CHARACTERIZATION OF HIGH-LEVEL WASTE SLUDGE AND DEVELOPMENT PLAN FOR REMOVAL

L. E. Rykken, M. A. Schiffhauer
West Valley Nuclear Services Co., Inc.

P. C. Newscom
Dames and Moore

ABSTRACT

Two objectives of the West Valley Demonstration Project are characterization (physical and chemical) of the stored wastes and formulation of a testing program and development plan to set the bases for the final design of a sludge mobilization and overall waste removal system. Characterization activities to date including the sludge sampling operation and the in-cell testing plan are presented. The application of the data and a conceptual description of the specific approach to be used in identifying a removal system are also discussed. In this paper, the sludge (wet solids) portion of the stored high-level waste is emphasized.

BACKGROUND AND HISTORICAL OVERVIEW

The West Valley Demonstration Project Act of October 1, 1980 directs the Department of Energy to carry out a high-level radioactive waste management demonstration project at the West Valley site. Under the Act, the Department is responsible for removing the high-level nuclear waste from the tanks and to solidify it in a form suitable for ultimate transportation to a Federal Repository for final disposal. The Department of Energy facility at West Valley, New York was formerly operated by Nuclear Fuel Services, Inc. as a commercial nuclear fuel reprocessing plant. West Valley Nuclear Services Co., Inc., a subsidiary of Westinghouse Electric Corp., and Dames and Moore were selected to implement the Project for the Department. Two tasks of this Project are characterization (physical and chemical) of the stored wastes and formulation of a development plan and testing program to set the basis for the final design of a sludge resuspension or mobilization and overall waste removal system.

DISCUSSION

Description of Wastes

Presently, there are approximately 2,280,000 litres of high-level radioactive waste safely stored at the West Valley Site. This waste consists of 2,250,000 litres of PUREX neutralized waste, consisting of approximately 2,080,000 litres of supernatant and 170,000 litres of sludge, and 34,000 litres of THOREX acidic nitrate waste. The neutralized waste is stored underground in a 2,840,000 litre carbon steel tank 21.34 metres in diameter and 8.23 metres high identified as 8D-2. The largest quantity of waste (that stored in 8D-2) was produced from the normal operation of metallic uranium and uranium oxide fuel reprocessing employing the standard PUREX separation process. This waste was neutralized with an excess of caustic (NaOH) which resulted in the formation of a bottom sludge layer consisting of insoluble solids and interstitial solution of salts. This sludge, which contains about one-half the total radioactivity, presents the greater challenge as far as mobilization, removal, solidification, and final tank decontamination are concerned. Factors complicating sludge removal are:

1. The internal structure of waste tank 8D-2 is complex. The tank roof is supported by forty-five 203 mm diameter pipe columns which, in turn, are supported by complicated gridwork designed to stiffen the tank floor. There are also six 762 mm diameter columns which support the surrounding concrete vault roof (see Fig. 1).

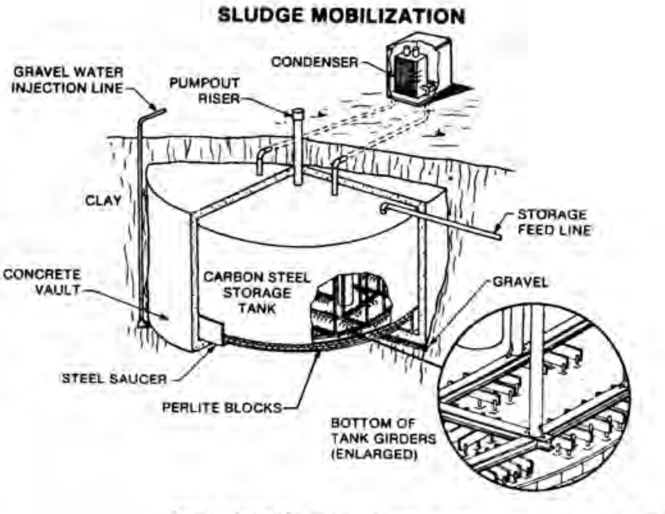

Fig. 1. West Valley High-Level Waste Storage Tank

2. There is a high degree of variance in the sludge topography and composition, both vertically and radially, resulting from the location of the feed inlet at one side of the tank, the campaigning nature of the additions, circulation due to thermal currents and the air spargers, intermittant operation of a heat exchanger, and varying specific gravity and particle sizes of the component solids.

3. Vitrification processing requirements of a controlled waste/glass product composition and activity necessitates a relatively homogeneous mixture as melter feed.

4. Tank access is limited. The only unobstructed access is a 610 mm diameter riser, designated M-1 and located near the center of the tank.

5. Information on the chemical composition and physical properties of the sludge in 8D-2 is limited. This presents a problem in planning and testing for the removal of the sludge from 8D-2 as will be discussed later.

The chemical composition of the solid wastes has been estimated based on supernatant analyses, theoretical fission product and transuranic content as a result of fuel processed, and plant records on chemical inputs. This composition is given in Table I, and consists primarily of iron, aluminum, manganese, chromium, uranium and nickel as insoluble hydroxides, oxides, and phosphates. The major radioactivity (>90 percent) is due to strontium-90 and its short-lived daughter product yttrium-90. Total curie content is estimated at 1.7×10^6 Ci.

In-Situ Sludge Characterization

As previously mentioned, sampling and analysis of the supernatant (found to be homogeneous) was used with other data to estimate the quantity and composition of the sludge solids. In addition, in-situ characterization tests were performed through the M-1 riser. These consisted of:

1. A Buoyancy Probe was used which consisted of an 8.5 kg stainless steel weight reeled out from a relatively frictionless pulley assembly. The apparent weight was measured by an electric load cell.

TABLE I

New Reference 8D-2 Solids Chemical Composition

Component	Kg in Tank
$Fe(OH)_3$	52,059
$FePO_4$	26,110
$Cr(OH)_3$	3,290
$UO_2(OH)_2$	3,087
$Al(OH)_2$	2,266
MnO_2	2,200
$Hg(OH)_2$	117
$R.E.(OH)_3$[a]	1,483
Other Fission Products:	
$F.P.SO_4$	510
F.P. Hydroxides	1,666
Actinides:	
PuO_2	37
AO_2[b]	23
TOTAL	95,585

[a] Rare earth fission products.

[b] TRU other than plutonium.

2. Shear vane testing comprising of a four-bladed vane attached to the end of a long vertical shaft which was slowly rotated (~1 rph) in the sludge was performed. The resistance torque was measured by means of an electric load cell. This test is similar to those performed, both in the field and in the laboratory, to evaluate ultimate and remolded shear strength characteristics of cohesive soils, particularly soft clays.

3. The Buoyancy Probe in Item 1. was used in conjunction with an articulated arm device to probe several points in a 1.5 m radius of the M-1 riser centerline.

Results from these preliminary probings are summarized here:

1. The specific gravity of the supernatant is constant down to the sludge level.

2. A slurry-like material is encountered at a height of 0.37 m to 0.64 m above the tank bottom. This material has a negligible shear strength, and most naturally occurring "muds" of this strength would not be able to support their own weight unless contained laterally. This material is readily penetrated by the buoyancy probe weight.

3. At a height of 0.15 m to 0.37 m above the tank bottom, a material is encountered that is unyielding to the Buoyancy Probe. Shear vane measurements resulted in peak shear strengths comparable to a medium stiff clay. Comparison of the torque curves generated with those previously obtained with sand and bentonite mixes lead to the conclusion that the material is quite cohesive.

4. The nature of the two sludge layers allowed the topography of the two layers to be determined in the immediate area of the M-1 riser with the Buoyancy Probe device. These are shown in Figures 2, 3, and 4. Further information on the in-situ characterization can be found in References 1 and 2.

Sludge Sampling and Testing

As a follow-up to the in-situ characterization tests, it was decided to obtain a vertical core sample of the sludge layer. The critieria that were used in the design of the sampling equipment were:

1. Sampling was to be performed through a 200 mm opening in the M-1 riser. This opening is made available by removal of a shield plug. All characterization activities, to date, have been done through this opening.

2. The core was limited to a 19 mm diameter based on exposure considerations.

3. An assurance of penetration to the tank bottom was desired.

4. A high probability of obtaining an undisturbed, i.e., nonsmeared sample was desired.

5. It was to have the capability of drawing the sample without exposure into a liquid-tight "primary containment", which in turn is inside a transfer cask with sufficient shielding to allow contact handling (<10 mR/hr).

6. It was to have the capability of transferring the primary containment in the transfer cask to the Analytical Cells and transfer the primary containment from the transfer cask into the shielded Analytical Cells without exposure.

7. There was to be the capability of removing the samples from the primary containment and to remove the sample from the sampler with Master-Slave Manipulators (MSMs) inside the Analytical Cell.

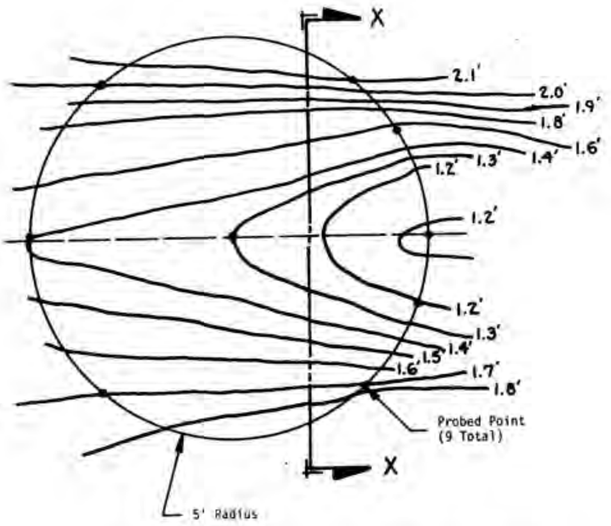

Fig. 2. Projected top sludge surface contours based on probing.

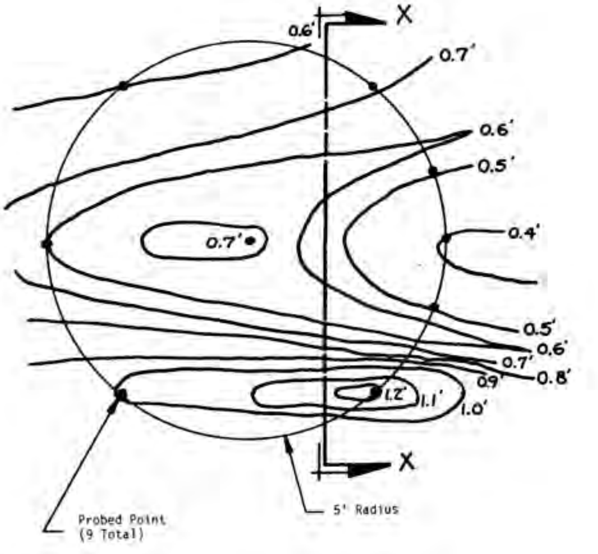

Fig. 3. Projected bottom sludge contours based on probing.

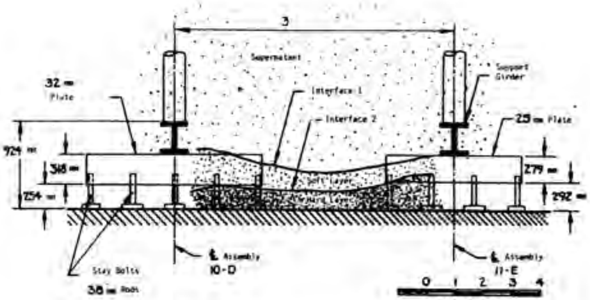

Fig. 4. Sludge layering. Sectional view X-X

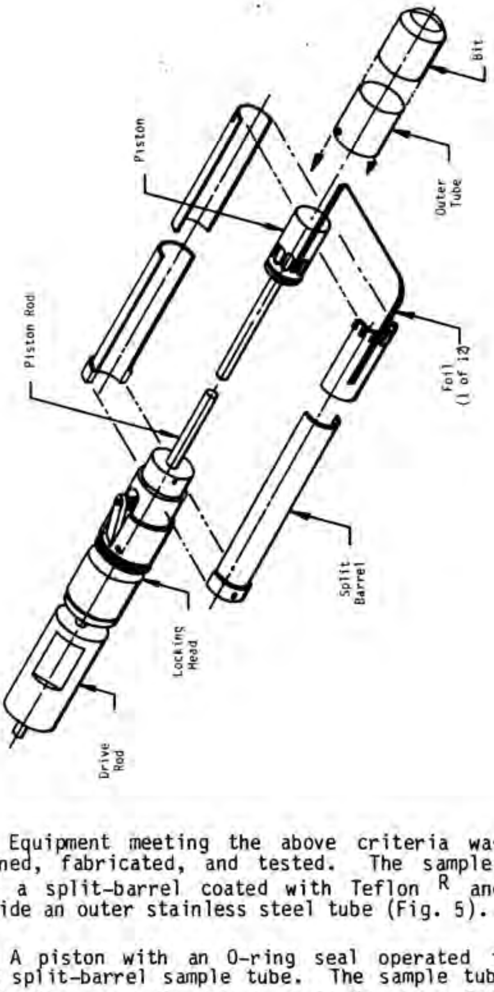

Fig. 5. Sludge sampler.

Equipment meeting the above criteria was designed, fabricated, and tested. The sample tube was a split-barrel coated with Teflon ^{R} and fit inside an outer stainless steel tube (Fig. 5).

A piston with an O-ring seal operated inside the split-barrel sample tube. The sample tube had protusions on each end so as to leave an 0.965 mm clearance between the sample tube and the outer tube. Twelve 4.3 mm wide x 0.25 mm deep slots were machined into one end of the sample tube. Thin stainless steel foils 0.025 mm (1 mil) in thickness were spot welded to notches milled into the piston. When assembled, the foils ran from the piston, around the notched end of the sample tube, and fit in the annular space between the sample and outer tube. When operated, i.e., when the sample is obtained, the piston is held stationary while the outer and sample tube move into the sludge. This forces the foils to move along the inside of the sampler. There is no relative motion between the sludge and the foil lining and this tends to prevent smearing. When the operation is complete, the foils line 85 percent of the interior of the sample tube. In addition, relative motion of the piston and sample tubes create a suction which tends to hold the sample. Further assurance of sample retention is provided by a notched bit on the end of the outer tube which is designed to crimp when driven against the bottom of the tank. Soil sampling using the foil-lined sampler principle was developed in Sweden in the 1940s [3], [4] in order to obtain undisturbed samples of the soft marine clays of Scandanavia.

The sampler is attached to a long (14+ m) 25 mm OD drive rod assembled in 1.5 m threaded sections. The rods were drilled so as to accommodate a 6.35 mm inner rod attached to the piston. By means of a framework, the whole assembly could be lowered into the riser down to the sludge level, the piston rod held stationary, and the drive rod forced down to capture the sample. The drive rod was driven by a "dynamic" driving mechanism consisting of two eccentrically-weighted shafts rotating in opposing directions on each side of the drive shaft. The rotary motion results in transmitting a gentle vertical vibrator motion which was presumed to increase the probability of high recovery.

After sampling, the assembly was lifted out of the riser. Placed on top of the riser was a transfer cask which provided 160 mm of lead shielding. Within this shielding was a Delrin ^{R} primary containment vessel. The sampler was raised into the containment such that it was sealed by a double o-ring seal on the top. Closing a ball valve on the bottom of the containment completed the retention of the sludge-containing sampler in the liquid tight primary containment.

The lead-shielded transfer cask was then transported to the Analytical Cell area. A 200 mm port had previously been cored in the 910 mm thick concrete wall of the Analytical Cells and fitted with a shielded access port. By raising the cask and rotating it 90°, the transfer cask could be fitted to the access port, a lead shutter raised, and the primary containment pushed into the Analytical Cells without any exposure.

Once in the cells, the apparatus was designed such that Master-Slave Manipulators together with relatively simple tooling could be used to remove the sampler from the containment and to disassemble the sampler to expose the sludge.

After thorough rehearsals, the sampling operation was accomplished on October 27, 1983. There was no contamination and personnel radiation exposure was minimal. A total depth of 508 mm was sampled at a location where previous probings had indicated a 210 mm depth of "hard" sludge overlain by 180 mm of "soft" sludge. The soft sludge sample did not retain its integrity and tended to wash out through the split barrel. Approximately 165 mm of the "hard" sludge was retained in the bottom portion of the sampler and was the source for a series of characterization experiments. After photographing, the core was placed over a compartmentalized sample tray so that the sample could be split into seven portions (each tray was 25 mm wide). Approximate 0.1 g portions were placed in sample vials for later analysis. The contents of each tray was then transferred to Petri dishes for further experimental work. The following tests are to be performed in-cell on the sample recovered:

1. Air drying to determine hygroscopic moisture.
2. Particle size distribution and settling characteristics by hydrometer methods.
3. Particle size distribution by a pipet method.
4. Specific gravity determination.
5. Oxalic acid dissolution studies.
6. Fractional filtration followed by scanning election microscopy.
7. Bench scale testing of the WVDP reference vitrification process.

The last experiment involves dissolving 20 g of the washed sludge solids in nitric acid, adding THOREX wastes and glass formers and melting to form small borosilicate glass specimens.

Waste Removal Objectives

Removal of the sludge from the main waste tank (8D-2) involves the following objectives:

1. Washing the sludge to remove impurities due to interstitial supernatant.
2. Homogenization of the sludge in the tank.
3. Dilution of the sludge to facilitate its transport to the vitrification cell.
4. Removal of as much radioactivity from the waste tank as practical to fulfill overall final decontamination objectives.

The first processing step will be transfer of the overlying supernatant from the waste tank 8D-2 to its spare, 8D-1. After the supernatant is decanted from 8D-2, the remaining approximately 170,000 litres of sludge will be slurried and mixed with fresh water to resuspend and homogenize the tank contents. After settling, the liquid would again be decanted to 8D-1. This could be repeated several times depending on the amount of supernatant that it will be necessary to displace (98.5 percent is being used for current planning purposes).

Detailed equipment specifications and procedures for the waste removal operation will be largely determined as part of a development testing program.

Existing Technology and Applicability to West Valley

A substantial amount of experience has been accumulated both at the Savannah River and Hanford defense facilities regarding removal of sludge from high-level waste (HLW) tanks. Although not directly applicable because of varying objectives, tank designs and sludge characteristics, developments from other facilities are being used.

Hanford has used a medium pressure sluicer which uses recirculating water or decontaminated supernatant external to the tank itself to resuspend and carry sludge from the storage tanks to a receiving tank. A 25 mm diameter nozzle delivers a 1,300-1,500 litre per minute sluicer stream into the tank. The sluicing nozzle is aimed precisely by means of a calibrated sluicer control unit that provides for both horizontal and vertical adjustments and allows accurate sluicing of the tank bottom area. A medium pressure pump (1.21 Pa) external to the tank supplies the sluicing fluid to the nozzle.

Savannah River Laboratories (SRL), on the other hand, has developed a low pressure system which differs from the Hanford system in that the sluicer and its supply pump are integral. This pump is a semi-open impeller, volute-type, long-shafted centrifugal pump which has been modified so that the pump discharge immediately exits horizontally from the volute through two sluicing nozzles located 3.14 radians apart. The pump has a capacity of 2,300 litres per minute through each of the 38 mm diameter exit nozzles. It was designed to be inserted through a 610 mm diameter riser. The pump unit is attached to a turntable enabling it to be rotated continuously from 0.2 to 0.5 revolutions per minute.

It is envisioned that a combination of these two concepts together with final chemical cleaning may be required to meet the waste removal objectives of the West Valley Demonstration Project.

Unlike the Savannah River sluicing pumps, the Hanford-type sluicers are not meant to operate submerged in the slurry that they are creating, being more suited to operate above the surface of the sludge. At West Valley, they can probably be used for adding fresh water to wash the sludge and, at the same time, to break the hardened sludge thereby lowering its yield strength. The Hanford-type sluicer would also be very useful at the end of the campaign for attacking localized sludge accumulations, washing down interior surfaces, and addition of chemical cleaning solutions.

Waste storage capacity at West Valley is limited. By introducing liquid into 8D-2 to sluice and suspend the sludge, we may exceed that capacity. Therefore, the Savannah River-type recirculation-sluicing pump would be ideally used to homogenize the complete tank without the need for additional sluicing fluids. A separate discharge pump is needed with the recirculation-sluicing pump to deliver the homogenized slurry to the vitrification process at the desired processing rate.

A major objective will be to determine the number and optimum location(s) of the proposed sluicing equipment and length of operation for various values of the hydraulic parameters, to both mobilize and homogenize, at a minimum, 90 percent of the tank sludge contents.

Waste Removal Development Plan

Several sludge removal systems and procedures have been proposed incorporating various combinations of turbine or recirculatory pumping, and hydraulic jet sluicing [5], [6]. However, to date no experimental work has been performed to verify these proposed systems and their predicted sludge removal performance. It is planned to utilize the development work and operating experience of SRL for determining a method for removing the sludge in Tank 8D-2. Experience at SRL has indicated that scaled testing provided valuable information for successful waste removal operation at the plant. Utilizing this approach we will provide a design for a waste removal system and demonstrate operability to assure a high level of confidence at full scale. Using a One-sixth Scale Model of Tank 8D-2, and a simulated West Valley sludge matching the rheology of the actual sludge, specific systems and procedures will be tested to determine the optimum method of sludge removal.

Theory and Scale Model Test Plan

Engineering problems that require complex mathematical or graphical analysis are generally studied by scale model tests using a technique known as dimensional analysis. A model is constructed which is geometrically similar to the full-size unit. Geometric similarity exists between two systems if the ratio of significant dimensions (length, height, diameter, etc.) is the same for the two systems. It makes no difference what the absolute scale is.

To apply dimensional analysis or modeling theory to a situation, one needs to know the independent variables that are involved. Identification of the essential variables enables the performance of the model to be related to that of the full-size unit and, therefore, one can predict the behavior of the latter.

Two important factors that enable a liquid jet to resuspend sludge are the velocities of the eddies in the jet stream and the impact of the stream on the sludge. Both of these parameters are dependent on the velocity of the stream itself. Therefore, the velocity of the jet at any distance from the nozzle can be taken as the measure of the slurry efficiency of the jet. A turbulent, high velocity, free jet of fluid discharging from a round opening entrains the fluid it is discharging in and expands as it leaves the outlet. Virtually all the slurrying takes place in the region of established flow.

In the fully established region of a turbulent high-velocity fluid jet discharging from a round opening. The jet velocity at any point is directly proportional to the product U_0D, where U_0 = average initial velocity through the jet opening and D = diameter of that opening[7], [8].

This quantity, U_0D, has been used at SRL to correlate their experimental data obtained with simulated sluicing pumps. The effective cleaning radius (ECR) is proportional to the U_0D product, which is, in turn, a direct measure of jet velocity in the region of established flow. The ECR is defined as the distance from the center of the jet to the point where slurried sludge is no longer detected. This effective cleaning radius is a measure of the cleaning ability of the pump or sluicer.

SRL has correlated both sludge characteristics and pump parameters with slurry pump performance using scale modeling and obtained correlation coefficients between 0.90 and 0.98 on full-scale verification[9]. By utilizing this same approach, key pump parameters will be identified (position, rotational speed, flow rate, discharge velocity) in single and multiple pump operations specific to the West Valley situation by using the One-sixth Scale Model of waste tank 8D-2 and a simulated West Valley sludge. The results will determine the number of pumps, their configuration, and their procedural operation for each intended application.

The test system is to be operated in such a way that a velocity similitude condition exists between the model and prototype. This will result from operating at the same jet discharge velocity in the model and prototype, thereby producing the same velocity pattern in both. To do this we keep the particle Reynolds Number (Re) and Froude Number (Fr) identical in both the model and the full-size tank where:

$Re = d_p U_p \rho / \mu$ d_p = particle diameter

and U_p = particle resultant velocity

$Fr = U_p^2 / g d_p$ ρ = density of the mixture

μ = viscosity of the mixture

g = acceleration of gravity

and on scaling

Re = constant
Fr = constant

The requirement for using this approach is that identical solid particulates are to be suspended or dispersed on both scales, meaning that the simulated sludge must have the same relative particle size range as the actual sludge. Although dynamic similitude, which is a condition required for accurate modeling, does not exist for the system as a whole, it will apply to the individual particles. That is, the forces acting on an individual particle will be the same in each system. The scale-down dimensionally reduces all locations and sizes to one-sixth that of the full-scale waste tank. Time and pump speed are increased by a factor of six to maintain the same velocity and flow continuity at all points in the One-sixth Scale Tank.

The ECR will scale by one-sixth, given that

$$ECR \propto U_0 D$$

where U_0 = nozzle discharge velocity

D = nozzle diameter

then $ECR_p \propto U_0 D_p$

and $ECR_m \propto U_0 D_m$

and since $D_m = 1/6 \, D_p$

therefore $ECR_m = 1/6 \, ECR_p$

Therefore using simulator equipment, the parameters U_0 and D as well as equipment location, sludge level, sluicing time, etc. will be investigated using the model.

It is important to note that we are not scaling down the mechanical parts of sluicing equipment but are scaling the hydraulic parameters and investigating the dependent variable, ECR, specific to the West Valley waste tank under various operating parameters.

SUMMARY

Waste Characterization projects have consisted of supernatant sampling and analysis, in-situ sludge characterization, and obtaining a sludge core sample for physical and chemical characterization. This information is being used to support a waste removal development program by matching the physical characteristics of the actual HLW sludge to a suitable simulant sludge for use in One-sixth Scale Model tests. SRL has experienced excellent correlation between reduced scale and full scale; in view of their success with the approach, it is our plan to construct a scale model test facility and use it to develop the required sludge removal system.

ACKNOWLEDGEMENT

The authors are indebted to James A. Strom, Senior Development Engineer, Dames and Moore, for his creative and thorough design of the in-situ sludge characterization devices and the sludge sampling equipment.

REFERENCES

1. L. E. RYKKEN, "8D-2 Sludge Characterization Data", WD:82:0375, West Valley Nuclear Services (1982)

2. L. E. RYKKEN, "8D-2 Sludge Topographic Data" WD:83:0502, West Valley Nuclear Services (1983)

3. M. J. HVORSLEV, "Subsurface Exploration and Sampling of Soils for Civil Engineering Purposes", US Army Core of Engineers, Waterway Experiment Station, Vicksburg, Miss. (1949)

4. W. KJELLMAN, T. KOLLSTENIUS, and O. WAGER, "Soil Sampler with Metal Foils", Royal Swedish Geotechnical Institute Proceedings, No. 1, Stockholm, Sweden (1950)

5. E. R. JOHNSON ASSOCIATES INCORPORATED, Final Report, Task 1, "Removal of Waste From Nuclear Fuel Services Incorporated, High-Level Waste Storage Tanks", JAI-128, ANLK - 784190-1, Prepared for Argonne National Laboratory, Vienna, Virginia (March 31, 1978)

6. G. P. JANICEK, "West Valley Waste Removal Study", Informal Report RHO-LD-146, Rockwell International Hanford Operations (April 1981)

7. R. F. BRADLEY, "Technology for Removing Sludge and Cleaning Savannah River Plant Radioactive Liquid Waste Tanks", DP-MS-76-88, E. I. du Pont de Nemours and Co. (1976)

8. R. M. MOBLEY, et al, "A Low-Pressure Hydraulic Technique for Slurrying Radioactive Sludges in Waste Tanks," DP-1468, E. I. du Pont de Nemours and Co. (1977)

9. Savannah River Plant and Laboratory, "Waste Management Program Technical Progress Report", DP-81-125-1 (January - March 1981)