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TECHNOLOGY APPLICATIONS FOR RADIOACTIVE WASTE MINIMIZATION*

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To be presented at
Spectrum '94: International Nuclear and Hazardous Waste Management
Atlanta, GA
August 14-18, 1994

*Work supported by the U.S. Department of Energy Office of Technology Development, under contract W-31-109-ENG38

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ABSTRACT

The nuclear power industry has achieved one of the most successful examples of waste minimization. The annual volume of low-level radioactive waste shipped for disposal per reactor has decreased to approximately one-fifth the volume about a decade ago. In addition, the curie content of the total waste shipped for disposal has decreased. This paper will discuss the regulatory drivers and economic factors for waste minimization and describe the application of technologies for achieving waste minimization for low-level radioactive waste with examples from the nuclear power industry.

INTRODUCTION

For generators of radioactive waste, waste minimization is not only required by the federal and state legislations, it is an economic necessity. The Low-Level Waste Policy Act of 1980 transferred the responsibility of low-level radioactive waste (LLW) to the States. The States are required to develop their own disposal facilities or form compacts and develop facilities for servicing such compacts. The Low-Level Waste Policy Amendment Act of 1985 set milestones for developing such facilities, imposed allocations on the volumes of waste that the generators could ship to disposal facilities, and set forth further restrictions, including surcharges on waste disposed. By January 1, 1993 (by which time the States or compacts were supposed to have new facilities open), it was clear that no new facilities would be open in the near future. The State of South Carolina, where the Barnwell Site (which accepts the bulk of the commercial radioactive waste) is located, has imposed stiff surcharges on the out-of-state waste. In addition, there are surcharges on the curie content of the waste.

Thus, in addition to the restrictive federal and state regulations, increased disposal costs have provided a powerful economic incentive for application of waste minimization technologies. The steep increase in disposal cost is obvious from Figure 1; the disposal cost of LLW rose from approximately $5/ft^3 in 1980 to about $280/ft^3 in 1993. Industry estimates of disposal costs at new sites (yet to be developed by compacts) range as high as $700/ft^3.

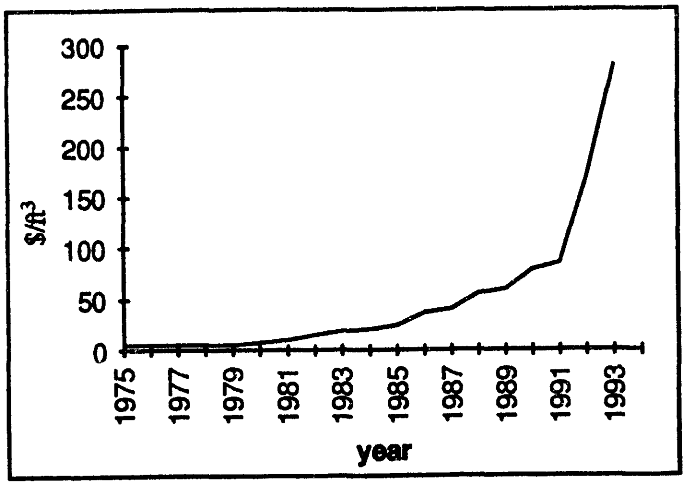

Figure 1. Disposal cost

WASTE MINIMIZATION STRATEGY

For the purpose of this paper, the term waste minimization is used in a broader context and includes waste source reduction as well as waste volume reduction. A generic waste minimization strategy should include both elements.

Generation source analysis and strategies to achieve source reduction are fundamental to effective radioactive waste management. The quantities of waste generated affect the handling, treatment, storage, and disposal cost for plant operators. It should be recognized that for an operational facility that generates wastes on a continual basis, even incremental improvements in waste minimization are worth the effort in the long run. At industrial research generation sources, waste minimization can sometimes be achieved by substituting different feedstock material, changing process technologies, or streamlining production processes. This may be less applicable in the case of nuclear power plants. However, waste minimization at most generation sources depends on

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management practices. The volume of waste generated can be effectively reduced through the implementation of new procedures, quality assurance programs, and programs to educate workers on minimizing contaminated waste and avoiding cross-contamination.

Cross-contamination can be avoided by designating appropriate areas for collecting and storing contaminated materials such as trash, laundry, and equipment . Waste should be segregated at the point of generation. The recyclable material such as tools, laundry, and rewashable items, should be separately collected from the dry active waste, which will undergo treatment for storage or disposal.

Decontaminating major equipment and segregating rewashable tools, protective clothing and other materials allow resource recovery and reuse and minimize the waste ultimately needing treatment and/or processing and disposal. Resin reuse (removal of resins before they are fully exhausted and then reuse in other systems with lower requirements) and resin cleaning (e.g., ultrasonic cleaning) are also being applied in the nuclear power industry.

Waste that is generated requires application of treatment technologies to process and condition it for storage or disposal. In the nuclear power industry, a number of technologies have been successfully applied, including the following: evaporation, distillation, crystallization, precipitation, centrifugation, filtration, sedimentation, incineration, ion exchange, ultrafiltration, and reverse osmosis for liquid waste; sedimentation, drying, dewatering, dehydration, and incineration for wet solids; and decontamination, compaction, shredding, baling, and incineration for dry solids.

Primary technologies that are currently in use for such waste minimization practices are briefly summarized below.

TECHNOLOGIES

Most of the wastes generated in the power plant are either solids or liquids. Any wet solids can generally be dewatered using centrifuge systems, tank dewatering devices, or dewatering filters. This paper focuses on the solid and liquid wastes that are generated during power plant operations. Other technologies used in remedial actions, such as the decontamination of concrete, are outside the scope of this paper. It should be noted that the *below regulatory concern* or *de minimis* levels (for which the policy in the U.S. is currently on hold) will have a major on the waste volumes in the nuclear power industry.

Both for solid and liquid wastes, a systematic approach requires early consideration of these key questions:

1. Can the waste be stored to allow short-lived isotopes to decay?

2. Can the wastes be safely and cost-effectively treated, stabilized, and disposed of?

3. What strategies and technologies are relevant to reduce the waste volume? Should the liquid waste streams be treated separately (with separate technologies) or mixed (chemical composition, radionuclides and activity levels will need to be considered)?

4. What type of conditioning will be necessary before disposal?

Technologies for Solid Wastes

Compaction and Supercompaction

The volume of dry solid waste can be reduced through the use of compactors, either hydraulic or pneumatic. The volume reduction achieved depends on the void space in the waste, its bulk density, its spring-back characteristics, and the force applied during compaction. Examples of compactible materials are plastics, paper, cloth, and other absorbent material. In fact, plastics and paper account for nearly 70% of the compacted waste at nuclear power plants; cloth, adsorbent material, rubber, and other miscellaneous materials account for the rest. Noncompactible materials include metal pipes and valves, wood, filters and resins, and miscellaneous items such as glass, tools, and concrete. Wood, pipes and valves account for nearly 50% of the noncompactible waste; conduit, filters, concrete, tools, dirt, glass, and other miscellaneous materials account for the rest.

Most dry active waste originates from routine plant operating, maintenance, and housekeeping activities. It is also generated during modifications to plant equipment or during decontamination activities. The key radionuclides in such waste include Cs-137, Cs-134, Co-60, Co-58, Fe-55, Ni-63, and Mn-54.

The low-pressure compactors, where the applied force may be only a few tons, can provide a volume reduction factor of about 2 to 5 for contaminated trash waste. High-pressure compaction, also known as supercompaction, uses compaction forces of the order of 1000 tons or more and can provide a volume reduction factor of about 6 to 10. Supercompactors can exert a force in excess of 7,000 psi and can also compact items such as metal pipes or wood that cannot be processed with low-force compactors. It is also used to compact (flatten) waste-filled drums. Important factors that must be considered for the compaction process include the elasticity of the waste (elastic wastes may need to be mixed with inelastic waste to reduce the potential for re-expansion) and the final overpacking of the compacted waste for storage or disposal. Compaction is widely used at nuclear power plants, and it is also offered as a commercial service, with some facilities employing mobile units.

Baling

Some solid LLW can be baled for volume reduction (in certain cases after compacting). Baler units are available in various types and sizes; however, rectangular bales are currently the most widely used to containerize waste for storage or disposal. Baling of waste can also be used as an interim storage convenience for combustible waste that will eventually be incinerated (e.g., during shutdown periods of the incinerator).

Shredding

Shredding contaminated paper, cloth and plastic waste can reduce the volume to about one-third. Shredding can also be used on combustible waste before incineration. Proper waste segregation is important, because metallic pieces in the general waste have been known to damage or break the cutting blades of shredders.

Cutting

Contaminated plant hardware can be cut into pieces for better packaging and storing. Discarded contaminated piping at nuclear power stations is often cut into sections to fit into (and to reduce the void space in) the transportation casks or storage containers. For this type of hardware, there is usually no intention of decontaminating and reusing the material. In addition to traditional saw cutting, specialized cutting technologies--such as oxyacetylene cutting and plasma arc torch cutting-- are used.

Smelting

Contaminated metals with low levels of radioactivity can be recycled through smelting into useful items such as shielding blocks and low-specific-activity waste containers.

Incineration

If waste can be properly segregated at the source, incineration may be the best option for dealing with the combustible portion. It is estimated that about half of the solid waste generated at nuclear power plants and the bulk of the waste generated at R&D institutions (including the biological waste) are combustible. Volume reductions of 100:1 or higher are common.

Incineration technologies are well-advanced, and various designs are commercially available such as starved-air incineration, excess-air incineration, and pyrolytic or thermal decomposition. However, the capital costs required for incinerator systems are high compared to other treatment processes, so the waste is generally shipped to an operating commercial incinerator. The ash or residue left from the incineration process can be drummed for transportation and storage or immobilized through incorporation into matrices such as concrete, bitumen, glass, epoxy, or polyethylene for eventual disposal. Two specific examples are discussed below.

The Scientific Ecology Group Inc. incinerator at Oak Ridge, TN is an automated, controlled-air incinerator capable of high throughput, 1,000 lbs. of waste per hour. The primary chamber operates at about 1000° C. The hearth ash, which comprises approximately 95% of the residue (by weight), may be compacted and disposed of if it passes the Toxicity Leaching Characteristic Procedure (TCLP) test. The flyash which typically constitutes about 1% of the residue (the remainder being scrubber salt), is stabilized by solidification in concrete or epoxy. The hearth ash contains approximately 97% of the total activity.

The incinerator at Chalk River Laboratories (1) has achieved a volume reduction of about 170:1 (on as-received volume basis) for miscellaneous combustible uncompacted trash generated at the laboratories from the operation of research reactors and other R&D activities. Baled waste has also been successfully incinerated here. The primary chamber operates at about 500° C and the afterburner chamber at about 1000° C. Typically the resultant ash has contained these radionuclides: Co-60, Cs-137,Sb-125, Cs-134, Ru-106, Ce-144, Ag-100m, Ce-141, Ru-103, Nb-95, Zr-95 and Zn-65. Due to the radioactive decay of the shorter-lived radionuclides, the total activity in the ash after two and a half years in storage is reduced by a factor of five. Thus, storage of ash can be a significant step allowing the radioactivity to decay before the ash is processed for disposal.

Technologies for Liquid Wastes

For liquid wastes containing primarily short-half-life radionuclides, storing wastes in hold-up tanks to allow the radioactivity to decay may be one cost-effective strategy.

The technologies for achieving volume reduction for liquid wastes can be physical (e.g., sedimentation, evaporation, filtration, ultra filtration, reverse osmosis) or chemical (e.g., precipitation, ion exchange). They are briefly described below.

Sedimentation

Solids suspended in liquid waste can be separated out through sedimentation, which is essentially settling by gravity. This process is generally used for bulk quantities of liquid, such as sedimentation ponds for sludge waste. For small suspended particles, agglomeration can be achieved through flocculation.

Evaporation

Evaporation is a well-established and highly efficient process (i.e., allows very large volume reduction) that is widely used in the nuclear industry even though the high costs limit its use to high-activity, low-volume liquid waste streams. It is most suitable for liquids with high concentration of dissolved salts or other solids. A single-stage evaporator can provide decontamination factors (on an activity basis) of up to 10^4. The evaporator designs can be varied, such as natural circulation, forced circulation, spray film, roto-spray, or submerged U-tube. The concentrate containing radionuclides can be incorporated into cement or bitumen for eventual disposal.

The potential problems associated with evaporators include corrosion, scaling, and foaming.

Filtration/Ultrafiltration

Filtration can be used to remove the fine particles from the liquid waste stream or as a pretreatment step before the ion exchange. Because natural filtration is slow, pressure or vacuum filtration is generally employed. The filter material may be pressed paper, matted fibers, or porcelain. Typically, disposable cartridges are used; however, backflushable, precoated filters are also in use.

Ultrafiltration systems can handle particle sizes that are much less than 1 micron (e.g., 0.05 micron). Ultrafiltration has been coupled with reverse osmosis systems in many liquid waste processing systems.

Reverse Osmosis

The process of reverse osmosis can be used to achieve a concentrated liquid from a dilute liquid by using semipermeable membranes such as cellulose acetate. Commercially available systems include spiral-wound, tubular or hollow fiber designs. For a single-stage system, decontamination factors can range between 10 to 10^2. Membrane fouling problems gradually decrease the efficiency of the system over a period of time.

Precipitation

Radionuclides in aqueous streams can be chemically precipitated as hydroxides, oxalates, or phosphates by adding relatively small quantities of appropriate reagents. The process is relatively inexpensive and particularly suitable to treating large volumes of aqueous wastes containing low concentrations of radionuclides. Decontamination factors can range between $10\text{-}10^3$. The process may require pretreating the waste stream and adjusting the chemical conditions. Solid-liquid separation techniques may also be necessary.

Ion-Exchange

Ion-exchange systems are widely used in the nuclear power industry to remove soluble radionuclides from reactor coolant systems or from liquid waste streams.

Ion-exchange material contains ionizable polar groups (organic or inorganic) and is loaded in ion-exchange columns. The process involves the exchange of ionic species between the liquid and solid matrix. The ion-exchange materials are generally synthetic resins in the form of small porous beads. When columns become fully loaded, they can be removed and treated as radioactive waste. In some cases, the ion-exchange materials may be regenerated by strong acids or bases yielding radioactive liquid waste. Decontamination factors generally range between $10^2\text{-}10^4$. The presence of colloids, detergents, or dissolved organics in the waste stream can cause difficulties in the ion-exchange systems through resin fouling.

SUCCESSFUL APPLICATION

The nuclear power industry has successfully applied waste minimization during the past decade and a half. Waste minimization techniques and technologies have had a large impact at Duke Power Co. (2). In the past, the PWR units at Duke's three sites (Oconee, McGuire, and Catawba) generated waste well above the average national data for PWRs. In 1989, per-reactor-waste totaled 5,212 ft^3, approximately 700 ft^3 above the average. The peak occurred in 1982 at the Oconee station, when 36,046 ft^3 of waste was generated. [These abnormally high volumes resulted from many factors, including several in-service inspection outages, modifications, cleanup activities from a steam generator tube rupture and inadequate administrative controls (2)]. Through a series of operational and technical actions, the per-unit-volume at Oconee was reduced to 11,022 ft^3 in 1989 and 5,194 ft^3 by 1990. The company has invested heavily in radioactive waste processing facilities and has employed the following techniques/technologies to achieve these drastic reductions in waste volume: source controls, administrative controls, liquid waste minimization, decontamination, compaction, supercompaction, incineration, evaporation, ion exchange, and filtration.

The generation data for radioactive waste in the nuclear power plant industry is available in a survey report published by the Electric Power Research Institute (3). The overall industry trend is shown in Figure 2 (4), where for both the PWR and BWR reactors, the annual waste volume per MW(e), and normalized to 1980 values are plotted. During the same period, Figure 3 (4) shows normalized activity in the waste shipped.

Thus, after ten years the waste volumes were reduced by a factor of five and activity by an order of magnitude. The decrease has been more dramatic from 1984, when the disposal costs began to rise substantially. Even though the disposal costs have continued a steep climb with the imposition of stiff surcharges, the average waste volume generated at a nuclear power plant appears to have reached a plateau by 1990. This may result from two factors. First, the industry has already implemented successful waste minimization strategies and volume reduction technologies. Further potential reductions in waste volume may not be cost-effective. Second, for certain treatment technologies, further efficiency may not be feasible. Supercompaction for example, has already reached compaction efficiencies close to theoretical density limitations for the compacted waste.

CONCLUSIONS

Waste minimization in the nuclear power industry is driven by regulatory pressures and the steep increases in waste disposal cost. The industry has effectively applied the techniques and technologies to produce one of the most successful examples of waste minimization. As a national average, the waste volumes per reactor have successively decreased over the past decade. A number of technologies are currently available for volume reduction of solid and liquid wastes. However, an integrated and systematic approach is necessary to implement waste minimization cost-effectively and safely.

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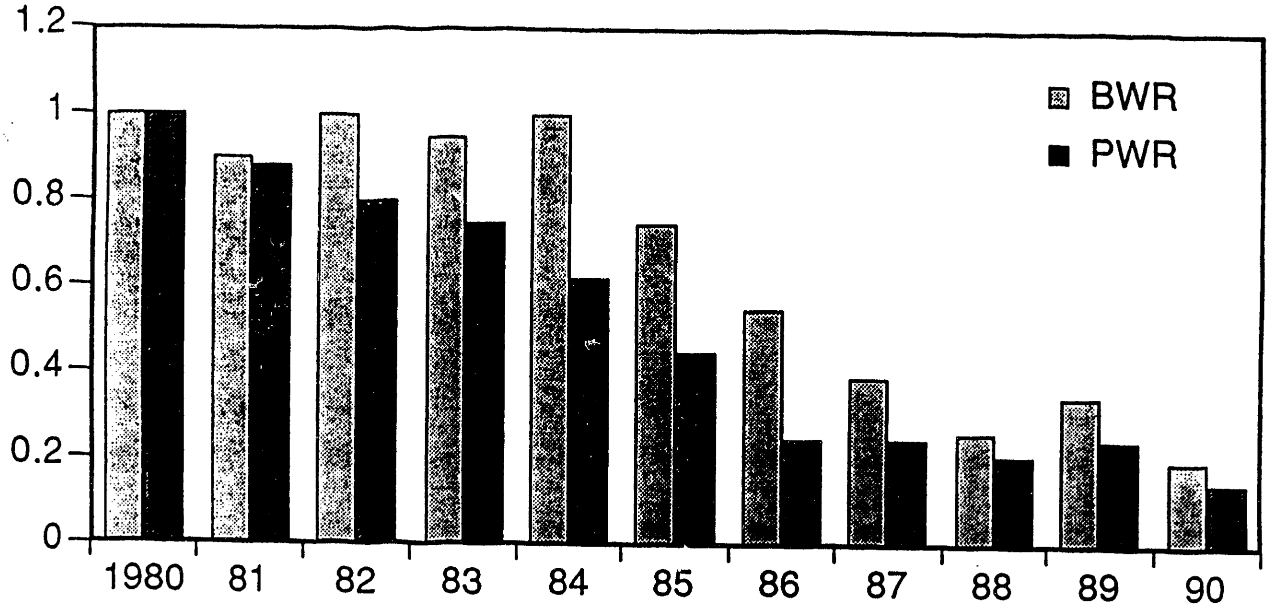

Figure 2. Annual volumes of PWR and BWR LLW shipped per MW(e) generated, 1980 through 1990 normalized to 1980 values (ref. 4)

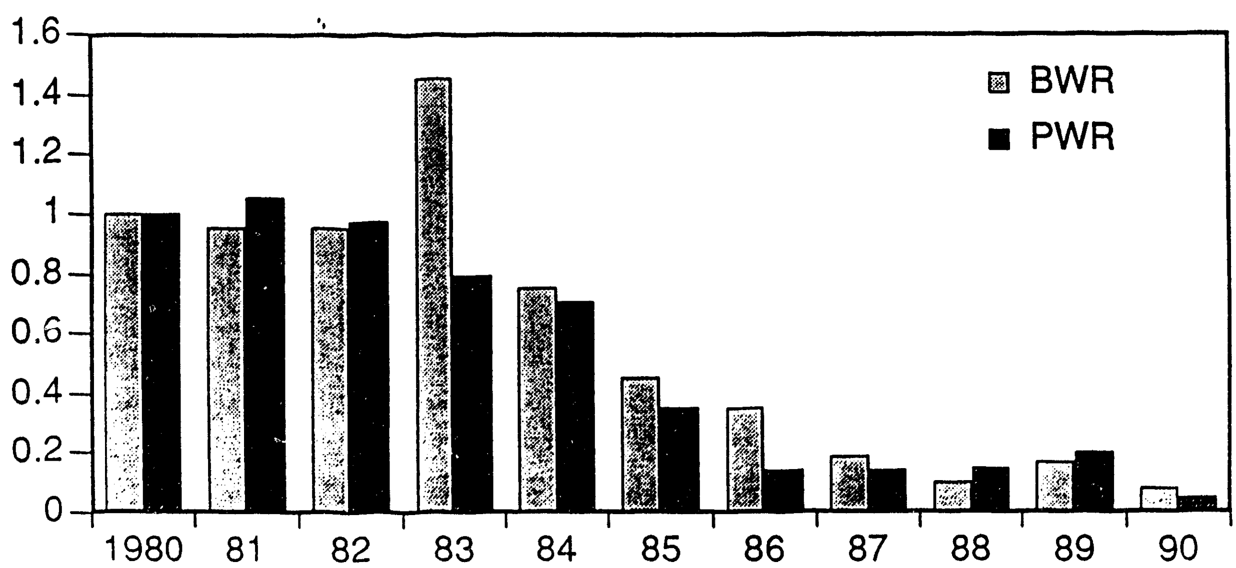

Figure 3. (Volume X Activity) of PWR and BWR LLW shipped annually from 1980 to 1990, per MW(e) normalized to 1980 values (ref. 4)

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