranging potentially from 19:1 to 92:1. Yet even if the final Net Disposal VR was only 10:1, the benefits to the nuclear industry are substantial. For the purposes of this subsection, the VR of 54:1 determined above will be used in all calculations.

Cradle-to-grave economics vary according to the previously calculated VR efficiency and the contributing factors. Economics also vary according to such factors as applied onsite labor, container costs, transportation charges, processing fees, disposal fees and surcharges, etc. Some of these factors can be excluded, as they generally apply regardless of whether or not steam reforming is employed. For example, on a national average, transportation charges to the off site processor will be offset in a roughly equivalent amount by reduced transportation charges to the disposal site, with some plants paying more and others paying less. Similarly, the number of shipments from the generator's site will remain the same, which suggests that applied labor will also remain the same for the generator.

From a national, industry-wide perspective, the competing factors which are most critical to the economic equation are:

- Container costs
- Processing fees
- Disposal gate fees
- Activity surcharges

Filter Generation Volume and Frequency

The life of a new nuclear reactor is 60 years. A full high activity filter container is typically generated approximately once every two fuel cycles, or every three years for plants on an 18-month fuel cycle. Over the life of a new reactor, this translates to the generation of 20 high activity filter containers.

Container Cost Savings

Container cost savings arise from the ability to reuse collection containers. From the most simplistic perspective, new 8-120 liners and HICs have an average cost of around $7000. In contrast, the dewatering laterals of containers can be refurbished, allowing them to be recycled. The cost for this procedure currently ranges from around $2000 to $5000, depending primarily on the container construction material, laterals, and ownership (vendor lease or utility owned). For the purposes of this study, the mid-range value of $3500 will be used. The net cost savings per shipment is: $7000 - $3500 = $3500.

Using a VR of 54:1, only one filter container will be disposed over the life of the plant, and the remaining 19 containers will be recycled:

Container Cost Savings = $3500 * 19 = $66,500 over 60 years

Conversion Reforming Cost Savings

Disposal and processing costs tend to run fairly close together on a per cubic foot basis. Both increase at roughly the same rate according to similar dose rate multipliers. The most significant difference is that waste processing is normally charged based on the net waste volume, whereas disposal is charged based on the external container volume.

Recall that the average external volume of an 8-120 container is 124 ft^3 (3.5 M^3), and the average net waste volume is 30 ft^3 (0.8 M^3). Assume that high activity filter waste is both processed and disposed at an average cost of \$500/ft^3. The comparative disposal and processing costs are:

Disposal cost = 20 containers * 124 ft^3 * \$500/ft^3 = \$1,240,000

Processing cost = 20 containers * 30 ft^3 * \$500/ft^3 = \$300,000

Conversion Reforming Cost Savings = \$940,000 over 60 years

Activity Surcharge Savings

Some disposal facilities impose a surcharge based on the waste activity, which is typically a certain amount per curie. For example, disposal at Barnwell in 2003 typically is met with a curie surcharge of \$380/curie, and roughly half the US commercial nuclear reactors pay this surcharge. Across the industry, high activity filter containers average between 50 and 150 curies, with PWRs generally having the highest activity containers. Using 100 curies as the average, disposal of a filter container would incur a curie surcharge of \$38,000 per container, or \$760,000 over the life of the plant.

Some plants will choose to ship filter containers for conversion reforming and commingle the reformed filter residue with reformed resin residue, which is the same disposal waste form. If this processing and disposal occur in the same year that the waste is generated, then the generator will incur all of the curie surcharges (i.e., no curie decay cost savings would be realized).

On the other hand, if the generator holds all filter waste (or uses a process and return approach for a partially filled reformed residue container), then most of the curie surcharges will dissipate while the container is in interim storage. The container need not be shipped while waiting to accumulate enough reformed filter residue to justify a disposal shipment. Given the VR of 54:1, the entire life cycle of the plant will pass before the waste is shipped, and the great majority of the activity and associated curie surcharges will decay away. For simplicity, assume that 75% of the total 60-year accumulated filter activity has decayed away. This translates to a cost savings of:

Activity Surcharge Savings = \$760,000 * .75 = \$570,000 over 60 years

Total Projected Cost Savings

1. Plant which accumulates filters for the life of the plant:

   Container Cost Savings..............................$ 66,500 over 60 years
   Conversion Reforming Cost Savings..........$ 940,000 over 60 years
   Activity Surcharge Savings........................$ 570,000 over 60 years
   Total Savings ....$ 1,576,500 over 60 years
   ($ 26,275 per reactor per year)

2. Plant which disposes of filters as they are generated (i.e., no activity surcharge savings):

   Container Cost Savings..............................$ 66,500 over 60 years
   Conversion Reforming Cost Savings..........$ 940,000 over 60 years
   Activity Surcharge Savings........................$ 0 over 60 years
   Total Savings ....$ 1,006,500 over 60 years
   ($ 16,775 per reactor per year)

Assuming an average remaining life of 25 years for the 103 operating reactors, the above calculations result in an industry-wide benefit of:

Scenario 1 (includes activity surcharge savings) = $67.7 million
Scenario 2 (no activity surcharge savings) = $43.2 million

Similarly, for a fleet of 20 new advanced light water reactors (ALWR), the above calculations result in a combined benefit of:

Scenario 1 (includes activity surcharge savings) = $31.5 million
Scenario 2 (no activity surcharge savings) = $20.1 million

3.5.2 Disposal Volume Reduction Benefit

Volume reduction benefits are important to the plant and the industry as part of our efforts to minimize environmental impacts and extend the life of disposal facilities. As previously determined, the volume reduction efficiency used for conversion reforming of filters is 54:1. Using an average external container disposal volume of 124 ft^3 (3.5 M^3) and twenty filter containers generated over a 60-year life of the plant, the following disposal volume reduction benefits apply:

ALWR (over the 60-year average life)
= (direct disposal volume) - (reformed residue disposal volume)
= (124 * 20) – (124 * 20 / 54) = 2434 ft^3 = 70 M^3 per reactor
= 20,284 ft^3 = 574 M^3 per block of 20 reactors

Existing plants (over the 25-year average life remaining)

= (124 * 20 * 25/60) – (124 * 20 * (25/60) / 54) = 1014 ft^3 = 29 M^3 <u>per reactor</u>

= 104,462 ft^3 = 2958 M^3 <u>for existing 103 existing reactors</u>

The above data suggests another benefit. Assume that in 2008 the Barnwell LLW Disposal Facility closes to out-of-compact waste, as is currently required by South Carolina law. The majority of utilities will be forced to store high activity filter waste. If the filter waste is shipped for conversion reforming, no ALWR and no existing plant will end up disposing of more than one filter container, even if required to store for the life of the plant.

3.6 Limitations of Conversion Reforming

3.6.1 Existing TCR Equipment Limitations

The existing TCR is intended for manual loading of low activity filters. Studsvik has completed the design engineering for adapting the loading port of the TCR to accept filters up to ten inches (25 cm) in diameter. Design engineering has also been developed for the main pyractor (the large one used for resin steam reforming) to accept large, bulk quantities of high activity filters with diameters up to 18 inches (45 cm). As is to be expected, implementation of this design change is a business decision based in part on the projected return on investment. If only a few plants switch to nonmetal filters with the intent of processing the waste by conversion reforming, then the economics will not favor implementation of the design change. Thus it becomes important for the entire industry to evaluate the potential for switching to nonmetal filters and explore the plant-specific economics of filter conversion reforming. EPRI's Waste Logic Solid Waste Manager is capable of handling such analyses.

3.6.2 Materials Limitations

Studsvik is currently using its conversion reforming process for a variety of nonmetal filters, as well as testing the process on other materials. Materials which have been successfully processed through the TCR have predominantly been comprised of synthetic materials, cellulous, polyethylene, polypropylene, polyurethane, polystyrene, and other plastics. Various rubbers, paper, cardboard, and wood have also been tested successfully in the TCR. Excess, used high integrity containers made of polyethylene and polypropylene are routinely cut into small pieces and processed through the TCR.

The following filter media is not suitable for conversion reforming:

- Metal is excluded from the TCR, because it cannot be destroyed thermally and presents an unnecessary challenge to the residue transfer system or otherwise interferes with proper bed operation. Incidental quantities of metal are acceptable. If in doubt, a sample should be sent to Studsvik for laboratory analysis and certification.
- Materials containing halides (chlorine and fluorine); therefore, polyvinylchloride (PVC) materials are not suitable.

- Most fibrous materials, such as fiberglass (other than incidental fiberglass). Many filters used in the nuclear industry contain small, incidental concentrations of fiberglass, which are acceptable for steam reforming. However, filters which consist primarily of fiberglass media are excluded. If in doubt, a sample should be sent to Studsvik for laboratory analysis and certification.

3.6.3 GTCC Waste

Generation and Storage

The potential exists for concentrating high activity waste to the point where it becomes "greater than Class C" (GTCC) waste. At the present time, there is no disposal option in the US for disposal of GTCC waste generated at a commercial nuclear facility. For this reason, every effort has been made to avoid the generation of GTCC waste with little regard for the cost impact. From a processing perspective, it is usually necessary to blend the waste to be reformed with other wastes to reduce the waste classification and avoid generating GTCC waste.

Recent regulatory changes have established clear guidance for interim storage of GTCC waste for both operating plants and decommissioning plants. Thus, the decision on avoidance of GTCC waste generation shifts to being a matter of economics and net waste disposal volume. In the case of filter waste processed by conversion reforming, the volume reduction is so significant that it easily outpaces any current efforts to minimize volumes. Even if 100% of all high activity waste was concentrated as GTCC waste through conversion reforming (i.e., no blending is applied), the resulting reformed residue would produce an extremely small quantity of stored GTCC waste.

Economic Considerations

As for the economics of GTCC waste disposal, that remains an unknown. Current laws governing GTCC waste do not require that the DOE develop cost profiles for dispositioning GTCC waste, and the economics of GTCC waste disposal will likely remain elusive for the foreseeable future.

However, it is possible to project the operational economic benefits to the plant. At the present time, many plants—especially PWRs—replace filters based on a specific dose rate. The replacement dose rate is determined based on the probability of generating a GTCC filter. If storage of GTCC waste was an acceptable option to the generator—recognizing that it would be a very small amount of GTCC waste over the life of the plant—then filters would be replaced based on differential pressure instead of dose rate. This would extend the life of the filter by as much as 50% to 100%, resulting in a net cost savings through source reduction and avoided filter replacement costs.

ALARA Considerations

Including the generation of GTCC waste within the operational plan for filter management would result in the generation of filters which range to hundreds of R/hr and possibly exceed 1000 R/hr (10 Sv/hr). This is within the capabilities of nuclear plants to manage safely, and it is within the prior experience base for some plants. It is true that such high dose rates are greater than are currently being managed by most plants; however there are ALARA benefits which arise from reducing the number of filter replacements. Each replacement would likely result in a minor, if any, increase in personnel exposure, but fewer replacements would result in a net exposure reduction. This benefit has been demonstrated by many nuclear plants (otherwise most plants would be changing their filters at dose rates much lower than current procedural norms).

GTCC Waste Reduction Through Blending

As a final note, reformed filter residue is essentially identical to reformed resin residue. Both can be mixed in the same waste container to create an homogeneous waste form. In some cases, this will work to benefit the generator by using low activity resin and filters to offset the potential for GTCC waste in reformed filter residue. The downside of this approach is that low activity wastes can usually be disposed at a licensed Class A LLW disposal facility or at a regulated diminimus landfill at much lower costs.

3.7 In-Plant Activities to Optimize the Use of Filter Conversion Reforming

Based on the preceding discussions, there are actions which generators can implement to optimize the use of filter conversion reforming:

1. Evaluate each filter application and identify opportunities and types of nonmetal filters which can be used as replacements. Many of the existing filter applications use metal filter casings to provide the required structural strength and support. Disposable media filters exist for most and perhaps all of these applications. (See Attachment A for further information on disposable media filters.)

2. Metal is excluded from the pyractor, so conversion reforming requires that plants switch to nonmetal filters. Fiberglass filters also are excluded from conversion reforming. (Incidental quantities of fiberglass and metals can be accepted after analysis and certification.)

3. Most plastic filters offer the highest volume reduction efficiencies, followed closely by synthetic filters. However, materials containing halides (chlorine and fluorine) are not suitable for conversion reforming; therefore, polyvinylchloride (PVC) materials are excluded. A generator which desires to use conversion reforming will need to select filters which do not contain PVC and which contain very low or no residual chlorine or fluorine.

4. VR is affected by vermiculite and other absorbents which do not break down at conversion reforming temperatures (650 degrees C). Once a generator commits to conversion reforming, it is best to dewater filter waste without adding absorbents to the waste collection container. (Collecting filters within plastic bags is okay, whereas plastic bags partially filled with absorbent material is <u>not</u> okay.)

   It should be noted that alternative <u>organic</u> absorbent materials are available which can be processed through the conversion reformer. Among these are PVA absorbent pads. For example, a PVA mop placed in a filter bag is capable of absorbing water equivalent to seven times the mop weight. If in doubt about a specific absorbent material, submit a sample to Studsvik for certification for conversion reforming.

5. If filter waste is to be shipped for conversion reforming, it should not be sheared nor shredded for loading into the collection container.

6. Re-examine in-plant prohibitions against generating GTCC waste, and balance this against the potential long range storage volumes of Class BC wastes. Determine whether the optimum approach is to pursue blending of high activity reformed residues with low activity residues to minimize GTCC waste, although this may increase the dispositioning cost of low activity wastes.

3.8 Conclusions and Recommendations

3.8.1 Conclusions

1. Conversion reforming is a viable volume reduction technology applicable to nuclear plant spent filters.

2. A wide range of nonmetal filters are available to replace existing metal-reinforced filters. Most of these can be pyrolyzed in a conversion reformer.

3. Conversion reforming offers an exceptionally high volume reduction efficiency for filter wastes. In this study, the net disposal VR was 54:1. Even if it was only 10:1, conversion reforming would produce very substantial benefits to the nuclear industry.

4. If the nuclear industry broadly embraced nonmetal filters and conversion reforming technology, industry-wide cost savings over the next 25 years would reach into the tens of millions of dollars.

5. The exceptionally high VR efficiency for conversion reforming translates to a very substantial reduction in disposed waste volumes. It also translates to a substantial reduction in stored LLW volumes for plants which do not have access to a disposal facility.

6. The exceptionally high VR efficiency opens the potential for creating GTCC waste. However, this may be mitigated through the blending of wastes with low activity filters and spent resin.

3.8.2 Recommendations

1. Encourage industry use of nonmetal filters through focused, plant-specific studies and field trials at selected utilities. This should be accomplished for both PWRs and BWRs.

2. Perform a full-scale testing at Studsvik of contaminated process filters generated at an operating nuclear plant. The objective of the study is to verify VR data captured for this report, capture cradle-to-grave economic data, calculate cost savings and volume reduction benefits, and capture any lessons learned.

3. Develop industry guidance on mixing reformed resin residue and reformed filter residue for disposal characterization and concentration averaging. This should be submitted through NEI for NRC endorsement.

4. Demonstrate that this is a technology which the nuclear industry desires and will support. This is essential to encouraging Studsvik to expand their existing capabilities to handle bulk quantities and higher activity filters through automated processes.

4 ADVANCED LLW MANAGEMENT STRATEGIES – SEGREGATION/REDUCTION OF CLASS BC WASTE

4.1 Overview

As discussed earlier in this report, South Carolina law currently requires the Barnwell LLW Disposal Facility to stop accepting waste from generators located outside the Atlantic Compact, with an effective date of July 1, 2008. For the majority of nuclear plants, the impact will be the forced interim storage of Class B and C wastes. Thus a time table has been established during which nuclear plants must examine their existing Class BC waste generating practices and explore opportunities to reduce generation, disposal, and interim storage volumes.

Long-range, advanced strategies must be developed which include a combination of operating practices, segregation by waste Class, and advanced volume reduction technologies. The previous chapter examines the potential application of nonmetal filters and conversion reforming technologies as one advanced strategy for minimizing disposal and storage volumes for filter wastes. This chapter moves beyond a specific technology and examines a wide range of existing, commonly used techniques, technologies, and system modifications which can further reduce wet solid waste volumes. In addition, this chapter addresses the use of EPRI's Waste Logic Solid Waste Manager software to evaluate the potential waste reduction practices across a nuclear power plant fleet. Specifically, it summarizes the results of EPRI's wet solid waste review for the six STARS nuclear stations, all of which are pressurized water reactors. This chapter documents $1.4 million in annual cost savings <u>already being realized</u> by independent station initiatives for wet solid waste reduction. It also projects cost savings of an additional $1.8 million by replicating these existing initiatives across the entire STARS alliance, with the savings arising primarily from:

- Segregation and alternative packaging of spent resin.
- Reduced spent resin generation.
- Segregation and alternative packaging of spent filters.

4.2 Previous STARS Wet Solid Waste Minimization Experience

The Strategic Teaming and Resource Sharing (STARS) alliance is a group of six PWRs: Callaway, Comanche Peak, Diablo Canyon, Palo Verde, South Texas Project, and Wolf Creek. Since the early 1990's, all six STARS stations have shipped Class BC waste to Barnwell, SC. Diablo Canyon has the longest shipping distance to Barnwell in the US, and the associated high shipping costs have imposed a greater incentive for Diablo Canyon to reduce Class BC wet waste generation than for other power plants. Accordingly, Diablo Canyon has examined and implemented more Class BC waste minimization practices than most other nuclear plants. All STARS plants have already implemented various wet solid waste minimization strategies with documented successes. The Diablo Canyon experience is the most extensive of the STARS plants, so it is described in detail in the following paragraphs.

Wet waste reduction efforts began at Diablo Canyon with the liquid radwaste treatment system:

- The application of a cesium-selective resin bed extended the life of cation resin for the removal of other nuclides, thereby reducing Class BC resin generation.
- The use of segregated cation and anion beds versus mixed beds enabled the full capacity of each resin bed to be consumed, thereby extending bed life and reducing waste generation.

The high costs associated with wet solid waste shipping and disposal drove Diablo Canyon to apply these same wet waste reduction practices from the liquid radwaste system to other radioactive liquid treatment systems, including the Spent Fuel Pool (SFP) cleanup system, chemical and volume control system (CVCS), and the boron recycle system.

- Where single vessel mixed beds were provided for SFP and CVCS clean up, higher cation to anion resin loads were used. This extended the life of the bed, which previously had to be replaced when the cation resin reached depletion prior to anion depletion. The challenge was to find the right resin mix so that both the cation and anion reached depletion at approximately the same time.

  (Note that mixed resin beds are typically supplied at a 1:2 cation:anion ratio. In many cases, a 1:1 or even a 2:1 cation:anion ratio is more successful and significantly increases the life of the resin bed.)
- Diablo Canyon also found that alternate cation resin had a longer life in the SFP, CVCS and boron recycle systems (Reference 1).
- Segregation of cation from anion resin within the boron recycle system also allowed the resin to be segregated into separate waste collection containers according to waste Class. This resulted in additional resin transfers and separate packaging shields. However, it also resulted in a reduction in the disposal cost of anion resin, since spent anion resin is typically low in dose rate (minimizing dose rate surcharges) and low in activity (minimizing curie surcharges). A change in the Final Safety Analysis Report (FSAR) was issued for the boron recycle system to allow an anion bed versus a mixed bed to be loaded downstream of a cation bed.
- Short loading certain resin beds, such as CVCS shutdown crud burst beds, resulted in lower resin production, reduced disposal volumes, and corresponding cost savings.

Packaging and waste minimization strategies for spent filter waste also varied across the STARS fleet. Diablo Canyon and Palo Verde obtained shielded filter shears to conduct on-site volume reduction of filters. (Note that a filter shear is a cutting technology that differs significantly from a filter shredding technology.) Using the shear, both stations were able to reduce their filter liner shipments by a factor of four (a 4:1 VR). In this case, the shear paid for itself in its first year of operation. Callaway and Wolf Creek purchased a filter shear to be shared by both stations, although Callaway is currently the exclusive user with a VR of at least 3:1. Comanche Peak also placed a filter shear in service in 2002. The initial learning curve has demonstrated a 2:1 VR; 2003 expectations are on track for at least a 3:1 VR.

Over the past decade, all of the STARS stations had explored or attempted to implement the above wet solid waste minimization techniques for spent resin and filters with varying degrees of success. The most significant inhibitors to successful implementation were:

- no external driver, such as losing access to a Class BC disposal facility;
- inability to quantify accurately the potential benefits and return on investment for such changes;
- limited funding for implementing changes or for making plant modifications;
- limited personnel resources (engineering, safety analyses, certification programs, etc.); *resulting in a*
- low plant operational priority and limited management support for system or operational changes.

The pending loss of access to the Barnwell LLW Disposal Facility became an external driver and a significant new motivator for pursuing wet solid waste minimization programs. However, without the ability to quantify accurately the potential benefits, it was clear that the funding and personnel resources would not be made available to implement more aggressive minimization efforts. STARS decided that an outside assessment for wet solid waste reduction might meet this need for identifying potential changes for each STARS plant and for quantifying the potential benefits arising from implementing such changes. EPRI had conducted a successful assessment for STARS on a joint DAW cost and volume minimization project in 2001 using the Waste Logic Solid Waste Manager, so EPRI was asked to employ Waste Logic to the task of quantifying wet solid waste project benefits.

4.3 Objectives

There were two objectives for this study:

- Identify options for minimizing wet solid waste volumes, with the primary focus on reducing Class BC waste volumes.
- Use Waste Logic software to quantify the potential cost and volume reduction benefits of wet solid waste minimization strategies.

Many plants commingle Class A and Class BC wet solid wastes. Reductions in Class A wet solid wastes can therefore achieve the first objective of reducing waste which must be disposed in a Class BC facility. Accordingly, Class A wet solid waste reductions were also evaluated as part of this study.

4.4 Approach

The following summarizes the general approach used for this study. This approach can be used by other nuclear plants pursuing similar objectives.

- Identify wet solid waste **sources** (each vessel, volume, change frequency, etc.) for each participating nuclear station.
- Capture all related cradle-to-grave **costs**.
- Determine the most probable true **waste Class at the source** (vessel).
- Identify methods, equipment, or potential plant modifications needed to **segregate by waste Class** the as-generated waste prior to commingling.
- Identify methods to **reduce generation** of wet solid wastes, with the primary focus on Class BC wastes.
- Identify alternative low cost, high efficiency **post-generation volume reduction** options.
- **Quantify** the potential **benefits** of the plant-specific alternative approaches using EPRI's Waste Logic Solid Waste Manager software.
- Use the results to **highlight excellent performance** already achieved.
- Make the detailed cost savings benefits available to each plant to use in the development of **business cases** to justify implementing the recommended changes.

4.5 Application of EPRI Waste Logic Software to Project Benefits/Impacts

Wet solid waste (resin, filter) data was collected from all six of the STARS nuclear stations using a spreadsheet survey format. The survey instrument also included a generic questionnaire to identify potential waste segregation and minimization techniques or approaches used by each facility. The intent of the survey and questionnaire was to capture as much applicable data as possible in advance of site visits and to standardize the types and scope of data collected. Examples of the type of data include:

- Plant system, vessel, and media type
- Media volume per vessel, number of vessels, and media replacement frequency
- Media replacement cost
- Waste containers and costs
- As-generated and as-shipped waste Class (Class A or BC)
- Waste processing (volume reduction) technology and typical VR efficiency
- Transportation, processing, and disposal costs

After receiving the results of the survey, four of the stations were visited to collect data, and two provided the data via a live internet feed and concurrent phone discussions. Any incomplete data or questionnaires were resolved during the site visits. This data was entered into EPRI's Waste

Logic Solid Waste Manager to obtain an annualized profile of the wet solid waste management program for each participating station. A separate cost and volume profile was developed for each station which identified and captured the cradle-to-grave costs for each applicable waste stream on an "annualized" basis.

Using annualized data (as opposed to annual waste generation data) was a critical consideration to the study. Annual waste generation data looks only at the waste transferred to collection containers and/or shipped off site in any given year. "Annualized" data is very different; it begins with the volume of each resin vessel and the replacement frequency; this data is averaged over a twelve-month period. For example, a 60 ft^3 resin bed that is replaced once every three years results in an annualized (average annual) volume of 20 ft^3, even though the actual disposal volume in two of the three years is zero ft^3.

Another critical component of the study was to identify for each waste type (resin, filter) and each vessel the true, stand-alone waste Class (Class A or BC). Many nuclear plants, especially single-unit plants and plants with only one spent resin tank, commingle Class A and BC wastes, which results in disposing of all the waste as Class BC.

Both the annualized data profiles and the results of the questionnaire included with the survey instrument were used to develop a wide range of plant-specific "What-If scenarios." These scenarios quantify the potential cost savings and disposal volume reduction benefits by implementing alternative approaches to wet solid waste management and from potential equipment or system modifications. Since many of the What-If scenarios were already being implemented successfully at other STARS plants, their cost savings history served as a sanity check on the potential cost savings which each STARS plant could obtain. When a practice had already been implemented by a plant, the associated dollar savings was reported and highlighted as a benefit <u>already being received</u>.

Once the annualized Waste Logic results were obtained, an additional analysis was performed to determine the cost savings benefits which would be realized during the year in which each spent resin bed was replaced. Annualizing (averaging) waste generation volumes over a single year are beneficial to capturing all waste sources and generation data, but they can minimize the "apparent" cost savings and suggest a long period of return on investment. On the other hand, if the savings are calculated for the year in which any given resin bed or filters are replaced, the actual cost savings benefits can be substantially higher and, therefore, <u>make a stronger business case with a shorter return on investment period.</u> It also assists the plant to prioritize and create a long-term schedule for implementing advanced strategies, system changes, plants modifications, etc. based on the shortest return on investment period.

It is important to note that the costs for implementing a particular strategy (e.g., engineering costs, labor costs, new equipment costs) were not estimated as part of the EPRI assessment; only the projected cost savings and disposal volume reductions associated with waste dispositioning were determined. The purpose of calculating the potential cost savings was to quantify the <u>possible</u> annual savings without determining the payback period for any specific strategy at any given plant. Once the potential cost savings for each practice are derived, plant management can determine which strategies to pursue and in what order. Most importantly, the cost savings figures were then available to prepare a business case for implementing advanced strategies which require a design change, an internal study or evaluation, or the procurement of a new component, tool, or other equipment.

For example, if a large, high activity resin bed is replaced and disposed once every five years at a cost of $120,000, then a $100,000 plant modification in the replacement year would realize a short return on investment period. On the other hand, if the cost savings is annualized, then the average savings would only be $24,000/year and would suggest a five-year return on investment. The first case would likely be approved, whereas the five-year return period would likely be disapproved. If the resin bed is scheduled for replacement in 2006, then the plant might schedule the modification to occur in early 2006 to minimize the return on investment period.

4.6 Limitations of the Study

The advanced waste strategies study was limited to wet solid wastes: resins and filters. The study also was limited to an evaluation of six nuclear stations (11 reactors), all of which were large (> 1000 MWe) pressurized water reactors. Accordingly, the basic approach of the study is applicable to all nuclear plants, although the specific analyses and results are not universally applicable. For example, further studies are necessary to identify significant recommendations which are broadly applicable to BWRs.

4.7 Strategies Evaluated

None of the strategies and recommended program enhancements addressed in this section are new concepts. They are already being implemented successfully by many nuclear plants, including one or more STARS stations. Note that the implementation of some strategies will offset the benefits available for other strategies, which highlights the importance of developing a comprehensive, long-range strategy with optimum implementation timing and priorities. Since plants will differ in terms of which individual components can be applied to their long-range strategy, all of the applicable analyses evaluated in the STARS study are discussed below.

4.7.1 Strategy Group A – Segregation and Packaging of Spent Resin

1. Three of the STARS stations had already implemented aggressive programs for segregating all of their spent Class A resin from Class BC resin. Typically, this segregation effort was made easier through a supportive plant design, such as multiple spent resin tanks, extensive spent resin tank valving options, and/or a waste transfer truck bay sufficiently large to hold multiple spent resin containers. By eliminating the commingling of spent resin, the volume of Class BC resin was reduced, and all of the Class A resin could be managed at a lower packaging, transportation, processing, and disposal cost. The cost savings benefit <u>already being achieved</u> by these plants was easy to capture and verify, and they ranged from $149,000 to $310,000 annually.

2. Segregation of spent resin by waste Class is not always easy to implement. One advanced strategy which allows segregation of spent resin by waste Class is the installation of a spent resin bypass line, and it is especially useful for plants with a single spent resin tank. This would allow Class A resin to bypass the spent resin tank and transfer directly into a Class A

collection container in the truck bay used for resin dewatering. The downside is that this would require an expensive plant modification, and a business case is needed to justify the expenditures. This also means that the potential cost savings benefits must be quantified, which is where EPRI's Waste Logic Solid Waste Manager comes into play. The following three examples illustrate how this was applied during the study for one specific station; the fourth example applies to a different plant with a similar challenge.

a. Boron thermal recycle system (BTRS) anion resin is typically Class A resin, but some plants ship it commingled with Class BC resin. At this example station, the annualized resin volume is 25 ft^3 and the vessel size is 74 ft^3 for each of five vessels; all of the resin is <u>generated</u> as Class A resin. If this resin were segregated from Class BC resin, the <u>annualized cost savings</u> would be $30,000. Although these resin beds are replaced infrequently (once every 15 years), in the year they are replaced the cost savings would be $88,800/vessel * 5 vessels = $444,000.

   As is commonly the case, this is not an easy strategy to implement. For this example plant, there is a single spent resin tank to collect all resin, and there is no bypass mechanism for the spent resin tank. Implementing this strategy would require that the tank be emptied/purged of all Class BC resin prior to transferring BTRS resin into the tank, thereby avoiding commingling the two waste classes. For some plants, this may be a procedural function, or it may involve a permanent spent resin bypass mechanism allowing the resin to go directly to a collection container located in the truck bay. Typically, it would be difficult to justify a plant modification to install a bypass line with annualized cost savings of only $30,000. However, when it is time to replace all five vessels, the single year cost savings of $444,000 will likely result in an immediate payback.

b. Chemical volume and control system (CVCS) delithiating cation resin is normally Class A resin, but some plants are forced to ship this resin commingled with Class BC resin. For the example plant, the <u>annualized</u> resin volume for this bed is only 23 ft^3 and the vessel size is 35 ft^3. If this resin were segregated from Class BC resin, the <u>annualized cost savings</u> would be $27,600. These resin beds are replaced each fuel cycle (every 18 months); in the year they are replaced, the cost savings would rise to $42,000.

   However, as with the previous example, segregation would require a separate waste stream characterization and probably a mechanism to bypass the spent resin tank. Yet in the example plant, there is no sampling mechanism for this resin upstream of the spent resin tank, and there is no resin-specific characterization on this bed. Also, there is no bypass mechanism for the spent resin tank which would allow Class A resin to transfer to a waiting collection container in the truck bay. It may be difficult to justify a sampling mechanism and a bypass line as a plant modification for delithiating cation resin alone. However, when combined with BTRS resin—both of which call for the same solution—the annualized cost savings rises to $57,000, and the cost savings in the year the BTRS resin is replaced rises to $486,000.

c. Recycle evaporator feed resin is also normally Class A resin, but for the example plant, it was again shipped commingled with Class BC resin. The annualized resin volume for this bed is only 4 ft^3 and the vessel size is 30 ft^3. If this resin were segregated from Class BC resin and shipped for steam reforming, the annualized cost savings would be just $4,800. These resin beds are replaced every 15 years; so in the year they are replaced the cost savings would rise to $42,000/vessel * 2 vessels = $82,000.

However, as in the preceding scenario, segregation of this resin also requires a bypass line for the spent resin tank. Once again, it may be difficult to justify a bypass line as a plant modification for this resin alone. However, when combined with BTRS resin and delithiating cation resin, the annualized cost savings rises to $62,000, and the cost savings in the year all of the resin is replaced rises to $558,000. This would make a strong business case for implementing this plant modification.

d. At a different STARS plant, both BTRS anion resin and recycle holdup tank resin are commingled with Class BC resin, although they are both Class A resin. An analysis was performed to determine the cost savings benefit of bypassing the spent resin tanks and transferring these resin beds directly into a Class A disposal container. The average annual cost savings benefit would be $27,000, rising to $56,000 in the year these resins are all replaced.

3. Another station is working toward segregating Class A resin from Class BC resin by using one of two existing spent resin storage tanks as, essentially, a "wide spot in the pipe." This is being accomplished in lieu of installing a bypass line. At this particular plant, some resin is clearly Class A, and some is clearly Class BC. Unfortunately, other spent resin is borderline at the upper limit of Class A. This forces the plant either to (1) capture all suspect resin entering either spent resin tank as Class BC waste, or (2) sample each resin bed as it arrives in the spent resin tanks before deciding which tank it should be mixed with. Theoretically this would require a Class A tank, a Class BC tank, and a third temporary holding tank, which simply does not exist in the original plant design.

   This particular plant has a waste processing truck bay which is sufficiently large to hold a spent resin waste collection container at all times. Accordingly, one of the existing spent resin tanks is used to collect Class BC spent resin, and Class A resin is collected in the container in the truck bay. The other spent resin tank was emptied and purged. Class A resin passes directly through this clean tank into the Class A collection container in the truck bay (hence the term "wide spot in the pipe"). Spent resin which is suspect as to its waste Class is moved into the clean tank and held for sampling. Once the waste Class is determined, it is either moved into the Class BC tank or into the Class A collection container, as appropriate.

   This approach provides a significant improvement in the segregation of Class A and Class BC resin. For this specific plant, 60 ft^3 of Class A resin is removed from the Class BC resin containers each year and produces a net recurring annual cost savings benefit of $33,000. If all BTRS beds were replaced in the same year, this strategy would result in an exceptional cost savings of $496,000. This is an advanced strategy which can be replicated at other nuclear stations who are struggling with segregation by waste Class.

4. The boron recycle system (BRS) feed resin beds at one dual-unit station are replaced every four years. The replacement schedule is staggered, so that one of the two beds is replaced every two years for each reactor unit. Each bed consists of 30 ft^3 of resin; this translates to an average generation rate of 30 ft^3/year (120 ft^3 over four years).

In this plant, these resin beds are mixed beds and are disposed as Class BC waste. Since there are two such mixed beds per reactor unit, it is possible to separate the anion and cation resin, which effectively separates the resin according to its eventual disposal waste Class. Specifically, if the mixed beds were changed to a cation bed followed by an anion bed, this would reduce 15 ft^3 of resin from Class BC to Class A each year. The resultant cost savings would be $11,000 per year ($22,000 in the year each cation resin bed is actually replaced). Of course, separating the anion and cation resin should also extend the life of the anion resin bed, which typically is not fully depleted in the standard mixed bed configuration. This extended life consideration was not evaluated. Implementation of this segregated bed arrangement will likely involve an FSAR change and a procedure change, but no plant modification is required. This same approach can be implemented for liquid processing systems at other nuclear plants which have dual mixed resin beds in series.

5. Media from the ALPS system at one plant is used to top off Class BC resin liners. Since ALPS media (resin/charcoal) is normally Class A waste, it would be far less expensive to segregate it from Class BC waste and dispose of it separately. This scenario would generate an annual cost savings benefit of $48,000.

   Note that capturing these cost savings requires that the ALPS media is collected in a 14-215 HIC (or similar size). If an 8-120 HIC is used, the cost savings benefit drops to only $20,000. The difference in cost savings can be attributed to a combination of decreased container costs, shipping costs, and the minimization of void space due to using half as many containers.

6. At one plant, the chemical and volume control system (CVCS) delithiated cation bed is managed as Class BC resin. As discussed above, this same resin at other STARS plants is Class A resin. For this particular plant, the higher waste classification is due to previous fuel failures which significantly increased cesium concentrations for several years. Continued monitoring and analysis will be required by the plant to determine when cesium levels return to normal. An analysis was performed to determine the potential benefits of segregating this resin from Class BC to Class A once the cesium challenge is resolved. This will produce an annual cost savings benefit of $17,000.

7. One STARS plant recently received approval to dispose of its diminimus activity secondary resin in a local industrial landfill licensed to receive small quantities of activity. For that specific utility, this strategy will produce an annual cost savings of $47,000. There are only a handful of plants located in states which license industrial landfills for diminimus activities. This approach could be replicated by those plants and produce a substantial cost savings with a rapid return on invested effort.

8. One plant uses a 14-215 FEDX model HIC to ship Class A resin to a waste processor. The design of the dewatering internals for that specific HIC employs many large filters that consume space which would otherwise hold spent resin. The 14-215 FEDX model HIC accepts a net waste volume of roughly 150 ft^3; in contrast, a 14-215 FR model HIC accepts 180 ft^3 of net waste. By switching from an FEDX to an FR model, the annual cost savings would be $6000. This is a fairly easy change to implement, and the strategy is easily transportable to other nuclear plants.

4.7.2 Strategy Group B – Reduce Spent Resin Generation

As discussed earlier, Diablo Canyon is one of the most successful nuclear plants in terms of reducing spent resin generation. Diablo Canyon's experience in this area suggested important opportunities where other STARS plants might realize significant cost savings, including:

- The use of high cation to anion ratio resin beds for the spent fuel pool (SFP) and reactor cleanup system (RCS) shutdown clean up beds.
- The use of a high cation to anion ratio lithiated mixed bed.
- The use of segregated resin beds (separate cation and anion beds) in the boron recycle and liquid radwaste systems.
- Bypassing steam generator blowdown (SGBD) beds and placing them in service only in the event of a large primary to secondary tube leak.

The above advanced strategies are also being applied at other STARS plants, although Diablo Canyon had the most extensive program at the time of the study. They serve as excellent benchmarks against which other plants in the nuclear industry can plan their own long range, advanced wet solid waste program strategy. The following examples from the STARS study provide an indication of the typical challenges faced by individual plants and the potential cost savings benefits of overcoming those challenges.

1. Two STARS plants—one dual-unit station and a single-unit station—are able to recycle their BTRS resin to eliminate the need for replacement (i.e., an average recycled bed life of at least 15 years). In contrast, some plants replace BTRS resin every fuel cycle. The Waste Logic software was used to evaluate the annual cost savings benefits for the two plants which have successfully implemented this strategy, demonstrating cost savings <u>already being realized</u> of $134,000 (single-unit plant) and $291,000 (dual-unit plant) each year. This suggests opportunities for similar cost savings at other nuclear plants by replicating this approach.

2. At one evaluated plant, each crud burst (shutdown) resin bed is 70 ft^3, and one such bed is replaced every fuel cycle (18 months). It may be possible to <u>short-load</u> the resin bed (use less than 70 ft^3) during shutdown, thereby reducing resin volume by at least 20 ft^3/fuel cycle for each of two reactors. The net Class BC waste reduction is 27 ft^3/year. This alternative approach translates to an annual cost savings of $35,000, including resin replacement costs. This rises to $51,000 in the year the bed is replaced. (A second plant showed savings in the replacement year of $78,000, suggesting a significant range of potential benefits for any given plant. (For any plant evaluating this strategy, it should be tested in small increments, such as 10 ft^3/cycle, to identify the optimum bed loading.)

3. For most STARS plants, spent fuel pool resin is the largest single contributor to Class BC resin. Extending the life of these beds may be possible either by changing the mix (ratio) of cation to anion resin or by not aligning the spent fuel pool bed 100% of the time (i.e., align the bed only based on chemical analysis for controlling specific ion concentrations or for dose rate control). Implementation of both of these strategies could more than double the life of SFP resin, so an analysis was performed to determine the potential benefit.

For one example dual-reactor plant which replaces SFP resin every 18 months, doubling the bed life would reduce the SFP resin volume by 48 ft^3/year. Since this is Class B resin, the cost savings benefit for this example plant was $55,000 annually, including the cost savings from resin procurement cost. More importantly, in the year the resin is actually replaced, the one-year cost savings rises to $83,000. This is a strategy which is fairly easy to replicate at other nuclear plants and can be accomplished without plant modifications.

4. Another STARS plant tested IRN-170 resin in its SFP beds. This particular dual-unit station has four SFP beds, two for each unit. Resin beds 1A and 2A both ran for eight years using IRN-170 resin. In contrast, beds 1B and 2B ran for three years or less using IRN-150. An analysis was performed to determine the cost savings benefit of switching to IRN-170 for resin beds 1B and 2B. The resulting annualized cost savings would be $98,000 per year, including avoided resin replacement costs. This cost savings benefit would rise to $295,000 in the year the resin beds are actually replaced. Again, this strategy is easily transportable to other nuclear stations and is already being evaluated by other STARS plants.

5. Two of the STARS dual-unit stations are at the initial stages of evaluating implementation of an ion-specific filter to reduce either cesium or cobalt concentrations upstream of the resin beds. The net effect is the extension of resin bed life in exchange for a small increase in filter waste generation. The plant which is furthest along in its evaluation estimates that this approach would most likely INCREASE filter waste by approximately 5 ft^3 annually and would DECREASE Class BC resin waste by approximately 40 ft^3 annually by extending resin life. The projected annually recurring cost savings benefit is projected to reach $57,000.

6. Some STARS plants are pursuing cost savings by increasing the cation:anion ratio and shortloading the CVCS lithiated mixed bed. It must be recognized that lithiated cation resin is very expensive, so increasing the cation concentration increases replacement cost. However, at least one plant reduced the bed size (short loaded the amount of anion resin added to the vessel) while maintaining the same cation volume and capacity. This reduced the total resin replaced each time by roughly 50%, thereby reducing resin replacement costs, generating less spent resin, and producing a significant cost savings. The annualized cost savings for one single-unit plant was projected at $34,000, including resin cost savings. The total cost savings in the year the bed is replaced rises to $51,000.

7. A similar analysis was performed to evaluate the potential benefits of adjusting the cation:anion ratio of the recycle evaporator feed demineralizer mixed beds to 2:1. The expectation is that this would extend the life of the beds significantly and would result in an annualized cost savings benefit of nearly $28,000.

   This scenario was extended to include shortloading of each bed by 30 ft^3, which resulted in an additional $27,000 in annualized savings. (Again, this should be accomplished in small increments of 10 ft^3 to evaluate performance over time.) The combined annualized cost savings for adjusting the cation:anion ratio and shortloading the recycle evaporator feed demineralizer beds was $55,000 annually. In the year the resin beds are replaced, the cost savings rises to $83,000.

8. At some plants, ALPS beds are automatically replaced once per 18-month fuel cycle. If they were run to full exhaustion, they would likely last at least 24 months. This extended bed life

would decrease annual Class BC waste generation by 43 ft^3 and result in an annualized cost savings of $42,000 per year, rising to $63,000 in the year of replacement. This is an easy concept to implement for any PWR or BWR which replaces ALPS media on an automatic schedule rather than at bed depletion.

9. At the time of the review, one plant was not generating steam generator blowdown (SGBD) resin, as the system was out of service. A modification is planned which will return the system to service, and SGBD resin is expected to be shipped again in 2004. An analysis was performed to determine the cost impact of collecting this diminimus activity resin in B-25 boxes and shipping it to a vendor green-is-clean bulk monitoring program. If this approach is successful, the annual cost increase for processing and disposal will only be $6600. However, the projected annual cost for resin procurement will be $24,000, bringing the cradle-to-grave cost to $31,600/year.

   It should be noted that two other STARS plants continuously bypass SGBD resin unless there is a known primary to secondary leak. A similar approach might be considered for other plants, thereby reducing the quantity of secondary resin generated. This bypass strategy would effectively save the plant $31,600/year.

Alternative Design Considerations

Palo Verde is a Combustion Engineering plant design, whereas the other five STARS plant are Westinghouse designs. Different plant designs affect the specific mix of strategies which can be employed, although some can be applied across a wide range of designs (such as extending SFP bed life, running ALPS beds to depletion, limiting the use of SGBD resin beds, application of ion-specific filters). In other cases, the generic concepts can be applied (such as short loading certain resin beds, adjusting cation:anion ratios). The next two strategies arise from the Palo Verde study. The first offers a new resin reduction strategy not previously discussed; the second demonstrates how generic concepts can be applied to alternative plant designs.

10. Palo Verde reuses its spent condensate demineralizer resin in its evaporator distillate ion exchange beds (two per reactor times three reactors, for a total of six beds). Condensate demineralizer resin beds have an average life of at least ten years at Palo Verde, and the partially spent condensate demineralizer resin can be recycled for use in the evaporator distillate ion exchangers. With 21 total condensate demineralizer beds among the three reactor units, the annualized (average) resin replacement volume is 630 ft^3. In contrast, the average annual replacement volume for the six evaporator distillate beds is only 150 ft^3/year, which means there is more than enough partially spent condensate demineralizer resin to meet the demands of the evaporator distillate beds.

    By reusing the partially spent resin, Palo Verde avoids the purchase of 150 ft^3 of new resin for the evaporator distillate beds each year, resulting in a purchase cost savings of $20,400 annually. This excellent approach also reduces the annualized volume of spent resin which must be disposed by 150 ft^3 by extending the useful life through recycle; the resultant cost savings is $58,000 annually. The combined annually recurring cost savings from avoided resin purchase and dispositioning is nearly $79,000, ***a benefit which is already being received.*** This approach is also transportable to other plants that operate boron recycle or waste evaporators.

11. The cation:anion ratio of the Palo Verde condensate demineralizer beds is currently 2:1 (i.e., heavy on cation resin). The plant has determined that the percentage of anion resin could be increased to 1:1 with no adverse impact on the life of the condensate demineralizer resin beds. However, since spent condensate demineralizer resin is used in the evaporator distillate resin beds, the additional anion concentration could extend the life of the resin beds by as much as 50% (1 year). Extending the life of the beds has the same effect of reducing the evaporator distillate resin disposal volume by 50%, or 75 ft^3/yr. The resultant cost savings would be $29,000 annually. Once again, this strategy is transportable to other plants running evaporators and, in some cases, could be applied directly for evaporator distillate resin beds even if condensate demineralizer resins are not recycled.

4.7.3 Strategy Group C – Segregation and Packaging of Spent Filters

The primary mechanisms for reducing filter waste generated at STARS plants are segregation by waste class, supercompaction of lower activity filters, and the use of filter shears.

1. Four of the six STARS stations use a filter shear to improve packaging efficiency in filter HICs. Experience at these plants demonstrate an average VR between 3:1 and 4:1. Recognizing that the number of reactors among these four stations varies from one unit to three units—and recognizing variations in spent filter waste generation volumes—the annual cost savings benefits from filter shear vary widely. Using the Waste Logic Solid Waste Manager software, annual cost savings ranged from $13,000 to $90,000/station. This strategy is clearly transportable to many other nuclear stations.

2. Many nuclear plants, including some STARS plants, combine their high activity Class A filter waste with Class BC filter waste. This most commonly occurs due to the slow generation rate of filter waste and the limited space for filter collection containers in waste processing areas. Analyses were performed to determine the potential cost savings benefits of segregating Class A filters from Class BC filters and then:

   - Shipping lower dose rate Class A filters (<5 R/hr) for supercompaction.
   - Shipping higher activity Class A filters directly for disposal using either an EL-210 or a 14-215 high integrity container, with filters volume reduced on-site through filter shearing.

   Annual cost savings for these scenarios ranged from $31,000 to $207,000, depending largely on whether the station had already implemented a filter shear program and the volume of filters generated annually. Only two of the six stations projected additional annual cost savings at less than $100,000.

   The ALARA impact of implementing the above strategies must also be considered. For example, shipping lower activity Class A filters in drums for supercompaction will likely result in increased personnel exposure due to handling and shipping drums in a Type A Cask. If the station dose goals will allow this exposure, this option should be considered. Direct shipment for disposal could avoid the additional personnel exposure associated with shipment for supercompaction. However, facilities to provide a second filter collection container in the waste packaging location (typically a truck bay would be needed, and it is not always available).

One strategy which was not evaluated for filter waste was the use of nonmetal filters and conversion reforming. This technology was not sufficiently mature at the time of the STARS study to capture the cradle-to-grave economics.

A summary of the STARS cost savings from all of the above strategies is provided in Table 1. The row listed as "Other Cost Savings Opportunities" refers to alternative waste processing and proprietary contractual opportunities which were captured during the study.

Table 4-1
Average Annually Recurring Cost Savings Opportunities from Alternative Strategies

	PLANT A	PLANT B	PLANT C	PLANT D	PLANT E	PLANT F	TOTALS
Number of Reactor Units	1	1	2	2	2	3	11
Annual Savings Already Achieved	$ 291,000	$ 69,000	$ 134,000	$ 149,000	$ 310,000	$ 478,000	$ 1,431,000
Additional Savings from Segregation and Packaging of Spent Resin	$ 62,000	$ 44,000	$ 81,000	$64,000	$ 0	$ 0	$ 251,000
Reduce Spent Resin Generation	$ 137,000	$ 139,000	$ 252,000	$ 239,000	$ 0	$ 86,000	$ 853,000
Segregation and Packaging of Spent Filters	$ 104,000	$ 31,000	$ 111,000	$ 207,000	$ 32,000	$ 0	$ 485,000
Other Cost Savings Opportunities	$ 38,000	$ 0	$ 0	$ 0	$ 0	$ 188,000	$ 226,000
Total Cost Savings Benefits	**$ 341,000**	**$ 214,000**	**$ 444,000**	**$ 510,000**	**$ 32,000**	**$ 274,000**	**$ 1,815,000**

4.8 Conclusions and Recommendations

4.8.1 Conclusions

1. Numerous opportunities exist for reducing plant operating costs through segregation and reduction of wet solid wastes. These include opportunities for significant reduction in Class BC wastes, thereby minimizing the impact on interim storage.

2. None of the strategies discussed in this chapter are new; each strategy is already being implemented at one or more STARS stations. As indicated in Table 1, the cost savings benefits already being realized from previous implementation is $1.4 million dollars annually. By full implementation across the STARS fleet, an additional $1.8 million in savings could be realized. If this cost savings potential were extrapolated across the entire commercial nuclear industry, annual cost savings could reach $15 and $20 million.

3. EPRI's Waste Logic Solid Waste Manager is a very effective tool for quantifying the available cost savings and volume reduction benefits from various wet solid waste minimization strategies. The preceding discussion of waste segregation and waste reduction strategies documents:

    - A successful, systematic approach to evaluating and developing a long range wet solid waste reduction strategy.
    - An extensive listing of strategies applicable to large Westinghouse designs and transportable to other plant designs.
    - Typical cost savings benefits which could be realized by implementing the various strategies.

4. Wet solid waste minimization efforts require support from many organizations within a nuclear utility, and the projected reduction in waste dispositioning costs is often the key factor in catalyzing support for implementing these strategies. The use of the EPRI Waste Logic Solid Waste Manager can derive these costs savings, which can then be used to develop a business case for initiating program changes, internal reviews, FSAR changes, and even plant modifications.

5. Averaging waste generation volumes over a single year often minimizes the apparent cost savings. If the savings are calculated for the year in which any given resin bed or filters are replaced, the actual cost savings benefits can be substantially greater and, therefore, *make a stronger business case with a shorter return on investment.*

4.8.2 Recommendations

The strategies discussed in this chapter are applicable to many other stations, including those of different plant designs. Additional studies of this type should be pursued for other nuclear utilities and alliances, with special attention placed on minimizing Class BC wastes and the resultant cost savings.

A
DISPOSABLE MEDIA FILTERS

A.1 Concept and Structural Considerations

Many of the existing filter applications in nuclear power plants rely on metal filter casings to provide the required filter structural strength and support. Any suitable replacement filter must be capable of providing the equivalent structural capabilities. This is accomplished through the use of “disposable media filters.”

Framatome ANP developed and patented the concept of “disposable media filters” or DMF. Current designs exist for the majority of nuclear plant filter applications. The DMF is a two-part system consisting of a disposable media cartridge and a stainless steel adapter. These are illustrated in figure A-1. The photo at the left shows the both the cartridge and the stainless steel adapter. The photo at the right is a top view of the adapter, which shows how the cartridge would fit between the outer and inner structural supports.

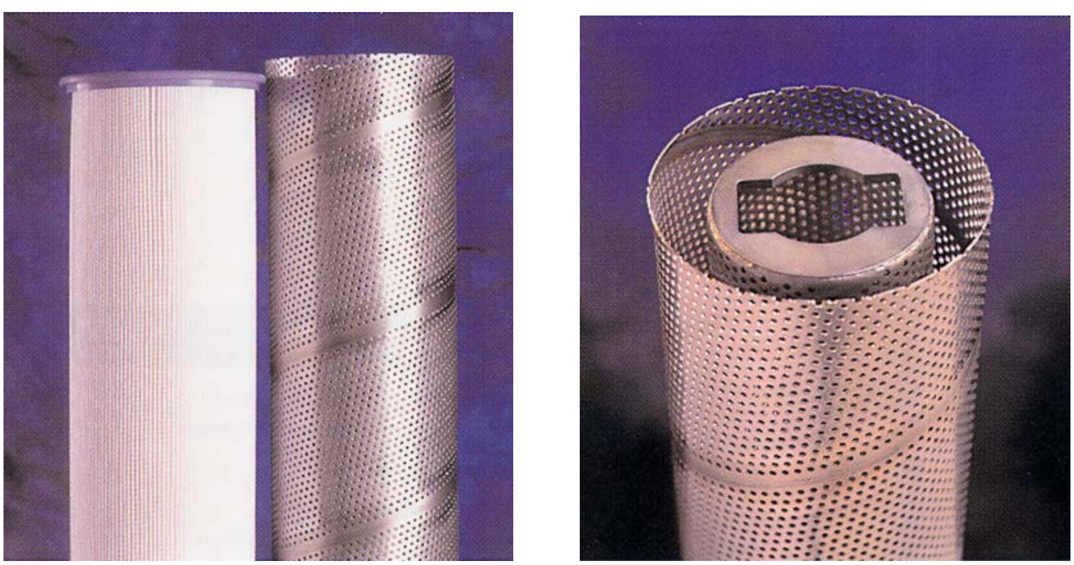

Figure A-1
Disposable Media Filter Cartridge and Stainless Steel Support Shell

The DMF stainless steel adapter provides the necessary structural interface between the filter cartridge and the plant filter vessel. In so doing, the adapter becomes a semi-permanent part of the filter vessel, taking the dynamic filtration loads and providing the strength necessary for the filter to maintain structural integrity. The DMF adapter provides service up to 75 psid (5 bar) at 250°F (121°C) for polypropylene and polysulfone filter media, and up to 230°F (110°C) for glass fiber media.

(Recall that fiberglass filter cartridges cannot be loaded in the conversion reformer. However, most filters contain only incidental glass fibers, which can be fed into the pyractor. The restriction here effectively applies to filters which are composed primarily of fiberglass media. If in doubt about a specific filter or filter media, submit a sample to Studsvik for certification for conversion reforming.)

For in-plant application, the DMF stainless steel adapter is inserted into the filter vessel in the same manner as the old metal-reinforced filter cartridge being replaced. The adapter is then locked into place, and the disposable media filter cartridge is inserted into the adapter.

When it is time to replace the filter cartridge, only the disposable media is replaced, leaving the adapter in place. If a filter sample is required of the spent filter, the absence of a metal casing allows for easier cutting and sampling of the filter. The disposable media can then be shipped for conversion reforming. (Framatome ANP recommends that the adapter be removed once every five years to replace the adapter-to-housing seal, or at a frequency based on the generator’s elastomeric life guidelines.)

A.2 Miscellaneous Considerations

1. Disposable media filters can be more economical than metal filters, as nonmetal filter cartridges are typically less expensive than filter cartridges.

2. For direct disposal, a greater volume of nonmetal filter cartridges can usually be loaded into a collection container, thereby reducing transportation costs, container costs, and disposal costs.

3. Most nonmetal filter cartridges can be volume reduced through thermal treatment processes, including incineration, glassification, and conversion reforming, thereby offering further cost savings opportunities.

4. The Framatome ANP disposable media filter cartridges provide the same high efficiency as other comparable filter cartridges. Filter media performance is certified by independent testing laboratories to meet standard ASTM F-795 test protocols.

5. Framatome ANP is working with OREX Technologies to produce polyvinyl alcohol (PVA) versions of the DMF cartridges.

6. <u>Framatome ANP and other suppliers also offer nonmetal filters which do not require metal support structures.</u>

B
PROCEDURES FOR CONVERSION REFORMING STUDY

B.1 Filter Sample Analysis Procedure

The following documents the detailed sample analysis plan employed by Studsvik for filters used in this study. This simple test plan addresses the requisite steps to verify that Studsvik's TCR process was effective for processing the supplied filter elements. It also demonstrates the process which will normally be employed to evaluate and certify future filter samples submitted by waste generators.

1. Upon receipt of the filter sample for analysis:

    a. The physical and chemical attributes were recorded on the Filter Characteristics Form.

    b. The filter was photographed as necessary, and the photographs will be retained for future reference as needed.

2. The filter sample was prepared as necessary to test in the SPF laboratory. This included segmenting the filter to fit in the oven where applicable.

    a. Each sample was uniquely identified.

    b. Each sub-sample was documented and it's data recorded on the Sample Analysis Form.

3. The sub-samples were analyzed in accordance with Studsvik's pyrolysis testing procedure, OP-LAB-001, at a temperature of 600 to 700 C for 12 hours to evaluate inorganic, organic, and soluble fractions. The fractions were used to determine the maximum volume reduction ratio (VR) and weight reduction ratio (WR).

    a. The results of the analyses were recorded on the Sample Analysis Form.

    b. A data report was generated to include pre-test and post-test data, photographs, VR and WR conclusions, and any other significant data identified during testing.

B.2 Conversion Reforming Procedure

The scope of the actual conversion reforming demonstration and evaluation was to process approximately five ft^3 (0.14 M^3) of the Framatome ANP and OREX filters through the TCR. The purpose was to demonstrate that the filters could be pyrolyzed using this technology and provide for a qualitative assessment of VR. The following procedure describes the demonstration and evaluation:

1. Filters were supplied by Framatome ANP and OREX Technologies and shipped to Studsvik.

2. The physical and chemical attributes for each filter were recorded on the Filter Characteristics Form.

3. Samples were taken and analyzed in the Studsvik lab to ensure pyrolysis in accordance with the procedure in B.1 above.

4. Filters which exceeded the maximum dimension criteria for feeding through the TCR manual feeder port were segmented and sized to fit the current TCR configuration.

   a. The segmented pieces were checked with, or loaded into, a 3” by 30” cardboard tube to ensure the pieces will fit into the manual feed port.

   b. Photographs of the sized pieces were taken and stored for future use as needed.

5. At least ten hours in advance of the demonstration and evaluation, the TCR was brought up to operating temperature and subsequently operated in accordance with the appropriate operating procedure.

6. Immediately prior to the demonstration and evaluation, the following activities were completed: (<u>It was considered as imperative that the subject vessels were rigorously emptied so as not to skew the results of this test</u>.)

   a. The FCR was **<u>thoroughly</u>** emptied of it’s contents into the TRR.

   b. The TRR was **<u>thoroughly</u>** emptied of it’s contents into an in-service RR HIC.

   c. A new RR HIC was installed in the packaging vault for the performance of this testing to ensure the most accurate assessment of VR.

   d. The filters and filter segments were staged in the feeding area in preparation of feeding them into the TCR.

7. EPRI and other participants were briefed for access, were provided with dosimetry, and were provided a facility tour to further explain the conversion reforming technology and equipment. Once all participants were positioned so as to observe the testing directly, an operator commenced feeding the filters and filter segments into the TCR.

8. After loading all filters and filter segments, the process continued to operate for an additional 0.5 hours to 0.75 hours to ensure complete pyrolysis; then the contents of the FCR were transferred into the TRR for cooling.

9. Once TRR indicated that temperature had reached the acceptable limit for transfer, the contents of the TRR were transferred into the HIC.

10. Upon completion of the transfer, the HIC was moved into the Transfer Vault and transferred to a top HIC Storage Vault for observation.

11. The volume of the transferred reformed residue within the HIC was then assessed, quantified and qualified.

    a. Using a "bullet" camera, a camera inspection of the reformed residue within the HIC was performed. This was set up to be viewed and recorded from the Control Room.

    b. A dose rate survey of the material in the bottom of the HIC was performed.

    c. A sample of the material in the bottom of the HIC was obtained, entered into the Sample Analysis Form, and analyzed for inorganic, organic, and soluble fractions, where possible.

12. The data report for the filter study was generated as the final step.

C
CONVERSION REFORMING FILTER SAMPLE DATA

The first four filter cartridges were analyzed extensively. All physical characteristics were documented, the filters were segmented and sampled, and they were ashed in a laboratory oven. The intent was to certify that they were acceptable for conversion reforming and to capture expected volume reduction efficiencies. Tables C-1 through C-3 provide detailed filter and sample data.

Table C-1
Physical Characteristics of Filter Cartridge Samples

	FILTER CHARACTERISTICS					
LAB ID	LENGTH (cm)	DIAMETER (cm)	WIDTH (cm)	WEIGHT (g)	EXTERNAL VOLUME (ml)	PHYSICAL DESCRIPTION
#1, PVA1A30P	9.525	6.35	6.35	71.807	384	White, cotton stands, plastic insert
#2, Filter, Bottom end	3.81	15.24	15.24	294.824	884	White corrugated poly w/ plastic dividers
#3, Filter, top end, silicone rubber	1.905	17.145	17.145	241.436	560	Blue, silicone rubber
#4, 3M, Filter Bottom end	10.16	3.81	7.62	64.293	295	White plastic, rubber O-ring, plastic netting, poly cloth filter material

Table C-2
Filter Cartridge Sample Analysis

	SAMPLE ANALYSIS (PART 1)				
LAB ID	CRUCIBLE TARE WT (g)	SAMPLE VOLUME (ml)	SAMPLE GROSS WT (g)	DRY GROSS WT (g)	INORGANIC GROSS WT (g)
#1, PVA1A30P	103.108	384	174.915	174.915	103.265
#2, Filter, Bottom end	100.537	221	174.243	174.243	100.595
#3, Filter, top end, silicone rubber	101.404	280	220.122	220.122	171.064
#4, 3M, Filter Bottom end	91.959	295	156.252	156.252	110.129

	SAMPLE ANALYSIS (PART 2)				
LAB ID	FILTER TARE WT (g)	INSOLUBLE GROSS WT (g)	ESTIMATED RESIDUE VOUME (ml)	VR ESTIMATE	NOTES
LAB ID	103.263	103.276	20	19.20	Very little residue remaining.
#2, Filter, Bottom end	100.690	100.748	20	11.05	Very little residue remaining.
#3, Filter, top end, silicone rubber	101.560	170.023	100	2.80	Hard and able to be crumbled by hand.
#4, 3M, Filter Bottom end	92.110	109.654	90	3.28	A fine powder.

Table C-3
Filter Cartridge Sample Results

	SAMPLE RESULTS				
LAB ID	ORGANIC %, BY WEIGHT	INORGANIC %, BY WEIGHT	INSOLUBLE %, BY WEIGHT	SOLUBLE %, BY WEIGHT	VR, BY WEIGHT
#1, PVA1A30P	99.8	0.2	0.0	0.2	457.4
#2, Filter, Bottom end	99.9	0.1	0.1	0.0	1270.8
#3, Filter, top end, silicone rubber	41.3	58.7	57.7	1.0	1.70
#4, 3M, Filter Bottom end	71.7	28.3	27.3	1.0	3.54

It should be noted that the VR estimates in Table C-3 are based on the segmented samples as opposed to the full filter cartridge and waste container, including all void spaces. The VR estimate of the laboratory oven ashed samples range from a factor of 2.8 to 19.2. Recall that the results in Chapter 3 for all filters was an average VR of 14.56:1. It can be reasonably assumed that scaling these sample VR ratios up to include the entire filter volume, the associated void spaces within the filter cartridge, and the void spaces in the waste containers would increase the net disposal VR substantially, as demonstrated in Chapter 3.

Table C-4 taps the Studsvik-USA historical records for filters removed from the dewatering laterals in spent resin containers. These filters ranged from a few mR/hr to more than 40 R/hr. The data is included here to demonstrate that the results of the filter study in this report are reliable when compared to actual waste filter results and should, therefore, be replicated in actual field trials.

Table C-4
Historical Data: Filter Cartridge Conversion Reforming Experience

Nuclear Plant Key	Initial Filter Volume	Final Waste Volume	VR (X:1)
4	2	0.12	17.0
8	2	0.07	29.8
12	2	0.12	16.9
12	3	0.30	10.0
12	3	0.13	22.4
12	4	0.15	26.4
12	9	0.52	17.2
12	9	0.48	18.9
12	10	0.50	19.8
12	12	0.80	15.0
12	24	1.29	18.6
12	24	0.86	27.8
12	25	0.76	33.0
12	27	1.27	21.3
12	40	0.71	56.3
14	3	0.12	24.9
17	0.8	0.05	15.4
17	0.8	0.04	22.8
17	0.9	0.05	19.8
17	1	0.05	19.3
17	1	0.05	19.3
17	2	0.05	39.6
21	0.8	0.05	14.7
21	2	0.10	19.8
38	15	0.44	33.8
43	3	0.12	24.9
47	1.7	0.14	12.5
47	2	0.14	14.2
47	2	0.13	14.9
47	2	0.12	16.5
47	2	0.12	16.7
47	2	0.12	16.7
47	2	0.11	18.5
47	2	0.10	19.8
47	2	0.10	19.8
47	2	0.09	22.6
47	2	0.07	29.8
47	2	0.05	39.6
47	2	0.05	39.6
47	2	0.05	39.6
47	2	0.05	39.6
47	2	0.05	39.7
47	2.1	0.04	59.2

Nuclear Plant Key	Initial Filter Volume	Final Waste Volume	VR (X:1)
47	3	0.12	24.9
47	3	0.12	25.6
47	3	0.11	28.1
47	3	0.10	29.0
47	3	0.10	29.5
47	3	0.10	29.9
48	0.79	0.04	19.1
48	2.6	0.16	16.0
48	3	0.10	29.8
48	7.5	0.19	39.6
48	20	0.45	44.5
49	3	0.20	14.9
51	3	0.10	29.5
54	2	0.07	29.8
54	2	0.05	39.6
54	2.3	0.18	12.5
54	3	0.14	21.3
54	3	0.08	39.6
54	5	0.26	19.3
54	6.5	0.38	17.1
55	1	0.08	12.9
55	2	0.10	19.8
55	2	0.05	39.6
55	4	0.13	29.8
55	4	0.10	39.6
55	7.5	0.42	17.8
55	8	0.30	27.0
55	8	0.23	35.2
55	9	0.46	19.6
55	10	0.37	26.8
55	12	0.54	22.1
55	12	0.48	24.8
55	12	0.48	24.8
55	12	0.32	37.4
55	13	0.68	19.1
57	2	0.07	29.8
58	2	0.07	29.8
59	2	0.08	26.4
60	2	0.09	22.5
60	2.5	0.06	40.2
60	4	0.12	33.8
62	2	0.13	14.9
62	2	0.08	25.0

Nuclear Plant Key	Initial Filter Volume	Final Waste Volume	VR (X:1)
47	3	0.20	14.9
47	3	0.20	14.9
47	3	0.14	21.3
47	3	0.14	21.4
47	3	0.14	21.4
47	3	0.14	22.1
47	3	0.13	22.4
47	3	0.13	22.4
47	3	0.12	24.9

Nuclear Plant Key	Initial Filter Volume	Final Waste Volume	VR (X:1)
62	2.5	0.08	31.0
62	3	0.20	14.8
62	3	0.16	18.7
62	3	0.16	18.7
62	3	0.14	22.1
62	3	0.13	22.4
62	3	0.13	22.4
62	4	0.20	19.9
62	7	0.19	37.4
Summary	**535.29**	**21.97**	**24.40**

The above historical table demonstrates an average VR ratio of 24.40:1, which is actually better than the 14.56:1 average achieved during the filter study covered by this report. This verifies the results of this study are reasonable and should be achievable in field trials by nuclear plants.

D
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