LOW-LEVEL WASTE VOLUME REDUCTION: PHYSICOCHEMICAL SYSTEMS

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INTRODUCTION

Until October 1979 the nuclear waste problem was a combination of diminishing burial space and inflating costs. Now, with recent low-level waste site closures, the problem is more straightforward and far more immediate — minimum burial space. Simply stated, on-site storage is a necessity and volume reduction is a necessity. In some cases, volume reduction (VR) equipment may be called upon to reduce noncombustible liquid wastes to essentially dry salts and/or oxides. In other cases, it may be called upon to reduce combustible solids and liquids to ashes and innocuous gases.

Speaking broadly, four kinds of processes are available to further reduce the volume of waste generated at nuclear facilities. These include high-solids evaporation (evaporator/crystallizers), alternative evaporative designs, extruders/mixers, and calciner/incinerators (oxidation). This paper discusses the following VR processes for radioactive wastes at nuclear facilities:

- Evaporator/Crystallizer;
- Fluid Bed Dryer/Incinerator;
- Fluid Bed Calciner/Incinerator;
- Inert Carrier Radwaste Processor;
- Molten Glass Incinerator.

Volume reduction processes not presented in this paper, but in companion papers at this Waste Management '80 Conference include:

- Thin Film Evaporator;
- Extruder/Evaporators;
- Compaction;
- Shredding;
- Incinerators (Cyclone, Controlled Air, Pyrolysis, Vortex, Rotary Kiln, Agitated Hearth, Moving Belt, Molten Salt,

Acid Digestion, and Microwave Plasma Torch).

Before addressing VR, the paper briefly presents some characteristics of typical radioactive wastes from nuclear reactor power plants to illustrate the types of waste to be reduced in volume.

WASTE CHARACTERISTICS

Nuclear facility low-level waste can be characterized as wet waste (high-purity, medium-purity, chemical, detergent, spent resin, filter precoat, secondary, miscellaneous) or dry waste (contaminated tools, piping, equipment, clothing, wood, trash, etc.) Tables I - V (taken from Ref. 1) summarize typical characteristics for commercial nuclear power plant wastes. Wet wastes are aqueous solutions with dissolved and/or suspended materials (mostly inorganic salts). Dry

Table I. Typical Characteristics of PWR Wet Wastes

Miscellaneous Chemical Waste[a]

Temperature, °F	170
pH	2.5 to 4.0
Boric Acid, wt %	12
Crud, wt %	0.1
Activity, μCi/cc	0.6

Secondary Side Condensate Polisher Regenerative Waste[a]

Temperature, °F	170
pH	2.5 to 4.0
Sodium Sulfate, wt %	14.9
Ammonium Sulfate, wt %	9.6
Sodium Chloride, wt %	2.0
Crud, wt %	0.1
Activity, μCi/cc	1.2

Detergent Wastes - Same as for BWRs.

Bead Resin - Same as for BWRs.

Filter Precoat Backwash - Same as for BWRs.

[a]Characteristics of miscellaneous chemical waste and secondary side condensate polisher regenerative waste are after concentration by evaporation at solubility limit of solution.

Table II. Typical Characteristics of BWR Wet Wastes

	Waste Type						
						Filter Precoat	
Characteristic	High Purity	Medium Purity	Chemical[a]	Detergent	Bead Resin	Powdered Resin	Diatomaceous Earth
Temperature, °F	70 to 150	70	170	70 to 150	70	70	70
pH	6 to 8	6 to 8	6 to 8	7 to 9	-	-	-
Conductivity, μmho/cm	<8	10 to 1000	>10,000	-	-	-	-
Density, g/cc	1.0	1.0	1.18	1.0	1 to 10	0.1 to 500	0.5
Activity (approx.), μCi	3×10^{-1}	3×10^{-3}	1.2-2.0	-	-	-	-
Constituents:							
Water,[b] wt %	>99	>99	75	99	50	50	40
Oils, ppm	trace amounts	<1 (normally)	-	-	-	-	-
Detergents, wt %	-	-	-	1	-	-	-
Suspended solids, ppm	<10	10 to 100	1000	1000	-	5	10
Sodium sulfate, wt %	-	-	22.9	-	-	-	-
Sodium chloride, wt %	-	-	2	-	-	5	-
Resins							
Bead,[c] wt %	-	-	-	-	50	-	-
Powdered,[d] wt %	-	-	-	-	-	40	-
Diatomaceous earth, wt %	-	-	-	-	-	-	40

[a]Characteristics of chemical waste are after concentration by evaporation to solubility limit of solution.

[b]For bead resin and filter precoat type waste, water content listed is interstitial water only.

[c]Bead resin is variable mix of anion and cation resin bead.

[d]Powdered resin is variable mix of powdered anion and cation resin bead.

Table II. Typical Characteristics of BWR Wet Wastes

Characteristic	Waste Type: High Purity	Medium Purity	Chemical[a]	Detergent	Bead Resin	Filter Precoat: Powdered Resin	Filter Precoat: Diatomaceous Earth
Temperature, °F	70 to 150	70	170	70 to 150	70	70	70
pH	6 to 8	6 to 8	6 to 8	7 to 9	-	-	-
Conductivity, μmho/cm	<8	10 to 1000	>10,000	-	-	-	-
Density, g/cc	1.0	1.0	1.18	1.0	1 to 10	0.1 to 500	0.5
Activity (approx.), μCi	3×10^{-1}	3×10^{-3}	1.2-2.0	-	-	-	-
Constituents:							
Water,[b] wt %	>99	>99	75	99	50	50	40
Oils, ppm	trace amounts	<1 (normally)	-	-	-	-	-
Detergents, wt %	-	-	-	1	-	-	-
Suspended solids, ppm	<10	10 to 100	1000	1000	-	5	10
Sodium sulfate, wt %	-	-	22.9	-	-	-	-
Sodium chloride, wt %	-	-	2	-	-	5	-
Resins							
Bead,[c] wt %	-	-	-	-	50	-	-
Powdered,[d] wt %	-	-	-	-	-	40	-
Diatomaceous earth, wt %	-	-	-	-	-	-	40

[a]Characteristics of chemical waste are after concentration by evaporation to solubility limit of solution.

[b]For bead resin and filter precoat type waste, water content listed is interstitial water only.

[c]Bead resin is variable mix of anion and cation resin bead.

[d]Powdered resin is variable mix of powdered anion and cation resin bead.

wastes include contaminated tools, equipment, piping, clothing and trash. The composition varies based on plant inventories. Hospital and institutional waste sources are not presented in this paper. Typical institutional waste sources are addressed in Ref. 2.

Table III. Characteristics of Typical Decontamination Waste Solutions

	Component Decontamination[a]	System Decontamination[b]
Temperature, °F	70	70
pH	4	4
Conductivity, μmho/cm	$>10^4$	$<10^4$
Dow NS-1,[c] wt %	7	7
Water, wt %	93	93
Iron oxide, ppm	600 to 900	1200
Cobalt-60, ppm	1.4 to 1.6	
Total Activity,[d,e] μCi/cc	1.2 to 2.2	0.4

	Building Decontamination[f]		
		Activity, μCi/cc	
Temperature	70	I-131	0.6
pH	5	Ce-134	0.4
Radiac Wash,[g] wt %	5	Ce-136	0.2
Crud, wt %	5	Ce-137	1.4
Oil, wt %	2	La-140	5.2
Water, wt %	80	Ba-140	3.6

[a]Data for component decontamination is based on decontamination of regeneration heat exchangers at Peach Bottom Units 2 and 3.

[b]Data for system decontamination is based on test loop set-up for decontamination of Dresden Unit 1 reactor coolant system.

[c]Dow NS-1 is a proprietary mixture of EDTA, inorganic salts, and organic inhibitors.

[d]Total activity for component decontamination is based on 50/50 vol % mixture of decon. solution and rinse water.

[e]Total activity for system decontamination is based on 30/70 vol % mixture of decon. solution and rinse water.

[f]Data for building decontamination is based on decontamination of auxiliary building at Three Mile Island Unit 2.

[g]Radiac wash is a proprietary decontamination solution.

Table IV. Characteristics of Typical Dry Waste Material from Commercial Reactors

Combustible Waste[a]

Content - Paper, rags, throw-away protective clothing, wood, etc.

Bulk Density - Varies greatly (usually >0.5 gm/cc)

Activity - 0.25 to 2.5 mCi/m^3

Limitations - no PVC
radiation field <5 mr/hr on contact

Compactible Waste[a]

Content - Paper, rags, throw-away protective clothing, etc.

Bulk Density - Varies greatly (usually >0.5 gm/cc)

Activity - Varies greatly (typically 0.25 to 2.5 mCi/m^3)

Limitations - Radiation field <200 mr/hr on contact

Noncombustible/Noncompactible Waste[a]

Content - Pipe, valves, tools, pump casings, air filters, pipe insulation, scrap metal from machine shop, etc.

Quantity - 272 m^3 in 1978

Core Components

Content - Control rods, poison curtains, in-core chambers, etc.

Activity - Varies greatly (typical values range from 5 Ci/ft^3 to 8000 Ci/ft^3)

Cartridge Filter Elements

Size - Varies (typically 7" dia. x 27" long)

Weight - Varies (typically 10 to 15 lbs per element)

Radiation Level - Varies (typically 20 to 100 R/hr on contact)

[a]Based on data from Bruce Nuclear Power Development Site.

Table V. Sources of Waste with Significant Amounts of Radioactive Material from Decommissioning the Elk River Nuclear Plant

Component	Inventory (Ci)	Maximum Contract Radiation Level-(R/hr)
Internals		
Upper shroud	770	2800
Lower shroud	35	175
Core and shroud plate	2370	8000
Core support stand	100	150
Inner thermal shield	3090	1000
Shadow shields	2330	3000
Feedwater distribution ring	75	60
Pressure Vessel	1110	115
Outer Thermal Shield	75	1
Total	9950	

ADVANCED VOLUME REDUCTION PROCESSES

Traditional processes used to treat and reduce the volume of low-level waste at nuclear facilities have been filtration, ion exchange, conventional evaporation, reverse osmosis, and compaction. Advanced VR processes are receiving much attention due to increasing economic and political pressure to reduce even more the waste volumes for ultimate disposal. Several of these are described in the following sections.

Evaporator/Crystallizer

The evaporator/crystallizer system is one of the processes for high-solids evaporation. In evaporative crystallization a supersaturated solution is generated by the evaporation of water from the solution. Control of the combined effects of nucleation rate, growth rate, heat balance, and material balance is used to produce the desired crystals and concentrated liquor. An evaporator/crystallizer system based on radwaste evaporator design, as used in several commercial nuclear power plants, is being marketed. The unit is a specifically designed forced-circulation evaporator consisting of a vapor body, recirculation pipe, large recirculation pump and heater. Liquor is withdrawn from the bottom of the vapor body, pumped at a high flow rate through the heat exchanger, and returned to the vapor body, where it flashes to steam. The vapors leave the vapor body and pass through a demister before being condensed in a shell and tube cooler/condenser. The demister can be attached directly to the vapor body or can be a separate vessel. Crystallizers are applicable to both PWR and BWR plants. They can process sodium sulfate, ammonium sulfate, and boric acid solutions to 50 percent total solids (by weight). A typical evaporator/crystallizer system is shown in Fig. 1.

Fluidized Bed Dryer/Incinerator

Fluidized bed drying of liquid radioactive waste is an incineration (oxidation) process. In this process (Fig. 2), the liquid waste is sprayed into a vessel containing a starter bed of granular material, such as fine sand, which is fluidized by a preheated stream of air. The bed is further heated by electrical heater elements to an operating temperature of 850° to 900°F. At this temperature, water in the waste feed is evaporated, leaving a dry, granular salt behind in the bed. Leaving the vessel is a gas stream consisting of water vapor, hot gases, and fine salt particles. A cyclone separates the solid materials from this stream and drops them into a product storage hopper. To maintain a constant bed depth as more waste material is processed, a portion of the bed is periodically removed through a screw conveyor, cooled, and taken to the product storage hopper. Liquid wastes are processed in the fluid bed dryer. Dry combustible waste and contaminated oil are volume reduced by oxidation in a separate, fluidized bed, incinerator vessel (Fig. 2). Combustible waste passes through a metal detector, is shredded, and blown into the vessel. Combustion of this waste takes place at a temperature of 1,450°F. The products of this combustion process, both solid and gaseous, are removed as an overhead stream and processed in the off-gas system described previously for the fluid bed dryer. Since no waste material is added to the bed, it is normally not necessary to remove any bed material from the vessel during operation.

Fluidized Bed Calciner/Incinerator

A fluidized bed calciner/incinerator for volume reducing radioactive liquid wastes and combustible dry waste is being commercially marketed (Fig. 3). Calcination is a high temperature process in which aqueous salt solutions, dewatered resins, or combustible dry wastes are burned to form stable, free-flowing, inorganic salts or

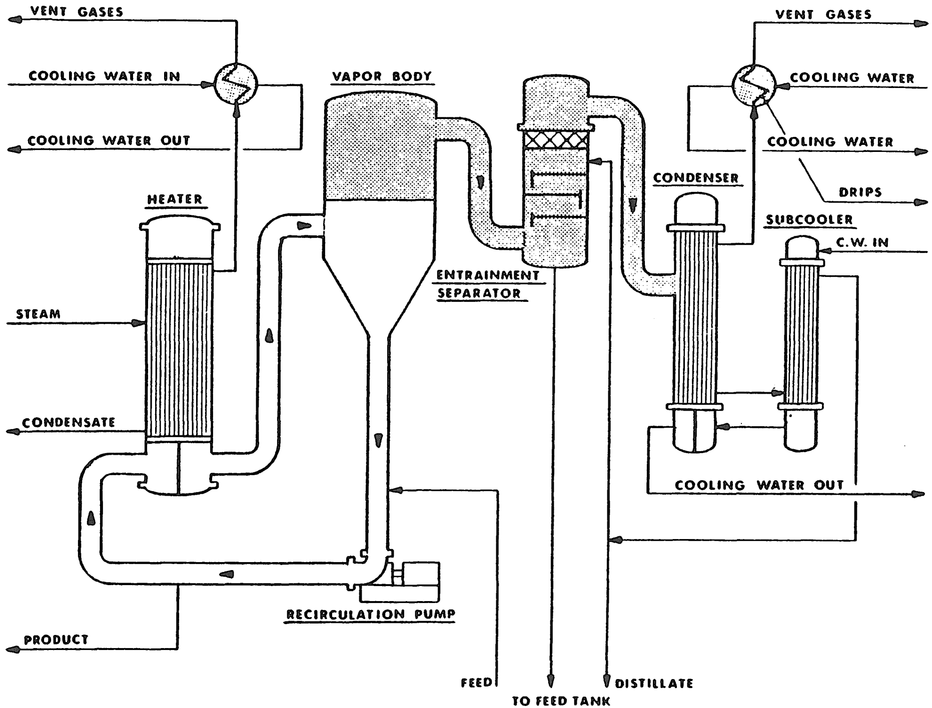

Fig. 1. Evaporator/Crystallizer Flow Diagram.

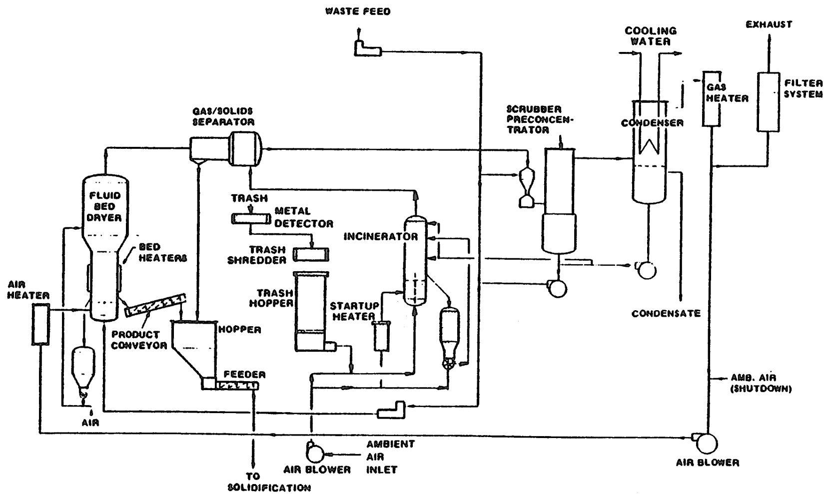

Fig. 2. Flow Diagram of Fluidized Bed Dryer/Incinerator Using Separate Vessels for Drying and Incinerating.

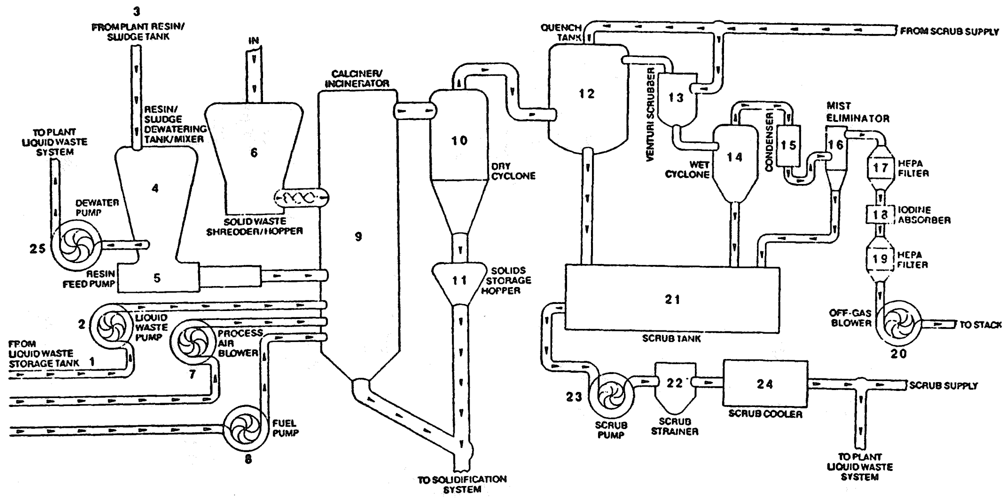

Fig. 3. Flow Diagram of Fluidized Bed Calciner/Incinerator Using Single Vessel for Calcination and Incinerating.

oxides. The calciner is similar in operating principle to the fluidized bed dryer discussed previously. However, for the calciner system, both the liquid wastes and dry combustible wastes are processed in one vessel containing an air fluidized bed of inert granular material. The bed is heated by injecting kerosene or a similar heating fuel into the bed. By adding an excess quantity of fluidizing air to the calciner vessel, all of the calcination products formed (both liquid and solid waste feed stocks) are removed with the off-gas. These solids are then separated from the off-gas in a dry cyclone and drop by gravity into a product storage hopper. Any remaining particulate matter in the off-gas stream is removed by a quench tank and wet cyclone/wet scrubber system. The off-gas passes through a condenser and demister section to remove residual moisture before passing through HEPA filters and an iodine absorber prior to discharge.

Inert Carrier Radwaste Process (ICRP)

The ICRP is an extension of well-developed technology initially used to separate dangerous chemicals such as rocket propellants in a safe environment. The system as shown in Fig. 4 consists of a simple pot evaporator, an external shell and tube heater, and a large capacity pump which continuously recirculates an inert heat transfer fluid between the heater and pot boiler. The ICRP is said to be able to handle all types of liquid and slurry wastes generated at commercial nuclear power plants. It is claimed that the maximum possible volume reduction factor (without going to a system that breaks the waste down into elemental compounds) can be achieved by this method. Although it is being marketed as a combined volume reduction/solidification system, the ICRP can also be used simply to take the waste feed to dryness without solidification. Feed/distillate decontamination factors have not yet been determined for radionuclides, but all tests with nonradioactive wastes have resulted to date in distillates of high quality. Concern about possible scaling or epoxy adhering to the walls of the vessels and piping has led to the use of Teflon linings on most internal surfaces. The durability of this lining in a thermally hot, radioactive environment over long periods of time has not yet been fully demonstrated.

Molten Glass Incinerator

The molten glass incinerator has been developed for incineration and solidification of combustible material using an electric glass melter or "electromelter." The electromelter, which has been used for over thirty years in the glass industry, is a refractory-lined, electric furnace in which a fixed volume of molten glass is

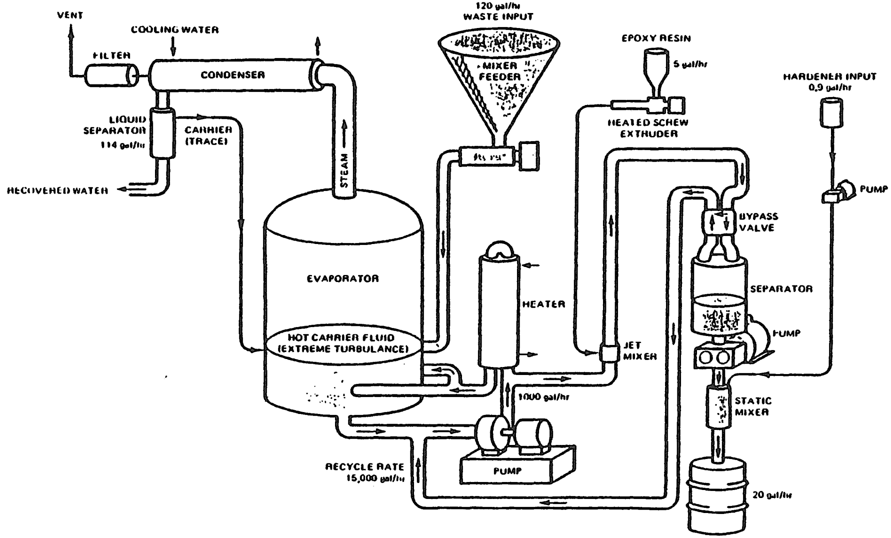

Fig. 4. Flow Diagram of ICRP Volume Reduction System.

maintained at 2,300°F. Waste is fed into the unit and completely burned as a result of the high temperatures. The ash product mixes with the molten glass. Periodically, when the molten glass/waste mixture reaches a certain level, a small portion is drawn off through a gravity drain line and into a drum where it cools and solidifies. The solidified product is reported to be a very stable solid with excellent leach resistance properties. A small test unit electromelter has been installed to demonstrate the feasibility of this method of waste incineration/solidification. Currently, a full-scale, prototype of the unit proposed for commercial operation is under construction. This unit, sized to process 2,000 lb/hr of paper waste, or 20 wt % boric acid solution, is shown in Fig. 5.

CONCLUSION

The nuclear industry has needed development of enhanced volume reduction processes to reduce the quantities of waste shipped to burial sites. The pressure placed on the nuclear operators have caused the industry to advance and speed up technological development of advanced volume reduction equipment and systems. Through the efforts of dedicated scientists and operators utilizing advanced volume reduction equipment, the quantity of waste shipped from nuclear sites to disposal sites can be drastically reduced.

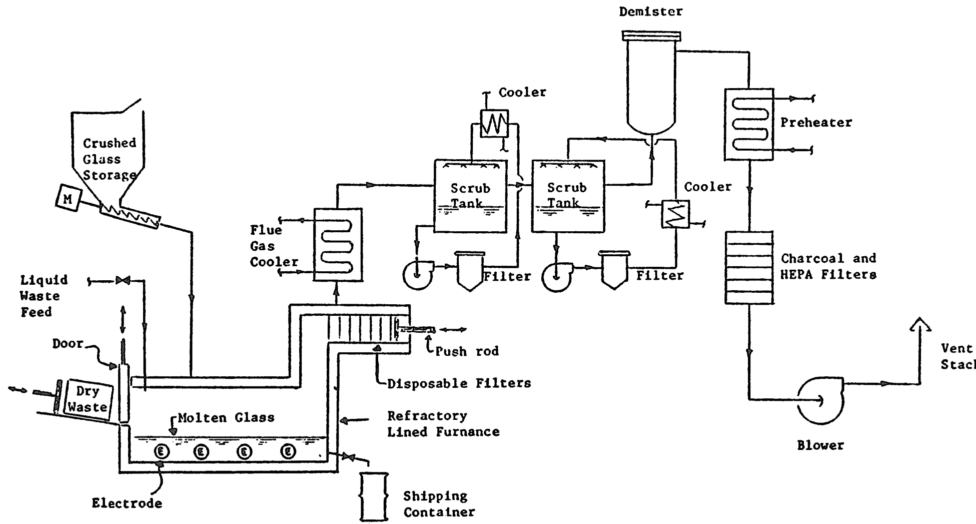

Fig. 5. Flow Diagram of Molten Glass Incinerator.

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1. Anon. "State of the Art Review of Radioactive Waste Volume Reduction Techniques for Commercial Nuclear Power Plants," Gilbert/Commonwealth, Reading, Pennsylvania, December 1979.

2. T. J. Beck, L. R. Cooley, and M. R. McCampbell, "Institutional Radioactive Wastes - 1979", NUREG/CR-1137 (October 1979).