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Decision Analysis for the Selection of Tank Waste Retrieval Technology

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Abstract

A Multi-Attribute Utility Analysis was conducted to support the selection of a technology to retrieve the radioactive sludge from Hanford Single Shell Tank 241-C-104. The following six alternatives were considered: (1) sluicing; (2) sluicing with a vehicle mounted transfer pump; (3) borehole mining; (4a) a vehicle with an attached sluicing nozzle and pump; (4b) an articulated arm with an attached sluicing nozzle; and (5) mechanical dry retrieval. The alternatives were evaluated on the basis of cost, schedule, environmental impacts, and safety to workers and the general public. Sensitivity analyses include rank correlation of uncertain inputs to decision utility and sensitivity to the various decision attribute values. Branch case and parametric investigations for Decision-Maker value judgements and risk tolerance were performed. The results indicate that three of the alternatives are not competitive. The preferred alternative is, for most cases, one of the vehicle alternatives. The sluicing alternative is competitive in some instances where expedient deployment is crucial, but is less favorable for value judgments not highly focused on deployment. Alternative 1 is also a less favorable alternative for most branch cases. The alternatives that employ vehicles are the most favorable under the suite of circumstances investigated herein.

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1. INTRODUCTION

The objective of this report is to supplement the C-104 Alternatives Generation and Analysis (AGA) by providing a decision analysis for the alternative technologies described therein [Num99]. The decision analysis used the Multi-Attribute Utility Analysis (MUA) technique. To the extent possible information will come from the AGA. Where data is not available, elicitation of expert opinion or engineering judgement is used and reviewed by the authors of the AGA. A key element of this particular analysis is the consideration of varying perspectives of parties interested in or affected by the decision.

The Decision Plan [Dew99] is the primary reference for the AGA. The Plan describes the technologies to be considered and the criteria for selection of a preferred alternative. The technologies under consideration are listed in Table 1. Throughout most of the report, the alternatives will be indicated by number. This is, in part, an effort to promote objectivity and avoid bias for or against any alternatives. In results and conclusion sections the alternatives will be referred to by descriptive text in order to more clearly convey the compared alternative technologies.

Table 1. Retrieval Technology Alternatives.

Alternative 1	Sluicing
Alternative 2	Sluicing with vehicle mounted transfer pump
Alternative 3	Borehole Mining
Alternative 4a	Vehicle with attached sluicing nozzle and pump
Alternative 4b	Articulated arm with attached sluicing nozzle
Alternative 5	Mechanical Dry Retrieval

The Decision Plan identifies a number of decision criteria that can be characterized by six decision attributes. However, only four of the attributes are distinct. The distinct attributes are:

* *Schedule*
* *Cost*
* *Environmental Impact*
* *Safety*

The other remaining two attributes, *Ensure Operability* and *Maximize Technical Feasibility*, are critical in selecting between the technology alternatives. However, they are considered through uncertainty in Cost and Schedule.

The decision is on a relatively long time scale and is of interest to many parties. Therefore, it is susceptible to numerous potential changes. Some of the potential changes can be anticipated and are considered in this analysis. Each of the following susceptibilities is considered by constructing a scenario, or branch case, investigation.

1) Value judgements of the Decision-Maker or interested party,
2) Risk tolerance of the Decision-Maker,
3) Changes in the required deployment schedule, and
4) Relative importance of meeting operations and deployment schedule.

In order to interpret the results of various scenarios, each scenario has a common calculation point, or base case. The base case is defined, assuming the conditions listed below:

1) The Decision-Maker value for the four attributes is nearly equal,
2) The Decision-Maker is risk neutral, as defined later in this report,
3) The required time for deployment is the end of the sixth project year, and
4) The deployment and operating schedule requirements are equally important.

2. DESCRIPTION OF THE INDIVIDUAL ATTRIBUTES

In general, any decision is made by considering factors (attributes) that impact (the objectives of) the Decision-Maker. A common element to all rational decision making is that, once determined, the attributes are evaluated, qualitatively, or where practical, quantitatively. For the decision regarding tank retrieval technology, the decision is to be based on quantitative information to the maximum practical extent. The following subsections describe the basic data and assumptions for the calculation of the attribute values. For detailed information, or for data not listed herein, the reader is referred to the Alternatives Generation and Analysis (AGA).

2.1 Schedule

The Decision Plan identifies two aspects as criteria for the evaluation of schedule. One is the deployment of the technology by a required date. Another is whether or not the technology is capable of retrieving a required volume of waste within a defined operating period. For the purpose of this analysis, as defined in the AGA, the required date for deployment is December 2005 (the end of the sixth project year) and the required operating period is a normal operating year (250 12-hour shifts).

Using expert judgement, a confidence level of meeting the deployment date has been estimated for each technology alternative. For alternatives that are below a confidence of 10% of meeting the deployment date, the date estimated to be the 10% confidence deployment date has been determined. The estimated deployment date corresponding to a confidence level of 90% is also estimated. These values are provided in the AGA. Although there is no indication that the deployment date will change, there is potential advantage to understanding the effect that any change in the deployment date may have on the technology selection. This decision analysis is structured to accommodate changes in the deployment date of 6-month intervals up to a maximum change of 5 years. A tabular structure is used to provide intermediate confidence levels as well as confidence levels outside the range of 10% to 90% confidences. The table is constructed at 6-month intervals, end-of-year (EOY) or middle-of-year (MOY) over a five year time period (see Table 2). The confidence levels at EOY 6, and the 10% and 90% are provided in the AGA as data. The remainder of the table is completed using the following assumptions:

- Confidence is assumed to increase linearly up to a confidence level of 90%.
- Confidence is assumed to increase to 95% in the next 6-month time period and
- Confidence is assumed to increase by 1% each 6-month period thereafter until a maximum confidence level of 99% is achieved.

Table 2. Confidence of Deployment for Various Deployment Dates.

Deployment Date*	Alt 1	Alt 2	Alt 3	Alt 4a	Alt 4b	Alt 5
EOY 6	95	75	35	75	0	0
MOY 7	*96*	90	*55*	90	10	0
EOY 7	*97*	*95*	*75*	*95*	*40*	10
MOY 8	*98*	*96*	90	*96*	*65*	*26*
EOY 8	*99*	*97*	*95*	*97*	90	*42*
MOY 9	*99*	*98*	*96*	*98*	*95*	*58*
EOY 9	*99*	*99*	*97*	*99*	*96*	*74*
MOY 10	*99*	*99*	*98*	*99*	*97*	90
EOY 10	*99*	*99*	*99*	*99*	*98*	*95*

* EOY = End-Of-Year, MOY = Middle-Of-Year

Italics = ssumed values.

For consistency with the deployment of the technology, the ability of an alternative to meet an operating schedule is also expressed by a confidence level. The current baseline [Kir97] requires the delivery of C-104 waste contents in a one-year time frame. The Single Shell Tank (SST) Waste Feed Delivery (WFD) program requires delivery of a waste volume of 800 cubic meters [Gre99]. This corresponds to 85% of the estimated 250,000 gallons of sludge in tank C-104. That confidence level is determined as follows. It is assumed that the number of shifts available in one year is 50 weeks per year and 5 twelve-hour shifts per week. The best case number of shifts required to remove the solid waste volume is shown in Table 3. Appendix E of the AGA provides an estimated number of shifts required to meet the one-year WFD requirement and is provided in column 2 of Table 3.

Table 3. Number of Shifts to Retrieve Required Waste.

Alternative	Minimum Number of Shifts to Retrieve Waste
1	25
2	11
3	25
4a	13
4b	13
5	148

Using this 'Minimum Number of Shifts' as a starting point, the confidence of meeting operating schedule objectives is estimated. It is assumed that the increase in the actual number of shifts is comprised of two parts. One part is due to inefficiencies that are not dependent on the technology selected, i.e., site or facility requirements and occurrences. The second part is inefficiencies that are associated strictly with the operations, potential failure mechanisms, and the probability and recovery time associated with those failures modes. It is assumed that the non-technology-specific efficiency ranges uniformly from 0% to 50%. The minimum number of shifts required is divided by the non-technology-specific efficiency to adjust the number of shifts required to retrieve the desired quantity of material.

Two tables are constructed for the determination of technology specific down times. Table 4 identifies failure modes and the range of expected recovery times for those failures. Table 5 contains the probability of each failure mode for each technology alternative. The probability of failure in Table 5 is the probability of failure per shift of operation. Data in Tables 4 and 5 is elicited from the authors of Numatec 1999.

Table 4. Down Time Range Due to Failure Modes.

Failure Mode	Min (days)	Max (days)
Transfer line plugging	10	30
Transfer line leak	120	360
Sluicer failure	30	60
Pump failure	60	90
C farm booster pump failure	30	60
Decant pump failure	60	90
AY farm booster pump failure	30	60
Car/UMS failure	30	60
Borehole failure	90	120
Waste separator failure	10	30
Arm failure	120	360
Conveyance/separator failure	30	360

Table 5. Probability of Failure Modes.

Failure Mode	Failure Probability (per shift)					
	Alt 1	Alt 2	Alt 3	Alt 4a	Alt 4b	Alt 5
Transfer line plugging	0.002	0.002	0.002	0.002	0.002	0.002
Transfer line leak	0.001	0.001	0.001	0.001	0.001	0.001
Sluicer failure	0.005	0.003	0	0	0	0
Pump failure	0.002	0	0.100	0	0	0
C farm booster pump failure	0.002	0.002	0.002	0.002	0.002	0.002
Decant pump failure	0.002	0.002	0.002	0.002	0.002	0.002
AY farm booster pump failure	0.002	0.002	0.002	0.002	0.002	0.002
Car/UMS failure	0	0.011	0	0.017	0	0
Borehole failure	0	0	0.017	0	0	0
Waste separator failure	0	0	0.008	0	0	0
Arm failure	0	0	0	0	0.008	0.008
Conveyance/separator failure	0	0	0	0	0.011	0.017

The likelihood of non-failure within the required operating period is given by Equation 1.

$$P_{Non-failure} = \left(1 - P_{Failure\ per\ shift}\right)^{Number\ of\ shifts} \quad \text{(Eq 1)}$$

If a failure mode occurs, then the downtime is randomly determined by sampling the distribution defined in Table 4. It is assumed that the operations are routinely performed at one 12-hour shift per day and therefore, each day of downtime is equivalent to a 12-hour shift. It is also assumed that any error in this assumption is dominated by the effect of other uncertainties. The down times from all failure modes, should more than one failure mode have occurred, are summed and added to the number of shifts, including the adjustment for generic inefficiency, to retrieve the waste. Implicit in Equation 1 is the assumption that each mode of failure occurs no more than once during the operating period.

A distribution of the number of shifts required to actually retrieve the waste is determined from the minimum number of shifts required (Table 3) by incorporating the non-technology-specific inefficiencies and the alternative specific failure downtimes as discussed in the previous paragraphs. The likelihood that the number of required retrieval shifts is less than the number of shifts available in the one-year operating period is defined to be the operating schedule metric. This metric is referred to as the confidence of meeting the operating schedule.

For the baseline calculations, the schedule metric is assumed to be the average of the confidences of meeting the deployment and operating schedule requirements. In consideration of the possibility that meeting a deployment date and completing retrieval within a one year operating period may not have equal importance to the decision-maker, the relative weighting of these two confidences in the schedule metric can be varied.

2.2 Cost

Cost data for estimated life cycle costs provided by the AGA are given in Table 6.

Table 6. Life Cycle Cost Estimates and Contingency.

Cost Type	Alt 1	Alt 2	Alt 3	Alt 4a	Alt 4b	Alt 5
Project	$69.3M	$92.6M	$83.9M	$90.1M	$104.5M	$120.1M
Operation	$5.0M	$3.5M	$5.0M	$3.5M	$3.5M	$30.0M
D&D	$1.7M	$1.8M	$1.2M	$1.1M	$2.3M	$3.2M
Contingency	25%	35%	40%	35%	40%	50%

The uncertainty associated with the Project Cost is estimated using the DOE Cost Estimating Guidelines, Chapter 11 on contingency for projects at various levels of developmental maturity. Table 6 also contains the contingencies applied to the project costs. [DOE97] The reference document provides a lower and upper limit to be applied as the contingency cost amount. The AGA provides a single value for the contingency, based on the maturity of the technology. The decision analysis assumes that the AGA contingency percentage is at the mid-point of the lower and upper contingency provided in the reference. For the purpose of the decision analysis the value for contingency is assumed to vary normally across the range defined by a standard deviation of one half-width of the reference document range. The normal distributions allow for costs that may extend beyond, either below or above, the range suggested by the DOE Cost Estimating Guidelines. Based on discussions with the AGA authors, the uncertainty associated with Operations and with decontamination and decommissioning (D&D) activities, qualitatively provided by the AGA is assumed less than the project cost uncertainty and more uniform across alternatives (Table 7). The uncertainty is applied as uniform +/- the percent listed in the table.

Table 7. Uncertainty of Operations and D&D Costs.

Operations and D&D Cost Uncertainty	Alt 1	Alt 2	Alt 3	Alt 4a	Alt 4b	Alt 5
Qualitative	Moderate	Moderate	Slightly High	Slightly High	Extreme	Extreme
Quantitative	10%	10%	12.5%	12.5%	15%	15%

The Decision Plan identifies Funding Manageability as a criterion for the Cost attribute. This criterion is addressed as follows. The funding profile has been estimated for the life of the project. [Num99] This allows a quantifiable metric to be determined for describing funding fluctuations. Larger changes in funding from year to year are expected to be detrimental to the success of the project. Therefore, an incremental cost of one standard deviation of the annual project cost is added to the life cycle cost of each alternative.

2.3 Environmental Impact

Environmental Impact metric consists of leak potential, waste remaining in the tank, hardware remaining in the tank, and waste generated by the process. Relative weighting of these criteria was determined by elicitation of the AGA authors and is provided in Table 8.

Table 8. Weighting of Environmental Impact Criteria.

Quantity	Weighting Factor
Leak Potential	1.0
Hardware Remaining	0.1
Waste Remaining	10.0
Waste Generated	1.0

The philosophy behind the factors in Table 8 is that each gallon of waste remaining in the tank contains a similar amount of hazardous material as 10 gallons of potentially leaked dilute material. Hardware items are postulated to pose a hazard similar to one-tenth of a gallon of leak potential. Results indicate little to no sensitivity to the weight on the hardware items remaining in the tank. The AGA provides data for the determination of the Environmental Impact. That information is summarized in Table 9.

Table 9. Environmental Impact Data.

Alt	Hardware Remaining (Items)	Solid Waste Remaining (Gallons)	Construction and Operations Waste Generated (Gallons)	D&D Waste Generated (Gallons)	Non Catastrophic Leak Potential (Gallons)	Catastrophic Leak Potential (Gallons)
1	5	20720	2080	1660	6860	31000
2	5	3200	1590	3250	6180	31000
3	6	6400	890	2980	5760	30000
4a	6	3200	1770	3250	3170	16500
4b	5	0	2040	6060	3170	16500
5	5	37500	1870	7060	2500	2500

Hardware Remaining (items) represents the number of items remaining in the tank after waste removal. This value is relatively well known; however, it is not absolutely certain. Therefore this value has been assumed to vary uniformly about the value in Table 9 with an error of +/-2 items.

Waste Remaining is the number of gallons of waste remaining in the tank after operations prior to any major modifications, replacements or additional equipment. The uncertainty in the volume of waste remaining is elicited from the authors of the AGA. The Waste Remaining uncertainty is shown in Table 10. The uncertainty is used along with the value of waste remaining to construct a triangular distribution.

Table 10. Uncertainty in Waste Remaining.

Alternative	Uncertainty
1	+/- 20%
2	+/- 20%
3	+/- 40%
4a	+/- 20%
4b	+/- 40%
5	+/- 40%

The total waste generated is assumed normally distributed about the values in Table 9, with a standard deviation of 20%. This assumption, although arbitrary, will allow identification of the importance of Waste Generated to the decision.

The AGA provides volumes for leak potential due to non-catastrophic and catastrophic failures. The decision analysis assumes that the minimum leak potential is zero and constructs a triangular uncertainty distribution for the leak potential using zero, non-catastrophic leak potential volume and catastrophic leak potential volume as the minimum, mode, and maximum, respectively. Although these values are not the expected values, the criterion for leakage considerations is that amount that may potentially be leaked. If a more detailed system or performance assessment is done, a rigorous investigation (or formal elicitation) of the probability of leakage volumes would be warranted.

2.4 Public and Worker Safety

Radiation Safety and Industrial Safety are to be combined into a single metric to represent Safety. Radiation exposure is assumed to be the sum of doses from construction, operations, and equipment removal. The total dose due to construction activities varies with alternative and is provided in Table 11.

Table 11. Nominal Construction Dose by Alternative.

Alternatives	Dose
1	40 R
2	25 R
3	10 R
4a	30 R
4b	40 R
5	25 R

It is assumed (arbitrarily) that the uncertainty in construction dose consists of a linear uncertainty (5 R) plus an amount that is a function of the predicted quantity (a normal distribution is assumed).

The operations dose is assumed to be a singular value for the baseline retrieval technique (sluicing). Consensus Operations Dose of 10 R +/- 5 R elicited from AGA authors. Operations doses, qualitatively described as 'Baseline', 'Moderately Higher', or 'Substantially Higher', are arbitrarily assumed to be a multiplier of 1.0, 1.2 and 1.5, for operations and equipment removal dose.

The equipment removal dose for the baseline retrieval technique (sluicing) is assumed to have a nominal value of 100, but could range from 50 to 150. Equipment Removal doses, qualitatively described 'Baseline', 'Moderately Higher', or 'Substantially Higher', arbitrarily assumed to be a multiplier of 1.0, 2.0 and 3.0, for operations and equipment removal dose.

Based on input form the authors of the AGA, the radiation dose from the most recent pit entries was 10 to 15 R. This provides a basis for equating the industrial hazard (pit entries) to the radiation hazard, expressed as exposure in R. The equivalence is modeled as ranging uniformly from 5 to 20 R per pit entry.

Industrial Safety is assumed to consist of the weighted sum of the number of pit entries, critical lifts, and uncommon hazards (Table 12). Uncertainties are assumed for pit entries (+/-2) and critical lifts (+/-3). No uncertainty is assumed for Uncommon Hazards. Based on elicitation of the AGA authors, each Uncommon Hazard is assumed equally important and equal to the value of a single Pit Entry. Critical Lifts are assumed to be of lesser impact on industrial safety. Each critical lift is assumed to be worth a value, randomly determined, between 1 and 0.1 Pit Entries.

Table 12. Uncommon Hazards by Alternative.

Hazard	Alt 1	Alt 2	Alt 3	Alt 4a	Alt 4b	Alt 5
Remove Saltwell	X	X	X		X	X
Damage to In-Tank Hardware		X	X	X	X	X
Waste Above Grade		X	X	X	X	X
Potential Unrecoverable Failure					X	X
Leak Aggravation				X	X	
Vacuum Damage to Tank					X	
New Riser						X

3. MULTI-ATTRIBUTE UTILITY

A key element of decision making is the trade-off of things being considered in the decision. Decisions are generally made based on more than one decision attribute, as is the case here. Furthermore, for complex decisions, with a need for defensibility, it is critical to use a formal approach for the incorporation of the decision attributes into the decision metric. One formal process for determining the decision metric is Multi-Attribute Utility Analysis (MUA). MUA combines attribute values linearly into a single metric. A value, or distribution of values, is calculated for each attribute metric. This has been done as described in the previous section of this report. For the current investigation, the four attributes and metrics are listed in column 1 and 2 of Table 13. Each attribute metric is translated into utility for that individual attribute. This is the single attribute utility, or attribute utility. Attribute utilities are typically scaled from 0 to 1, least desirable to most desirable values. Such is the case in this investigation. Each decision attribute is then given an attribute weight (from 0 to 1). The attribute weight is the relative fraction of the decision that is based on that particular attribute. Attribute weights incorporate the value judgements of the decision-maker. The sum of attribute weights is typically normalized to sum to unity. In mathematical terms, this process can be represented by

$$U = \sum_{i=1}^{\#\,of\;attributes} w_i U_i(V_i) \qquad \text{(Eq 2)}$$

where,

V_i is the attribute value,

U_i is the attribute utility,

w_i is the attribute weight, and

U is the multi-attribute utility.

The following approach is used for the construction of the utility functions. Each of the four decision attributes, schedule, cost, environmental impact, and safety, has a distribution of potential values. That distribution characterizes the attribute's uncertainty. For each attribute a low value and a high value are selected such that the selected values span the entirety of realized attribute values (Figure 1) for all alternatives.

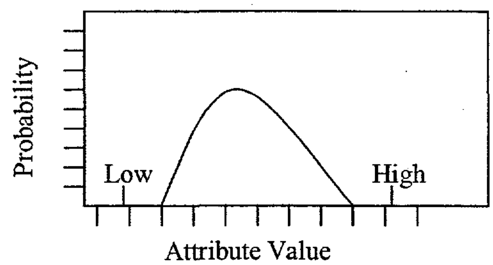


Figure 1. Selection of Low and High Values to Span Range of Expected Attribute Values.

Some attributes favorably affect the utility of a decision as they increase, e.g., confidence of meeting schedule. These have a positive utility slope. Others, such as cost, have a negative effect on utility as the attribute increases. Such an attribute has a negative utility slope. The utility slope of each decision attribute is provided in Table 13. Figure 2 illustrates a positive and a negative utility slope.

Table 13. Attribute Utility Slopes.

Attribute	Metric or Scale	Utility Slope
Schedule	Confidence of Meeting Schedule Requirements	Positive
Cost	Total Cost	Negative
Environmental Impact	Equivalent Gallons of Waste Remaining	Negative
Safety	Equivalent R	Negative

A utility function must be constructed for each attribute, such that the attribute value can be transformed to a single attribute utility scale ranging from 0 to 1. The utility function will represent the risk tolerance of the Decision-Maker.

3.1 Risk Tolerance of the Decision-Maker

One of the primary considerations to be investigated is the Risk Tolerance of the Decision-Maker or Makers. The method used here attempts to provide extreme representations for risk tolerance. The objective is to determine the potential impact of changes in the attitudes or identity of the Decision-Maker. By varying the utility curves, representing the risk tolerance of the Decision-Maker, the analysis can identify the need or benefit in performing any lengthy and formal elicitation of the single attribute utility curves.

For a risk neutral Decision-Maker the utility function is assumed to be linear between the high and low values that span the range of attribute uncertainty as shown in Figure 1.

The utility functions for the risk averse and the risk prone Decision-Makers are constructed as follows. Both the risk averse and the risk prone functions are assumed to be quadratic, with the end points defined by the low and high values described previously. The risk prone Decision-Maker is one that is willing to accept more risk, i.e., assign higher utility to higher cost or assign higher utility to a lower confidence of meeting schedule. The risk averse Decision-Maker is one who is less willing to accept those risks, i.e., assign lower utility away from the highest utility value. In order to complete the quadratic the following boundary condition is applied. The slope of the (quadratic) utility curve is defined to be zero at utility of 0 for the risk averse Decision-Maker and at utility of 1 for the risk prone Decision-Maker.

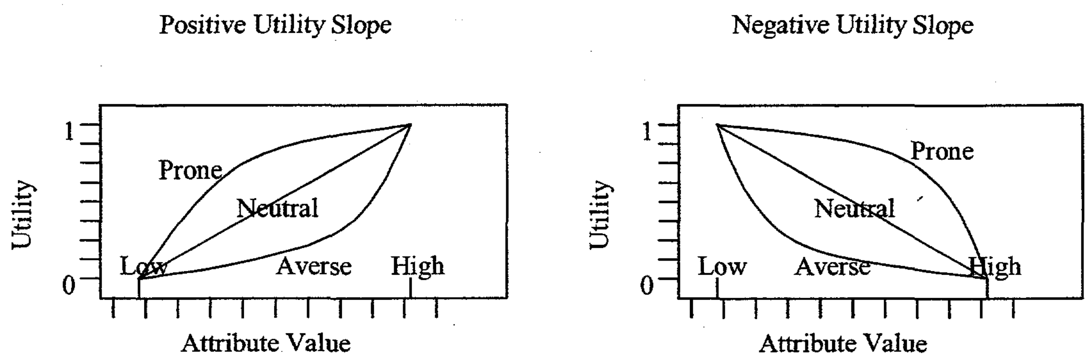


Figure 2. Illustration of Risk Tolerance Utility Curves.

For the positive utility slope the Utility, U, is given by Equations 3a, 3b, and 3c, where V is **the attribute value.**

$$U_{neutral} = \frac{(V - V_{Low})}{(V_{High} - V_{Low})} \quad \textbf{(Eq 3a)}$$

$$U_{prone} = \frac{V^{2} + 2\times(V - V_{Low})\times V_{High} + V_{Low}^{2}}{(V_{Low} - V_{High})^{2}} \quad \text{(Eq 3b)}$$

$$U_{averse} = \frac{(V - V_{Low})^{2}}{(V_{Low} - V_{High})^{2}} \quad \text{(Eq 3c)}$$

For the negative utility slope, the equations for utility are given by Equation 4a, 4b, and 4c.

$$U_{neutral} = \frac{(V - V_{High})}{(V_{Low} - V_{High})} \quad \text{(Eq 4a)}$$

$$U_{prone} = \frac{-V^2 + 2 \times (V - V_{High}) \times V_{Low} + V_{High}^2}{(V_{High} - V_{Low})^2} \quad \text{(Eq 4b)}$$

$$U_{averse} = \frac{(V - V_{High})^2}{(V_{High} - V_{Low})^2} \quad \text{(Eq 4c)}$$

The concepts illustrated in Figures 1 and 2 are developed into the utility functions described by Equations 3 and 4. The values in Table 14 complete the necessary information to calculate utility for each attribute. The values in Table 14 are selected based on the results of the attribute calculations in order to ensure that the utility functions span the range of attribute uncertainty.

Table 14. Attribute High and Low Values.

Attribute	Metric or Scale	Utility = 1	Utility = 0
Schedule	Confidence of Meeting Schedule Requirements	1	0
Cost	Total Cost	$50M	$250M
Environmental Impact	Equivalent Gallons of Waste Remaining	0	600k gal
Safety	Equivalent R	100 R	1400 R

3.2 Value Judgements of the Decision-Maker

A rigorous Multi-Attribute Utility Analysis uses a formal elicitation of attribute weightings from a Decision-Maker. [Kea76] Use of surrogate Decision-Makers may be expedient or necessary and can be used successfully in many instances. [Dav98] Although the Decision Plan identifies a single Decision-Maker for this activity, there are many perspectives that should be considered in making this decision. The selection of a retrieval technology affects the Management and Operating Contractor, operations organizations, and the public at large. Therefore a new approach is employed in this analysis. Rather than elicit a single explicit weighing of attributes from the specified Decision-Maker, representing that individual's value judgements, several perspectives will be considered. The perspectives are represented by attribute weighting schemes constructed to emphasize the varied value judgements of those maintaining the different perspectives.

The baseline weighting is arbitrarily selected as an individual who considers each of the four attributes equally. Also considered is a budget driven Decision-Maker, who considers that cost is the most important aspect of the retrieval technology selection. Also considered are Decision-Maker perspectives that emphasize environmental impacts (Stakeholder Friendly), public and worker Safety (Worker Friendly), and meeting of schedule requirements (Schedule Driven). The attribute weightings are listed in Table 15.

Table 15. Attribute Weights for Various Decision-Maker Perspectives.

Decision-Maker Perspective	Schedule	Cost	Environmental Impact	Safety
Level Weight (Baseline)	0.25	0.25	0.25	0.25
Budget Driven	0.25	0.40	0.15	0.20
Schedule Driven	0.50	0.15	0.15	0.20
Stakeholder Friendly	0.15	0.15	0.50	0.20
Worker Friendly	0.15	0.15	0.20	0.50

The benefit of considering various Decision-Maker perspectives through the use of attribute weights is the identification of vulnerability to changes in the corporate, political, and cultural environment in which the decision must be made. It is hopeful that the decision selected will be relatively robust and defensible to all of these different perspectives. The risk of this approach is the possible identification of preferred alternatives that vary considerably from perspective to perspective. In such a case a formal elicitation of attribute weights would be necessary.

A final consideration of MUA results with respect to value judgements is the weighting of the schedule criteria in the calculation of the schedule metric. A parameter is included in the decision analysis that allows the relative importance of meeting operating schedule and meeting deployment schedule to be varied. The ratio can be 1:1, 3:1, or 1:3. The effect of this weighting on the outcome of the analysis is discussed in the results section.

4. RESULTS

The attributes and utility calculations were performed using the decision analysis software, Analytica Version 1.1 [Ana97]. The model is a text file that is read by Analytica. The model text file is included in Appendix E of this document.

4.1 Attribute Results

A primary benefit of the Multi-attribute Utility technique used here is the explicit representation of uncertainty. By representing uncertainty in the lowest level estimates, the effects of uncertainty are propagated through the decision analysis and are manifest as uncertainty distributions in the results. Careful consideration of these uncertainties is critical to any decision making process.

A logical place to begin the decision analysis is the examination of the single attribute results, including the uncertainty of these intermediate results. Each decision attribute will be discussed. The Multi-Attribute Utility results for the base case will be presented followed by a discussion of branch case results.

4.1.1 Schedule

Table 16 shows results for the Schedule attribute. Recall the base case results are those that correspond to the EOY 6 deployment requirement. One of the extra considerations given to this decision is that of possible deferral of the deployment date. The schedule metric for potential extended deployment times is given in the remainder of the table.

Table 16. Schedule Metric.

Deployment Date	EOY 6	MOY 7	EOY 7	MOY 8	EOY 8	MOY 9	EOY 9	MOY 10	EOY 10
Alt 1	0.80	0.80	0.80	0.81	0.81	0.81	0.81	0.81	0.81
Alt 2	0.85	0.89	0.91	0.91	0.91	0.91	0.92	0.92	0.92
Alt 3	0.51	0.56	0.61	0.65	0.66	0.66	0.66	0.67	0.67
Alt 4a	0.85	0.89	0.90	0.90	0.90	0.91	0.91	0.91	0.91
Alt 4b	0.56	0.59	0.66	0.73	0.79	0.80	0.80	0.80	0.81
Alt 5	0.00	0.00	0.02	0.06	0.10	0.14	0.18	0.22	0.24

Alternatives 2 and 4a have the highest, and most desirable, measure for schedule. Alternative 1 is slightly behind. Although alternative 1 has a higher likelihood of deployment by the EOY 6 time, its ability to meet the operating schedule is lower than that of the other desirable alternatives. This is due to the exponential in Equation 1. It should be noted that the performance of all alternatives increases by the deferral of the required deployment date. However, it is particularly noteworthy that the desirability of Alternative 1 increases only slightly whereas the other alternatives increase significantly.

4.1.2 Cost

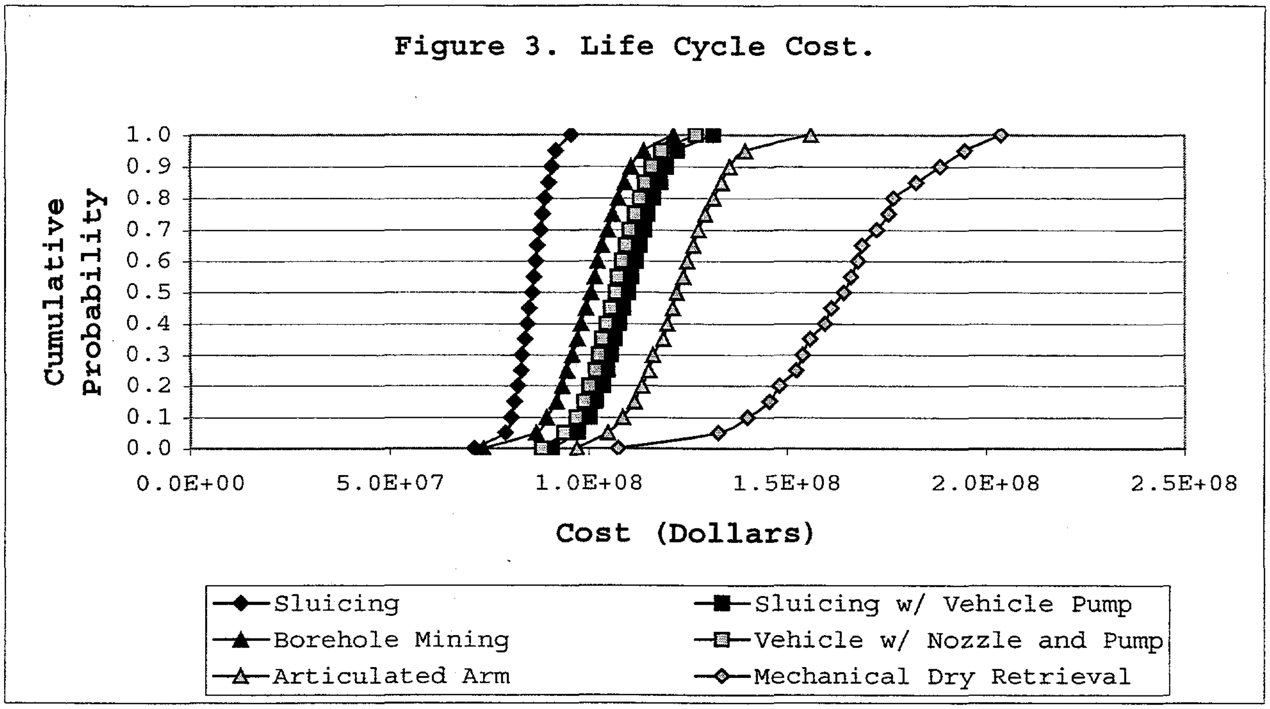
Figure 3 shows the cumulative probability distribution for the Life Cycle Cost of each alternative. The results are consistent with the information from the AGA. Alternative 1 (Sluicing) is the lowest cost alternative due primarily to the maturity of the technology. Table 17 provides statistical information of the data in Figure 3.

Table 17. Life Cycle Cost Statistics.

	Min	Mean	Max	σ
Alt 1	$70M	$82M	$92M	$4M
Alt 2	$86M	$107M	$126M	$8M
Alt 3	$73M	$96M	$119M	$8M
Alt 4a	$86M	$104M	$123M	$7M
Alt 4b	$88M	$118M	$149M	$11M
Alt 5	$112M	$158M	$209M	$18M

It is evident from both Figure 3 and Table 17 that Alternative 1 is preferable in terms of cost with Alternatives 2, 3 and 4a about 30% more and alternatives 4b and 5 clearly lagging in the cost criteria.

The cost utility is calculated assuming a risk-neutral decision-maker using Eq 4a and data in Table 14. The cost utility is plotted in Figure A.1 of Appendix A.

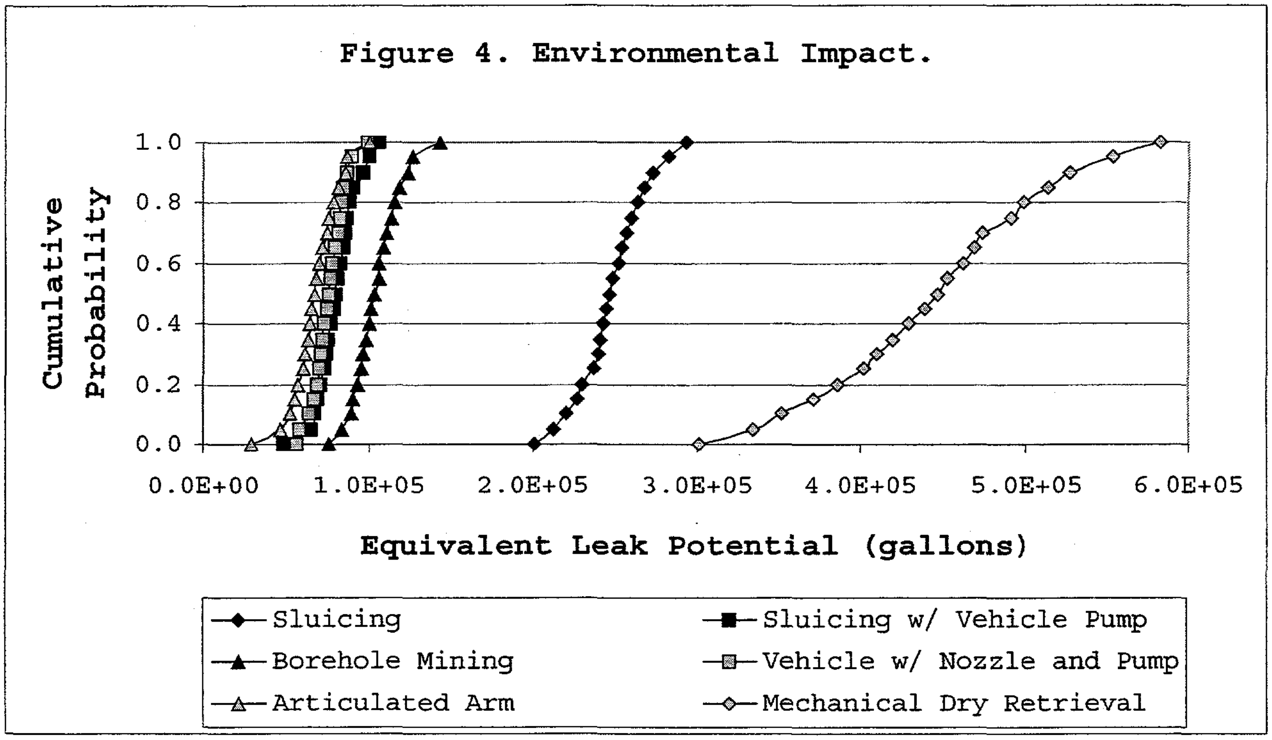


4.1.3 Environmental Impacts

Figure 4 shows the cumulative probability for the Environmental Impact metric. The metric shown represents the accumulation of waste generated, hardware remaining and leak potential in terms of waste remaining in the tank. Although the scale in Figure 4 is not actual gallons, it is intended to be nearly equivalent in terms of environmental impact to gallons of waste remaining.

The figure indicates that Alternatives 2, 4a, and 4b are highly preferable to the others in terms of environmental impact. This is due to the combined effects of leak potential and waste remaining in the tank.

The environmental impact utility is calculated assuming a risk-neutral decision-maker using Eq 4a and data in Table 14. The environmental impact utility is plotted in Figure A.2 of Appendix A.

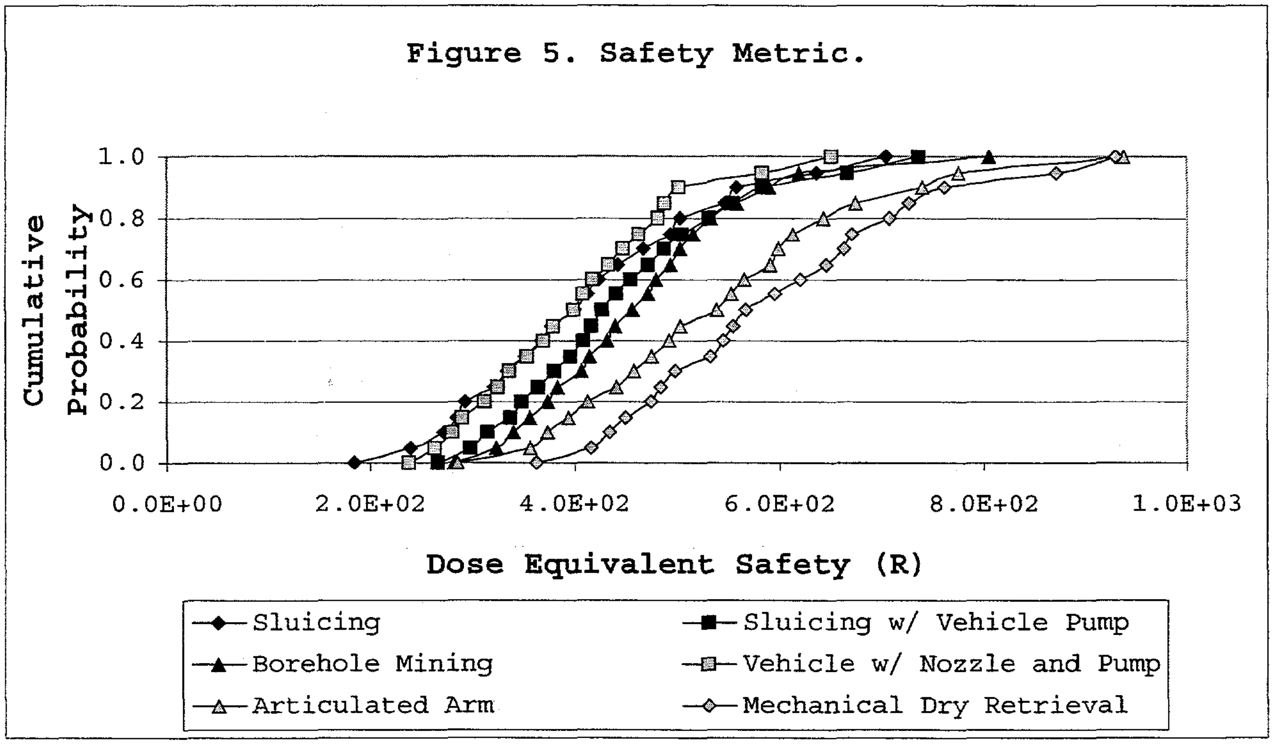


4.1.4 Safety

Figure 5 shows the cumulative probability distribution for the safety metric. The metric is in terms of equivalent R and thus a high value is not desirable.

Figure 5 shows that Alternatives 1 and 4a are favorable in terms of safety. Other alternatives are progressively less favorable, in the order of Alternative 2, 3, 4b, and then 5. Note that the disparity between alternative in terms of the safety metric is as much as 50%.

The safety utility is calculated assuming a risk-neutral decision-maker using Eq 4a and data in Table 14. The safety utility is plotted in Figure A.3 of Appendix A.



4.2 Multi-Attribute Utility Results

The objective of Multi-attribute utility analysis is to consider several different factors that affect a decision and provide a common scale for the consideration of those factors into the single decision at hand.

Recall that the base case analysis consists of equally weighted attributes with equal importance placed on meeting the end of the sixth project year deployment schedule and operating schedule, and a risk neutral decision-maker.

Figure 6 shows the cumulative probability distribution of Utility for the six alternatives under consideration. Table 18 provides summary of statistics on the Utility results.

Figure 6. Base Case Multi-Attribute Utility.

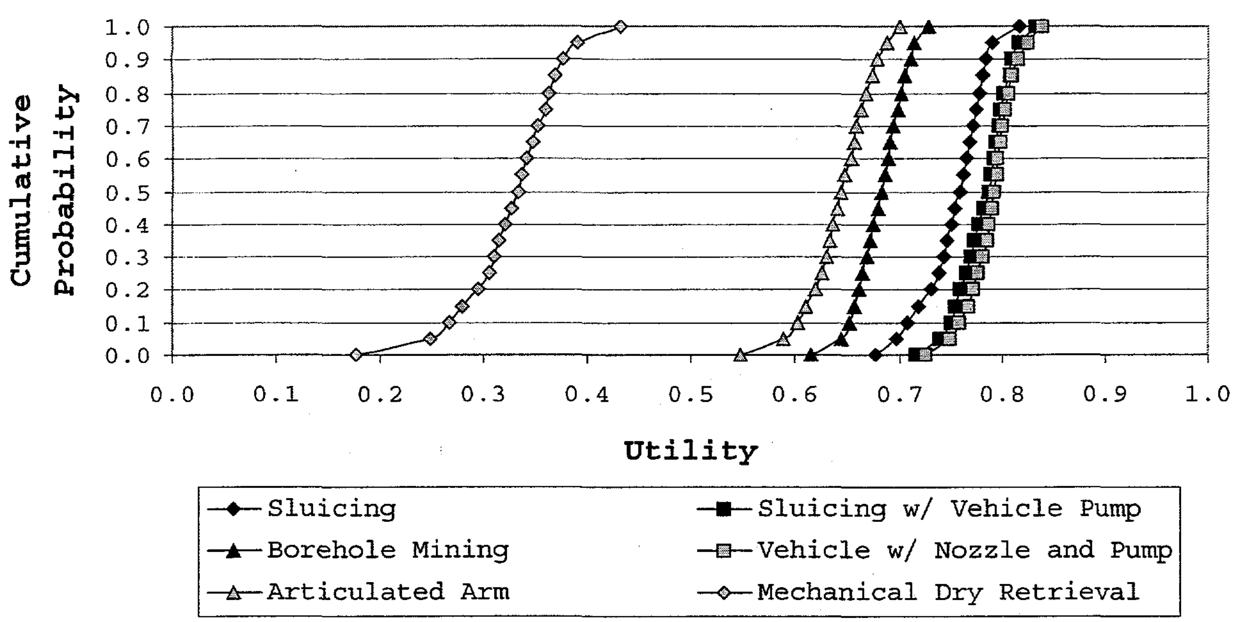
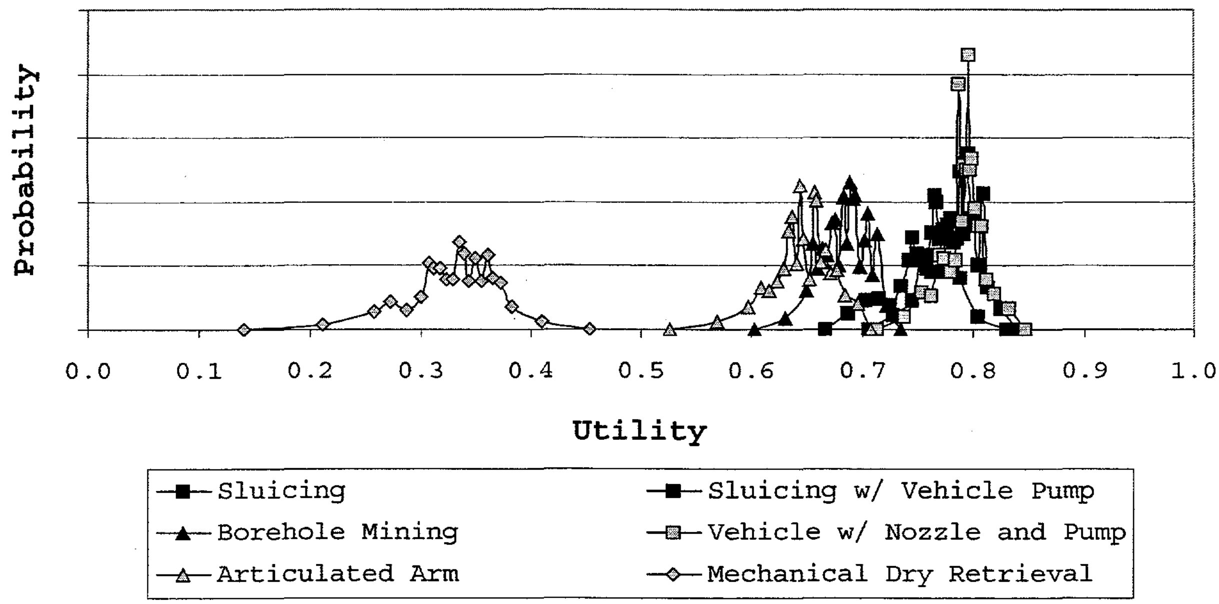


Table 18. Statistical Results for Baseline MUA.

	Min	Mean	Max	σ
Alternative 1	0.70	0.77	0.82	0.03
Alternative 2	0.75	0.82	0.88	0.02
Alternative 3	0.66	0.72	0.77	0.02
Alternative 4a	0.77	0.83	0.88	0.02
Alternative 4b	0.61	0.71	0.77	0.03
Alternative 5	0.20	0.36	0.46	0.05

For the base case, as illustrated in Figure 6 and Table 18, Alternatives 2 and 4a are preferable to all others. Although σ is based on assumptions of normality which are not valid in this case, it, along with the probability distribution in Figure 7, does indicate that the differences between the alternatives is significant and the alternatives are distinguishable.

Figure 7. Multi-Attribute Utility PDF.



The comparison between the alternatives that are of similar utility is, at this point, qualitative. The following approach is used to provide a quantitative measure to distinguish between the alternatives. The calculation of each attribute is based on sampled values from uncertain distributions. A single value for utility (for each alternative) is constructed from a vector of the sampled values being propagated through the attribute and utility calculation models. Consequently, each unique input vector (set of sampled values for the uncertain parameters) produces a unique utility value for each alternative. Therefore, for each input vector the value of the utility for one alternative can be compared to the utility for another alternative. This comparison exists for each input vector constructed by sampling. So for each sample the alternative utilities can be compared directly or by ratio.

Figure 8 shows the cumulative probability distribution for the ratio of Alternative 2 (Sluicing with Vehicle Pump) utility to Alternative 1 (Sluicing) utility. For results where Utility of Sluicing exceeds the Utility of Alternative 2 (Sluicing with Vehicle Pump), the ratio will be less than 1.0. For results where the Utility of Sluicing with Vehicle Pump is greater, the ratio will be greater than 1.0.

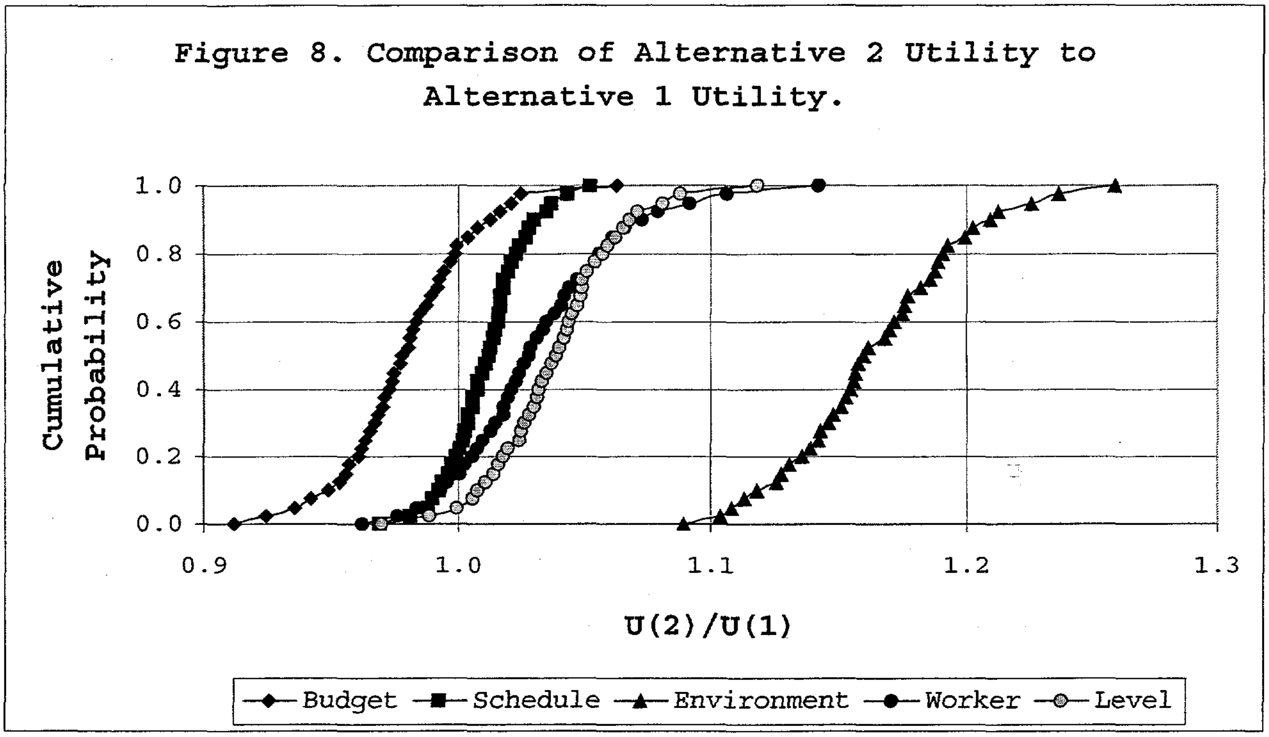
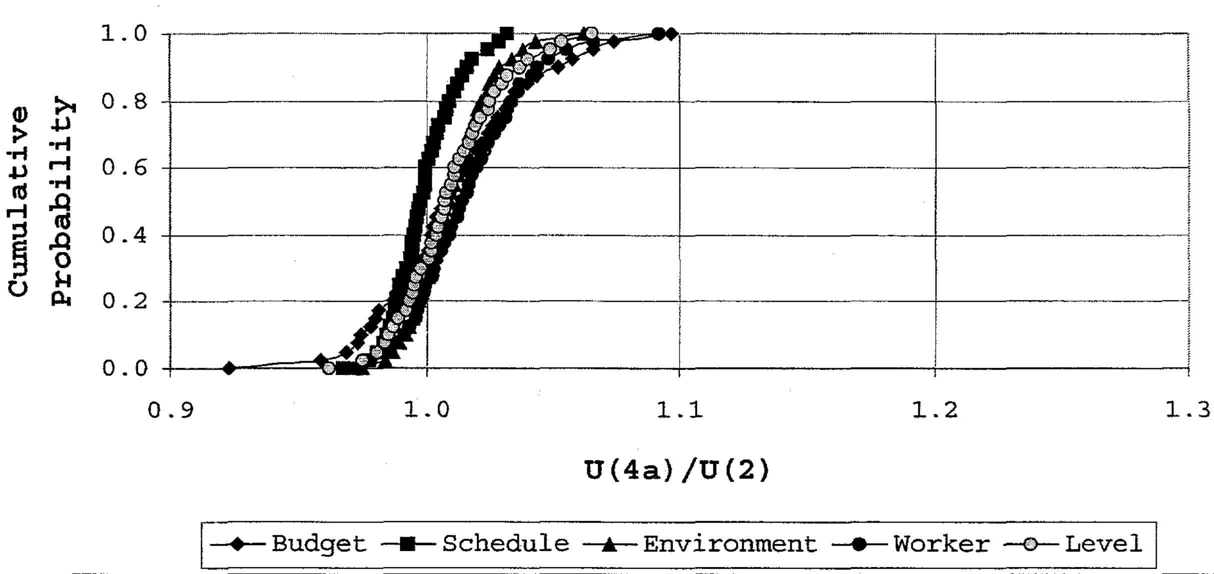


Figure 8 indicates that for the Budget-Driven Decision-Maker Value Judgements, Sluicing is 84% preferable to the Vehicle Pump alternative. However, for all other Value Systems, The Sluicing with Vehicle Pump alternative is more than 75% preferable to Sluicing. In fact, for the Environment Friendly Value System, Sluicing is never preferable under the conditions and assumptions used here.

Figure 9 shows the ratio of Alternative 4a (Vehicle with Nozzle and Pump) Utility to Alternative 2 (Sluicing with Vehicle Pump) Utility. The graphs indicate that the two alternatives are similar for the Schedule Minded Decision-Maker, with the Vehicle with Nozzle and Pump alternative slightly (about 70%) preferable for all other value systems.

Figure 9. Comparison of Alternative 4a Utility to Alternative 2 Utility.



4.3 Sensitivity Analysis and Branch Cases

4.3.1 Importance Analysis (Rank Correlation)

In this analysis, importance is the correlation of the input parameter to the output value. Specifically, it is the absolute value of the rank correlation of the uncertain input and the uncertain utility. It is a measure of the monotonic relationship between the values. In table 19, Importance values below 0.1 are generally deemed not to indicate a correlation.

A couple of points can be made from the information in the table. One, the correlation between Cost and Utility is due almost exclusively to the Project Cost, as the importance values for Life Cycle Costs are almost identical to those for Project Cost. Operations and D&D Cost correlation to utility is insignificant. Two, alternatives 1, 3, and 5 are more strongly correlated to the Waste Remaining and Leak Potential than the other alternatives.

Table 19. Importance Values.

Utility_inputs	Alt 1	Alt 2	Alt 3	Alt 4a	Alt 4b	Alt 5
Life Cycle Costs	0.03	0.41	0.52	0.49	0.54	0.49
Project Cost	0.01	0.41	0.52	0.50	0.54	0.47
Op + D&D Cost	0.11	0.08	0.04	0.10	0.02	0.19
Retrieval Rate	0.11	0.16	0.01	0.09	0.07	0.11
Efficiency That is not Alternative Specific	0.17	0.09	0.16	0.00	0.14	0.06
Waste Remaining	0.21	0.11	0.25	0.14	0.05	0.60
Leak Potential	0.21	0.01	0.21	0.09	0.10	0.09
Generic Generated Waste	0.01	0.00	0.07	0.00	0.03	0.03
Operations Dose	0.10	0.04	0.13	0.09	0.15	0.01
Construction Dose	0.06	0.10	0.03	0.02	0.29	0.07
Equipment Removal Dose	0.05	0.35	0.53	0.30	0.21	0.32
Pit Entries	0.20	0.25	0.13	0.15	0.28	0.03
Critical Lifts	0.09	0.10	0.01	0.19	0.07	0.00
Weight of Critical Lifts	0.56	0.39	0.24	0.44	0.36	0.35
Dose Equivalent to Industrial Safety	0.62	0.58	0.35	0.51	0.65	0.33

Table 20. Utility Sensitivity to Attribute Utility.

	Schedule	Cost	Environmental Impact	Safety
Alternative 1	.8765	.9221	1.288	1.002
Alternative 2	.9514	1.113	.8993	1.066
Alternative 3	1.485	.9226	.8352	.9565
Alternative 4a	.9741	1.105	.9081	1.033
Alternative 4b	1.746	.9987	.7181	.9676
Alternative 5	.5779	1.335	2.214	.9354

Table 20 illustrates that Alternatives 3, 4b, and 5 have a highly varied sensitivity to the attribute utilities. Alternatives 2 and 4a are not particularly sensitive to any single attribute. Alternative 1 shows somewhat more sensitivity to Environmental Impact than the other competitive alternatives.

4.3.2 Risk Tolerance of the Decision-Maker

Variability of decision-maker values was considered in the previous branch case. A natural extension of this is to assess vulnerability of the decision to the risk tolerance of the decision-maker. Assuming a fixed value system (level attribute weighting) and then varying the utility curves to represent risk-prone and risk-averse decision-makers does this. The attribute calculations are not affected by this branch case. Therefore, the values in Tables 16 and 17, and Figures 3, 4, and 5 remain valid. For the previous results presented, it was assumed that the decision-maker is risk-neutral and Equations 3a and 4a are valid. The corresponding results multi-attribute utility cumulative distribution is shown in Figure C.1 of Appendix C. For a risk prone Decision-Maker, one who is willing to accept more risk, Equations 3b and 4b are used instead of Equations 3a and 4a. The risk-prone utility cumulative distribution is shown in Figure C.2 of Appendix C. For a more conservative, risk averse Decision-Maker, willing to accept less risk, Equations 3c and 4c are used. The risk-averse utility cumulative distribution is shown in Figure C.3 of Appendix C. The results in Appendix C indicate that the preferred decision alternative is not sensitive to the risk tolerance of the decision-maker.

4.3.3 Value Judgments of the Decision-Maker

Table 21 provides the mean utility for each of the various Decision-Maker perspectives discussed previously in this report. Graphical representations are provided in Appendix B.

Table 21. Utility for Various Perspectives.

	Budget Driven	Schedule Driven	Stakeholder Friendly	Worker Friendly
Alternative 1	0.78	0.79	0.70	0.75
Alternative 2	0.76	0.79	0.81	0.77
Alternative 3	0.67	0.59	0.73	0.70
Alternative 4a	0.78	0.80	0.82	0.79
Alternative 4b	0.61	0.55	0.73	0.66
Alternative 5	0.34	0.23	0.32	0.43

Table 21 indicates that Alternatives 1, 2, and 4a are preferable to all other alternatives regardless of the Decision-Maker perspective. For the Budget Driven and the Schedule Driven perspectives, the differences are indistinguishable given the uncertainties involved. Particular emphasis might be placed on any of the perspectives. However, a particular case could be made for the Stakeholder Friendly perspective being representative of regulatory agencies and the general public. In this case, the utility of Alternative 1 decreases significantly while the utility of all other alternatives increase.

4.3.4 Importance of Deployment and Operating Schedule

The schedule criterion is comprised of the confidence of meeting a deployment requirement and the confidence of meeting a one-year operating requirement. For the base case, it was assumed that the two schedule components are equally weighted. In order to assess the vulnerability to this assumption, the relative importance of these two schedule components, meeting the deployment schedule and meeting the operating schedule, is varied. The base case assumptions are maintained with the exception of the relative weighting of the schedule attribute components. Both deployment and operations are certain to have some impact, assumed to be a minimum of one-fourth of the schedule attribute. Therefore, three cases are considered: 1) A deployment emphasized scenario, where the relative importance of the deployment is 3 times that of meeting operations requirements; 2) A scenario that emphasizes deployment and operations equally within the schedule attribute (same as the base case); and 3) A scenario that emphasizes operations 3 times more than deployment.

5. ANALYSIS CONCLUSIONS

Alternatives 3, 4b, and 5 are clearly not competitive technologies. The deficiencies of these alternatives cannot be eliminated by any reduction in uncertainty. Each of these alternatives would require a considerable improvement in more than one of the decision criteria.

Alternative 1 is marginally competitive. For Alternative 1 to be competitive, the decision must strongly emphasize deployment schedule. That emphasis necessarily comes at the expense of other attributes, such as environmental impact.

Alternatives 2 and 4a are very similar. As such, it may be feasible to continue development of these alternatives concurrently for some period of time. Further investigation and clarification of the factors that may distinguish these alternatives is warranted. These factors include, but may not be limited to, refinement of uncertainty in decision criteria, improved estimates of decision criteria data (cost, dose, etc), and more rigorous treatment of attribute weightings.

6. REFERENCES

Ana97 Analytica. *Analytica User Manual.* Lumina Decision Systems, Denver Colorado, 1997.

DOE97 DOE Cost Estimating Guide, DOE-G-430.1-1, Department of Energy, Washington, DC, 1997.

Dav98 Davis, F. et al, "A Multi-Attribute Utility Decision Analysis for Treatment Alternatives for the DOE/SR Aluminum-Based Spent Nuclear Fuel Sandia National Laboratories," SAND98-2146, Albuquerque, New Mexico, October 1998.

Dew99 DeWeese, G. C., "Decision Plan for the Selection of the 241-C-104 Retrieval Technology," HNF-3969, March 1999.

Gre99 Grenard, C. E., and Leonard, M. W., "System Specification for the Single Shell Tank System," HNF-3912, Rev 0, Numatec Hanford Corporation, Richland, WA, 1999.

Kea76 Keaney, R. L. and Raiffa, H. *Decisions With Multiple Objectives*, Wiley, New York, 1976.

Kir97 Kirkbride, R. A., et al, "Tank Waste Remediation System Operation and Utilization Plan," HNF-SD-WM-SP-012, Rev 0A, Numatec Hanford Corporation, Richland, WA, 1997.

Num99 Numatec Hanford Corporation, "Alternatives Generation and Analysis C-104 Single Shell Tank Waste Feed Delivery," TWR-4454, Richland, WA, (Preliminary) June 1, 1999.

APPENDICES

Appendix A Single Attribute Utility Distributions

The purpose of this appendix is to present the single attribute utility cumulative distributions for the base case. The base case assumes that the decision-maker is risk-neutral, as described in the body of the text. It is also assumed that each of the decision attributes is weighted equally.

Figure A.1. Cost Utility.

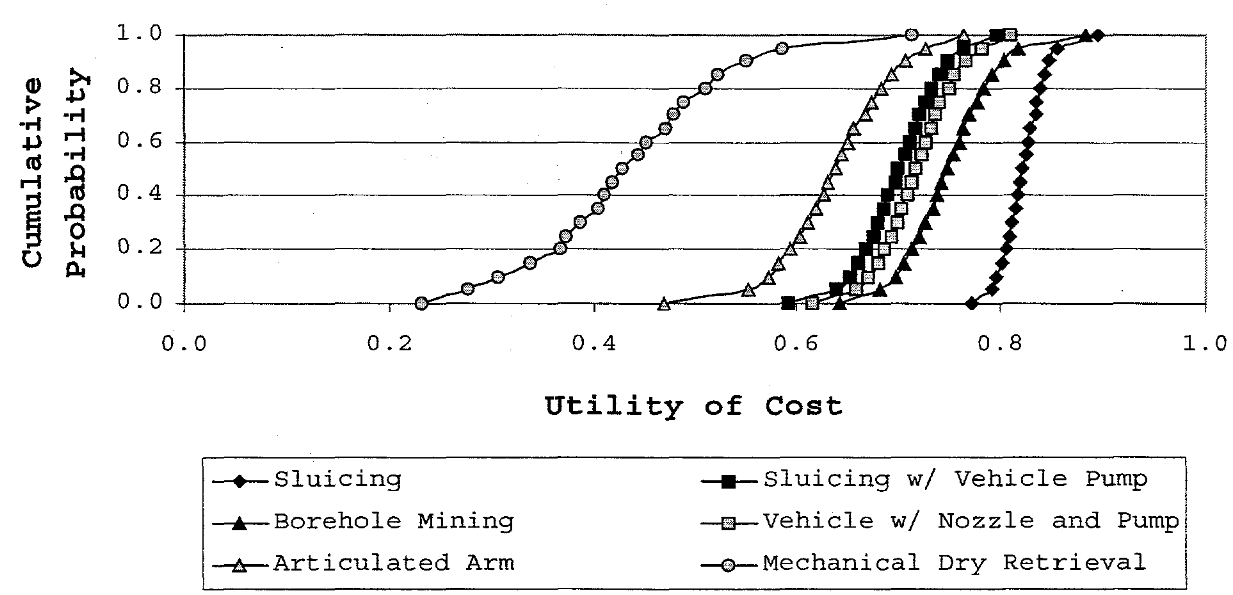


Figure A.2. Environmental Impact Utility.

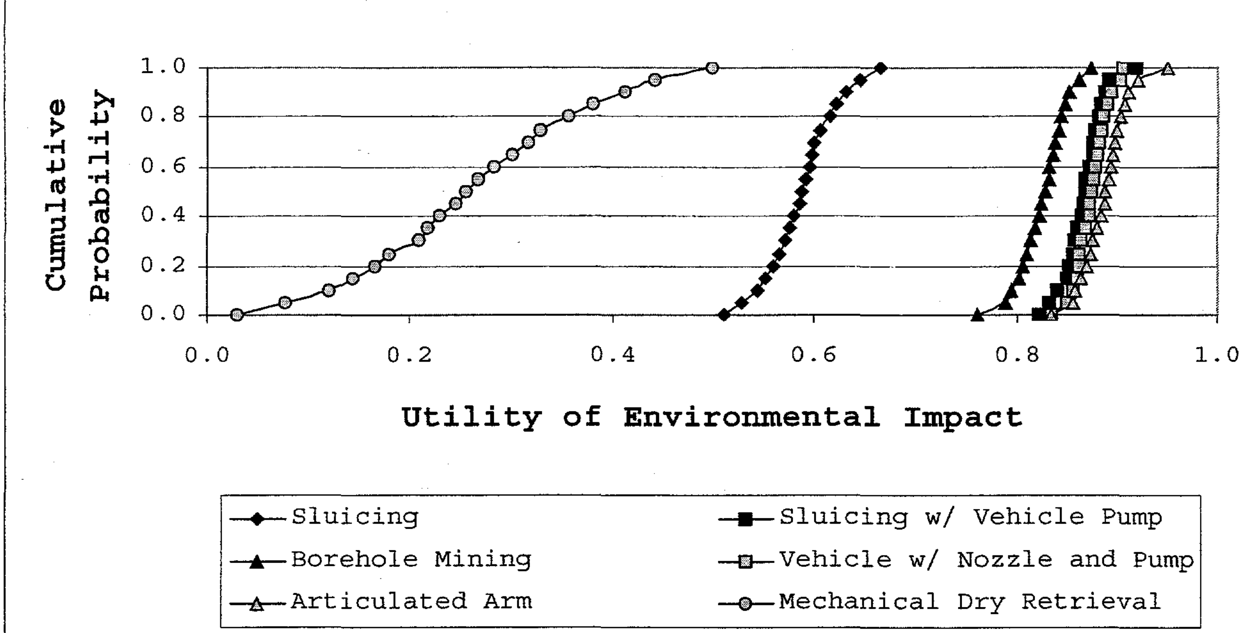
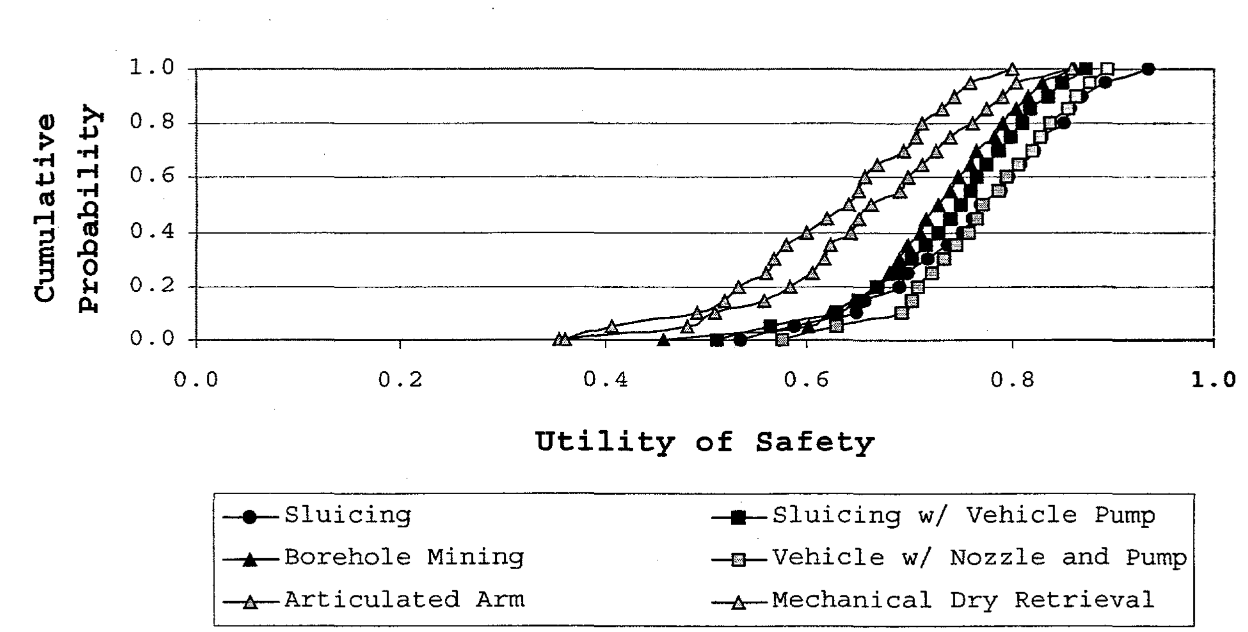


Figure A.3. Safety Utility Distribution.



Appendix B Utility Distributions for Decision-Maker Perspectives

The purpose of this appendix is to provide the comparison figures for the alternatives using various decision-maker perspectives, i.e., different attribute weighting schemes.

Figure B.1 Budget Driven Perspective.

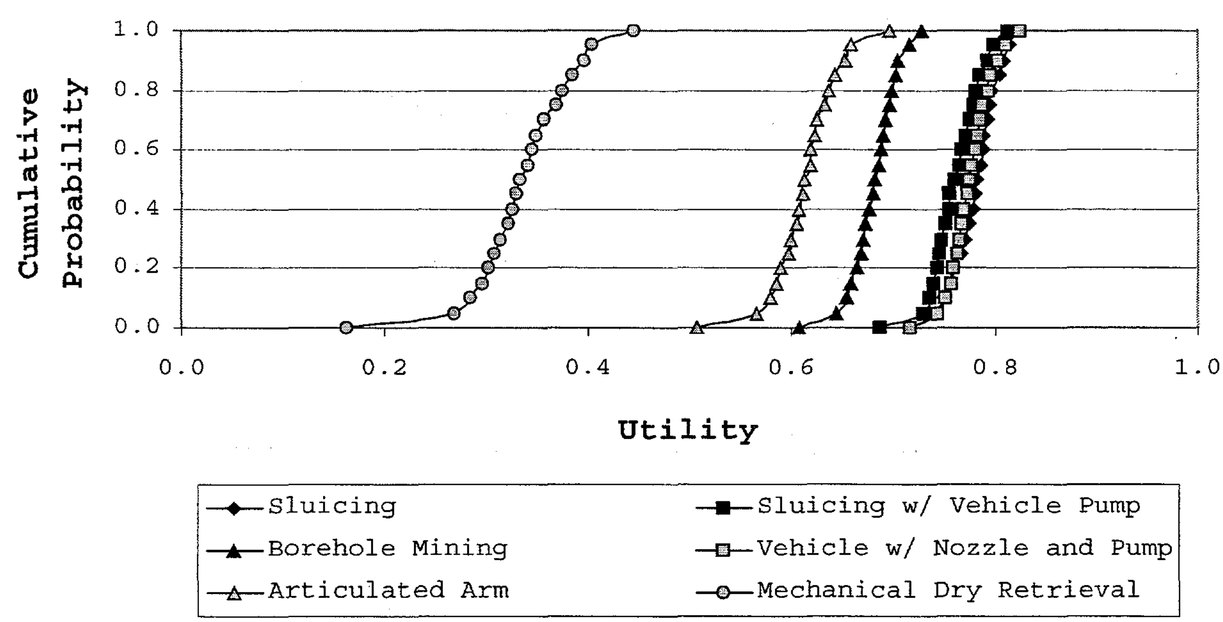


Figure B.2. Schedule Driven Perspective.

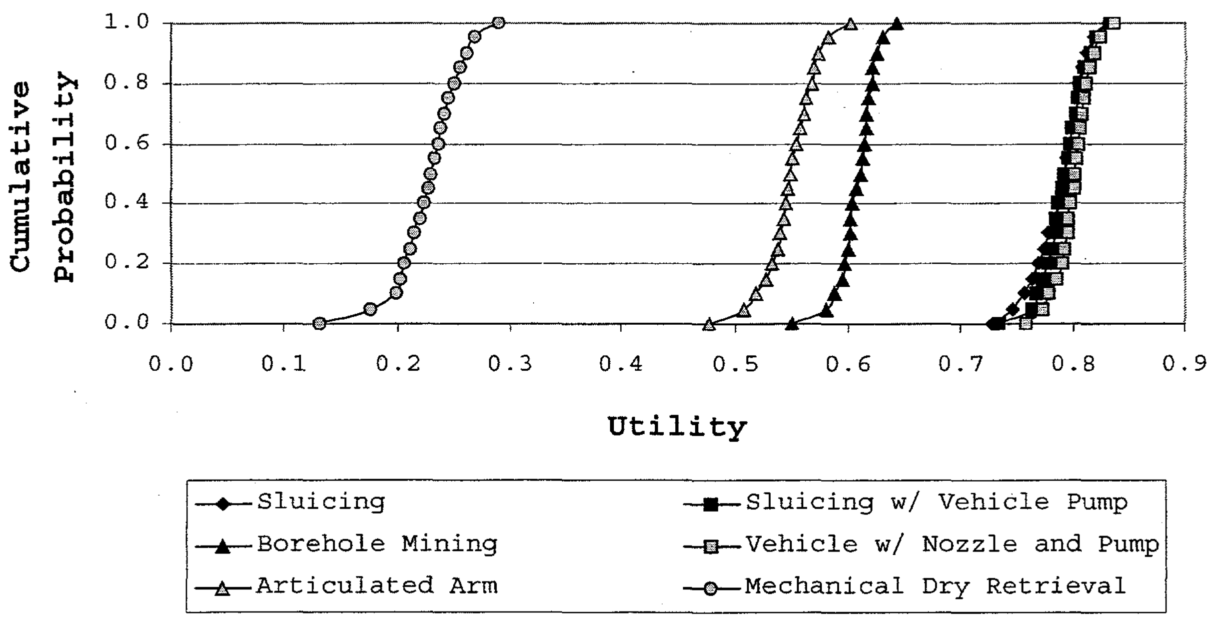
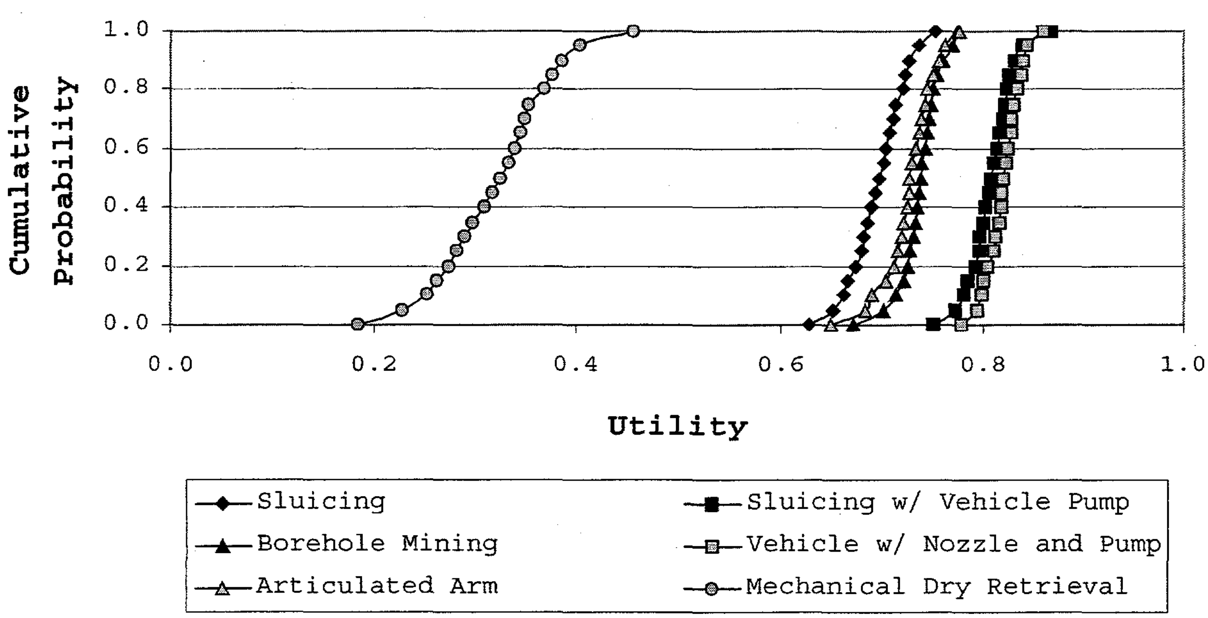


Figure B.3. Stakeholder Friendly Perspective.



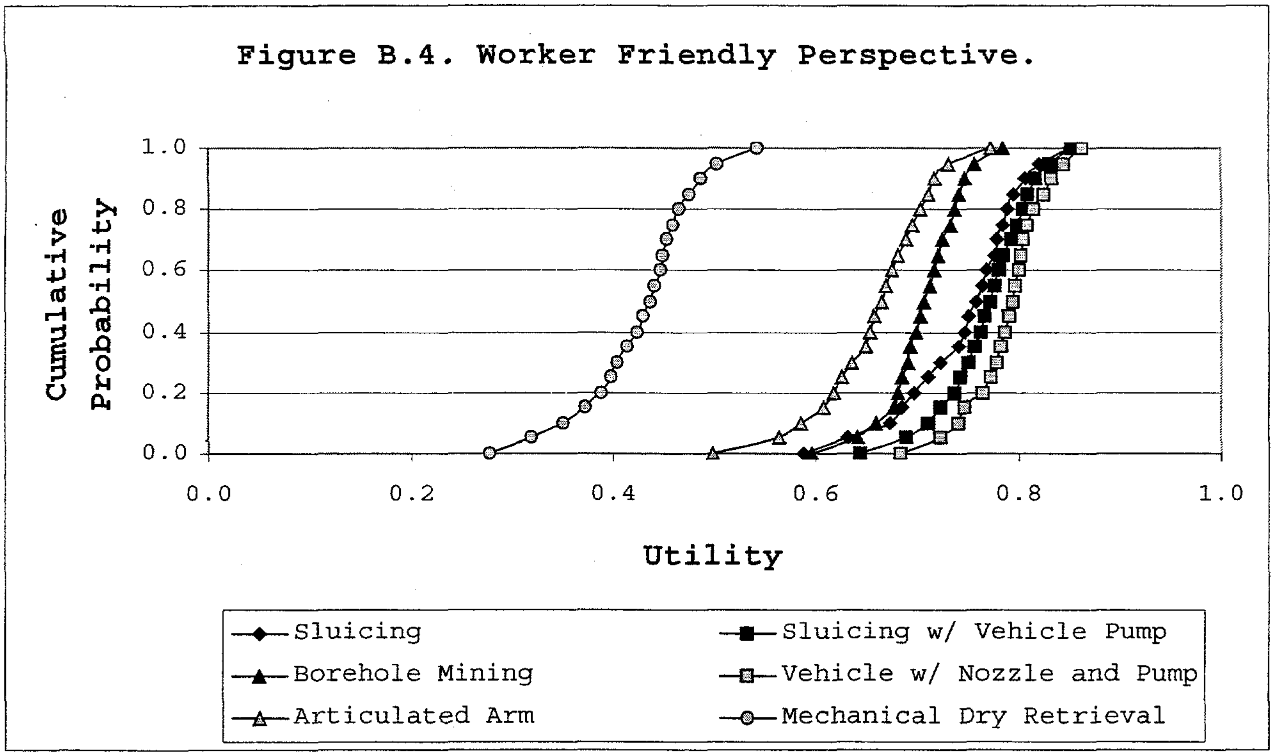
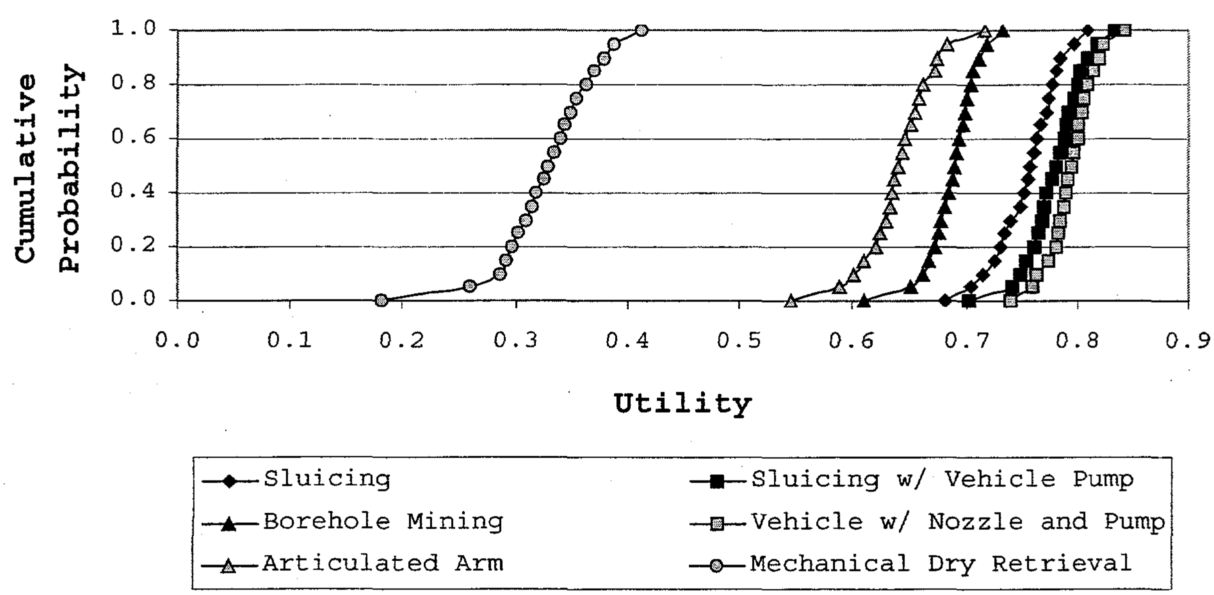


Figure B.4. Worker Friendly Perspective.
Cumulative Probability
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
Utility
Sluicing
Borehole Mining
Articulated Arm
Sluicing w/ Vehicle Pump
Vehicle w/ Nozzle and Pump
Mechanical Dry Retrieval

Appendix C Utility Distributions for Decision-Maker Risk Tolerances

The purpose of this Appendix is to provide the cumulative distributions for the various risk tolerances of the Decision-Maker. It is assumed in the generation of each of these figures that the Decision-Maker perspective equally weights each of the decision attributes.

Figure C.1. Risk Neutral Decision-Maker.



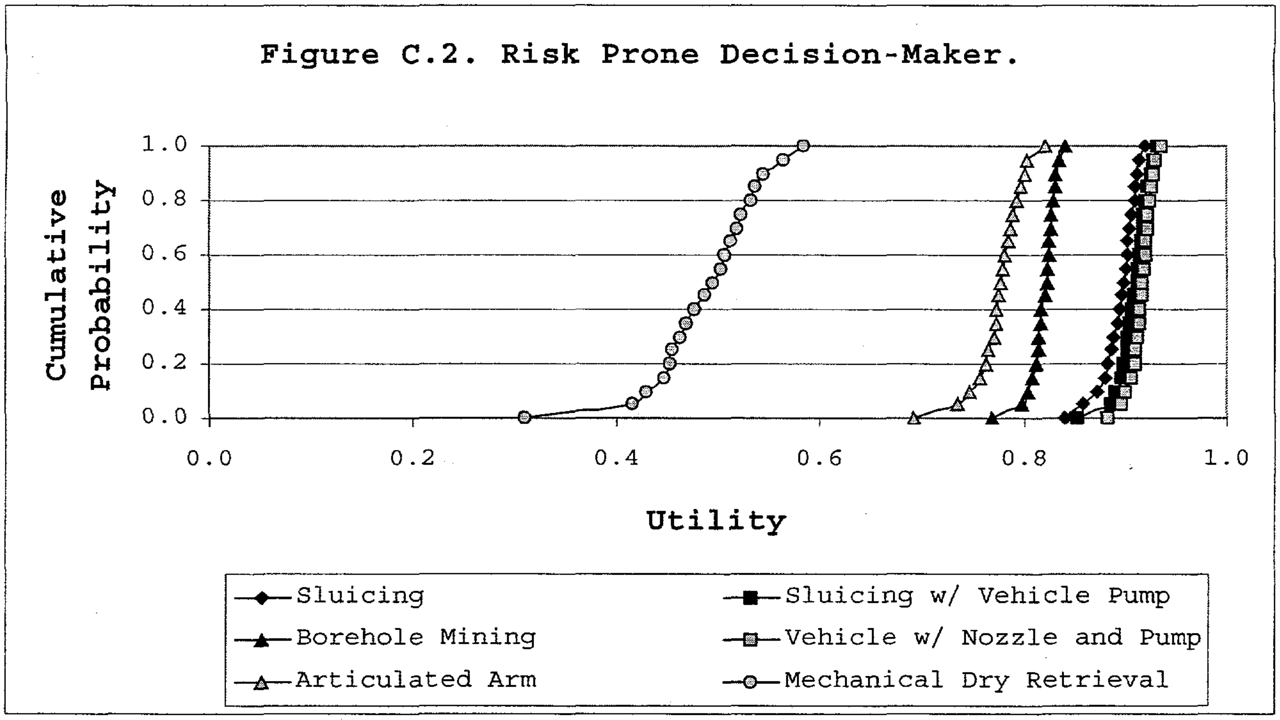


Figure C.2. Risk Prone Decision-Maker.
Cumulative Probability
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
Utility
Sluicing
Borehole Mining
Articulated Arm
Sluicing w/ Vehicle Pump
Vehicle w/ Nozzle and Pump
Mechanical Dry Retrieval

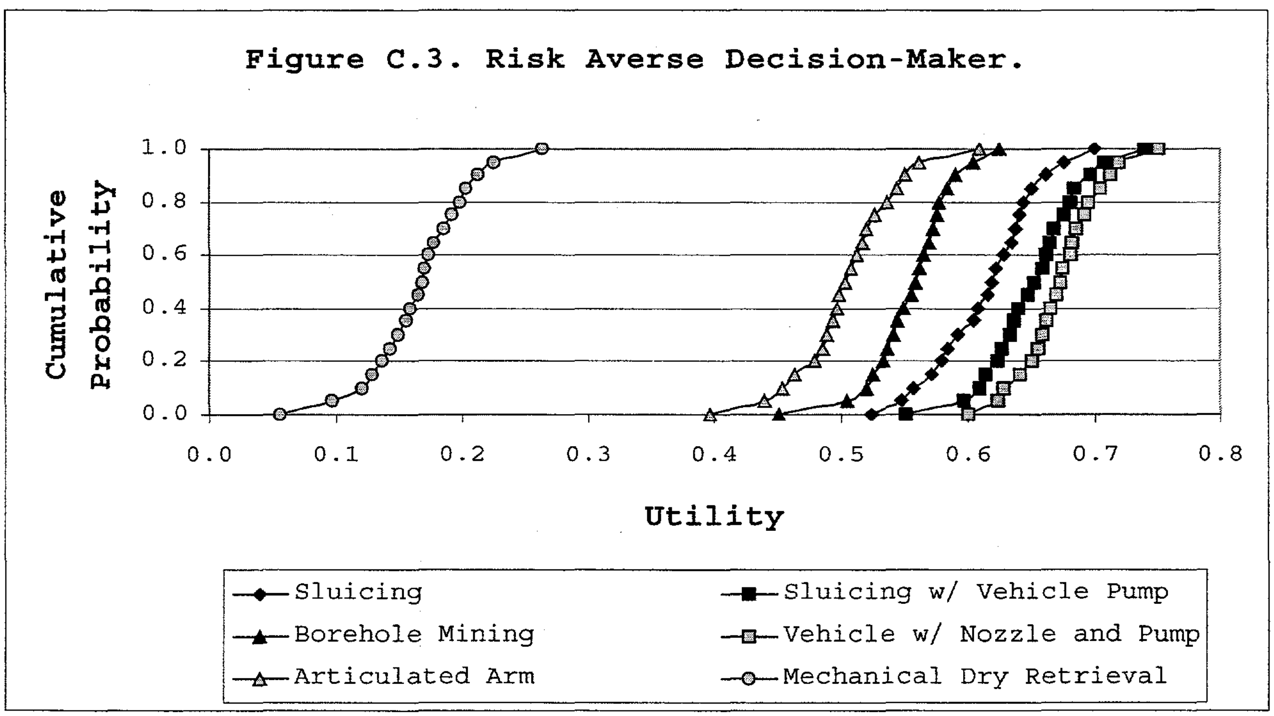


Figure C.3. Risk Averse Decision-Maker.
Cumulative Probability
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Utility
Sluicing
Borehole Mining
Articulated Arm
Sluicing w/ Vehicle Pump
Vehicle w/ Nozzle and Pump
Mechanical Dry Retrieval

Appendix D Utility Dependence on Relative Importance of Deployment and Operations

The purpose of this Appendix is to provide the cumulative distributions for the variation in the relative importance of meeting the base case deployment schedule and meeting the one year waste feed delivery requirement. It is assumed that the Decision-Maker perspective corresponds to the level-weighting scheme.

Figure D.1. Deployment/Operations Relative Importance 3:1.

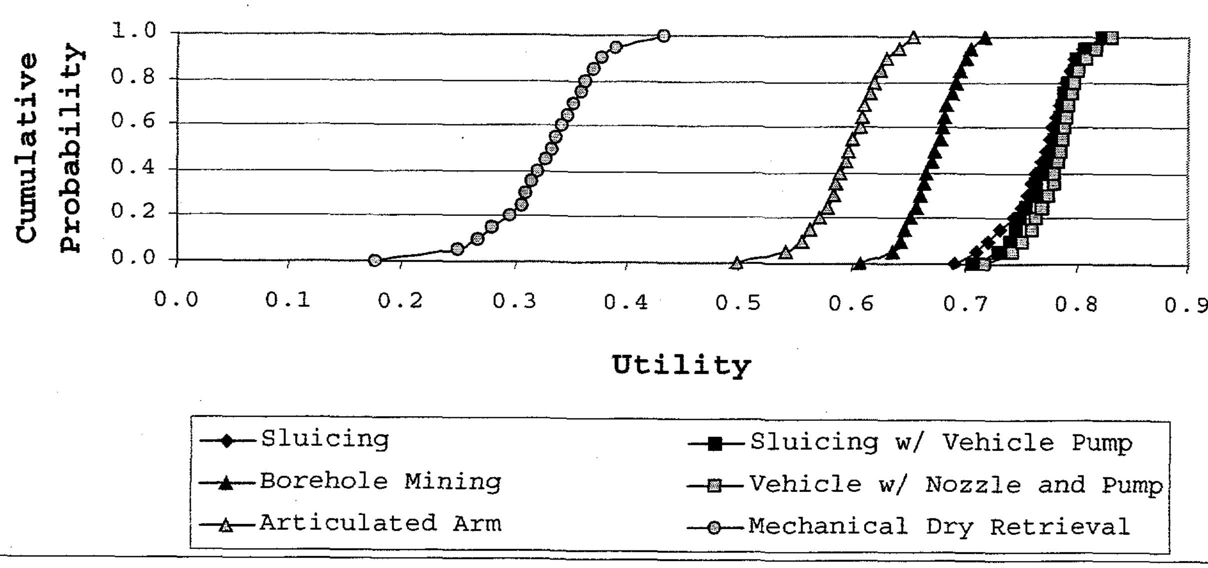


Figure D.2. Deployment/Operations Relative Importance 1:1.

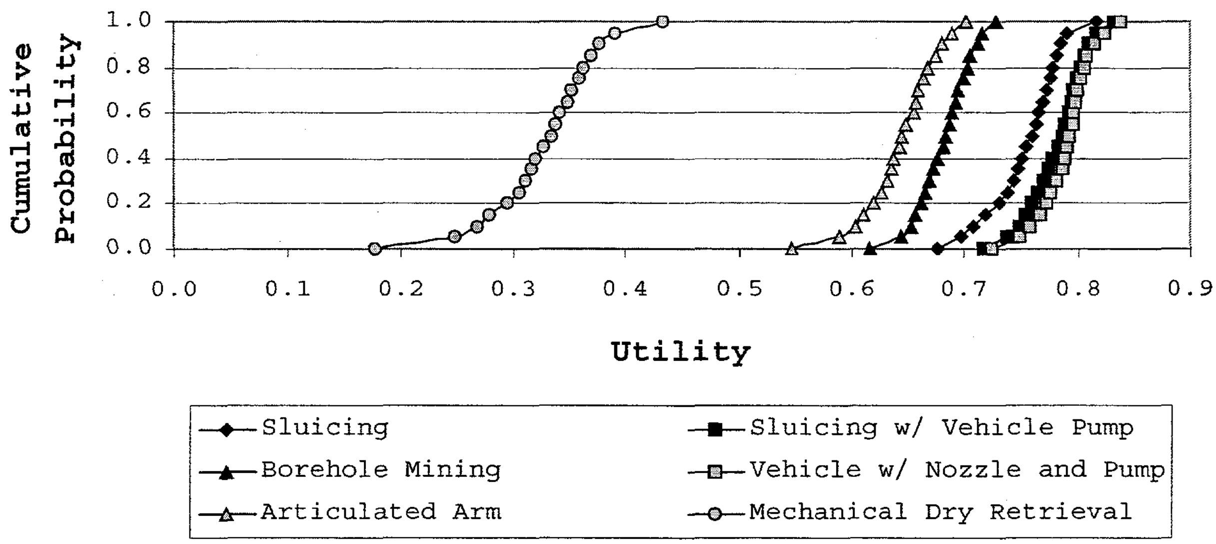
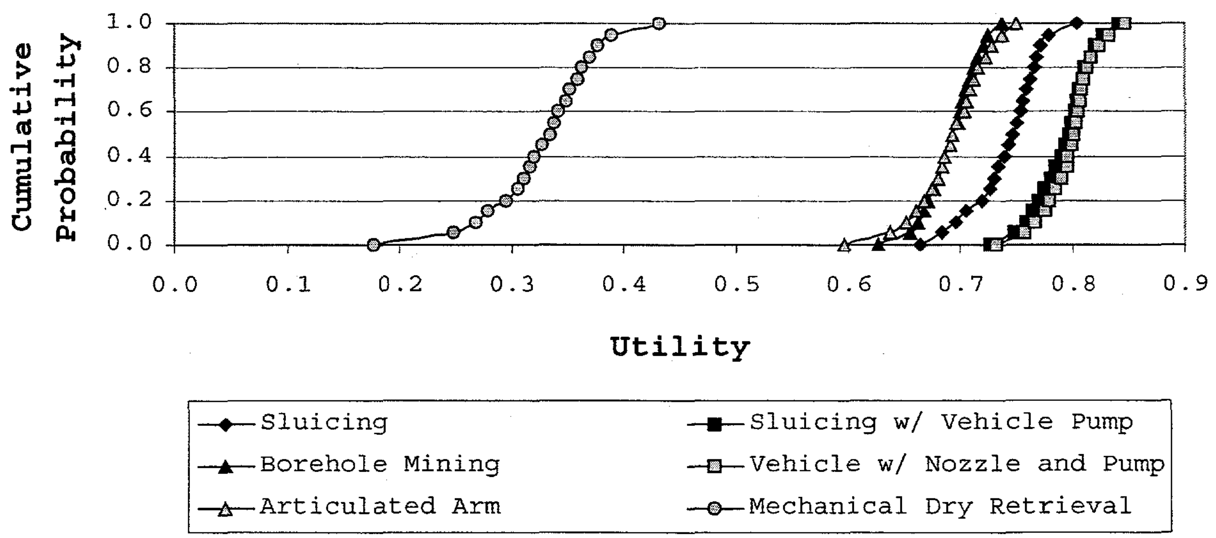


Figure D.3. Deployment/Operations Relative Importance 1:3.



Appendix E Analytica Model Text File

This appendix contains the text file that is the Analytica model used in this analysis.

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{ From user fjdavis, Model C104prelim at Wed, Aug 04, 1999 9:23 AM}
Softwareversion 1.1


{ System Variables with non-default values: }
Samplesize := 200
Windows := 2
Sampletype := 1
Typechecking := 1
Checking := 1
Graphwindows := 5
Saveoptions := 2
Savevalues := 0
Distresol := 25
Webhelper := -1
Allwarnings := 0


{ Non-default Time SysVar value: }
Time := [0,1,2]
Title Time: Time

Model C104prelim
Title: Final Model for Tank 241-C-104 Technology Alternatives
Author: fjdavis
Date: Wed, Mar 31, 1999 9:44 PM
Saveauthor: fjdavis
Savedate: Wed, Aug 04, 1999 9:23 AM
Defaultsize: 48,24
Diagstate: 1,4,4,478,511,17
Fontstyle: Arial, 13
Fileinfo: 0,Model C104prelim,1,2,0,E:\A_models\Hanford\C104 MUA Model~~
\Pc104d.ANA

Module Cost
Title: COST
Author: cgelcock
Date: Thu, Apr 01, 1999 11:43 AM
Defaultsize: 48,24
Nodelocation: 160,104
Nodesize: 72,24
Diagstate: 1,231,298,390,193,17

Module Life_cyclecosts
Title: Life CycleCosts
Author: cgelcock
Date: Thu, Apr 01, 1999 11:43 AM
Defaultsize: 48,24
Nodelocation: 256,96
Nodesize: 52,24
```

```
Diagstate: 1,94,33,469,428,17

Variable Project_costs_lc
Title: Project Costs LC
Units: dollars
Description: Summary of Estimated Life Cycle Costs from AGA Section 6~~
.1.1 draft received 3/31/1999
Definition: Table(Alternatives)(
69.3M,92.6M,82.9M,90.1M,104.5M,120.1M)
Nodelocation: 88,112
Nodesize: 52,24
Windstate: 1,56,191
Defnstate: 1,112,259,416,303,0,MIDM
Valuestate: 1,304,48,416,303,0,MIDM

Variable Operation_costs_lc
Title: Operation Costs LC
Units: dollars
Description: Summary of Estimated Life Cycle Costs from AGA draft rec~~
eived 3/31/1999
Definition: Table(Alternatives)(
5M,3.5M,5M,3.5M,3.5M,30M)
Nodelocation: 88,168
Nodesize: 52,24
Valuestate: 1,306,161,416,303,0,MIDM

Variable D_d_costs_lc
Title: D&D Costs LC
Units: dollars
Description: Summary of Estimated Life Cycle Costs from AGA Appendix ~~
A, draft dated 06/01/1999
Definition: Table(Alternatives)(
1.7M,1.8M,1.2M,1.1M,2.3M,3.2M)
Nodelocation: 88,224
Nodesize: 52,24
Valuestate: 1,168,182,416,303,0,MIDM

Chance Life_cycle_costs
Title: Life Cycle Costs
Units: dollars
Definition: Project_cost_distrib+Op___d_d_cost_distri
Nodelocation: 216,264
Nodesize: 48,24
Windstate: 1,34,20
Defnstate: 1,414,158,416,303,0,MIDM
Valuestate: 1,91,123,527,319,1,CDFP
Graphsetup: Graphtool:0~
Distresol:10~
Diststeps:1~
Cdfresol:5~
Cdfsteps:1~
Symbolsize:6~
Linestyle:10~
Frame:2~
Grid:0~
Ticks:1~
Mesh:1~
```

```
Scales:1~
Rotation:45~
Tilt:0~
Depth:70~
Frameauto:1~
Showkey:1~
Xminimum:0~
Xmaximum:500M~
Yminimum:0~
Ymaximum:1~
Zminimum:1~
Zmaximum:6~
Xintervals:0~
Yintervals:0~
Includexzero:0~
Includeyzero:0~
Includezzero:0~
Statsselect:[1, 1, 1, 1, 1, 0, 0, 0]~
Probindex:[5%, 25%, 50%, 75%, 95%]~

Fontstyle: Times New Roman, 8

Objective Life_cycle_cost_uf
Title: Life Cycle Cost UF
Definition: If(Risk_tolerance='neutral') then (Max_life_cycle_cost-Lc~~
_cost_incl_funding)/(Max_life_cycle_cost-Min_life_cycle_cost) else ~
if (Risk_tolerance='prone') then~
(-Lc_cost_incl_funding^2+2*(Lc_cost_incl_funding-Max_life_cycle_cost)~~
*Min_life_cycle_cost+Max_life_cycle_cost^2)/(Max_life_cycle_cost-Min_~~
life_cycle_cost)^2 else~
if (Risk_tolerance='averse') then~
(Lc_cost_incl_funding-Max_life_cycle_cost)^2/(Max_life_cycle_cost-Min~~
_life_cycle_cost)^2 else 999
Nodelocation: 336,352
Nodesize: 48,24
Windstate: 1,498,60
Valuestate: 1,122,56,514,378,1,CDFP
Graphsetup: Graphtool:0~
Distresol:25~
Diststeps:1~
Cdfresol:5~
Cdfsteps:1~
Symbolsize:6~
Linestyle:1~
Frame:1~
Grid:1~
Ticks:1~
Mesh:1~
Scales:1~
Rotation:45~
Tilt:0~
Depth:70~
Frameauto:1~
Showkey:1~
Xminimum:0~
Xmaximum:0.8~
Yminimum:0~
```

```
Ymaximum:1~
Zminimum:1~
Zmaximum:6~
Xintervals:0~
Yintervals:0~
Includexzero:0~
Includeyzero:0~
Includezzero:0~
Statsselect:[1, 1, 1, 1, 1, 0, 0, 0]~
Probindex:[5%, 25%, 50%, 75%, 95%]~


Variable Max_life_cycle_cost
Title: Max Life Cycle Cost
Definition: 250M
Nodelocation: 216,376
Nodesize: 48,24
Valuestate: 1,88,98,416,303,0,MIDM

Variable Min_life_cycle_cost
Title: Min Life Cycle Cost
Definition: 50M
Nodelocation: 216,328
Nodesize: 48,24
Valuestate: 1,120,130,416,303,0,MIDM

Variable Lc_cost_incl_funding
Title: LC Cost incl Funding Profile Adjustment
Definition: Life_cycle_costs+Incremental_cost_of_ +~
Closure_cost_requir1
Nodelocation: 336,264
Nodesize: 48,40
Windstate: 1,42,176
Valuestate: 1,128,95,490,304,0,STAT
Numberformat: 1,D,4,0,0,0

Variable Closure_action_requi
Title: Closure cost required to meet RCRA
Description: This value is the cost required to get the tank from the~~
 condition of that quantity of waste that remains after exercising th~~
e technology to its expected depolyment capability to the state of me~~
eting the RCRA requirements (by volume) for closure.
Definition: Table(Alternatives)(
25M,5M,30M,10M,2M,10M)
Nodelocation: 104,48
Nodesize: 76,32
Windstate: 1,102,90
Valuestate: 1,264,274,416,303,0,MIDM

Variable Closure_cost_requir1
Title: Closure Cost Required
Definition: if(Fraction_waste_left_>0) then Closure_action_requi*Meet~~
_rcra_closure_re else 0
Nodelocation: 336,48
Nodesize: 48,32

Chance Project_cost_distrib
```

```
Title: Project Cost Distribution
Description: Uniform((Project_costs_lc/(1+Cost_risk_contingenc/100)*L~~
ower_contingency_mu),(Project_costs_lc/(1+Cost_risk_contingenc/100)*U~~
pper_contingency_mu))
Definition: Normal(Project_costs_lc,Project_costs_lc*Contingency_half~~
_ran)
Nodelocation: 216,112
Nodesize: 48,24
Valuestate: 1,152,166,463,279,0,STAT

Chance Op___d_d_cost_distri
Title: Op + D&D Cost Distribution
Definition: Uniform((D_d_costs_lc+Operation_costs_lc)*(1-Operational_~~
cost_unc),(D_d_costs_lc+Operation_costs_lc)*(1+Operational_cost_unc))~~

Nodelocation: 216,192
Nodesize: 48,32
Valuestate: 1,168,182,416,303,0,STAT

Close Life_cyclecosts

Module Funding_profile
Title: Funding Profile Managability
Author: cgelcock
Date: Thu, Apr 01, 1999 11:43 AM
Defaultsize: 48,24
Nodelocation: 136,56
Nodesize: 52,32
Diagstate: 1,7,215,592,270,17

Variable Funding_profile1
Title: Funding Profile
Units: dollars
Description: A Matrix of funding versus year versus alternative
Definition: Table(Alternatives,Cost_years)(
6M,7.3M,5.9M,17.8M,15.8M,15.6M,1M,0,0,0,0,
8.7M,12.5M,12.4M,21.2M,17.9M,18.9M,900K,0,0,0,0,
7.9M,9.8M,7.6M,22M,16.9M,17.6M,1.1M,0,0,0,0,
8.7M,12.3M,11M,21.4M,13.7M,21.1M,900K,0,0,0,0,
9.8M,13.3M,13.7M,22.5M,16M,18.9M,10.4M,0,0,0,0,
11.4M,17.6M,17.8M,15.1M,17.9M,17.9M,17.3M,5.2M,0,0,0
)
Nodelocation: 64,56
Nodesize: 52,24
Windstate: 1,261,35
Defnstate: 1,41,179,524,301,0,MIDM
Valuestate: 1,19,154,475,303,0,MIDM
Reformdef: [Alternatives, Cost_years ]
Reformval: [Alternatives, Cost_years ]

Variable Funding_profile_mean
Title: Funding Profile Mean
Description: Determine the mean annual funding. The purpose is for th~~
e determination of a variation parameter in order to quantify 'Fundin~~
g Profile'
Definition: Sum(Funding_profile1,Cost_Years)/A_n_
Nodelocation: 128,120
```

```
Nodesize: 52,24
Windstate: 1,271,28
Valuestate: 1,135,-4,163,209,0,MIDM

Variable Funding_profile_sd
Title: Funding Profile SD
Description: This function is not precisely the Standard deviation. I~~
t probably should be checked at some point, referenced etc. However, ~~
it is not material since the value is ONLY intended to represent the ~~
fluctuation in necessary annual funding levels.
Definition: Sqrt( Sum(((Funding_profile1-Funding_profile_mean)^2)/(A_~~
n_),Cost_years) )
Nodelocation: 248,120
Nodesize: 52,24
Windstate: 1,271,28
Valuestate: 1,73,128,227,235,0,MIDM
Reformval: [Alternatives, Cost_years ]

Variable Determine__n__for_ye
Title: Determine 'n' for years
Definition: If(Funding_profile1<>0) then 1 else 0
Nodelocation: 184,56
Nodesize: 52,24
Valuestate: 1,72,82,416,303,0,MIDM
Reformval: [Alternatives, Cost_years ]

Variable A_n_
Title: 'n'
Definition: Sum(Determine__n__for_ye,Cost_years)
Nodelocation: 304,56
Nodesize: 52,24
Valuestate: 1,88,98,416,303,0,MIDM

Variable Incremental_cost_of_
Title: Incremental Cost of Funding Manageability
Definition: Funding_profile_sd
Nodelocation: 400,120
Nodesize: 72,28
Valuestate: 1,118,299,185,255,0,MIDM
Graphsetup: Graphtool:0~
Distresol:25~
Diststeps:1~
Cdfresol:5~
Cdfsteps:1~
Symbolsize:6~
Linestyle:9~
Frame:1~
Grid:1~
Ticks:1~
Mesh:1~
Scales:1~
Rotation:45~
Tilt:0~
Depth:70~
Frameauto:0~
Showkey:1~
Xminimum:1~
```

```
Xmaximum:7~
Yminimum:0~
Ymaximum:200M~
Zminimum:1~
Zmaximum:1~
Xintervals:0~
Yintervals:2~
Includexzero:0~
Includeyzero:0~
Includezzero:0~
Statsselect:[1, 1, 1, 1, 1, 0, 0, 0]~
Probindex:[5%, 25%, 50%, 75%, 95%]~

Fontstyle: Arial, 2

Close Funding_profile

Module Cost_risk
Title: Cost Risk
Author: cgelcock
Date: Thu, Apr 01, 1999 11:43 AM
Defaultsize: 48,24
Nodelocation: 136,128
Nodesize: 52,24
Diagstate: 1,180,54,468,260,17

Variable Cost_uncertainty_tab
Title: Cost Uncertainty Table~
(qualitative)
Definition: Table(Alternatives)(
'Moderate','Moderate','Slightly High','Slightly High','Extreme','Extr~~
eme')
Nodelocation: 160,48
Nodesize: 48,40
Defnstate: 1,549,262,198,205,0,MIDM
Valuestate: 1,104,118,416,303,0,MIDM

Variable Cost_risk_contingenc
Title: Cost Risk Contingency
Definition: Table(Alternatives)(
25,35,40,35,40,50)
Nodelocation: 160,120
Nodesize: 48,24
Windstate: 1,52,26
Defnstate: 1,56,70,195,226,0,MIDM

Variable Contingency_half_ran
Title: Contingency Half Range
Description: it is assumed from the Cost Estimating Guidelines that t~~
he Range from lower limit to upper limit is related to the square of ~~
the the value of the contingency at that stage of development. ~

Definition: (0.0074*Cost_risk_contingenc^2-0.2037*Cost_risk_contingen~~
c+6.2963)/100
Nodelocation: 160,184
Nodesize: 48,24
Windstate: 1,236,176
```

```
Variable Upper_contingency_mu
Title: Upper Contingency Multiplier
Definition: 1+Cost_risk_contingenc/100+Contingency_half_ran
Nodelocation: 288,120
Nodesize: 48,32
Valuestate: 1,294,157,416,303,0,MIDM

Variable Lower_contingency_mu
Title: Lower Contingency Multiplier
Definition: 1+Cost_risk_contingenc/100-Contingency_half_ran
Nodelocation: 288,184
Nodesize: 48,32
Valuestate: 1,132,156,416,303,0,MIDM

Variable Operational_cost_unc
Title: Operational/D&D Cost Uncertainty
Definition: If (Cost_uncertainty_tab='Moderate') then 0.1 else~
If (Cost_uncertainty_tab='Slightly High') then 0.125 else~
If (Cost_uncertainty_tab='Extreme') then 0.15 else~
99
Nodelocation: 288,48
Nodesize: 48,32
Valuestate: 1,120,134,416,303,0,MIDM

Close Cost_risk

Close Cost

Module Schedule
Title: SCHEDULE
Author: cgelcock
Date: Thu, Apr 01, 1999 11:43 AM
Defaultsize: 48,24
Nodelocation: 160,48
Nodesize: 72,24
Diagstate: 1,240,45,445,327,17

Module Deployment
Title: Deployment Schedule
Author: cgelcock
Date: Thu, Apr 01, 1999 11:43 AM
Defaultsize: 48,24
Nodelocation: 128,48
Nodesize: 52,24
Diagstate: 1,165,69,399,146,17

Variable Deployment_date
Title: Deployment Date
Definition: Choice(Self,1)
Nodelocation: 112,48
Nodesize: 48,24
Aliases: Formnode Deployment_date1
Domain: ['EOY 6','MOY 7','EOY 7','MOY 8','EOY 8','MOY 9','EOY 9','MOY~~
 10','EOY 10']

Variable Confidence_of_meetin
```

```
Title: Confidence of Meeting Deployment Date
Description: There are only a few points for which Confidence of depl~~
oyability by a date is provided. The remainder of the table is comple~~
ted assumeing that confidence increases by 10% every 3 moths up to 75~~
% confidence and then increases by 5% every 3 months thereafter up to~~
 95%. Confidence is assumed to remain at 95% for one year and then be~~
come 99% for the remainder of time period considered.~
~
FJD 5/03/99~
~
Only the first confidence level is provided by the AGA. The first non~~
-zero value in each column is consistent with the AGA as of 6/15/99. ~~
FJD
Definition: Table(Deployment_date,Alternatives)(
95,75,35,75,0,0,
96,90,55,90,10,0,
97,95,75,95,40,10,
98,96,90,96,65,26,
99,97,95,97,90,42,
99,98,96,98,95,58,
99,99,97,99,96,74,
99,99,98,99,97,90,
99,99,99,99,98,95
)
Nodelocation: 248,48
Nodesize: 48,40
Windstate: 1,102,90
Defnstate: 1,136,146,507,301,0,MIDM
Valuestate: 1,88,102,570,300,0,MIDM
Reformdef: [Alternatives, Deployment_date ]
Reformval: [Alternatives, Deployment_date ]
Numberformat: 1,F,4,0,0,0

Close Deployment

Module Operating
Title: Operating Schedule
Author: cgelcock
Date: Thu, Apr 01, 1999 11:43 AM
Nodelocation: 128,112
Nodesize: 52,24
Diagstate: 1,51,27,515,520,17

Chance Retrieval_rate__shif
Title: Retrieval Rate (shifts)
Units: shifts
Description: This is the number of shifts required to remove the mini~~
mum quantity (85%) of solid waste volume. The tabular values will req~~
uire updating as the AGA data is revised.~
~
This is the best case number of shifts required.~
This number will be coupled with technical maturity and number of mov~~
ing parts which affect the uncertainty of maintaining the system to d~~
efine the system maintainability and THUS the ability of the alternat~~
ive to meet the operations schedule.~
~
Last revision based on Appendix E of the 90% AGA~
```

```
FJD 6/15/1999  [25,11,25,13,13,148]~
~
In order to identify the sensitivity to this value, an uncertainty of~~
 +/-2 has been applied.~
~
FJD
Definition: Table(Alternatives)(
Uniform(23,27),Uniform(9,13),Uniform(23,27),Uniform(11,15),Uniform(11~~
,15),Uniform(146,150))
Nodelocation: 72,136
Nodesize: 52,24
Windstate: 1,102,94
Defnstate: 1,282,158,325,221,0,MIDM
Valuestate: 1,147,30,263,211,0,MIDM

Chance Efficiency_that_is_n
Title: Efficiency That is not Alternative Specific
Description: This is the range of efficiency that is attributable to ~~
factors that are not alternative specific.~
~
FJD 5/03/99~
~
Uniform 0 to 50% based on email from AGA Authors.~
FJD 6/10/99
Definition: Uniform( 0, 0.5 )
Nodelocation: 192,184
Nodesize: 84,24
Valuestate: 1,200,210,416,303,1,PDFP

Variable Retrival_rate
Title: Retrival Rate
Description: This element of the decision model will need to be revis~~
ed. The issue of efficiency must be considered in terms if 1) non-alt~~
ernative specific efficiency, 2) alternative specific efficiency, and~~
 3) semi-catstrophic downtimes. Items 2 and 3 can be considered toghe~~
ther or seperately, provided that they are defined appropriately.~
~
FJD 5/20/99
Definition: (Retrieval_rate__shif+Meet_rcra_closure_re*Shifts_remain~~
ing_to_/Retrieval_inefficien)*(1.0/Efficiency_that_is_n)+Failure_dura~~
tion
Nodelocation: 288,136
Nodesize: 56,24
Windstate: 1,296,263
Valuestate: 1,153,244,544,194,0,STAT
Graphsetup: Graphtool:0~
Distresol:25~
Diststeps:1~
Cdfresol:5~
Cdfsteps:1~
Symbolsize:6~
Linestyle:10~
Frame:1~
Grid:1~
Ticks:1~
Mesh:1~
Scales:1~
```

```
Rotation:45~
Tilt:0~
Depth:70~
Frameauto:0~
Showkey:1~
Xminimum:0~
Xmaximum:500~
Yminimum:0~
Ymaximum:1~
Zminimum:1~
Zmaximum:6~
Xintervals:0~
Yintervals:0~
Includexzero:0~
Includeyzero:0~
Includezzero:0~
Statsselect:[1, 1, 1, 1, 1, 0, 0, 0]~
Probindex:[5%, 25%, 50%, 75%, 95%]~

Fontstyle: Arial, 4

Variable Shifts_available_to_
Title: Shifts Available to Meet 1 year Delivery
Description: IT is assumed that the number of shifts available in one~~
 year is 50 weeks per year and 5 twelve-hour shifts per week.~
~
FJD 5/04/99
Definition: 50*5
Nodelocation: 408,104
Nodesize: 56,32
Valuestate: 1,104,114,416,303,0,MIDM

Variable Confidence_of_meeti1
Title: Confidence of Meeting Operating Schedule
Definition: If(Shifts_available_to_/Retrival_rate>1.0) then 1.0 else ~~
(0)
Nodelocation: 408,208
Nodesize: 52,40
Valuestate: 1,82,104,568,240,0,STAT

Index Failure_mode
Title: Failure Mode
Definition: ['transfer line plugging','transfer line leak','sluicer f~~
ailure','pump failure','C farm booster pump failure','decant pump fai~~
lure','AY farm booster pump failure','car/UMS failure','borehole fail~~
ure','waste separator failure','arm failure','conveyance/separator fa~~
ilure']
Nodelocation: 64,256
Nodesize: 48,24
Windstate: 1,106,94

Variable Probability_of_failu
Title: Probability of Failure per Shift by failure type
Definition: Table(Alternatives,Failure_mode)(
2m,1m,5m,2m,2m,2m,2m,0,0,0,0,0,
2m,1m,2.5m,0,2m,2m,2m,0.01111111,0,0,0,0,
2m,1m,0,0.1,2m,2m,2m,0,0.016666667,8m,0,0,
```

```
2m,1m,0,0,2m,2m,2m,0.016666667,0,0,0,0,
2m,1m,0,0,2m,2m,2m,0,0,0,8m,0.011111111,
2m,1m,0,0,2m,2m,2m,0,0,0,8m,0.01666667
)
Nodelocation: 64,320
Nodesize: 52,40
Valuestate: 1,75,70,640,320,0,MIDM
Reformdef: [Alternatives, Failure_mode ]
Reformval: [Alternatives, Failure_mode ]
Numberformat: 1,F,4,3,0,0

Chance Probability_of_fail1
Title: Failure/Non-Failure (0/1)
Definition: Bernoulli( (1-Probability_of_failu)^Retrieval_rate__shif ~~
)
Nodelocation: 176,320
Nodesize: 52,24
Valuestate: 1,37,7,497,409,0,STAT

Chance Failure_time
Title: Failure Time
Definition: Table(Failure_mode)(
Uniform(10,30),Uniform(120,360),Uniform(30,60),Uniform(60,90),Uniform~~
(30,60),Uniform(60,90),Uniform(30,60),Uniform(30,60),Uniform(90,120),~~
Uniform(10,30),Uniform(120,360),Uniform(30,360))
Nodelocation: 176,392
Nodesize: 48,24
Windstate: 1,245,16
Defnstate: 1,462,191,454,333,0,MIDM
Valuestate: 1,168,178,416,303,0,STAT
Numberformat: 1,F,4,0,0,0

Variable Failure_duration
Title: Failure Duration
Definition: Sum(Failure_time*(Probability_of_fail1-1)*-1,Failure_mode~~
)
Nodelocation: 288,352
Nodesize: 52,24
Valuestate: 1,119,73,516,230,0,STAT

Variable Shifts_remaining_to_
Title: Shifts Remaining to meet RCRA
Definition: Fraction_waste_left_*Retrieval_rate__shif
Nodelocation: 144,64
Nodesize: 56,32

Variable Retrieval_inefficien
Title: Retrieval Inefficiency Factor Near RCRA Volumes
Definition: Choice(Self,2)
Nodelocation: 288,56
Nodesize: 56,48
Valuestate: 1,56,66,416,303,0,MIDM
Domain: [0.1,0.2,0.3,0.4,0.5]

Chance Op_sched_confidence
Title: Op Sched Confidence
Description: Mean(Confidence_of_meetil)
```

```
Definition: Mean(Confidence_of_meeti1)
Nodelocation: 408,304
Nodesize: 56,24
Valuestate: 1,56,66,416,303,1,MIDM
Graphsetup: Graphtool:0~
Distresol:25~
Diststeps:1~
Cdfresol:5~
Cdfsteps:1~
Symbolsize:6~
Linestyle:10~
Frame:1~
Grid:1~
Ticks:1~
Mesh:1~
Scales:1~
Rotation:45~
Tilt:0~
Depth:70~
Frameauto:0~
Showkey:1~
Xminimum:0~
Xmaximum:1~
Yminimum:-2~
Ymaximum:2~
Zminimum:1~
Zmaximum:5~
Xintervals:0~
Yintervals:0~
Includexzero:0~
Includeyzero:0~
Includezzero:0~
Statsselect:[1, 1, 1, 1, 1, 0, 0, 0]~
Probindex:[5%, 25%, 50%, 75%, 95%]~

Fontstyle: Arial, 6

Close Operating

Objective Schedule_metric_base
Title: Schedule Metric Based on Confidence of Meeting Schedule
Description: The Schedule attribute is assumed to be composed of meet~~
ing each of the two schedule requirements. Meeting the deployment sch~~
edule is described as a %confidence. Meeting the operations schedule ~~
is expressed as a ratio of the time required to complete the operatin~~
g requirements to the operating reqiorement, expressed in twelve-hour~~
 shifts.~
~
FJD 5/04/99
Definition: Op_sched_confidence*Fraction_of_schedule+Confidence_of_me~~
etin/100*(1-Fraction_of_schedule)
Nodelocation: 256,80
Nodesize: 48,56
Windstate: 1,224,211
Valuestate: 1,29,155,500,377,1,MIDM
Graphsetup: Graphtool:0~
Distresol:10~
```

```
Diststeps:1~
Cdfresol:5~
Cdfsteps:1~
Symbolsize:6~
Linestyle:1~
Frame:1~
Grid:1~
Ticks:1~
Mesh:1~
Scales:1~
Rotation:45~
Tilt:0~
Depth:70~
Frameauto:1~
Showkey:1~
Xminimum:0~
Xmaximum:1~
Yminimum:0~
Ymaximum:1~
Zminimum:1~
Zmaximum:6~
Xintervals:0~
Yintervals:0~
Includexzero:0~
Includeyzero:0~
Includezzero:0~
Statsselect:[1, 1, 1, 1, 1, 0, 0, 0]~
Probindex:[5%, 25%, 50%, 75%, 95%]~

Reformval: [Deployment_date, Alternatives ]

Variable Schedule_metric_max
Title: Schedule Metric Max
Definition: 1
Nodelocation: 128,176
Nodesize: 48,24

Variable Schedule_metric_min
Title: Schedule Metric Min
Definition: 0
Nodelocation: 128,224
Nodesize: 48,24

Objective Schedule_uf
Title: Schedule UF
Definition: If(Risk_tolerance='neutral') then (Schedule_metric_base-S~~
chedule_metric_min)/(Schedule_metric_max-Schedule_metric_min) else ~
if (Risk_tolerance='prone') then~
(-Schedule_metric_base^2+2*(Schedule_metric_base-Schedule_metric_min)~~
*Schedule_metric_max+Schedule_metric_min^2)/(Schedule_metric_min-Sche~~
dule_metric_max)^2 else~
if (Risk_tolerance='averse') then~
(Schedule_metric_base-Schedule_metric_min)^2/(Schedule_metric_min-Sch~~
edule_metric_max)^2 else 999
Nodelocation: 256,200
Nodesize: 48,24
Windstate: 1,102,45
```

```
Valuestate: 1,103,108,416,303,0,MIDM
Reformval: [Alternatives, Deployment_date ]

Variable Fraction_of_schedule
Title: Fraction of Schedule weight placed on Operating Schedule
Definition: Choice(Self,2)
Nodelocation: 368,80
Nodesize: 48,56
Aliases: Formnode Fraction_of_schedul1
Domain: [0.25,0.5,0.75,1]

Close Schedule

Module Environmental_impact
Title: ENVIRONMENTAL IMPACTS
Author: cgelcock
Date: Thu, Apr 01, 1999 11:43 AM
Defaultsize: 48,24
Nodelocation: 160,160
Nodesize: 72,24
Diagstate: 1,72,63,578,460,17

Variable Hardware_remaining
Title: Hardware Remaining~
(items)
Description: The value represents the number of items remaining in th~~
e tank after waste removal. The number of items must be removed and t~~
reated prior to tank closure.~
This value is provided by the AGA~
~
FJD 6/16/99
Definition: Table(Alternatives)(
5,5,6,6,5,5)
Nodelocation: 72,168
Nodesize: 52,32
Windstate: 1,214,172
Defnstate: 1,254,302,416,303,0,MIDM
Valuestate: 1,56,70,416,303,0,MIDM

Variable Waste_remaining
Title: Minimum Waste Remaining
Description: This is the number of gallons of waste remaining in the ~~
tank at the point that redeployment or modification is necessary to r~~
etrieve additional waste.~
This quantity drives whether or not additional measures are required ~~
in order to achieve closure.~
The closure requirement is specified in one of the higher level docum~~
ents. ~
~
Denaturate water has been discounted from this value.~
~
Data from AGA revision as of 6/16/99 FJD with the following exception~~
. A value of 100 gallons has been entered for Alternative 4b in order~~
 that each alternative can be modelled similarly and avoid numerical ~~
errors associated with the zero value. This is deemed to have zero im~~
pact on the results.~
~
```

```
Definition: Table(Alternatives)(
20.72K,3200,6400,3200,100,37.5K)
Nodelocation: 72,248
Nodesize: 52,32
Windstate: 1,240,100
Defnstate: 1,298,196,416,303,0,MIDM
Valuestate: 1,521,38,237,234,0,MIDM
Numberformat: 1,F,4,0,0,0

Chance Waste_remaining_unce
Title: Waste Remaining Uncertainty
Definition: Triangular( Waste_remaining*(1-Waste_remaining___un), Was~~
te_remaining, Waste_remaining*(1+Waste_remaining___un) )
Nodelocation: 192,248
Nodesize: 52,32
Valuestate: 1,56,66,505,470,1,CDFP

Objective Environmental_impac1
Title: Environmental Impact Metric
Description: It is assmed that the Enviromental Impact Metric consist~~
s of Leak Potential, Waste Remaining in the tank, and Hardware Remain~~
ing in the tank. ~
These quantities are weighted as follows:~
Leak Potential 1.0~
Hardware Remaining 0.1~
Waste Remaining 10
Definition: 0.1*Hardware_remaining+Leak_potential_2+10*Waste_remainin~~
g_unce+Waste_generated
Nodelocation: 312,168
Nodesize: 64,24
Windstate: 1,353,155
Valuestate: 1,144,52,511,327,0,STAT
Graphsetup: Graphtool:0~
Distresol:25~
Diststeps:1~
Cdfresol:5~
Cdfsteps:1~
Symbolsize:6~
Linestyle:1~
Frame:1~
Grid:1~
Ticks:1~
Mesh:1~
Scales:1~
Rotation:45~
Tilt:0~
Depth:70~
Frameauto:1~
Showkey:1~
Xminimum:0~
Xmaximum:500K~
Yminimum:0~
Ymaximum:1~
Zminimum:1~
Zmaximum:6~
Xintervals:0~
```

```
Yintervals:0~
Includexzero:0~
Includeyzero:0~
Includezzero:0~
Statsselect:[1, 1, 1, 1, 1, 0, 0, 0]~
Probindex:[5%, 25%, 50%, 75%, 95%]~


Constant Rcra_waste_remaining
Title: RCRA waste remaining closure criterion
Description: Based on 360 ft3~
converted by~
0.00058 ft3 per in3~
231 in3 per gallon
Definition: 2700
Nodelocation: 392,392
Nodesize: 76,28
Valuestate: 1,232,242,416,303,0,MIDM

Variable Environmental_impac2
Title: Environmental Impact UF
Description: 1-Environmental_impac1/500000
Definition: If(Risk_tolerance='neutral') then (Environmental_metri1-E~~
nvironmental_impac1)/(Environmental_metri1-Environmental_metric) else~~
 ~
if (Risk_tolerance='prone') then~
(-Environmental_impac1^2+2*(Environmental_impac1-Environmental_metri1~~
)*Environmental_metric+Environmental_metri1^2)/(Environmental_metri1-~~
Environmental_metric)^2 else~
if (Risk_tolerance='averse') then~
(Environmental_impac1-Environmental_metri1)^2/(Environmental_metri1-E~~
nvironmental_metric)^2 else 999~

Nodelocation: 456,224
Nodesize: 60,24
Windstate: 1,43,166
Valuestate: 1,70,105,559,412,1,CDFP
Graphsetup: Graphtool:0~
Distresol:25~
Diststeps:1~
Cdfresol:5~
Cdfsteps:1~
Symbolsize:6~
Linestyle:1~
Frame:1~
Grid:1~
Ticks:1~
Mesh:1~
Scales:1~
Rotation:45~
Tilt:0~
Depth:70~
Frameauto:1~
Showkey:1~
Xminimum:0~
Xmaximum:1~
Yminimum:0~
```

```
Ymaximum:1~
Zminimum:1~
Zmaximum:6~
Xintervals:0~
Yintervals:0~
Includexzero:0~
Includeyzero:0~
Includezzero:0~
Statsselect:[1, 1, 1, 1, 1, 0, 0, 0]~
Probindex:[5%, 25%, 50%, 75%, 95%]~


Variable Waste_remaining___un
Title: Waste Remaining % Unc
Definition: Table(Alternatives)(
0.2,0.2,0.4,0.2,0.4,0.4)
Nodelocation: 72,312
Nodesize: 52,24
Valuestate: 1,136,146,416,303,0,MIDM

Variable Likely_waste_remaini
Title: Likely Waste Remaining
Definition: (50000-Waste_remaining)*Waste_remaining___un +Waste_remai~~
ning
Nodelocation: 192,312
Nodesize: 48,24
Windstate: 1,439,49
Valuestate: 1,159,96,416,303,0,MIDM

Variable Environmental_metric
Title: Environmental Metric Min
Definition: 0
Nodelocation: 320,80
Nodesize: 56,24
Windstate: 1,38,28

Variable Environmental_metri1
Title: Environmental Metric Max
Definition: 600k
Nodelocation: 432,80
Nodesize: 56,24

Variable Meet_rcra_closure_re
Title: Meet RCRA Closure Requirement (Y=1/N=0)
Definition: Choice(Self,1)
Nodelocation: 104,392
Nodesize: 88,28
Aliases: Formnode Meet_rcra_closure_r1
Domain: [0,1]

Variable Fraction_waste_left_
Title: Fraction Waste left to Meet RCRA
Definition: if(Waste_remaining_unce>Rcra_waste_remaining)  then (Wast~~
e_remaining_unce-Rcra_waste_remaining)/250k else 0
Nodelocation: 392,304
Nodesize: 48,32
Windstate: 1,102,90
```

```
Valuestate: 1,243,212,587,330,0,SAMP
Reformval: [Alternatives, Run ]

Module Leak_potential_model
Title: Leak Potential Model
Author: fjdavis
Date: Sun, Jun 20, 1999 6:29 AM
Nodelocation: 192,96
Nodesize: 48,32
Diagstate: 1,104,151,447,226,17

Variable Catastrophic_leak_po
Title: Catastrophic Leak Potential
Description: The volume of catastrophic leak potential from the AGA 9~~
0%~
~
FJD 6/16/99
Definition: Table(Alternatives)(
31K,31K,30K,16.5K,16.5K,2500)
Nodelocation: 136,64
Nodesize: 56,24
Valuestate: 1,40,54,416,303,0,MIDM
Numberformat: 1,F,4,0,0,0

Variable Non_catastrophic_lea
Title: Non-Catastrophic Leak Potential
Description: The Non-Catastrophic leak potential volume from the AGA ~~
90%~
FJD 6/16/99
Definition: Table(Alternatives)(
6860,6180,5760,3170,3170,2500)
Nodelocation: 136,136
Nodesize: 56,32
Valuestate: 1,168,182,416,303,0,MIDM
Numberformat: 1,F,4,0,0,0

Chance Leak_potential_2
Title: Leak Potential 2
Description: This is believed to be a conservative estimate of the le~~
ak potential. It does, regardless of actual risk/consequence consider~~
ations, put all alternatives on an equal metric.~
~
The leak potential is assumed to be triangular between zero and the c~~
atastrophic leak potential with a mode at the non-catastrophic leak p~~
otential. Values are expressed as a volume.~
~
FJD 6/16/99
Definition: Triangular(0,Non_catastrophic_lea,Catastrophic_leak_po)
Nodelocation: 272,104
Nodesize: 56,24
Valuestate: 1,168,178,611,324,1,CDFP

Close Leak_potential_model

Module Waste_generation
Title: Waste Generation
Author: fjdavis
```

Date: Sun, Jun 20, 1999 6:29 AM
Nodelocation: 192,40
Nodesize: 48,24
Diagstate: 1,83,76,455,283,17

Variable Const_ops_waste
Title: Const/Ops Waste
Description: Values in cubic feet.~
~
From AGA 90%~
~
FJD 6/16/99
Definition: Table(Alternatives)(
2080,1590,890,1770,2040,1870)
Nodelocation: 136,64
Nodesize: 56,24
Valuestate: 1,120,134,416,303,0,MIDM

Variable D_d_waste
Title: D&D Waste
Description: Values in cubic feet.~
~
From AGA 90%~
~
FJD 6/16/99
Definition: Table(Alternatives)(
1660,3250,2980,3250,6060,7060)
Nodelocation: 136,136
Nodesize: 56,24
Valuestate: 1,136,150,416,303,0,MIDM

Variable Waste_generated
Title: Waste Generated
Description: Waste Generated is assumed to include Const/Ops Waste an~~
d D& D Waste ONLY, DS T Waste being equal for all alternatives.~
This value is converted from ft3 to gallons~
Based on 0.00058 ft3 per in3 and 231 in3 per gallon~
~
FJD 6/16/99
Definition: ((Const_ops_waste+D_d_waste)/0.00058/231)*Generic_generat~~
ed_wa
Nodelocation: 280,64
Nodesize: 56,24
Windstate: 1,461,45
Valuestate: 1,120,130,416,303,1,PDFP

Chance Generic_generated_wa
Title: Generic Generated Waste Uncertainty (Normal +/-20%)
Description: This is a generic uncertainty multiplier to be applied t~~
o the Waste Generated. ~
~
The assumed distribution is normal with mean = 1 and SD = 0.2~
~
FJD 6/16/99
Definition: Normal(1, 0.2)
Nodelocation: 280,136
Nodesize: 72,40

```
Close Waste_generation

Close Environmental_impact

Module Public___worker_heal
Title: PUBLIC & WORKER HEALTH & SAFETY
Author: cgelcock
Date: Thu, Apr 01, 1999 11:43 AM
Defaultsize: 48,24
Nodelocation: 160,216
Nodesize: 72,24
Diagstate: 1,105,101,399,344,17

Module Radiation_exposure
Title: Radiation Exposure
Author: cgelcock
Date: Thu, Apr 01, 1999 11:43 AM
Nodelocation: 88,64
Nodesize: 52,24
Diagstate: 1,42,52,649,453,17

Variable Construction
Title: Construction
Description: Radiation exposure in R during the construction phase.~
(From the time of entry to the timeof re-entry based on review presen~~
tation materials Alt 4b changed from 10 to 40 plz check)~
~
FJD - 4/01/1999~
confirmed from 60% AGA presentation viewgraphs 5/03/99 FJD
Definition: Table(Alternatives)(
40,25,10,30,40,25)
Nodelocation: 208,32
Nodesize: 52,24

Constant Operations_baseline
Title: Operations Dose Relative to Baseline
Units: R
Description: This is the qualitative expression of operations radiati~~
on exposure. It is noted that the Baseline is 'past practice sluicing~~
'~
~
FJD - 4/30/1999
Definition: Table(Alternatives)(
'Baseline','Moderately Higher','Moderately Higher','Moderately Higher~~
','Substantially Higher','Substantially Higher')
Nodelocation: 80,168
Nodesize: 52,32
Valuestate: 1,88,102,416,303,0,MIDM

Constant Equipment_removal_ba
Title: Equipment Removal Dose Relative to Baseline
Units: R
Description: This value is the qualitative assessment of dose relativ~~
e to the baseline technology alternative (sluicing).~
~
FJD - 4/30/1999
```

```
Definition: Table(Alternatives)(
'Baseline','Moderately Higher','Substantially Higher','Moderately Hig~~
her','Moderately Higher','Substantially Higher')
Nodelocation: 80,264
Nodesize: 52,40
Valuestate: 1,104,118,416,303,0,MIDM

Variable Translator_of__relat
Title: Translator of 'Relative to Baseline'
Definition: If (Operations_Baseline='Baseline') then 1.0 else~
If (Operations_Baseline='Moderately Higher') then 1.2 else~
If (Operations_Baseline='Substantially Higher') then 1.5 else~
 100
Nodelocation: 208,176
Nodesize: 52,32
Windstate: 1,156,40
Valuestate: 1,56,70,416,303,0,MIDM

Chance Baseline_operations_
Title: Baseline Operations Dose w/ Uncertainty
Description: The operations dose is assumed to be a singular value fo~~
r the baseline retrieval technique (sluicing). ~
~
Consensus Operations Dose of 10 R +/- 5 R elicited from Greg Bogen an~~
d Will Pickett~
~
FJD 5/18/99
Definition: Uniform( 5, 15 )
Nodelocation: 208,104
Nodesize: 52,40
Valuestate: 1,120,134,416,303,1,PDFP

Chance Construction__dose_u
Title: Construction ~
Dose With Uncertainty
Description: It is assumed (arbitrarily) that the uncertainty in cons~~
truction dose consists of a linear uncertainty (5 red) plus some amou~~
nt that is a function of the predicted quantity (a normal distributio~~
n is assumed).~
~
FJD 4/30/99
Definition: Truncate(Normal(Construction,5+sqrt(Construction)),0.0)
Nodelocation: 336,40
Nodesize: 52,32
Valuestate: 1,120,134,416,303,1,PDFP
Graphsetup: Graphtool:0~
Distresol:25~
Diststeps:1~
Cdfresol:5~
Cdfsteps:1~
Symbolsize:6~
Linestyle:1~
Frame:1~
Grid:1~
Ticks:1~
Mesh:1~
Scales:1~
```

```
Rotation:45~
Tilt:0~
Depth:70~
Frameauto:1~
Showkey:1~
Xminimum:-20~
Xmaximum:80~
Yminimum:0~
Ymaximum:0.1~
Zminimum:1~
Zmaximum:6~
Xintervals:0~
Yintervals:0~
Includexzero:0~
Includeyzero:0~
Includezzero:0~
Statsselect:[1, 1, 1, 1, 1, 0, 0, 0]~
Probindex:[5%, 25%, 50%, 75%, 95%]~


Variable Operations_dose
Title: Operations Dose
Description: The operations dose is the Operations Baseline Dose with~~
 Uncertainty multiplied by the factor associated mwith the relative (~~
qualitative) assessment to the baseline case.~
~
FJD 4/30/99
Definition: Baseline_operations_*Translator_of__relat
Nodelocation: 336,136
Nodesize: 52,24
Valuestate: 1,136,150,416,303,1,PDFP

Variable Translator_of__rela1
Title: Translator of 'Relative to Baseline'
Description: The values were elicited informally from Greg Bogen and ~~
Will Pickett~
FJD 5/18/99
Definition: If (Equipment_removal_ba='Baseline') then 1.0 else~
If (Equipment_removal_ba='Moderately Higher') then 2.0 else~
If (Equipment_removal_ba='Substantially Higher') then 3.0 else~
 100
Nodelocation: 208,264
Nodesize: 56,32
Valuestate: 1,72,86,416,303,0,MIDM

Variable Equipment_removal_do
Title: Equipment Removal Dose
Definition: Baseline_equipment_r*Translator_of__rela1
Nodelocation: 336,304
Nodesize: 56,24
Valuestate: 1,88,102,416,303,1,PDFP
Graphsetup: Graphtool:0~
Distresol:25~
Diststeps:1~
Cdfresol:5~
Cdfsteps:1~
Symbolsize:6~
```

```
Linestyle:1~
Frame:1~
Grid:1~
Ticks:1~
Mesh:1~
Scales:1~
Rotation:45~
Tilt:0~
Depth:70~
Frameauto:1~
Showkey:1~
Xminimum:0~
Xmaximum:800~
Yminimum:0~
Ymaximum:0.02~
Zminimum:1~
Zmaximum:6~
Xintervals:0~
Yintervals:0~
Includexzero:0~
Includeyzero:0~
Includezzero:0~
Statsselect:[1, 1, 1, 1, 1, 0, 0, 0]~
Probindex:[5%, 25%, 50%, 75%, 95%]~


Chance Baseline_equipment_r
Title: Baseline Equipment Removal Dose w/ Uncertainty
Definition: Triangular( 50, 100, 150 )
Nodelocation: 208,344
Nodesize: 56,40
Valuestate: 1,136,150,416,303,1,PDFP

Objective Radiation_dose
Title: Radiation Dose
Description: The radiation dose is the sum of the construction dose, ~~
the operations dose and the equipment removal dose. ~
~
If it is desired to meet the RCRA closure requirement for volume, the~~
n the additional operations dose and an additional equipment removal ~~
dose are added. The second equipment removal dose is assumed equal to~~
 the first equipment removal dose. The operations dose is scaled by t~~
he numebr of shifts required. to meet the RCRA volume
Definition: Construction__dose_u +~
Equipment_removal_do +~
Operations_dose + Meet_rcra_closure_re*(Operations_dose_to_m+Equipmen~~
t_removal_do)
Nodelocation: 488,176
Nodesize: 56,24
Valuestate: 1,42,28,416,303,1,PDFP
Graphsetup: Graphtool:0~
Distresol:50~
Diststeps:1~
Cdfresol:5~
Cdfsteps:1~
Symbolsize:6~
Linestyle:1~
```

```
Frame:1~
Grid:1~
Ticks:1~
Mesh:1~
Scales:1~
Rotation:45~
Tilt:0~
Depth:70~
Frameauto:1~
Showkey:1~
Xminimum:0~
Xmaximum:800~
Yminimum:0~
Ymaximum:0.02~
Zminimum:1~
Zmaximum:6~
Xintervals:0~
Yintervals:0~
Includexzero:0~
Includeyzero:0~
Includezzero:0~
Statsselect:[1,1,1,1,1,0,0,0]~
Probindex:[0.05,0.25,0.5,0.75,0.95]~


Variable Operations_dose_to_m
Title: Operations Dose to meet RCRA
Definition: Operations_dose*Fraction_waste_left_/Retrieval_inefficien~~

Nodelocation: 336,208
Nodesize: 52,32
Windstate: 1,102,90

Close Radiation_exposure

Module Industrial_safety
Title: Industrial Safety
Author: cgelcock
Date: Thu, Apr 01, 1999 11:43 AM
Nodelocation: 88,120
Nodesize: 52,24
Diagstate: 1,242,97,481,423,17

Constant Pit_entries
Title: Pit Entries
Description: The number of pit entries.~
~
This information is extracted from the 60% AGA viewgraphs.~
Estimated error plus or minus 2~
FJD 5/03/99
Definition: Table(Alternatives)(
6,4,2,3,5,4)
Nodelocation: 96,56
Nodesize: 56,24

Constant Critical_lifts
Title: Critical Lifts
```

```
Description: The number of Critical Lifts.~
~
This information is extracted from the 90% AGA Table.~
~
Estimated error plus or minus 3~
FJD 6/16/99
Definition: Table(Alternatives)(
26,18,11,15,22,21)
Nodelocation: 96,184
Nodesize: 56,24
Valuestate: 1,264,278,416,303,0,MIDM

Chance Pit_entries_w__uncer
Title: Pit Entries w/ Uncertainty
Definition: Round (Uniform(Pit_entries-Uncertainty_in_pit_e,Pit_entri~~
es+Uncertainty_in_pit_e))
Nodelocation: 232,56
Nodesize: 56,24
Valuestate: 1,56,66,416,303,1,CDFP

Chance Critical_lifts_w__un
Title: Critical Lifts w/ Uncertainty
Definition: Round (Uniform(Critical_lifts-Uncertainty_in_criti,Critic~~
al_lifts+Uncertainty_in_criti))
Nodelocation: 232,184
Nodesize: 56,24
Valuestate: 1,72,82,674,312,1,CDFP
Graphsetup: Graphtool:0~
Distresol:10~
Diststeps:1~
Cdfresol:5~
Cdfsteps:1~
Symbolsize:6~
Linestyle:10~
Frame:1~
Grid:1~
Ticks:1~
Mesh:1~
Scales:1~
Rotation:45~
Tilt:0~
Depth:70~
Frameauto:0~
Showkey:1~
Xminimum:5~
Xmaximum:30~
Yminimum:0~
Ymaximum:0.2~
Zminimum:1~
Zmaximum:6~
Xintervals:0~
Yintervals:0~
Includexzero:0~
Includeyzero:0~
Includezzero:0~
Statsselect:[1, 1, 1, 1, 1, 0, 0, 0]~
Probindex:[5%, 25%, 50%, 75%, 95%]~
```

Fontstyle: Arial, 6

Variable Uncertainty_in_pit_e
Title: Uncertainty in Pit Entries
Description: Assumed arbitrarily to be +/- 2~
~
FJD 5/03/99
Definition: 2
Nodelocation: 96,112
Nodesize: 56,24

Variable Uncertainty_in_criti
Title: Uncertainty in Critical Lifts
Description: The uncertainty in the number of Critical Lifts Required~~
~
~
Arbitrarily assumed to be +/- 3.~
~
FJD 5/03/99
Definition: 3
Nodelocation: 96,240
Nodesize: 56,24

Variable Uncommon_hazards
Title: Uncommon Hazards
Description: This table indicates which Uncommon Hazard Types are pos~~
sible for each Alternative~
~
Reflects AGA 90%~
~
FJD 6/16/99
Definition: Table(Alternatives,Uncommon_hazard_type)(
1,0,0,0,0,0,0,
1,1,1,0,0,0,0,
1,1,1,0,0,0,0,
0,1,1,0,1,0,0,
1,1,1,1,1,1,0,
1,1,1,1,0,0,1
)
Nodelocation: 96,312
Nodesize: 56,24
Defnstate: 1,4,117,768,356,0,MIDM
Reformdef: [Alternatives, Uncommon_hazard_type]

Variable A__of_uncommon_hazar
Title: # of Uncommon Hazards
Definition: Sum(Uncommon_hazards,Uncommon_hazard_type)
Nodelocation: 224,312
Nodesize: 52,32
Valuestate: 1,243,113,416,303,1,MIDM

Constant Weight_of_pit_entrie
Title: Weight of Pit Entries
Description: The Number of Pit Entries, Critical Lifts, and Uncommon ~~
Hazards are assumed to constitute the Industrial Safety Metric.~
~

It is assumed that these three values may be combined in some way. Th~~
e following was elicited from Greg Bogen and Will Pickett. ~
Pit Entries are equivalent to about 10 Critical Lifts.~
~
It was also elicited that the equivalence between Pit entries and rad~~
iation exposure (R) is made. Therefore, Industrial SAfety will be exp~~
ressed in terms of Pit Entries.~
~
FJD 5/18/99
Definition: 1.0
Nodelocation: 232,112
Nodesize: 52,24

Chance Weight_of_critical_l
Title: Weight of Critical Lifts~
(Uniform 0.1,1.0)
Description: The Number of Pit Entries, Critical Lifts, and Uncommon~~
 Hazards are assumed to constitute the Industrial Safety Metric.~
~
It is assumed that these three values may be combined in some way. Th~~
e following was elicited from Greg Bogen and Will Pickett. ~
Pit Entries are equivalent to about 10 Critical Lifts.~
~
It was also elicited that the equivalence between Pit entries and rad~~
iation exposure (R) is made. Therefore, Industrial Safety will be exp~~
ressed in terms of Pit Entries.~
~
FJD 5/18/99
Definition: Uniform(0.1, 1)
Nodelocation: 232,240
Nodesize: 52,40

Constant Weight_of_uncommon_h
Title: Weight of Uncommon Hazards
Description: The Number of Pit Entries, Critical Lifts, and Uncommon ~~
Hazards are assumed to constitute the Industrial Safety Metric.~
~
It is assumed that these three values may be combined in some way. Th~~
e following was elicited from Greg Bogen and Will Pickett. ~
Each Uncommon Hazard is equivalent to about 10 Critical Lifts.~
~
It was also elicited that the equivalence between Pit entries and rad~~
iation exposure (R) is made. Therefore, Industrial Safety will be exp~~
ressed in terms of Pit Entries.~
~
FJD 5/18/99
Definition: 1.0
Nodelocation: 224,376
Nodesize: 52,32

Variable Industrial_safety_me
Title: Industrial Safety Metric~
(Hazards)
Description: The Number of Pit Entries, Critical Lifts, and Uncommon ~~
Hazards are assumed to constitute the Industrial Safety Metric.~
~
It is assumed that these three values are combined linearly (their we~~

```
ights are assumed to sum to 1.0, no check is written for that sum)~
~
FJD 5/04/99
Definition: Pit_entries_w__uncer*Weight_of_pit_entrie + ~
Critical_lifts_w__un*Weight_of_critical_l + ~
A__of_uncommon_hazar*Weight_of_uncommon_h
Nodelocation: 392,200
Nodesize: 52,32
Windstate: 1,30,280
Valuestate: 1,88,102,416,303,1,CDFP
Graphsetup: Graphtool:0~
Distresol:20~
Diststeps:1~
Cdfresol:5~
Cdfsteps:1~
Symbolsize:6~
Linestyle:1~
Frame:1~
Grid:1~
Ticks:1~
Mesh:1~
Scales:1~
Rotation:45~
Tilt:0~
Depth:70~
Frameauto:1~
Showkey:1~
Xminimum:2.5~
Xmaximum:15~
Yminimum:0~
Ymaximum:1~
Zminimum:1~
Zmaximum:6~
Xintervals:0~
Yintervals:0~
Includexzero:0~
Includeyzero:0~
Includezzero:0~
Statsselect:[1,1,1,1,1,0,0,0]~
Probindex:[0.05,0.25,0.5,0.75,0.95]~


Chance Dose__in_rads__equiv
Title: Dose (in Rads) Equivalent to Industrial Safety
Description: It is assumed that the Industrial Safety and the Radiati~~
on Safety are to be combined into a single metric. Therefore, to comb~~
ine these values each unit of Industrial Safety must be equivalent to~~
 a certain number of Rads~
~
Based on discussion with Greg Bogen and Will Pickett (AGA Co-authors)~~
, single pit entries have been observed as 10 R and 15 R.~
~
In order to cover this range the dose per pit entry will be assumed u~~
niform on the range of 5 R to 20 R~
~
FJD 5/18/99
Definition: Uniform( 5, 20 )
```

```
Nodelocation: 392,296
Nodesize: 52,40
Windstate: 1,102,94
Valuestate: 1,152,162,416,303,1,PDFP
Aliases: Formnode Dose__in_rads__equil

Variable Industrial_hazards_t
Title: Industrial Hazards to meet RCRA
Definition: (Pit_entries_w__uncer*Weight_of_pit_entrie +
Critical_lifts_w__un*Weight_of_critical_l +
Weight_of_uncommon_h)
Nodelocation: 392,80
Nodesize: 56,32

Close Industrial_safety

Objective Safety_metric
Title: Safety Metric
Description: It is assumed that the Industrial Safety and the Radiati~~
on Safety are to be combined into a single metric. Therefore, to comb~~
ine these values each unit of Industrial Safety must be equivalent to~~
 a certain number of Rads.~
~
FJD 5/04/99
Definition: Radiation_dose+Industrial_safety_me*Dose__in_rads__equiv+~~
Meet_rcra_closure_re*Industrial_hazards_t
Nodelocation: 224,88
Nodesize: 48,24
Valuestate: 1,104,118,601,271,0,STAT

Variable Safety_metric_uf
Title: Safety Metric UF
Definition: If(Risk_tolerance='neutral') then (Safety_metric-Safety_m~~
etric___0) / (Safety_metric___1-Safety_metric___0) else ~
if (Risk_tolerance='prone') then~
(-Safety_metric^2+2*(Safety_metric-Safety_metric___0)*Safety_metric__~~
_1+Safety_metric___0^2)/(Safety_metric___0-Safety_metric___1)^2 else~
if (Risk_tolerance='averse') then~
(Safety_metric-Safety_metric___0)^2/(Safety_metric___0-Safety_metric_~~
__1)^2 else 999
Nodelocation: 224,232
Nodesize: 48,24
Windstate: 1,102,94
Valuestate: 1,120,130,416,303,1,CDFP

Constant Safety_metric___1
Title: Safety Metric = 1
Description: This is the value of the Safety Metric that corresponds ~~
to Maximum Utility =1~
~
FJD 5/04/99
Definition: 100
Nodelocation: 88,208
Nodesize: 48,24

Constant Safety_metric___0
Title: Safety Metric = 0
```

```
Description: This is the value of the Safety Metric that corresponds ~~
to 0 utility.~
~
FJD 5/04/99
Definition: 1400
Nodelocation: 88,256
Nodesize: 48,24

Close Public___worker_heal

Module Index_module
Title: Index Module
Author: cgelcock
Date: Thu, Apr 01, 1999 12:37 PM
Defaultsize: 48,24
Nodelocation: 224,360
Nodesize: 148,16
Nodeinfo: 1,0,0,1,1,1,0,,0,
Diagstate: 1,115,19,190,315,17

Index Alternatives
Title: Alternatives
Definition: ['Alt 1','Alt 2','Alt 3','Alt 4a','Alt 4b','Alt 5']
Nodelocation: 72,32
Nodesize: 52,24

Index Cost_years
Title: Cost Years
Description: This is the index for establishing a matrix of funding t~~
hrough years X to X+10.
Definition: ['FY X','FY X+1','FY X+2','FY X+3','FY X+4','FY X+5','FY~~
 X+6','FY X+7','FY X+8','FY X+9','FY X+10']
Nodelocation: 72,96
Nodesize: 52,24
Windstate: 1,650,56

Index Index1
Title: index
Definition: Sequence( 0, 50, 5 )
Nodelocation: 72,152
Nodesize: 48,24
Windstate: 1,491,353

Index Uncommon_hazard_type
Title: Uncommon Hazard Types
Definition: ['Remove Saltwell','Damage to ITH','Waste Above Grade','P~~
otential Unrecoverable Failure','Leak Aggrivation','Vacuum Damage to ~~
Tank','New Riser']
Nodelocation: 72,216
Nodesize: 48,32

Close Index_module

Module Utility
Title: UTILITY
Author: cgelcock
Date: Tue, May 04, 1999 5:53 PM
```

```
Nodelocation: 312,128
Nodesize: 52,28
Diagstate: 1,114,25,559,422,17

Variable Mua_weight_alternati
Title: MUA Weight Alternatives
Description: This table contains the attribute weights that represent~~
 the value judgements of the decision maker. Alternatives exist in or~~
der to parametrically investigate sensitivity to the value judgement.~~
~
~
A construct exists for selection of individual weighting schemes only~~
 to minimize clutter in the results and facilitate the decision analy~~
sis. It is possible to consider all of the available weighting combin~~
ations.~
~
FJD 5/05/99
Definition: Table(Attributes,Weighting_combinatio)(
0.25,0.5,0.15,0.15,0.25,
0.4,0.15,0.15,0.15,0.25,
0.15,0.15,0.5,0.2,0.25,
0.2,0.2,0.2,0.5,0.25
)
Nodelocation: 56,160
Nodesize: 56,24
Defnstate: 1,48,100,579,308,0,MIDM
Valuestate: 1,88,102,589,297,0,MIDM
Reformdef: [Attributes, Weighting_combinatio ]
Reformval: [Attributes, Weighting_combinatio ]

Index Attributes
Title: Attributes
Definition: ['Schedule','Cost','Enviromental Impact','Safety']
Nodelocation: 56,40
Nodesize: 52,24
Windstate: 1,0,13

Index Weighting_combinatio
Title: Weighting Combinations Index
Definition: ['Budget','Schedule','Stakeholder','Worker','Level Weight~~
']
Nodelocation: 176,40
Nodesize: 60,24

Objective Utility1
Title: Utility
Definition: Sum(Attribute_weightings*Table_of_attribute_v,Attributes)~~

Nodelocation: 328,200
Nodesize: 52,24
Windstate: 1,356,88
Valuestate: 1,27,12,677,366,0,STAT
Aliases: Formnode Utility2
Graphsetup: Graphtool:0~
Distresol:25~
Diststeps:1~
Cdfresol:5~
```

```
Cdfsteps:1~
Symbolsize:6~
Linestyle:10~
Frame:2~
Grid:3~
Ticks:1~
Mesh:1~
Scales:1~
Rotation:45~
Tilt:0~
Depth:70~
Frameauto:1~
Showkey:1~
Xminimum:0~
Xmaximum:1~
Yminimum:0~
Ymaximum:1~
Zminimum:1~
Zmaximum:6~
Xintervals:10~
Yintervals:5~
Includexzero:0~
Includeyzero:0~
Includezzero:0~
Statsselect:[1,1,1,1,1,0,0,0]~
Probindex:[0.05,0.25,0.5,0.75,0.95]~

Fontstyle: Arial, 2
Reformval: [Alternatives, Statistics1 ]

Variable Select_attribute_wei
Title: Select Attribute Weighting
Definition: Choice(Self,0)
Nodelocation: 176,96
Nodesize: 56,24
Aliases: Formnode Select_attribute_we1
Domain: ['Budget','Schedule','Stakeholder','Worker','Level Weight']

Variable Attribute_weightings
Title: Attribute Weightings in Use
Description: This Variable contains the attribute weight set selected~~
 for use in generating the Multi-attribute Utility currently investig~~
ated.~
~
It is possible to select ALL of the combinations of weighting and pro~~
pagate them. However, it is likely to be more difficult visually.~
~
FJD 5/05/99
Definition: Subscript(Mua_weight_alternati,Weighting_combinatio,Selec~~
t_attribute_wei)~

Nodelocation: 176,160
Nodesize: 56,32
Windstate: 1,154,81
Valuestate: 1,184,198,497,303,0,MIDM
Reformval: [Select_attribute_wei, Attributes ]
```

```
Variable Table_of_attribute_v
Title: Table of Attribute Values
Description: This variable exists ONLY as a convenient place to store~~
 the single attribute utility distributions, prior to multiplication ~~
with the attribute weights.~
~
FJD 5/05/99
Definition: Table(Attributes)(
Schedule_metric_base,Life_cycle_cost_uf,Environmental_impac2,Safety_m~~
etric_uf)
Nodelocation: 176,240
Nodesize: 56,32
Windstate: 1,29,111
Defnstate: 1,213,64,416,303,0,MIDM
Reformval: [Alternatives, Attributes ]

Variable Sensitivity_to_waste
Title: Sensitivity to Waste Remaining~
(%Util per kgal)
Definition: Dydx( Utility1, Waste_remaining_unce )*100*1k
Nodelocation: 328,128
Nodesize: 68,24
Valuestate: 1,104,118,565,324,0,MIDM
Reformval: [Select_attribute_wei, Alternatives ]
Numberformat: 1,E,2,2,0,0

Variable D_utility__d_attribu
Title: d(utility)/d(attribute)
Definition: dydx(Utility1,Table_of_attribute_v)
Nodelocation: 328,264
Nodesize: 52,24
Valuestate: 1,88,102,564,355,0,MIDM
Graphsetup: Graphtool:0~
Distresol:25~
Diststeps:1~
Cdfresol:5~
Cdfsteps:1~
Symbolsize:6~
Linestyle:9~
Frame:1~
Grid:1~
Ticks:1~
Mesh:1~
Scales:1~
Rotation:45~
Tilt:0~
Depth:70~
Frameauto:0~
Showkey:1~
Xminimum:1~
Xmaximum:7~
Yminimum:0~
Ymaximum:4~
Zminimum:1~
Zmaximum:6~
Xintervals:0~
Yintervals:0~
```

Includexzero:0~
Includeyzero:0~
Includezzero:0~
Statsselect:[1, 1, 1, 1, 1, 0, 0, 0]~
Probindex:[5%, 25%, 50%, 75%, 95%]~

Fontstyle: Arial, 6
Reformval: [Attributes, Alternatives]

Variable Alt_1_utility_slice
Title: Alt 1 Utility Slice
Description: Slice(Slice(Slice(Utility1, select_attribute_weighting_~~
combination, 5),deployment_date,1),Alternatives,1)
Definition: Slice(Slice(Utility1, deployment_date,1),Alternatives,1)~~

Nodelocation: 472,152
Nodesize: 56,24
Windstate: 1,170,388
Valuestate: 1,26,257,668,249,0,STAT
Graphsetup: Graphtool:0~

Distresol:25~

Diststeps:1~

Cdfresol:5~

Cdfsteps:1~

Symbolsize:6~

Linestyle:1~

Frame:1~

Grid:1~

Ticks:1~

Mesh:1~

Scales:1~

Rotation:45~

Tilt:0~

Depth:70~

Frameauto:1~

Showkey:1~

Xminimum:0.2~

Xmaximum:0.9~

Yminimum:0~

Ymaximum:1~

Zminimum:1~

Zmaximum:6~

Xintervals:0~

Yintervals:0~

Includexzero:0~

Includeyzero:0~

Includezzero:0~

Statsselect:[1, 1, 1, 1, 1, 0, 0, 0]~

Probindex:[5%, 25%, 50%, 75%, 95%]~

Reformval: [Alternatives, Statistics1]

Variable Alt_2_utility_slice
Title: Alt 2 Utility Slice
Definition: Slice(Slice(Utility1,deployment_date,1),Alternatives,2)
Nodelocation: 472,216
Nodesize: 56,24

Variable Alt_4a_utility_slice
Title: Alt 4a Utility Slice
Definition: Slice(Slice(Utility1,deployment_date,1),Alternatives,4)
Nodelocation: 472,272
Nodesize: 56,24

Objective Alt2_alt1
Title: Alt2/Alt1
Definition: Alt_2_utility_slice/Alt_1_utility_slice
Nodelocation: 400,336
Nodesize: 56,24
Valuestate: 1,40,54,905,544,0,CDFP
Graphsetup: Graphtool:0~

Distresol:25~

Diststeps:1~

Cdfresol:5~

Cdfsteps:1~

Symbolsize:6~

Linestyle:1~

Frame:1~

Grid:1~

Ticks:1~

Mesh:1~

Scales:1~

Rotation:45~

Tilt:0~

Depth:70~

Frameauto:1~

Showkey:1~

Xminimum:0.9~

Xmaximum:1.3~

Yminimum:0~

Ymaximum:1~

Zminimum:1~

Zmaximum:5~

Xintervals:0~

Yintervals:0~

Includexzero:0~

Includeyzero:0~

Includezzero:0~

Statsselect:[1, 1, 1, 1, 1, 0, 0, 0]~

Probindex:[5%, 25%, 50%, 75%, 95%]~

Reformval: [Select_attribute_wei, M_step.41]

Objective Alt4a_alt2
Title: Alt4a/Alt2
Definition: Alt_4a_utility_slice/Alt_2_utility_slice
Nodelocation: 264,336
Nodesize: 56,24
Valuestate: 1,431,166,509,412,1,CDFP
Graphsetup: Graphtool:0~

Distresol:25~

Diststeps:1~

Cdfresol:5~

Cdfsteps:1~

Symbolsize:6~

Linestyle:1~

Frame:1~

Grid:1~

Ticks:1~

Mesh:1~

Scales:1~

Rotation:45~

Tilt:0~

Depth:70~

Frameauto:1~

Showkey:1~

Xminimum:0~

Xmaximum:200~

Yminimum:0.9~

Ymaximum:1.1~

Zminimum:1~

Zmaximum:1~

Xintervals:0~

Yintervals:0~

Includexzero:0~

Includeyzero:0~

Includezzero:0~

Statsselect:[1, 1, 1, 1, 1, 0, 0, 0]~

Probindex:[5%, 25%, 50%, 75%, 95%]~

```
Reformval: [M_step.41, Select_attribute_wei ]

Close Utility

Formnode Utility2
Title: Utility
Definition: 1
Nodelocation: 224,280
Nodesize: 148,16
Nodeinfo: 1,0,0,1,0,1,0,,0,
Nodecolor: 65535,1,43696
Original: Utility1

Module Parametric_inputs
Title: Parametric Inputs
Author: cgelcock
Date: Tue, May 18, 1999 7:53 PM
Nodelocation: 224,320
Nodesize: 148,16
Nodeinfo: 1,0,0,1,1,1,0,,0,
Diagstate: 1,103,22,459,275,17

Formnode Select_attribute_we1
Title: Select Attribute Weighting
Definition: 0
Nodelocation: 240,104
Nodesize: 148,16
Nodeinfo: 1,0,0,1,0,1,1,,0,
Nodecolor: 19664,65535,19661
Nodefont: Times New Roman, 13
Original: Select_attribute_wei

Formnode Deployment_date1
Title: Deployment Date
Definition: 0
Nodelocation: 240,72
Nodesize: 148,16
Nodeinfo: 1,0,0,1,0,1,1,,0,
Nodecolor: 19664,65535,19661
Nodefont: Times New Roman, 13
Original: Deployment_date

Formnode Dose__in_rads__equi1
Title: Dose (in Rads) Equivalent to Industrial Safety
Definition: 0
Nodelocation: 240,40
Nodesize: 148,16
Nodeinfo: 1,0,0,1,0,1,1,,0,
Nodecolor: 19664,65535,19661
Nodefont: Times New Roman, 13
Original: Dose__in_rads__equiv

Variable Risk_tolerance
Title: Risk Tolerance
Definition: Choice(Self,2)
```

```
Nodelocation: 232,288
Nodesize: 48,24
Nodeinfo: 1,1,1,1,1,1,0,,0,
Windstate: 1,85,239
Aliases: Formnode Risk_tolerance1
Domain: ['averse','neutral','prone']

Formnode Risk_tolerance1
Title: Risk Tolerance
Definition: 0
Nodelocation: 240,136
Nodesize: 148,16
Nodeinfo: 1,0,0,1,0,1,1,,0,
Nodecolor: 19664,65535,19661
Nodefont: Times New Roman, 13
Original: Risk_tolerance

Formnode Meet_rcra_closure_r1
Title: Meet RCRA Closure Requirement (Y=1/N=0)
Definition: 0
Nodelocation: 240,168
Nodesize: 148,16
Nodeinfo: 1,0,0,1,0,1,1,,0,
Nodecolor: 19664,65535,19661
Nodefont: Times New Roman, 13
Original: Meet_rcra_closure_re

Formnode Fraction_of_schedul1
Title: Fraction of Schedule weight placed on Operating Schedule
Definition: 0
Nodelocation: 240,200
Nodesize: 148,16
Nodeinfo: 1,0,0,1,0,1,1,,0,
Nodecolor: 19664,65535,19661
Nodefont: Times New Roman, 13
Original: Fraction_of_schedule

Close Parametric_inputs

Close C104prelim
```

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