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PHYSICOCHEMICAL CHARACTERIZATION OF SOLIDIFICATION AGENTS USED
AND PRODUCTS FORMED WITH RADIOACTIVE WASTES AT LWR
NUCLEAR POWER PLANTS*

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The radioactive wastes (radwastes) routinely generated onsite at light-water-cooled nuclear reactor (LWR) power plants comprise the largest volume of radwastes generated annually in the commercial nuclear fuel cycle, mill tailings excepted. In this consideration, spent fuel is not categorized as waste. The principal wastes considered here are the evaporator concentrates, filter sludges, and spent ion exchange resins that are derived from cleanup of the liquid streams recirculating within or being discharged from LWR plants. From 1975 through 1977, the annual thermal power output from LWRs in the United States was close to 6×10^8 MWhr, and the accompanying average annual waste volume shipped to licensed shallow land burial sites was approximately 3×10^4 m³, as shown in Figures 1 and 2 (1). Until now, most filter sludges and spent resins have merely been dewatered but were not incorporated into a solid matrix, as will be required by future regulations. The introduction of solidification agents to immobilize these sludges and resins can increase the volume of these wastes by a factor of slightly over 1 to greater than 2, depending on the binder chosen.

The agents and methods used or proposed for use in solidification of LWR power plant wastes (2,3) are generally suitable for treating most of the other-than-high-level wastes generated throughout the entire fuel cycle. Among the solidification agents most commonly used or suggested for use are the inorganic cements and organic plastics, which are listed in Table 1 and compared in Table 2.

Portland cements, especially Types I and II, have been widely used throughout the world for several decades. They were the principal solidification agents used at LWR plants in the United States until about 5 years ago when urea-formaldehyde (UF) resins

Figure 1. Annual thermal output.

Figure 2. Annual waste volume.

Table 1. Waste solidification agents used or proposed for use at LWR power plants

I. Cementitious inorganic binders (ambient to moderate temperatures)

Portland cements	Cements plus clays
Alumina cements	Gypsum
Cements plus silicates	Water glass

II. Thermoplastics (moderate temperatures)

Asphalts	Polypropylenes
Polyethylenes	Waxes

III. Thermosetting resins (~ ambient temperatures)^a

Urea-formaldehyde	Unsaturated polyester
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^aCatalysts are used instead of heat to set resins.

Table 2. Some considerations that influence the choice of a solidification agent for use in the radwaste system of an LWR nuclear power plant

Consideration	Solidification agent			
	Cement	Urea-formaldehyde resin	Unsaturated polyester resin	Asphalt
Availability	Excellent	Good	Good	Good to excellent
Relative cost per mass of agent per mass of waste	Low Moderate to high	Moderate Moderate	Moderate to high Moderate to high	Low to moderate Low to moderate
Shelf-life	Long	Limited	Limited	Long
Special storage requirements	Low humidity	Relatively low temperature	Fire prevention for initiator/promoter	Fire prevention
Special handling problems	Dusting	Corrosiveness of catalyst	Flammability of initiator/promoter	Flammability
Flexibility regarding				
Waste types	Fair to good	Fair to good	Good	Good
Activity levels	Excellent	Good	Good	Good
Product containers	Good	Fair	Good	Good
Compatibility with waste constituents				
H ₂ O ₃				
(as Na salts)	Fair	Good	Fair to good	Good
Na ₂ SO ₄	Good	Fair	Good	Good (anhydrous)
Oxidants	Good	Unknown	Unknown	Poor
Detergents	Poor to fair	Fair	Fair	Fair
Antifoams	Unknown	Unknown	Unknown	Fair to good
Oils	Poor to fair	Fair	Fair	Fair to good
Other organics	Poor to fair	Fair to good	Fair to good	Fair to good
Hard resins	Poor to good	Fair to good	Good	Fair to good
Powdered resins	Fair	Good	Good	Good
Filter aids	Good	Good	Good	Good
Product properties				
Leachability, g cm ⁻² day ⁻¹	10 ⁻¹ to 10 ⁻²	~10 ⁻² to 10 ⁻³	~10 ⁻² to 10 ⁻³	10 ⁻¹ to 10 ⁻²
Density, g/cm ³	1.5 to 2.5	1.1 to 1.3	1.1 to 1.5	1.1 to 1.9
Dry waste solids content, wt %	5 to 55	8 to 20	10 to 50	40 to 60
Volumetric ratio, product/liquid waste	1.5 to 3.0	1.3 to 2.0	1.4 to 1.5	0.2 to 1.1
Radiation resistance, rad	>10 ¹⁰	~10 ⁹	~10 ⁹	~10 ⁹
Mechanical resistance, kg/cm ²	100 to 300	Oozes water	200 to 1000	Plastic
Maximum stable temperature, °C	300 to 500 (dehydrate)	300 to 500 (char)	300 to 500 (char)	350 to 450 (ignite)

emerged as a dominant solidification agent. The use of UF resins seemed to offer the advantages of an all-liquid system up to the point of solidification and to overcome some of the problems (e.g., dusting and flash or premature setting) encountered with cements. However, the use of UF was not without problems. In particular, the occurrence of unbound ("free") liquid in the container of "solidified" waste was frequently observed making the package unacceptable for burial.

Asphalts have been used extensively in Europe and other parts of the world to incorporate nuclear wastes, but they have not yet been used in the United States. The domestic debut of asphalt may be imminent, however, since at least two U.S. power plants have ordered asphalt solidification equipment. Unsaturated polyester

resins have recently been developed as solidification agents for nuclear wastes. To date, none has been used for full-scale, routine LWR power plant waste incorporation. Polyester and UF resins, as well as asphalts, are organics; they are flammable to varying degrees and provisions must be made to handle them accordingly. A summary of some of the considerations important in choosing a solidification agent are presented in Table 2. All of the solidification agents mentioned above have exemplary qualities as well as physical and/or chemical limitations. The processes utilizing thermoplastics are less sensitive to the chemical conditions of the system than are the processes which use inorganic cements or the thermosetting organic resins as binders. Some selected behavioral characteristics of these various solidification systems, as well as qualitative evaluations of some typical solidified waste products, are also included in Table 2. Another recent survey of this type (4) points out that further research is needed to aid future decision making in handling nuclear wastes. Two such U.S. research programs are reported in references 5 and 6.

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