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Sensitivity Analyses of Alternative Methods for Disposition of High-Level Salt Waste: A Position Statement

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SAVANNAH RIVER SITE

HIGH LEVEL WASTE SALT DISPOSITION SYSTEMS ENGINEERING TEAM

POSITION PAPER

ON THE

SENSITIVITY ANALYSES OF ALTERNATIVE METHODS FOR DISPOSITION OF

HIGH LEVEL SALT WASTE

APPROVED: ______________________ DATE: 6/26/98
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SENSITIVITY ANALYSES OF ALTERNATIVE METHODS FOR DISPOSITION OF HIGH LEVEL SALT WASTE

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SENSITIVITY ANALYSES OF ALTERNATIVE METHODS FOR DISPOSITION OF HIGH LEVEL SALT WASTE(U)

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PURPOSE

The Savannah River Site (SRS) High Level Waste Salt Disposition Systems Engineering Team ("Team") was chartered (Reference 1) to systematically develop and recommend an alternative method for disposition of High Level Waste (HLW) Salt by the end of Fiscal Year 1998. The Team Charter prescribes a number of major milestones to be met in accomplishing the task. A key support activity for the downselect process is the detailed definition and use of weighted evaluation criteria to systematically evaluate the "Initial List" of alternatives for selection of the "Short List" (Reference 2).

This Position Paper provides the approach and detail pertaining to a sensitivity analysis for the Phase II definition of weighted evaluation criteria. The sensitivity analysis seeks to determine the potential effect of changes in evaluation criteria weights and utility function values on the total utility scores for each Initial List alternative due to uncertainty and bias in engineering judgment.

BACKGROUND

The DOE complex in the U.S., and other organizations worldwide, have been developing and implementing high level waste immobilization and disposal methods for the past several decades.

In Europe, as well as other foreign countries, waste has been predominately stored in a concentrated acid form in stainless steel tanks. Immobilization processes have then relied on direct vitrification of that waste stream. In the U.S. (SRS, Hanford, West Valley, Oak Ridge) the waste was neutralized with strong caustic and stored in carbon steel tanks. This separates the waste into an insoluble sludge fraction (about 10%) of hydrated metal oxides containing most of the radionuclides (strontium, plutonium, uranium, and others). The remaining salt solution is primarily sodium nitrate, hydroxide, and nitrite with cesium-137 as the predominant radionuclide. This is stored as a concentrated solution or saltcake.

At SRS, an organic precipitating agent (sodium tetraphenylborate) was selected as the preferred method of separating cesium and feeding that to the DWPF for treatment, mixing with the radioactive sludge, and feeding to the melter. The decontaminated salt (which is the bulk of the waste) can then be fed to a lower cost grouting facility for onsite disposal. The precipitation process was developed and demonstrated on a full scale radioactive tank in the mid 1980's. However, recent large scale tests and an extensive R&D program have shown operating and authorization basis drawbacks sufficient for SRS to re-evaluate the alternatives for salt treatment processes to minimize the risks.

TECHNICAL APPROACH

A strategy for sensitivity analysis of the Weighted Evaluation Criteria process (Reference 1) for the Initial List alternatives is presented. The strategy is multifaceted in that the following scenarios or simulations are evaluated.

1. Changing the Level 1 criteria weights.
2. Changing the Level 2 criteria weights.
3. Changing the combination of Level 1 and Level 2 weights.
4. Changing the utility function values.

The sensitivity analysis is done by statistical simulation as described in the remainder of this report. The primary analysis tool is SAS[1], Release 6.12, which is a commercial fourth generation computer programming language. JMP, Release 3.2.1, another commercial software package from SAS Institute, is also used for the technical review and substantiation of SAS results.

Simulation 1

Changing the Level 1 criteria weights

The Level 1(L1) weights, as recorded on the Evaluation Criteria Assessment Form (Reference 2), are shown in Table 1 below. These same weights are used for all 18 Initial List alternatives. The Minimum values in Table 1 correspond to a 10% decrease in the i^{th} Level 1 weight (W_i) while the Maximum corresponds to a 10% increase, for the i^{th} Level 1 weight.

Typically, in a sensitivity study, we review the impact on the rating outcome, i.e. the total utility score, for each alternative, for all 2^6 combinations of minimums and maximums. However, we are constrained by the fact that the sum of the L1 weights must equal unity. Therefore, the proper selection of weight combinations will lie on the surface defined by $\sum W_i = 1$.

The extreme vertices of this region were selected - points on the edges of the five dimensional region defined by the minimums and maximums, in addition to the centroid. This was implemented using the SAS ADXINIT and ADXXVERT macros (Reference 3) and resulted in 53 different combinations of L1 weights for sensitivity analysis. No Level 2 (L2) weights or utility function (UF) values will be varied in this simulation.

The L2 weights and utility function values will be as recorded on the Evaluation Criteria Assessment Form. The total utility scores will be generated for each of the 53 different combinations of L1 weights and for all of the 18 alternatives.

Table 1
Sensitivity Ranges for 10% Change in Level 1 Weights

Evaluation Criteria	L1 Weight (W_i)	10% Change Minimum	10% Change Maximum
1.0	0.23	0.207	0.253
2.0	0.15	0.135	0.165
3.0	0.07	0.063	0.077
4.0	0.23	0.207	0.253
5.0	0.20	0.180	0.220
6.0	0.12	0.108	0.132

The 53 combinations of L1 weights are shown in Table A1 in the Appendix. The total utility scores for all 18 alternatives will be statistically evaluated as indicated in the Data Analysis section of this position statement.

Simulation 2

Changing the Level 2 criteria weights.

The comprehensive approach consistent with the selected sensitivity test algorithm for simulation 1 would be to determine the extreme vertices for each set of L2 weights which require the sum-to-unity constraint. All possible combinations of each set with another would lead to a total of 42,875 combinations. Therefore, a more limited but technically justifiable sensitivity analysis of L2 criteria will be performed.

One weight within the L2 set (i.e. those L2 weights contained within a selected L1 evaluation criteria) will be changed by + or - 10% while the other L2 weights within that set will be proportionally decreased or increased, respectively, in order to preserve the sum-to-unity constraint. This process will be repeated for each of the other weights within the L2 set for all six L1 Evaluation Criteria. All other L2 weights outside of the selected set will be held constant at their nominal values (see Table 2).

The L2 weights as recorded on the Evaluation Criteria Assessment Form are presented in Table 2. These weights will remain the same for all 18 alternatives.

Table 2
Level 2 Weights

Evaluation Criteria	X.1	X.2	X.3	X.4	X.5
1.0	0.40	0.40	0.20		
2.0	0.25	0.15	0.10	0.20	0.30
3.0	1.00				
4.0	0.45	0.35	0.20		
5.0	0.25	0.25	0.25	0.25	
6.0	0.50	0.30	0.20		

Note: For Level 2 Evaluation Criteria, the identification number is described by X.1, X.2, etc. where "X" is the level 1 Evaluation Criteria number.

Consider evaluation criteria 1.0 to illustrate the procedure. We have transposed the weights for convenience in Table 3. Two examples are presented.

Table 3
Evaluation Criteria 1.0, Level 2 Weights

	10% Increase	10% Decrease
Situation 1		
X.1 0.40	0.440	0.360
X.2 0.40	0.373	0.427
X.3 0.20	0.187	0.213

Table 3 (cntd.)
Evaluation Criteria 1.0, Level 2 Weights

	10% Increase	10% Decrease
Situation 2		
X.1 0.40	0.373	0.427
X.2 0.40	0.440	0.360
X.3 0.20	0.187	0.213

Note: For Level 2 Evaluation Criteria, the identification number is described by X.1, X.2, etc. where "X" is the level 1 Evaluation Criteria number.

The L2 weights within L1 evaluation criteria 2.0 through 6.0 will be similarly adjusted, except for L1 evaluation criterion 3.0 which has no L2 weights. The L1 weights will not vary from their nominal values, i.e. those specified in the assessment forms, for this simulation. Since there are 18 L2 weights, 36 total utility scores will be generated for each of the 18 Initial List alternatives.

These scores will be statistically evaluated as indicated in the Data Analysis section below.

Simulation 3

Changing the combination of Level 1 and Level 2 weights

Changing the combination of L1 and L2 will be accomplished by pairing a single design point from the set of L1 extreme vertices with each design point in the set of 36 changes to L2 weights described above. We determined that changing the *product* of L1 and L2 weights by +/- 10% would not be appropriate because of the constraint that the sum of both the L1 and L2 weights, independently, must equal unity. Therefore, we choose to simultaneously adjust the L1 and L2 weights by pairs. To preserve the sum-to-unity constraint among L2 weights within each evaluation criterion, the increase by 10% to one L2 weight was decreased proportionately among the other L2 weights within that evaluation criterion. All other L2 weights were held constant at their nominal values. Again, since their are 18 L2 weights, there will be 36 design points for the one-at-a-time increase of decrease to a given weight.

We will determine all test combinations of weights from both Simulations 1 and 2. The total utility scores will be generated for each of the 18 alternatives by crossing the 53 L1 weight combinations from Simulation 1 with all 36 L2 weight combinations from Simulation 2. This will result in 53 x 36 = 1,908 combinations or total utility scores per alternative.

These scores will be statistically evaluated as indicated in the Data Analysis section below.

Simulation 4

Changing the utility function values.

Each of the 19 utility function (UF) values that comprise an alternative will be adjusted by a fixed percentage of the entire scale, one value at a time. Once a value is selected for adjustment, all others will remain at their nominal values. For this simulation, the L1 and L2 weights will remain constant at their nominal values regardless.

Specifically, each utility function value will be adjusted by p= ±20% of the entire scale (i.e. in utility units). If, for example, UF is 60, this will result in considering UF=80 and UF= 40. Note that the UF is constrained to lie between 0 and 100. In this case, there will be 38 different total utility scores associated with each of the 18 alternatives.

These scores will be statistically evaluated as indicated in the Data Analysis section below.

DATA ANALYSIS

The average total utility score, average rank, minimum, maximum, and standard deviation will be calculated for each alternative for each simulation run. In addition, a Box-and-Whisker Plot will be produced to show the range and variation in total utility scores for each of the 18 Initial List alternatives. A graphic will be produced to show the Box-and-Whisker Plots for all 18 alternatives. One such graphic will be produced for each simulation.

Each Box-and-Whisker plot will display the minimum and maximum values, the 25th, 50th(median) and 75th percentiles, and the mean. The box will be aligned vertically and enclose the interquartile range(the 25th to 75th percentile). The upper part of the box represents the 75th percentile while the lower part represents the 25th percentile. Extreme points will also be shown (whiskers) extending from the box. Figure A1 in the Appendix is an example.

The Box-and-Whisker Plots will show how the top Short List alternatives (targeted to be approximately 5), i.e. those with the highest total utility scores calculated from their nominal values, will compare when allowing for theoretical uncertainty or bias in the measurement of total utility. In addition, the Box-and-Whisker Plots will show if there are close competitors to the Short List alternatives.

The ranking of the Short List alternatives will be determined once the Evaluation Criteria Assessments Forms are completed and will be based on the nominal values specified by the Team. The robustness of the Short List alternatives to changing the L1 and L2 weights and also the Utility Function Values will be determined as described above. The ordering of alternatives for presentation in the graphic of Box-and-Whisker Plots described above will be determined by a ratio value (R_i). We define

$$R_i = \frac{IQR_i}{Median_i}$$

as the ratio of the interquartile range (IQR_i) to the 50^{th} percentile ($Median_i$) for the i^{th} Initial List alternative. That alternative with the smallest R_i value will be ordered first (i.e. the highest rank of 1), while the largest R_i value will be ordered last (i.e. receive the lowest rank of 18). This ordering process will aid in the comparison of alternatives among the four simulations.

In addition, the computer programs can be re-run in later "what if" scenarios for a different value in percentage change (p) among weights or utility function values. Initially, p=10% for L1 weights and L2 weights individually and p=20 units among utility function values.

R. A. Anderson will produce all SAS programming code to both generate the total utility scores data, Box-and-Whisker Plot graphics, and tables of summary statistics.

SOFTWARE VERIFICATION AND VALIDATION (V&V)

The primary software package employed in deriving the sensitivity analysis results is SAS, Release 6.12. JMP Release 3.2.1 will be used by the technical reviewer to verify the generation of extreme vertices for the Evaluation Criterion 1, and as verification of total utility scores by each of the four simulations performed in SAS. Both programs are commercial off the shelf software (COTS). Both programs are statistical tools that have been previously employed to perform statistical analyses at SRS. In this application the programs perform standard statistical and arithmetic base functions as well as vendor supplied algorithmic functions. The algorithms were constructed and placed within the program to provide a tailored structure to the analysis and to appropriately relate and execute SAS and JMP base functions during the analysis. These algorithmic functions and procedures in SAS and those in the JMP formula calculator are not products of the SRTC statisticians, but are technically maintained by the vendor. A verification of the correctness of the sensitivity algorithm developed by SRTC statisticians in SAS was performed using the JMP software. A validation of the software performance (i.e. programming results) will be accomplished by analyzing a representative sample of input data and comparing output data to a hand calculated output for each of the four sensitivity analyses. This calculation by an alternative method also verified the SAS and JMP base functions. Two design points and the centroid will be selected at random for each of the four proposed simulations. A design point is a single set of values for L1 and L2 weights, for a single set of utility functions values (i.e. one of the 18 alternatives). Total utility scores were generated by calculator for all 12 design points. These scores were compared to the scores produced by the SAS program and technically verified by the JMP software. The justification for the sample selection will be verified by the technical reviewer and the difference between the results, if any, will also be verified to lie within an acceptable error band (i.e. 3 significant figures per number) suitable for this application.

The V&V method for the SAS and JMP software as described above is consistent with the E7 procedures in Reference 4. Documented algorithm verification, representative sample selection verification, and error band acceptability review is documented in Reference 5. The sample selection statement, input data, output data, hand calculation and error band definition, and software V&V is documented in Reference 6.

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3. SAS/QC® Software: Reference. 1989. Version 6 First Addition. Cary, NC: SAS Institute Inc., 660pp.

4. Conduct of Engineering and Technical Support Procedure Manual, E7, "Engineering Calculations(U)," Procedure 2.31, Rev. 0, September 30, 1993.

5. WSMS-SAE-M-98-00068, Memorandum From George R. Morton to Gavin C. Winship, "Review of the Sensitivity Analysis Algorithm Employed for the Prioritization of the ITP Alternatives Dated June 24, 1998".

6. SRT-SCS-98-027 Software Verification and Validation for Sensitivity Analyses of Alternative Methods for Disposition of High Level Salt Waste. June 23, 1998.

APPENDIX

Table A1

**Extreme Vertices for Evaluation of Level 1 Weights
Assuming up to a 10% Change**

	Level 1 Weight					
Run	**W1**	**W2**	**W3**	**W4**	**W5**	**W6**
1	0.253	0.165	0.077	0.207	0.180	0.118
2	0.253	0.165	0.077	0.207	0.190	0.108
3	0.253	0.165	0.077	0.217	0.180	0.108
4	0.253	0.165	0.063	0.207	0.180	0.132
5	0.253	0.165	0.063	0.207	0.204	0.108
6	0.253	0.165	0.063	0.231	0.180	0.108
7	0.253	0.135	0.077	0.207	0.220	0.108
8	0.253	0.135	0.077	0.207	0.196	0.132
9	0.253	0.135	0.077	0.223	0.180	0.132
10	0.253	0.135	0.077	0.247	0.180	0.108
11	0.253	0.135	0.063	0.253	0.180	0.116
12	0.253	0.135	0.063	0.253	0.188	0.108
13	0.253	0.135	0.063	0.207	0.220	0.122
14	0.253	0.135	0.063	0.207	0.210	0.132
15	0.253	0.135	0.063	0.221	0.220	0.108
16	0.253	0.135	0.063	0.237	0.180	0.132
17	0.253	0.135	0.071	0.253	0.180	0.108
18	0.253	0.151	0.077	0.207	0.180	0.132
19	0.253	0.143	0.063	0.253	0.180	0.108
20	0.253	0.149	0.063	0.207	0.220	0.108
21	0.207	0.165	0.077	0.253	0.180	0.118
22	0.207	0.165	0.077	0.253	0.190	0.108
23	0.207	0.165	0.077	0.207	0.220	0.124
24	0.207	0.165	0.077	0.207	0.212	0.132
25	0.207	0.165	0.077	0.223	0.220	0.108
26	0.207	0.165	0.077	0.239	0.180	0.132
27	0.207	0.165	0.063	0.253	0.180	0.132
28	0.207	0.165	0.063	0.253	0.204	0.108
29	0.207	0.165	0.063	0.213	0.220	0.132
30	0.207	0.165	0.063	0.237	0.220	0.108
31	0.207	0.165	0.069	0.207	0.220	0.132
32	0.207	0.135	0.077	0.253	0.220	0.108
33	0.207	0.135	0.077	0.253	0.196	0.132
34	0.207	0.135	0.077	0.229	0.220	0.132
35	0.207	0.135	0.063	0.253	0.220	0.122
36	0.207	0.135	0.063	0.253	0.210	0.132
37	0.207	0.135	0.063	0.243	0.220	0.132

Run	W1	W2	W3	W4	W5	W6
			Level 1 Weight			
38	0.207	0.151	0.077	0.253	0.180	0.132
39	0.207	0.157	0.077	0.207	0.220	0.132
40	0.207	0.149	0.063	0.253	0.220	0.108
41	0.217	0.165	0.077	0.253	0.180	0.108
42	0.223	0.165	0.077	0.207	0.220	0.108
43	0.239	0.165	0.077	0.207	0.180	0.132
44	0.231	0.165	0.063	0.253	0.180	0.108
45	0.213	0.165	0.063	0.207	0.220	0.132
46	0.237	0.165	0.063	0.207	0.220	0.108
47	0.223	0.135	0.077	0.253	0.180	0.132
48	0.247	0.135	0.077	0.253	0.180	0.108
49	0.229	0.135	0.077	0.207	0.220	0.132
50	0.221	0.135	0.063	0.253	0.220	0.108
51	0.237	0.135	0.063	0.253	0.180	0.132
52	0.243	0.135	0.063	0.207	0.220	0.132
53	0.230	0.150	0.070	0.230	0.200	0.120

Figure A1

Example Definition For a Box-and-Whisker Plot