WASTE HANDLING AND PACKAGING PLANT DEVELOPMENT SUPPORT

J. B. Berry, E. L. Youngblood, J. F. Walker
T. L. White, J. H. Evans, F. J. Schultz
Oak Ridge National Laboratory*
P.O. Box 2008
Oak Ridge, TN 37831-6046

ABSTRACT

The primary purpose of the Waste Handling and Packaging Plant (WHPP) will be to repackage remotely handled transuranic waste for eventual disposal at the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico. Many special features, involving both equipment and operational procedures, will be required to enable the remote operations and maintenance of the WHPP. Development of solid and liquid waste processes was pursued until the fall of 1990 when uncertainty in final waste form and withdrawal of funding caused development to be delayed. The areas of development that will be pursued when funding is reinstated are: (a) slurry process development, (b) solids process development, and (c) waste characterization.

A spectrum of unit operations will be developed to remotely treat liquid transuranic mixed waste. Sludge and supernate will be removed from existing storage tanks, and the resultant slurry will be transported to the WHPP process cell. Radioactive species will be separated using inorganic ion exchange and filtration, the sludge and radionuclides will be solidified using a thin-film evaporator and/or microwave system, and the solidified waste will be packaged for shipment to WIPP. Sludge and supernate processing and solidification will involve minimizing the volume of waste requiring disposal at WIPP and simplifying remote operation and maintenance.

Solids process development includes a unique double-lid transfer system that accommodates large concrete casks and allows transfer of the cask contents into the WHPP Process Cell while maintaining area confinement integrity. The critical elements for remote operations and maintenance will include an advanced servomanipulator, the manipulator transporter, a remotely operated and maintained crane, and a closed-circuit television (CCTV). State-of-the-art communication systems will be investigated for use in the WHPP cell CCTV system. Two of the primary goals will be to reduce the quantity of in-cell video cabling and to ensure system reliability.

Development of waste characterization technology includes a process to collect data to certify waste for WIPP. A nondestructive assay (NDA), which will be based on the use of a linear accelerator (LINAC), will be developed. The LINAC will also provide the necessary photon source to examine the contents of waste packages in a process known as real-time radiography (RTR).

This paper focuses on specific needs for continued development required to ensure that a viable facility for processing/repackaging ORNL remote-handled (RH) solid and liquid transuranic (TRU) wastes can be realized.

SLURRY PROCESS DEVELOPMENT

RH liquid radioactive waste has been generated at ORNL since the inception of Laboratory operations. The waste, as generated, is primarily nitric acid contaminated with radionuclides and minor concentrations of organic liquids and hazardous metals as defined by the Resource Conservation and Recovery Act (RCRA). This waste is collected in tanks, neutralized with sodium hydroxide (to an alkaline state), concentrated by evaporation, and stored for future processing and disposal. Upon cooling, the concentrated waste separates into sludge and supernate phases. The supernate is approximately 4-5 M sodium nitrate contaminated with soluble radionuclides, primarily Cs-137 and Sr-90, while the sludge consists primarily of precipitated carbonates and hydroxides, with calcium carbonate and magnesium hydroxide being the major components. Since radioactive actinides, such as TRU elements and most metals, are insoluble in alkaline liquid waste, these constituents also precipitate.

RH liquid waste is continually generated by Laboratory research operations and decontamination and decommissioning activities. This concentrated liquid waste

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is accumulating in tanks with limited storage capacity. In anticipation of a shortage of storage space, short-term projects are being implemented that will slow the rate at which the maximum capacity of available tanks ~575,000 gal) is reached (1). Thus, time to construct a suitable waste treatment plant (i.e., WHPP) will be available.

The primary objective of the WHPP is to repackage the major portion of the current RH TRU inventory plus any newly generated RH TRU waste at ORNL. This plant will process the TRU wastes so that they are acceptable for disposal in the WIPP in Carlsbad, New Mexico. Processing steps consist of (a) sludge retrieval, (b) decontamination and denitration of supernate stream sodium nitrate, and (c) drying and solidification of the sludge. These operations are illustrated in the schematic representation of the WHPP facility presented in Fig. 1 and discussed below.

Sludge Retrieval

Radioactive sludge was retrieved from the South Tank Farm at ORNL during the gunite tank cleanout campaign (2). ORNL is utilizing the knowledge gained in this earlier work in developing methods for retrieving sludge from the MVSTs. Procedures for sample collection and analysis have been developed. (3, 4, 5) A slurry transport loop has been constructed and tested to determine appropriate models for pressure drop of ORNL's TRU (non-Newtonian) slurry (6, 7, 8). Models (1/6-scale and ~2/3-scale) of an MVST have been located at the WHPP Development Facility (WDF), and preliminary tests have been completed (9). ORNL staff members have completed vendor contacts (10) and identified robotic sludge/supernate retrieval devices that may warrant testing. ORNL Engineering has proposed a concept for a floating pump that was included in the Conceptual Design Report for the WHPP (11).

Continuation of the development work will result in a generalized approach to sludge mixing, retrieval, and transport. This approach would be applicable to various sludge mobilization operations at ORNL and could extend to sludge mobilization operations throughout the DOE system. The proposed work will build on research conducted at ORNL. Existing expertise; equipment; facilities; and quality assurance, safety, and NEPA documentation will be used. Four areas will be addressed to develop reliable technology for sludge retrieval: DOE system integration; waste characterization; dynamic modeling; and equipment evaluation.

DOE sites will be surveyed for research and development needs regarding sludge processing, and similarities between sites will be identified. Vendors of sludge-handling equipment will also be surveyed for future testing. ORNL could sponsor a periodic exchange of technical information among sites throughout the life of the project.

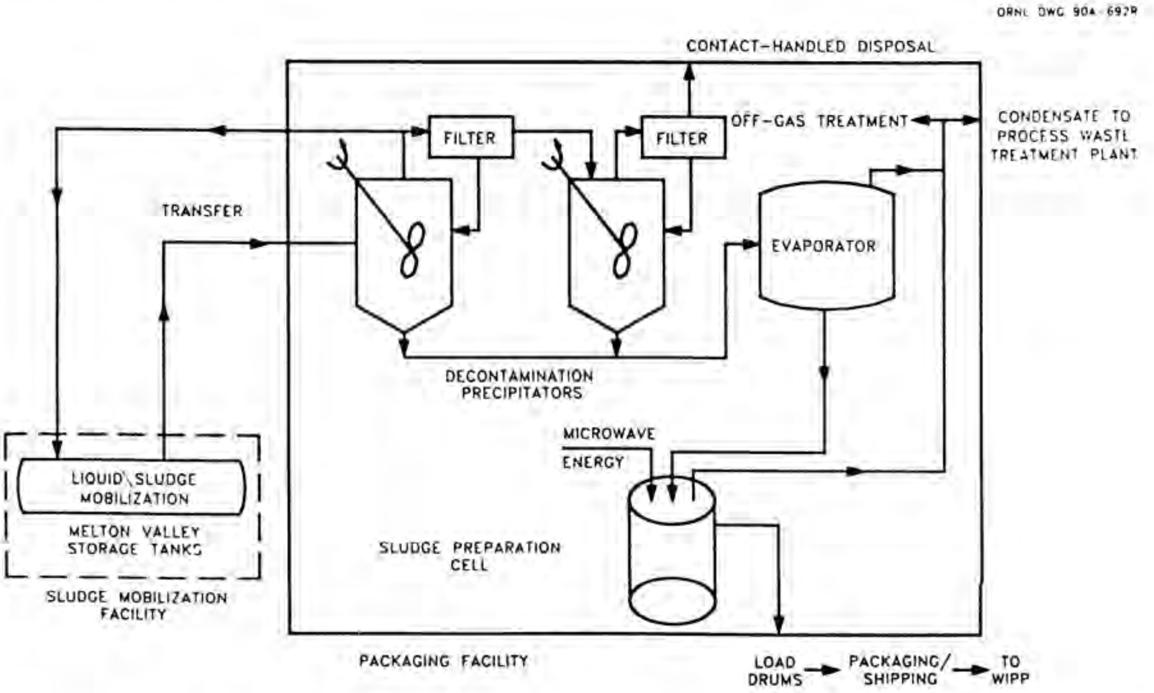

Fig. 1. Waste handling and packaging plant conceptual slurry processing with decontamination of supernate.

A data base will be prepared, which will include operability, reliability, and maintainability data on identified equipment, instrumentation, and methods. In order to provide data for risk assessments, mean-time-to-failure data will be included in the data base. This task will build upon previous work on sludge mobilization at ORNL; one equipment option to remotely mobilize sludge has been identified, and initial testing has been conducted.

Continuation of waste characterization will be required to develop a generalized approach to quantify and evaluate a given sludge-mobilization operation. Key chemical and rheological properties of the sludge will be identified, including density of carrier fluid; void fraction of sludge; chemical composition; viscosity at varying rate of shear; and settling rates. Laboratory methods to measure and interpret key parameters will be recommended. Typically, limited samples of sludge would be available, and, because the sludge is radioactive, laboratory methods would need to use smaller volumes of sludge than would conventional methods for obtaining required data in order to prevent unacceptable personnel exposure. ORNL staff members have developed methods for determining settling rates and viscosity at low shear rates for radioactive sludge. This expertise could be expanded for more general application. An approach to formulating a surrogate sludge, based on chemical and rheological properties of the actual sludge, will be developed. Nonhazardous, nonradioactive materials that accurately mimic the behavior of DOE wastes will be recommended. Surrogate sludge will be used in tests of equipment for sludge mobilization operations.

The development of dynamic models specific to DOE sludge-mobilization operations was initiated in FY 90 and will continue through the life of the development project. The physical constraints of the given storage tanks and associated piping will be evaluated, and a generalized method for determining representative physical constants will be developed. Mixing, retrieval, and transport equipment will be modeled to determine viability of a proposed operation. Examples of correlations that will be further developed include:

1. pressure drop correlations for Bingham plastic fluids developed by Hanks (12) and by Thomas (13).
2. pressure drop correlations for power law fluids developed by Dodge and Metzner (14).
3. correlations for critical deposition velocity developed by Thomas (15) and by Wasp (16).

Reynolds numbers for jet mixing in a given tank configuration or given piping system could be determined. Correlations for slurries could be developed that are similar to those developed for clear liquids. Models could be developed for mixing, mobilization, and transport of sludge contained in large storage tanks. Such models directly apply to the solution of DOE sludge retrieval problems and could contribute to the understanding of engineering principles that govern two-phase, non-Newtonian fluid behavior.

During FY 89 and FY 90, facilities were constructed at ORNL to evaluate the effectiveness of sludge mixing, retrieval, and transport equipment; however, the funding for this effort has been discontinued. The use of this equipment and completion of construction of the sludge-mobilization test system will be used to test and evaluate ORNL and DOE sludge-handling operations.

The effectiveness of mixing equipment for given tank configurations and waste rheological properties will be determined. Consideration will be given to mixing in preparation for sample collection as well as in preparation for sludge retrieval. Based on previous work conducted at ORNL, jet mixing appears to be favored for large tanks. Other methods that could utilize existing equipment (such as existing pumping systems) will be explored. Equipment will be modified for remote operation in a radioactive environment after the method has been chosen.

The effectiveness of retrieval equipment will also be evaluated. Robotic devices such as mobile suction devices (Superscavenger), floating pump, a rover robot (used at Three Mile Island), and a single-point jet sluicer will be assessed.

Pressure drop as a function of waste viscosity will be measured in the existing ORNL slurry-transport test loop. The highly instrumented system will be used to determine friction factors for various pipe fittings. The critical velocity of particles at varying linear velocities, time-dependent changes that occur at a given shear rate, the transient behavior of the slurry when pumping is stopped, and line flushing requirements will be determined. ORNL staff will procure, test, and evaluate innovative pumping techniques (e.g., fluidic pumps) and conventional pumps (e.g., progressive cavity) for use in remote slurry-handling operations. Qualitative observations will be documented, and data will be correlated to recommend piping systems for transportation of non-Newtonian slurries. Failure-rate data will be included in the data base.

Instrumentation will be tested throughout the life of the development project; however, a percent-solids monitor will require significant development. A sensing system that can detect solids in a dense carrier fluid (e.g., 4 M NaN03) will be located or developed. The system will be capable of (a) measuring the weight-percent solids in a stirred solution or during transfer and (b) detecting the elevation of the interface between the sludge and supernate of a settled solution.

Decontamination of Radioactive Aqueous Sodium Nitrate

Development of a reliable, cost-effective process to separate cesium and strontium from a slurry of sludge and supernate has been proposed so that the sodium nitrate supernate can be managed inexpensively. The process concept utilizes two inorganic ion exchangers, a hexacyanoferrate compound for cesium removal and sodium titanate for strontium removal. The use of sodium nickel hexacyanoferrate to remove several metals from solution has been reported (5). In this process, "seeded ultrafiltration," finely divided hexacyanoferrate was added to a waste stream to absorb contaminants and was then removed by filtration. This method is reported to be effective for the removal of radionuclides from aqueous waste streams. In related work at ORNL, Campbell et al.2 report high decontamination factors in the presence of 8 M NaNO3 and 1 M KNO3.

The development of this decontamination-clarification step will include selection of the appropriate geometric form of the ion-exchange materials required for (a) sorption of cesium and strontium, and (b) removal of this material from solution in the clarification portion of this step. Previous experience indicates that a close relationship exists between clarification and decontamination due to the need to remove the ion exchange materials from the solution . The effectiveness of this combined operation will determine the number of stages required--two stages are shown in Fig. 1--to achieve the desired level of decontamination.

Development of decontamination and clarification will utilize the simulated waste. The decontamination step will be investigated by studying the effect of varying pH, geometric form of the ion-exchange materials, impeller speed, mixing time, and number of stages required. Variables to be investigated with respect to clarification will be the effect of mainstream feed velocity through the filter, pressure requirements to obtain an acceptable permeate rate, and filter pore size.

The feasibility of long-term, continuous operation of crossflow filters has been demonstrated using ORNL radioactive waste supernate (3). This work will be extended to the selected filter system. An existing crossflow filter system, with some modifications, will be utilized to investigate (a) filter performance with actual waste in the presence of ion-exchange materials (hexacyanoferrate and titanate particles), (b) the degree of concentration that could be achieved, and (c) the decontamination levels of the filtered product.

Installation of the selected filter system in the existing WDF will permit pilot-scale demonstration of this process using simulated waste. The complete slurry treatment process (sludge mobilization and transport, supernate decontamination and clarification, and solidification), as prestated in the Conceptual Design Report (CDR) for the WHPP, will be demonstrated at the WDF. Operation of this system will provide design data in sufficient detail to prepare the design criteria for the WHPP. Continuing development activities would then be used to qualify the processes.

Drying and Solidification of Sludge

The Preliminary Conceptual Design Report (PCDR) for the WHPP was completed in FY 89; the CDR incorporated results of development work and was drafted in FY 90. The PCDR called for the slurry from the MVSTs to be transferred to a liquid/solids separator. The liquid stream from the separator would enter a kettle evaporator for concentration at 110°C. The concentrate (bottoms) from the evaporator, along with solids from the separator, would be transferred to an extruder for further processing. The melt from the extruder, which would operate at 350°C, would be discharged into a drum and microwave heated to ensure efficient filling of the liner. Development efforts during FY 89 and FY 90 led to the decision to use a wiped-film evaporator and a microwave applicator for the WHPP CDR in FY 90. Additional development is needed to determine if both an evaporator and a microwave will be needed or if the process will rely on one or the other technology.

An agitated thin-film evaporator (ATFE) contains two or more rotating blades which either ride on the inside wall of the exchanger or are supported very close to the wall. These rotating blades maintain a thin layer of fluid on the heated surface of the exchanger, thus promoting high heat-transfer coefficients. As a result of the high-heat transfer coefficients, the overall heat-transfer area required is less. Because these units can handle feeds with high total solids concentrations, the use of an ATFE will allow the unit to replace both the liquid/solid separator and the kettle evaporator specified in the PCDR. Tests with ATFEs using a MVST sludge at vendors' test facilities have demonstrated that the ATFE can be used to concentrate the waste and produce a bottoms product that is a slurry, a powder, or a melt. Therefore, the ATFE was specified in the CDR to replace the extruder in the PCDR as well as to replace the separator and the kettle evaporator, which greatly simplified the overall process.

Further development of the ATFE is required to provide design data for the WHPP. A vertical ATFE with 5.4 ft2 of heat-transfer area will be evaluated at the WDF. The primary objectives of the test include: (a) testing the unit in the production of a slurry, a powder, and a melt; (b) determining the physical properties of the waste forms that are important in determining if the waste forms will be acceptable by WIPP; (c) evaluating the evaporator during long-term processing; (d) obtaining the data necessary for scaleup and operation of the full-size system for WHPP; and (e) testing the peripheral equipment. A dynamic model of the ATFE has been initially evaluated (17).

The WHPP process equipment will be contained in a shielded hot cell and will be remotely operated and maintained. The microwave applicator will contain a minimum of moving parts to effect heat transfer and, therefore, enhance maintainabilities. Conventional heat-transfer methods, such as that using an ATFE, employ a rotor and associated bearings that must be maintained in the cell. The microwave system will be designed to heat the waste in a liner that will fit into the final disposal container, thus greatly simplifying the handling requirements of high- temperature materials after melting. This system should, therefore, require less maintenance than conventional evaporation and solidification methods. An additional advantage of the microwave system over conventional processes is its capability of achieving temperatures that are high enough to vitrify the waste should WIPP require an improved waste form.

The microwave solidification principle has been proven by tests conducted with non-radioactive surrogate waste. These tests have focused on an in-drum process to dry the liquid and sludge in the drum-liner-type container and then melt the salt residues to form a solid monolith. This final waste form meets the current waste acceptance criteria for the WIPP. Initial bench-scale tests with a surrogate sludge, conducted at Rocky Flats (18), demonstrated the principle of the microwave process. ORNL bench-scale tests (19) confirmed and extended the work to include a patented, acoustic emission control system and a method to control arcing. Bench-scale experiments with surrogate waste demonstrated that wet or dry slurry can be processed into solid monoliths that meet the WIPP waste acceptance criteria. An extensive literature search was also conducted and reported (20, 21). A 1/3-scale proprietary microwave applicator was designed, fabricated, and tested to demonstrate the essential features of the microwave design and to provide input to design of the full-scale applicator. Design, fabrication, and installation of the full-scale system in the WDF have been planned.

Continued development of the microwave process will include both pilot- and full-scale testing. The microwave energy field produced by the prototype applicator will be measured and documented. Tests will evaluate the effectiveness of various operating schemes, such as continuous or batch fed. The design of the full-scale system will be modified to incorporate the results of the 1/3-scale tests. Testing and evaluation will include optimizing the processing method. Heat-transfer models will be developed and will be used to evaluate alternative operating scenarios. The microwave system will be operated with diluted slurry and more concentrated feed materials; as shown in Fig. 1, it will be coupled with an existing ATFE to simulate the slurry processing flowsheet that is included in the CDR for the WHPP.

SOLIDS PROCESS DEVELOPMENT

Remote Maintenance and Operation

A reliable, functional, and cost-effective remote maintenance system is vital to the successful implementation of the WHPP project. This system is comprised of (a) the in-cell manipulators or mechanical arms called slaves; (b) the control system and the master arms, which are mostly located out of cell; (c) the control system; (d) a communications and CCTV network, which allows the out-of-cell systems to communicate with and transmit commands to the in-cell systems; and (e) the manipulator transporter, which positions the slaves and CCTV within the cell. At present, an acceptable system is not available from industry. Various systems are being developed in the United States and in other countries, but none are aimed specifically at the WHPP need. It is critically important that equipment for the WHPP, as it is presently conceived, be developed if the project is to be successful.

Slave development will optimize the in-cell mechanical and structural system, striking an appropriate balance among performance, reliability, maintainability, and cost. The initial activity will be to select a reference system concept and architecture to be pursued in succeeding project phases. An advanced conceptual design and the preparation of a formal cost estimate for the remainder of the project will follow.

A master and control system will provide design and implementation of an effective human factors-based human-machine interface for the manipulator system using reliable and maintainable control-system hardware. Initial activities will include deciding whether to buy or build the master arms, selecting the control-system bus and operating system, and programming environment/language.

To reduce the number of hot-cell penetrations and the amount of cabling required in the WHPP facility, an improved video and manipulator signal-distribution system is proposed. The proposed system will multiplex several video and manipulator signals on the same coaxial cable. This is analogous to the capability of phone companies to now combine several conversations on the same fiber optic cable, whereas in the past they used dedicated wires for each conversation. Capital operational and maintenance cost savings will result from fewer cell penetrations and less cable. In addition, the proposed system will provide greater functionality in that video displays at each operator station will be readily accessible at the operator's command. Without the proposed system, expensive, rudimentary video-switching gear would be utilized, resulting in a significant increase in switching and operator time.

The test-bed platform for the WHPP remote-maintenance manipulator system will make use of the existing

Advanced Integrated Maintenance System (AIMS). Modifications to the control system and cabling will be necessary in order to support the new manipulator, and a mechanical interface will be necessary. System testing will be designed to verify compliance with design requirements. Testing will include all significant design points, such as force-reflection sensitivity, maximum capacity, and tip velocities.

Double-Lid Transfer System

The conceptual design for the WHPP includes use of a large-diameter double-lid transfer system for the transfer of RH TRU solid waste into the process cell. Presently, there are commercially available systems that are intended for use with specially designed 55-gal drums. These drums are approximately 23 in. in diameter. However, to accommodate ORNL's concrete waste storage casks, the double-lid transfer system necessary for the WHPP must be 60 in. in diameter. There are ~350 casks presently in storage with about 6 being generated annually. The design of this 60-in.-diameter system, though based on the same concept as the commercially available systems, is totally unique and must be demonstrated.

A first-generation developmental version, using a shortened double-lid transfer container, has been designed and fabricated for testing. The container has the actual 60-in. diameter; but it is only 45 in. in height, since this parameter does not affect the functionality of the system. The major components include the docking port cover and flange subassembly and the container body.

Initial testing of the mechanical and remote-maintenance steps, which is necessary to evaluate the existing design, has been completed and demonstrated the feasibility of the system. Improvements were identified that will decrease the time required to change a gasket. Another area of testing addresses annulus decontamination. An annulus is formed by the port flange, port cover, container lid, and the container body when the transfer container is docked to the WHPP process cell. This annulus may become contaminated when it is exposed to the contaminated atmosphere of the process cell. If the annulus does become contaminated, it introduces an increased potential for spreading contamination to the clean areas of the facility unless it is decontaminated before the undocking occurs. Initial testing has been completed to evaluate the effectiveness of the annulus decontamination, and an attempt was made to identify specific decontamination parameters.

Improvements to the design of the double-lid transfer system were identified during initial test requirements. Modifications will be made to the system, and development will be continued; however, complete demonstration of the system will be necessary prior to operation of the WHPP.

WASTE CHARACTERIZATION

Linear accelerator (LINAC)-based nondestructive assay (NDA) and nondestructive examination (NDE) instrumentation will be developed for the in-process examination and assay of ORNL RH TRU solid wastes processed in the WHPP. Assay and examination capabilities will be provided at the receipt and discharge portions of the WHPP flow stream. One LINAC device will provide the energy source required for both real-time radiography examination (NDE) and passive/active neutron assay (NDA). Wastes will be examined at the WHPP to determine processing requirements. After process completion, the waste will be certified prior to shipment to the WIPP.

Design, construction, and development of an operating NDE/NDA system using a LINAC for RH TRU waste are necessary to develop this technology for use in the WHPP. The work will consist of (a) preparation of a site for the system, (b) design and construction of a small-scale version of the system for conducting research and development leading to a design for a full-scale system, (c) design and construction of suitable test samples, and (d) construction and operational testing of the full-scale system. Additional work will then be needed to fully characterize the calibration and operating parameters of the system.

CONCLUSION

The WHPP design includes unique features for remote operation and maintenance that require significant development activities. If the WHPP process is demonstrated to the level required to ensure successful design and operation, tests will be conducted with actual and simulated waste and unique equipment will be demonstrated. The following categories will be developed: (a) slurry process; (b) solids process, and (c) waste characterization.

WHPP development work has been delayed due to the uncertainty regarding the waste form required for disposal. However, much of the research and development required to support the project is not waste-form specific and could be continued. Development tasks that could be continued are discussed in this paper. Tasks are discussed in detail because significant work and specific planning have been completed.

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