# THE FEASIBILITY OF USING FLY ASH AND ZEOLITES AS VOID SPACE FILLER IN LOW-LEVEL WASTE PACKAGES TO MITIGATE POST CLOSURE SUBSIDENCE AT A LOW-LEVEL WASTE DISPOSAL CELL

Brian K. Perkins
Hazardous & Medical Waste Services Inc. (HAZMED)
Las Vegas, Nevada
hazmedlv@worldnet.att.net

Greg R. Stephenson
Hazardous & Medical Waste Services Inc. (HAZMED)
Las Vegas, Nevada
stephenson@nv.doe.gov

Kevin D. Leary
Waste Management Division
U.S. Department of Energy, Nevada Operations Office
Las Vegas, Nevada
leary@nv.doe.gov

## DISCLAIMER



## ABSTRACT

Great potential exists for subsidence of closed low-level waste (LLW) disposal cells at many LLW disposal sites across the United States. This post-closure subsidence can greatly increase the potential for radionuclides to be released to the environment through the infiltration of water into the waste cell and/or the release of radioactive gases. Post-closure subsidence can be caused by a variety of factors, but two of the primary causes are package void space and package degradation.[1]

The Department of Energy, Nevada Operations Office (DOE/NV) is currently evaluating the consequences and mitigation of post-closure subsidence for its Radioactive Waste Management Sites (RWMSs) at the Nevada Test Site (NTS). The RWMSs are LLW disposal sites currently used for the land disposal of U.S. Department of Energy (DOE) LLW waste generated at various sites across the United States. As a potential mitigation measure, DOE/NV has conducted this

study to evaluate imposing a limitation on package void space and the use of fly ash and zeolites as package filler material to reduce the amount of void space within LLW packages. Currently the NTS does not impose limitations on package void space, although the minimization of void space is encouraged in the NTS waste acceptance criteria (NTSWAC).[2] Fly ash and zeolites were evaluated for use as filler materials due to their abilities to sorb certain radionuclides and reduce migration potential. The physical, chemical, and absorptive properties of fly ash and zeolites were evaluated, as well as their availability and associated costs.

LLW generators currently approved to ship LLW to the NTS were surveyed to determine if the imposition of a NTS package void space limitation would impact their current LLW operations. LLW generators were also surveyed to determine what programmatic costs and impacts would be realized if fly ash and zeolites were required to fill container void space.

The observations and recommendations resulting from this study are summarized as follows:

Observations

1. The magnitude and timing of subsidence are directly related to package void space and package degradation rates.

2. There is limited knowledge of the rates of package degradation in an arid environment (especially steel packages), therefore, the timing of subsidence is difficult to predict.

3. Uncertainty exists in the actual amount of void space in LLW packages that have been, and are currently being disposed. Therefore, the magnitude of subsidence is difficult to predict.

4. Due to the heterogeneity of waste, subsidence will occur in a differential fashion and will not subside uniformly as one unit.

Recommendations

1. Additional research is needed on the degradation rates of the LLW containers disposed of at the NTS. This will provide a better understanding of the timing and magnitude of subsidence (differential versus uniform).

2. Restrictions on LLW container void space should be implemented at the NTS in order to limit, or at least better estimate, the magnitude of potential subsidence.

3. The use of fly ash (coal ash) or zeolite clays as filler material in LLW containers should be encouraged when practical for the generators.

Since void space is a major contributor to post-closure subsidence and the amount of void space will affect the magnitude of subsidence, controlling the amount of container void space would provide for the ability to better estimate the magnitude of subsidence. This, in turn, will decrease the amount of uncertainty associated with both the design of the closure cover and minimize the adverse impacts from subsidence on vadose zone monitoring systems. LLW generators have indicated that the imposition of a void space limitation would not severely impact their programs. However, LLW generators have also indicated that using coal ash or zeolites as filler material in LLW containers may present health and safety concerns related respirable particulate matter for workers during handling and that it may be prohibitive because of the increased costs to their LLW programs.

## INTRODUCTION

The land disposal of LLW is governed by the Nuclear Regulatory Commission (NRC) and the DOE. The NRC regulates commercial LLW disposal facilities and the DOE regulates LLW disposal sites at DOE sites across the country. Under both regulatory schemes, LLW is managed in a manner intended to isolate the waste in order to be protective of human health and the environment. LLW land disposal at commercial and DOE facilities involves burial in disposal cells consisting of shallow pits, trenches or vaults. Once a disposal cell has reached capacity or is no longer needed, it is closed by covering it with soil or other types of engineered closure cap. Due to the long half-lives of many radionuclides, personnel at LLW disposal sites must continue to monitor disposal cells long after they have been closed to ensure that radionuclides are not being released into the environment.

Once disposal cells are closed there will be subsidence of the ground surface above the disposal cell resulting from the degradation of waste containers and the soil densification into void spaces. Even in arid areas such as the NTS, where evaporation exceeds precipitation, subsidence will still occur as a result of backfill compaction, waste decomposition, and especially void space.[1] Disposal cell subsidence has the potential to impact the ability of the disposal cells to contain the waste and meet established performance objectives. Disposal cell performance could be altered as a consequence of long-term and short-term subsidence leading to several possible contaminant release scenarios.[3]

## PURPOSE AND SCOPE

This study evaluates the feasibility of limiting void space in LLW packages and the use of specific filler materials for package void space. Fly ash and zeolite materials were evaluated for use as filler material due to their ability to sorb radionuclides and decrease migration potentials, and their ability to absorb any excess moisture present in the waste. The feasibility of limiting container void space was evaluated through the investigation of current practices at commercial and DOE LLW disposal facilities and products currently available to limit void space. Potential impacts to LLW generators, the NTS Radioactive Waste Acceptance Program (RWAP), and NTS radioactive waste disposal operations were also evaluated.

**BACKGROUND**

The NTS disposes of LLW generated from NTS operations and offsite DOE and Department of Defense waste generators. LLW is disposed of at the RWMSs located in Areas 3 and 5 at the NTS. The Area 5 RWMS began disposal of LLW in 1961. Included in the Area 5 RWMS are deep augered shafts, known as Greater Confinement Disposal, where high specific activity wastes were disposed of from 1983 - 1989. The Area 5 RWMS contains a series of unlined pits and shallow trenches and currently accepts packaged LLW for disposal. The Area 3 RWMS was established in 1979 for the consolidation and disposal of atmospheric test debris. The Area 3 RWMS utilizes disposals cells that were created from excavating between subsidence craters resulting from nuclear tests and accepts LLW in bulk containers (transportainers and Supersacks®).[3,4]

The current closure plans for LLW disposal cells at the NTS are to cover LLW disposal cells with designed closure caps. The closure cap designs have not been finalized. However, designs being considered include a thickened operational cap, evapotranspiration cover with vegetation, and evaporative soil covers.[5]

The requirements for the management and disposal of LLW at DOE sites are established in DOE Order 5820.2A, *Radioactive Waste Management*. DOE Order 5820.2A requires LLW disposal sites to prepare and maintain a radiological Performance Assessment (PA). The purpose of the PA is to demonstrate that the disposal site will meet the performance objectives as required in DOE Order 5820.2A. The PA must reasonably demonstrate that established performance objectives are met during active disposal as well as after closure of the disposal cells, including an institutional control period of 100 years and an established compliance period of 1,000 years.[6,7]

The DOE Peer Review Panel (PRP), responsible for reviewing disposal site PAs, concluded that Revision 2.0 of the 1995 PA for The NTS Area 5 RWMS (Shott *et al.*, 1995)[8] did not adequately address the consequences of disposal cell subsidence resulting from waste package degradation. As a result of the PRPs conclusions, Revision 2.1 of the Area 5 RWMS (Shott *et al.*, 1997)[9] was developed to address the impacts of subsidence and was conditionally approved by the PRP pending completion of a Composite Analysis for the Area 5 RWMS.

Also resulting from the PRP conclusions was the formation of a DOE/NV sponsored working group that developed the Consequences of Subsidence Report (COSR). The results of the working group appear in Arnold, *et al.*, 1998. The objectives of the working group were to evaluate the consequences of subsidence at Areas 3 and 5 and to make recommendations regarding the mitigation of the adverse impacts of subsidence. The COSR identifies the following factors as contributing to subsidence of the ground surface above the disposal cells: the amount of dunnage in the disposal cells and associated void space; the amount of void space initially present in the container; the type of waste (amount of decomposable material); and the gradation and compaction of backfill soils. The COSR also provides several recommendations relative to mitigating the effects of subsidence, including the minimization of void space within waste packages.

Following the issuance of Shott *et al.,* 1997 and the COSR, Bechtel Nevada performed an Alternative Evaluation Study (AES) for the purpose of developing recommendations relative to the closure of disposal cells and the mitigation/accommodation of subsidence at the RWMSs. The AES (Barker 1997) recommended the use soft covers for closure caps, bulk disposal when possible and to encourage waste generators to minimize package void space without implementing void space restrictions. The AES also recommended not implementing deep grout injection or dynamic compaction primarily due to excessive costs and technical and/or physical feasibility.

The COSR and AES provide recommendations for mitigation of the possible consequences resulting from subsidence. Both of these reports recognize that there are two aspects of subsidence mitigation, waste already existing in disposal cells and future waste disposal. Subsidence resulting from waste that is already in the disposal cells may be mitigated via post disposal methods such as thick soft cover closure caps, institutional control and accelerated degradation during institutional control. This study focuses on the evaluation of mitigation measures relative to void space within LLW packages that will be disposed in the future.

## LITERATURE SEARCH

**Container Void Space:** There have been several subsidence investigations on containerized waste and bulk waste placed directly into a disposal unit. Containerized waste is subject to subsidence at a much greater rate than bulk waste.[10] LLW accepted for disposal at the NTS has historically been received in containers made of a variety of materials, including wooden and steel packages. The majority of waste currently received at the NTS is contained in drums, boxes, or transportainers. Use of well designed and fabricated containers is very important, but even well designed and fabricated containers will decay over time.[11] The decay rate for wooden boxes is estimated between 20 and 150 years. Even steel containers will only maintain integrity for no more than 1,400 years. With these differences in decay rates, areas of a disposal cell containing wooden packages could subside hundreds of years before those areas containing steel packages. This differential subsidence could impact disposal cell performance through thinning of the disposal cell cover at the subsidence interface, increased erosion, and increased water infiltration in subsidence depressions, cracks, or fissures.[3] Thinning of the disposal cell cover would not be expected to be as severe if the disposal cell were to experience instantaneous areal subsidence.

Once a container fails, any void space is immediately filled with overburden. The collapse of several containers with void space quickly adds to the total void space, with substantial subsidence to follow. Waste containers must be filled to prevent void space. Waste containers should be placed in a disposal unit only when they contain as little void space as possible. Unfortunately, the amount of void space within waste containers is rarely known.[10] LLW generators have indicated that previously disposed individual steel drums can contain almost 50% void space although most are between 75% and 95% full.

Past practices for LLW disposal via shallow land burial present several disposal site management problems relative to subsidence mitigation. Early disposal practices did not require the level of detail that is required for current practices regarding the identity of contaminants, levels of contamination, package void space, etc., In addition, many of the early disposal records pertaining to LLW disposal have been lost, destroyed, or contain very general information about the types of waste, levels of contamination, packages, and quantity of waste. The lack of specific knowledge for earlier disposed LLW creates uncertainty in estimating the amount of void space present in the disposal cells and in predicting the timing and magnitude of subsidence.

Commercial and DOE LLW disposal sites are taking several different approaches to addressing and/or controlling container void space. Commercial LLW Disposal facilities such as Envirocare® dispose of LLW unpackaged. The waste is placed in the cell unpackaged, blended with clay and compacted. This approach greatly reduces the potential for subsidence because both intra and inter-container void space is eliminated during active disposal of the waste. Because Envirocare ® only accepts low activity wastes (NRC-Class A), disposing of unpackaged waste does not present unacceptable health and safety risks to on-site workers.

The inventories of waste disposed at most DOE LLW disposal sites include higher activity wastes that must remain packaged in order to adequately control worker exposure. This limits the subsidence mitigation measures for active disposal, to controlling the void space within LLW containers and between LLW packages placed within the disposal cells. The NTS has taken several steps to address void space in disposal cells including: screening of backfill material to minus 7.6 cm (3 in.), use of spacers between drums and boxes to encourage soil flow into the spaces between boxes and drums, changes to the NTSWAC to allow boxes with removable skids, and allowing packaging of more than one waste stream into a waste container.[3,5] Also, DOE/NV recently performed an assessment of subsidence mitigation options for the LLW RWMS. The results of the assessment are documented in Crowe et al. 1998.[12]

**Fly Ash:** In evaluating fly ash as a filler material for LLW container void space, consideration was given to the fly ash produced by coal combustion and fly ash resulting from the incineration of municipal, biological, and radiological wastes.

The ash resulting from the incineration of municipal waste is either placed in a sanitary landfill or packaged and sent to a shallow land burial facility.[13] This is due to the fact that most ash from municipal incinerators contains concentrated levels of heavy metals such as chromium, cadmium, lead, and arsenic and will frequently fail the Environmental Protection Agency (EPA) Toxicity Characteristic Leaching Procedure (TCLP). This requires the ash to be disposed in a RCRA Subtitle C Facility and precludes it from being used as filler material in LLW containers.

For medical waste incineration, the process of incineration will destroy polyvinyl chloride (a common ingredient in biological “red” bags) and create furans and dioxins. Furans and dioxins, which are regulated under the Resource Conservation and Recovery Act Land Disposal

Restrictions, will concentrate in the ash, making medical waste incineration ash unusable as well.[14]

The incineration of LLW creates particulate ash that is normally disposed of in shallow land burial sites. The presence of existing radioactivity and the possibility of airborne radioisotopes may cause unacceptable health and safety risks. In addition, the limited availability of LLW incineration ash would mean substantial transportation costs. These concerns make the use of LLW incinerator ash as a filler material undesirable.

The combustion of coal at power generating plants produces coal combustion products (CCPs) consisting of fly ash, boiler slag and bottom ash. Fly ash is the finely-divided material collected by the electrostatic precipitators from the flue gases. Boiler slag and bottom ash are the heavier and coarser coal combustion byproducts. Fly ash that is produced as a byproduct of coal combustion (coal ash) possesses physical and chemical characteristics that are beneficial for many industrial applications. Coal ash is very similar to natural pozzolans (volcanic ash) that have been used as hydraulic cements for more than 2,000 years. Due to its particle size and pozzolanic nature, coal ash is utilized in the concrete industry as a cement additive. The addition of coal ash fills the void spaces between cement particles that would normally fill with water. Another application is the use of ash as a controlled density fill material because of its propensity to be self-leveling, self-compacting and non-settling. Government agencies have even encouraged the use of CCPs. The EPA has recently issued procurement guidelines which specify that coal ash should be an option in all concrete purchased either directly or indirectly with federal funds.

Coal ash is also used in the waste management industry for waste stabilization because of its adsorptive properties. The ionic exchange/adsorption properties of coal ash have proven beneficial in the stabilization of sludges and soils contaminated with heavy metals. Field and laboratory tests have shown coal ash to greatly improve the soil retention of most radionuclides except the actinides.[15]

The chemical properties of coal ash vary depending on the source of the coal and the loss of ignition values. Generally, coal from higher grade deposits that is combusted at higher temperatures produces coal ash that is chemically benign from a regulatory standpoint. However, coal ash can contain toxic heavy metals and Naturally Occurring Radioactive Materials (NORM). There are two primary classifications for coal ash: Class ‘F’ fly ash (coal ash) which consists primarily of Silica ($SiO_2$), Aluminum Oxide ($Al_2O_3$), and Iron Oxide ($Fe_2O_3$); and Class ‘C’ fly ash consists primarily of Silica, Aluminum Oxide, and Calcium Oxide (CaO) (AEP, 1998). Chemical analysis of the two classes of coal ash indicate that Class F generally contains the lowest concentrations of toxic heavy metals.[16] Most companies marketing coal ash use analysis to segregate coal ash with high levels of metals and divert the material to disposal.
Nearly 870 million tons of coal was burned throughout 1996 to generate electricity. Approximately 90 million tons of ash are produced, 85% percent of which is coal ash with eight million tons of coal ash being used in high quality concrete and cement applications. Current use of CCPs is around 25 million tons, leaving a significant quantity of unused CCPs which are

normally land filled.[17] The availability and adsorptive properties of coal ash make it a viable filler material for LLW package void space.

**Zeolites:** Zeolite clays are another material that may be useful as a void space filler. Zeolites are minerals classified as hydrated aluminosilicates due to their chemical structure and are comprised of hydrogen, oxygen, aluminum and silica. There are more than 35 different species of zeolites including several, such as chabazite, erionite, phillipsite, mordenite and faujasite, whose absorptive properties rival those of many synthetic molecular seives. The crystal structure of zeolites is an interconnecting lattice which gives rise to a honeycomb frame work. This unique crystal structure contributes to several attractive physical and chemical properties, including ion exchange and adsorption.[18]

Zeolites are found in several different geologic settings. In the 1950s, they were discovered as major constituents in numerous volcanic tuffs in saline-lake deposits in the western United States. Since the 1950s, over 1,000 occurrences of zeolite deposits in sedimentary rocks of volcanic origin have been reported in more than 40 countries. For the last 15 years, over 300,000 tons of zeolitic tuff have been mined each year internationally.[18] Industrial applications for zeolites include: fillers in the paper industry, additives to cement, waste water treatment filtration, agricultural applications such as soil amendment, water absorption, gas adsorption, and ion exchange applications.

Several studies have been conducted relative to in-situ zeolites present in the volcanic tuffs at the proposed Yucca Mountain Repository. Yucca Mountain is being investigated as a permanent repository of high-level radioactive nuclear waste. The properties of the zeolites present at the site have been studied to determine their ability to retard the migration of certain radionuclides. The cation exchange property of zeolites allows them to form a natural sorption barrier, thus mitigating radionuclide migration in both the vadose zone and ground water systems.[19]

Specific zeolitic reactions are very similar to those of coal ash, the by-product of coal-burning power plants.[18] Coal ash has not been studied under the same conditions as zeolites, but some of the results can be extended to coal ash due to their similar compositions. Boyd (1947) realized that zeolite adsorption affinities are primarily determined by the charge and radii of the ions of interest. Investigations of clay and zeolite properties have concluded that mixtures of both natural and synthetic zeolites are good sorbers of Cs and Rb.[20] Other studies have corroborated the adsorbent properties of zeolites, especially the ability to adsorb Cs, which is sorbed practically completely on all the zeolites at concentrations less than $10^{-2}$ *M*. The sorption of Sr, on the other hand, exhibited large variations among different zeolites".[21]

Zeolites are currently used to remove Cs-134, Cs-137, and Sr-90 through the process of ion-exchange. One such application is the British Nuclear Fuels, Ltd. Site Ion Exchange Efficient Plant at Sellafield, England. Another large application is found at the DOE West Valley, NY, site where phillipsite is used to selectively remove Cs-137 and Sr-90.

While the availability of zeolites may not be as extensive as coal ash, zeolites have become a widely recognized industrial mineral resource with many beneficial industrial applications. The ion exchange/adsorptive properties of zeolites warrant consideration as a filler material for LLW package void space.

## FEASIBILITY STUDY

**Container Void Space:** LLW generators that currently ship waste to the NTS were surveyed to determine if the implementation of a LLW package void space criteria would adversely impact their LLW certification programs. Of the thirteen generators surveyed, eight provided written responses and one responded verbally. Two generators indicated that a void space restriction would have no impact to their current program, the remaining responses indicated procedure changes, employee training, waste packaging practices, and void space verification costs would be realized with an implemented void space restriction. As previously mentioned, the NTSWAC has been revised to allow waste generators to package multiple waste streams into a LLW package provided the wastes are compatible and do not create adverse reactions. This revision to the NTSWAC was made with the specific intention of making it more feasible for generators to package LLW more efficiently and reduce package void space. Since this revision has become effective, there has been increased effort by generators to combine waste streams in packages when it is economically feasible. However, the amount of void space in LLW packages is currently not limited, determined nor documented. Therefore, there is still a high level of uncertainty related to the magnitude of future subsidence at the disposal cells currently receiving waste.

**Fly Ash:** The generators were also surveyed regarding local sources of fly ash (coal ash) and costs of coal ash (See Table I). Of the nine sites responding, eight indicated that a local source of ash was available. The costs of procuring coal ash ranged from $4 per ton to $200 per ton. Specific information relative to how the costs per ton were calculated was not requested as part of the survey. It is reasonable to assume that some of the variation in costs is due to the proximity of the source of ash and the associated transportation costs.

**Table I**
**Generator Sites With Local Fly Ash or Zeolite Sources**

| Site | Local Fly Ash Source | Local Zeolite Source | Costs |
|---|---|---|---|
| Rocky Flats | Yes | No | Fly Ash: bulk - $11.50/yd<br>Packaged - $3.70/70lbs<br><br>Zeolite Clay: $250.00/ton |
| RMI | Yes | No | Fly Ash: No costs provided<br><br>Zeolites: $150.00/ton (Oregon source) |
| Pantex | Yes | Yes | Minimal costs, both are inexpensive |
| FEMP | Yes | Yes | Fly Ash: $4.00-5.00/ton<br><br>Zeolite clay: $130.00/ton |
| Allied Signal, K.C | Yes | Yes | Fly Ash: No cost provided<br><br>Zeolites: $.07/lb |
| LRRI | Yes | No | No costs provided |
| IT Corp. | Yes | No | No cost per unit measure provided |
| General Atomics | No | No | Fly Ash: $200.00/ton<br><br>Zeolite clay: $97.00/ton |
| Aberdeen Proving Ground | Yes | Yes | No costs provided |

As an example, the transport of coal ash from Indianapolis to Lexington by pneumatic trailer truck runs almost $22/ton.[16]

None of the generators that responded indicated that they had TCLP data pertaining to the local coal ash sources. As to the feasibility of using coal ash as a filler material in LLW packages, three generators indicated that it would be feasible, one indicated that it would be feasible with additional personnel protective measures, and the remaining five generators indicated using coal ash would have a low feasibility. The low feasibility was associated with the health and safety concerns (airborne respirable particulates) and costs associated with procurement, storage, transportation, and packaging. One generator indicated the local source of coal ash contained unacceptable levels of NORM.

Survey responses indicate that using coal ash would impact generators current LLW certification program by increasing the cost associated with processing the LLW. Increased costs identified would not only include the costs of the coal ash but also the costs associated with the analysis of coal ash, additional training, additional health and safety measures, procedure revisions, and increased inspections.

In evaluating the use of coal as a filler material, consideration was given to impacts on package weight limits. Container weight limits could be exceeded if coal ash were added to a particularly dense waste stream. LLW packages that are certified by the manufacturer to meet package strength requirements are only certified to a specified maximum weight. If the maximum container weight limits are exceeded, the integrity of the container would be jeopardized. There are LLW packages received at the NTS with appreciable amounts of void space that contain dense waste forms (concrete stabilized matrices) and are at or near the weight limitation specified in the NTSWAC.

**Zeolites:** Generators were presented the same questions in the survey for zeolites as they were for fly ash. Four generator sites indicated that a local source was available and the remaining five sites indicated that local sources were not available or that they were unaware of any local sources.

The costs of zeolite material ranged from $97 per ton to $250 per ton. Specific information relative to how the costs per ton as calculated were not requested as part of the survey. It is reasonable to assume that some of the variation in costs is due to the proximity of the zeolite source and the cost of transportation.

TCLP data was not requested for zeolite materials as it is a raw material that is processed for specific uses rather than a byproduct such as coal ash. The responses to the feasibility of using zeolites as a filler material for LLW package void space were almost identical to those pertaining to coal ash. The generators raised concerns relative to the feasibility of procuring, storing, transporting, and packaging of zeolites.

The majority of the survey responses indicated that using zeolites would impact current LLW certification programs by increasing the cost associated with processing the LLW. Increased costs identified would include the costs associated with the zeolite material, analysis of material, additional training, procedure revisions, and increased inspections. Health and safety concerns were not as great with zeolites as they were with coal ash due to a lesser respiratory concern.

Again, the addition of material to a particularly dense waste stream could jeopardize the integrity of the container if the container weight limits were to be exceeded.

## RECOMMENDATIONS

LLW packages received at the NTS for disposal contain varying amounts of void space. The amount of void space is dependent upon the waste type and associated waste matrix contained within the package. Packages may contain void space because the waste is very dense and the container cannot be completely filled and still meet the specified weight limitations. LLW packages may contain void space because the waste is heterogenous and cannot be packaged to preclude void spaces, or the waste may be a soft compactible trash that is placed into a container without compaction. While the NTSWAC encourages void space minimization, there are no limits placed on the amount of void space within packages. LLW package void space is not determined or documented by LLW generators or the Radioactive Waste Acceptance Program during generator audits. Therefore, there is a good deal of uncertainty regarding how much void space exists in LLW packages being disposed.

Package void space is directly related to the magnitude of subsidence that will occur at the disposal site after it is closed. The uncertainty associated with the amount of void space within the disposal cell makes it difficult to estimate the magnitude of subsidence that will occur in the post-closure time frame. The degradation rates of LLW packages directly relate to the timing of subsidence and the difference in degradation rates of the various LLW packages disposed will affect the extent of differential versus uniform subsidence. The degradation rates for LLW packages, especially steel packages, in an arid environment do not appear to be well understood and should be further evaluated.

Anticipating the timing and magnitude of subsidence is critical for ensuring that the closure cap and vadose zone monitoring systems chosen for the disposal cells will accommodate the full extent of subsidence and the disposal site will continue to meet performance objectives.

One method of decreasing the uncertainty associated with the magnitude of subsidence is to implement a limitation on container void space. The NTS is one of the few DOE disposal sites that does not have a void space limitation specified in its waste acceptance criteria. The implementation of a void space criteria is recommended as it would provide a mechanism to better predict the magnitude of subsidence and would reduce the likelihood of extreme differential subsidence in future waste cells.

Package void space can be verified via Real-Time Radiography (RTR), procedural controls, and documented inspections much the same way that the absence of materials prohibited by the NTSWAC are verified. LLW generators have indicated that some additional costs may be associated with meeting void space criteria. These costs are associated with adding procedural and verification steps to their programs.

When LLW package void space cannot be limited by combining waste streams, filler materials such as coal ash or zeolites should be used. These materials will not only reduce the void space in the packages, but they also have the ability to absorb excess moisture that may be present in the waste and most importantly possess ion exchange/adsorption properties that can limit the migration of radionuclides once the LLW package has degraded. The use of materials that limit nuclide migration could lead to less stringent monitoring requirements and increased stakeholder acceptance of LLW disposal activities. NTS LLW generators have indicated that the use of coal ash and zeolites may be cost prohibitive. Based on this, the use of these materials should be encouraged when feasible.

## REFERENCES


1. Mezga, L.J. May 1984, *The Role of Trench Caps in the Shallow Burial of Low-Level Wastes*. Oak Ridge National Laboratory, Oak Ridge, TN.
2. U.S. Department of Energy, Nevada Operations Office, August 1997, *Nevada Test Site Waste Acceptance Criteria*, DOE/NV-325, Revision 1.
3. Arnold, B.W., T.J. Brown, J.R. Cochran, R.B. Gilbert, B.A. Luke, F.S. Shuri, E.A.Strassburger, G.V. Wilson and S.R. Wirth, September 1998, *Consequences of Subsidence for the Area 3 and Area 5 Radioactive Waste Management Sites, Nevada Test Site*.
4. U.S. Department of Energy, 1996, *Final Environmental Impact Statement for the Nevada Test Site and Ofsite Locations in the State of Nevada*, DOE/EIS-0243.
5. Barker, Lawrence. August 1997. *Methods to Mitigate/Accommodate Subsidence for the Radioactive Waste Management Sites at the Nevada Test Site, Nye County Nevada, With Special Focus on Disposal Cell U-3ax/bl*. Bechtel Nevada, Las Vegas, NV.
6. U.S. Department of Energy, 1988, *Radioactive Waste Management*, Order 5820.2A.
7. U.S. Department of Energy, April 1996, *Guidance for a Composite Analysis of the Impact of Interacting Source Terms on the Radiological Protection of the Public from Department of Energy Low-Level Waste Disposal Facilities*.
8. Shott, G.J., C.J. Muller, L.E. Barker, D.E. Cawlfield, F.T. Lindstrom, D.G. Linkenheil, and M.J. Sully, 1995, *Performance Assessment for the Area 5 Radioactive Waste Management Site at the Nevada Test Site, Nye County Nevada (Revision 2)*. Reynolds Electrical & Engineering Co., Inc., Las Vegas, Nevada.
9. Shott, G. J., L. E. Barker, S. E. Rawlinson, and M. J. Sully, 1997, *Performance Assessment for the Area 5 Radioactive Waste Management Site at the Nevada Test Site, Nye County Nevada (Revision 2.1)*. Bechtel Nevada, Las Vegas, Nevada.
10. Obi, C.M., G.J. Shott, C.J. Muller, and L.E. Barker, October 1996, *Preliminary Estimates of Future Waste Subsidence, Hydrogeology Impact, and Contaminant Concentrations for Area 3 RWMS Disposal Units at the Nevada Test Site*, Bechtel Nevada, Las Vegas, NV.
11. Jacobs, D.G., J.S. Epler, and R.R. Rose, March 1980, *Identification of Technical Problems Encountered in the Shallow Land Burial of Low-Level Radioactive Waste*, Evaluation Research Corporation, Oak Ridge, TN.
12. Crowe, B.M., K.D. Leary, H. Bensinger, M.R. Dolenc, 1998, *An Informal Judgment Assessment of Subsidence Mitigation options for Lwo-Level radioactive Waste Management Sites on the Nevada Test Site*, U.S. Department of Energy, Nevada Operations Office.
13. Cooley, L.R., M.R. McCampbell, and J.D. Thompson, April 1982, *Use Plan for Demonstration Radioactive-Waste Incinerator*, University of Maryland at Baltimore. Baltimore, MD.
14. U.S. Environmental Protection Agency, Office of Research and Development. (1991). *Medical and Institutional Waste Incineration: Regulations, Management, Technology, Emissions, and Operation*. Cincinnati, OH.
15. Leary, K.D., December 1985, *The Mechanisms and Effects of Soil Sorption on Radionuclide Migration*.
16. American Electric Power, May 1998, *Coal Combustion Products*.

17. Robl, Tom, *We Are Running Out Of Fly Ash*, Energeia Vol.7, No.4, 1996.
18. Mumpton, F.A., 1975, *Commercial Utilization of Natural Zeolites*, Industrial Minerals and Rocks, American Institute of Mining, Metallurgical, and Petroleum Engineers Inc., Baltimore, MD.
19. Smyth, J.R., August 1988, *Physical and Chemical Properties of Zeolite Minerals Occurring at the Yucca Mountain Site*, Mifflin and Associates, Inc., Las Vegas, NV.
20. Boyd, G.E., J. Shubert, and A.W. Adamson, *The Exchange Adsorbtion of Ions from Aqueous Solutions by Organic Zeolites*, Journal of American Chemical Society. November 1947, Vol. 69. Pgs 2818-2829.
21. Komarneni, Sridhar, and R. Roy, *Superoverpack: Tailor-Made Mixtures of Zeolites and Clays*, Materials Research Laboratory, University Park, PA.
22. Hultgren, A., C Airola, S. Forsberg, L. Faith, May 1983, *Preparation of titanates and their uses in radioactive waste management, particularly in the treatment of spent resins*.