ALTERNATIVE EVALUATION STUDY:

**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/b1**

AUGUST 12-15, 1997

by

**Lawrence Barker
Bechtel Nevada**

September 1997

**Prepared for the U. S. Department of Energy
Nevada Operations Office
under Contract Number
DE-AC08-96NV11718**

CONTENTS

SAFETY AND HEALTH
ENVIRONMENT
AND WASTE CENTER

EXECUTIVE SUMMARY	iv
1.0 INTRODUCTION	1
1.1 Facility Description and Closure Plans	1
1.2 What is An Alternative Evaluation Study (AES)?	5
1.3 Process Leading Up to This AES	5
2.0 PURPOSE OF THIS AES	9
2.1 Why an AES?	9
3.0 BACKGROUND INFORMATION	11
4.0 AES PROCEDURES	13
4.1 Evaluation Criteria	13
5.0 AES DELIBERATIONS	15
5.1 Recommendations/Observations of the COSR	15
5.1.1 Regulatory Standards for Radioactive Waste Disposal and Cover Design	15
5.1.2 Implications of Subsidence for PA	15
5.1.3 Recommended Engineering Performance Standards	15
5.1.4 Implications of Subsidence for the Existing Closure Cover Design	16
5.1.5 Alternative Closure Cap Design	16
5.1.6 Options for the Remediation of Void Spaces in Waste Packages	16
5.1.7 Private Sector Disposal Practices and Implications for Disposal Practices at NTS	19
5.2 Recommendations Concerning Closure of Disposal Unit U-3ax/bl	19
5.2.1 Options for Closure of Disposal Unit U-3ax/bl	20
5.2.1.1 Subsidence Reduction at Disposal Unit U-3ax/bl	20
5.2.1.2 Subsidence Encouragement at Disposal Unit U-3ax/bl	20
5.2.1.3 Soft Operational Cover and Monitoring	21

CONTENTS

5.2.2	Further Evaluation by a Demonstration Project	23
5.2.3	RCRA Compliance for Disposal Cell U-3ax/bl	23
5.2.4	Recommended Path Forward	24
5.3	Recommendations Concerning Closure of Other Disposal Units	25
6.0	CONCLUSION	27
6.1	Key Ideas of this AES	27
6.2	Summary of Recommendations	27
7.0	REFERENCES	29
Appendix A	Definitions	A-1
Appendix B	Summary of Background Material Presented To AES Panel on August 12, 1997	B-1
Appendix C	AES Participants	C-1
Appendix D	Estimation of Costs of Selected Alternative Methods of Subsidence Mitigation/Accommodation	D-1

List of Figures

Figure 1	Location of the Nevada Test Site Within the State of Nevada	2
Figure 2	Location of the Areas 3 and 5 Radioactive Waste Management Sites Within the Nevada Test Site	3
Figure 3	Plan View of the Area 3 Radioactive Waste Management Site	4
Figure 4	Plan View of the Area 5 Radioactive Waste Management Site	6
Figure 5	Overview of the TOC Cover	22

List of Tables

Table 1	Estimated Costs of Subsidence Mitigation/accommodation at a Generic Disposal Cell, Described in Appendix D	17
Table 2	Tentative Scope of Work for an Independent Audit, and How Each Item Has Been/Will Be Resolved	18
Table 3	Evaluation of Grouting for Subsidence Reduction at Disposal Unit U-3ax/bl	20
Table 4	Evaluation of DDC for Subsidence Encouragement at Disposal Unit U-3ax/bl	21
Table 5	Evaluation of a TOC Cover for Disposal Unit U-3ax/bl	23
Table 6	Evaluation of a Demonstration Project for Disposal Unit U-3ax/bl	24
Table 7	Comparison of the TOC Cover with RCRA Requirements	24

ACRONYMS

AES	Alternative evaluation study
ALARA	As low as reasonably achievable
CA	Composite analysis
COSR	Consequences of Subsidence Report
DDC	Deep dynamic compaction
DOE	United States Department of Energy
DOT	United States Department of Transportation
ES	Evaporative soil
ESV	Evapotranspirative soil vegetation
FEMA	Federal Emergency Management Administration
FEMP	Fernald Environmental Management Project
FY	Fiscal Year
GCD	Greater confinement disposal
GIS	Geographic Information System
GPS	Global Positioning System
ISO	International Organization for Standardization
LLW	Low level radioactive waste
MLLW	Mixed low level radioactive waste
NTS	Nevada Test Site
NV	Nevada Operations Office
PA	Performance assessment
PRP	Peer review panel
RCRA	Resource Conservation and Recovery Act
RWMS	Radioactive Waste Management Site
TOC	Thickened operational closure
WAC	Waste Acceptance Criteria

EXECUTIVE SUMMARY

An Alternative Evaluation Study is a type of systematic approach to problem identification and solution. An Alternative Evaluation Study was convened August 12-15, 1997, for the purpose of making recommendations concerning:

- Closure of Disposal Cell U-3ax/bl and of other disposal cells.
- Mitigation/accommodation of waste subsidence at the Radioactive Waste Management Sites at the Nevada Test Site.

The results of this Alternative Evaluation Study can be broadly summarized in three observations/recommendations:

- Without expensive and difficult-to-implement remedial measures, some waste subsidence will occur in all disposal cells. However, even without mitigation of waste subsidence, both the Areas 3 and 5 Radioactive Waste Management Sites meet all performance objectives of Department of Energy Order 5820.2A.
- Anticipated waste subsidence can be accommodated using a simple and relatively inexpensive cover design, described in Section 5.2.1.3.
- Some steps can be taken now to reduce future waste subsidence. Those that are reasonable and represent best engineering practice should be taken.

A partial list of specific recommendations follows:

- Close all Nevada Test Site waste cells with soft covers, possibly thicker versions of the presently employed operational covers.
- Do not grout or use deep dynamic compaction on any Nevada Test Site waste cells.
- Encourage generators to minimize waste container void spaces. However, specific void-space restrictions should be avoided.
- Create a database of waste container locations and observed waste subsidence.
- Whenever possible, consider bulk waste disposal.

Recommendations were made on the grounds of cost, implementability, long-term performance, operational feasibility, and likely stakeholder acceptance.

1.0 INTRODUCTION

The Nevada Test Site (NTS) has two Radioactive Waste Management Sites (RWMSs) for disposal of Low-Level Radioactive Waste (LLW), although some disposal cells contain Mixed Low-Level Radioactive Waste (MLLW). One RWMS is located in Operational Area 3 of the NTS, and is referred to as the Area 3 RWMS. The other RWMS is located in Operational Area 5 of the NTS, and is referred to as the Area 5 RWMS. Figure 1 is a map showing the location of the NTS within the state of Nevada. Figure 2 is a map showing the location of the Areas 3 and 5 RWMSs within the NTS.

1.1 Facility Description and Closure Plans

The Area 3 RWMS presently contains three disposal cells: Disposal Cell U-3ah/at, which currently receives LLW; Disposal Cell U-3bh, which currently receives unpackaged bulk soils; and Disposal Cell U-3ax/bl, which stopped receiving LLW prior to September 26, 1988, when U.S. Department of Energy (DOE) Order 5820.2A came into effect.

Disposal Cell U-3ah/at was created by excavating the space between craters U-3ah and U-3at. These craters resulted from underground nuclear testing-induced subsidence. Disposal Cell U-3ah/at has been used for the disposal of containerized debris from the NTS Atmospheric Testing Debris Disposal Program, as well as packaged bulk LLW from off-site DOE generators.

Disposal Cell U-3bh is located in crater U-3bh. Crater U-3bh was created by underground nuclear testing-induced subsidence.

Disposal Cell U-3ax/bl was created by excavating the space between craters U-3ax and U-3bl. These craters resulted from underground nuclear testing-induced subsidence. Disposal Cell U-3ax/bl contains bulk uncontainerized waste from the NTS Atmospheric Testing Debris Disposal Program, as well as containerized waste. Some hazardous waste, such as the antifreeze and lubricants contained in contaminated vehicles disposed there, was disposed in Disposal Cell U-3ax/bl. No record of quantity or precise composition exists. A plan view of the Area 3 RWMS appears in Figure 3.

The Area 5 RWMS contains multiple shallow unlined pits and trenches. Some of these currently receive LLW. Others are in operational closure, pending permanent closure. In addition to pits and trenches, the Area 5 RWMS contains several greater confinement disposal (GCD) units, not all of which contain waste. Closure of GCD units is not considered in this document. All pits and trenches in the Area 5 RWMS were excavated for the express purpose of being waste disposal cells. Pit 3, in the Area 5 RWMS, is designed to receive MLLW; however, Pit 3 has been relatively inactive since 1990, when the disposal of MLLW which was not generated at NTS was suspended.

Figure 2 Location of the Area 3 and 5 Radioactive Waste Management Sites within the Nevada Test Site

Figure 3 Plan View of the Area 3 Radioactive Waste Management Site

The Area 5 RWMS accepts only containerized waste. Container strength and integrity have varied over time. Waste has been disposed in steel drums; boxes of cardboard, plywood, or steel; and in "nonstandard" containers, meaning containers other than standard-sized drums or boxes. Estimates of the rate of degradation for each container type appear in Arnold *et al.* (1997). A plan view of the Area 5 RWMS appears in Figure 4.

Waste cells containing no hazardous waste and receiving waste only after September 26, 1988, will be closed under DOE Order 5820.2A. Waste cells containing hazardous wastes or accepting waste prior to September 26, 1988, will be closed under the Resource Conservation and Recovery Act (RCRA).

1.2 What is An Alternative Evaluation Study (AES)?

An AES is a systematic approach to problem identification and solution. An AES uses an organized team approach to creatively generate alternatives satisfying a specific need. The study approach is similar, but not identical, to standard value engineering principles. Procedures used in this AES were modified from those described in MK-Ferguson (1991), as agreed to by all panel members.

1.3 Process Leading Up to This AES

DOE Order 5820.2A requires all disposal facilities receiving waste on or after September 26, 1988, to have an approved Performance Assessment (PA). A PA is a systematic analysis of the potential risks posed by a waste management system to the public and environment, and a comparison of those risks to established performance objectives. DOE has established a Peer Review Panel (PRP), consisting of technical personnel from throughout the DOE complex, to evaluate all PAs. The PRP is responsible for recommending approval of those PAs it finds technically acceptable.

In 1995, Revision 2.0 of the PA for the Area 5 RWMS (Shott *et al.*, 1995), was submitted to the PRP. The PRP concluded that, as containers degrade, disposal cells will eventually subside. Shott *et al.* (1995) did not consider the potential consequences of subsidence on the impact of disposal of waste at the Area 5 RWMS on the public and environment. In response, Revision 2.1 of the PA for the Area 5 RWMS (Shott *et al.*, 1997a) was prepared. The impacts of waste subsidence, among other issues not earlier addressed to the satisfaction of the PRP, were considered in Shott *et al.* (1997a). Shott *et al.* (1997a) was given conditional approval, contingent on completion of a Composite Analysis (CA) for the Area 5 RWMS. A CA is an assessment of the potential dose to the public from a waste disposal facility and all other DOE operations that interact with that disposal unit. Work on a CA for the Area 5 RWMS is scheduled to begin in Fiscal Year (FY) 1998.

While Shott *et al.* (1997a) was in preparation, DOE Nevada Operations Office (NV) convened a working group to further consider the consequences of subsidence at both the Areas 3 and 5 RWMSs and to make recommendations concerning final closure. This group's findings and recommendations appear in Arnold *et al.* (1997), identified here as the Consequences of Subsidence Report (COSR). Discussions of the findings and recommendations of the COSR appear throughout this document, as need arises.

Following the completion of Shott *et al.* (1997a), work began on a joint PA/CA for the Area 3 RWMS (Shott *et al.*, 1997b). Shott *et al.* (1997b), considering the subsided case as the base case, showed that a fully subsided Area 3 RWMS meets all PA performance objectives and meets the CA goals for dose incurred by members of the public.

Despite Shott *et al.* (1997a) and Shott *et al.* (1997b) showing that the fully subsided Areas 3 and 5 RWMSs meet all PA performance objectives, several waste subsidence-related issues require further consideration. For example, Shott *et al.* (1997a) showed that waste subsidence degrades the performance of the Area 5 RWMS. Hence, adherence to best engineering practices dictates that reasonable steps resulting in either mitigation or accommodation of subsidence should be taken.

2.0 PURPOSE OF THIS AES

This AES was convened to:

- Consider the recommendations of the COSR.
- Provide input concerning a closure cap for Disposal Unit U-3ax/bl that meets all requirements without being prohibitively expensive.
- Make recommendations concerning possible steps which could be taken to mitigate or accommodate subsidence in other waste disposal cells.

The order of the above tasks does not represent, in any fashion, the order of importance. Definitions of terms used in this AES appear in Appendix A.

2.1 Why an AES?

An AES is neither foolproof nor inexpensive. However, an AES is a recognized method of building consensus and providing recommendations concerning engineering alternatives. Engineering and scientific professionals meet in a formal structured atmosphere where they debate alternatives. A neutral facilitator, without ties to any group or alternative, ensures a fair and vigorous discussion. A recorder takes notes at all times. Evaluation criteria are specifically developed for the task at hand. Deliberations are democratic, in that all participants vote using the evaluation criteria, and those in the minority are given special opportunity to sway the majority (however, all decisions reached in this AES were unanimously supported by the panel members). A final report, containing a record of decisions and justifications, is prepared. A final presentation disseminates the recommendations to a wider audience.

The task of an AES panel is to make recommendations. It is the responsibility of management, DOE/NV in this case, to accept or reject those recommendations.

3.0 BACKGROUND INFORMATION

The first day of AES panel meetings, August 12, 1997, was devoted to outlining AES structure and dissemination of background information, delivered by a variety of speakers. Reproducing that information in its entirety is neither practical nor desirable. However, Appendix B summarizes all presentations and facilitates understanding of the information from which the AES panel worked.

A few key points from the background information, highly relevant to the AES panel's deliberations, follow:

- PA analyses indicate that all waste cells scheduled to be closed under DOE Order 5820.2A meet the performance objectives of DOE Order 5820.2A. This is true even under the assumptions of: no subsidence mitigation, instantaneous subsidence, use of an operational cover, and instantaneous waste package degradation.
- Adding void-space limitations to the Waste Acceptance Criteria (WAC) would substantially increase the generators' cost for disposing waste at NTS. To ensure that such limitations had been met, NTS would have to monitor incoming waste packages. This could increase operational costs, have serious health and safety impacts, or both.
- Bechtel Nevada Waste Operations mitigates subsidence as it occurs. Operational steps, such as changes in the WAC that make void-space reduction easier for generators and introduction of policies for waste placement that encourage the flow of soil between containers, have already been taken. Steps taken at other DOE facilities to mitigate waste subsidence, in general terms, resemble those taken at NTS.
- RCRA provides the only applicable guidance for closure cap design. RCRA requirements, strictly speaking, apply only to waste disposal units that accepted hazardous waste before September 26, 1988. Only waste disposal units that accepted low-level radioactive waste on or after this date will be closed under DOE Order 5820.2A.

4.0 AES PROCEDURES

Background information was distributed to all panel members on August 12, 1997. The "rules" of conducting an AES were discussed and agreed to by all panel members. The second and third day of deliberations, August 13 and 14, 1997, were spent comparing alternatives and working toward reaching consensus. On August 15, the final day of the AES, consensus on all issues was reached and a presentation was prepared for Bechtel Nevada and DOE/NV management. The presentation, detailing the main issues considered by the AES panel and the consensus recommendations reached, was delivered on August 15, 1997. Two external observers reviewed the presentation prior to delivery. The presentation was revised in accordance with their suggestions. A list of AES participants, their affiliations, and the role they played in the AES appears in Appendix C. Appendix C also includes the names and affiliations of the external observers.

4.1 Evaluation Criteria

As part of the AES structure, alternatives are compared according to criteria on which the panel agrees. In general, these criteria are developed as early in the discussion as possible to discourage defining criteria which favor one particular alternative.

Here, five criteria were used. No weighting or order of importance was assigned to the criteria. In particular, the order of presentation of the criteria is without meaning. The criteria were:

- **Cost.** This criterion measured the anticipated costs to implement, monitor, and maintain a proposed alternative. Possible costs ranged from "very expensive" (least desirable) to "very low expense" (most desirable).
- **Implementability.** This criterion measured the practicality of implementation, including consideration of labor and equipment required, past experience, and possible changes/advances of technologies. Possible implementabilities ranged from "not implementable" (least desirable) to "very easy to implement" (most desirable).
- **Long-Term Performance.** This criterion is a relative measure of risk reduction, as measured by the meeting of the PA performance objectives and the CA goals; response to subsidence; and control of infiltration, erosion, and biointrusion. Possible long-term performances ranged from "poor anticipated performance" (least desirable) to "excellent long-term performance" (most desirable).
- **Operational Feasibility.** This criterion measured practicality of the proposed closure, the likelihood of its being effective, and the reasonableness of undertaking postclosure monitoring and maintenance. Possible operational feasibility ranged from "extremely difficult" (least desirable) to "very easy" (most desirable).
- **Stakeholder Acceptance.** This criterion measured anticipated potential public, DOE, and regulator acceptance and promotion; appearance of closure; protection of the environment; and compliance with regulatory statutes and orders. Possible stakeholder acceptances ranged from "highly unlikely" (least desirable) to "highly likely" (most desirable).

Not all options considered were fully rated. If one or more criteria allowed an option to be effectively ruled out (e.g., if the AES panel believed the stakeholders would not accept an option), that option was not considered further.

5.0 AES DELIBERATIONS

This AES was convened for three purposes: to consider the recommendations of the COSR; to make recommendations concerning the closure of Disposal Unit U-3ax/bl; and to make recommendations concerning future closures. Although discussion of these issues overlapped during the actual AES, they are presented sequentially, in the above order, in Sections 5.1 through 5.3. The order of discussion is not intended to represent, in any fashion, the importance of the items considered.

5.1 Recommendations/Observations of the COSR

The COSR contained seven recommendations/observations. The AES panel considered each in turn. Results are detailed in Sections 5.1.1 through 5.1.7.

5.1.1 Regulatory Standards for Radioactive Waste Disposal and Cover Design

The COSR surveyed the applicable regulatory standards for radioactive waste disposal and cover design. The AES panel agreed that the survey was complete and thorough.

5.1.2 Implications of Subsidence for PA

The COSR recommended that assumptions concerning closure made in the PA analysis be verified during design of the closure caps. The primary assumptions made in the PAs for the Areas 3 and 5 RWMSs that could be impacted by waste subsidence are:

- After complete subsidence, the soil cover will not be thinner than 1.8 meter (m) (6 feet [ft]).
- Subsidence-induced cracks and fissures self-heal after subsidence is complete.

The AES panel agreed that all waste cells should be closed in such a manner that these assumptions are met. Either the evapotranspirative soil vegetation (ESV), evaporative soil (ES), or thickened operational closure (TOC) cover, discussed in Section 5.2.1.3, would, with appropriate thickness, meet this requirement.

5.1.3 Recommended Engineering Performance Standards

The COSR recommended that closure caps be designed to meet both certain engineering standards and a dose-based standard (e.g., meet the performance objectives of DOE Order 5820.2A). The COSR proposed four engineering standards:

- At least 30 centimeters (cm) (1 ft) of clean soil should cover the waste at all times.
- Average annual gas flux above the waste should not exceed the average annual gas flux at the waste perimeter.
- The thickness of the soil layer over the waste should be greater than the average annual depth of infiltration.
- Average annual infiltration should be less than 1 percent of the average annual precipitation.

Evaluating these standards was beyond the AES panel's scope of work. Hence, the AES panel chose to make no recommendations concerning these proposed standards. Informal discussions indicated general agreement with the first three. Some panel members felt that the fourth criterion might be too stringent because regulations governing construction of landfills in populated areas often allow greater infiltration than this proposed criterion.

5.1.4 Implications of Subsidence for the Existing Closure Cover Design

The COSR concluded that the hard cover design selected in Johnjack and Elletson (1994) was not cost effective and would not survive anticipated subsidence-induced slumping. A form of soft cover was suggested in its stead.

The AES panel agreed that the hard cover was not the most cost-effective design. The hard cover design required a layer of bentonite. The bentonite required for construction would have to be transported to the RWMSs. The AES panel concluded that an ESV, ES, or TOC cover would be adequate. Such mono-layer covers, constructed solely from native alluvium, would cost considerably less than the hard cover design. Because other cover designs are adequate and less expensive than the hard cover design, the AES panel chose to not evaluate the performance of the hard cover design.

5.1.5 Alternative Closure Cap Design

The COSR proposed a mono-layer closure cap of native alluvium, of thickness approximately 3 m (10 ft). The ESV cover is equivalent to the COSR-recommended cover, and the AES panel agreed that the ESV cover is an adequate and relatively low-cost option. However, in view of Shott *et al.* (1997a) and Shott *et al.* (1997b), the AES panel believed the existing operational covers might be adequate. In particular, the AES panel held that the TOC cover would meet all design needs and, as it is a natural outgrowth of normal operations, would be extremely cost effective.

5.1.6 Options for the Remediation of Void Spaces in Waste Packages

The COSR had three findings/recommendations on this issue:

- Subsidence mitigation actions, such as deep dynamic compaction (DDC), grouting, and surcharging, are not practical.
- Modify waste placement procedures to discourage subsidence of waste placed in the future.
- Hire an independent consultant to evaluate waste packaging, transportation, and disposal operations in general, and methods for reducing void spaces in particular.

Responses of the AES panel are:

Subsidence Mitigation Actions. Subsidence mitigation for waste already in place is not a reasonable option. Appendix D contains estimates of the cost of remediating a generic disposal cell, similar to those in the Area 5 RWMS and described in Appendix D, using grouting, DDC, and a TOC cover. Cost ranges appear in Table 1.

Table 1 **Estimated Costs of Subsidence Mitigation/accommodation at a Generic Disposal Cell, Described in Appendix D**

Method of Mitigating/Accommodating Waste Subsidence	Range of Costs (millions of dollars)
Grouting	1.86 to 10.33
DDC	0.81 to 1.34
TOC Cover	0.16 to 0.22

Accommodating subsidence with a TOC cover would cost, very crudely, about one-fifth of what decreasing subsidence with DDC would cost and at least an order of magnitude less than preventing subsidence with grouting would cost. Because the TOC cover accommodates waste subsidence, other options considered are not recommended.

Surcharging was not explicitly considered by the AES panel. Informal discussions indicated that surcharging might have stakeholder acceptance and implementability problems.

In addition to grouting and DDC, the AES panel considered the possibility of excavating and replacing the waste in a denser form. This option was rejected on grounds of health and safety and implementability.

Grouting could be applied to future waste streams. However, the cost of doing so, although not explicitly estimated by the AES panel, would still be much greater than the cost of accommodating waste subsidence by means of a TOC cover. Hence, the AES panel does not recommend the grouting of either future waste or waste in place.

Waste Placement Procedures. Changes in waste placement policy can only impact subsidence of waste not yet in place. As noted in Shott *et al.* (1997a), waste currently being received tends to be denser than older waste. Therefore, waste currently being received is expected to subside less than older waste. Hence, changes in waste placement policy can have only a comparatively small impact on future waste subsidence. Because the environmental impacts of the RWMSs are small, even if fully subsided, the benefits of subsidence avoidance are also small. However, best engineering practices and social responsibility indicate that steps to minimize subsidence that are of low cost and do not jeopardize worker health and safety should be taken.

Four specific recommendations, each having a low dollar cost and no adverse operational impacts, are made:

- Without placing specific void-space restrictions on the generators (which would increase operating costs and be difficult to verify), encourage waste packaging to minimize void spaces.
- Currently, boxes in which waste is disposed have skids attached to the bottoms, producing void spaces between boxes. Skids should be incorporated into boxes, eliminating these void spaces.

- Currently, wooden dunnage is disposed in the sides of the trenches. Because wood will collapse before metal boxes, this practice encourages differential subsidence. Further, this practice might encourage biointrusion via termites. Dunnage should be disposed in some other manner. For example, dunnage could be used as auxiliary fuel in an incinerator-based LLW treatment system. Alternately, dunnage could be disposed separately from other wastes, perhaps in a special-purpose trench.
- Whenever "as low as reasonably achievable" (ALARA) considerations allow, bulk disposal of waste should be considered. Because bulk waste can be readily compacted, settlement potential is substantially reduced.

Independent Evaluation. The AES panel did not see substantial benefit to an independent review of waste disposal practices at NTS because of ongoing work and practices. A tentative scope of work for an independent audit was created by AES panel member E. Strassburger, one of the COSR authors. This scope of work is reproduced in Table 2. Upon examination, the AES panel concluded that each item had already been or would soon be resolved. These resolutions are listed in Table 2.

Table 2 Tentative Scope of Work for an Independent Audit, and How Each Item Has Been/Will Be Resolved

Item	Resolution
Review regulations for requirements concerning packaging, transport, and disposal.	U.S. Department of Transportation (DOT) requirements for packaging and transport are well known. All disposal requirements are in RCRA or DOE Order 5820.2A, depending on the authority under which the waste is to be disposed.
Evaluate waste generation practices to determine whether wastes are minimized.	DOE requires each waste generator to have a waste minimization program in place. These programs provide assurance that waste is, to the extent practical, minimized.
Evaluate role of transportation on container selection and void generation.	J. Gnoose, of Fluor Daniels, volunteered to raise this issue at the next meeting of the Waste Generators Working Group. The AES panel concurred that it is appropriate for the Waste Generators Working Group to address this issue.
Evaluate disposal practices on container selection and void generation.	In September 1996, the WAC was modified to allow removable skids on boxes, thereby reducing void spaces; and the disposal of multiple waste streams within a single container, thereby facilitating generators' filling of containers. A number of recommendations for reducing void spaces has come out of this AES.

Table 2 (continued)

Item	Resolution
Develop uniform container standards that provide good stacking.	In September 1996, the WAC was modified to include engineering specifications, with 1.3-cm (0.5-in) tolerance, for uniformity in sizes of boxes and drums. This size specificity will facilitate stacking and reduce void spaces.
Develop pricing schedule that encourages minimization of subsidence based on bulk density.	The current pricing schedule for waste disposal at NTS encourages bulk disposal of waste, which minimizes subsidence. The AES panel agreed that too many factors play a role in determining final subsidence for bulk density, or any other readily measured waste characteristic, to be the determining feature.

5.1.7 Private Sector Disposal Practices and Implications for Disposal Practices at NTS

The COSR recommended continuing monitoring and maintenance of the RWMSs. The AES panel concurred that the RWMSs should be monitored and, throughout the institutional control period, subsidence of the cap should be remediated as it occurs. In addition, the AES panel recommended:

- A Geographic Information System (GIS) database be established containing, as well as can be determined, the locations of the waste packages. This would be useful for predicting the magnitude and timing of subsidence (e.g., cardboard and wooden containers are expected to collapse before steel containers) and for tracking the locations of waste packages with unusually large concentrations of radionuclides. The AES panel was aware of the poor quality of some of the older data. However, the AES panel concluded that the database would be useful despite some lapses in data quality.
- Maintain a record of the location and magnitude of subsidence as it occurs, rather than simply remediating it, as is current practice. The recording of these data would be facilitated by the use of a Global Positioning System (GPS) which, with the establishment of a base unit, would allow the location of subsidence to be precisely determined. Monitoring of any shifts in the caps, either operational or final, should be conducted at least monthly.

5.2 Recommendations Concerning Closure of Disposal Unit U-3ax/bl

Disposal Unit U-3ax/bl, in operational closure since 1987, is the first disposal unit scheduled for final closure. Disposal Unit U-3ax/bl is scheduled to be closed under RCRA. Options for closure of Disposal Unit U-3ax/bl are compared in Section 5.2.1. The criteria of Section 4.1 lead to a clear choice, and that option is recommended. A demonstration project, in which

performance of various cap designs is compared experimentally, is considered in Section 5.2.2. A discussion of how Disposal Unit U-3ax/bl can be closed while meeting RCRA requirements occurs in Section 5.2.3. A path forward for the closure of Disposal Unit U-3ax/bl, unanimously agreed to by the AES panel members, appears in Section 5.2.4.

5.2.1 Options for Closure of Disposal Unit U-3ax/bl

Three options for closure of Disposal Unit U-3ax/bl, listed in the titles of Sections 5.2.1.1 through 5.2.1.3, were considered. Based on the evaluation criteria of Section 4.1, adoption of a TOC cover was recommended. It was the unanimous finding of the AES panel that subsidence mitigation, beyond remediation of subsidence as it occurs; the recommendations appearing in Section 5.1.6; and construction of a soft cover of sufficient flexibility and thickness to accommodate waste subsidence, is not necessary.

5.2.1.1 Subsidence Reduction at Disposal Unit U-3ax/bl

Because Disposal Unit U-3ax/bl was operationally closed in 1987, all waste is already in place. Hence, subsidence could be reduced only by applying methods of subsidence reduction that are applicable to waste in place. Evaluation of grouting, in accordance with the criteria laid out in Section 4.1, appears in Table 3.

Table 3 Evaluation of Grouting for Subsidence Reduction at Disposal Unit U-3ax/bl

Criterion	Evaluation
Cost	Extremely expensive, as discussed in Section 5.1.6.
Implementability	Extremely difficult to implement. Penetrating the metal debris would be difficult to impossible. There are significant worker health and safety issues.
Long-term performance	Grouting would eliminate waste subsidence, resulting in excellent long-term performance.
Operational feasibility	Monitoring and maintenance of a grouted disposal site would be very easy.
Stakeholder acceptance	Likely to be accepted due to perceived reduction of risk and because of the long-term minimization/elimination of waste subsidence. However, these options would delay final closure; therefore, stakeholder acceptance was rated as 'likely', rather than 'highly likely.'

5.2.1.2 Subsidence Encouragement at Disposal Unit U-3ax/bl

Because Disposal Unit U-3ax/bl was operationally closed in 1987, all waste is already in place. Hence, subsidence could be reduced only by applying methods of subsidence reduction that are applicable to waste in place. Evaluation of DDC, in accordance with the criteria of Section 4.1, appears in Table 4.

Table 4 Evaluation of DDC for Subsidence Encouragement at Disposal Unit U-3ax/bl

Criterion	Evaluation
Cost	Extremely expensive, as discussed in Section 5.1.6. Because DDC would reduce (but not eliminate) waste subsidence, the cost/benefit ratio of DDC would be undesirably large.
Implementability	Extremely difficult to effectively implement due to significant depth of the waste. There are significant worker health and safety issues.
Long-term performance	DDC would reduce, but not eliminate, waste subsidence.
Operational feasibility	Very easy. A cap over waste that has been subjected to DDC would require some maintenance due to remaining waste subsidence.
Stakeholder acceptance	Likely to be accepted, due to perceived reduction of risk and the long-term minimization of waste subsidence.

5.2.1.3 Soft Operational Cover and Monitoring

The soft cover designs considered were the ESV, ES, and TOC covers. The ESV cover is a closure cap consisting of a layer of vegetated soil that controls infiltration by runoff, evaporation, and transpiration. The soil thickness is chosen to control biointrusion and to accommodate waste subsidence. The ES cover is similar, but without vegetation. The ES cover would control infiltration by evaporation and temporary retention in soil voids. The TOC cover is similar to the ES cover during the operational period, but is assumed to be emplaced during operational maintenance. As such, it would begin as an operational cap, but would eventually become the permanent cap.

The TOC cover is created by adding soil to the existing operational cover. During the institutional control period, soil is added to the operational cover to mitigate subsidence as it occurs. Soil, of depth equaling that of anticipated future waste subsidence, is added prior to the end of the institutional control period. This additional soil is anticipated to cause the TOC cover to be at or near grade after subsidence is complete. The TOC cover is illustrated in Figure 5.

The TOC cover was chosen as the focus of evaluation because it can be constructed during normal maintenance operations, thereby simultaneously reducing cost, biointrusion, and the potential for differential subsidence to expose waste. Evaluation of the TOC cover, in accordance with the criteria of Section 4.1, appears in Table 5.

In view of the evaluation criteria, the AES panel recommends adoption of the TOC cover. Issues of the TOC cover's RCRA suitability are addressed in Section 5.2.3.

Figure 5 Overview of the TOC Cover

Table 5 Evaluation of a TOC Cover for Disposal Unit U-3ax/bl

Criterion	Evaluation
Cost	Very low. The TOC cover can be constructed from native alluvium, readily available at NTS, over the full period of institutional control.
Implementability	Very easy to implement. Given the go-ahead, this option could be implemented now.
Long-term performance	Studies to show the TOC cover's RCRA equivalency are underway. The TOC cover corresponds to good engineering practice, as it responds to subsidence and controls infiltration and bio-intrusion. The Area 3 RWMS, which includes Disposal Unit U-3ax/bl, meets the CA goals with all disposal cells closed with operational covers; replacing an operational cover with a TOC cover would further reduce the composite dose.
Operational feasibility	Extremely simple technology would be required. The TOC cover is easy to construct, monitor, and maintain.
Stakeholder acceptance	Immediate DOE acceptance was anticipated by the AES panel. Initial objections from some other stakeholders, because of the unproven nature of the design's effectiveness, could occur. However, the AES panel members thought that eventual stakeholder acceptance of the TOC cover was likely if the TOC cover is shown equivalent to a RCRA cover.

5.2.2 Further Evaluation by a Demonstration Project

A demonstration project would consist of construction of one or more test cover(s) with monitoring devices at nondisposal cell locations for a predetermined period. Test cell data would be evaluated at the end of this period, and the closure cap found most appropriate could be used for closure of Disposal Cell U-3ax/bl, or of other disposal cells.

A demonstration project is a study to evaluate closure options, rather than a closure option itself. However, the concept of conducting a demonstration project for closure of Disposal Unit U-3ax/bl was evaluated in accordance with the criteria of Section 4.1. This evaluation appears in Table 6.

The discussion of *Table 6* applies only to the construction of multiple demonstration caps to select a cover design for U-3ax/bl. It does not apply to the construction of a single demonstration cap, built for purposes of validating short-term, design-specific studies.

5.2.3 RCRA Compliance for Disposal Cell U-3ax/bl

Disposal Cell U-3ax/bl will be closed under RCRA. As a check on the suitability of the TOC cover, the option recommended by the AES panel, the characteristics of the TOC cover were compared to RCRA closure requirements. Table 7 shows that a TOC cover qualitatively

Table 6 Evaluation of a Demonstration Project for Disposal Unit U-3ax/bl

Criterion	Evaluation
Cost	Moderate to very high, depending on the number of test covers constructed.
Implementability	Easy to construct the covers.
Long-term performance	Not applicable.
Operational feasibility	Not applicable.
Stakeholder acceptance	Stakeholder acceptance is thought unlikely. A demonstration project would delay final closure, while teaching us little we do not already know about cover performance. The performance of an off-cell cover might not match that of an on-cell cover.

Table 7 Comparison of the TOC Cover with RCRA Requirements

Requirement	Comparison of TOC Cover with Requirement
Minimize liquid migration.	The TOC cover would act as an evapotranspiration barrier, thereby limiting and controlling infiltration.
Minimize maintenance.	The AES panel interpreted this requirement as meaning "keep maintenance to a manageable level." While the TOC cover would require regular maintenance, such maintenance could readily be performed in normal operations during the period of institutional control.
Minimize cover erosion.	Dikes and berms would be constructed to mitigate the 100-year flood hazard. Vegetation would be planted on the cover at the end of the institutional control period, reducing aeolian and hydraulic erosion.
Accommodate subsidence.	The TOC cover is sufficiently flexible to adjust to differential or complete subsidence, thereby retarding waste exposure, gas migration, and/or rainwater infiltration.
Permeability of cover less than or equal to that of base.	The base of Disposal Unit U-3ax/bl is constructed from compacted soil. The TOC cover could also be constructed of compacted soil. Sufficient compaction of the cover would ensure that the cover's permeability is not less than that of the base.

meets all RCRA closure requirements. While the TOC cover's equivalency to a standard RCRA cap has yet to be formally established, the AES panel anticipates that this will be accomplished.

5.2.4 Recommended Path Forward

After extensive deliberations, the AES panel unanimously agreed that the closure of Disposal Unit U-3ax/bl should proceed via the following sequential steps:

- Conduct characterization to support design. Required characterization consists of studies to locate the top of the waste, locate a source of borrow materials, and determine the suitability of those materials for constructing the cover.
- Design closure cover. The selected design must accommodate anticipated subsidence and satisfy all regulatory requirements.
- Construct closure cover. Build a soft cover of native materials, with instrumentation to support monitoring of conditions.
- Monitor conditions. Conduct 30-year monitoring to evaluate conditions, such as infiltration, gas migration, and cover deformation.
- Implement institutional control. Reevaluate conditions and monitoring programs for 100-year maintenance under institutional control.

5.3 Recommendations Concerning Closure of Other Disposal Units

The AES panel members unanimously agreed that the following path forward is applicable to all disposal units at NTS:

- Conduct characterization to support design. Required characterization consists of studies to locate the top of the waste (for some disposal cells, location of the top of the waste may be known well enough to render additional study unnecessary), locate a source of borrow materials, and determine the suitability of those materials for constructing the cover. Sources of borrow material can be used for more than one disposal cell. Mapping of waste container locations, by general type, will be required for some disposal cells.
- Design closure cover. The selected design must accommodate anticipated subsidence and satisfy all regulatory requirements. If the TOC cover design is chosen, the cover's thickness depends on the anticipated magnitude of subsidence. Therefore, thickness of TOC covers would vary among disposal cells.
- Construct closure cover. Build a soft cover of native materials, with instrumentation to support monitoring of conditions.
- Monitor conditions. Conduct 30-year monitoring to evaluate conditions, such as infiltration, gas migration, and cover deformation.
- Implement institutional control. Reevaluate conditions and monitoring programs for 100-year maintenance under institutional control.

The preceding path strongly resembles the path forward appearing in Section 5.2.4, with appropriate modifications. This is deliberate; while closure of disposal cells is anticipated to vary among cells, it is anticipated that closures will be more similar than different.

The AES panel unanimously agreed that grouting, DDC, and other methods of subsidence reduction/encouragement are not recommended for use with waste in place in any disposal cell at NTS, given current knowledge. However, actions that can be taken with future waste streams that will reduce subsidence, but do not have high costs or significant health and safety risks associated with them, should be taken. In addition to the operational recommendations appearing in Section 5.1.6, the AES panel recommended:

- Further investigation of rates of container decay and magnitude of subsidence, so the timing and magnitude of waste subsidence can be better anticipated.

6.0 CONCLUSION

In Section 6.1, the key ideas of this AES are succinctly stated. In Section 6.2, a summary of the recommendations of the AES appear. These two sections distill the results of the AES deliberations into an easily usable form.

6.1 Key Ideas of this AES

Results of this AES can be, broadly speaking, summarized in three key observations/recommendations.

- Unless expensive and difficult remedial measures (e.g. grouting) are implemented, some waste subsidence will occur in all disposal cells. However, even without mitigation of waste subsidence, both the Areas 3 and 5 RWMSs meet all performance objectives of DOE Order 5820.2A (Shott *et al.*, 1997a; Shott *et al.*, 1997b).
- Waste subsidence that occurs during the period of institutional control can be accommodated by ongoing operations and maintenance. Waste subsidence anticipated for the postinstitutional control period can be accommodated using a simple and relatively inexpensive cover design, the TOC cover.
- There are some steps that can be taken now to reduce future waste subsidence. Those steps that are reasonable and represent best engineering practice should be taken.

6.2 Summary of Recommendations

Recommendations are scattered throughout this document. To enhance usability, a summary of all recommendations follows. Recommendations, with order not necessarily implying importance, are:

- Do not consider grouting or DDC as methods of waste subsidence mitigation for any waste cell at NTS.
- Close all waste cells on NTS with soft covers, such as the TOC cover.
- Do not convene an independent audit of NTS waste operations.
- Create a database containing locations of waste containers.
- Monitor performance of existing operational covers and, once they are in place, final covers.
- Encourage generators to pack waste to minimize void spaces. However, specific void-space restrictions should not be developed.
- Incorporate skids into boxes used for waste disposal.
- Dispose of dunnage in some manner other than by placing it in the sides of the trenches.
- When ALARA considerations allow, consider bulk disposal of waste.
- Further investigate rates of container decay and magnitude of waste subsidence to reduce uncertainty in waste cell performance.
- Evaluate the practicality of hexagonal drums.
- Consider new trench designs and geometry, which promote cover stability.
- Consider a return to the use of cardboard "triwall" containers for appropriate waste streams, thereby increasing the amount of waste subsidence occurring during the institutional control period.

7.0 REFERENCES

- Arnold, W. W., T. J. Brown, J. R. Cochran, R. B. Gilbert, B. A. Luke, F. S. Shuri, E. A. Strassburger, G. V. Wilson, and S. Wirth, 1997. *Consequences of Subsidence for the Area 3 and Area 5 Radioactive Waste Management Sites, Nevada Test Site*. Prepared for the U.S. Department of Energy/Nevada Operations Office, Las Vegas, Nevada.
- Johnejack, K. R., and L. W. Elletson, 1994. *Alternative Evaluation Study: Generic Cells for Arid Areas and Covers for the U-3ax/bl Disposal Unit*. Reynolds Electrical & Engineering Co., Inc., Las Vegas, Nevada.
- Miller, J. J., D. L. Gustafson, and J. S. Schmeltzer, 1994. A Multiple-Method Approach to Flood Assessment at a Low-Level Radioactive Waste Management Site, DOE/Nevada Test Site, Nye County Nevada. *Proceedings of Waste Management '94*. 3:1715:1718.
- MK-Ferguson, 1991. *Procedure for Performing Alternative Evaluation Studies*. Morrison and Knudsen Company, Report ED/CDs-2.
- Shott, G. J., C. J. Muller, L. E. Barker, D. E. Cawfield, 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 2.0). Reynolds Electrical & Engineering Co., Inc., Las Vegas, Nevada.
- Shott, G. J., L. E. Barker, S. E. Rawlinson, and M. J. Sully, 1997a. *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.
- Shott, G. J., L. E. Barker, S. E. Rawlinson, M. J. Sully, and V. Yucel, 1997b. *Performance Assessment/Composite Analysis for the Area 3 Radioactive Waste Management Site, Nye County, Nevada* (Revision 2.0), Bechtel Nevada, Las Vegas, Nevada.

APPENDIX A

DEFINITIONS

Definitions of certain key terms, written and agreed to by the AES panel, follow.

Deep dynamic compaction—the use of a weight, repeatedly dropped from a height, to compress buried waste. Deep dynamic compaction causes waste subsidence to occur during the period of institutional control.

Evaporative soil cover—a soil cover consisting of a single layer of soil, without vegetation, that controls infiltration by evaporation and retention in soil voids.

Evapotranspirative soil vegetation cover—a closure cap consisting of a thick layer of soil with vegetation that controls infiltration by runoff, evaporation, and transpiration. The soil thickness is chosen to control biointrusion and to accommodate anticipated waste subsidence.

Grouting—the insertion of cement, sand, or some other filler into the void spaces within/between containers of buried waste. Grouting reduces or prevents waste subsidence.

Hard cover—a closure cap containing a hard layer which will act in a brittle fashion under subsidence. An example of a hard cover is the cover, consisting of a layer of soil, a bentonite layer, a soil cement layer, and a stabilized layer, selected in Johnnejack and Elletson (1994).

Mono-layer—a cover consisting of a single layer. The evaporative soil cover, consisting of a single layer of soil, is an example of a mono-layer.

Operational cover—the cover that is or will be placed on the waste as a part of normal operations.

Soft cover—a closure cap that is relatively plastic and ductile, so as to deform without cracking. Such a cover could be a mono-layer of alluvium.

Surcharging—the use of static weight, usually in the form of a layer of soil, to compress buried waste. Surcharging causes waste subsidence to occur during the period of institutional control.

Thickened operational closure cover—the thick soil cover that would result from the placing of a designed thickness of soil atop the operational cover, with the thickness chosen to accommodate anticipated subsidence, and the soil subsequently added to bring the cover back to grade as subsidence occurs. Thus, the thickened operational closure cover is an evapotranspirative soil cover constructed over the entire period of institutional control. At the end of institutional control, the thickened operational closure cover could be planted with shallow-rooted native vegetation. The performance of the thickened operational closure cover would then equal that of the evapotranspirative soil vegetation cover.

APPENDIX B

SUMMARY OF BACKGROUND MATERIAL PRESENTED TO AES PANEL ON AUGUST 12, 1997

Eight presenters, some of whom were also panel members and some of whom were not, were called on to provide the panel with background material. Overviews of the material presented follow.

B.1 Recommendations Appearing in the COSR (Presenter: E. Strassburger, Bechtel Environmental)

Conducting this AES without all panel members being cognizant of Arnold *et al.* (1997), also called the COSR, would clearly be counterproductive. Many of the AES panel members had not seen the COSR, and only E. Strassburger had seen more than a preliminary draft. Hence, it was decided that E. Strassburger would deliver a detailed account of the COSR. Only the major observations and recommendations of the COSR are reproduced here.

- None of the regulations for disposal of LLW at the NTS include specific design requirements for closure caps.
- PA models should be used in developing strategies and designs for closure of waste disposal sites. The models need to include assessments of closure cap design; radiological releases for all transport pathways, including upward to the ground surface; and the effects of subsidence-induced changes on system components.
- Closure cover designs should satisfy minimum engineering performance standards, as well as dose-related standards.
- The cover design of Johnjack and Elletson (1994), tentatively considered for use in Disposal Cell U-3ax/bl, will not perform as intended because of the effects of subsidence. The design could be modified by increasing the thickness of the upper alluvial-fill layer. However, the modified design would not be cost effective.
- A mono-layer closure cover design, consisting of a thick layer of vegetated native alluvium, should be developed for application at the RWMSs. The cover should rely on thickness and evapotranspiration to provide containment. The alternative cover can use materials from local surface deposits and is more cost effective than the design selected in Johnjack and Elletson (1994).
- Void spaces within the waste and packaging should be minimized to the extent practical before the waste is placed in the landfill. An independent consultant should be hired to evaluate methods for reduction in void spaces and should be guided by practices in the private sector. Mitigation methods for void-space reduction are possible, but are not generally practical.
- The cover should be monitored during the institutional control period to determine actual performance and allow modification and maintenance if necessary.

B.2 Site Hydrologic Model (Presenter: M. Sully, Bechtel Nevada)

The climate of the NTS is arid, with an evaporative demand far surpassing precipitation. The alluvium is generally sandy and dry. Depths to groundwater beneath the two RWMSs are approximately 235 m (770 ft) (Area 5) and 490 m (1,600 ft) (Area 3).

Water reaches the ground surface through precipitation and run-on. At a depth of 1 to 3 m (3 to 10 ft), episodic infiltration, evaporation, and root uptake occur. At a depth of 2 to 5 m (6 to 15 ft), nearly steady upward flux exists, although some root uptake does occur. From these depths to a depth of approximately 120 m (400 ft), a nearly steady upward flux occurs. A static zone, in which flux is nearly zero, occurs at a depth of approximately 120 m (400 ft). Below this, steady downward flux occurs.

B.3 Flood Issues (Presenter: D. Gustafson, Bechtel Nevada)

Consideration of flooding issues is mandated by DOE Orders, RCRA, and the Federal Emergency Management Agency (FEMA). Miller *et al.* (1994) assessed the 6-hour, 100-year flood at the Areas 3 and 5 RWMSs using standard FEMA methods. One corner of the Area 5 RWMS, not used for waste disposal, was found to be contained in the flood plain of the 6-hour, 100-year flood. None of the Area 3 RWMS was found to be contained in the flood plain of the 6-hour, 100-year flood. With appropriate engineered protection in place, flooding is not considered likely to damage either the Area 3 or the Area 5 RWMS.

B.4 Regulations Impacting Closure (Presenter: P. Matthews, Bechtel Nevada)

Some disposal cells at the NTS will be closed under DOE Order 5820.2A. Others will be closed under RCRA. DOE Order 5820.2A contains no specific guidance for closure caps. RCRA regulations state that a cap must:

- Provide long-term minimization of liquid migration through the closed landfill.
- Function with minimal maintenance.
- Promote drainage and minimize cover erosion or abrasion.
- Accommodate settling and subsidence so that the cover's integrity is maintained.
- Have a permeability not exceeding the permeability of any bottom liner system or natural subsoils present.

In addition, closure must be conducted to meet all relevant groundwater protection standards.

B.5 Steps Taken at NTS and at Other Facilities to Discourage/Delay Subsidence (Presenter: L. Barker, Bechtel Nevada)

Subsidence can result from collapsing of packages, filling of void spaces between packages, and compaction of the waste. At NTS, the following steps have been taken to delay or reduce collapse of packaging:

- The use of cardboard packaging ("triwalls") was discontinued in 1988. According to Arnold *et al.* (1997), 90 percent of the degradation of cardboard containers occurs within 20 years of burial, and essentially 100 percent occurs within 75 years. No type of packaging is expected to degrade more rapidly than this. The discontinuation of the use of cardboard packaging delays, rather than reduces, subsidence.
- Boxes currently used for disposal are required to support 16,325 kg/m² (3,357 pounds/ ft²). Boxes capable of supporting less weight per unit area would pose a risk to the workers, as collapse during operations would be possible.
- The WAC encourages filling packages "to the maximum extent practical," although no quantitative measure of this exists. No steps have been taken to encourage densification of waste.
- The WAC has been modified to allow different waste streams to be mixed within a given container. This makes filling containers prior to shipping for disposal easier for generators.

The following steps have been taken to reduce void spaces between packages:

- Since 1992, all backfill soil has been screened to minus 7.6 cm (3 in).
- Wood spacers are placed between drums and boxes, encouraging soil to flow into the spaces between the drums and boxes.
- The WAC has been modified to allow boxes with removable skids.

Measures taken at other DOE sites are generally similar to those taken at NTS. The following sites have taken unusual steps:

- Los Alamos requires generators to have no more than 10 percent void space in containerized waste (personal communication, Charles Peper, Manager of Waste Operations for Los Alamos National Laboratories, 1997).
- The Savannah River Site has used DDC on trenches of depth between 3.7 and 4.6 m (12 and 15 ft). Grouting was considered, but rejected (personal communication, Dutch Conrad, Manager of Waste Operations for the Savannah River Site, 1997).
- Oak Ridge has used cement grouting with steel drums (Arnold *et al.*, 1997).

B.6 Operational Considerations (Presenter: Bruce Becker, Bechtel Nevada)

The primary operational issue is worker health and safety. In particular, changes in waste packaging and placement should be considered only if such changes do not jeopardize the health and safety of workers. It would be ill-considered to cause immediate injury, as from a collapsing stack of boxes, to avoid some small future dose to hypothetical future residents of the land that is now NTS.

B.7 Packaging Considerations (Presenter: J. Gnoose, Fluor Daniels)

At the Fernald Environmental Management Project (FEMP), waste is packed in half-height boxes (.61 m x 1.22 m x 2.14m [2 ft x 4 ft x 7 ft]), full-height boxes (1.22 m x 1.22 m x 2.14 m [4 ft x 4 ft x 7 ft]), International Organization for Standardization (ISO) boxes

(2.44 m x 2.44 m x 6.11 m [8 ft x 8 ft x 20 ft]), and drums. Packaging is usually governed by FEMP/NTS/DOT regulations, applicability of container, and ALARA considerations.

Typically, a full-height box contains less than 5 percent void space, and an ISO box contains 5 to 10 percent void space. Typically, 10 to 12 boxes or one ISO box constitute a truckload.

A requirement for zero void space would place a serious burden on FEMP, and presumably on other generators as well. Additional costs would be incurred due to:

- Modification of existing procedures/task orders.
- Revision to NTS Application and Quality Assurance checklists.
- Training of affected personnel.
- Expanded use of absorbent materials as filler.
- Increased person-hours per package.

Additional logistics difficulties would arise from a zero void space policy. Logistics problems would include:

- Re-engineering to determine optimal packaging configuration.
- Evaluation of ALARA.
- Design of nonstandard containers to fit packaging needs.
- Introduction of gels, foams, concrete, etc., to fill void spaces after container packaging.

The situation would be similar if void-space limitations were added to the WAC for NTS. In addition, to determine that these limitations had been met, NTS would have to either build a real-time radiography facility (which would add to the expense of handling waste) or open waste packages (which could have serious health and safety impacts and might violate the ALARA principle).

B.8 Results from PAs (Presenter: G. Shott, Bechtel Nevada)

Shott *et al.* (1997a) is a PA for the Area 5 RWMS. This PA considered both subsided and unsubsid cases. A 10,000-year compliance period was used.

In the course of performing the PA for the Area 5 RWMS, it was assumed that:

- Subsidence was repaired during the institutional control period.
- The cover thins and cracks and that infiltration increases between 100 and 1,000 years after closure.
- Following 1,000 years, subsidence is complete and cracks self-heal.
- Only the operational cover is in place.

The following transport processes were considered:

- Gaseous diffusion. Subsidence-induced cracking and thinning increases release.
- Liquid advection. Downward liquid advection can occur in a subsided scenario.

- Plant uptake. Increased infiltration increases primary plant productivity in a subsided scenario. Cover thinning allows deeper root penetration into waste.
- Burrowing insects. Subsidence-induced cover thinning allows deeper burrow penetration into waste.

Shott *et al.* (1997a) took no credit for waste packaging. Under these assumptions, peak results during the 10,000-year compliance period were as depicted in Table B.1.

Table B.1 Comparison of Results from PA for Area 5 RWMS to Performance Objectives of DOE Order 5820.2A

Scenario or Constituent	Unit	Nonsubsided Case	Subsided Case	Performance Objective
Transient visitor (recreational or industrial use)	mrem/year	0.6	0.8	25
Open rangeland (ranching use)	mrem/year	0.2	0.3	25
Resident farmer (subsistence agriculture; not a practical scenario for NTS)	mrem/year	3	17	25
Total Ra in groundwater	pCi/l	<detection limit	0.3	5
Gross Alpha in groundwater	pCi/l	6	9	15
Committed effective dose equivalent	mrem/year	No release	1	4
Radon flux	pCi/m ² /s	6	10	20

These results were obtained under extremely conservative assumptions. For example, peaks from different pathways were summed regardless of nonsimultaneous occurrence. Groundwater impacts, which depend heavily on the amount of rainfall, were assessed under the assumption that three consecutive 200-year storms occurred in the first three years following end of institutional control. Finally, these results account for the waste disposed in the classified trenches, but not for the waste disposed in the GCD units.

Shott *et al.* (1997b) contains a PA for the Area 3 RWMS, in which subsidence was taken as the base case. This PA used a 1,000-year compliance period. The compliance period of the PA for the Area 3 RWMS differs from that of the PA for the Area 5 RWMS because of a change in DOE guidance that occurred between the two PAs being performed. An

operational cover was assumed, and no credit was taken for waste packaging. As calculations for Shott *et al.* (1997b) had not been completed as of August 12, 1997, no results were presented. However, preliminary calculations indicate that the environmental impacts of the Area 3 RWMS are much smaller than those of the Area 5 RWMS, and that the Area 3 RWMS easily meets all performance objectives and CA goals.

Thus, even under the assumption that only an operational cover is in place, that waste packaging deteriorates immediately, and that no subsidence mitigation occurs, both the Areas 3 and 5 RWMSs meet all PA performance objectives. The composite doses resulting from the Area 3 RWMS meets all CA goals. The composite dose resulting from the Area 5 RWMS is scheduled to be evaluated in FY 1998.

APPENDIX C

AES PARTICIPANTS

Panel Members:

David Anderson, Bechtel Nevada
Bruce Becker, Bechtel Nevada
Max Dolenc, Bechtel Nevada
Jerry Gnoose, Fluor Daniels
Jesus Lopez, Sandia National Laboratories
Stuart Rawlinson, Bechtel Nevada
Eric Strassburger, Bechtel Environmental (Oak Ridge, Tennessee)

Facilitator:

Jack Caldwell, GeoSyntec Consultants

Recorder:

Lawrence Barker, Bechtel Nevada

External Observers:

Robert Gilbert, University of Texas at Austin
Fred Penrod, DOE/NV

APPENDIX D

ESTIMATION OF COSTS OF SELECTED ALTERNATIVE METHODS OF SUBSIDENCE MITIGATION/ACCOMMODATION

Costs presented here are informal calculations, and not formal defensible cost estimates. These costs are only intended to be order-of-magnitude correct.

Approximate costs for three alternative approaches to subsidence mitigation/accommodation for waste already in place are calculated here. The three alternatives considered are:

- Grouting.
- DDC.
- TOC cover.

Costs for subsidence mitigation/accommodation at a given disposal cell depend on the area of the disposal cell, the thickness of the operational cover, magnitude of anticipated subsidence, and possibly volume of the unsubsidized disposal cell. Here, all calculations are done with a generic disposal cell, called Disposal Cell A. Disposal Cell A, illustrated in Figure D.1, is typical of disposal cells in the Area 5 RWMS.

Disposal Cell A covers 0.4 hectare (ha) (1 acre [ac]). Disposal Cell A has an operational cover 2.4 m (8 ft) thick; prior to subsidence, half the operational cover's thickness is above grade and half is below grade. The anticipated final subsidence for Disposal Cell A is 4 m (13 ft). The depth from grade to the bottom of Disposal Cell A is 6.1 m (20 ft). Disposal Cell A has an unsubsidized volume of 24,400 m³ (31,622 yd³). Disposal Cell A is assumed to have 65 percent void space; hence, the volume of the void space in Disposal Cell A is 15,900 m³ (20,600 yd³).

Approximate costs for subsidence mitigation/accommodation in Disposal Cell A are calculated below. In addition to differences in cost, these approaches are fundamentally different in their ultimate effect. Grouting would eliminate waste subsidence. DDC would reduce waste subsidence, but would not eliminate it, because waste too deep to be further compacted by DDC would still eventually subside. The TOC cover would accommodate waste subsidence, in the sense that, after waste subsidence occurred, the TOC cover would be an approximately at-grade cover.

Figure D.1 Overview of Disposal Cell A, a Notional Disposal Cell Similar to Disposal Cells in the Area 5 RWMS.

D.1 Approximate Cost of Grouting of Disposal Cell

Cost of grouting equals:

(cost per volume of grouting)
times
(volume of void space)
times
(fraction of void space that must be grouted).

The second of these (volume of void space) is, by assumption, known. Estimates must be provided for the first (cost per volume of grouting) and third (fraction of void space that must be grouted). Substituting high- (low-) end estimates for the first and third gives us high- (low-) end estimates for the total cost of mitigating Disposal Cell A through grouting.

Cost per volume of grouting ranges from \$390 to \$650 per m³ (\$300 to \$500 per yd³). Engineering evaluations, not performed by the AES panel, would be required to determine how much of the void space within Disposal Cell A would be filled. On the high end, all void spaces might have to be filled (fraction of void spaces to be filled equals 1.0). Alternately, it might be possible to construct "columns" of grout that the closure cap could easily bridge. For purposes of this estimate, a low-end estimate of the fraction of void space that must be grouted is 0.3. This number is relatively large because substantial horizontal void spaces exist between containers; preventing grout from entering these void spaces in waste already in place would be almost impossible.

Accordingly, the high-end estimate of the cost of mitigating subsidence at Disposal Cell A via grouting is:

$$(\$650/\text{m}^3) \times (15,900 \text{ m}^3) \times (1.0) = \$10,335,000$$

and the low-end estimated of the cost of mitigating subsidence at Disposal Cell A via grouting is:

$$(\$390/\text{m}^3) \times (15,900 \text{ m}^3) \times (0.3) = \$1,860,000.$$

D.2 Approximate Cost of DDC of Disposal Cell

DDC compacts waste already in place. Assuming an at-grade cover is desired, the subsidence generated by DDC must be compensated for by introduction of soil. Here, we assume native alluvium is used to bring the crater resulting from DDC up to grade.

Cost of DDC equals:

(cost per area for DDC) times
(area subjected to DDC)

plus

(volume of resulting crater) times
(cost per volume of filling crater).

DDC can produce densification equal to about 30 percent of the waste depth for trenches of depths up to about 3.7 to 4.6 m (12 to 15 ft). In Disposal Cell A, this would result in a crater of area 0.4 ha (1 ac) and depth $0.3 \times \{3.7 \text{ to } 4.6 \text{ m}\}$ (12.1 to 15.0 ft) = 1.1 to 1.4 m (3.6 to 4.6 ft), with a total volume of 4,400 to 5,600 m³ (5,700 to 7,260 yd³). Cost of placing native alluvium on NTS approximately ranges from \$14.70 to \$19.40 per m³ (\$11.40 to \$15.00 per yd³). DDC roughly costs between \$1,853,000 and \$3,089,000 per ha (\$750,000 and \$1,250,000 per ac).

Substituting high- (low-) end estimates gives us high- (low-) end estimates for the total cost of mitigating Disposal Cell A through DDC. Accordingly, the high-end estimate of the cost of mitigating subsidence at Disposal Cell A via DDC is:

$$(\$3,089,000/\text{ha}) \times (0.4 \text{ ha}) + (\$19.40/\text{m}^3) \times (5,600 \text{ m}^3) = \$1,344,000$$

and the low-end estimate of mitigating subsidence at Disposal Cell A via DDC is:

$$(\$1,853,000/\text{ha}) \times (0.4 \text{ ha}) + (\$14.70/\text{m}^3) \times (4,400 \text{ m}^3) = \$806,000.$$

D.3 Approximate Cost of Closing Disposal Cell with TOC Cover

A TOC cover could be put in place as a normal part of operational maintenance. Because the operational maintenance will be done anyway, the cost of operational maintenance is not included in this estimate. Accordingly, the cost of the TOC cover equals:

(volume of soil placed for cover) times
(cost per volume of placing soil).

The anticipated final subsidence for Disposal Cell A is 4.0 m (13 ft). Disposal Cell A has an operational cover 2.4 m (8 ft) thick; prior to subsidence, half the operational cover's thickness is above grade and half is below grade. Hence, to bring Disposal Cell A up to grade, following subsidence, $(4.0 - 1.2) = 2.8 \text{ m}$ (9.1 ft) of soil would have to be added. Disposal Cell A covers 0.4 ha (1 ac). Therefore, the volume of the soil that would be added is 11,200 m³ (14,500 yd³). Cost of placing native alluvium on NTS ranges from about \$14.70 to \$19.40 per m³ (\$11.40 to \$15.00 per yd³).

Substituting high- (low-) end estimates for the first and third gives us high- (low-) end estimates for the total cost of closing Disposal Cell A with a TOC cover. Accordingly, the high-end estimate of the cost of closing Disposal Cell A with a TOC cover is:

$$(11,200 \text{ m}^3) \times (\$19.40 \text{ per m}^3) = \$217,000$$

and the low-end estimate of the cost of closing Disposal Cell A with a TOC cover is:

$$(11,200 \text{ m}^3) \times (\$14.70 \text{ per m}^3) = \$165,000.$$