EVALUATING REQUIREMENTS FOR STEWARDSHIP OF CONTAMINANT ISOLATION FACILITIES

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ABSTRACT

A new methodology for evaluating requirements for stewardship of contaminant isolation facilities (such as uranium mill tailings, low level radioactive and hazardous chemical disposal sites) is presented. This methodology consists, of (i) the development of a database from the experience of monitoring of remediated mill tailings piles for facilitating data accessing for analysis and visualization, (ii) using the database to determine system events (e.g. erosion, bio-intrusion, etc.), and their likelihood and consequences, (iii) the development of event/response scenarios and logic diagrams, (iv) the use of the probabilistic approach to determine the impact of potential events on risk and cost, (v) the use of this information to improve design and post-closure responses, and (vi) comparison of costs and risks of remediation versus no action taking into account changes in risk in time. The paper provides details concerning the approach to model development and the results of the analyses performed for the erosion scenario at uranium mill tailings remediation sites.

INTRODUCTION

Stewardship of DOE sites has become important because it is realized that not all sites can be remediated to free release status with present technology or only remediated at an exorbitant cost and risk. Long term stewardship had been defined by DOE as "the physical controls, institutions, information and other mechanisms needed to ensure protection of people and the environment at sites where DOE has completed or plans to complete 'cleanup' (e.g., landfill closures, remedial actions, removal actions, and facility stabilization). This concept of long term stewardship includes *inter-alia*, land use controls, monitoring, maintenance, and information management."[1]. A number of reports have been published that explain what stewardship means and try to derive the requirements [2-9]. However, none of them even attempt to quantify what will physically be required for stewardship-what a prudent person would do. Without a quantitative examination of the range of needs for stewardship and their costs and risks, it is impossible to determine whether remediation will achieve its objectives or not.

The purpose of the research presented here is to (i) evaluate stewardship requirements for contaminant isolation facilities, (ii) estimate the types and likelihoods of events indicative of unanticipated and undesirable performance (e.g., erosion, bio-intrusion, standing water, etc.), event consequences, responses, costs and risks, (iii) do probabilistic analysis of the costs and risks of stewardship of DOE facilities, and (iv) compare these results to no action over time.

As an initial effort, the US Uranium Mill Tailings disposal sites were used as a model system because of the large amount of data available for these sites in the annual inspection reports prepared by the Grand Junction Office (i.e., as much as 10 years of data for some of the sites [10]). This paper does not do a performance assessment of the US Uranium Mill Tailings disposal Sites but rather seeks to improve the understanding of potential outcomes and provide possible solutions. This paper presents the new methodology developed for evaluating

stewardship requirements for contaminant isolation facilities and summarizes the preliminary results of the analysis. The methodology is still under development.

METHODOLOGY

The methodology proposed for evaluating requirements for stewardship of contaminant isolation facilities includes [11]:
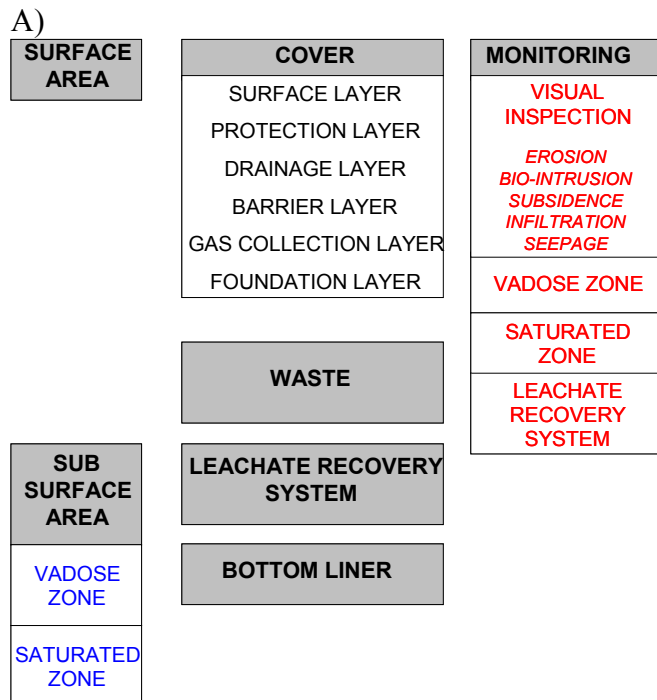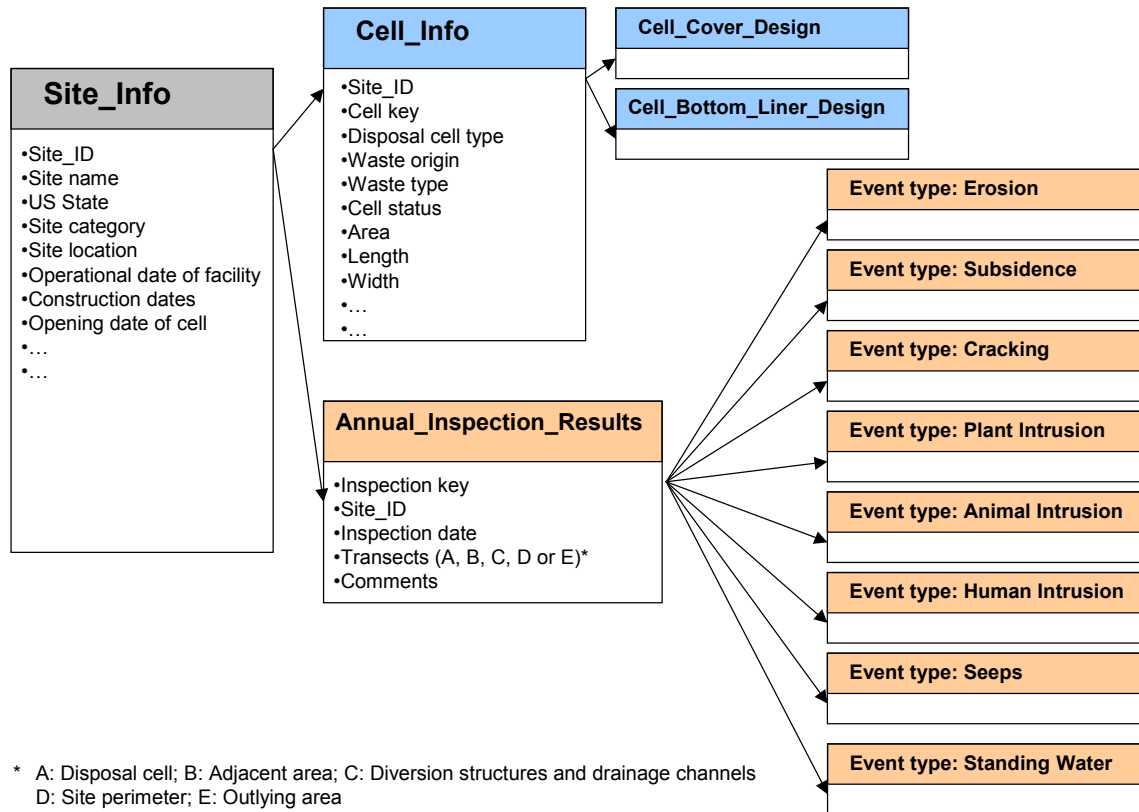
- Review of pertinent documents (DOE LTS documents, etc.);
- Development of a database for facilitating analysis and visualization;
- Determination of system events (e.g. erosion, bio-intrusion, etc.) and their likelihood and consequences;
- Development of event/response scenarios and logic diagrams;
- Use of a probabilistic approach to determine impact of potential events on risk and cost; and,
- Use of this information to improve design of remediation facilities and post-closure responses.

Development of an MS Access Database

A Microsoft Access database was developed and implemented at Vanderbilt University based on the annual inspection reports of the US Uranium Mill Tailings disposal sites prepared by the Grand Junction Office. The objectives of this database (VU UMT database) are to facilitate determining causes of the events and the frequency of their occurrence for use as input parameters in probabilistic modeling of events. Thus, the VU UMT database is comprised of twelve (12) interrelated tables (Figure 1A). General information concerning the sites such as site name, site location, construction dates, opening dates of the cell, climate, hydrogeology, etc. can be found in a main table called *Site_Info*. This table is related using a one-to-many relationship to two other tables: a table containing information concerning the cell design (i.e., *Cell_Info* table) and a table containing information concerning the annual inspection results (i.e., *Annual_Inspection_Results* table). The *Cell_Info* table is related via a one-to-one relationship to two other tables: one for the cover design and one for the bottom liner design when applicable. Finally, the *Annual_Inspection_Results* table is related to eight tables, including each considered possible event (i.e., erosion, plant intrusion, animal intrusion, human intrusion, subsidence, cracking, seeps and standing water). To the best of our knowledge, no such database exists today. Such a database is necessary to facilitate data analyses and obtain frequency of occurrence of the different events considered. Queries were developed to allow retrieving data from one or more tables by using specified criteria and then displaying them in the specified order (e.g., what is the frequency and magnitude of erosion in the cover layers at remediated sites?)

Five sites of the approximately 25 sites remediated to date, considered representative of all sites in terms of cover type (i.e., rock cover, soil cover, early and later cover design), climate (arid, humid), etc., were selected for inclusion into the database. Thus, complete sets of annual inspection reports have been examined and entered in the VU UMT database for Canonsburg (1990-2000), Burrell (1990-2000), Rifle (1997-2000), Lakeview (1991-2000) and Shiprock (1990-2000). Analyses of the results showed that the events most likely to occur are erosion and bio-intrusion, especially plant intrusion. These unanticipated and undesirable performances were observed almost immediately, although the cell covers were designed with the objective to last for a minimum of 200 years. However, natural processes are difficult to predict and control. As sophisticated cell covers can be, after construction, natural processes will quickly tend to degrade

them. These observations lead one to think that one of the challenges is to propose alternative designs that might be simpler, enabling easier and more effective monitoring and maintenance.

A)

Site_Info

- Site_ID
- Site name
- US State
- Site category
- Site location
- Operational date of facility
- Construction dates
- Opening date of cell
- ...
- ...

Cell_Info

- Site_ID
- Cell key
- Disposal cell type
- Waste origin
- Waste type
- Cell status
- Area
- Length
- Width
- ...
- ...

Cell_Cover_Design

Cell_Bottom_Liner_Design

Annual_Inspection_Results

- Inspection key
- Site_ID
- Inspection date
- Transects (A, B, C, D or E)*
- Comments

Event type: Erosion

Event type: Subsidence

Event type: Cracking

Event type: Plant Intrusion

Event type: Animal Intrusion

Event type: Human Intrusion

Event type: Seeps

Event type: Standing Water

* A: Disposal cell; B: Adjacent area; C: Diversion structures and drainage channels
D: Site perimeter; E: Outlying area

B)

SURFACE AREA	COVER	MONITORING
	SURFACE LAYER	VISUAL INSPECTION
	PROTECTION LAYER	*EROSION*
	DRAINAGE LAYER	*BIO-INTRUSION*
	BARRIER LAYER	*SUBSIDENCE*
	GAS COLLECTION LAYER	*INFILTRATION*
	FOUNDATION LAYER	*SEEPAGE*
		VADOSE ZONE
	WASTE	SATURATED ZONE
SUB SURFACE AREA	LEACHATE RECOVERY SYSTEM	LEACHATE RECOVERY SYSTEM
VADOSE ZONE	BOTTOM LINER	
SATURATED ZONE		

Fig. 1. A) VU UMT database design and B) Land disposal (containment) systems.

Development of Event/Response Scenarios and Logic Diagrams

Typically, containment systems consist of a cover made of different layers (e.g., surface layer, protection layer, drainage layer and barrier layer), the waste itself (e.g., tailings), and, in some cases, a leachate recovery system and a bottom liner (Figure 1B). These systems interact with the environment at the surface and in the vadose and saturated zones. There are four possible ways of monitoring such complex systems. The first, which is rather qualitative, consists of visual inspection of the surface and identification of events such as erosion, bio-intrusion, subsidence, infiltration or seepage. The second, third and fourth, more quantitative, consist of analyzing samples from the vadose zone, the saturated zone and leachate from the leachate recovery system, respectively.

Based on this realization, a series of logic diagrams for events of land disposal system have been developed to provide event/response scenarios. The events considered were erosion, bio-intrusion, subsidence, infiltration, seepage, contaminant in leachate recovery, contaminant in vadose zone and contaminant in saturated zone (Figure 2A).

For the erosion, bio-intrusion, subsidence and infiltration events, four possible scenarios have been envisaged: (i) repair of the cover and layers of concern (scenario 1), (ii) removal of the waste and closure of the site (scenario 2), (iii) stabilization of the waste (scenario 3), and (iv) treatment of the waste (scenario 4). For scenario 1 (Figure 2B), the following questions have to be answered: how frequent will repairs be necessary, how extensive will they be, what are the different options available and what will be the cost? Eventually, answer the question, how much do these remediation activities reduce the risk and how does this change over time? For scenario 2, the questions that need to be answered concern the different options available for such operation and the cost. Finally, for scenarios 3 and 4, the techniques and cost of stabilization or treatment of the waste have to be considered along with the options for the subsequent repair of the cover and costs associated with it.

For seepage events, where contaminants are found in the leachate recovery system, in the vadose zone and in the saturated zone, the event/response scenarios considered, in addition to the ones discussed previously, were (i) diversion of overland flow and (ii) diversion of ground water flow including possibly collection and treatment.
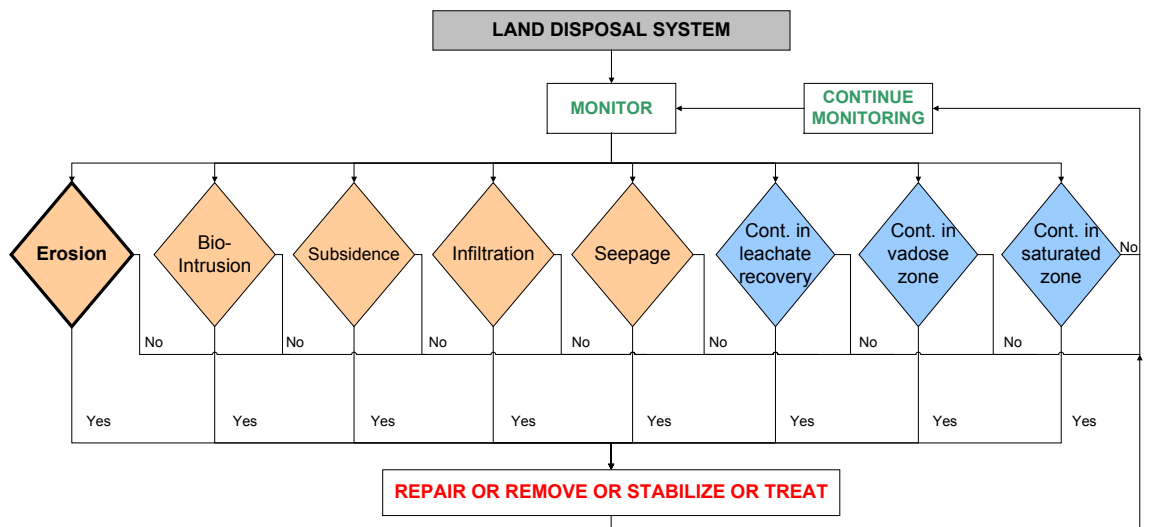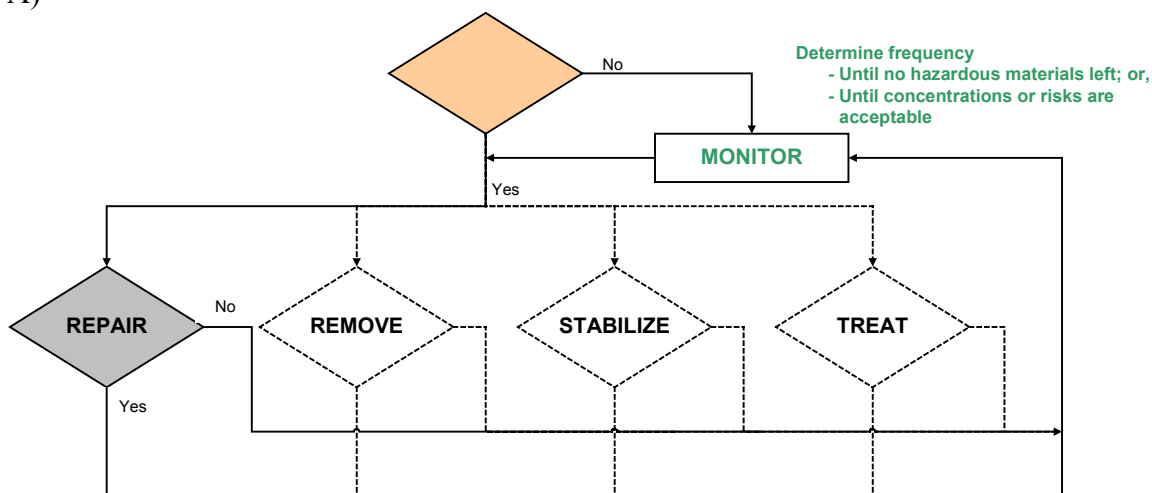
Fig. 2. A) Logic diagram for events of land disposal system and B) Event of erosion – Scenario 1: repair of the cover and layers of concern.

Development of a Cost-Estimating Model for Erosion Events

A cost-estimating model for erosion events was developed in Microsoft Excel Version 7.0 using Palisade Corporation's @Risk[a] risk analysis software. @Risk allows defining uncertain cell values in Excel as probability functions and executing simulations of Excel models using Monte Carlo sampling techniques.

The flowchart of the cost-estimating model developed is presented in Figure 3. As a first approach, the model assumed that the eroded material, considered a parallelepiped (conservative estimate), in the different layers of concern is replaced. Thus, the knowledge of the percentage of

the eroded surface area and depth of erosion ($h_{erosion}$) allow estimating the volume of material that needs to be replaced within each layer.
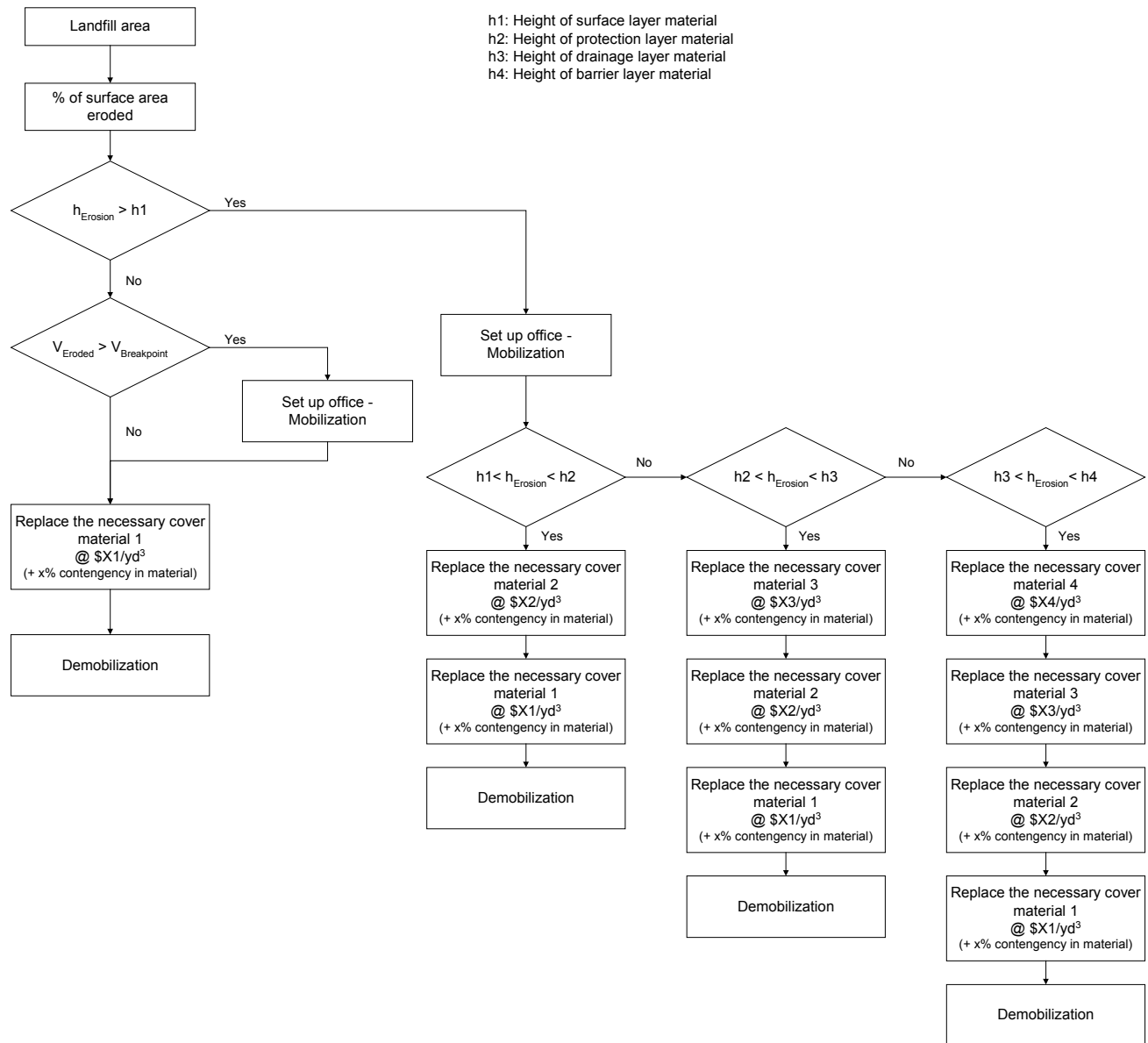

Fig. 3. Flowchart of the cost-estimating model for erosion events.

Four layers (L = 1 to 4), as typically found in cover systems [12], were considered: a surface layer (depth h_1), a protection layer (depth h_2), a drainage layer (depth h_3) and a barrier layer (depth h_4).

Replacement of the cover material of concern involved the definition of unit tasks and costs associated with them. Thus, as a first approach, four tasks were identified for each layer, L:

- Task 1. Excavate the new material;
- Task 2. Load and haul the new material to the site;
- Task 3. Excavate the damaged material; and
- Task 4. Put the new material in place.

For the top layer (i.e., surface layer), a capping task was also considered.

For each task, a material cost ($MC_{L, Task\_i}$; i=1 to 4) and a labor cost ($\underline{LC}_{L, Task\_i}$; i=1 to 4) were considered. The material cost (MC_L; L = 1 to 4) and labor cost ($\underline{LC}_L$; L = 1 to 4) of each layer are then given by equations E1a and E1b and equations E2a and E2b, respectively.

Material cost

$$\left\{ \begin{aligned} &MC_1 = \sum_{i=1}^{4} MC_{1, Task\_i} + MC_{Capping} && \text{(E1a)}\\ &MC_{L}\big|_{L=2\,to\,4} = \sum_{i=1}^{4} MC_{L, Task\_i} && \text{(E1b)} \end{aligned} \right.$$

Labor cost

$$\left\{ \begin{aligned} &\underline{LC}_1 = \sum_{i=1}^{4} \underline{LC}_{1, Task\_i} + \underline{LC}_{Capping} && \text{(E2a)}\\ &\underline{LC}_{L}\big|_{L=2\,to\,4} = \sum_{i=1}^{4} \underline{LC}_{L, Task\_i} && \text{(E2b)} \end{aligned} \right.$$

Because material volume (V_L; L=1 to 4) impacts the material cost, material unit prices ($UP_{L, Task\_i}$; L=1 to 4; i=1 to 4) were considered for each task. Material unit prices were defined as the $ amount per unit volume of material. In addition, excess material volume to account for possible losses (E_{Losses}) was considered for task 1 (i.e., excavate the new material) and task 2 (i.e., Load and haul the new material to the site). The material cost of each layer (L = 1 to 4) is then given by equations E3a and E3b.

$$\left\{ \begin{aligned} &MC_1 = \sum_{i=1}^{2} UP_{1, Task\_i} \times V_1 \times (1 + E_{Losses}) + \sum_{i=3}^{4} UP_{1, Task\_i} \times V_1 + MC_{Capping} && \text{(E3a)}\\ &MC_{L}\big|_{L=2\,to\,4} = \sum_{i=1}^{2} UP_{L, Task\_i} \times V_L \times (1 + E_{Losses}) + \sum_{i=3}^{4} UP_{L, Task\_i} \times V_L && \text{(E3b)} \end{aligned} \right.$$

With
$$\left\{ \begin{aligned} &V_L = S_{eroded} \times h_L && \text{if } h_{eroded} > \sum_{n=1}^{L} h_n && \text{(L= 1 to 4)}\\ &\text{or} \\ &V_L = S_{eroded} \times \left(h_{eroded} - \sum_{n=1}^{L-1} h_n \right) && \text{if } h_{eroded} < \sum_{n=1}^{L} h_n && \text{(L=1 to 4)} \end{aligned} \right.$$

Labor cost, estimated for each task, required consideration of unit process rates and labor rate. Unit process rates of each task (PR_{Task_i} ; i=1 to 4) were defined as the number of man-hours necessary per unit volume of material. The unit process rate of the capping task ($PR_{Capping}$) was defined as the number of man-hours necessary to install a unit surface area. Labor rate ($\underline{LR}$) was defined as the $ amount per man-hour and was assumed to be identical for each task.

The labor cost for each layer (L = 1 to 4) is then given by equation E4a and E4b.

$$\underline{LC}_1 = \left(\sum_{i=1}^{2} PR_{1,\,Task\_i} \times V_L \times (1 + E_{Losses}) + \sum_{i=3}^{4} PR_{1,\,Task\_i} \times V_1 + PR_{Capping} \times S_{eroded} \right) \times \underline{LR} \qquad (E4a)$$

$$\underline{LC}_{L|_{L=2\,to\,4}} = \left(\sum_{i=1}^{2} PR_{L,\,Task\_i} \times V_L \times (1 + E_{Losses}) + \sum_{i=3}^{4} PR_{L,\,Task\_i} \times V_L \right) \times \underline{LR} \qquad (E4b)$$

With
$$\begin{cases} V_L = S_{eroded} \times h_L & \text{if } h_{eroded} > \sum_{n=1}^{L} h_n \qquad (L=1 \text{ to } 4) \\ \text{or} \\ V_L = S_{eroded} \times \left(h_{eroded} - \sum_{n=1}^{L-1} h_n \right) & \text{if } h_{eroded} < \sum_{n=1}^{L} h_n \qquad (L=1 \text{ to } 4) \end{cases}$$

The overall material cost (MC_{total}) is then the sum of the material cost associated with replacement of the layers of concern and costs associated with contingencies (MC_{Cont}) such as mobilization/demobilization of job trailer. Similarly, the overall labor cost ($\underline{LC}_{total}$) is the sum of the labor cost associated with replacement of the layers of concern and cost associated with contingencies ($\underline{LC}_{Cont}$) such as set up of job trailer, removal of job trailer or site clean-up. Mobilization/demobilization was considered when either the depth of erosion was greater than the thickness of the surface layer or when the volume of eroded material (V_{eroded}) was greater than a breakpoint volume ($V_{breakpoint}$) where a site presence needs to be established.

The total material cost (MC_{total}) and labor cost ($\underline{LC}_{total}$) are then given by equations E5 and E6, respectively.

Total material cost
$$\begin{cases} MC_{total} = MC_1 & \text{if } h_{eroded} < h_1 \text{ and } V_{eroded} < V_{breakpoint} & \text{E5a} \\ MC_{total} = \sum_{L=2}^{4} MC_L + MC_{Cont} & \text{if } V_{eroded} > V_{breakpoint} \text{ or } h_{eroded} > h_1 & (E5b) \end{cases}$$

Total labor cost
$$\begin{cases} \underline{LC}_{total} = \underline{LC}_1 & \text{if } h_{eroded} < h_1 \text{ and } V_{eroded} < V_{breakpoint} & \text{E6a} \\ \underline{LC}_{total} = \sum_{L=2}^{4} \underline{LC}_L + \underline{LC}_{Cont} & \text{if } V_{eroded} > V_{breakpoint} \text{ or } h_{eroded} > h_1 & (E6b) \end{cases}$$

Thus, the total cost (TC) is the sum of the total material cost (MC_{total}) and the total labor cost ($\underline{LC}_{total}$) as shown in E7a and E7b.

$$
\begin{cases}
\text{If } h_{eroded} < h_1 \text{ and } V_{eroded} < V_{breakpoint}, \text{ then} \\
TC = MC_{total} + \underline{LC}_{total} = CM_1 + \underline{LC}_1 \\
\\
\text{If } V_{eroded} > V_{breakpoint} \text{ or } h_{eroded} > h_1, \text{ then} \\
TC = MC_{total} + \underline{LC}_{total} = \left(\sum_{L=1}^{4} MC_L + MC_{Cont} \right) + \left(\sum_{L=1}^{4} \underline{LC}_L + \underline{LC}_{Cont} \right)
\end{cases}
$$

(E7a)

(E7b)

PRELIMINARY RESULTS FROM THE COST-ESTIMATING MODEL FOR EROSION EVENTS

Results presented below are for model testing purpose only and do NOT intend to simulate a real case. For this exercise, a disposal cell of 16 acres comprised of a surface layer of 18 in, a drainage layer of 6 in and a barrier layer of 18 in was used as the model system.

Input Parameters

Material unit prices and process rates used were taken from [13] and are summarized in Table I and II, respectively. Deterministic values and distribution functions used as input parameters for the simulations presented below were, as a first approach and because of the lack of information, estimated. Deterministic values and distribution functions are summarized in Table III.

Table I. Material unit price* used for cost estimate of erosion event.

Tasks	Unit Price	Units
Excavate the new material	0.60	$/yd^3
Load and haul the material to the site	0.15	$/yd^3/miles
Excavate the damaged material	0.60	$/yd^3
Put in place the new material	14.77	$/yd^3
Mobilization of job trailer	2,000	$

* From [13].

Table II. Process rate* used for cost estimate of erosion event.

Tasks	Process rate	Units
Excavate the new material	0.025	mh/yd^3
Excavate the damaged material	0.025	mh/yd^3
Put in place the new material	0.025	mh/yd^3
Load and haul the material to the site	0.012	mh/yd^3
Capping	260	mh/acre
Set up of job trailer	23	mh/each
Removal of job trailer	23	mh/yd^3
Site clean-up	0.008	mh/yd^2

* From [13].

Table III. Deterministic values and distribution functions used as input parameters for simulations of cost estimate of erosion event.

Input parameters	Unit	Deterministic value	Distribution functions
Cell area	Acres	16	None
Depth of surface layer (h_1)	in	18	None
Depth of protection layer (h_2)	in	0	None
Depth of drainage layer (h_3)	in	6	None
Depth of barrier layer (h_4)	in	18	None
Depth of erosion ($h_{erosion}$)	in	---	RiskTriang function (0, (h_1+h_2+h_3+h_4)/2, h_1+h_2+h_3+h_4)
Percentage of eroded surface	%	---	RiskTriang function(0, 10, 100)
Excess for losses	%	10	None
Labor cost	$/mh	---	RiskTriang function (30, 30, 15)
Breakpoint volume	ft^3	200	None
Hauling distance	miles	---	RiskTriang function (5, 25, 75)

The depth of erosion was arbitrarily set to a random value using a RiskTriang function (triangular distribution) as defined in Table III, where the minimum value is 0, the maximum value is the total depth of the cell and the most likely value is the maximum value divided by 2. The percentage of eroded material was also arbitrarily set to a random value using a RiskTriang function as defined in Table III, where the minimum value is 0%, the maximum value is 100% and the most likely value is 10%.

The labor cost was arbitrarily set to a random value using a RiskTriang function (Table III), where the minimum value is $30/mh, the maximum value is $45/mh and the most likely value is $30/mh. This distribution insures that the labor cost will not decrease and allows the maximum to increase by $15/mh regardless of the initial value (i.e., most likely value).

The breakpoint value where a site presence is required was set to an arbitrary value of 200 ft^3. This value will be checked with contractors. Mobilization/demobilization only includes the cost for transport of a job trailer. The distance of transportation was arbitrarily set to a stochastic value using a RiskTriang function (Table III), where the minimum value is 25 miles, the maximum value is 100 miles and the most likely value is 50 miles. It was assumed that only one job trailer is necessary to be mobilized and the cost for the job trailer was arbitrarily estimated at $2,000.

For the hauling task, the distance was arbitrarily set to a random value using a RiskTriang function (Table III), where the minimum value was set to 5 miles, the maximum value to 75 miles and the most likely value to 25 miles.

Output Values

Three model outputs were considered: the total material cost (MC_{total}), the total labor cost (LC_{total}) and the total cost (TC). The distribution outputs presented in Figure 4A, 4B, and 4C represent a single simulation of 5000 iterations. Distribution outputs were generated by taking all possible inputs values using Monte Carlo sampling techniques. Thus, for each iteration, all distribution functions were sampled; sampled values were returned to the appropriate cells and formulas of the worksheet; the worksheet was recalculated and values calculated for output cells

were collected from the worksheet. Stability of the output distributions was monitored every 100 iterations by comparing for each output distribution the average percent change in percentile values (0% to 100% in 5% steps), the mean and the standard deviation. The convergence-monitoring criterion was set to less than 1% statistical changes.

Within the accuracy of the material unit prices and process rates used, for a disposal cell with a surface area of 16 acres comprised of a surface layer of 18 in, a drainage layer of 6 in and a barrier layer of 18 in, the mean total cost (i.e., TC, material and labor cost) in case of an erosion event would be $500,000 with a range of values of $26,000 (minimum) to $ 2,100,000 (maximum). The mean total material cost (MC_{total}) would be $370,000 and the mean total labor cost ($\underline{LC}_{total}$) would be $130,000. With the uncertainty inherent in the assumptions made, these numbers should be limited to 2 significant figures.

Sensitivity analysis of each output variable to each input distribution indicated that the most critical input parameters were the percentage of eroded surface area and the depth of erosion ($h_{erosion}$) followed by the task of material hauling (Figure 4D). For the assumptions made in the model and the input data, these results indicated that further efforts should concentrate in a better and more realistic definition of the distribution functions used for these input parameters.

Although more realistic distributions and data used in this exercise need to be defined for more accurate cost estimates, the use of probabilistic analysis allows for determining (i) some bounded levels of confidence on the results, (ii) distribution frequencies and (iii) an insight on which items have the most impact. This type of analysis is important for better and more informed decision.
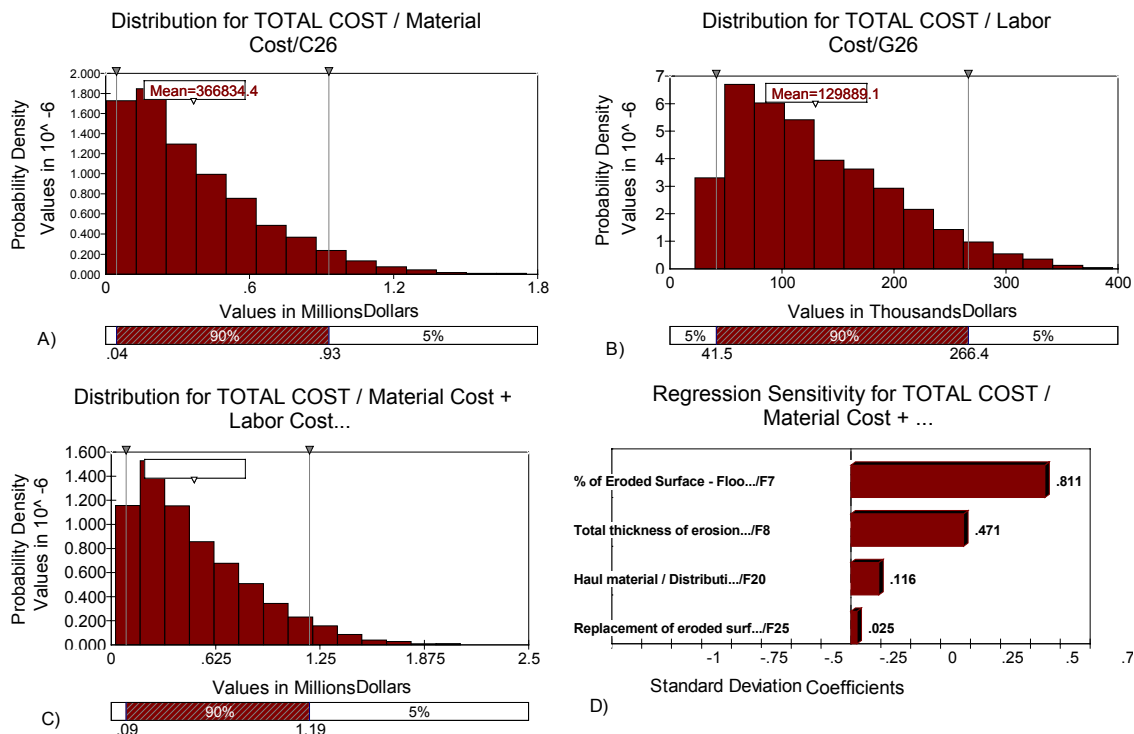

Fig. 4. Simulation results of the cost-estimating model for erosion events. Case of a disposal cell of 16 acres comprised of a surface layer of 18 in, a drainage layer of 6 in and a barrier layer of 18 in. A) Total material cost (MC_{total}); B) Total labor cost ($\underline{LC}_{total}$); C) Total cost (TC); and D) Sensitivity analysis of total cost (TC) from the cost-estimating model for erosion events.

CONCLUSIONS

The preliminary analysis of costs for repair of erosion events at remediated uranium mill tailings piles although not intended to simulate a real case, confirmed our intuition that little data are available on the fate of remediated sites. Asking these kinds of questions before the event occurs can provide valuable insight concerning possible new approaches to facility and monitoring program design. Thus, potential outcomes and applications of this work include more realistic input to financial vehicles, better information concerning the relationship between remediation objectives and stewardship requirements, and improved design of the systems and post closure monitoring and maintenance. These alternative designs might be simpler, enabling easier and more effective monitoring and maintenance. Additionally, better quantification and earlier consideration of the stewardship costs for containment options may result in more serious consideration given to contaminant reduction options.

Table IV. NOMENCLATURE

Notations	Descriptions	Units
h_1	Depth of surface layer	in
h_2	Depth of protection layer	in
h_3	Depth of drainage layer	in
h_4	Depth of barrier layer	in
h_{eroded}	Depth of erosion	in
i	Task Number (i=1 to 4)	---
L	Layer Number (L=1 to 4)	---
LC	Labor Cost	$
MC	Material Cost	$
PR	Process Rate	Man-hour/volume of material
S_{eroded}	Surface area eroded	ft^2
TC	Total Cost	$
UP	Unit Price	$/volume of material
$V_{breakpoint}$	Breakpoint volume	ft^3
V_{eroded}	Volume of eroded material	ft^3

FOOTNOTES

[a] @Risk is a spreadsheet add-on risk analysis and simulation tool developed by Palisade Corporation, Newfield, NY.

REFERENCES

1. U.S. Department of Energy, Office of Environmental Management, Office of Stewardship, Long-Term Stewardship Study (Volumes I and II), Final Study, October 2001

2. John S. Applegate and Stephen Dycus, 1998. Institutional Controls or Emperor's Clothes? Long-Term Stewardship of the Nuclear Weapons Complex, Environmental Law Reporter, vol. 28, p. 10631, Nov. (1998).

3. U. S. Department of Energy, Office of Environmental Management, Accelerating Cleanup: Paths to Closure, DOE/EM-0362, June, 1998.

4. Jarvis, T.T. W.B. Andrews, J.W. Buck, G. M. Gelston, L. R. Huesties, T.B. Miley and M.S. Peffers. Rule Based Requirements for Long Term Stewardship: A Proof-of-Principle Analysis of an Analytic Method Tested on Selected Hanford Locations, PNNL-11852, Pacific Northwest National Laboratory, (1998).

5. Probst, Katherine N. and Michael H. McGovern, Long-Term Stewardship and the Nuclear Weapons Complex: The Challenge Ahead, Center for Risk Management, Resources for the Future, Washington D.C., 1198.

6. U. S. Department of Energy, Office of Environmental Management, From Cleanup to Stewardship (a Companion Report to Accelerating Cleanup: Paths to Closure), DOE/EM- 0466, October 1999

7. DOE. From Cleanup to Stewardship: A Companion Report to Accelerating Cleanup: Paths to Closure and Background Information to Support the Scoping Process Required for the 1998 PEIS Settlement Study, Office of Environmental Management DOE/EM-0466, Washington D.C. (1999).

8. National Research Council, Long-Term Institutional Management of U. S. Department of Energy Legacy Waste Sites, National Academy Press, Washington D.C., 2000.

9. DOE, 2001. The NDAA Long-Term Stewardship Report to Congress, (2001).

10. http://www.doegjpo.com/programs/ltsm/

11. Clarke, J.H.; Parker, F.L.; Sanchez, F.; Hamilton, W.P.; Kosson, D.S. Long-term Stewardship – Do we need a new paradigm? Proceedings of the 2001 International Containment and Remediation Technology Conference, Orlando (Florida), (2001).

12. Daniel, D.E. Surface Barriers: Problems, Solutions, and Future Needs. In: In-situ remediation: scientific basis for current and future technologies: thirty-third Handford Symposium on Health and the Environment, November 7-11, 1994, Pasco, Washington. Edited by Glendon W.Gee and N. Richard Wing, (1994).

13. Ayers, K.W. Parker, F.L. Abkowtiz, M.D. et al. Reuse of concrete from contaminated structures. Dept. of Civil and Environmental Engineering, Vanderbilt University, Nashville (TN). Report January 29, 1999. Grant number DE-FG05-94OR22343, (1999).