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Sandia National Laboratories
Waste Isolation Pilot Plant (WIPP)

Compaction Behavior of Emplaced Waste
Test Plan TP 08-01
Rev. 1

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1 ABBREVIATIONS, ACRONYMS, AND INITIALISMS

Cal Lab	SNL Primary Standards Calibration Laboratory
DAS	Data Acquisition System
DOE	Department of Energy
DOE/CBFO	Department of Energy/Carlsbad Field Office
DRZ	Disturbed Rock Zone
EPA	Environmental Protection Agency
ES&H	Environmental Safety and Health
FEA	Finite Element Analysis
ID	Inside Diameter
LVDT	Linear Variable Differential Transformer
MgO	Magnesium Oxide
NP	(SNL WIPP) Nuclear Waste Management Procedure
NQ	non-QA
OD	Outside Diameter
PA	Performance Assessment
PHS	Primary Hazard Screening
PI	SNL/CPG Principal Investigator or Designee
POP	Pipe Overpack
QA	Quality Assurance
QAPD	QA Program Document
Records Center	SNL/CPG Records Center
SAF	Soils and Foams Model
SN	Scientific Notebook
SNL	Sandia National Laboratories
SNL/CPG	Sandia National Laboratories/Carlsbad Programs Group
SP	(SNL WIPP) Activity/Project Specific Procedure
SwRI	Southwest Research Institute
TP	Test Plan
US	United States
TRU	Transuranic
TWD	Technical Work Document
WC	Weidlinger Cap Model
WIPP	Waste Isolation Pilot Plant
Work Control	WIPP Work Control Process

2 REVISION HISTORY

This is the second version (Revision 1) of this test plan (TP). The purpose and content of any future changes and/or revisions will be documented and appear in this section of revised editions. Changes to this TP, other than those defined as editorial changes per Sandia National Laboratories Waste Isolation Pilot Plant (SNL WIPP) Quality Assurance (QA) Procedure NP 6-2 "Document Control Process", shall be reviewed and approved by the same organization that performed the original review and approval. All TP revisions will have at least the same distribution as the original document.

TP 08-01, Revision 1 includes changes discussed within this paragraph. Revisions were made to incorporate suggestions brought about by Surveillance IS 10-06 conducted March 1, 2010 in Albuquerque, NM at the Geomechanics Laboratory, Building 849. Changes made based on the suggestions from the surveillance include: i) Include degraded waste testing (along with ¼- and full scale testing) throughout Section 5, ii) Duplicate copies of all data, scientific notebooks, etc., will be made every two months, not monthly (Section 5.4), and iii) The technique used to subtract out deformation of the testing system in order to determine deformation of a sample was referred to as a stiffness calibration and is now referred to as a system response measurement (Global). Additional revisions have been made to incorporate updated sample preparation techniques and testing methods for degraded waste testing in Sections 4.3.4 and 4.3.5.

3 PURPOSE AND SCOPE

The Waste Isolation Pilot Plant (WIPP) is a United States (US) Department of Energy (DOE) mined, underground repository, certified by the Environmental Protection Agency (EPA), and designed for the safe management, storage, and disposal of transuranic (TRU) radioactive waste resulting from the United States defense programs. The wastes are emplaced in panels excavated at a depth of 2,150 ft in the Permian Salado Formation. Following emplacement of waste and the MgO engineered barrier material, the panels will be isolated from the operational mine using an approved closure system. The repository is linked to the surface by four shafts that ultimately will be decommissioned and sealed.

Performance Assessment (PA) modeling of WIPP performance requires full and accurate understanding of coupled mechanical, hydrological, and geochemical processes and how they evolve through time. This test plan focuses on room closure, specifically the compaction behavior of waste and the constitutive relations to model this behavior. A principal goal of this study is make use of an improved waste constitutive model parameterized to well designed data. This will address certain technical issues arising from the use of the earlier waste model. Ultimately, any changes in the room closure model or other elements of the underground evolution will require peer review and acceptance by EPA.

The specific objectives of this Test Plan are:

- Perform hydrostatic, uniaxial and triaxial loading tests on ¼-scale standard waste packages filled with a representative range of simulated virgin waste forms to allow for the determination of a complete set of waste constitutive model parameters. One-fourth-scale testing is convenient for this task since we have available all axial loading and pressure equipment that can accommodate simulated waste packages of this size. For these tests, both axial displacements and total volume changes will be measured to fill in data that were not generated by previous experiments. Assuming the deformations are approximately axisymmetric, all three principal components of stress and deformation can be measured as the waste package is compacted.

- Perform full-scale hydrostatic and uniaxial loading tests to validate the scaling assumptions and provide a basis for evaluating the performance of the waste constitutive model in predicting the compressive behavior of standard waste package systems. These will be carried out following evaluation of the results of the ¼-scale tests.

- Perform hydrostatic and triaxial loading tests on simulated degraded waste. Previous work (Hansen et al., 1997) has been done on different recipes of material for spallings analyses but did not provide data needed to correlate volume change to other test parameters. Hansen also performed triaxial tests on surrogate degraded waste mixtures but only at a limited number of confining pressures given the spallings application being evaluated. A suitable range of confining pressures will be run to assist in the modeling efforts for the long term effects of WIPP room closure characteristics. Possible future, to-be-developed

surrogate materials will undergo a similar suite of tests.

- Perform a limited number of ¼-scale and full-scale tests on alternative waste containers (from the standard 55-gallon drum) that may make up a significant fraction of waste packages in some rooms or panels. Prior to these tests the behavior of these alternative waste containers will be evaluated using numerical analysis.

4 EXPERIMENTAL PROCESS DESCRIPTION

This section of the TP describes the experimental rationale and processes required to develop the data sets necessary to evaluate the parameters of a cap plasticity model for the standard 55-gal drum waste package with a variety of contents and for partially degraded surrogate waste materials without a container. The modeling program will be implemented in a large deformation, thermal-mechanical finite element program called JAS3D. Detailed studies will be performed on ¼-scale waste packages followed by a few tests on full-scale packages that will be used to verify the data from the scaled tests and to provide a data set for validation of a cap plasticity model. In addition to the drum compaction tests, a suite of tests will be performed on simulated degraded waste. These tests will assist in the performance assessment for long term room closure characteristics.

While the standard waste drum will make up approximately 80% of the packages emplaced in WIPP, there are other waste package configurations that if emplaced in significant numbers, might result in different closure characteristics of specific rooms. These alternate waste forms could be in many different configurations and quantities. Configurations under consideration for placement will be evaluated analytically before inclusion at the WIPP. A revised TP will describe the details of specific alternate waste forms should simulated testing become necessary.

4.1 One-Quarter-Scale Waste Package Tests

4.1.1 Discussion of Previous Work

Initial efforts to determine the mechanical response of waste packages for WIPP were undertaken by Huerta et al. (1983) with a focus on transportation system response rather than post-emplacement response. A second study was undertaken in 1988 (Butcher et al., 1991) to determine the response of simulated waste and full-scale waste packages under emplacement conditions. A major conclusion of these studies was that the response of 55-gal prototype waste drums undergoing moderate amounts of deformation is well characterized in ¼-scale experiments using No. 12 food cans (Baker et al., 1980) to simulate the waste packages. Even though some differences were noted in the lip-closure configurations, the lid and drum wall thickness, and yield and ultimate strengths of the food can material versus the waste drums (Huerta et al., 1983 and Baker et al., 1980), the investigators concluded that the ¼-scale drum tests appeared to provide all the information needed to perform valid simulations.

A second scaled drum compaction study was performed by VandeKraats (1987). In this study, large assemblages of ¼-scale drums were confined by crushed salt backfill in trenches and loaded normal to the lateral direction. The effect of confinement by backfill on the strength of the cans and the load transmission through the backfill were examined. Again, one significant conclusion of the study was that ¼-scale (No. 12 food cans) waste packages were adequate to simulate behavior in full-scale. Finally, Wawersik (2001) tested seven-pack arrangements of ¼-scale packages with simulated waste mixes similar to those tested by Butcher et al. (1991). In these tests, lateral confinement was provided by crushed salt backfill packed around the cans. The study

concluded that the axial load bearing ability of each ¼-scale can in the confined seven pack arrangement was substantially greater than that of an isolated, unconfined can.

The currently available data on compaction of waste canisters with some confinement is derived mainly from tests that use backfill as a confining media (Wawersik, 2001). While some measurements of maximum lateral stresses were made, the exact load path experienced by the waste and container is highly uncertain. Therefore, these data should not be used directly in determining parameters for the waste package model. In addition, in other previous studies only axial load – axial deformation measurements or lateral load – lateral deformation measurements were made on either the ¼-scale or the full-scale tests. No hydrostatic tests were made. Thus, it is not possible to distinguish between uniaxial compression along the major axis of the waste drum and confined compaction, where lateral stresses are present. This lack of multi-axial data, led modelers to adopt an isotropic, volumetric plasticity approach that can provide good predictability under unconfined conditions, but not under multi-axial states of stress and has resulted in some observed non-physical behavior of the material model. To provide a more complete data set that will allow determination of parameters for more complex models, e.g. a cap model, multi-axial tests are required. Even though existing data is inadequate for model parameter development, it has great value in providing measured response to deformation scenarios not used in the model calibration. Therefore, these data will be used to compare against model predictions of the compaction tests with backfill to provide an initial validation of the cap plasticity model (for the waste and canister system) and the backfilled salt.

4.1.2 Load Paths and Deformation States

Modeling of assemblages of waste packages requires a few basic assumptions, no mater what constitutive model is employed. The most fundamental assumption is that the waste package forms the basic “unit cell” of the model. Thus, we are after a constitutive relationship that best describes the behavior of a single waste package and then use continuum mechanics assumptions to “smear” that average behavior over large assemblages of packages. Examining the structure of the “unit cell” it is clear that an ideal description would be something approaching a transversely isotropic material. However, getting to that level of detail and complexity in a model for system level performance assessment is not viable. Thus, for this next increment of improved modeling, we will stick with the assumption that each unit cell is homogeneous, isotropic, porous, and pressure sensitive (plastic shear deformation and failure is sensitive to the imposed mean stress). These assumptions lead us to the general class of models known as “cap plasticity” models to best simulate the waste packages as a continuum. The difference between the current soils and foams (SAF) model and other cap plasticity models is in the level of complexity adopted in the formulation. The SAF model was degenerated to a pure volumetric plasticity formulation that is simple, but assumes that in the absence of shear failure, all three principal plastic strains are equal. Figure 4-1 illustrates the essentials of this model in stress space where the ordinate is proportional to the maximum shear stress and the abscissa is the mean stress or pressure. Any load path between hydrostatic (along the abscissa, path x-y-z in Figure 4-1) and uniaxial compression (path a-b-c) will result in similar compaction of the material once the stress reaches the plastic yield surface or “cap”. Thus, under uniaxial stress (path a-b-c), all three principal plastic strains will be equal, leading to a uniform volumetric compaction, in contradiction to experimental results. Attempts to

adjust the slope of the shear limit surface (adjusting parameter a_1 to less than 3), only result in yielding at lower stress (with subsequent volumetric plastic compaction) and reducing the apparent load bearing capacity of the waste drum. To redress this problem with the model, a slightly different formulation is required. Cap plasticity models appear to have the basic formulation that will allow for both shear compaction or dilation and volumetric compaction.

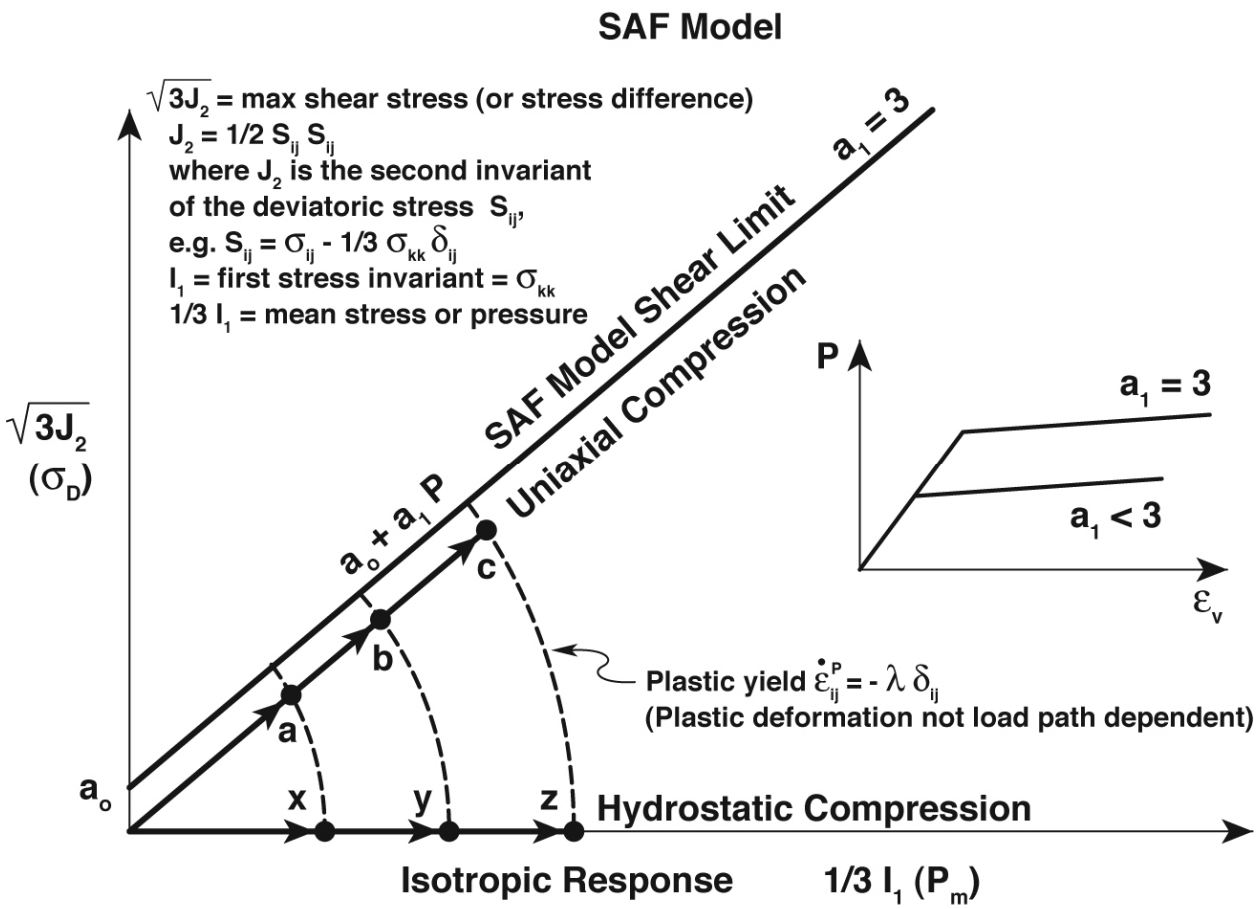

Figure 4-1: Illustrates the essentials of the SAF model in stress space. The ordinate is proportional to the maximum shear stress and the abscissa is the mean stress or pressure.

In order to develop a complete set of model parameters for a cap plasticity model that will allow for better simulation of waste package deformation under multi-axial states of stress, tests employing three basic load paths are required. The load paths are illustrated in Figure 4-2.

First, uniaxial compression tests, similar to those performed previously, are required. However, for this series of tests both axial and lateral deformations need to be determined. Second, hydrostatic compaction with direct measurement of volume change is needed to determine the behavior of the cap. This load path also has a secondary benefit of allowing an assessment of the degree of validity of the assumption of isotropy. Third, loading paths between uniaxial and hydrostatic are required to determine the slope of the shear surface and the shape of the cap. Typically these tests are done in a standard axisymmetric triaxial test configuration where a confining pressure is first applied then deviatoric stress is applied by increasing the axial load.

Because the initial primary mode of plastic deformation will be the buckling of the container, an alternative load path may be used that follows a proportional loading trajectory. That is, the sample is loaded by increasing the confining pressure and axial load simultaneously in a fixed proportion. The details of these tests and the preparation of the samples are described in the following subsections.

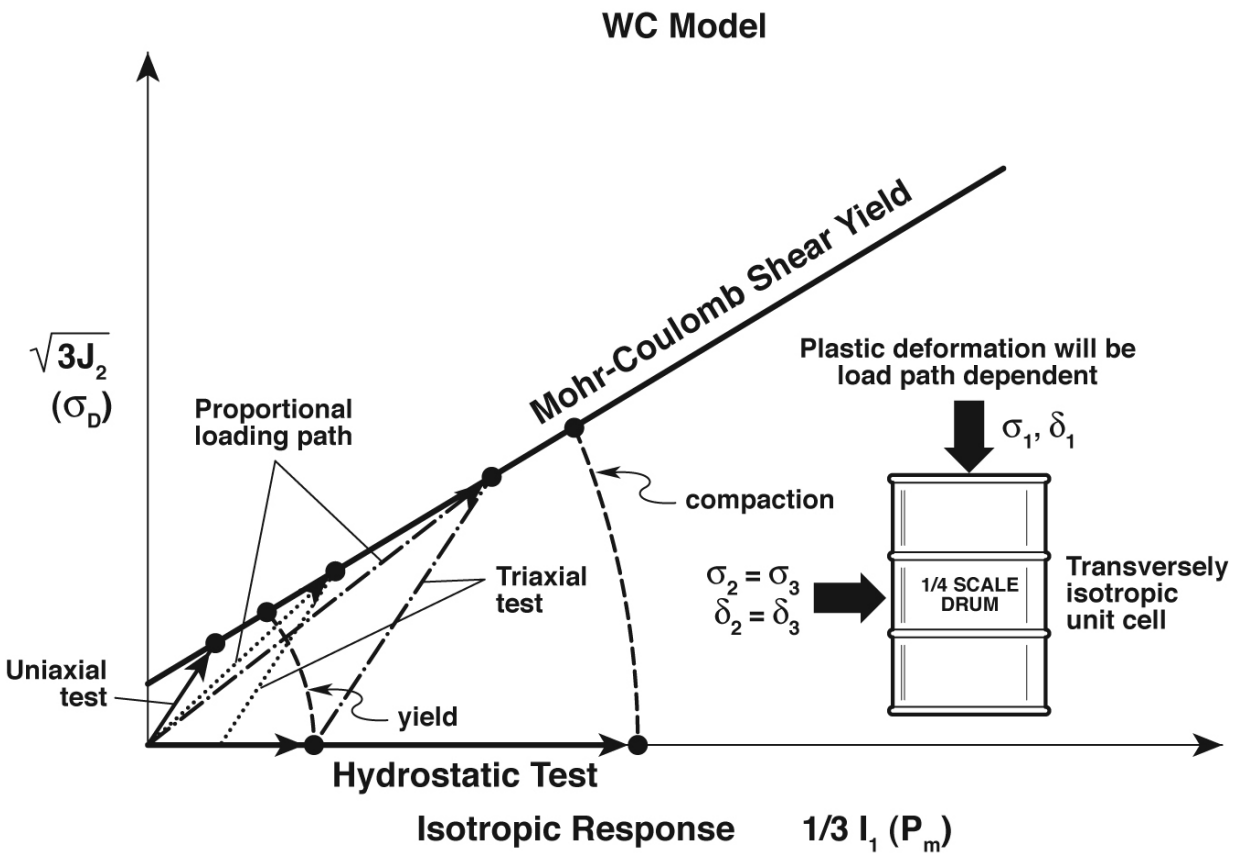

Figure 4-2: Graph of load paths representing uniaxial, hydrostatic and axisymmetric triaxial tests.

4.1.3 Simulated Waste Packages and Waste Forms

The ¼-scale waste container will be composed of a standard #12 food can with crimped lid to simulate the DOT 17C standard (55-gallon) waste drums. A comparison of the dimensions of the #12 food can with the full-scale drum and the exact ¼-scale dimensions is given in Table 4.1. Table 4.1 shows that the linear dimensional scaling is quite good except for the thickness of the metal, which results in the #12 food can being slightly thinner than optimally desirable. In addition, it should be recognized the construction of the containers is somewhat different. The principal difference is in the lid attachment: the DOT drums use a ring clamp secured with a bolt whereas the food can lids are crimped in place. Previous studies (Huerta et al., 1983 and VandeKraats, 1987) using #12 food cans as ¼-scale models have found that its behavior is quite good except under lateral compaction where the DOT drum lids tend to separate at 8-10% lateral crush and the food can lids usually remain intact. This is not deemed to be a critical difference for our uniaxial loading and multi-axial loading tests since Huerta et al. (1983) demonstrated that the later crush force – displacement data on full-scale drums compared favorably with data from ¼-scale tests when dimensions were scaled by ¼ and forces were scaled by 1/16.

Table 4.1 Comparison of full-scale with proposed ¼-scale container dimensions.

Container Type	Rim Diameter (mm)	Height (mm)	Material Thickness (mm)
DOT 17C Drum	605.8	884.4	1.59
Exact ¼-Scale	151.5	221.1	0.398
#12 food can	156.7	222.3	0.315

Two simulated waste mixtures for filling both the ¼-scale and full-scale containers are proposed. The first is “Combustible Waste” as described by Hansen et al. (1997, Tables 1 and 2, Appendix A). Details for individual ingredients of the ¼-scale recipe will also reference those used by Wawersik (2001, Section 4.0). It should be noted that certain materials listed in Hansen’s report are difficult to obtain and/or cost prohibitive (i.e. tantalum, platinum, etc.). Hansen et al. recommended that these materials can be represented by similar products and the contribution of these materials to the overall behavior of the waste drum is likely to be insignificant. The second proposed waste mixture is referred to as “Sludge Waste” as described in Butcher et al. (1991, Tables 2-9 and 3-1). The sludge waste mix will be an alternating layered mixture of moist sand and dry Portland cement along with small quantities of plastics and sorbents. At ¼-scale, these layers will be approximately 25 mm of Portland cement followed by 50 mm of moist sand and repeated as necessary to fill the can.

The two simulated waste mixtures described above were chosen because they represent the end members of the range of simulated waste forms used in past experiments in terms of average compliance. The combustible waste mix is the most porous and compliant whereas the sludge represents the highest density and stiffest waste form. It is anticipated that using these two bounding cases will provide sufficient data to allow reasonable representations of waste mixes with densities, porosities, and strengths that are intermediate to the two tested. It should be noted that alternative waste drums as described in Section 4.4 are considered outlier cases and the sludge and combustible waste forms span the range for normal waste forms.

In assembling the waste packages for testing, the waste form will be prepared, weighed, and measured as needed to meet the specifications given in Hansen et al (1997) and Wawersik (2001). The waste package will then be filled and sealed by placing the food-can lid on top and crimping it in place using a standard can sealing device. The space formed above the lid and within the can lip created by the sealing process may be filled with a malleable material to better distribute the axial load applied to the can during testing. All preparation steps and measures will be recorded in the Scientific Notebook (SN) in accordance with WIPP QA Procedure NP 20-2. Each prepared package will be uniquely numbered and identified in accordance with WIPP QA Procedure NP 13-1 so that its contents are easily associated with the SN recordings. In addition, photographs will be taken to document the waste mix and packing into the packages before packages are sealed. The weight, dimensions, and volume of each package will be recorded in the SN after the package is assembled and sealed.

4.1.4 Uniaxial Compression Tests

Uniaxial compression tests on the quarter-scale waste packages will be conducted using the general methodology outlined in ASTM Standard Test Method for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperature (ASTM Standard D7012-07). This method cannot be followed explicitly because the waste packages are less than the required L/D ratio and the large axial displacements experienced by a crushing can will require different axial and volume strain measurements. Figure 4-3 depicts the general test arrangement. A pressure vessel will be used to contain a fluid, just as in a triaxial test, but the fluid will remain at atmospheric pressure. The purpose of the fluid is to allow for measurement of the change in volume of the can. The pressure vessel sits on the hydraulic loading piston of the load frame, which is displaced upward at a controlled rate. The crosshead of the machine contains a load cell to measure the force applied to the top piston that penetrates through the top of the vessel and contacts the top of the can. The relative movement of the piston to the load frame is measured by a linear variable differential transformer (LVDT). Thus, no measurements will be made directly on the can. Because of the large displacements expected during can crush up, it is not viable to place gages on the can itself.

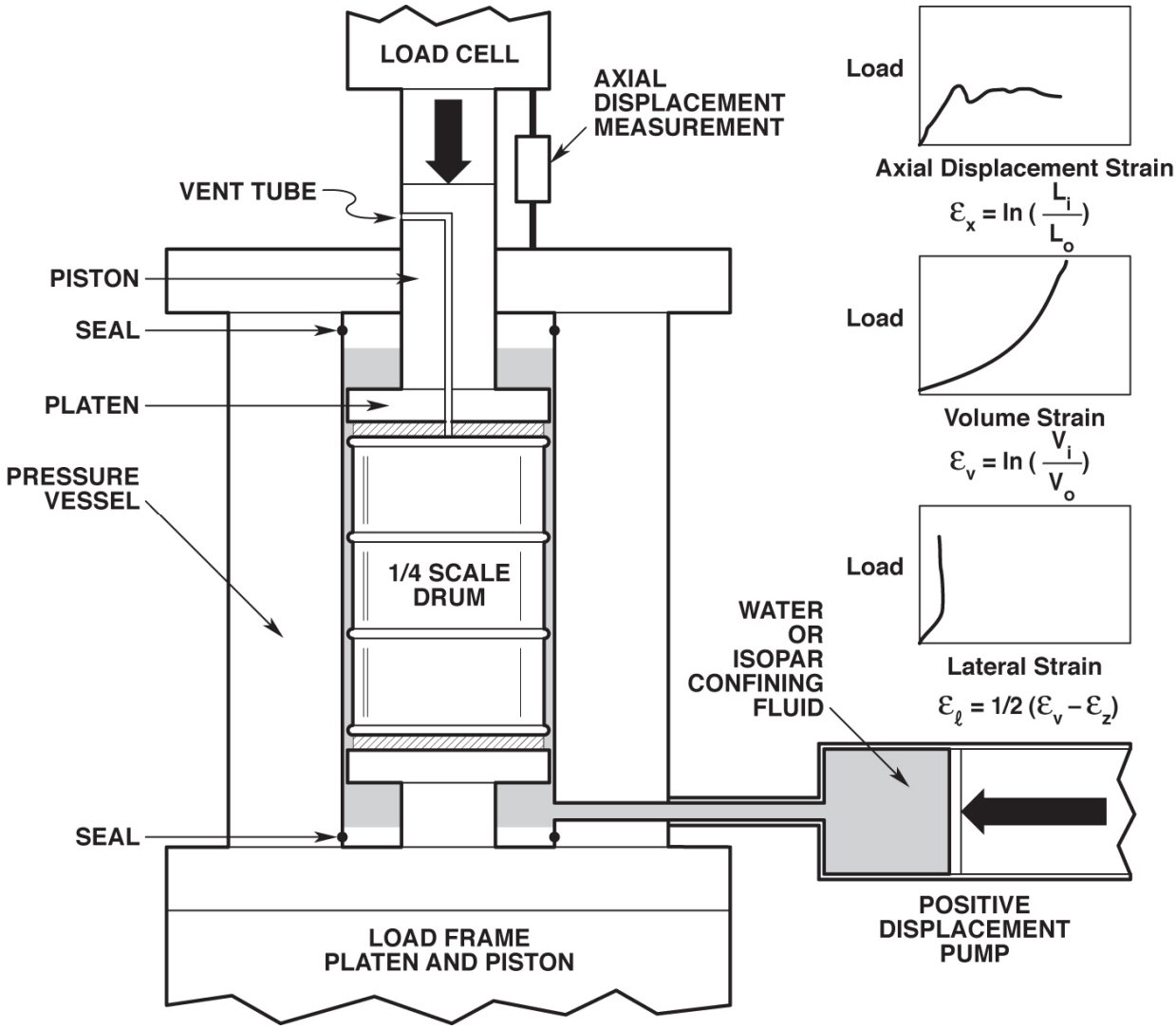

Figure 4-3: General test arrangement for the ¼- and full-scale uniaxial test and ¼-scale axisymmetric triaxial tests

As force is applied to the can, it will deform elastically initially and then buckle plastically to crush up. By maintaining a constant fluid level in the vessel, the volume change of the can during deformation can be measured. Fluid will be added or withdrawn from the vessel to maintain zero pressure. The net volume of fluid added or withdrawn will be a function of the change in volume of the sample and the change in volume of the piston in the vessel. The latter is directly related to the axial deformation of the sample. An alternate method to measure volume change might be used. This method involves using the vent tube of the ¼-scale drum as shown in Figure 4-3 to measure the volume of air escaping or entering the drum and can also determine if the container has been breached. A spirometer would likely be used to precisely measure the changes in air volume. Volume measurements using either changes in confining fluid volume or air volume assume the container is not breached during pressurization. This assumption will be examined prior to testing and, if invalidated, other volume measurement techniques will be considered and implemented as appropriate.

To determine accurately the change in length of the sample, the stiffness of the load frame system must be determined and used as a correction factor on the LVDT measurement of the relative movement of the hydraulic ram. A system response measurement is done by placing a solid metal cylinder of known elastic properties in the system in place of the can and loading the system to the maximum load expected. The deformation due do stretching of the machine and compressing the solid metal sample is determined. Knowing the modulus of the solid metal cylinder allows for the determination of the amount of the measured displacement at each load step due to the stretching of the machine alone. In addition, unload-reload cycles will be performed during the system response measurement to evaluate if changes in loading direction affect the correction factors.

The basic measurements made for each test will be
(1) axial force applied to the can;
(2) the change in fluid and/or air volume that is required to keep the vessel at zero pressure or a constant fluid level; and
(3) the relative displacement between the load frame and the hydraulic loading piston.

These three measurements, known geometry of the specimen, and the system response measurement will allow for determination of
(1) axial stress applied to the waste package;
(2) axial deformation (strain) of the waste package at each load increment; and
(3) the change in volume of the waste package at each load increment.

Measured axial strain and volume strain will allow a calculation of the mean lateral strain of the waste package. All three principal stresses and strains are then determined and can be used as input data for fitting a cap plasticity model. Because the total strain is the sum of the elastic strain and the plastic strain, the elastic strain must be known in order to determine the plastic strain increments for fitting the model. This is done by performing unloading and reloading loops at several loads during the test. It is assumed that the cans will unload elastically, thus unloading provides a direct measure of the elastic strain.

4.1.5 Hydrostatic Compression Tests

Hydrostatic compression tests will be performed on the quarter-scale waste packages as illustrated in Figure 4-4. The waste drums with specified simulated waste will be prepared as described in Section 4.1.3. They will be inserted into a pressure vessel and then sealed to the atmosphere, however the ¼-scale cans may be vented external to the pressure vessel to prevent rupture and spillage of contents into the confining fluid system. This also prevents build up of back pressure in the container that would be unlikely in an emplaced waste container because they are vented. The pressure vessel will be filled with a fluid and the air will be purged from the system. Fluid pumped into the vessel will provide a means to measure the change in volume of the can as the vessel is pressurized. As the fluid is being pumped into the pressure vessel, a pressure transducer will measure real time pressure changes. Accurate determination of the quantity of fluid pumped into the pressure vessel will be determined by either a flow meter or dilatometer. Measurement of air movement through the vent tube shown in Figure 4-4 might also be used as a technique to measure

volume change of the waste drum. Volume measurements using either changes in confining fluid volume or air volume assume the container is not breached during pressurization. This assumption will be examined prior to testing and, if invalidated, other volume measurement techniques will be considered and implemented as appropriate.

Prior to running the hydrostatic compression tests, a system response measurement will be performed on the pressure vessel and the fluid. The system response measurement will account for volume changes resulting from any deformation the pressure vessel undergoes as fluid pressure is applied as well as any minor compression of the fluid. The fluid volume change in the pressure vessel will be plotted as a function of fluid pressure and can be factored out when computing the volumetric strain of the waste drum. A solid metal specimen having dimensions approximately equal to those of the scaled waste package will be placed in the pressure vessel to ensure the fluid volumes in both the calibration run and the tests are equivalent. The pressure will be cycled to evaluate the effect of unload-reload on the system response.

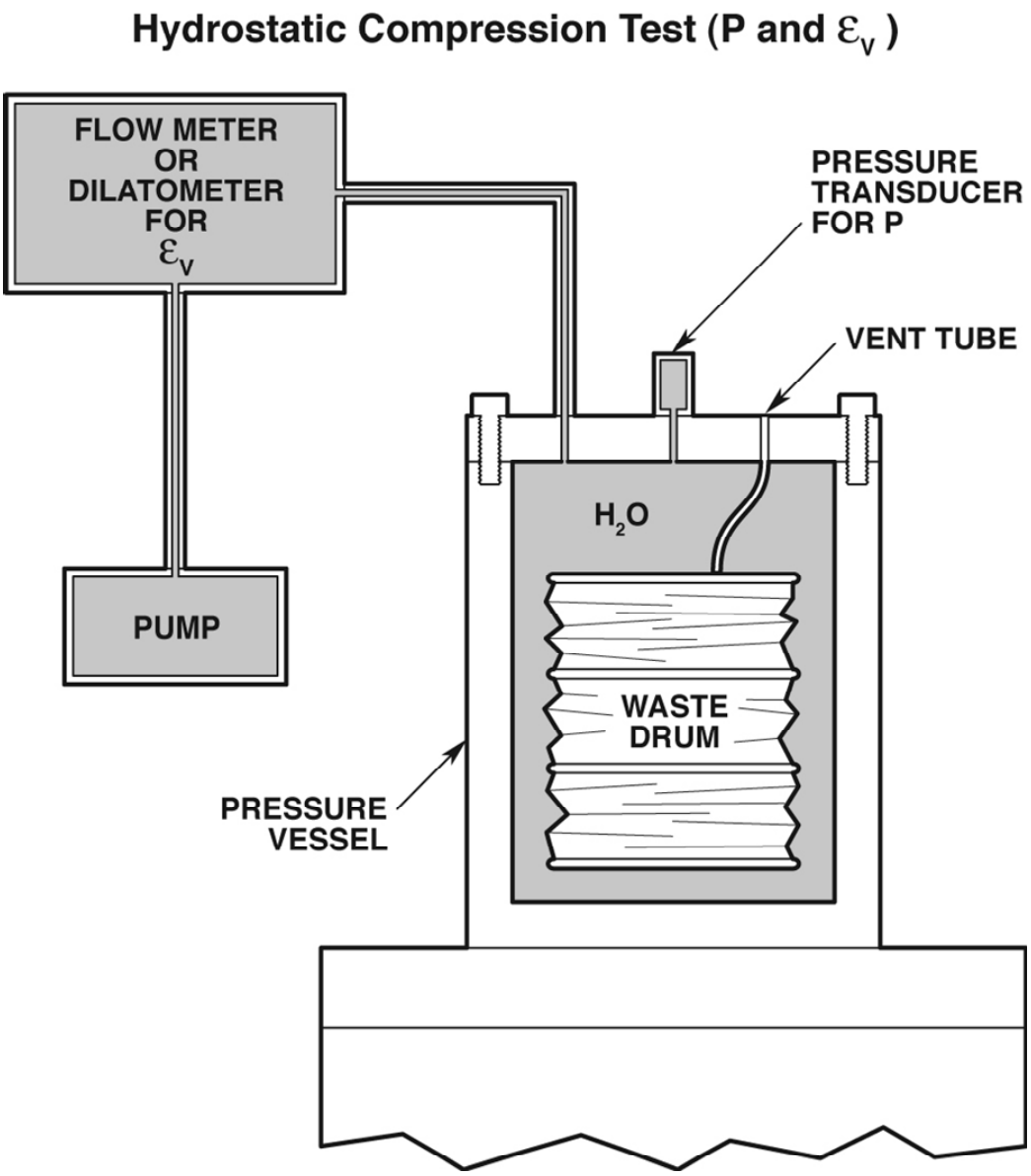

Figure 4-4: Illustration of test arrangement for the ¼- and full-scale hydrostatic test.

The basic measurements for each test will be
(1) pressure applied to the can;
(2) volume of fluid pumped into the pressure vessel to crush the can; and
(3) volume of air vented from the can.

These measurements along with the pressure vessel system response measurement will allow for determination of
(1) pressure applied to the waste package; and
(2) volumetric strain of the waste package.

While there is some redundancy in waste drum volume measurements (fluid and air measurements), these readings will provide a cross check for volume strain calculations. Because the total strain is the sum of the elastic strain and the plastic strain, the elastic strain must be known in order to determine the plastic strain increments for fitting the model. This is done by performing unloading and reloading loops of the confining fluid at several pressures during the test. It is assumed that the cans will “relax” elastically, thus releasing confining pressure provides a direct measure of the elastic strain. The behavior of the plastic cap will be further defined with the addition of the hydrostatic test and also, the assumption of isotropy can be verified.

4.1.6 Axisymmetric Triaxial Compression Tests

Axisymmetric triaxial compression tests on the quarter-scale waste packages will be conducted using the general methodology outlined in ASTM Standard Test Method for Triaxial Compressive Strength of Undrained Rock Core Specimens Without Pore Pressure Measurements (ASTM Standard D 2664-04). This method cannot be followed explicitly because the waste packages are less than the required L/D ratio as stated in ASTM Standard D 4543 and the large axial displacements experienced by a crushing can will require different axial and volume strain measurements. In addition, the triaxial tests could be performed in a configuration allowing draining of internal sample air to the atmosphere to mitigate rupture due to internal pressure buildup. Figure 4-3 depicts the general test arrangement. Note that this figure is the same test setup used for the uniaxial compression test with the most significant difference being the utilization of a sealed pressure vessel. The pressure vessel will be used to contain a fluid that will confine the waste drum at different pressures as an axial load is applied using a hydraulic loading piston inside a load frame. The loading piston is displaced upward at a controlled rate. The crosshead of the machine contains a load cell to measure the force applied to the top piston that penetrates through the top of the vessel and contacts the top of the can. The relative movement of the piston to the load frame is measured by a LVDT. Thus, no measurements will be made directly on the can. Because of the large displacements expected during can crush up, it is not viable to place gages on the can itself.

Typically for a triaxial compression test a confining pressure is first applied then deviatoric stress is applied by increasing the axial load. Due to the initial primary mode of plastic deformation being buckling of the waste drum, an alternate load path may be used that follows a proportional loading trajectory. The proportion of the loading trajectory will likely range from ratios of 1:3 to 1:5. To achieve a proportioned loading path the sample is loaded by increasing the confining pressure and axial load simultaneously in a fixed proportion. To determine accurately the change in length of the sample, the stiffness of the load frame system must be determined and used as a correction factor on the LVDT measurement of the relative movement of the hydraulic ram. This process is the same as outlined in Section 4.1.4.

The basic measurements made for each test will be
(1) axial force applied to the can;
(2) the pressure inside the triaxial cell for known axial forces;
(3) the relative displacement between the load frame and the hydraulic loading piston; and
(4) volume of air vented from the can and/or volume change of the confining fluid..

These three measurements, known geometry of the specimen, and the system response measurement will allow for determination of
(1) axial stress applied to the waste package;
(2) confining stress applied to the waste package for known axial stress quantities;
(3) axial deformation (strain) of the waste package at each loading increment;
(4) volumetric strain of the waste package; and
(5) lateral strain of the waste package.

As discussed in Section 4.1.4 unloading and reloading loops of the axial load could be used in determining the elastic strain at several stages throughout the test. In the case of a triaxial test, the confining pressure would likely remain fixed at each axial unloading point. Determination of the slope or friction angle of the shear surface and shape of the plastic cap can be determined when combining the triaxial test data along with uniaxial and hydrostatic test data.

4.2 Full-Scale Waste Package Tests

4.2.1 Discussion of Previous Work

Although Huerta et al. (1983) was the first to perform full-scale waste package tests, the focus of the study was on transportation system response rather than post-emplacement response. Butcher et al. (1991) performed a study to characterize the response of simulated waste and full-scale waste packages under emplacement conditions. Good agreement was found between the ¼-scale and full-scale data, however the study was limited to uniaxial drum failure modes.

Since the current emplacement method does not include packing of backfill around the waste containers, it is anticipated that early deformation resulting from vertical closure will occur with little confinement until the ribs close sufficiently to contact the packages, consistent with current full-scale data. However, in the previous studies only axial load – axial deformation measurements or lateral load – lateral deformation measurements were made on either the ¼-scale or the full-scale tests. No hydrostatic tests or other reliable pressure versus volume change measurements were made. Thus, it is impossible to distinguish between uniaxial compression along the major axis of the waste drum and confined compaction, where lateral stresses are present. As room closure progresses, increasing lateral confinement will be applied to the waste packages. This load path has not, to date, been simulated in laboratory experiments. To provide a more rational and complete data set for modeling, multi-axial tests must be conducted on the full-scale waste packages.

4.2.2 Load Paths and Deformation States

Full-scale waste package tests will follow the load path and model parameter discussion stated within the first paragraph of Section 4.1.2. To complement the ¼-scale testing, provide scale validation, and provide a basis for evaluating the performance of a cap plasticity model in predicting the compressive behavior of waste package systems, two load paths will be performed on the full-scale waste containers. The load paths are illustrated in Figure 4-2. First, uniaxial

compression tests, similar to those performed previously are required. However, for this series of tests both axial and lateral deformations need to be determined. Second, hydrostatic compaction with direct measurement of volume change is needed to determine the behavior of the cap. This load path will be performed offsite due to the size of pressure vessel required for testing. Southwest Research Institute (SwRI), located in San Antonio, Texas, is a possible candidate for providing the equipment necessary to perform full-scale hydrostatic tests. SwRI's large vertical pressure chamber is capable of housing a full-scale 55 gallon drum and achieving pressures up to 6000 psig. The second load path also has the benefit of allowing an assessment of the degree of validity of the assumption of isotropy. The details of these tests and the preparation of the samples are described in the following subsections.

4.2.3 Simulated Waste Packages and Waste Forms

The full-scale tests will incorporate DOT 17C (55 gallon) equivalent drums (UN 1A2/X 320/S or UN 1A2/Y 1.4/100) that are the same specification as the original drums used for waste containment. They have a ring clamp secured with a bolt for keeping the top opening sealed. The drums will be filled with two simulated waste mixtures similar to the ¼-scale containers with sizes and weights scaled up to full size. As discussed in Section 4.1.3 the mixtures will be "Combustible Waste" and "Sludge Waste" and will follow the recipes of Hansen et al. (1997) and Butcher et al. (1991). In addition, individual ingredients will follow the preparation described by Butcher et al.

The two simulated waste mixtures described above were chosen because they represent the end members of the range of simulated waste forms used in past experiments in terms of average compliance. The combustible waste mix is the most porous and compliant waste form whereas the sludge represents the highest density and is the stiffest. It is anticipated that using these two bounding cases will provide sufficient data to allow reasonable representations of waste mixes with densities, porosities, and strengths that are intermediate to the two tested.

In assembling the waste packages for testing, the waste form will be prepared, weighed, and measured as needed to meet the specifications given in Butcher et al. (1991). The waste package will then be filled and sealed by securing the ring clamp in place and tightening the pinch bolt. All preparation steps and measures will be recorded in the Scientific Notebook (SN) in accordance with WIPP QA Procedure NP 20-2. Each prepared package will be uniquely numbered and identified in accordance with WIPP QA Procedure NP 13-1 so that its contents are easily associated with the SN recordings. In addition, photographs will be taken to document the waste mix and packing into the packages before packages are sealed. The weight, dimensions, and volume of each package will be recorded in the SN after the package is assembled and sealed.

4.2.4 Uniaxial Compression Tests

Uniaxial compression tests on the full-scale waste packages will be conducted using the general methodology outlined in ASTM Standard Test Method for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperature (ASTM Standard D 7012-07). This method cannot be followed explicitly because the waste packages are less than the required L/D ratio and the large axial displacements experienced by a crushing can will require different axial and volume strain measurements. Figure 4-3 depicts the general test

arrangement. A sample container will be used to hold a fluid, just as in a triaxial test, but the fluid will remain at atmospheric pressure. The purpose of the fluid is to allow for measurement of the change in volume of the drum. The pressure vessel sits on the hydraulic loading piston of the load frame, which is displaced upward at a controlled rate. The crosshead of the machine contains a load cell to measure the force applied to the top piston that penetrates through the top of the sample container and contacts the top of the drum. The relative movement of the piston to the load frame is measured by a LVDT. Thus, no measurements will be made directly on the drum. Because of the large displacements expected during drum crush up, it is not viable to place gages on the drum itself.

As force is applied to the drum, it will deform elastically initially and then buckle plastically to crush up. By maintaining a constant fluid level in the sample container, the volume change of the drum during deformation can be measured. The net volume of fluid added or withdrawn will be a function of the change in volume of the sample and the change in position of the piston in the sample container. The latter is directly related to the axial deformation of the sample. An alternate method to measure volume change might be used. This method involves using the vent tube of the waste drum as shown in Figure 4-3 to measure the volume of air escaping or entering the drum. A spirometer would likely be used to accurately measure changes in air volume. Volume measurements using either changes in sample container fluid volume or air volume assume the drum is not breached during pressurization. This assumption will be examined prior to testing and, if invalidated, other volume measurement techniques will be considered and implemented as appropriate.

To correctly determine the change in length of the sample, the stiffness of the load frame system must be determined and used as a correction factor on the LVDT measurement of the relative movement of the hydraulic ram. This process is the same as outlined in Section 4.1.4.

The basic measurements made for each test will be
(1) axial force applied to the can;
(2) the change in fluid and/or air volume that is required to keep the vessel at zero pressure or a constant fluid level; and
(3) the relative displacement between the load frame and the hydraulic loading piston.

These three measurements, known geometry of the specimen, and the system response measurement will allow for determination of
(1) axial stress applied to the waste package;
(2) axial deformation (strain) of the waste package at each loading increment; and
(3) the change in volume of the waste package at each load increment.

Measured axial strain and volume strain will allow calculation of the mean lateral strain of the waste package. All three principal stresses and strains are then determined and can be used as input data for fitting a cap plasticity model. Because the total strain is the sum of the elastic strain and the plastic strain, the elastic strain must be known in order to determine the plastic strain increments for fitting the model. This is done by performing unloading and reloading loops at several loads

during the test. It is assumed that the cans will unload elastically, thus unloading provides a direct measure of the elastic strain.

4.2.5 Hydrostatic Compression Tests

Hydrostatic compression tests will be performed on the full-scale waste packages at a facility capable of housing a 55-gallon drum inside a pressure vessel. SwRI, located in San Antonio, Texas, owns a large pressure vessel capable of pressures up to 6000 psig and is being considered a possible location for testing. Regardless of the location, Sandia personnel will perform the experiment using Sandia calibrated test equipment to record necessary parameters, log data, etc. Figure 4-4 illustrates the general test arrangement and Figure 4-5 shows a pressure vessel located at the SwRI. The waste drum will be inserted into the pressure vessel and then the pressure vessel will be sealed to the atmosphere. Air will be purged from the system by the influx of fluid into the vessel. The fluid will provide a means to measure the change in volume of the drum as the vessel is pressurized. Alternately the venting system configured for the waste drum might be used to measure specimen volume changes. Volume measurements using either changes in confining fluid volume or air volume assume the container is not breached during pressurization. This assumption will be examined prior to testing and, if invalidated, other volume measurement techniques will be considered and implemented as appropriate. As fluid is being pumped inside the pressure vessel, a pressure transducer will measure real time pressure changes. Prior to running the hydrostatic compression tests, a system response measurement will be performed on the pressure vessel to determine any deformation of the pressure vessel as a result of fluid pressure. Vessel deformation will be plotted as a function of fluid pressure and can be factored out when computing the volumetric strain of the waste drum. Accurate determination of the quantity of fluid pumped into the pressure vessel will be determined by either a flow meter or dilatometer and factoring in the above mentioned pressure chamber calibration offset.

Figure 4-5: A pressure vessel suitable for full-scale hydrostatic testing. Vessel is owned by the Southwest Research institute.

The basic measurements for each test will be
(1) pressure applied to the drum;
(2) amount of fluid pumped into the pressure vessel to crush the drum; and
(3) volume of air vented from the waste drum.

These measurements along with the pressure vessel system response measurement will allow for determination of
(1) pressure applied to the waste package; and
(2) volumetric strain of the waste package.

Plastic cap behavior and the assumption of isotropy will be further defined with the addition of the hydrostatic test.

4.2.6 Evaluation of Scaling

One of the purposes in performing full-scale tests is for evaluation of the scaling parameters used in the ¼-scale waste containers. Previous studies (Butcher et at. 1991) for example have found good correlation between the ¼-scale and full-scale tests, however all previous tests have not incorporated any volumetric strain measurements. With a new set of measurements proposed for the current test plan, i.e. hydrostatic tests, pressure versus volume change, and lateral strain from known axial and volumetric strain measurements, additional scaling verification comparing ¼-scale tests to full-scale tests can be performed.

4.3 Degraded Waste Tests

4.3.1 Discussion of Previous Work

Previous interest in the mechanical properties of degraded waste arose from two primary reasons as discussed by Hansen et al. (1997): 1) Degraded waste strength greatly influences potential spall release and 2) Mechanical properties are used in modeling methods to understand the response should the waste be subject to accidental human intrusion. The current interest in understanding the behavior of the waste stems from long term modeling capabilities that provide a well defined performance assessment of the closure of the rooms. It is assumed that a cap plasticity model will also be adequate to model the response of degraded waste. While Hansen et al. performed tests on simulated degraded waste to determine various mechanical properties, there was no measurement taken to understand the volumetric strain response of the material in relation to other mechanical properties. In addition, only two confinement pressures were tested in the triaxial test arrangement. To enhance assessment of long term room closure characteristics, additional triaxial confining pressures are needed to better define the failure surface. Uniaxial strain tests may also be run and are valuable in testing a model’s ability to predict the outcome of these tests. The load paths of the aforementioned tests are presented in the next section.

4.3.2 Load Paths and Deformation States

To develop parameters for modeling room closure based on degraded waste, two basic load paths are necessary. First, hydrostatic tests will be performed to understand volumetric strain versus pressure behavior. There has been no hydrostatic testing measuring volume change in the past on simulated degraded waste. Second, triaxial compression tests with a sufficient variety of confinement pressures will allow determination of the slope of the shear surface and the shape of the cap. Triaxial testing performed by Hansen et al. lacks the magnitude and variety of confinement pressures necessary to develop these parameters. These tests will be performed by first applying the appropriate confining pressure and then adding deviatoric stress by increasing the axial load. Some triaxial test material will be pre-compacted hydrostatically while other material will be compacted at different pressures in the triaxial chamber either as part of the triaxial test or in preparation for the test. Pre-compaction could be necessary for all the specimens because if a high level of initial deformation occurs, the shape of the sample could change such that it would affect the accuracy of post test calculations. Additional tests such as uniaxial strain may be performed to assist in model validation. Uniaxial strain tests would allow a model compatibility check by using the model to predict the test results. This process would add further confidence in the model parameters. The details of these tests and the preparation of the samples are described in the following subsections.

4.3.3 Simulated Degraded Waste Forms

The degraded waste will initially follow the recipe given by Hansen et al. (1997). Hansen et al. presented four cases of simulated degraded waste. The cases are 50% and 100% degraded both with and without MgO. The recipe currently accepted for the Spallings model parameters is 50% degraded without MgO. Excluding the cementing effect of MgO provides a conservative material strength value. The plan is to test two recipes, 50% and 100% degraded without MgO. Emphasis will be placed on the 50% degraded waste because performance models indicate this is a more likely end state for the regulatory period than is the 100% degraded waste. Some testing of 100% degraded waste will still be performed however for comparison with previous test results and for validation of the test methods. Figure 4-6 shows compacted forms of both 50% and 100% simulated degraded waste. The 50% degraded material contains larger pieces of various ingredients compared to the 100% degraded which looks like brown soil. All specimens will be saturated with brine and allowed to dry to varying degrees to simulate the preparation performed by Hansen et al. 1997.

In addition, other surrogate waste materials developed based on an alternative evolution of the underground (i.e., Hansen and Stein, 2005) may also be tested. For example, some tests on degraded surrogate waste may incorporate MgO given its current use in emplacement drifts. In the event it is decided to proceed with tests of alternate surrogate waste recipes, the SN will document the description and details of the materials.

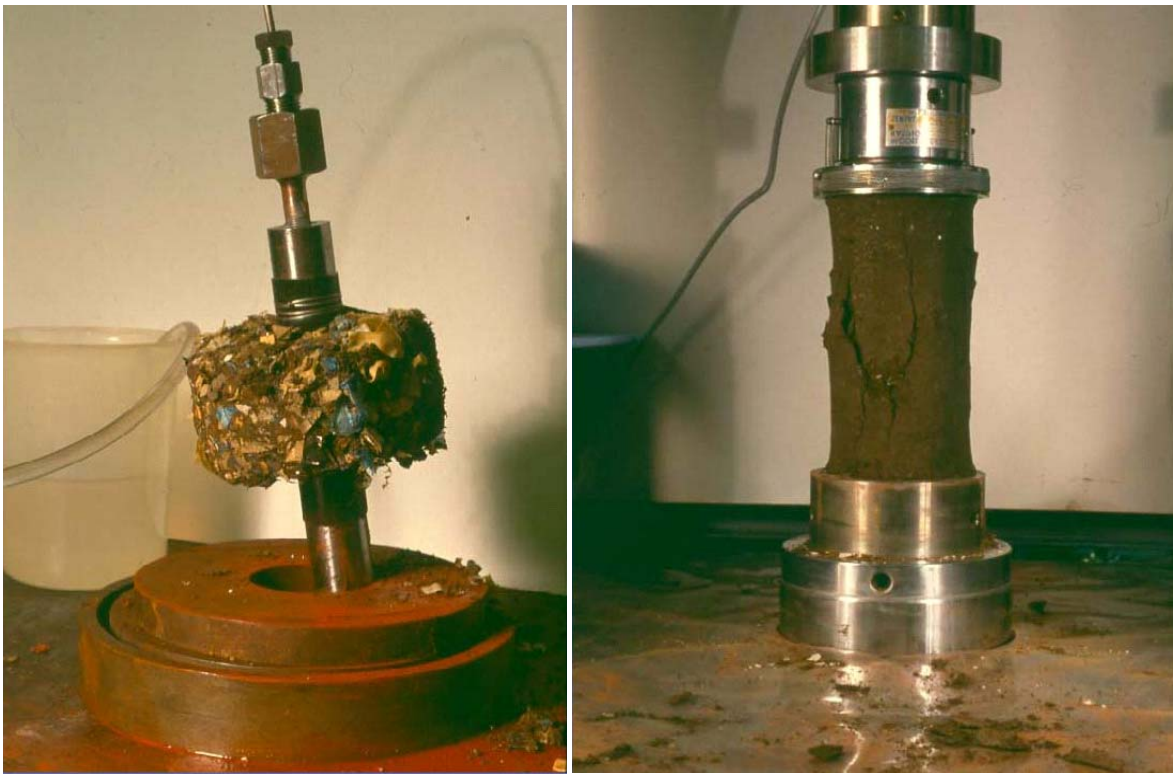

Figure 4-6: Surrogate waste material specimens tested by Hansen et al. Shown left is 50% degraded and right is 100% degraded.

In assembling the materials for testing, the degraded waste forms will be prepared, weighed, and measured as needed to meet the specifications given in Hansen et al. The material subject to hydrostatic pre-compaction will likely be post processed by trimming or machining into a cylindrical shape prior to triaxial testing and allowed to dry if necessary. All preparation steps and measures will be recorded in the SN in accordance with WIPP QA Procedure NP 20-2. Each prepared specimen will be uniquely numbered and identified in accordance with WIPP QA Procedure NP 13-1 so that its contents are easily associated with the SN recordings. In addition, photographs will be taken to document the waste constituents prior to and after their compaction. The weight, dimensions, and volume of each compacted specimen will be recorded in the SN prior to triaxial testing.

4.3.4 Hydrostatic Compression Tests

Hydrostatic compression tests will be performed on the degraded waste in a setup similar to that shown in Figure 4-4. The primary difference will be the replacement of the waste drum with degraded waste. The 50% and 100% degraded materials will likely be sealed in a “balloon” style pouch to protect it from the confining fluid. The “balloon” style pouch will be thick enough to isolate sharp objects within the sample from the confining fluid. Another method could make use of malleable lead jackets that can deform easily at low pressure and thus conform to the shape of the deforming waste without breaching.

The degraded waste will be prepared as described in Section 4.3.3, inserted into a pressure vessel, and then sealed to the atmosphere. The pressure vessel will be filled with a fluid and the air will be purged from the system. Fluid pumped into the vessel will provide a means to measure the change in volume of the material as the vessel is pressurized. As the fluid is being pumped into the pressure vessel, a pressure transducer will measure real time pressure changes. Accurate determination of the quantity of fluid pumped into the pressure vessel will be determined by either a flow meter or dilatometer. The proposed maximum hydrostatic compaction pressure is 15 MPa and was chosen based on the maximum overburden pressure on the waste. Multiple target pressures will be incorporated into the hydrostatic degraded waste testing. The target pressures will likely include 1, 3, 5, and 15 MPa. Upon reaching each target pressure, the pressure will be held for a yet to be determined time (approximately 24 hours likely) to allow for sample settling. After the pressure hold time, an unload/reload pressure loop will be performed to determine the elastic stiffness of the material. The pressure will then be increased to the next target hydrostatic pressure. This process will be repeated until an unload/reload pressure loop is performed at 15 MPa. The pressure vessel will then be unloaded at a rate similar to the pressure load rate.

Prior to running the hydrostatic compression tests, a system response measurement will be performed on the pressure vessel and the fluid. The system response measurement will determine any deformation the pressure vessel has as various fluid pressures are applied including any minor compression of the fluid. The fluid volume change in the pressure vessel will be plotted as a function of fluid pressure and can be factored out for computing the volumetric strain of the degraded waste.

The basic measurements for each test will be
(1) pressure applied to the material inside the pressure vessel;
(2) volume of fluid pumped into the pressure vessel to compress the degraded waste; and
(3) volume of air from the can containing the 50% and 100% degraded waste.

These measurements along with the pressure vessel system response measurement will allow for determination of
(1) pressure applied to the degraded waste; and
(2) volumetric strain of the waste package.

Because the total strain is the sum of the elastic strain and the plastic strain, the elastic strain must be known in order to determine the plastic strain increments for fitting the model. This is done by performing the aforementioned unloading and reloading loops of the confining fluid at several pressures during the test. It is assumed that the degraded waste will “relax” elastically, thus releasing confining pressure provides a direct measure of the elastic strain.

4.3.5 Triaxial Compression Tests

Triaxial compression tests on the simulated degraded waste will be conducted using the general methodology outlined in ASTM Standard Test Method for Triaxial Compressive Strength of Undrained Rock Core Specimens without Pore Pressure Measurements (ASTM Standard D 2664-04). The pressure vessel will be used to contain a fluid that will confine the degraded waste

at different pressures as an axial load is applied using a hydraulic loading piston inside a load frame. The loading piston is displaced upward at a controlled rate. The crosshead of the machine contains a load cell to measure the force applied to the top piston that penetrates through the top of the vessel and contacts the top of the specimen. The relative movement of the piston to the load frame is measured by a LVDT. Internal LVDT's might be affixed directly to the specimen in order to provide a direct measure of axial and lateral deformation. Direct displacement measurements eliminate the need to factor out test frame deformation. If displacement measurements can not be made directly on the specimen then the deformation of the load frame must be factored out. The details of this procedure are given in Section 4.1.4.

The triaxial test material will likely be prepared by first compacting the material using a die. A split die will likely be used to eliminate the need of large forces to extrude the material out of the die. When the target uniaxial stress is obtained, the material will remain under this stress state for approximately two hours. After uniaxial compaction, end caps and jacketing material will immediately be placed around the sample to keep the sample material from drying. The jacket material will likely be heat shrink. The sample assembly (including instrumentation) will then be placed inside a pressure vessel and the required hydrostatic pressure will be applied for approximately 14 hours.

There will be two groups of triaxial tests. The first group will likely be tested using a confining pressure equal to the hydrostatic compaction pressure. The hydrostatic compaction pressures, and thus the triaxial confining stresses for this group will likely be 1, 3, 5, and 15 MPa. The second group of samples will likely be tested triaxially at 1, 3, and 5 MPa. However, all of these tests will be hydrostatically compacted to 15 MPa. This testing matrix will determine what effect a pre-consolidation condition has on specimen failure tested at lower confining pressures when compared with pre-consolidation pressures matching tested confining pressures. A set of specimens tested at 10 MPa could be included pending preliminary analysis of data at the aforementioned test pressures.

The basic measurements made for each test will be

(1) axial force applied to the degraded waste;
(2) the pressure of the triaxial cell for known axial forces;
(3) the relative displacement between the load frame and the hydraulic loading piston;
(4) axial displacement of the sample using sample mounted LVDT(s); and
(5) radial displacement of the sample using a sample mounted LVDT.

These measurements, known geometry of the specimen, and the system response measurement (if applicable) will allow for determination of

(1) axial stress applied to the specimen;
(2) confining stress applied to the specimen for known axial stress quantities;
(3) axial deformation (strain) of the specimen at each loading increment;
(4) lateral strain of the specimen; and
(5) volumetric strain of the waste package.

As discussed in Section 4.1.4 unloading and reloading loops of the axial load could be used in determining the elastic strain at several stages throughout the test. In the case of a triaxial test, the confining pressure would likely remain fixed at each axial unloading point. Determination of the slope or friction angle of the shear surface and shape of the plastic cap can be determined when combining the triaxial test data along with hydrostatic test data.

4.3.6 Uniaxial Strain Tests

A few tests may be performed in a uniaxial strain configuration. In this test, a cylindrical specimen is constrained radially by confining fluid so that the resulting lateral strain throughout the test is zero. The test setup is similar to a triaxial test setup as discussed in Section 4.3.5 but the confining pressure is kept at the necessary pressure to enforce the zero lateral strain condition. The sample is then compressed axially until sample strength begins changing noticeably relative to axial deformation. The uniaxial strain test can serve as a check against an existing model such as the cap plasticity model. The model is run to predict the values of the test rather than the test being used directly as an input parameter to the model. Thus, the uniaxial strain test serves as a model validation tool.

4.4 Tests on Alternative Waste Package Configurations

4.4.1 Rationale

To date a percentage of waste has been received at the WIPP that is different in form with previously tested contents contained within 55-gallon waste drums. For example, Park and Hansen 2004 performed a finite element analysis (FEA) on waste packages known as pipe overpack (POP) containers (TRU waste that is placed into a stainless steel pipe before placement into a 55-gallon drum). The POP waste form has been shown not to be significant to performance however, multiple alternative forms exist that may or may not change existing modeling parameters. Various configurations of current WIPP containers will be assessed and a determination made as to which could be analyzed in the TP.

4.4.2 Tests

Provided additional time and resources allow, testing of alternate waste package configurations could be in a variety of forms including but not limited to ¼-scale drum compaction, full-scale drum compaction, and material contained within container types other than cylindrical drums. These tests would likely be configured as uniaxial compression tests similar to the setup discussed in Section 4.1.4. A summary of the parameters follows.

The basic measurements made for each test will be

(1) axial force applied to the alternate waste assembly;

(2) the change in fluid volume that is required to keep the vessel at zero pressure or a constant fluid level; and

(3) the relative displacement between the load frame and the hydraulic loading piston.

These three measurements, known geometry of the specimen, and the system response measurement, as discussed earlier in the report, will allow for determination of

(1) axial stress applied to the alternate waste assembly;

(2) axial deformation (strain) of the alternate waste assembly at each loading increment; and

(3) the change in volume of the alternate waste assembly at each load increment.

Measured axial strain and volume strain will allow a calculation of the mean lateral strain of the waste package. All three principal stresses and strains are then determined and can be used as input data for a cap plasticity model to include the alternate waste assembly. Because the total strain is the sum of the elastic strain and the plastic strain, the elastic strain must be known in order to determine the plastic strain increments for fitting the model. This is done by performing unloading and reloading loops at several loads during the test. It is assumed that the alternate waste assembly will unload elastically, thus unloading provides a direct measure of the elastic strain.

In the event it is decided to proceed with tests of alternate waste assemblies, this TP will be revised to incorporate the description and details of the specific tests planned.

5 QUALITY ASSURANCE

SNL/CPG activities are conducted in accordance with the requirements specified in the DOE/CBFO Quality Assurance Program Document (QAPD), CAO-94-1012, current revision. The requirements of the DOE/CBFO QAPD, and any revisions thereto, are passed down and implemented through the SNL WIPP QA Procedures.

The NPs that may apply to work performed under this TP include:

- NP 4-1, “Procurement;”
- NP 6-1, “Document Review Process;”
- NP 9-1, “Analyses;”
- NP 9-2, “Parameters;”
- NP 12-1, “Control of Measuring and Test Equipment;”
- NP 13-1, “Control of Samples and Standards;”
- NP 17-1, “Records;”
- NP 19-1, “Software Requirements;”
- NP 20-1, “Test Plans;”
- NP 20-2, “Scientific Notebooks”

5.1 Sample Preparation and Control

Each ¼-scale, full-scale, or degraded waste package will be considered as a unique "sample". Preparation of individual samples will be done as described in Section 4.1.3 (for ¼-scale), 4.2.3 (for full-scale), and 4.3.3 (for degraded waste). The preparation steps for each sample will be recorded in the SN and photographic documentation will be used to record the package contents and preparation process steps. Each sample will be labeled with a unique identifier (alpha-numeric sequence), the date of fabrication, the initials of the person assembling the sample, and the SN identification and page number(s) where the preparation of the sample was documented.

Once prepared, samples will be kept under controlled storage (locked cabinet or room) except during test setup, actual testing, and follow up examination and documentation. Because the SNL Geomechanics Laboratory (Department 6315) will maintain custody of the samples from creation to disposition, it is anticipated that no chain of custody process will be used (e.g. SP 13-1 "Chain of Custody" will not be applied). After testing, sample remains (deformed can and simulated waste) will be sealed in a plastic bag, labeled appropriately following NP 13-1, and placed in secure storage until it is determined that the sample is no longer required. If archiving for more than one year is deemed necessary, the samples will be transferred to more permanent storage at SNL/CPG.

5.2 Calibration and Data Quality

Equipment needed for the ¼-scale, full-scale, and degraded waste tests described within the current TP will consist of equipment located in the Geomechanics Laboratory at SNL with the exception of the pressure vessel for full-scale hydrostatic tests (location to be determined). All measurement devices used will follow the supplier's operation and calibration specifications and will be documented as part of the QA records and controlled following NP 12-1. Specifically, SNL will maintain all measurement equipment for use in execution of this TP to the specifications stated within NP 12-1 (Control of Measuring and Test Equipment).

5.3 Data Acquisition System

5.3.1 Equipment

Both manually and electronically-collected data will be acquired during the ¼-scale, full-scale, and degraded waste tests. The following types of data may be recorded:

- electronically-collected displacement and load data (LVDT and load cell) from the Data Acquisition System (DAS) or data logger.
- electronically-collected pressure and dilatometer data from the DAS or data logger.
- electronically-collected air volume measurements from the spirometer.
- manually-collected load, displacement, pressure data when necessary or for backup purposes.

5.3.2 Scientific Notebooks

A scientific notebook(s) will be used in accordance with NP 20-2 to document all SNL activities and decisions during the testing phase. Specific information that may be entered in the scientific notebook(s) consists of:

- a statement of the objectives and description of work to be performed, as well as a reference to this TP;
- a written account of all activities associated with the development and implementation of the ¼-scale, full-scale, and degraded waste tests;
- documentation of safety meetings;
- a list of equipment used during each activity, including make, model, and operating system (if applicable);
- traceable references to calibration information for instruments and/or gauges calibrated elsewhere; and
- discussions of the information and/or observations leading to decisions to initiate, terminate, or modify test activities.

All entries in the scientific notebook(s) will be signed and dated by the person making the entry. The scientific notebook(s) for this TP will be reviewed by an independent, technically-qualified individual at least every six months or if work is finished earlier then upon completion of the activities governed by this TP to verify that sufficient detail has been recorded to retrace the activities and confirm the results.

5.4 Data Identification and Use

A data logger will be the primary data collection system used. The DAS will be used as a reference check for engineering parameters during testing. Data loggers will provide a read-out in the form of voltages and will be calibrated by Sandia's Primary Standards Laboratory located in Albuquerque, New Mexico. Methods for conversion of data to engineering units will be documented in a scientific notebook and include the use of Microsoft Excel software to facilitate calculations. Also, electronic data file-management information will be documented in the scientific notebook(s) for these activities. These electronic data files will be submitted as QA records according to NP 17-1. Additional analysis of data and development of model parameters from the experimental data will be covered under a separate analysis plan.

Care will be taken throughout the performance of the operations for this TP to ensure the integrity of all data collected including documentation on hard copy and data collected on electronic media. Duplicate copies of all data will be produced no less frequently than every two months and the duplicate copies will be maintained at a location separate from the testing location to ensure that data are not lost. Data collected shall not be released unless and until the data are reviewed and approved by the PI.

5.5 Training and Qualifications

All personnel who will perform quality-affecting activities under this TP must have training in the SNL QA program (Form NP 2-1-1) and must read SNL NP 12-1, NP 13-1, NP 20-2, and SP 13-1. They must also read the procedures outlined in this TP, the Primary Hazard Screening (PHS), and all applicable NPs and SPs, but no additional training in those procedures is required. No other special training requirements are anticipated in addition to the safety briefings described in Section 6.

Existing procedures implemented in the laboratory cannot be expected to anticipate every possible event affecting the tests. Therefore, the PI is expected to implement appropriate measures during the conduct of the tests. These technical decisions will be documented in the scientific notebook.

5.6 Records

Records will be maintained as described in this TP and applicable QA implementing procedures. These records may consist of bound scientific notebook(s), loose-leaf pages, forms, printouts, or information stored on storage media. The PI will ensure that the required records are maintained and are submitted to the Records Center according to NP 17-1 (see Subsection 9.4).

5.6.1 Required QA Records

As a minimum, QA records will include:

- Scientific notebook(s);
- SPs used;
- Calibration records for all controlled equipment;
- Equipment-specification sheets or information (if available);
- Data files collected by the datalogger, with a log listing the files and defining their contents;
- Excel files of raw data converted to engineering units;
- All forms containing manually-collected data;
- Core logs of all core samples (if extracted); and
- Reports provided by SNL/CPG Laboratory facility personnel.

5.6.2 Miscellaneous Non-QA Records

Additional records that are useful in documenting the history of the activities, but are considered non-QA records, may be maintained and submitted to the WIPP Records Center. These records include:

- safety briefings;
- ES&H documentation;
- as-built diagrams of equipment supplied by contractors;

- as-built diagrams of equipment supplied by vendors;
- equipment manuals and specifications;
- equipment manifests; and
- cost and billing information regarding contracted services.

These records do not support performance assessment (PA) or regulatory compliance and, therefore, are not quality-affecting information.

5.6.3 Submittal of Records

Records resulting from work conducted under this TP, including forms and data stored on storage media, may be submitted to the SNL/CPG QA Dept. for review and approval in individual pieces. Where possible, the records will be assembled into a records package(s), which will be reviewed by the PI before being submitted for QA review.

6 HEALTH AND SAFETY

6.1 Hazard Description and Mitigation

Safety practices and polices will meet the requirements of the SNL ES&H Manual. The operation of the Geomechanics laboratory is governed by the safety procedures outlined in SOP 472481. The following hazard descriptions and mitigation techniques pertain to SNL Geomechanics laboratory, building 849. For more detailed descriptions see SOP 472481. The main hazards common to the operation of equipment in the Rock Mechanics Facility are:

- Hazards Associated with Closed-Loop Servo Controlled Testing

  The hazard exists because the automatic shutdown may not occur rapidly enough to prevent equipment damage or personal injury. If the specimen should fail in an unexpected manner or if the controlling transducer should fail, the ram may reach velocities as high as several mm/s and may travel 50 to 75 mm before automatic shutdown.
- Hazards Associated with Operation of Pressure Vessels

  There is a remote possibility in triaxial tests that the pressure vessel or interconnecting tubing could burst producing high velocity jets of confining fluid (e.g., Isopar) which could cause personal injury. In rare instances, these bursts may possibly produce hazardous solid fragments that could also cause injury.
- Rupture of pressurized hydraulic supply hoses.
- Fire hazard created by mist of pressure fluid (hydraulic oil or Isopar) at deficient or leaky connections.
- Rock fragments and other debris ejected from the tests during deformation and failure of the rock samples.
- Injuries associated with the lifting and movement of heavy machinery, rock samples, and reconfiguration of the testing equipment.
- The potential for injuries in the form of cuts, bruises, broken bones, and sight impairment caused by improper operation of power tools, sample preparation, and other mechanical equipment.
- Spills of hydraulic oil or solvents.
- Discharge of hydraulic oil, solvents or potentially hazardous coolants into the sewer drains in Building 849 or in the rock preparation room (west side of Building 849).

The hazards above are mitigated by the following measures:

- Recommended safeguards for closed-loop load, stroke or strain control are as follows:
  a. Unconfined or contained samples should be positioned in the testing machine only if the system is turned off or if it is in stroke control.

b. When loading a specimen, the load should be controlled by one of the stroke control modes.

c. The operator should always be near the control console and within reach of the emergency shutdown button during a test.

d. Hands shall be kept away from the ram and load cell to prevent injury in the event that the controlling transducer is accidentally disturbed and the ram takes a sudden jump

- Mitigation of pressure vessel hazards is accomplished through:

  a. Safety factors of four (or greater where possible) and use of rupture disks (rated below the maximum operating pressure of the system).

  b. Use of barricades or shields, when the safety factors are less than four.

  c. Periodic inspection and recertification of the pressure vessels and high pressure parts.

  d. Logbook records of the loading histories of the pressure vessels. These records and time in service of pressure vessels and pressure intensifiers determine the schedules of inspections and recertifications.

  e. Implementation of an appropriate check list.

- Because of the isolated nature of the 849 Laboratory and the industrial hazards associated with the operation of equipment in this building, two persons must be present in the building when any equipment is being operated (two-man rule).
- No smoking is allowed in Building 849.
- Open flames and intense heat sources such as electric heaters must be kept at least 20 ft away from all testing systems for as long as hydraulic supply lines are pressurized.
- Lifting and movement of heavy machinery, rock samples, and a reconfiguration of the testing equipment must be done in accordance with safe-lifting practices described in the ES&H Manual, MN471001, Chapter 3, Office Safety.
- Eye protection is required inside all marked areas during the performance of experiments.
- The use of head protection is required for work on or under the 5 MN (1,100 kip) testing machine in Room 1.
- Hydraulic supply hoses are inspected annually by MTS Systems Corporation as part of system maintenance and calibration and are exchanged, if necessary. All hoses are anchored to prevent whipping in the event of a failure.
- Failures of hydraulic supply hoses require immediate shut-down by pressing the red emergency shut-down button on any control console. Six emergency shutdowns are located in Room 1 of Building 849.
- Fluid discharge in the rock preparation room west of Building 849 must be limited to water and rock fines as identified in a posted permit.
- All personnel must be familiar with posted actions to be taken in the event of fluid spills.

- Rubber plugs in all floor drains in Room 1 of Building 849 may only be removed when the hydraulic supply is shut off. The plugs are normally sealed into these drains and leak-tested with tap water.
- Waste oil must be disposed of in approved containers. Each container must receive only compatible wastes and be properly labeled.
- Flammable chemicals are stored in a flammable chemicals storage cabinet in Room 1 Building 849.
- All personnel must be familiar with the content of all Material Safety Data Sheets (MSDSs) of chemicals used in their specific work assignments, particularly with regard to instructions on handling, storage, health hazards, personal equipment/clothing, and emergency response requirements.
- Eating and drinking is permitted only in Room 3, Building 849, which is a declared and marked chemical free room. The water fountain located in the hall way outside Room 3 is considered part of the chemical free room.

Mitigation of specific hazards associated with operation of the equipment is provided by the use of the respective operating procedure for that piece of equipment.

6.2 Work Controls and Laboratory Procedures

All work performed within the Geomechanics laboratory, building 849 is controlled under Primary Hazard Screening (PHS) number SNL07A00110-001. The laboratory then follows the outline in the Standard Operating Procedure (SOP) number SP472481 with individual tests performed in accordance with the Operating Procedures (OP) necessary for sample preparation and testing. These operational safety procedures are under control of the Sandia ES&H program and not under the control of the WIPP QA program.

The following OPs could apply to the tests outlined in this TP:

- OP-6315-22 (for the 22 KIP MTS load frame).
- OP-6315-220 (for the 220 KIP triaxial testing system).
- OP-6315-SHOP (for the use of machine shop equipment in building 849).
- OP-6315-400 (for the 400 KIP triaxial testing system).
- OP-6315-1100 (for the 1100 KIP triaxial testing system).
- OP-6315-CHEM (for laboratory scale use of hazardous chemicals).
- OP-6315-GLA (for General Lab Activities Requiring Mechanical and Thermal Loading, Pressurization and Elevated Voltage).

Required safety training is listed on page 18 of the PHS, number SNL07A00110-001, mentioned above.

6.3 Off-Site Test Controls

One test type (full-scale hydrostatic test) will be performed outside of the Geomechanics laboratory with the current location to be determined. A separate operating procedure will be written when the site and equipment details have been determined. It should be noted that all data collection will be performed by Sandia personnel including test setup procedures and instrumentation. Off-site personnel will operate their equipment following their own safe operation procedures and within their own prescribed device limitations.

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