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WASTE IMMOBILIZATION PROCESS DEVELOPMENT AT THE SAVANNAH RIVER PLANT

by

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ABSTRACT

Processes to immobilize various wasteforms, including waste salt solution, Transuranic waste, and low-level incinerator ash, are being developed. Wasteform characteristics, process and equipment details, and results from field/pilot tests and mathematical modeling studies are discussed.

INTRODUCTION

High-level, Transuranic (TRU) and low-level wastes are produced as a result of routine operation of the Savannah River Plant (SRP) and Savannah River Laboratory (SRL). Various processes are used or are planned to prepare these wasteforms for ultimate disposal, including vitrification, incineration, compaction, immobilization/stabilization, and shredding. Table 1 is a summary of the wasteforms, processes, and ultimate disposition of the wasteforms. This paper has three sections, addressing:

- immobilization of decontaminated salt from the high-level waste (Saltstone);
- TRU waste processing; and
- stabilization of low-level incinerator ash.

Note that, while the other wasteforms are not addressed here, the processing technology is similar to those discussed.

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* The information contained in this article was developed during the course of work under Contract No. DE-AC09-76SR00001 with the U.S. Department of Energy.

TABLE 1. Waste Processing at SRP - Overview

Wasteform	Processing Methods	Ultimate Disposal
High-level waste	Vitrification Immobilization	Repository Vault
TRU waste	Size Reduction Decontamination Incineration	Repository Recovery
Low-level waste	Incineration Compaction	Low-level disposal
"Mixed" waste	Incineration Immobilization	RCRA approved landfill or "delisting"
RCRA Hazardous	Incineration Immobilization	RCRA approved landfill or "delisting"

A facility to solidify the high-level waste now stored in waste tanks at SRP by vitrification into borosilicate glass is scheduled to begin operations in 1990. Waste will be prepared for vitrification by processing in the existing waste storage tanks. A resulting low-level decontaminated salt solution will be solidified with a cement/flyash mixture and disposed of in surface vaults at SRP. Data from large-scale lysimeters and numeric models have been used to develop the disposal area design.

As a result of normal operation and decommissioning activity at SRP, TRU waste is generated and is being retrievably stored on concrete storage pads. To retrieve, process, and prepare this waste for disposal, a TRU Waste Facility will be designed and built in the late 1980's. Development work to support this effort is in progress, which includes testing and cold run-in of a large, low-speed shredder and material handling system, a robotically controlled manipulator,and an incineration process. As part of this work, a simple model of radiolytic gas generation and diffusional transport has been developed that gives realistic results.

Low-level solid and solvent wastes are currently being burned in a Beta-Gamma Incinerator (BGI). A process to stabilize the ash and produce a wasteform that resists subsidence or leaching upon burial is in progress. A self-contained ash-solidification unit is now being tested.

SALTSTONE

The Defense Waste Processing Facility (DWPF) is being built at SRP (Figure 1A and 1B) to solidify high-level defense waste, now stored in waste tanks, by vitrification into borosilicate glass. The vitrified waste will initially be stored in an interim storage facility at SRP for eventual shipment to a federal repository.

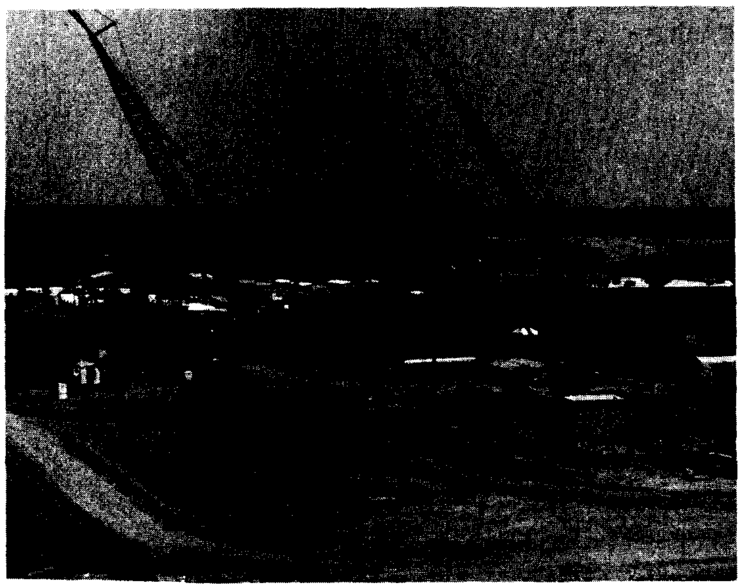

FIGURE 1A. DWPF Plant Under Construction

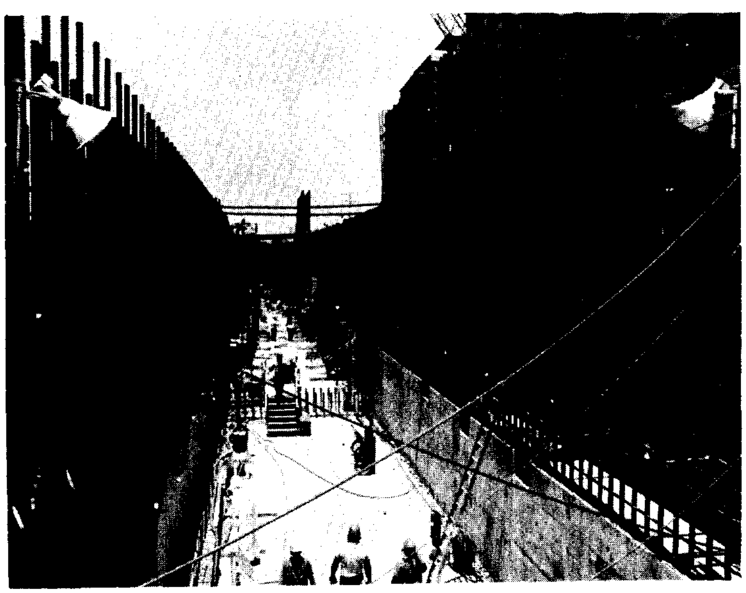

FIGURE 1B. DWPF Canyon Under Construction

Figure 2 shows an overall flowsheet for the DWPF. In-tank processing is accomplished by:

- precipitation of cesium by adding sodium tetraphenylborate; and
- removal of strontium by adsorbtion onto sodium titanate

to produce a decontaminated salt solution and a precipitate (see Figure 3). The precipitate is vitrified along with the sludge in the DWPF. The waste salt, a low-level radioactive (200 micro-Curies/liter) and hazardous (pH>12.5 and chromium of 160 ppm) waste (see Table 2), is mixed with a blended cement and pumped into surface disposal vaults.

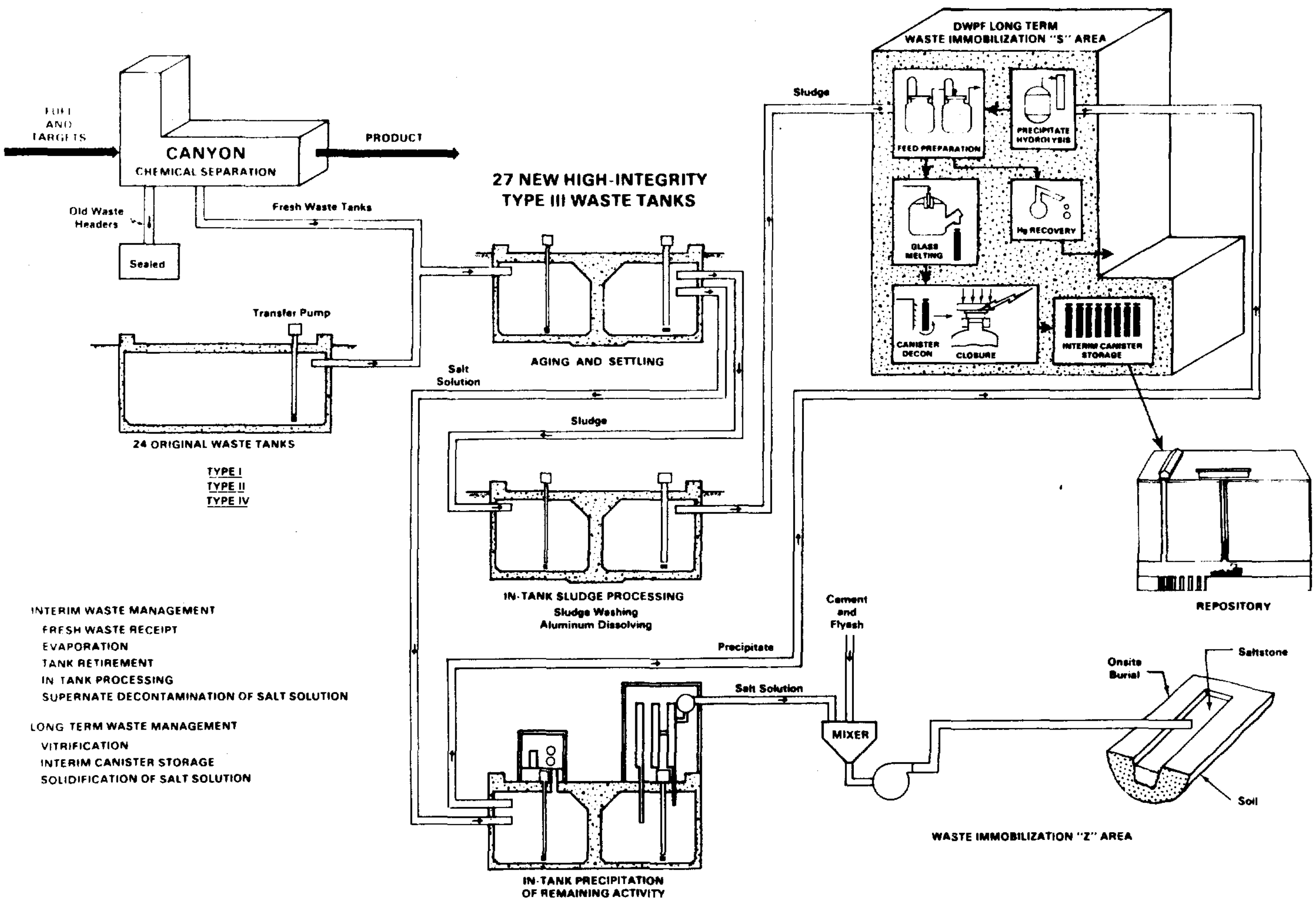

FIGURE 2. High-Level Liquid Waste Management, SRP

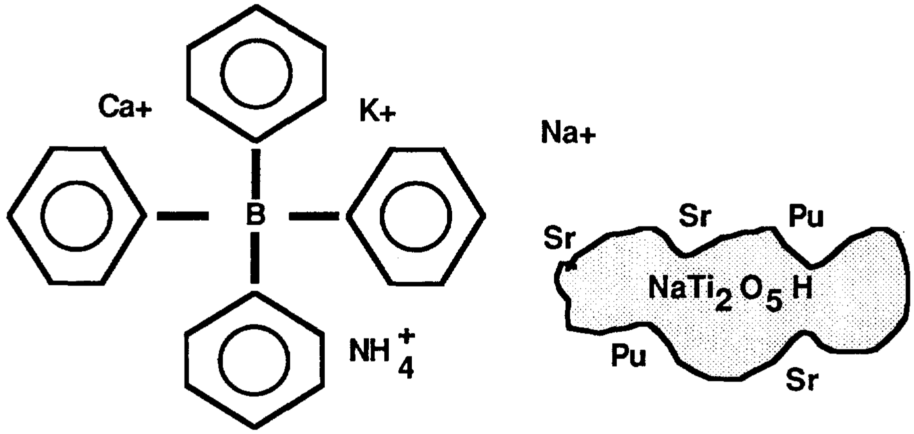

FIGURE 3. Precipitation Process Chemistry

TABLE 2. DWPF Salt Solution Composition

Nonradioactive Component	g/L	Radioactive Component	mCi/L
Na^-	117	^{90}Sr	0.9
NO_3	130	^{99}Tc	36.9
$NO_2^=$	30	^{137}Cs	24.6
OH^-	20	Alpha emitters	0.2
$NaB(C_6H_5)_4$	69		
Cr	0.2 (160 ppm)	Total radioactivity	200
Hg	1.5×10^{-6} (0.01 ppm)		
Ag	1.2×10^{-7} (0.0008 ppm)		

The Saltstone formulation (Table 3) results in a nonhazardous wasteform. Testing by the Extraction Procedure-Toxicity Test has shown that chromium and other metals in the leachate are at acceptable levels.

TABLE 3. Blended Cement Formulation

Portland cement (Class H)		11.5 wt %
Flyash (Class C)		46.0 wt %
	Subtotal	57.5 wt %
Salt		12.3 wt %
Water		30.2 wt %

Even though the formulation passed EP-Toxicity tests for hazardous constituents, the State of South Carolina has adopted the EPA drinking water standards as the groundwater quality standards to be met at the disposal area boundary. Therefore, leaching of the nitrates is of substantial interest and has been studied by laboratory tests, field tests, and mathematical modeling to develop a concept for design of the disposal area.

Laboratory Studies

Laboratory leach studies showed that diffusion controls the release of nitrates, technetium, and cesium while strontium is probably a dissolution-controlled mechanism. The effective diffusion coefficient of nitrates was found to be 1.04×10^{-8} cm^2/sec. Leaching tests were also done using unsaturated soil to simulate burial of saltstone in earthen trenches. No effect on leach rate was observed until the soil water was reduced to 1% (natural field capacity is about 20% water by volume). This showed that diffusion of salts from saltstone into the surrounding medium is the controlling mechanism and the observed leach rate is expected to be the same.

Field Studies

In 1983, three lysimeters were built to test the performance of the disposal of saltstone in earthen trenches. Thirty-ton monoliths of saltstone were prepared from actual decontamination SRP waste salt solution. Each monolith was formed by pouring saltstone grout into an earthen trench contained in a Hypalon-lined basin (see Figure 4). One lysimeter contains only the monolith, the next contains a monolith covered by a clay cap, and the third monolith is covered by a gravel cap. Samples of percolate water (sump) and soil moisture are periodically collected and analyzed.

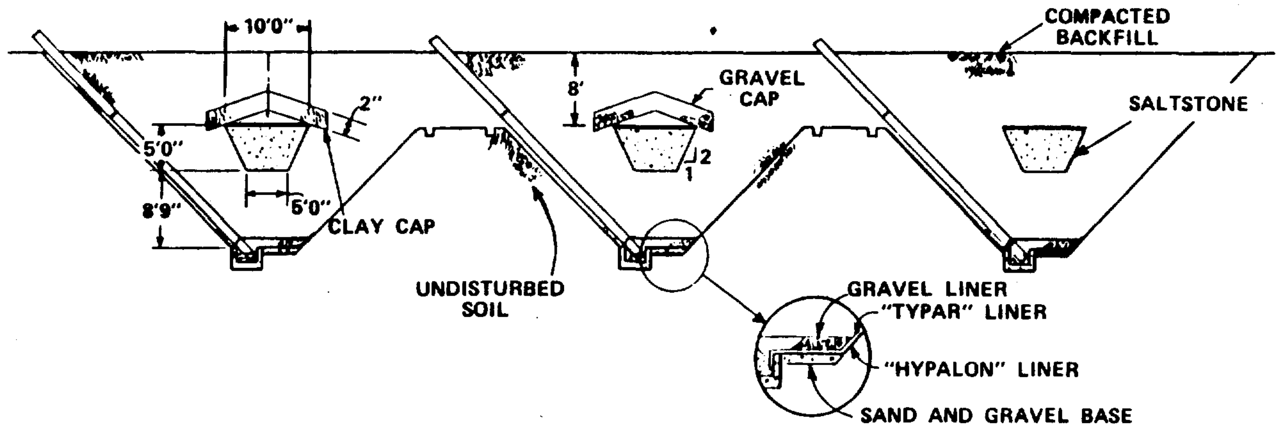

FIGURE 4. Saltstone Lysimeter Tests

Nitrate concentrations from the three lysimeter sumps are shown in Figure 5. Nitrate in the two capped lysimeters is coincident with natural levels in the groundwater, thus only the uncapped lysimeter has released significant levels of nitrate to the sump. Technitium-99 has also been found in the uncapped lysimeter, but not in the capped ones.

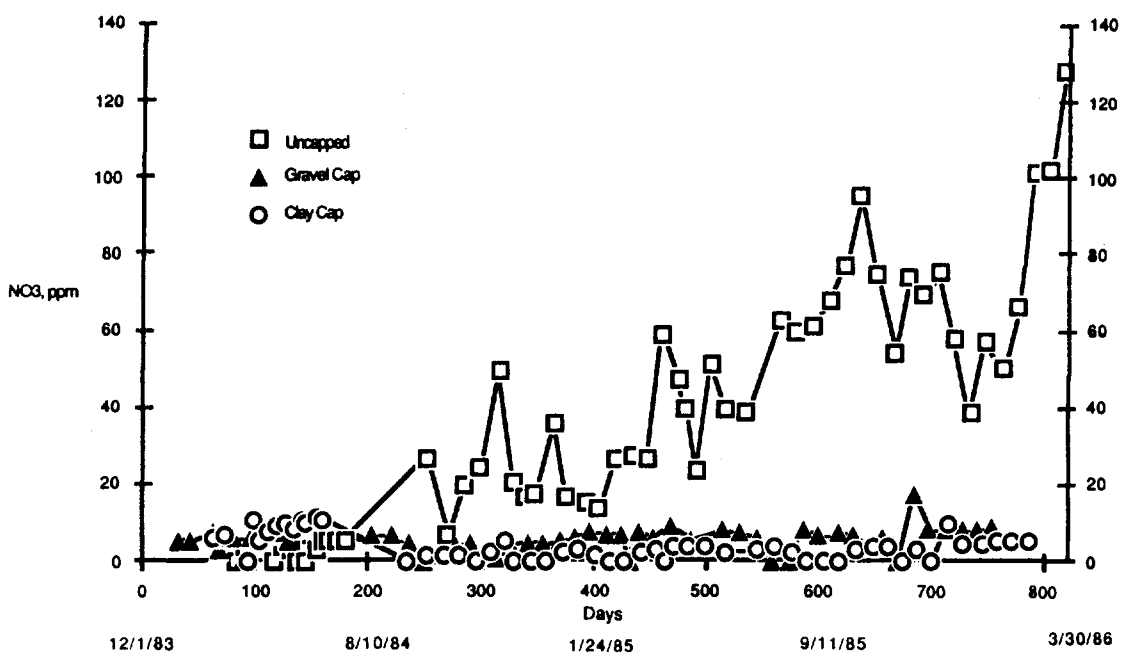

FIGURE 5. Saltstone Lysimeters - Nitrate Release

Release Modeling

Numeric models were used at SRL and by a subcontractor (Intera Technologies, Austin, TX) and have been validated by comparing model results with lysimeter observations (Figure 6).

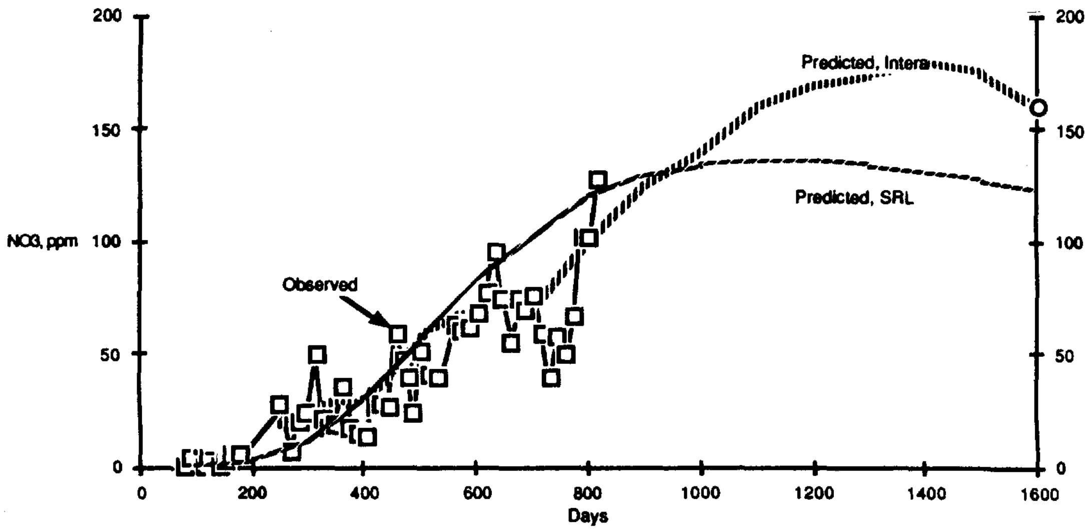

FIGURE 6. Uncapped Saltstone Lysimeter SRL and Intera Model Results

The SRL model assumes that water moves through the soil as if it were saturated with water; the Intera model uses a two-phase, unsaturated model to simulate rainfall moving through unsaturated porous media. Based on the model results, nitrate concentrations in groundwater would exceed standards if unlined earthen trenches were used for disposal.

Disposal Area Design

Table 4 shows affects of liners, caps, and monolith size on nitrate release rates. The preferred conceptual design (Figure 7) is a surface disposal vault made of concrete. The floor, sides, and sloped top are 2.5, 1.5, and 2 feet thick, respectively.

TABLE 4. Factors to Reduce Releases

o Monolith size:	Release proportional to surface area/volume Year-size monolith reduces releases by 3X
o Monolith liner:	2 feet of concrete reduces releases by 14X 5 feet of clay reduces releases by 11X
o Landfill cap:	98% effective cap reduces releases by 5X 99% effective cap reduces releases by 7.7X

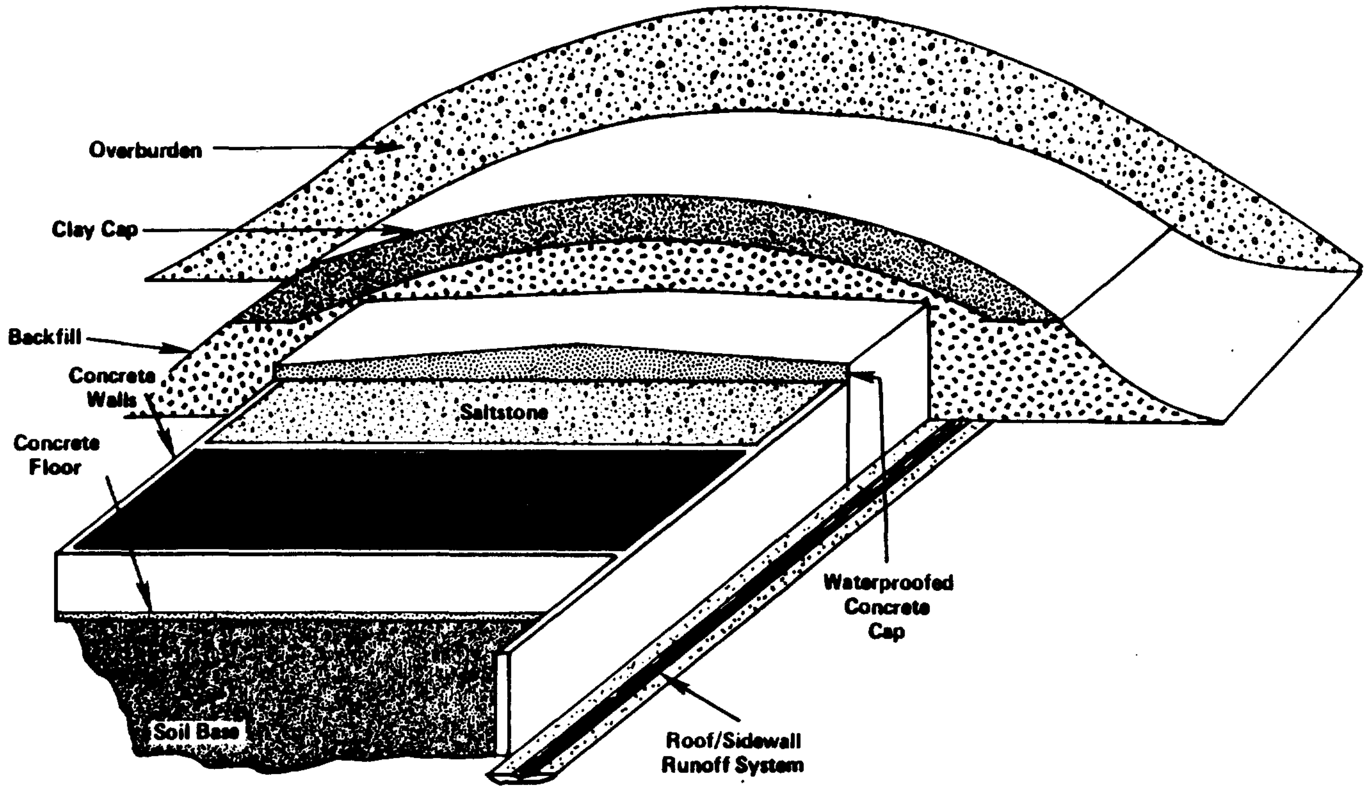

FIGURE 7. Saltstone Surface Disposal Vault

Predicted maximum concentrations of contaminants from the surface vault are below groundwater standards (Table 5). No contaminants are released to the groundwater for the first 200 years; maximum groundwater concentrations do not occur until 1000 years after final closure.

TABLE 5. Predicted Maximum Release from Saltstone (1000 Years After Decommissioning)

Component	Concentration in Saltstone	Predicted Peak Groundwater Content	Groundwater Standard
NO3-	9300 ppm	0.6 ppm	10.0 ppm
^{90}Sr	0.3 nCi/g	3.0×10^{-10} pCi/L	8.0 pCi/L
^{99}Tc	26.0	700.0	900.0
^{106}Ru	12.0	$<1.0 \times 10^{-10}$	30.0
^{137}Cs	9.0	2.3×10^{-8}	200.0

TRU WASTE

TRU waste (mostly Pu-238 and Pu-239 contaminated material) is defined as waste that contains >100 nCi/gram of alpha-emitting transuranium radionuclides with half-lives greater than 20 years. It is generated as a result of production, laboratory, and decommissioning activity at SRP and SRL. The noncombustible fraction of the waste consists of decommissioned gloveboxes and process equipment; the combustible fraction includes plastic, cellulose, rubber and tramp metal, and glass from job control waste. About 140,000 ft^3 of this waste, containing 600,000 Ci, has been stored retrievably on concrete storage pads within a low-level waste burial ground since 1974 (see Figure 8) in drums, steel boxes, and drums inside concrete culverts.

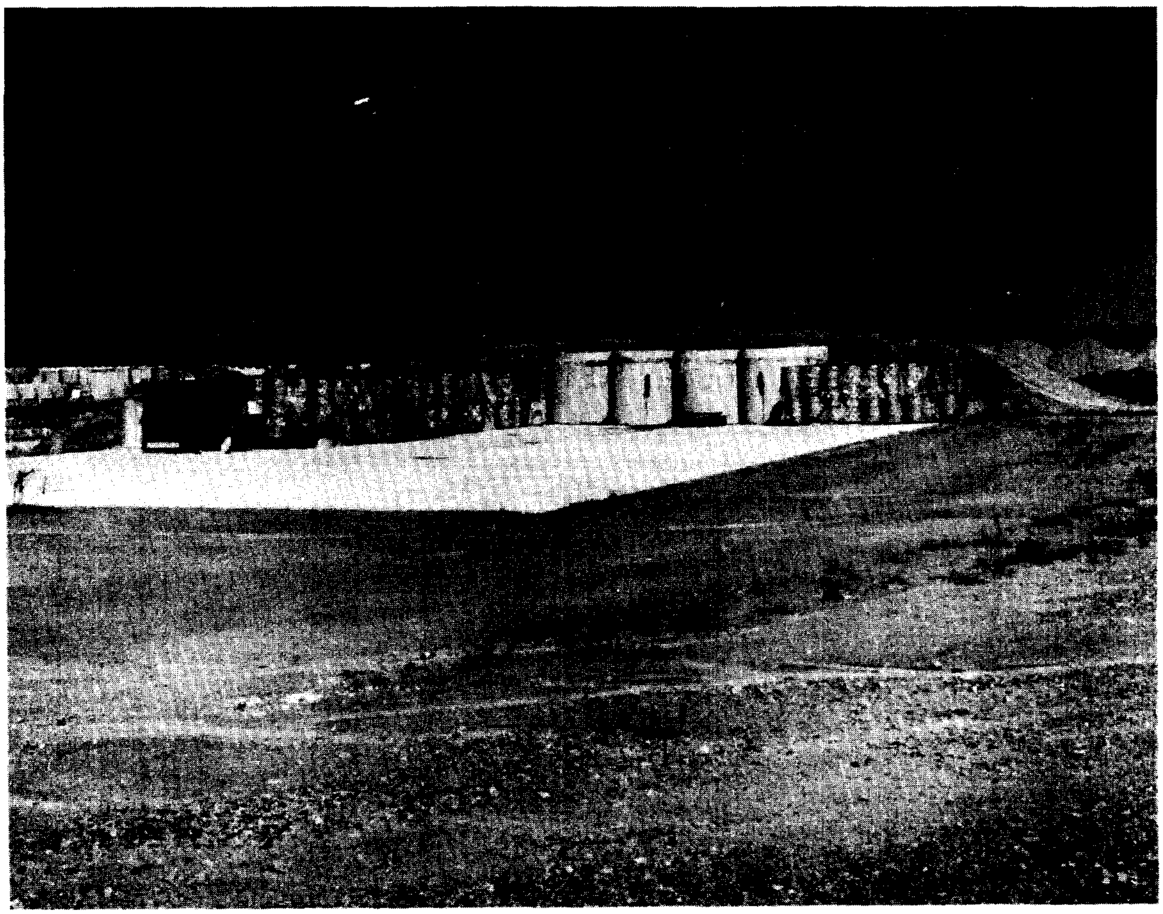

FIGURE 8. TRU Pads

SRP TRU Waste Plan

The SRP TRU Waste Management Plan is shown in Figure 9. The Pu-239 contaminated waste will be certified and shipped to the Waste Isolation Pilot Plant (WIPP); the Pu-238 waste will either be certified and shipped to WIPP or will be processed for recovery or incorporation into the high-level waste/DWPF system.

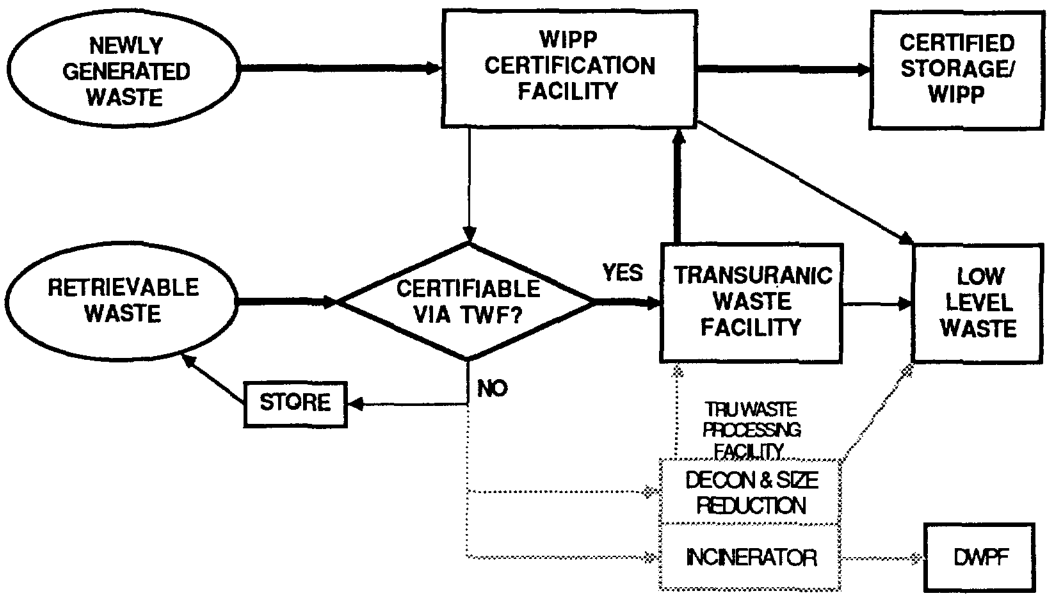

FIGURE 9. SRP TRU Waste Management Plan

The x-ray and assay parts of the WIPP Certification Facility have been started up for preliminary checkout. SRP will begin certifying and storing waste for eventual (late '80's or early 90's) shipment in mid-1986. A TRU Waste Facility is planned (proposed by FY'88 project authorization) to retrieve the waste and prepare it for shipment to WIPP. The project will process Pu-239 contaminated waste; later modules will be added to allow processing of the Pu-238 waste.

Flowsheet - Pu-239 Waste

The flowsheet for the Pu-239 waste is shown in Figure 10. At the TRU pad, the four-foot layer of soil will be removed using conventional earth moving equipment. The remaining soil will be vacuumed up with a large vacuum truck. Drums will be picked up remotely (as the potential for explosive mixtures of radiolytically generated hydrogen gas exists within some drums) and placed in a transportation cask.

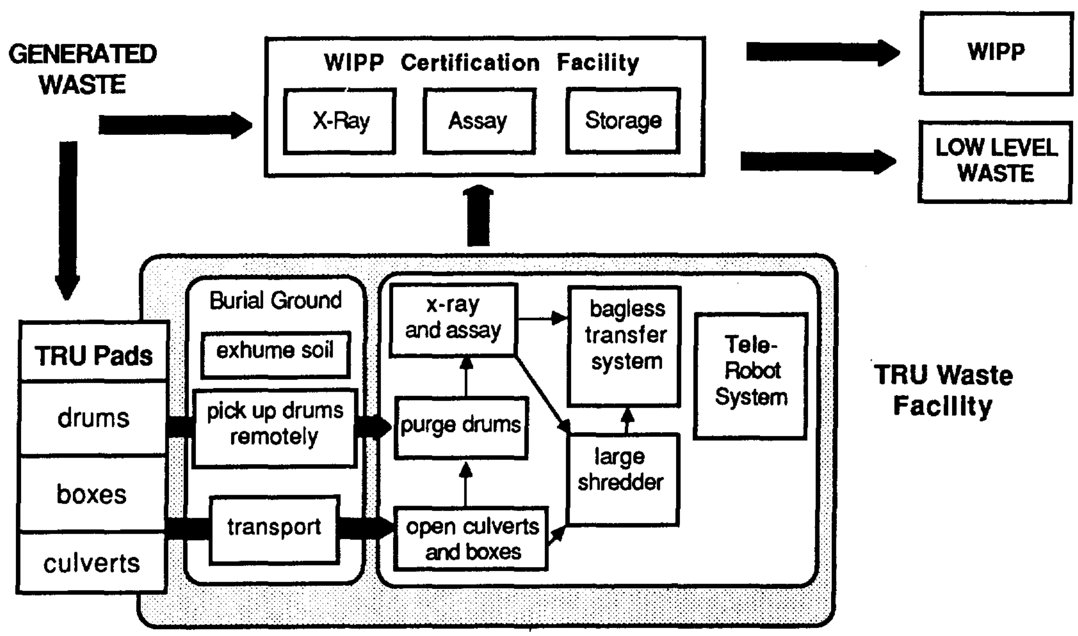

FIGURE 10. Pu-239 Waste Flowsheet

After transport to the central facility, the drums will be unloaded, purged and vented, inspected, x-rayed, and assayed. If necessary, the drums can be overpacked or shredded. Drums that do not meet the WIPP Certification Criteria are sent back to the storage pads for later processing. A 9-axis electro-mechanical manipulator (Telerobot) will be used for all remote operations and will be capable of assisting with equipment maintenance. The initial project will provide equipment needed to demonstrate culvert opening.

The status of the technology for each step in the flowsheet is shown in Table 6. Preliminary tests of the large shredder and material handling system, and bagless transfer system are complete. A prototype Telerobot has been received and is being tested. Prototype remote drum handling and culvert opening machines will be received within the year for testing. An integrated test facility is now being built that will allow extended performance and maintenance testing of the shredder, material handling systems, bagless transfer system, and Telerobot (see Figure 11). This facility will startup 1Q-FY-87 and will be operated for two years.

TABLE 6. Pu-239 Waste: Certification and Retrieval Technology Status

Certification	
X-ray	developed
Assay	Los Alamos - some SRL assistance in training will be required
Retrieval (Burial Ground)	
Exhume soil	known
Remote drum handling	SRL - authorization pending
Transport	known
Processing	
Drum purging	Idaho National Engineering Lab technology - SRL demonstration authorization pending
Culvert opening	SRL development
Shredding and material handling	SRL demonstration - in progress
Bagless transfer	complete
Telerobot	SRL development - in progress

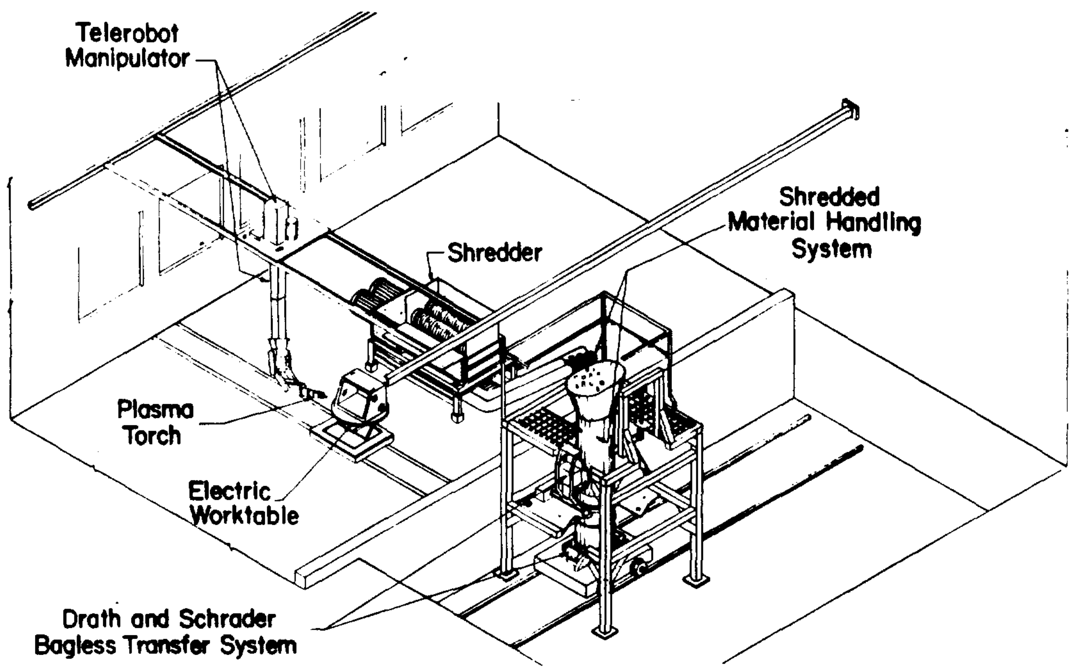

FIGURE 11. Size Reduction and Material Handling Demonstration Facility

Shredder and Material Handling Tests

The size reduction and material handling demonstration facility (Figure 11) will demonstrate remote size reduction and material handling techniques to be used in processing items such as gloveboxes, piping, valves, small process vessels, etc. Feed materials are prepared using the Telerobot in conjunction with an electric worktable. After preparation, items are placed onto the shredder loading door and raised into the shredder. Shredded material drops onto a conveyor and is carried into a drum hopper. A level sensing device shuts down the conveyor and shredder when the drum hopper is full and the contents drop into the bagless transfer system for removal.

The Telerobot uses several specially adapted hand tools to prepare feed for shredding. Items too large to fit into the shredder are cut with a plasma torch. The electric worktable clamps, lifts, tilts, rotates, and moves items that weigh up to 3800 pounds.

The shredder (Figure 12) is a low speed, 160 horsepower, electrically driven unit (Shred-Pax Model AZ-160). Its hopper is completely enclosed during operation to avoid kickback of material and to reduce noise levels. Inner wall construction includes steel backed rubber to absorb the high impact of large, heavy items bouncing around during shredding.

FIGURE 12. Large Shrudder and Material Handling System

Four sets of tests of the large shredder and material handling system have been completed. Feed materials included both scrap and fabricated stainless and carbon steel boxes. These tests have shown that the system can consistently shred a 3 x 4 x 5 foot by 1/4 inch enclosed stainless steel box in less than two hours. The material handling system works well. About 475 pounds of shredded metal fit into each drum without shaking or compaction (see Figure 13). Volume reductions averaged 10:1 using boxes similar to gloveboxes.

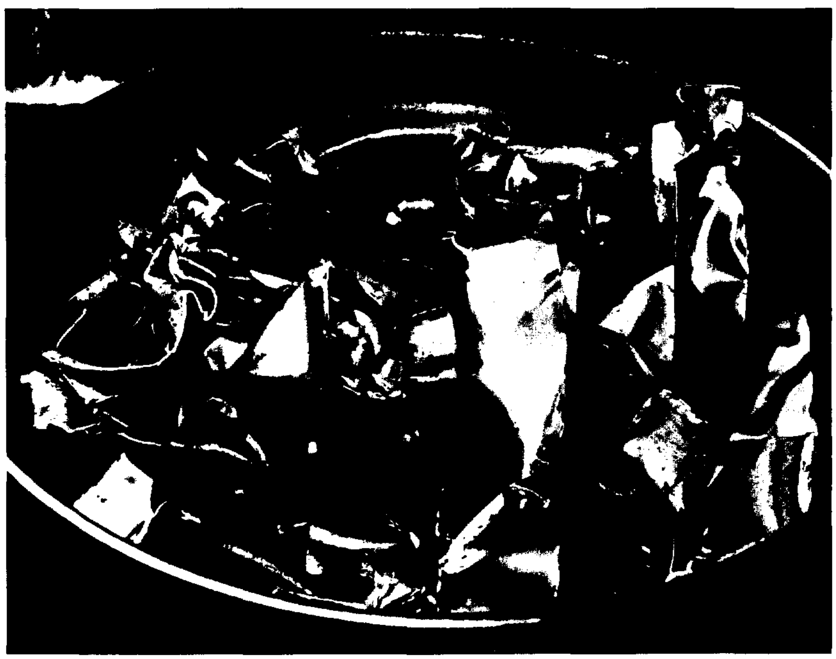

FIGURE 13. Drum of Shredded Material

During the four sets of tests, it was discovered that a variable reversing timer was needed to control feed rate and particle size. The initial shredder blade configuration, one-by-one, would not shred 1/4" thick material and resulted in frequent shredder jams; changing to a two-by-two blade configuration eliminated these problems. With the two-by-two configuration, two blades are stacked next to one another rather than spaced singly, resulting in cuts twice as wide. Twice as much power is delivered to each cut. Table 7 summarizes the last set of tests, which used the two-by-two shredder blade configuration.

TABLE 7. Shredder Test Results - 2 x 2 Blade Configuration

Test	Box Size	Material	Final Time (hr.)	Volume	Piece Size
13	3 x 4 x 5	1/4" carbon steel	1-3/4	3/4 drum	4" x 6"
14	3 x 4 x 6	1/4" stainless	1-1/2	1-1/3 drum	4" x 6"
15	3 x 4 x 5	1/8" stainless	1-1/6	3/4 drum	4" x 8"
16	3 x 4 x 5	1/8" stainless	1	3/4 drum	4" x 8"

Sound levels as high as 116 db were measured during shredding. The shredder hopper and loading door have been redesigned and will be lined with 1-1/2" of Armaplate® (Goodyear), a steel-backed rubber plate, to absorb the energy of items bouncing into the walls. The new hopper design is complete and will be installed when the shredder is reinstalled in the integrated demonstration.

The bagless transfer system (Figure 14) is a converted German Drath and Schrader unit. The device is used to remotely remove contaminated waste, which is especially important when removing sharp edged shredded materials.

The Drath and Schrader bagless transfer system was set up with a relay control system and over 4000 cycles were completed with only minor maintenance to the unit. A leak test using DOP smoke after the cycles verified that the unit maintained a good seal with no leaks.

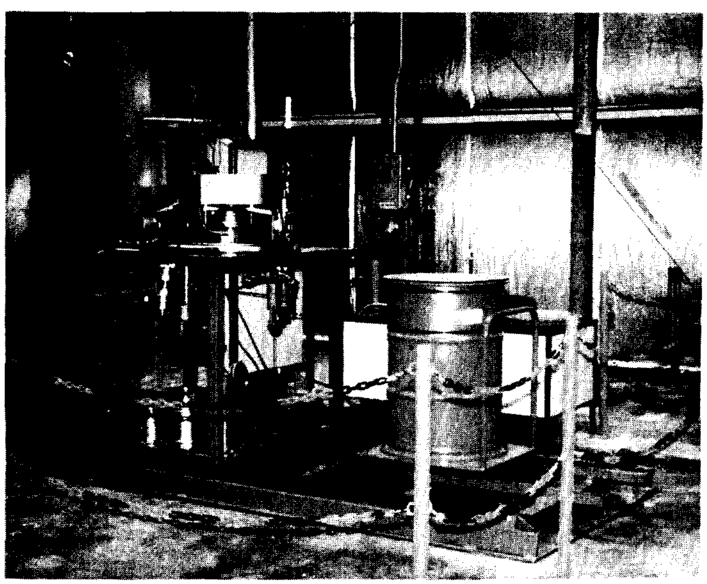

FIGURE 14. Drath and Schrader Bagless Transfer System

Telerobot System

The Telerobot (Figures 15, 16) is a combination of gantry mounted nuclear hot-cell manipulator and industrial robotic technology. A 6-axis manipulator is connected to a 3-axis bridge, with all nine axes controlled by a "Cimroc 2" (GCA) robotic controller. Capacity is 300 lb at the manipulator hand and 3000 lb at a hook beneath the shoulder pivot point. The support structure has an 18' span, is 65' long, and is 20' high.

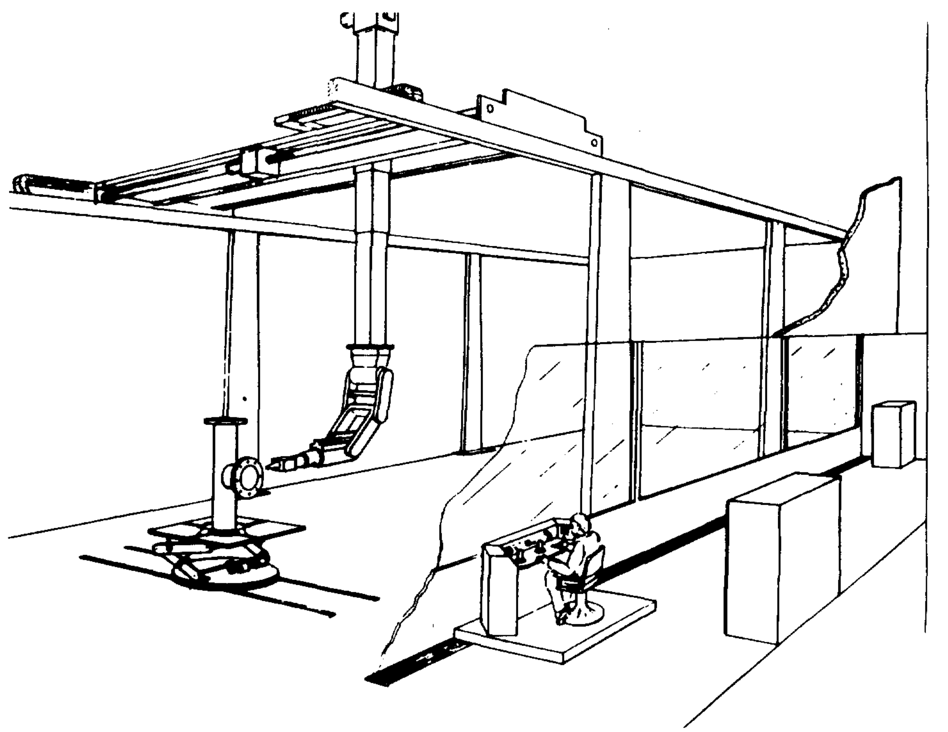

FIGURE 15. Telerobot Conceptual Drawing

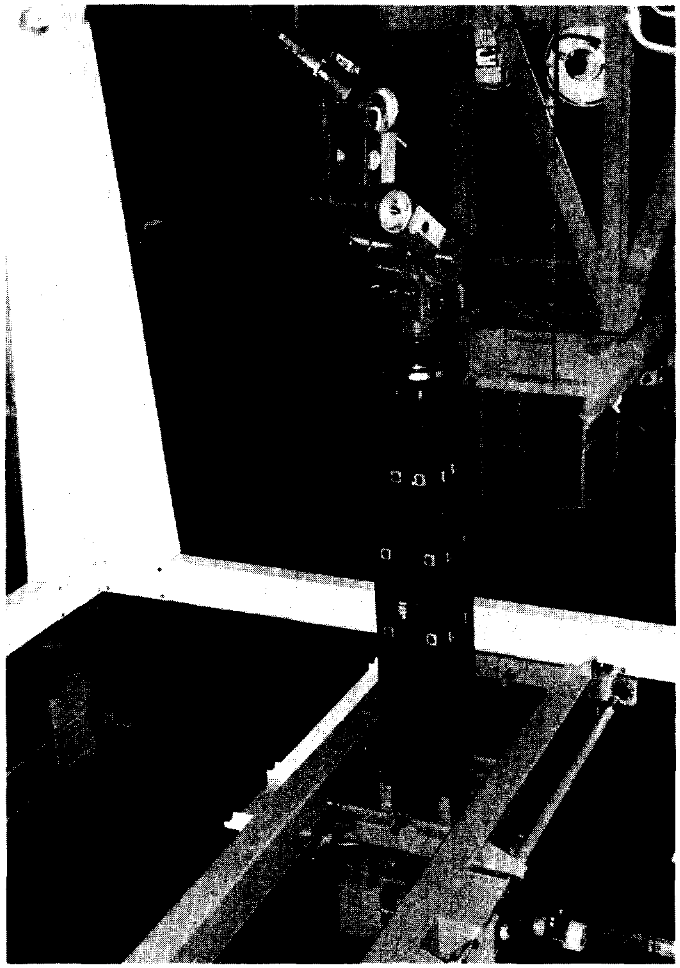

FIGURE 16. Telerobot Arm

The central computer controls all executive control functions and a trajectory processor controls all linear interpolated movements. Unlike conventional nuclear hot-cell manipulators which use a separate control for each axis of movement, the Telerobot operates either in preprogrammed, semi-automatic, or computer-assisted manual modes. Two 3-axis potentiometer joysticks are used for calculated rate control of the bridge axes and the axes of the manipulator arm in the manual and semi-auto modes. The arm can be removed from the gantry remotely using an arm removal attachment on the electric worktable.

The Telerobot has been set up at SRL for testing and is fully operational. Performance specifications have been met or exceeded.

Flowsheet - Pu-238 Waste

If the Pu-238 waste can ultimately be sent to the WIPP, the flowsheet for this waste will be identical to that of the Pu-239 waste except that a sand filter will be added to the building exhaust system. However, as it is not clear that all the regulatory and institutional barriers concerning shipment of Pu-238 waste to WIPP can be overcome, incineration and decontamination processes that can be added as modules to the central facility are being developed (see Figure 17).

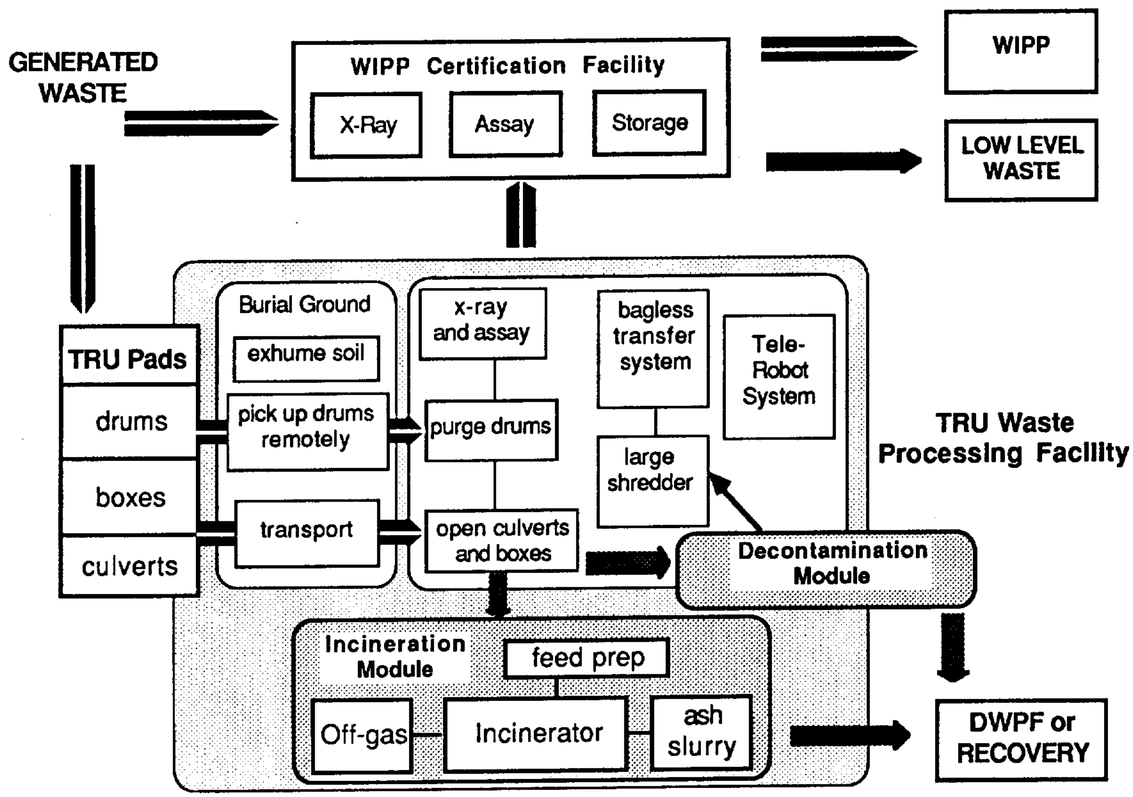

FIGURE 17. Pu-238 Waste Flowsheet

Noncombustible items will be decontaminated prior to shredding in a cell using multiple oxalic acid/permanganate and nitric acid rinses. Combustible items are shredded and fed to a controlled air, electrically heated, two-stage incinerator with a dry filtration off-gas system.

Incineration Process

Since the Pu-238 waste may not be shipped to WIPP, development work on an incinerator to burn the Pu-238 contaminated waste is in progress. A prototype Plutonium Waste Incinerator (PWI) process is being cold-tested at SRL. The incineration process consists of a continuous-feed preparation system, a two-stage, electrically fired incinerator, and a dry filtration off-gas system (see Figure 18). Design features to maximize the ability to remotely maintain the equipment were incorporated into the process. Interlock, alarm, and control functions are provided by a programmable controller.

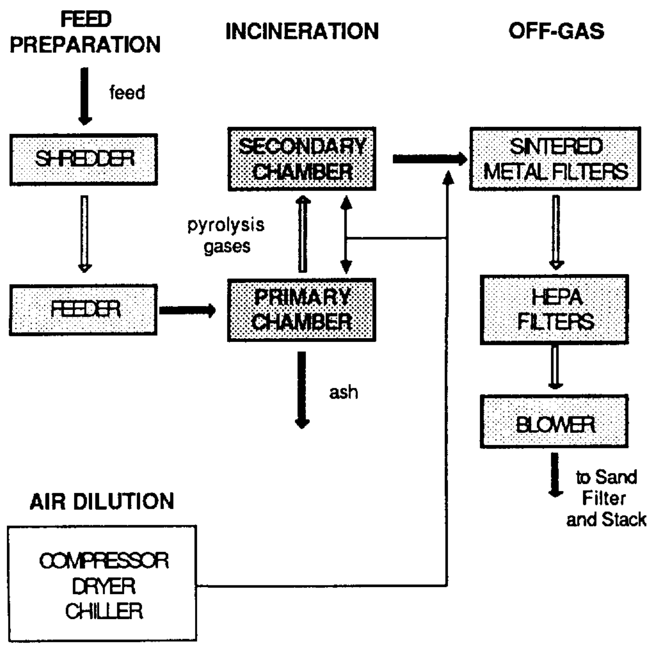

FIGURE 18. PWI Block Diagram

TRU waste is packaged in zinc galvanized 55-gallon drums with 90 mil polyethylene liners. The PWI feed preparation system remotely shreds the liner and its contents (and the drum if the liner cannot be removed) and delivers the shredded material to the incinerator at a controlled rate. This system was designed to:

- avoid manual handling or sorting of the waste, as it may contain tramp metal or glass which could present a hazard to personnel;
- avoid air classification of the waste, as the Pu-238 in the waste is too active to convey or separate this way;
- be totally enclosed and purged with nitrogen to eliminate the possibility of fire in the system; and

- be remotely operable and capable of processing materials made of wood, plastic (PVC, polyethylene), rubber, lead-lined gloves, paper, and tramp glass and metal.

The incinerator is a two-stage, controlled air, electrically fired incinerator. The primary chamber of the incinerator is designed to pyrolyze the waste in substoichiometric air concentrations. Pyrolysis gases from the primary chamber are mixed with excess air and burned to complete combustion products in the secondary chamber. This mode of operation, along with the electric heating design, minimizes carryover of radioactive particulates into the secondary chamber and from there into the off-gas system. The radioactive ash from the primary chamber will be slurried and pumped to the high-level waste tanks at SRP for ultimate disposal in DWPF, or will be retained for recovery of the Plutonium.

The primary chamber uses a slowly rotating woven wire mesh belt to slowly move material through the incinerator. Both the primary and secondary chambers are constructed of internal insulation and steel shells. Figure 19 is a schematic of the Shirco incineration system, Figure 20 is an isometric of the facility, and Figure 21 is a photograph of the incinerator.

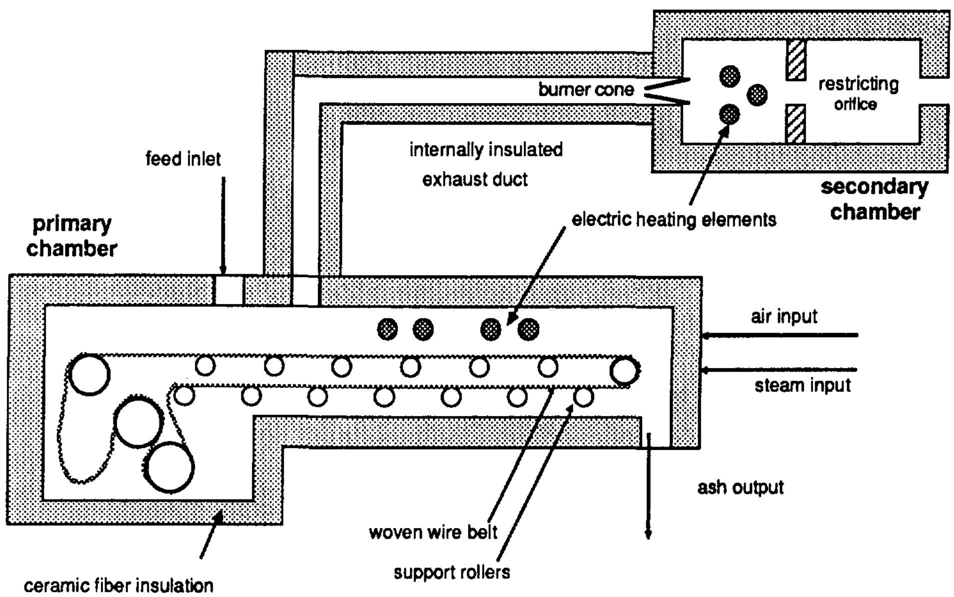

FIGURE 19. Shirco Incinerator System

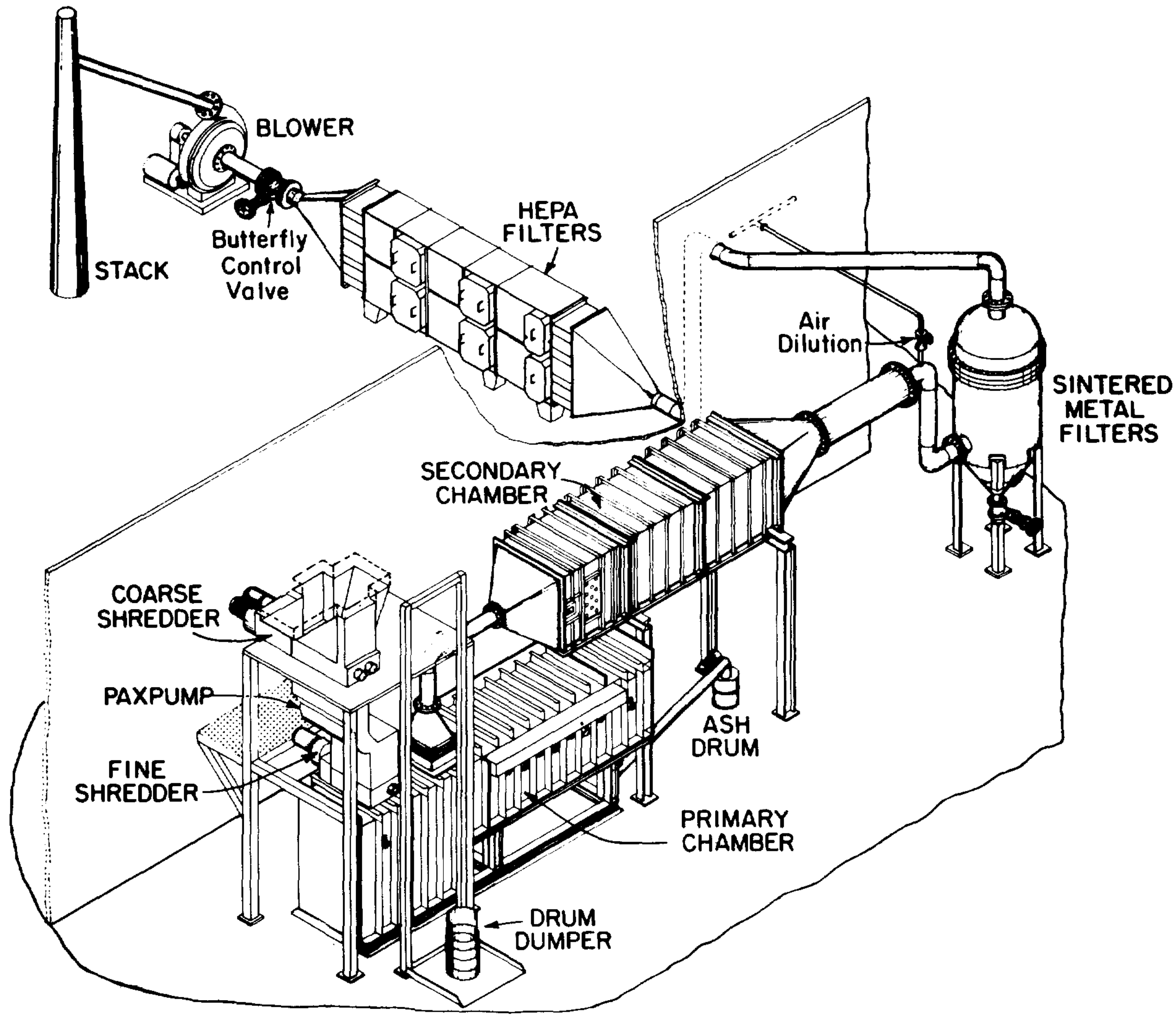

FIGURE 20. PWI Isometric Drawing

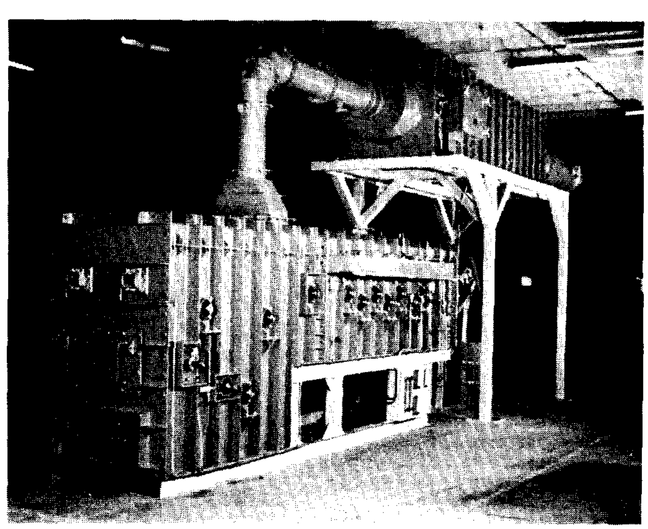

FIGURE 21. PWI Incinerator

The offgas system does not include a scrubber, and hence produces no liquid effluent. Dry instrument-quality air is used for dilution and cooling. This design minimizes the potential corrosion from burning polyvinylchloride. After cooling by air dilution, the offgas from the secondary chamber passes through sintered metal filters (SMF), high efficiency particulate air (HEPA) filters, and a sand filter before being stacked to the atmosphere. The gas released meets all South Carolina Department of Health and Environmental Control standards.

The sintered metal filters include a silica powder precoat system. The silica is used to prevent blinding of the filter tubes by tar-like residues from incineration of plastics. The silica will be blown off the filters based on pressure drop through the SMF. This silica is also compatible with DWPF, hence it will be slurried with the ash and pumped to the SRP high-level waste tanks. As HEPA filters become plugged, they will be changed out and the old filters shredded and processed in the PWI.

Incinerator operation at the proper process conditions produces an ash compatible with plutonium recovery processes. For plutonium recovery from incinerator ash to be feasible, a primary chamber operating temperature of 600-800C° must be maintained, and localized combustion must be avoided. Plutonium recovery generally involves dissolution of plutonium oxide in nitric acid and hydrofluoric acid. Oxides produced at temperatures less than 600C° are considered relatively easy to dissolve, while it becomes increasingly difficult with higher processing temperatures. Thus, incinerator operation is a key variable.

Pure pyrolysis produces a high carbon ash which is not suitable for plutonium recovery. Combustion is a highly exothermic reaction, and close temperature control is difficult. Incinerator operation in an air-starved steam environment (pyro-hydrolysis) promotes endothermic hydrolysis reactions which strip carbon from the ash and make temperature control much easier. No combustion reactions occur, so localized hot spots are not a problem. However, pyro-hydrolysis is a slower process than pyrolysis followed by combustion, so processing rates are adversely affected. This tradeoff between plutonium recovery potential and incineration capacity must be examined on an individual basis.

A two-year test program began in November, 1985. Technical data on the performance of individual process components is being obtained. The most critical aspect of process maintenance is the life of the rotating woven-wire belt. Corrosion of the belt is a key concern, as the belt is exposed to high temperatures and an alternating oxidizing/reducing atmosphere as it rotates through the incinerator. Based on a 400-hour small-scale belt test, a Haynes 188 belt is projected to last for at least 3000 operating hours. Initial test results indicate that the basic equipment functions well; the process control system is still being refined to demonstrate good vacuum control in the process.

Gas Generation

A computer model to describe the gas generation and transport within TRU waste drums was developed. Table 8 shows the objectives for this model:

TABLE 8. Radiolytic Gas Generation Model - Objectives

1. Predict hydrogen gas concentrations and the potential for formation of explosive gas mixtures.

2. Establish Pu-238 loading limits for TRU drums.

3. Evaluate the use of venting filters in the drum liner and in the drum lid for hydrogen gas venting.

Figure 22 shows a schematic of the TRU waste drum. Equations used in the model for generation and diffusion, flux, and gas generation are given in Appendix I. Figures 23 and 24 show predicted and measured pressure and hydrogen and oxygen concentrations for a typical drum of waste. Note that there is reasonable (but not perfect) agreement between the predicted and the actual concentrations.

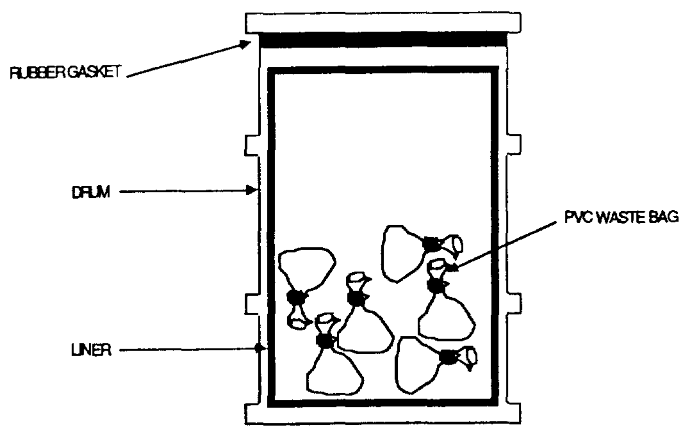

FIGURE 22. TRU Waste Drum Schematic

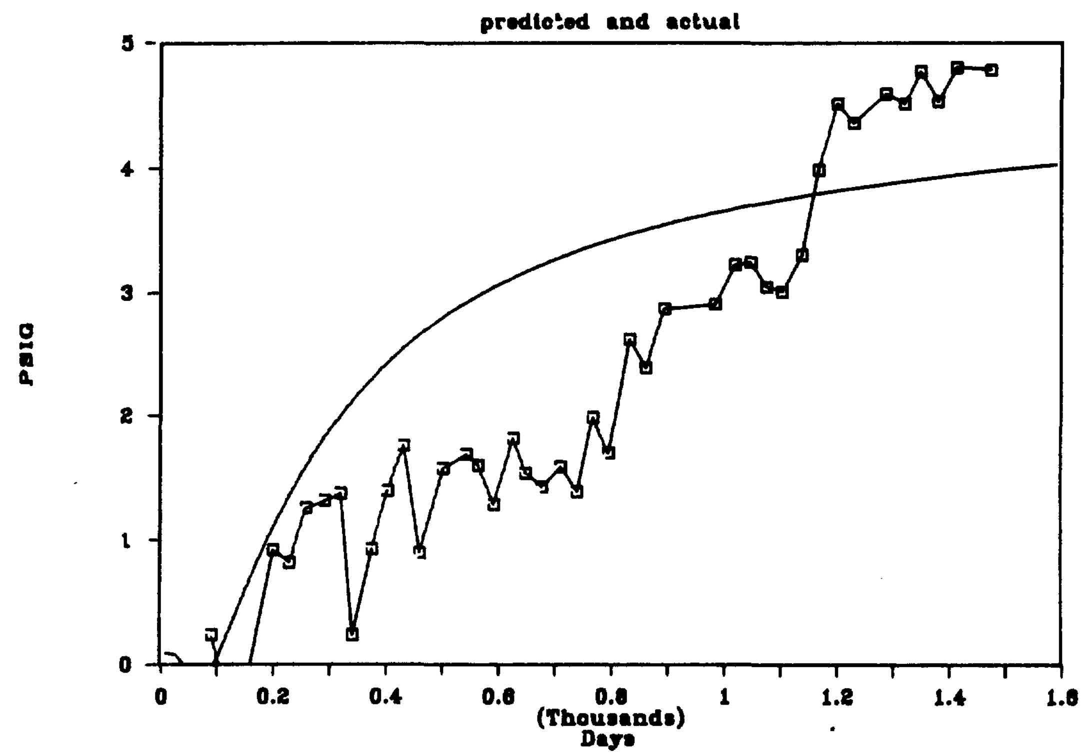

FIGURE 23. H2 Pressure Generation

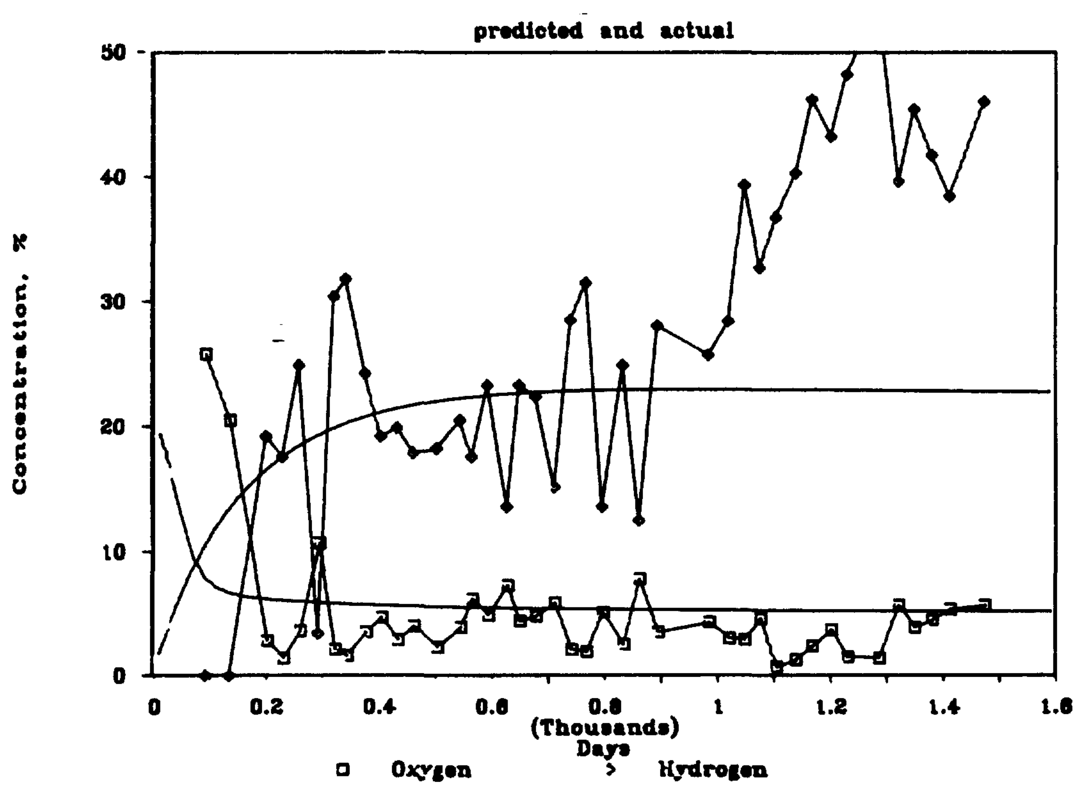

FIGURE 24. H2 Hydrogen Gas Generation

This model has been used to optimize the design of a small filter vent that is being installed in all drums and liners. Also, based on model predictions, filters will be installed in both drum liner lids and drum lids.

ASHCRETE

The Ashcrete process was designed to solidify ash generated by the Beta-Gamma Incinerator (BGI). The system remotely handles, adds material to, and tumbles drums of ash to produce Ashcrete, a stabilized wasteform. Full-scale testing of the ashcrete unit began at SRL in January 1984 using nonradioactive ash. Tests determined product homogeneity, temperature distribution, compressive strength, and final product formulation. Product formulations that yielded good mix homogeneity and final product compressive strength were developed. Drum pressurization and temperature rise (resulting from the cement's heat of hydration) were also studied to verify safe storage and handling characteristics. In addition to these tests, an expert system was developed to assist process troubleshooting.

The BGI burns slightly contaminated solid and solvent wastes. The Ashcrete program was started to stabilize ash from the BGI and produce a wasteform that would resist subsidence or leaching in a burial ground facility. Portland (type II) cement is used to stabilize (solidify) ash because of its low cost, shielding properties, and handling ease. A self-contained ash-solidification unit was built to remotely process both solid and solvent ash from the filter baghouse and incinerator chambers of the BGI.

The process equipment was purchased from Stock Equipment Company (Cleveland, Ohio) in January 1984 and installed for complete nonradioactive testing. To limit personnel exposure to radioactivity, the unit is fully automatic and enclosed. It processes ash within the same drum received from the BGI. The unit can also process large agglomerates and tramp metallic objects that may be present in the ash. Finally, there is no contact between the equipment and radioactive ash.

Drums of BGI ash are solidified as follows:

- Ash is loaded into empty 55-gallon drums at the ash-out ports of the BGI.
- Drums are loaded on the Ashcrete unit transfer car.
- Water, cement, and sand are successively added and mixed with the ash to produce a concrete wasteform.

Figure 25 is a photograph of the unit. Figures 26 and 27 show the major system components (transfer cart, enclosure, water, cement, and sand addition stations, capper mechanism, and drum tumbler). Peripheral equipment includes wet and dry feed systems for remote material addition. The process sequences are controlled by an Allen-Bradley PLC/230 programmable controller.

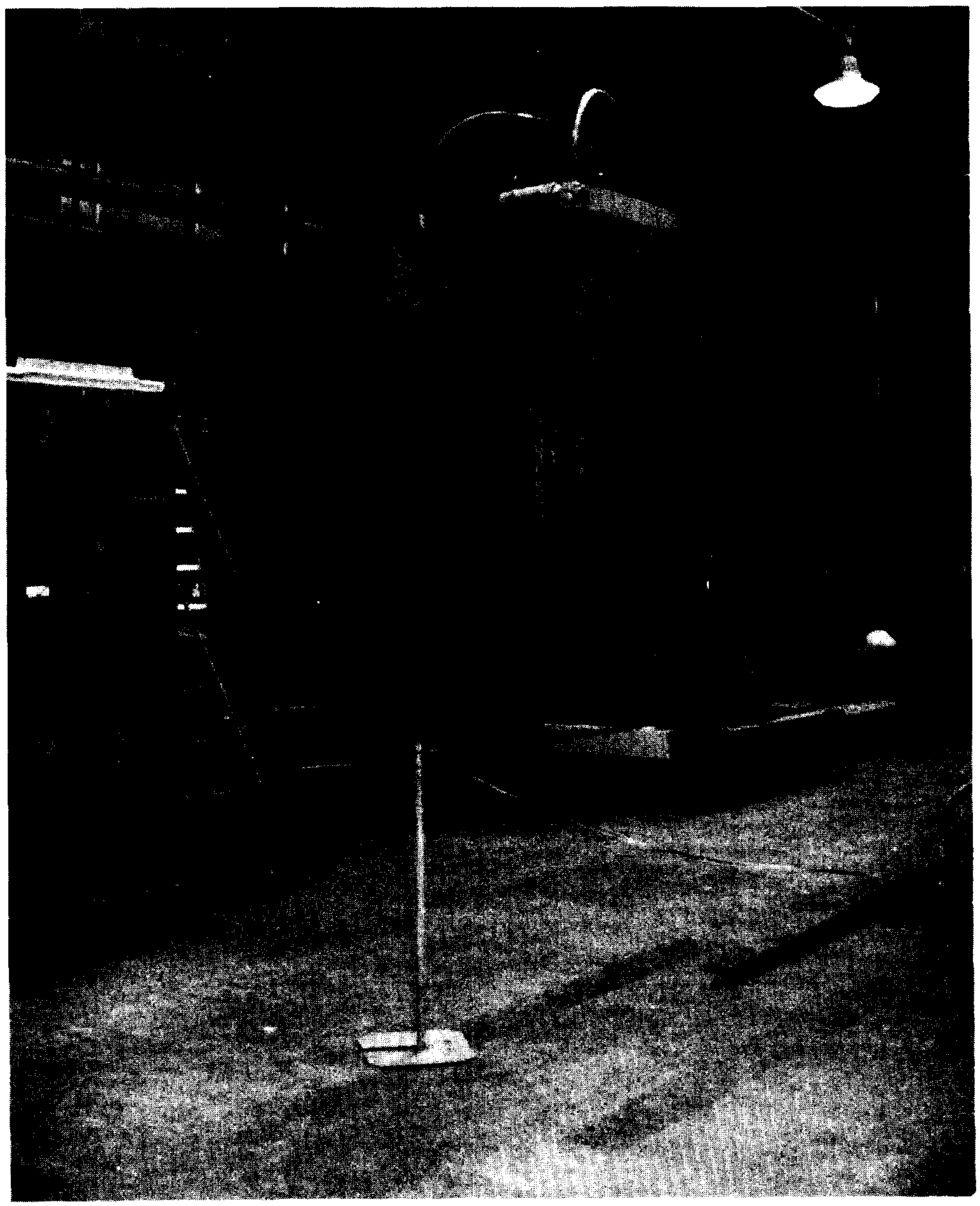

FIGURE 25. Ashcrete Unit

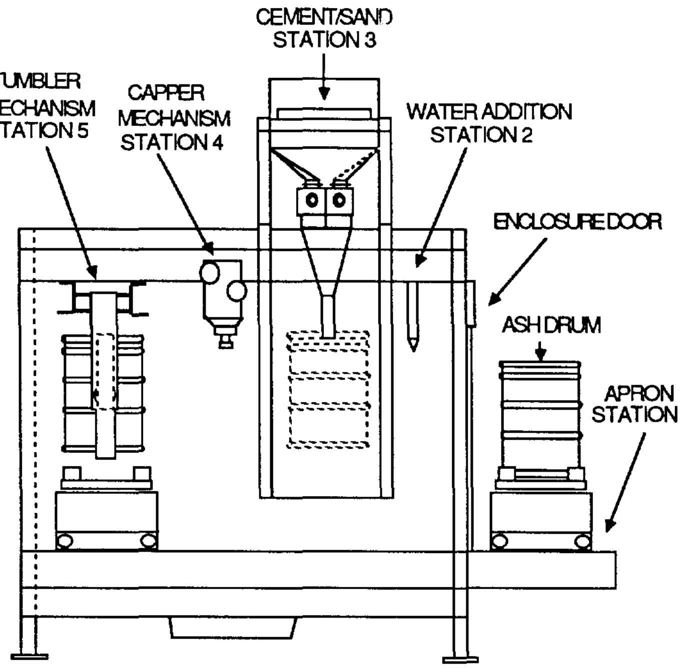

FIGURE 26. Ashcrete Schematic

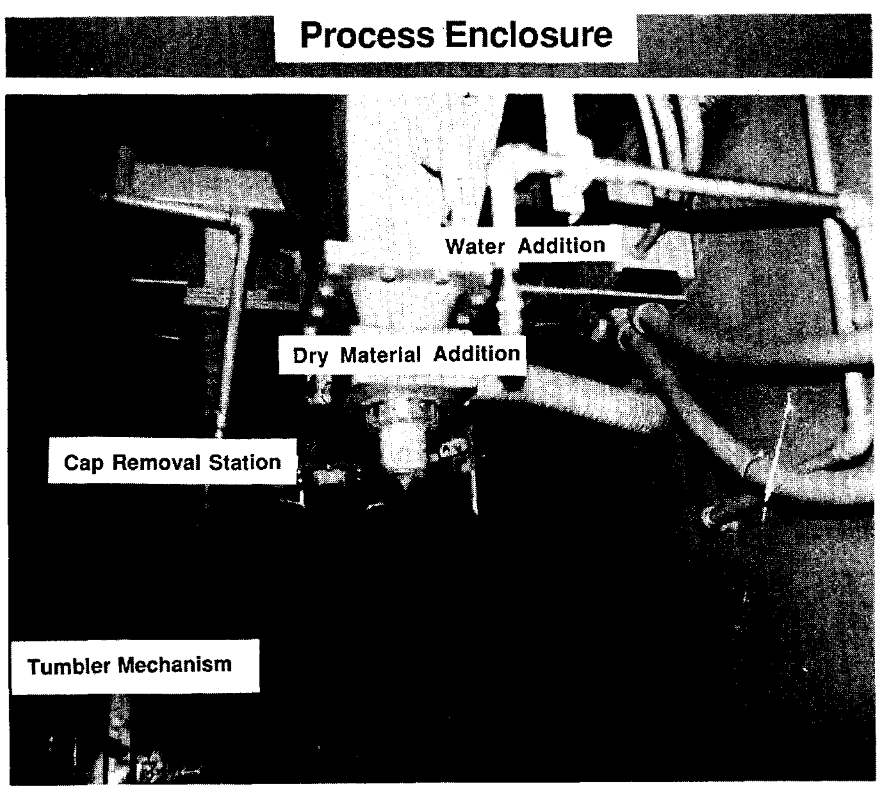

FIGURE 27. Ashcrete Stations

Tests were run to establish product integrity and process reliability. Ash formulations were developed to create a strong, durable product that could survive process and storage handling. Equipment was modified to increase process efficiency and reliability.

Ash Formulations

Slightly contaminated solid and solvent waste is burned in the BGI. Solid waste consists of job control waste that is slightly contaminated. Purex solvent is burned with tetrabutyltitanate (TBT) to form solvent ash. Ash is collected from both the incinerator and baghouse compartments. Baghouse ash has higher carbon content and smaller particulate size than incinerator ash. Each ashform was obtained (or approximated) with a substance of similar chemical and physical makeup for testing in the Ashcrete. SRL developed separate formulas for the solid and solvent incinerator ashes, and one formula for baghouse ashes.

To accurately simulate the chemical and physical makeup of each type of ash, drums of BGI solid and solvent incinerator ash were obtained from the BGI cold run-in. Sufficient quantities of baghouse ash were not available for testing because it is only 10% of all BGI ash produced. Powerhouse flyash was used in place of the BGI flyash because it is close chemically and physically to the actual baghouse ashes.

Parametric tests on solvent incinerator ash and baghouse flyash indicated the effects of chemical components on ash mix. The effect of calcium and phosphate present in solvent ash was tested by processing eight drums of tricalcium phosphate. Six drums of carbon black were processed to determine the effect of carbon content and particulate size on the homogeneity of baghouse ashcrete.

Product homogeneity and compressive strength determined preliminary product formulations. Small-scale testing was performed by Stock Equipment Co. These formulas were modified following full-scale testing at SRL. Table 9 lists the small- and large-scale test formulations for three different ash types.

TABLE 9. Ashcrete Formulations

Ash Type	Water/Ash	Cement/Ash	Sand/Ash
	Small-Scale Test Formulations		
Solid	1.00	1.00	0.33
Solvent	1.00	0.80	0.25
Baghouse	1.00	1.00	1.00
	Full-Scale Test Formulations		
Solid	1.00	1.50	(to fill)
Solvent	0.75	1.00	(to fill)
Baghouse	0.50	1.00	(to fill)

Compressive Strength

The minimum acceptable compressive strength is 100 psi (7-day cure) to enable processed drums to withstand all necessary burial ground storage handling. The limit was established assuming that the drums would be stored in columns of four drums.

Initially, sand was added to the formula to improve compressive strength. Dip samples taken from drums showed a higher strength, but pockets of unprocessed sand decreased overall drum strength. Steel mixing bars placed in the drums improved homogeneity, but were ineffective in eliminating sand pockets. The relatively quick setting time demonstrated by the ashcrete product inhibited the proper mixing of the sand.

Additional water and cement mixing steps were added to ensure proper ash/cement mixing. Tests determined that sand would be used solely as a loose filler. Its contribution to compressive strength was insignificant compared to the decreased homogeneity resulting from its addition.

Dip samples taken from processed drums were placed in one-cubic-foot brass molds and tested for maximum compressive strength (Table 10). Solid, solvent and flyash strengths were above the 10 psi limit after a 7-day cure. The final ashcrete compressive strengths were over 1000 psi for all wasteforms. Additional solid waste from the BGI cold run-in was processed on a limited scale. The results of these tests are included in Table 10.

TABLE 10. Compressive Strength Data

Ash Type	Cure (days)	PSI	Cure (days)	PSI
Solid	7	610	69	1300
Solvent	7	600	69	2100
Baghouse	7	1600	69	1630
Rubber	6	2000		
Paper	6	980		
Waste Mix	4	1770		

Maximum Drum Fill

The target fill level for Ashcrete drums is 90%. This level ensures drum integrity for subsequent burial ground handling. Initial ash weight is limited to 235 lbs to avoid overfill.

An ultrasonic level detector mounted in a protective housing with a Polaroid transducer (developed for Polaroid's self-focusing cameras) was installed. The detector was used following the final tumbler cycle and allowed the controller to calculate the sand backfill addition. The hostile environment and uneven product surfaces have limited the reliability of the detector. A new, more rugged detector is being designed for more reliable service.

Reliability Studies

Reliability tests were designed to establish the equipment's mechanical dependability. Process modifications were made after mechanical failures during formulation and temperature testing. Table II is a summary of the modifications that have been made to date.

TABLE 11. Ashcrete Modificastions

Process Step	Modification
Capper Mechanism	Added fourth guide finger and reduced the size of the unexpanded collet to strengthen the mechanism.
Tumbler Mechanism	Brake torque was increased to stop the drum in a vertical position. Basic controller logic was reformulated. Reduced clamp torque.

Decontamination System	Redesign
Programmable Contoller Logic	Added timer delays for each step.

Expert System

SRL developed an expert system on an IBM PC to identify process faults and suggest problem solutions. An EXSYS expert system development package provided the skeleton for the Ashcrete system. The EXSYS system asks the operator position and process status questions and recommends corrective action. Process enclosure graphics were added to simplify program operation. Each Ashcrete operation and related control panel element is visually identified. When the expert system specifies corrective action within the control panel, program graphics can specify the location of the suspicious indicator light or motor starter.

Program

Additional tests are in progress to verify mechanical reliability of the process equipment. Future modifications include the following:

- A more powerful decontamination system will be installed in the process enclosure.
- A Borescope camera system will be installed to allow operators to visually monitor the entire process.
- An expert system will be developed to monitor the Allen-Bradley Programmable Controller. The system will either prompt the operator or position and status confirmation, or provide an immediate solution without operator interaction.

This work will be completed by the end of FY 1986.

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APPENDIX I: GAS GENERATION EQUATIONS

Generation and Diffusion Model

- FOR HYDROGEN, OXYGEN, NITROGEN, CARBON DIOXIDE, AND CARBON MONOXIDE:

  VB d(CB)/d(t) = G(gas) - NB(gas)

  VL d(CL)/d(t) = NB(gas) - NL(gas)

  VD d(CD)/d(t) = NL(gas) - ND(gas)

WHERE:

VB, VL, AND VE = BAG, LINER, AND DRUM FREE VOLUMES

CB, CL, AND CD = GAS MOLAR CONCENTRATION

NB, NL, AND ND = GAS MOLAR FLUX FROM VOLUME

G(gas) = GAS MOLAR GENERATION RATE

APPENDIX I: GAS GENERATION EQUATIONS

Flux Expressions

N(i) = (DIFFUSION THROUGH THE MATERIAL BARRIER) +
(DIFFUSION THROUGH OPENINGS IN BARRIER)

N(i) = (AB)x(DB)x(P(i) - P(i+1))/(XB) +
(AO)x(DE)x(P(i) - P(i+1))/(XO)

WHERE:

AB = SURFACE AREA OF BARRIER

DB = DIFFUSION COEFFICIENT OF GAS THROUGH BARRIER MATERIAL

XB = THICKNESS OF BARRIER

P(i) = GAS PARTIAL PRESSURE INSIDE VOLUME

P(i+1) = GAS PARTIAL PRESSURE OUTSIDE VOLUME

AO = SURFACE AREA OF OPENINGS

DE = DIFFUSION COEFFICIENT OF GAS THROUGH OPENINGS
(ASSUME FREE DIFFUSION THROUGH STAGNANT AIR)

XO = THICKNESS OF OPENING

APPENDIX I: GAS GENERATION EQUATIONS

Gas Generation Expressions

$$G(gas) = Ci(PU\text{-}238) \times \sum_{j} g(gas,j) \times W(j)$$

WHERE:

Ci(PU-238) = CURIES OF PU-238 WITHIN BAGS

g(gas, j) = GAS GENERATION COEFFICIENT FOR MATERIAL j

W(j) = WEIGHT FRACTION OF MATERIAL j

j = CELLULOSE, POLYETHYLENE,

LATEX, PVC, OR INERT MATERIAL