

**AN INFORMAL EXPERT JUDGMENT ASSESSMENT OF SUBSIDENCE
MITIGATION OPTIONS FOR LOW-LEVEL RADIOACTIVE WASTE
MANAGEMENT SITES ON THE NEVADA TEST SITE**

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ABSTRACT

An assessment of options to mitigate the effects of subsidence at low-level radioactive waste disposal sites on the Nevada Test Site was conducted using an informal method of expert judgment. Mitigation options for existing waste cells and future waste cells were identified by a committee composed of knowledgeable personnel from the DOE and DOE-contractors. Eight ranking factors were developed to assess the mitigation options and these factors were scored through elicitation of consensus views from the committee. Different subsets of the factors were applied respectively, to existing waste cells and future waste cells, and the resulting scores were ranked using weighted and unweighted scores. These scores show that there is a large number of viable mitigation options and considerable flexibility in assessing the subsidence issue with a greater range of options for future waste cells compared to existing waste cells. A highly ranked option for both existing and future waste cells is covering the waste cells with a thick closure cap of compacted native alluvium.

INTRODUCTION

The U.S. Department of Energy, Nevada Operations Office (DOE/NV) operates and is responsible for future closure of two low-level radioactive waste facilities on the Nevada Test Site (NTS). These facilities, which are referred to as Radioactive Waste Management Sites

(RWMSs), currently receive and dispose low-level radioactive waste using shallow land burial (1). They are located, respectively, in Frenchman Flat (Area 5) and Yucca Flat (Area 3) on the NTS, more than 100 miles by highway from Las Vegas, Nevada. The DOE/NV has operated these facilities since 1961. The sources of disposed low-level waste include waste generated during past activities on the NTS and adjoining areas of the Nellis Air Force Range as well as waste shipped from DOE-approved generators from other DOE facilities nationwide. Descriptions of the disposal facilities in Frenchman and Yucca Flat are provided in multiple publications (1,2,3,4,5).

The management of the RWMSs on the NTS is regulated under Chapter III of DOE Order 5820.2A, Management of Low-Level Waste. This order requires that low-level radioactive waste disposal sites prepare and maintain a radiological performance assessment (PA) for demonstrating compliance with specified performance objectives. A PA has been completed and approved for the Frenchman Flat RWMS (3). A PA has been completed and is in review for the Yucca Flat RWMS (personal communication, Beth Moore, DOE/NV, 1999).

A concern that arose during review of the PA for the Area 5-disposal site was how subsidence would affect system performance. Subsidence of the ground surface above disposed waste will result from multiple processes: (5)

1. compaction associated with a combination of collapse and compression of void space within disposal containers;
2. degradation and collapse of the waste, waste containers and dunnage associated with waste emplacement practices; and
3. compaction of backfill soils between and overlying the waste.

Multiple steps were taken to assess the performance impacts of subsidence. Release and pathway scenarios were evaluated for a subsidence case in revised PA studies (3). Subsidence was inferred to cause reduction in cap thickness and enhanced plant-root production. Resulting subsidence depressions were assumed to be collection sites of water from runoff causing increased infiltration and secondarily, increased plant production. Performance assessment calculations for a worst-case subsidence scenario show increased radiological releases along selected pathways. However, all releases were well below the performance objectives (3). A working group was assembled to further assess the consequences of subsidence (5). They concluded that a preferred mitigation option was to develop an alternative closure cap design that could better accommodate subsidence. The proposed design was a single thick layer composed of compacted native alluvium. Native alluvium is a readily available material and has increased durability and longevity compared to engineered materials. A cover composed of thick compacted alluvium would serve to reduce the effects of subsidence and reduce moisture infiltration into the waste through reliance on natural evapotranspiration in the arid desert setting of the Nevada Test Site (5). The working group further suggested that the cover should be monitored during the 100-year period of institutional control to determine actual cover performance and to allow maintenance, if required (5).

To summarize, multiple lines of evidence show that subsidence will occur at low-level radioactive waste disposal sites on the NTS, but the performance impacts of that subsidence will not be significant with respect to public health and safety. Moreover, one reasonable and cost-effective approach to mitigating subsidence impacts is to cover the waste with a thick closure cap composed of deposits of native alluvial. The obvious conclusion is that subsidence is not a significant problem at the DOE/NV facilities on the NTS.

However, additional aspects must be considered with respect to the effects of subsidence. Multiple questions primarily involving operational and maintenance considerations remain. For example, current assessments of the effects of subsidence are largely concerned with existing disposed low-level waste. Can cost-effective steps be taken to reduce subsidence at active waste cells that are continuing to receive and bury radioactive waste? What is the role of institutional control in the mitigation strategies used to reduce the effects of subsidence? Do alternative technologies exist or can alternative technologies be developed either to mitigate subsidence for existing disposed waste or to reduce subsidence in future waste cells? Covering waste cells with a closure cap composed of thick alluvium is one viable solution to the problems of subsidence. Are other approaches or combinations of approaches possible? A subsidence mitigation committee was assembled and charged with assessing these questions.

APPROACH OF THE SUBSIDENCE MITIGATION COMMITTEE

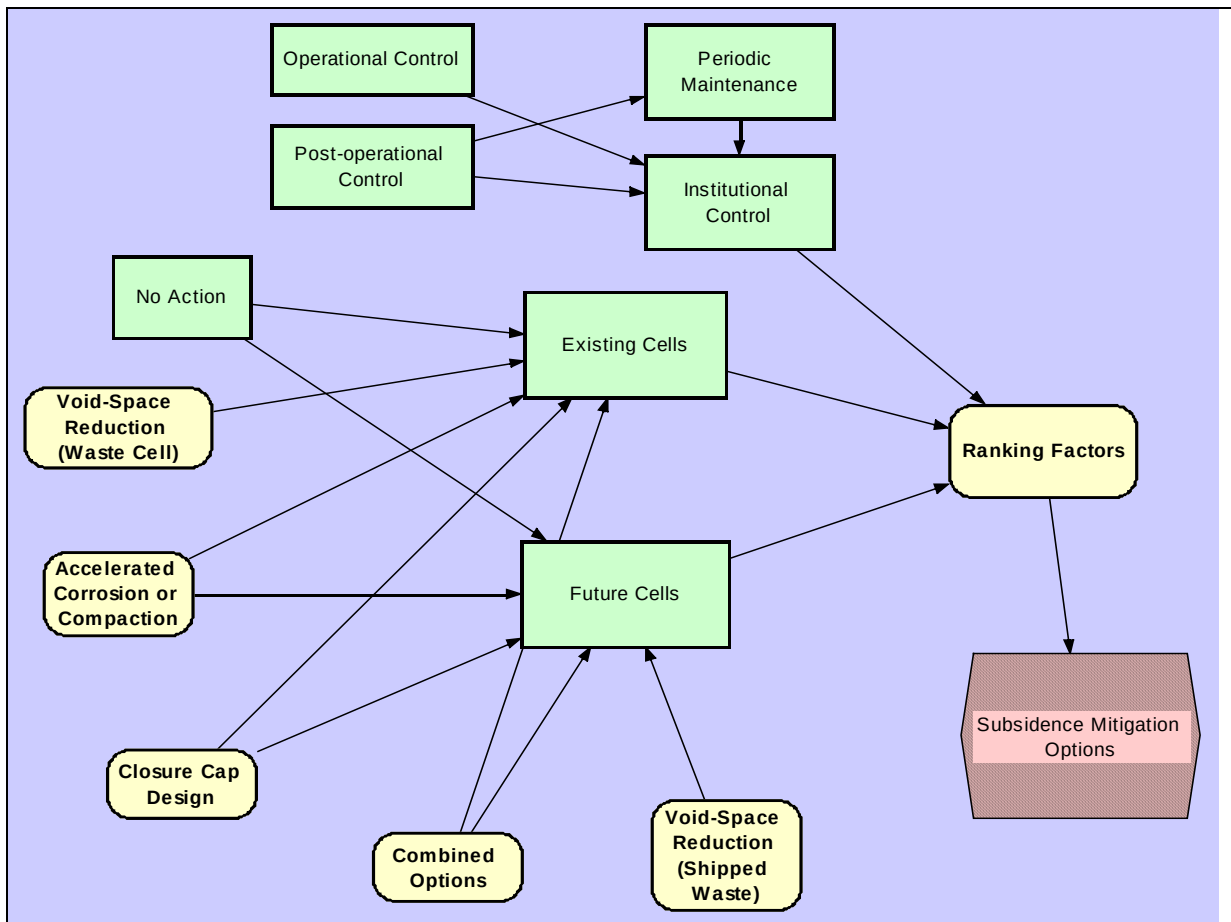
The subsidence mitigation committee was formed during a several month interval in fiscal year 1998 and was composed of at least 10 members that are either DOE personnel or DOE-contractors working on the DOE/NV waste management programs. The committee was tasked with multiple objectives and constraints:

1. Identify a range of viable options for mitigating the effects of long-term (up to 1,000 years) subsidence of low-level radioactive waste for both existing waste and future waste cells in Areas 5 and 3.
2. Develop a method for evaluating the relative ranking of alternative mitigation options.
3. Use an informal approach toward evaluation of subsidence mitigation options that has a minimum impact on personnel, schedule and resources;
4. provide documentation of the evaluation process; and
5. Report the results of the evaluation process to the DOE project managers.

Decision Logic and Structure: The influence diagram for the decision problem is presented in Figure 1. The diagram was developed using the ANALYTICA software package (6) and was designed so that the decision problem could be evaluated using Monte Carlo simulation modeling. However, the first stage of this study was accomplished using an EXCEL spreadsheet (results presented in a series of following tables).

The decision objective (ending decision node of Fig. 1) of the subsidence mitigation committee is to provide a ranking of potential subsidence mitigation options for the low-level radioactive waste disposal sites. This objective is achieved by subdividing alternative mitigation options into categories that include existing waste disposal cells and future waste disposal cells. Existing waste cells hold waste disposed in containers with significant amounts of void space; an option for future waste cells is to reduce the void space in containers prior to disposal. Chance variables are divided into groups of mitigation options and include the categories of no action, active methods to reduce void space (existing waste cells), methods to accelerate corrosion or compaction of waste and waste containers, accommodation of subsidence through cap design, combined approaches and void-space reduction at the site of the waste generator (left-side decision boxes of Fig. 1). These mitigation options are treated as discrete variables that are assigned scores by the expert panel according to their assessments of specific ranking factors.

Figure 1. Influence Diagram for the Subsidence Mitigation Options



An independent decision variable affecting the decision structure of the study is management control. The DOE has the option of imposing active management controls on the waste disposal sites. Management controls involve two aspects relative to the defined decision problem:

- 1) The duration of institutional control of disposal sites for both the pre-and post-closure intervals (operational and post-operational intervals); and
- 2) The option for periodic maintenance of a closure cap during the post-closure interval.

These variables are subject to policy decisions by the DOE and their potential impacts were factored into the scores assigned to the ranking factors of individual subsidence mitigation options (Fig. 1).

A simplified and informal mechanism of expert judgment was used to assess options for the mitigation of subsidence. Expert judgment refers to the process of elicitation of information from a subject-matter expert where an expert is a person identified to be highly qualified in a specific topic of interest (7,8,9). A range of formal and informal methods of elicitation of expert data can be used to gather data for topics that cannot easily be addressed through normal methods of data collection. In this case, information was obtained from a committee of DOE and contractor personnel who are experienced both directly and indirectly with multiple aspects of packaging,

shipping, disposal, waste-cell closure, and monitoring of low-level radioactive waste at the Nevada Test Site.

SCOPE AND ACTIVITIES OF THE SUBSIDENCE MITIGATION COMMITTEE

The committee on subsidence mitigation developed the decision logic and assessed the ranking factors during a series of meetings. The first meetings focused on identifying a full range of mitigation options for existing and future waste cells. No attempt was made to screen or rank mitigation options during the initial stage of identifying mitigation options.

Subsidence Mitigation Options. The committee developed 10 subsidence mitigation options for existing waste cells and 17 options for future waste cells. The following list of subsidence mitigation options are divided into categories of existing waste cells and future waste cells. The options are numbered according to the numbers assigned in following Tables (Tables I through IV).

Existing Waste Cells

1. *Above ground, deep, dynamic, in-situ compaction using specialized heavy equipment.* This option includes, but is not limited to, giant “thumpers” and/or a large ball and crane that is dropped onto and compresses disposed waste and waste containers. An assumption for this waste-cell category is that the compaction process would occur with an operational cap in place above the waste. Further, it is assumed that effective compaction could be achieved up to a maximum depth of 30 feet below the surface. Specific measures would be implemented to minimize health and safety issues for workers.
2. *Spray/irrigate above ground with highly saline water to accelerate corrosion of metal containers.* This option assumes that the volume of introduced water is insufficient to develop or increase groundwater recharge. Saline waters would be sprayed/irrigated onto the operational cap and would infiltrate downward into the waste. Vadose-zone modeling of the spray/irrigation process would be used to constrain the rate and duration of the application and the application is assumed to be a one-time event.
3. *In-situ grouting to fill void space.* Portable drill rigs would be used to inject grout slurry directly into disposed waste. The slurry would consist of either a bentonite or bentonite-cement mixture. It is assumed that the effective porosity of the in-situ material is insufficient to permit extensive lateral or vertical flow of the injected grouting through the fill material. Therefore, numerous drill holes would be required to efficiently grout the majority of void space in each waste cell.
4. *Enhance bio-degradation of waste containers through a combination of introducing specific bacteria and/or creating conditions (e.g., temperature, moisture, primary substrate nutrients, etc.) conducive for bio-degradation.* Ranking is based on the assumption that environmental enhancement is a continuous process necessary to initiate and maintain bio-degradation. Drilling and local injection of fluids/solids that enhance bio-degradation will be required. Control of the bio-degradation process should be somewhat difficult because of the presence of an operational cap.
5. *Subject existing buried metal containers to electrical charges to accelerate corrosion.* This would entail driving electrodes through the operational cap and into the waste to

establish electrical contact with the metal containers. We assume the process of subjecting the containers to an electrical charge would be repeated multiple times over several years to significantly accelerate corrosion.

6. *In-situ, "controlled" explosions to facilitate container structure failure and eliminate void space.* Explosive charges would be placed above and in the disposed waste and the forces from the explosions would be directed downward to compact the waste and mitigate the potential for surface release of radioactivity.
7. *A combination of the spray/irrigation option (option 2) and the electrical charge option (option 5).* Application of saline waters would be used in combination with the application of electrical charges to accelerate corrosion of the metal containers in the disposed waste.
8. *A combination of deep dynamic compaction (option 1) with spray/irrigation of water.* The introduction of water would enhance compaction of the alluvial materials. The fluid used in this case would be water, in contrast to saline waters used for option 2.
9. *The emplacement of a thick (8-10 feet), soft closure cap over the waste cells.* The cap would be constructed of locally available, native alluvium materials. The soft cap would be constructed above the 8-foot thick operational cap.
10. *A no action option is defined as using no special corrective action(s) to address current or future problems (e.g., subsidence and subsequent cap maintenance; adverse impacts on monitoring, etc.).* The no-action option includes an operational cap with a maximum thickness of 8 feet (already constructed on inactive waste cells). Also included in this option, by assumption, is periodic cap maintenance during and the operational period (see Fig. 1).

Future Waste Cells

1. *The emplacement of a thick (8-10 feet), soft closure cap over the waste cells.* This option is the same as option 9 for existing waste cells.
2. *Fill void space in the waste container prior to shipment with zeolitic material, flyash and/or other appropriate material.* This action was assumed to take place at the generator's site. Laboratory analysis of the flyash for heavy metals and radionuclides would have to be conducted prior to incorporating flyash into the waste stream to avoid classification as a mixed waste. The added materials would fill the container void space thereby reducing future subsidence of the waste cells.
3. *Recycle shipping containers by utilizing re-usable packages or disposable liners that will provide an added benefit of mitigating potential leakage of free-liquids.* The waste would be shipped in containers and disposed without the containers but with liners. The waste would be more conformable thereby decreasing void space and the potential for future subsidence. It is assumed that a new decontamination facility would have to be built at the NTS to decontaminate the containers and trucks (if necessary) prior to off-site release.
4. *Configure the dimensions of waste cells to the container shape and quantity to minimize inter-container void space in the landfill cell.*

5. *Segregate waste containers at the NTS according to void space, type of packaging, total activity, waste form, etc., and dispose of accordingly.* In addition, require the generators to mark estimated void space on each container.
6. *Enhance bio-degradation of waste containers either through introduction of specific bacteria and/or creation of conditions (e.g., temperature, moisture, primary substrate nutrients, etc.) conducive for bio-degradation.* This option is the same as option 4 for the existing waste cells. However, for future waste cells, the introduction of bacteria and/or conditions conducive for bio-degradation could be established prior to covering of the waste with an operation cap. The assumption is therefore, that the bio-degradation option for future waste cells would be easier to implement and have less impact on operations than the same option for existing waste cells.
7. *Compact the containers during waste cell operation.* The containers would be covered by a 1-2 foot thickness of soil cover (contrast with the same option for existing waste cells) and compacted using heavy equipment. Additionally, this option could be coupled with compaction of individual containers in a compactor prior to disposal in a waste cell.
8. *Design and fabricate containers out of materials that easily compact under vertical stress from landfill overburden, and/or construct containers out of materials that are susceptible to corrosion and/or biodegradation.* The primary benefit of this option is it promotes early compaction of containers (during the period of institutional control) thereby allowing maintenance of the closure cap and mitigation of subsidence.
9. *Design and fabricate containers that interlock and minimize inter-container void space.* This would be especially applicable to D & D waste forms such as concrete, soil and steel.
10. *Incorporate a financial incentive into the waste acceptance criteria (WAC) to discourage container void space.*
11. *Install remote handling capabilities for waste emplacement using robotics that permits bulk disposal and subsequent crushing and disposal of the waste containers in other waste cells.* The assumption is made that some research and development would be required to develop the necessary technology and equipment specific to remote handling.
12. *Combination of option 1 (thick soft cap), option 2 (fill container space) and option 3 (recycle outer container).*
13. *Combination of option 2 (fill container space), option 3 (recycle outer container) and option 10 (financial incentives).*
14. *Combination of option 4 (configure new waste cells) and option 9 (design and fabrication of interlocking containers).*
15. *Combination of option 1 (thick soft cap) and option 5 (segregate waste containers).*
16. *Combination of option 7 (compaction with thin cover) and option 8 (design and fabrication of interlocking containers).*
17. *No action option.* The same as option 10 for existing waste cells.

Development of Ranking Factors for Subsidence Mitigation Options. Ranking factors were developed for existing and future waste cells where individual factors represent topics judged important to the overall packaging, shipping and handling, disposal, system performance of waste and regulatory/stakeholder concerns. These factors include (the bolded heading in parenthesis is the column label used in Tables I-IV):

1. *Relative Costs: Short-Term and Long-Term Cost (Cost)*. These are expert judgement estimates of implementation costs including feasibility studies, research and development costs, laboratory costs, maintenance costs, equipment costs, materials and labor costs, clean-up costs, mitigation measures including implementing special safety measures, time to implement and complete the proposed action, and general total life-cycle cost estimates of each action (s). The implicit assumption is made that the recommended mitigation is technologically feasible. Higher scores are given to mitigation options with lower costs.
2. *Ease of Implementation (Implement)*. This factor incorporates the technical feasibility of the proposed action including implementation barriers (quantity and quality); anticipated outcome of the proposed action; availability of equipment and materials; impacts on worker safety; and time to implement and complete the proposed action. Higher (favorable) scores are assigned to technologies that are in use currently or are judged to have a high likelihood of successful deployment.
3. *Impacts on DOE/NV RWMS Operations (Operations)*. This factor includes adverse impacts on operations including waste handling (e.g., off-loading of waste); increased time and labor (e.g., waste container compaction and separation of wastes); equipment limitations; decontamination of containers and time, labor and facilities to complete this action; daily operational impacts such as impacts on daily cover and adjacent waste cells; worker health and safety; and impacts on closure construction. Higher scores are given to mitigation options that have limited impact on operations.
4. *Impacts on Generator Packaging and Handling (Pack&Hand)*. Impacts on generators include additional materials, time and labor to package and handle the waste and recycle containers; additional costs for newly developed, innovative shipment containers and filler material(s); new equipment to handle new containers; additional characterization required for the generators; impact on worker health and safety and impacts on general operations. Higher scores are given to options that have limited impact on waste generators.
5. *Impacts on Landfill Performance: Short and Long-Term (Performance)*. This includes any action that adversely impacts landfill performance such as premature release of waste radionuclides and subsequent exposure to the accessible environment. Release pathways include the dominant upward migration pathway to the accessible environment (e.g., upward advection, diffusive transport, plant uptake), and downward mass transport with the potential for groundwater contamination. Higher scores are assigned to mitigation options that are judged unlikely to decrease performance of a disposal site.
6. *Impacts on Monitoring (Monitor)*. The committee assumed that DOE would apply for a groundwater-monitoring waiver and therefore groundwater monitoring is not included in the ranking factors. Adverse impacts considered include monitoring access and adverse impacts on monitoring equipment, personnel accessing monitoring equipment, and operability/malfunctions (e.g., moisture, corrosion, void space, and subsidence). Higher

scores are given to mitigation options that are unlikely to adversely impact monitoring of the unsaturated zone.

7. *Regulatory and Stakeholder Acceptance (Reg/Stake)*. Ranking scores were based upon how readily the panel members assumed the pertinent regulatory authorities and the public will accept a specific action used to mitigate subsidence. The overriding factor influencing this perception is the impact of the mitigation option on reducing or eliminating subsidence of waste cells and presumably reducing radiological releases to the accessible environment. The committee assumed that the perceived protection of human health and safety were paramount in regulatory and stakeholder acceptance of a specific action.
8. *Impacts on Radioactive Waste Acceptance Program (RWAP) and Waste Acceptance Criteria (WAC)*. Any factor that adversely impacted the RWAP and WAC was considered with this ranking factor. The severity of the impact was included in the ranking factor with higher scores given to mitigation options that have limited effects on the RWAP. For example, generator financial incentives were considered to have minimal impact whereas implementing the design, fabrication, testing, regulatory/stakeholder acceptance, and generator acceptance of new, innovative containers was considered difficult.

SCORING OF THE RANKING FACTORS FOR SUBSIDENCE MITIGATION OPTIONS

The final step of the subsidence mitigation study was to develop a subjective scoring system for evaluating the alternative mitigation options. The committee considered two approaches for scoring the mitigation options against the ranking factors:

1. *Separate scoring of each option by each member of the subsidence mitigation committee*. The advantages of this approach are that each member provides unbiased scoring, and the range of scores can be used to define the uncertainty of the ranking factors. The disadvantages of this approach are that not all committee members possess equal knowledge of all mitigation options and ranking factors. Time constraints for the study did not allow sufficient information exchange to facilitate development of equal knowledge among all panel members. Additionally, because of schedule conflicts, not all committee members could participate fully in all aspects of the scoring process.
2. *Consensus scoring of each option through a formal process involving group discussion, scoring and iterative revision of scoring to reflect the agreements and perspectives gained through group discussion*. The primary advantage of this approach is the development of more complete understanding of options and rankings through discussion, a process that proved to be invaluable in the study. Additionally, this scoring method did not require all committee members to participate in every meeting or score every option. The disadvantages of consensus scoring are the loss of data variance in the scoring and the absence of a mechanism for handling minority opinions.

After discussion, the committee selected a modified version of option 2 for the scoring. The modification was that divergent opinions would be handled by a separate listing of minority scores. However, in practice, the committee was able to reach consensus on the scoring of all mitigation options.

Scoring was completed for each mitigation option for existing and future waste cells. Each mitigation option was assigned a consensus score and the assigned score was treated as a discrete variable ranging from 1 to 10. Ranking factors are assumed to be linearly distributed across the scoring range with no significant correlation between factors. After completion of scoring, the committee assigned weightings and assembled subsets of the ranking criteria for existing and future waste cells. The rationales for these assignments are:

1. *Existing Waste Cells:* A subset of 6 of the ranking factors was used for this category. The impacts on generator Packaging and Handling and the RWAP factors are not included because they have no application to disposed waste. The committee weighted relative costs, ease of implementation, impacts on landfill performance, and regulatory stakeholder acceptance equally (weighting factor = 1.0); impacts on operation and impacts on monitoring were judged to be less important and were assigned a weighting factor of 0.5. For clarity, the committee decided to develop two separate result tables for the existing waste category. The first table includes the results using equal weighting of all scoring factors (Table I) and the second table compiles the ranking results with application of weighting factors *excluding* the factor for regulatory and stakeholder acceptance (Table II). The latter was not included because the committee felt that judgments of regulatory and stakeholder acceptance were highly subjective and might not be appropriate factors to score, given the expertise of the committee members.
2. *Future Waste Cells:* All 8 ranking factors were used for the future waste category and all factors were equally weighted (weighting = 1.0), except for impacts on operations, impacts on monitoring and impacts on RWAP. The latter factors were assigned a weighting of 0.5. Two tables of scoring assignments were developed, similar to the Existing Waste category and include unweighted scores (Table III), and weighted scores without the regulatory and stakeholder category (Table IV).

RESULTS

Existing Waste Cells. The results of the unweighted scoring assignments for the existing waste cells are presented on Table I. The scores range from a maximum of 43 (soft cap) to a minimum of 18 (biodegradation); the mean score is 32 ± 8 . The top three options are (in order of decreasing score):

1. Option 9: Soft Cap
2. Option 1: Deep Dynamic Compaction.
3. Option 6: Controlled Explosions

Table II summarizes the results with the weights applied and with the Regulatory/Stakeholder Acceptance factor removed. The scores range from a maximum of 29 (soft cap) to a minimum of 12 (biodegradation); the mean score is 22 ± 6 . The revised order of the top three options using the weighted scores is:

1. Soft Cap
2. Controlled Explosions
3. Spray/Irrigate Saline

Table I. Scoring of Subsidence Mitigation Options by Ranking Factors for Existing Waste Cells (sorted in order of decreasing total score).

Option	Existing Cells	Cost	Implement	Operations	Performance	Monitor	Reg/Stk	Total
9	Soft Cap	7	10	5	5	8	8	43
1	Deep Dynamic Compaction	3	8	3	9	9	9	41
6	Controlled Explosions	6	7	6	8	8	2	37
10	No Action	7	9	8	3	4	4	35
2	Spray/Irrigate Saline	8	9	9	4	2	2	34
8	Compaction plus water	2	7	2	10	9	4	34
3	In-situ Grouting	2	2	6	7	8	8	33
5	Electrical Corrosion	5	6	4	3	4	5	27
7	Spray plus electrical	3	5	3	5	2	3	21
4	Bio-degradation	1	4	5	3	2	3	18

Table II. Scoring of Subsidence Mitigation Options by Ranking Factors for Existing Waste Cells *with Weighting of Ranking Factors and the Regulatory/Stakeholder Factor Removed* (sorted in order of decreasing scores).

Option	Existing Cells	Cost	Implement	Operations ¹	Performance	Monitor ¹	Total
9	Soft Cap	7	10	3	5	4	29
6	Controlled Explosions	6	7	3	8	4	28
2	Spray/Irrigate Saline	8	9	5	4	1	27
1	Deep Dynamic Compaction	3	8	2	9	5	27
10	No Action	7	9	4	3	2	25
8	Compaction plus water	2	7	1	10	5	25
3	In-situ Grouting	2	2	3	7	4	18
5	Electrical Corrosion	5	6	2	3	2	18
7	Spray plus electrical	3	5	2	5	1	16
4	Bio-degradation	1	4	3	3	1	12

¹ Weighting Factor = 0.5

Table III. Scoring of Subsidence Mitigation Options by Ranking Factors for Future Waste Cells (sorted in order of decreasing total scores).

Option	Future Cells	Cost	Implement	Operations	Pkg&Hand	Monitoring	Performance	Reg/Stake	RWAP	Total
7	Compaction with Thin Cover	6	9	2	10	9	9	9	10	64
2	Fill Container Space	9	8	9	1	10	9	10	7	63
1	Thick Soft Cap	6	9	6	10	8	5	8	10	62
4	Configure New Cells	8	9	7	10	6	5	4	10	59
3	Recycle Outer Container	7	8	2	9	9	9	5	7	56
10	Financial Incentives	9	8	9	7	6	6	3	7	55
17	No Action	8	9	8	10	4	2	1	10	52
5	Segregate Waste Containers	4	3	5	8	9	7	7	6	49
11	Remote Handling	1	2	1	10	9	9	7	10	49
12	1 plus 2 plus 3	5	8	2	1	8	9	10	6	49
13	2 plus 3 plus 10	7	8	2	1	6	10	10	5	49
15	1 plus 5	2	2	5	8	8	8	8	6	47
9	Interlocking Containers	5	5	9	4	6	7	5	5	46
8	Container Design/Fabricate	5	5	8	4	8	8	3	4	45
14	4 plus 9	4	4	7	4	6	8	5	5	43
16	7 plus 8	3	4	2	4	8	9	6	4	40
6	Biodegradation	4	2	1	10	2	4	3	10	36

Table IV. Scoring of Subsidence Mitigation Options by Ranking Factors for Future Waste Cells with *Weighting of Ranking Factors and Regulatory/Stakeholder criterion removed* (sorted in order of decreasing total scores).

Option	Future Cells	Cost	Implement	Operations ¹	Pkg&Hand	Monitoring	Performance	RWAP ¹	Total
7	Compaction with Thin Cover	6	9	1	10	5	9	5	45
4	Configure New Cells	8	9	4	10	3	5	5	44
3	Recycle Outer Container	7	8	1	9	5	9	4	43
1	Thick Soft Cap	6	9	3	10	4	5	5	42
10	Financial Incentives	9	8	5	7	3	6	4	42
2	Fill Container Space	9	8	5	1	5	9	4	41
17	No Action	8	9	4	10	2	2	5	40
13	2 plus 3 plus 10	7	8	1	1	3	10	3	33
5	Segregate Waste Containers	4	3	3	8	5	7	3	33
11	Remote Handling	1	2	1	10	5	9	5	33
8	Container Design/Fabricate	5	5	4	4	4	8	2	32
9	Interlocking Containers	5	5	5	4	3	7	3	32
12	1 plus 2 plus 3	5	8	1	1	4	9	3	31
15	1 plus 5	2	2	3	8	4	8	3	30
14	4 plus 9	4	4	4	4	3	8	3	30
16	7 plus 8	3	4	1	4	4	9	2	27
6	Biodegradation	4	2	1	10	1	4	5	27

¹ Weighting Factor = 0.5

The changes in the ranking reflects the strongly negative scoring given to the regulatory/stakeholder ranking factor for controlled explosions and spray/saline irrigation options; the removal of this criterion increases the relative total scores of these options with respect to the other options. The soft cap option remains as the top-rated option in both tables. The no action option is scored favorably in both Tables. The differences in scores between closely rated options are not significant statistically given the standard deviation of the mean for the total category. However, the scoring differences are significant between the top- and bottom-rated options.

Future Waste Cells. The result of the unweighted scoring assignments for the category of future waste is presented in Table III. The total scores range from 64 (compaction with thin cover) to 36 (biodegradation); the mean score is 51 ± 8 . The top three subsidence mitigation options are (in order of decreasing score):

1. Option 7: Compaction with Thin Cover
2. Option 2: Fill Container Space
3. Option 1: Thick Soft Cap

Table IV includes the same results as Table III but weightings are applied and the Regulatory/Acceptance criterion is not included, consistent with the approach used in Table II. In this case, the scores in Table IV range from 45 (compaction with thin cover) to 27 (biodegradation); the mean score is 35 ± 6 . The top three options for the weighted ranking factors are:

1. Option 7: Compaction with Thin Cover
2. Option 4: Configure New Cells
3. Option 3: Recycle Outer Container

The compaction with a thin cover remains as the top-scored option in both tables. However, the option of configure new cells moves to the second-rated option and the recycle outer container moves to the third-rated option. The fill container space option drops to the sixth position on Table IV, largely because of the package and handling costs. The thick soft cap option drops to the fourth position, but its score is virtually identical to the third-ranked option. The no-action option, in contrast with the existing waste tables, is *not* highly ranked in any of the tables for future waste cells (contrast with Tables I and II). The differences between closely rated options, like the scores for the existing waste cells, are generally not significant given the standard deviation of the average scores.

OBSERVATIONS AND RECOMMENDATIONS

This paper presents the results of a rapid and inexpensive evaluation of a range of options for subsidence mitigation in existing and future low-level waste cells at the NTS. An expert-judgment scoring system was used to score ranking factors and order alternative options for subsidence mitigation. The following observations and recommendations are provided as planning tools for future activities by the Waste Management Division.

1. There are a relatively large number of mitigation options that received high scores (within one standard deviation of the top-rated score). These include as many as six options for existing waste cells and seven options for future waste cells. There is, therefore, a range of potentially viable mitigation options and considerable flexibility in responding to the subsidence issue.

2. The differences between the top-rated and bottom-rated scores for the mitigation options on all tables are significant. Pending major changes in assumptions used in this evaluation, the bottom-rated options should *not* receive further consideration for subsidence mitigation. For existing waste cells, these options include bio-degradation, spray plus electrical, electrical corrosion, and in-situ grouting. For future waste, these options include biodegradation, interlocking containers, and container design-fabrication, as well as options that combine these low-rated options.
3. The scoring differences between top-rated options are not significant statistically, and the scores should not be used to select or reject individual options. Further evaluations should be conducted for groups of top-rated options. These evaluations could include more complete assessments of the rating factors used for these studies and an assessment of the uncertainty associated with the factors, thus allowing a probabilistic approach to scoring. Suggested options that could be grouped for existing waste cells are soft cap, deep dynamic compaction, controlled explosions, and spray/irrigate saline. Additionally, the no-action option is a viable but not top-rated option. Options that could be grouped for future waste cells include compaction with thin cover, thick soft cap, recycle outer container, and configure new cells. The fill container space option is a well-rated option *if* generator cost is not a significant ranking factor. Generally, there is an increased number of highly rated options for future waste cells, compared to existing waste cells.
4. The thick soft cap option emerged as a highly rated option for both existing and future waste cells and was a strongly recommended option in the report prepared by the committee on subsidence. Further consideration could be given to combining the soft cap option with other highly rated options. For example, the compaction option is a highly rated option for future waste cells. It received low scores for relative costs and impact on operations. Options for consideration could include mitigation of subsidence through the application of a thick soft cap coupled with filling of container void space or selective compaction of only components of future waste streams. Other combinations may merit consideration.
5. The no action option is a particularly *unappealing* option for future waste cells if an additional factor is added that was not considered in this study. The no-action option does not respond proactively to the subsidence issue.

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