SANDIA NATIONAL LABORATORIES

WASTE ISOLATION PILOT PLANT (WIPP)

Test Plan TP 00-05

Waste Erodibility with Vertical and Horizontal Sediment Flume

Task 1.1.01.02.07.02

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1.0 Approval Page

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3.0 Revision History

The following text is the original issue of this Test Plan; no prior revisions exist. Changes to this document shall be reviewed and approved by individuals having the same level of responsibility as those who performed the original review and approval. All revisions will have at least the same distribution as the original document.

4.0 Purpose and Scope

The primary objective of this testing program is to determine the critical shear stress for erosion of waste surrogate samples. This is needed to assess the critical shear stresses that might be experienced in a human intrusion scenario if an exploratory drill hole were to penetrate the sealed WIPP repository, after it is filled with radioactive waste. Critical shear stress, a measure of the erodibility of the waste, which can be determined with the use of a vertical and horizontal sediment flume, is a WIPP performance assessment (PA) parameter. In the Compliance Certification Application (CCA), this parameter was estimated conservatively from data for soft muds and non-cohesive sediments, which are not realistic analogues of future states of anticipated WIPP waste and backfill material. The data to be gathered in this test plan will provide experimental data of waste critical shear stress to be used in calculations supporting WIPP re-certification.

The vertical sediment flume is based on a horizontal sediment flume built and routinely used in the Department of Mechanical and Environmental Engineering, University of California, Santa Barbara (UCSB), CA (Jepsen *et. al*., 1997; Taylor and Lick, 1996). Initial studies testing the capability of the flume to determine critical shear stress using 10 cm x 15 cm waste surrogate materials (Jepsen *et. al*., 1998a) were conducted by UCSB under Sandia contract AX-9022 in FY98. The results obtained with the horizontal sediment flume demonstrated the feasibility of testing samples of various compositions prepared to simulate anticipated WIPP repository wastes. Surrogate waste will be fabricated from combinations of compressible components such as paper, rags, plastics, and rubber-based trash; rigid components such as broken and discarded glass, fire brick, construction debris (wood, sheet metal, piping, reinforcing steel); and high density, semi-plastic materials such as stabilized oils, resins, and sludges. Development of these samples is described in SAND97-1369.

A sediment flume is designed to allow a flowing fluid to erode a sample that is level with the wall of the flume channel by exerting a shear stress on the sample. This allows for the investigation and quantification of the erodibility of the sample, expressed as a critical shear stress value (N/m^2). The vertical sediment flume design will simulate a situation where a drilling operation penetrates a waste-filled panel or room of the WIPP repository. Fluid shear stress imposed by the flowing drill fluid may erode material near the borehole intrusion and transport it to the surface. Additionally, experiments will be performed to test the effect of mass failure mode erosion at high shear stresses (~10 N/m^2) and with the horizontal sediment flume to test the effect on erosion of the orientation of the surrogate waste material.

5.0 Experimental Process Description

Description of Vertical and Horizontal Sediment Flume. The information in this section is essentially the same as that reported in the Long Beach Harbor Sediment Study by Jepsen et al (1997b) and is partially based on the articles by McNeil et al (1996), Taylor (1996), and Jepsen et al (1997a). It should be noted that the horizontal sediment erosion capability/portion of this flume is essentially the same as the flume used in the initial, surrogate waste erosion, studies at UCSB (Jepsen et. al., 1998a). Also, the operation of the horizontal and vertical sediment erosion capabilities is essentially the same. Therefore, a detailed description of only the vertical sediment erosion capability will be given, however, when appropriate the differences between the two capabilities will be pointed out and discussed further.

The Vertical Sediment Flume is shown in Figure 1 and is essentially a straight flume, which has a test section with an open bottom through which a rectangular cross-section coring tube containing surrogate waste samples can be inserted. The main components of the flume are the coring tube; the test section; an inlet section for uniform, fully developed, turbulent flow; a flow exit section; a fluid storage tank; a pump to force fluid through the system; and a linear actuator to extrude the sample into the flow. The test section, inlet section, and exit section are made of clear Polycarbonate (Lexan) so that the sample-fluid interactions can be observed. The test section will be, 10 cm x 15 cm, sized to match the scale in the related can-crushing tests (Wawersik, 1999). The fluid in the vertical sediment flume will be contained in the 120-gallon storage tank. The surrogate waste debris from an eroded sample will be removed from the fluid by baffles placed in the reservoir and filtering the fluid before recirculating. The fluid is pumped through the system from the 120-gallon storage tank, through a 5 cm diameter pipe, and then into the rectangular duct. This duct is 5 cm in height, 10 cm in width, and 200 cm in length; it connects to the test section, which has the same cross-sectional area and is 15 cm long. A three-way valve regulates the flow so that part of the flow goes into the duct while the remainder returns to the tank. The flow rate of the circulating fluid will be monitored by an in-line flow meter. There is a small valve in the duct immediately downstream from the test section, which is opened at higher flow rates to keep the pressure in the duct and over the test section at atmospheric conditions.

At the start of each test, the coring tube and the surrogate waste sample it contains will be attached to the side of the test section. An operator will move the sample laterally using a piston, which is inside the coring tube and is connected to a linear actuator with a 20 cm drive. Extensions may be placed on the drive to allow the extrusion of up to a meter or more of surrogate waste sample. The linear actuator is driven by a stepper motor, which is regulated by a controller system. By this means, the sample can be moved and leveled with the side of the test section. The speed of the linear actuator movement can be controlled at a variable rate in measurable increments as small as 0.25 mm.

The fluid is forced through the enclosed channel and the test section over the surface of the sample. The shear produced by this flow causes the sample to erode. As the sample in the core erodes, it is continually moved laterally by the operator so that the sample-fluid interface remains level with the side of the test and inlet sections. The erosion rate is recorded as the lateral movement of the sample in the coring tube over time. The sample erodibility is visually monitored over time using a stopwatch and a micrometer. The time of erosion and the sample extrusion distance, for each run, will be recorded in the scientific notebook. The erosion rate is the sample extrusion distance divided by the time of extrusion and will also be calculated and recorded in the scientific notebook. The erosion rate data is generally reported in units of cm/s. The sample erosion activity will be documented using a digital video camera.

The flume does not have any software or computer hardware interfaces. There are two controls. One control is the flow rate of the circulating fluid, which is determined by the use of the single flow rate pump and three-way valve system. The rate of flow in the channel can exceed 100 gpm and will be monitored by an inline flow meter. The second control is the amount of sample extruded, as the flowing fluid erodes its surface. Both are manual processes performed by the operator.

It should be noted that the experiments described in this test plan have not been performed before. Therefore, the specific procedures for conduct of experiments described in this test plan will be written at a later time, as work progresses and decisions are made as to the best methods for optimizing and refining the process.

Sample Collection and Preparation. Two types of material will be tested in the flume, 50% degraded surrogate waste and MgO backfill material, both to be saturated in brine similar to the WIPP brine. Each material type will be placed into a steel form and subjected to pressures ranging from completely un-pressurized up to the lithostatic pressure of the repository (~2000 psi). These materials were developed and are described in SAND97-1369. The container and sample will be fastened to the channel test section for the erosion measurements.

Measurements of Waste Sample Erosion Rates. The procedure for measuring the erosion rates of the samples, with the vertical sediment flume, as a function of shear stress and depth are in development as this specific type of experiment has not been performed before. The following is a sample procedure based upon experience with the horizontal sediment flume used at the University of California at Santa Barbara.

The samples will be obtained as described above and then moved laterally or upward into the test section until the sample surface is even with the side of the test section. A measurement will be made of the length to the bottom of the sample in the tube. The flume will then be run at a specific flow rate corresponding to a particular shear stress. The equations used to convert flow rate to shear stress for these experiments can be found in Appendix A. The flume is capable of creating shear stresses exceeding 10 N/m^2 on the surface of the waste surrogate material. Erosion rates will be obtained by measuring the remaining sample depth at different time intervals, taking the difference between each successive measurement, and dividing by the time interval.

In order to measure erosion rates at several different shear stresses using only one sample, the following procedure will be used. Starting at a low shear stress, the flume will be run sequentially at higher shear stresses with each succeeding shear stress being twice the previous one. Generally, about three shear stresses will be run sequentially. Each shear stress will be run until at least 0.5 mm but no more than 1 cm is eroded. The time interval will be recorded for each run with a stopwatch and the sample extrusion distance will be recorded with a micrometer. The flow will then be increased to the next shear stress, and so on until the highest shear stress is run.

A detailed description of these procedures will be written at a later time, after the work has progressed and more has been learned about the best methods for proceeding.

Measurements of Critical Shear Stress for Erosion. A critical shear stress can be quantitatively defined as the shear stress at which a very small, but accurately measurable, rate of erosion occurs. For the present planned tests, this rate of erosion will be chosen to be 10^{-4} cm/s; this represents 1 mm of erosion in approximately 15 minutes. Since it would be difficult to measure all critical shear stresses at exactly 10^{-4} cm/s, erosion rates will generally be measured above and below 10^{-4} cm/s at shear stresses which differ by a factor of two. The critical shear stress will then be linearly interpolated to an erosion rate of 10^{-4} cm/s. This will give results with a 20% accuracy for the critical shear stress. Some of the samples may not be able to be eroded at rates greater than 10^{-4} cm/s within the range of shear stresses possible. For these samples, the test will be run at a particular shear stress for several hours in order to obtain a measurable amount of erosion.

The use of replicate samples will provide a measure of the precision of the method used and the variability of the critical shear stress measurements for different waste surrogate sample types and materials.

5.1 Planning Overall Strategy and Process

All activities conducted by Sandia National Laboratories or its contractors in support of this test plan (TP 00-05) shall be done in accordance with the current SNL NWMP QA program procedures (NPs and SPs), Technical Operating Procedures (TOPs) and ES&H procedures.

- The primary objective of this testing program is to determine the critical shear stress of various types of compacted surrogate waste materials with depth. Methods of measuring the critical shear stresses of differing surrogate waste materials relies upon the accurate measurement of the flow rate within the channel and the amount of material extruded to the level of the side of the channel.

- The critical shear stresses of different waste surrogate materials can vary by over an order of magnitude depending on the type of material tested as documented in the report to Sandia, “Development and Testing of Waste Surrogate Materials for Critical

Shear Stress", by Jepsen et al, (1998a). The critical shear stress of each different waste surrogate material is unique. Because the properties that the erosion of the waste surrogate material relies upon are not well understood, the erosion cannot be predicted from knowledge of such properties. Since the wastes to be tested in these experiments have never been tested before, there is no data to compare measurements. Comparisons of the critical shear stress of the waste will be made from duplicate samples, once the testing begins.

- The critical shear stress data will be used by the WIPP Repository Performance program in support and development of the Cavings model used to calculate direct releases to the surface during a drilling intrusion scenario. No compatibility problems with the conceptual or mathematical models are foreseen at this time. If problems become apparent during the testing phase, they will be documented in the project's scientific notebook, discussed and resolved with the program.

- The procedures used in these experiments are described in the Experimental Process Description section. These procedures are similar to those that have been previously developed for the horizontal sediment flume, which can be found in the literature (McNeil et al, 1996; Taylor et al, 1996; Jepsen et al, 1997a; Jepsen et al, 1997b; Jepsen et al, 1998a; Jepsen et al, 1998b; Jepsen et al, 1999; Roberts et al, 1999). Since the materials proposed for the experiments described in this test plan have not been tested before, the specific procedures for completion of the test plan will be written at a later time, when work progresses and decisions can be made as to the best methods for proceeding. Documentation will be recorded in the project's scientific notebook and supported by digital video recording.

- As the sample in the core erodes, it is continually moved upwards by the operator so that the sample-water interface remains level with the side of the test and inlet sections. When and how much material to extrude to the level of the bottom of the test section is determined by the operator and these data will be recorded in the project's scientific notebook. The results obtained using a similar, horizontal sediment flume have been shown to be reproducible within a ± 25% error and were independent of the operator (Jepsen et al, 1997a; Jepsen et al, 1997b; Jepsen et al, 1998a; Jepsen et al, 1998b; Jepsen et al, 1999; Roberts et al, 1999).

The following QA records are expected to be generated through implementation of this test plan:

- Copies of all instrument calibration records
- Activity/Project Specific Procedures (SP), and Technical Operating Procedures (TOP)
- A hard-copy of the data
- Any calculations performed as part of these activities. These items will be included in the project's scientific notebook (both manual and electronic)
- Digital video records (removable storage)

These records shall be submitted to the NWMP Records Center in accordance with NP 17-1 (Records).

5.2 Sample Control

- Samples shall be identified and controlled in accordance with NP 13-1 (Sample Control) and SP 13-1 (Chain of Custody). This NP specifies procedures for labeling and identification, Chain of Custody, sample storage and environmental controls, and sample disposition. Specimens will be prepared in Carlsbad, NM. Sample preparation specifications will follow documented procedures and any additional details will be documented using a scientific notebook.

- Examples of sample labeling nomenclature can be found in SP 20-1 (Waste Surrogate Development: Sample Material Acquisition and Preparation) in section 2.6.

- There are no specific environmental control requirements for sample storage, although, samples will not be stored in temperature extremes causing brittleness, melting, or other conditions affecting integrity. Also, samples will be stored in areas that are not open to the weather or where excessive humidity or moisture might affect the samples or sample labeling. Upon completion of the experiments the excess surrogate waste will be placed in the facility trash (i.e. sanitary waste) for disposal.

5.3 Data Quality Control

- Data and calculations performed as part of these activities will be recorded in the project's scientific notebook. The data will be verified by the technical reviewer who will note concurrence by co-signing the scientific notebook. If a discrepancy is found, that discrepancy and its resolution will be documented in the scientific notebook. All activities (stated here and in the rest of the document) involving the scientific notebook, its review, and any corrections to be made will be done in accordance with NP 20-2 (Scientific Notebooks) and NP 6-1 (Document Review Process).

- All activities shall be conducted in accordance with NP 12-1 (Control of Measuring and Test Equipment). Calibration schedules for laboratory testing equipment have already been established based on use and recommendations of the equipment manufacturers. These calibrations will be documented in the project's scientific notebook.

- Duplicate cores of waste surrogate material will be tested to verify the accuracy of the critical shear stress measurements. Any deviations from test procedures will be documented in the scientific notebook and reviewed by the technical reviewer in accordance with NP 6-1 (Document Review Process). The test samples and flume will be locked in a laboratory with access given only to appropriate project personnel.

5.4 Data Identification and Use

- Experimental data derived from the activities described in this test plan will be used in the development of a probability model for shear strength of wastes under WIPP conditions.

- Various data printouts will be attached directly to the project's scientific notebooks or submitted to the SNL NWMP Records Center. For instruments that do not have direct data printout, the instrument readings will be recorded directly into the scientific notebook. The data will be verified by the technical reviewer who will note concurrence by co-signing the scientific notebook. If a discrepancy is found, that discrepancy and its resolution will be documented in the scientific notebook.

- Data transfer and reduction shall be performed in such a way as to ensure that data transfer is accurate, that no information is lost in the transfer, and that the input is completely recoverable. Also, data transfer and reduction shall be controlled, in accordance with NP 9-1 (Analyses), to permit independent reproducibility by another qualified individual.

- From the scientific notebook(s) or from the instrument's direct electronic data output file, numerical data will be transferred into a Microsoft Excel (version 7.0 for Windows NT or later version) spreadsheet or into a Kaleidagraph graphing program (version 3.0 for Windows NT or later version). The data will be verified by a second person to ensure that no data transcription errors have occurred. The data will be directly analyzed, in accordance with NP 9-1 (Analyses), and plotted from the spreadsheet. Technical data, including scientific notebooks, submitted to the NWMP Records Center will be transmitted using the following file code: WIPP: 1.1.01.2.7:TD:QA:DPRP1:NF: Desired additional key words may be added.

6.0 Training

- All personnel involved in the experiments described in this document are trained and qualified for their assigned work. This requirement is implemented through NP 2-1 (Qualification and Training) for those working under the SNL WIPP QA Program. All qualification and QA training records are submitted to and maintained by the NWMP Records Center. The training records for the following ES&H courses are maintained in the SNL Laboratory Information System Training database, TEDS:

  ESH 100: ESH Awareness
  PRS 102: Basic Pressure Safety
  LAB 100: Laboratory Standard Information and Training

- Those personnel working under the SNL WIPP QA Program will be required to submit the following forms to the NWMP Records Center prior to beginning work, if the form is not currently on file:

Form NP 2-1-1 Qualification and Training Form

Also, Annual QA refresher training must be documented on form NP 2-1-2 if not indicated on form NP 2-1-1 prior to beginning any QA work.

- Training on assigned Nuclear Waste Management Program Procedures (NPs and SPs), Technical Operating Procedures (TOPs), this test plan, ES&H procedures, and any other required training shall be completed and documented prior to beginning work. Annual refresher QA training ensures that on-site personnel are trained to the WIPP QA Program. TOPs and standard operating procedures (SOPs) will be read and the attachment 'list of Authorized Users' will be signed and dated for each required TOP and SOP.

7.0 Health and Safety

- All the health and safety requirements relevant to sample preparation and testing for existing laboratory facilities are documented and described in SOPs. The laboratory has a Preliminary Hazard Screening, a Hazard Plan, and a Safety Plan. The ES&H SOPs identify radiation, pressure, and other hazards associated with routine experiments and describes the procedures to deal with these hazards, including all the training requirements for personnel involved in conducting these experiments. However, these activities are not expected to generate any hazards. Sample preparation and testing activities in the existing laboratory takes into consideration all the relevant ES&H requirements, specific design considerations, and procedures that have been discussed in previous sections. Any safety requirements are expected to have no direct impact on the technical aspects of this work.

8.0 Permitting/Licensing

- No permitting or licensing activities are required for this work.

9.0 References

Jepsen, R., Roberts, J., and Lick, W. (1997a). "Effects of bulk density on sediment erosion rates." Water, Air, and Soil Pollution, 99, 21-31.

Jepsen, R., Roberts, J., and Lick, W. (1997b). "Long Beach Harbor sediment study." Report to the U.S. Army Corps of Engineers, Los Angeles District.

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Disposal Room Processes, Sandia National Laboratories, Albuquerque, NM (WPO#49064)

Jepsen, R., Roberts, J., and Lick, W. (1998b). "New York Harbor sediment study." Report to the U.S. Army Corps of Engineers, New York District.

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McNeil, J., Taylor, C., and Lick, W. (1996). "Measurements of erosion of undisturbed bottom sediments with depth." Journal of Hydraulic Engineering, ASCE, 122(6), 316-324.

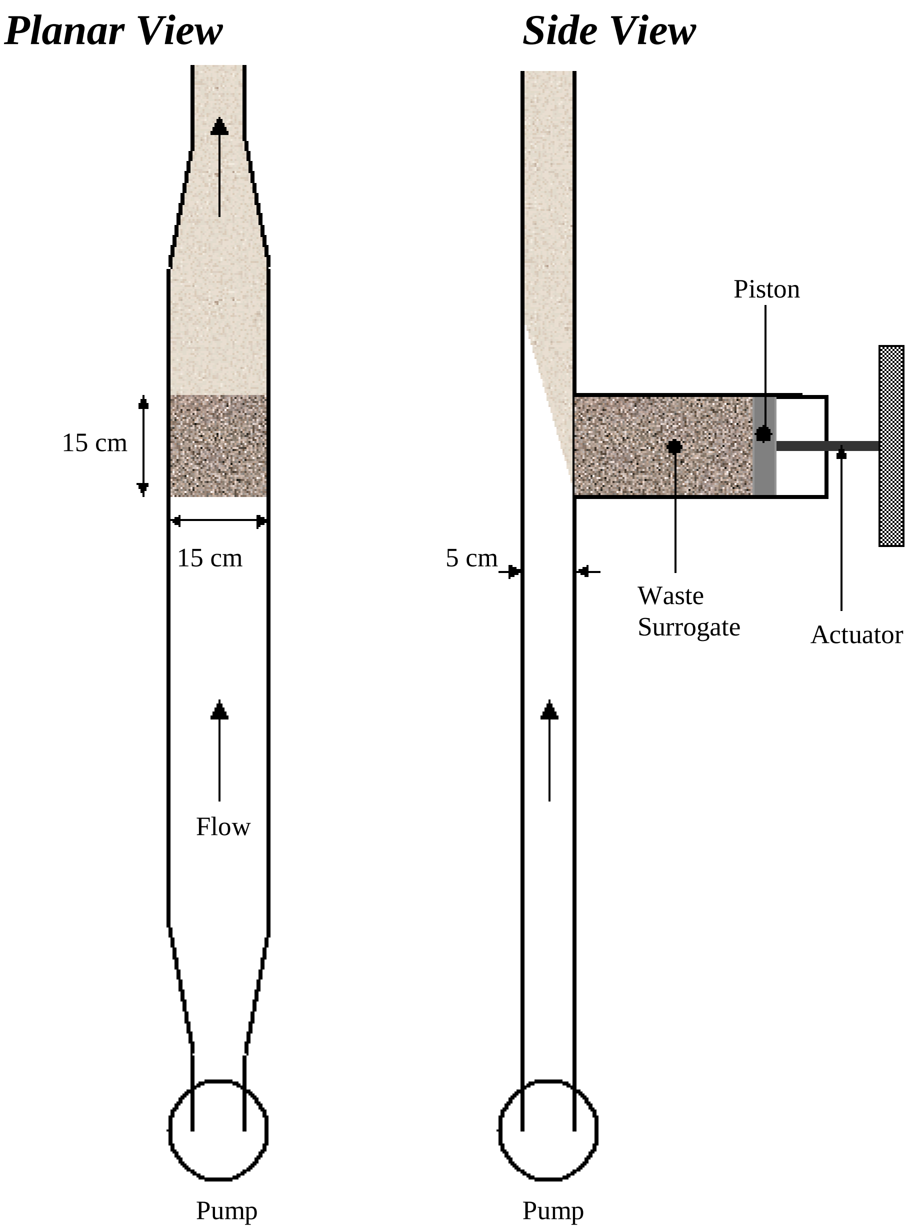
Roberts, J., Jepsen, R., and Lick, W. (1998). "Effects of particle size and bulk density on erosion of quartz particles." Journal of Hydraulic Engineering, ASCE, 124(12), 1261-1267.

Hansen, F.D., Knowles, M.K., Thompson, T.W., Gross, M., McLennan, J.D., Schatz, J.F., SAND97-1369. "Description and Evaluation of a Mechanistically Based Conceptual Model for Spall." Sandia National Laboratories, Albuquerque, NM.

Taylor, C., and Lick, W. (1996). "Erosion properties of Great Lakes sediments." Report, Department of Mechanical and Environmental Engineering, University of California, Santa Barbara, California.

Wawersik, W. R. (1998). "One-Quarter-Scale Laboratory Crush Tests on Unconfined Waste Cans and Confined Waste Packages in Support of WIPP". Technical Report, SAND98-2574. Sandia National Laboratories, Albuquerque, NM.

Figure 1. Schematic of Vertical Sediment Flume



Appendix 1: General Relationships for Internal Turbulent Flow

Flow Rate (Q): Q = Uhw

Coefficient of Resistance (λ): $\lambda = \frac{8\tau}{\rho U^2}$

Friction Velocity (v_*): $v_* = \sqrt{\frac{\tau}{\rho}}$

Hydraulic Diameter (d): $d = 2\frac{hw}{h+w}$

τ = Shear Stress
ρ = Density
U = Mean Velocity
h = channel height
w = channel width

Hydraulically Smooth Flow:

$$\frac{1}{\sqrt{\lambda}} = 2.0\log\left(\frac{Ud\sqrt{\lambda}}{\nu}\right) - 0.8$$

ν = kinematic viscosity

Completely Rough Flow:

$$\lambda = \frac{1}{\left(2.0\log\frac{r}{k_s} + 1.74\right)^2}$$

r = hydraulic radius (d/2)
k_s = height of protrusion from bed

$\frac{k_s}{r} < \frac{1}{15}$ for all experimental data.