TRANSPORTABLE VOLUME REDUCTION SYSTEM FOR SOLIDIFICATION OF LOW-LEVEL RADIOACTIVE WASTES

Steve Simpson and Dale Jessop
Associated Technologies, Inc.
222 South Church St.
Charlotte, NC 28202

INTRODUCTION

All liquid and some solid wastes generated at nuclear power stations require solidification before transportation and burial. These wastes include equipment and floor drains, chemical, decontamination, and laundry wastes. In the case of pressurized water reactors, equipment and floor drains can contain large amounts of boric acid used as a moderator and poison in the reactor. Usually dilute liquid streams are concentrated by use of waste evaporators before final solidification. Both bead and powdered resin waste and filter sludges are generated in cleanup systems and radwaste systems associated with power reactors.

Up until 1978 most architect/engineers and utilities selected either cement or urea-formaldehyde solidification systems. All systems available up to that time however did not include any provisions for volume reduction, i.e. removing water from either concentrated waste streams or from resins. Therefore, most systems installed were straight solidification systems. Urea-formaldehyde has now almost exclusively been abandoned because of the problems associated with the existence of free water upon solidification. There are a number of cement systems that have been installed and used for solidification. There are however many that have been abandoned because of process control problems associated with complete solidification and the fact that few of these systems were designed with ALARA principles in mind. Operators are reluctant to contaminate equipment which they feel will require high maintenance and subsequently incur considerable personnel radiation exposure. Many utilities have opted for mobile cement solidification systems instead of using their permanently installed equipment. In 1978 a number of volume reduction and solidification technologies were available on the American market. As a result, a number of utilities have purchased and are installing volume reduction and solidification systems to handle liquids, resins and combustible trash.

The capital cost of a volume reduction system ranges from about 2.5 million dollars to 5 million dollars depending on the technology for a complete system with all equipment required to receive, treat, volume reduce, and solidify radioactive waste. The cost of the structure and modifications to install such a system in a nuclear power plant however is much greater. For backfit of a 3 million dollar volume reduction and solidification system into existing building space another 5 to 7 million dollars is required to install the system and add shielding, piping and auxiliaries. The cost of installing a system in a new structure has been estimated at costs of 30 to 80 million dollars. TVA has estimated the cost of facilities for volume reduction of liquids, resin waste and combustible trash at 73 million dollars each at Sequoyah and Watts Bar Nuclear Plants.

Because of today's tight capital and high interest rates many utilities have deferred decisions with regard to addition of permanently installed volume reduction and solidification systems. Burial costs in 1975 were $\$1.10/ft^3$ (contact dose rate of less than 200 mrem/hr). Today's cost is on the order of $\$9/ft^3$ to $\$12/ft^3$ depending on the burial site. In a period of six years there has been a 900% to 1200% increase in the cost of burial. Although there has been considerable effort to establish regional burial sites it is not expected that the cost of disposing of wastes will be reduced. Certainly regulations such as 10CFR61 will cost to implement.

Transportation costs have risen considerably over the past few years primarily because of the oil embargoes and the subsequent increase in cost of diesel fuel . So even though a utility could justify equipment for volume reduction and solidification, many are deferring decisions because of the high interest rates and large capital involved in constructing facilities to house the equipment.

In 1981 a design was developed for a transportable or mobile volume reduction and solidification system. These systems would be fabricated in the shop and shipped in 1 to 3 pieces to a plant site, where after calibration of instruments and installation of shielding, volume reduction and solidification of wastes would begin. These systems would be operated by a vendor on a service basis. This type of service would offer the advantage of volume reduction over straight cement solidification services and would require little capital investment by the utility in order to achieve significant savings in transportation and burial costs. This concept of a transportable or mobile volume reduction and solidification service has generated considerable interest in the utility industry. This type of service could achieve savings within a matter of a few months whereas the procurement, fabrication, installation, and testing of a permanent system could require 4 to 8 years before any economic benefit would be derived. Furthermore, use of a transportable or mobile volume reduction and solidification service eliminates the risk of changing NRC and DOT regulations or burial site requirements which might make the procured system a "white elephant".

The use of this type of service would also allow utilities to evaluate a volume reduction and solidification process before making decisions about purchase and installation of such equipment.

The process used in the system was developed in France in the early 1960's. The process, a one-step volume reduction and bitumen solidification, is proven and has been operating in both BWR and PWR nuclear power plants for a number of years. In addition to operating power plants the system is being used in research, military and fuel reprocessing centers. The process has years of experience in volume reducing and solidifying both bead and powdered resins, sodium sulfate concentrates, boric acid concentrates, equipment and floor drain wastes, decontamination wastes and laundry wastes.

DESIGN CRITERIA AND SAFETY CONSIDERATIONS

Before design of the Transportable Volume Reduction (TVR) system was initiated a set of design criteria was developed based on maximizing the safety of operations associated with the receipt, treatment, processing, and drumming of power reactor wastes.

- The system is designed to contain all liquids which may leak as a result of failure of a radioactive fluid pressure boundary.
- The system will be prewired and prepiped to the maximum extent possible to minimize the number of field connections required.
- The system is designed to include a complete radiation monitoring system including airborne samplers and direct radiation monitors.
- The system is designed to have a completely self-contained air filtration system.
- The system is designed to include a self-contained fire detection and suppression system.
- The system is designed for personnel radiation protection utilizing lead and sand shielding.
- The system will include all necessary electrical equipment including a control panel, motor control centers, transmitters, and instrumentation.
- The system is designed to provide environmental control for all contained equipment, including motors, controls and instruments.
- The system is designed to provide material handling and decontamination of waste containers.

APPLICATIONS

The TVR System is designed to volume reduce and solidify most types of low level radwaste generated by nuclear power plants, research facilities and fuel reprocessing plants. Typical waste types which can be handled by the TVR System include the following:

- bead resins
- powdered resins
- filter demineralizer precoat sludges
- boric acid concentrates
- sodium sulfate concentrates
- incinerator ash slurries
- chemical drains
- floor and equipment drains
- decontamination solutions
- reverse osmosis laundry concentrates
- spent activated carbon slurries

SERVICE DESCRIPTION

Services

The vendor will provide all equipment, supervisors, operators and materials necessary to receive, process, drum and prepare for shipment radioactive process wastes generated from plant operations.

Maintenance of the system is the responsibility of the vendor. The vendor is also responsible for procuring chemical reagents, solidification agent, 55-gallon drums, and all other material required for waste processing and packaging.

User Requirements

The following space, services and support are required of the User:

1. Utilities

Utility	Quantity
Electricity @ 480 volts	
Total connected load	400 KW
Demand load	250 KW
Instrument Air	
@ 90 psig	10 SCFM*
Condenser Cooling Water	
@ 95°F	50 GPM*
Condensate or Demineralized Water	
Intermittent (flush water)	15 GPM

*Could be supplied if service is not readily available.

2. Additional Service Connections

Waste Transfer Piping	(concentrates and resins)
Sluice Water Return	(to resin sluice header)
Distillate Return	(to waste collection or monitor tanks)

3. Space Allocation

Processing Module	an area 15' by 56' or 86'
Dry Storage	for dry inorganic chemicals, 75 square feet
Outside Storage	55 gallon drums of chemical additives and empty waste containers-250 square feet

4. Technical Support

Radiochemical Analysis
Health Physics

SYSTEM DESCRIPTION

The TVR System is self-contained in an enclosed structural steel module. The module is transported to the site on a rail car or is divided into major skids and transported by truck. The system, which is a complete and operable volume reduction and bitumen solidification system, is prewired and prepiped to the maximum extent possible to minimize the number of field connections required.

A material handling system is provided for handling empty and filled drums.

Radiation protection is provided by lead and sand shielding. Metal bulkheads are filled on site with sand which has nearly the same attenuation coefficient as concrete.

Figure 1 is an artist's rendering of the rail-mounted TVR System. A smaller, skid-mounted system with only one batch tank is shown in Fig. 2.

PROCESS DESCRIPTION

The concept is a simple chemical and physical process for reliably and economically reducing the volume of radwaste and for incorporating radwaste into a solidified bitumen matrix. The process uses a Luwa Thin-Film Evaporator, which operates at a waste product temperature of 320^{o}F (160^{o}C). This results in the evaporation of all free water from the waste influents. The remaining solids are homogeneously dispersed in a bitumen matrix. Solidification of the end product occurs upon the natural cooling of the binder.

Figure 3 is the Basic Flow Diagram for the TVR System.

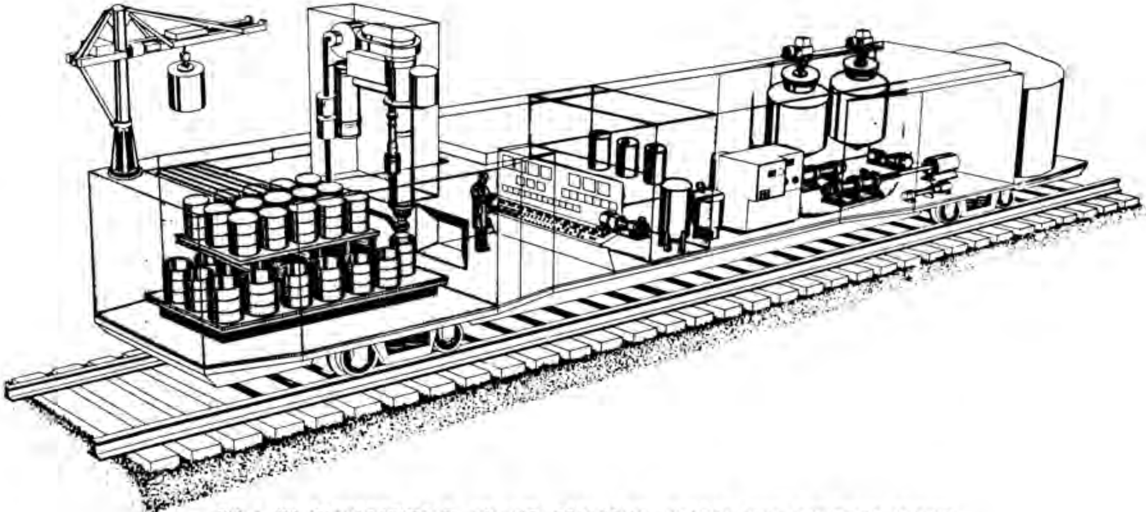

FIG. I ATI TRANSPORTABLE VOLUME REDUCTION SYSTEM, RAIL MOUNTED DESIGN

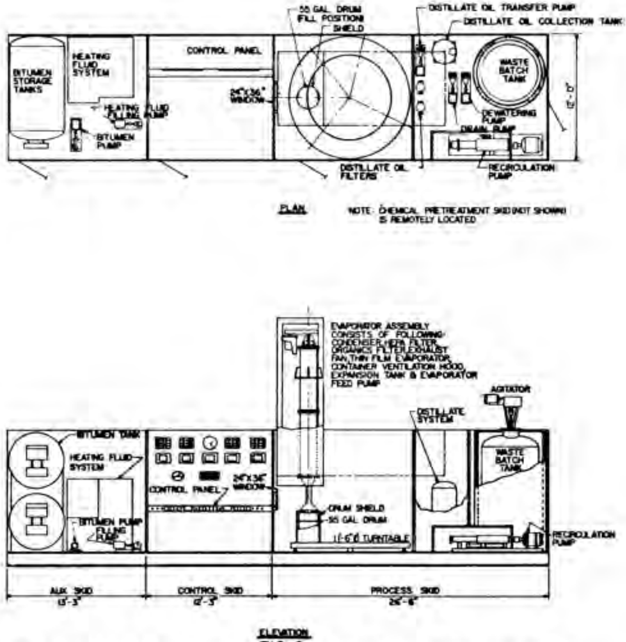

FIG. 2
ATI TRANSPORTABLE VOLUME REDUCTION SYSTEM, SKID MOUNTED DESIGN

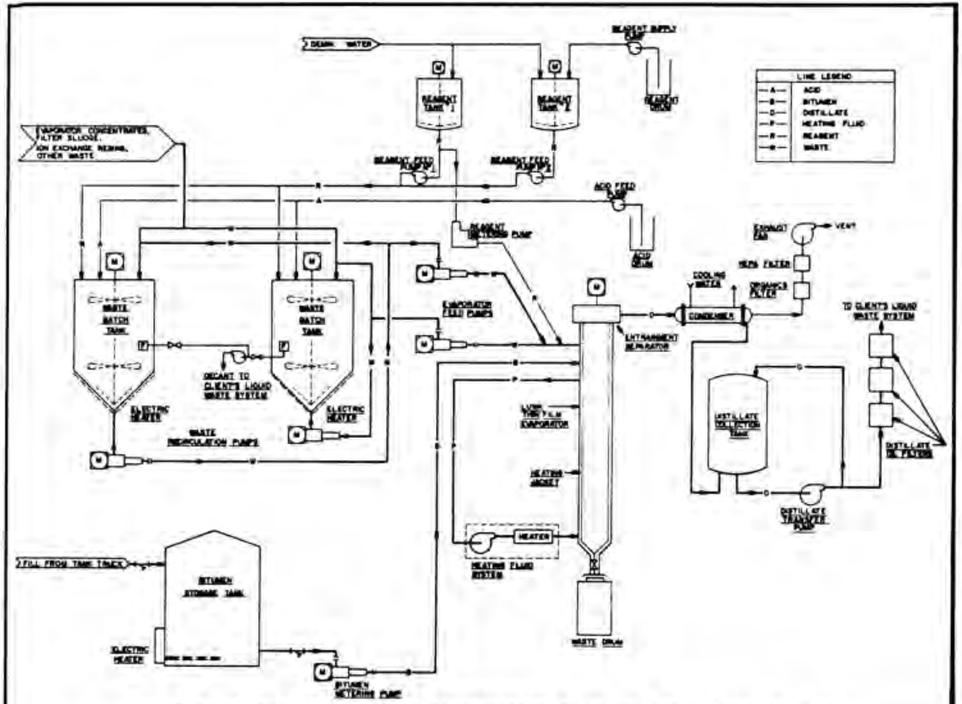

FIG. 3 BASIC FLOW DIAGRAM, ATI TRANSPORTABLE VOLUME REDUCTION SYSTEM

Waste to be processed is charged into one of the Waste Batch Tanks. There it is sampled and chemically pretreated to prepare it for processing. Water is decanted or added as required to obtain the desired concentration for processing.

When the waste has been conditioned for processing, it is fed at a controlled rate to the Luwa Thin-Film Evaporator, Fig. 4. Molten bitumen is also fed into the Evaporator through a second feed nozzle. The Evaporator is heated by means of a hot thermal fluid flowing through an external jacket.

The Evaporator rotor rotates within the cylindrical, heated body, maintaining the waste and bitumen in a thin, turbulent film against the heating surface. The action of the rotor and the force of gravity create a spiral flow path of waste/bitumen mixture as it flows from the top to the bottom of the Evaporator. As the waste flows through the Evaporator, the water is evaporated and the water vapor flows countercurrently upward and out of the Evaporator. The waste solids, which are mixed with molten bitumen, exit the bottom of the Evaporator, flowing into a waste container. Upon cooling, the waste/bitumen mixture solidifies into a free-standing, monolithic, water-free solid.

The water vapor leaving the Evaporator is condensed in a shell-and-tube Condenser and flows into the Distillate Collection Tank. When this tank is filled, the distillate is pumped through a series of activated carbon filters to remove any light oils that may have been vaporized from the bitumen in the Evaporator. The cleaned distillate then enters the plant's liquid waste system.

A Container Ventilation Hood extends from the Evaporator discharge pipe to the top of the waste container to capture any vapors and prevent their escape into the room. Sufficient flow of ventilation air is pulled into this hood (approximately 175 SCFM) to ensure sufficient capture velocities.

The collected vapors and ventilation air are then pulled through an Organics Filter and a HEPA Filter before entering the suction of the Exhaust Fan, which discharges the cleaned air to the plant ventilation system.

A small volume of air (approximately 10 SCFM) is pulled into the discharge pipe of the Evaporator to prevent the "puffing" of vapors out of the Evaporator through this pipe. This ensures the flow of vapors out the top of the Evaporator and into the Condenser.

In the rail-mounted system, a roller Conveyor is used for positioning the waste containers under the Evaporator for filling. When the level in the container reaches a predetermined level, the drive mechanism of the Conveyor is activated to index the drum. This places the next waste container in position for fill. Filled drums are capped by the Cap Crimper, which is located above the Conveyor. When a drum has been filled with

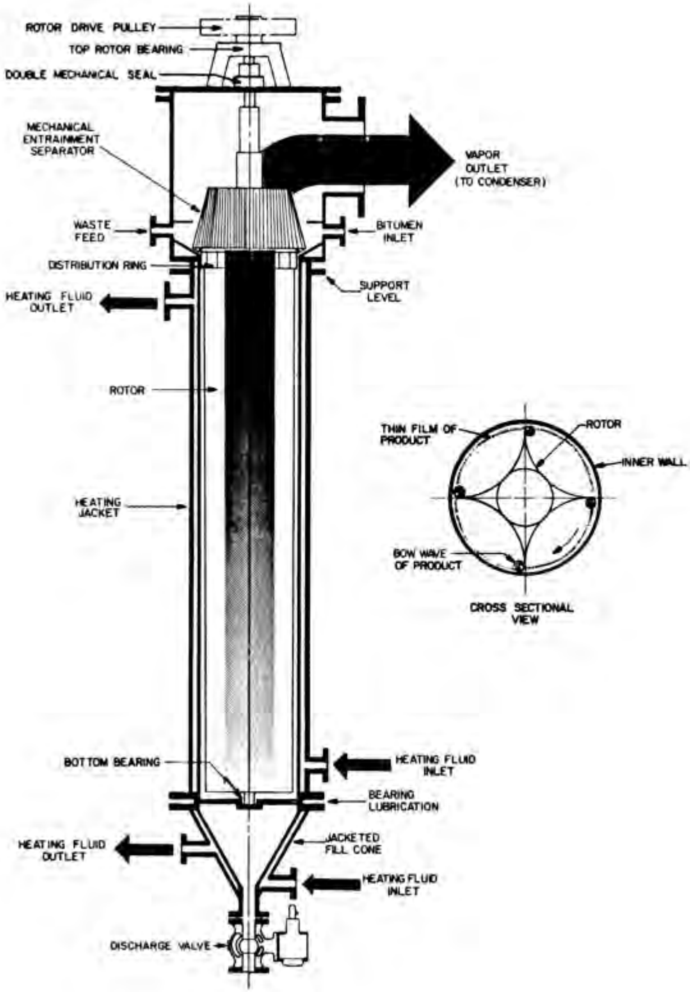

FIG. 4 LUWA THIN FILM EVAPORATOR SCHEMATIC

bituminized waste and has been capped, it is picked up by the Jib Crane and moved to the Storage Conveyor above the filling Conveyor. While the drum is still on the Conveyor it is monitored for contact dose rate by an activity monitor.

When waste is to be shipped, the Jib Crane moves the drums, with the drum shield, into the transportation cask.

EXPERIENCE

The bitumen process is the result of 20 years of operational experience that is made available to ATI through its license agreement with the French engineering firm SGN (General Society for New Technology), and with the French CEA (Atomic Energy Commission). This license agreement has been executed so that American utilities can be provided with a proven volume reduction/bitumen solidification system which is based on considerable research, development and operational experience.

The process has been used to volume reduce and encapsulate radioactive wastes from operating nuclear power plants, research facilities and military facilities, including bead and powdered resin slurries, filter sludge, decontamination wastes, sodium sulfate concentrates, and boric acid concentrates.

The TVR System is a mobile adaptation of the process licensed by the French. This process has been installed as a permanent system in France, Sweden, and Japan (see Table I) and is currently being marketed in the U.S. The mobile version of the system is very similar to the permanent system in its design and operation, but the equipment layout is adapted to facilitate installation on a railcar, or transportation by truck.

Table II is a list of radioactive substances that have been encapsulated in bitumen.

TABLE I. SYSTEM REFERENCE LIST

Facility	Operator	Type of Facility	Waste Type	Luwa Evaporator Model No.	Bitumen System Startup Date	Drums of Solidified Waste
Barsebeck Nuclear Power Station	Sydkraft (Sweden)	Two 590 MWe BWRs	bead resin, powdered resin, lab, decon, sodium sulfate	LN-0100	1975	2500 (as of 11/80)
Mihama Nuclear Power Station	Kansai Electric Power Co. (Japan)	Three PWRs 320, 470, & 780 MWe	boric acid, laundry, decon, chemical	LN-0200	1978	230 (as of 6/79)
Tsuruga Nuclear Power Station	Japan Atomic Power Co.	340 MWe BWR	sodium sulfate, decon, chemical, laundry	LN-0200	1977	250 (as of 6/79)
Advanced Thermal Reactor, Tsuruga	Power Reactor and Nuclear Fuel Development Corp.	200 MWe LWCHWR	equip. and floor drains	LN-0200	1977	33 (as of 6/79)
Cadarache Nuclear Research Center	CEA (France)	Research & Development	Various	LN-0050	1971	No Record

TABLE I. SYSTEM REFERENCE LIST
(cont.)

Facility	Operator	Type of Facility	Waste Type	Luwa Evaporator Model No.	Bitumen System Startup Date	Drums of Solidified Waste
Saclay Nuclear Research Center	CEA (France)	Research & Development	decon, EDTA, phosphates, nitrates, chlorides, ammonia, acids, bases	LN-0050	1975	1000 (as of 10/80)
Valduc Military Center	CEA (France)	Military Weapons	sodium nitrate, diatomaceous earth	LN-0050	1971	2500 (as of 10/80)
Monts d'Arree Nuclear Power Station	Electricite de France	70 MWe GCHWR	sodium nitrate, phosphates	LN-0050	1980	300 (as of 10/80)

TABLE II. RADIOACTIVE SUBSTANCES THAT HAVE BEEN ENCAPSULATED IN BITUMEN

Powdered Ion-Exchange Resins	Ferric Chloride	
Bead Ion-Exchange Resins	Aluminum Chloride	
Diatomaceous Earth	Aluminum Hydroxide	
Solka Floc	Ferric Nitrate	
Sodium Sulfate	Aluminum Sulfate	
Boric Acid	Aluminum Nitrate	
Sodium Borates	Sodium Hydroxide	
Potassium Chromate	Nickel Nitrate	
Sodium Chloride	Chromium Chloride	
Sodium Phosphate	Ammonium Chloride	
Sodium Nitrate	Sodium Citrate	
Trilaurylamine	Poly Phosphate	
Tributylbenzene	Magnesium Sulfate	
Iron Phosphate		
Ferric Hydroxide	Aluminum Oxide	)from
Copper Hydroxide	Calcium Sulfate	)incinerator
Nickel Ferrocyanide	Silica Dioxide	)ash
Ammonium Nitrate		
Calcium Chloride	Manganese Oxide	
Sodium Carbonate		
Potassium Chloride	Sodium Bicarbonate	)
Potassium Ferrocyanide	EDTA	)decontami-
Nickel Sulfate	Hydrogen Peroxide	)nation
Nickel Ferrocyanide	Detergents	)solutions
Ferric Phosphate	TURCO Agent	)
Calcium Phosphate	Radiac Wash	)
Calcium Hydroxide		

LICENSING

The NRC has stated that licensing of volume reduction and solidification services for a facility with an operating license would be addressed under 10CFR50.59 "Changes, Tests, and Experiments." After a determination by the utility that there are no unreviewed safety questions, the holder of an operating license could decide on its own to implement the use of such services.

ATI has published its Topical Report for the Volume Reduction and Bitumen Solidification System. We do not expect any significant changes as a result of NRC review, since the System has been operating in foreign PWR and BWR plants for a number of years.

ECONOMIC COMPARISON OF TREATMENT ALTERNATIVES

The following is an economic comparison of a volume reduction and bitumen solidification service to a cement solidification service. Table III shows the comparison for an 1100 MWe BWR located 600 miles from Barnwell and Table IV is an example for an 1100 MWe PWR located 2500 miles from Hanford.

TABLE III. ECONOMIC COMPARISON OF TREATMENT ALTERNATIVES FOR AN 1100 MWE BWR 600 MILES FROM BARNWELL

	Cement Solidification Service	Transportable Volume Reduction and Bitumen Solidification Service
Chemical Na_2SO_4 (13% wt)	10,000 CF/yr	10,000 CF/yr
Conc. Liquids Diss. solids (10% wt)	2,000 CF/yr	2,000 CF/yr
Resins & Sludges Dewatered	4,000 CF/yr	4,000 CF/yr
Cost of Service	$65/CF	$80/CF
Solidified Waste Volume	29,600 CF/yr	5,200 CF/yr
Treatment Cost (incl. equip. lease)	$1,148,000/yr	$1,280,000/yr
Container Size	200 CF	drums
No. of Shipments	78	53
Transportation Cost (incl. shield rental)	$254,000/yr	$156,000/yr
Burial Cost (at Barnwell)	$547,000/yr	$111,000/yr
Total Annual Cost	$1,949,000/yr	$1,547,000/yr

Savings $402,000/yr

TABLE IV. ECONOMIC COMPARISON OF TREATMENT ALTERNATIVES FOR AN 1100 MWE PWR 2500 MILES FROM HANFORD

	Cement Solidification Service	Transportable Volume Reduction and Bitumen Solidification Service
Conc. Liquids 6% H_3BO_3	10,000 CF/yr	10,000 CF/yr
Resins Dewatered	4,000 CF/yr	4,000 CF/yr
Cost of Service	\$65/CF	\$80/CF
Solidified Waste Volume	26,000 CF/yr	3,400 CF/yr
Treatment Cost (incl. equip. lease)	\$1,018,000/yr	\$1,120,000/yr
Container Size	200 CF	drums
No. of Shipments	69	35
Transportation Cost (incl. shield rental)	\$676,000/yr	\$337,000/yr
Burial Cost (at Hanford)	\$364,000/yr	\$47,000/yr
Total Annual Cost	\$2,058,000/yr	\$1,504,000/yr
Savings		\$554,000/yr